THIRD EDITION

Uptime

Strategies for Excellence in Maintenance Management

John D. Campbell • James V. Reyes-Picknell

CRC Press
Taylor & Francis Group
A PRODUCTIVITY PRESS BOOK

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John dedicated the first edition of Uptime *to his wife, Bev.*

The second edition was dedicated to both our spouses, Bev and Aileen.

This third edition is dedicated to Bev, Aileen and our daughter, Arianna.

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Foreword to the Third Edition

The first edition of *Uptime* (1995) was written by John Campbell. The second edition (2006) was by Campbell and James Reyes-Picknell. As Reyes-Picknell is extremely aware of developments in the workplace, he realized the necessity for this third edition. Yet the third edition of *Uptime* is more than a minor tweaking of a popular book. In many ways, it is an entirely new book, with the addition of new contributing authors and the major rewriting of chapters to reflect current thinking.

The third edition may still say "Campbell and Reyes-Picknell" on the jacket, but in fact, there are many contributors. Contributing authors include Larry Johnson, Carlo Odoardi, Richard (Doc) Palmer, Paul Picknell, Uri Wittenberg, and Ali Zuashkiani. By embracing insights from others, Jim has made this book even more valuable than the second edition.

Uptime includes trends in technology, reliability maintenance improvements, and the challenges of finding qualified maintenance personnel due to an aging labor force. In addition, it gives a thorough review of what it takes to achieve excellence in maintenance—a key business process in any capital-intensive industry. The book describes how changes in technology and changes in demographics (younger workforce, different values, ways of communicating, retirement of boomers) are combining to influence how maintenance is managed and how changes are implemented in the field. Technology has enabled the integration of business processes across enterprises, but the workforce has typically not kept up with the changes. A tendency on the part of technocratic leaders (not uncommon in the maintenance world) is to rely on technology and forget the human side.

This book achieves an appropriate balance between technology, including its use for decision-making processes, and human factors and will surely be welcomed by individuals and organizations seeking excellence in maintenance management practices.

Andrew K.S. Jardine, PhD, Professor Emeritus
University of Toronto

Foreword to the Second Edition

It has been about 7 years since the first edition of *Uptime—Strategies for Excellence in Maintenance Management* was published. A lot has happened in that time. The expected "new economy" did not materialize as rapidly as expected, but it is cropping up in selected sectors and industries. Y2K was a wake-up call for many businesses, my own included, and was one of many things that have led to the rapid and dramatic advances in computer and software technology. While computers, the Internet and Y2K were making the headlines, a quieter evolution was also taking place. The world of the maintenance manager was changing, and it continues to change.

In their quest for growing revenues, higher profits and increased shareholder value, companies have grabbed all the low-hanging fruit. Production processes have been upgraded and automated; computerization supports many business decisions; purchasing has become strategic procurement; supply chains have been rationalized and streamlined; many functions like information technology, knowledge management and payroll have been outsourced; and administrative functions are being replaced by intranet and portal technology. One of the last areas where profits can be squeezed from an existing organization is the maintenance of physical assets. The plants and equipment we use to produce our goods and the fleets we use to deliver services still break down and still require maintenance. Until very recently, we considered maintenance to be a necessary expense—perhaps even an evil.

Today, the money maintenance managers spend comes straight off earnings. If they do not spend, then their companies can be more profitable. The assets they are charged with maintaining generate much of the revenue that goes to the top line. The maintenance manager of only 10 years ago could be a highly skilled craftsperson with people and management skills. The maintenance manager of tomorrow must be a savvy businessperson.

As we entered the new millennium, I looked at the last chapter in the first edition of *Uptime* and was pleased that much of what I suggested would happen is happening. The watchwords of the future were going to be *flexibility* and *reliability*. They are. Interpreting condition-monitoring data was a growing challenge. Today, it is often left up to computers and experts.

Expert systems were in their infancy but growing. They were being programmed then; today, they are "learning" by themselves. Technicians were to become more multiskilled among trades and cross-skilled with operators, but that trend has not progressed rapidly. Real teams are still a rarity and may require a generation to take hold. Universities were beginning to recognize and teach maintenance management as a distinct specialty, and that trend has continued. Today, for example, we are teaching maintenance management principles in the University of Toronto's physical asset management certificate program. The roles of design engineer and maintainer are slowly blurring. The need to match increasingly sophisticated and complex assets with an equal level of expertise in maintenance strategy and tactics was growing, but a greater need for this has emerged. With demands often driven by legislation and regulation in an increasingly litigious society, safety, environmental concerns and even our license to operate in some industries depend on reliable assets. As companies look for the fixes without the need to invest, the need for sophistication has never been more challenging. Accounting terminology is increasingly commonplace in all aspects of our businesses. Indeed, the new millennium is proving to be every bit as challenging as predicted—and then some.

Around the time that *Uptime* was first published in 1995, I hired an ex–navy engineer who had served time in several other industries in maintenance and asset management. Since graduating with a degree in mechanical engineering in 1977, Jim Picknell has worked as a ship's engineer, a rotating equipment specialist in petrochemicals and a maintenance and reliability engineering manager in shipbuilding and aerospace, all before he joined my relatively young practice. His focus on reliability seemed a good fit with my predicted vision of the future.

Since then, Jim and I have worked closely together, building a strong practice in physical asset management. We have become, in addition to good friends, leading thinkers whose opinions are sought after. We have worked in a very diverse set of industries on remarkably challenging problems, and we have learned a great deal. Our joint experiences range from Mickey Mouse to rocket science: Our clients have included operators of world-class amusement parks and world-leading space launch and vehicle maintenance facilities. We have helped improve maintenance management practices in large scrap-metal operations; open-pit, surface and underground mines; large hospital complexes; Ivy League universities; oil refineries; airlines; thermal and nuclear power generation plants; gas transmission pipelines and stations; electric transmission and distribution networks; fertilizer plants; automotive plants; furniture and office equipment plants; pulp and paper mills; tissue-converting plants; sawmills; plywood and engineered-wood-product plants; asphalt and cement plants; and elsewhere.

As our practice grew, we saw and heeded the need to change our services. Some of these changes were propelled by a shift in focus from computer system installation (i.e., the old silver bullet) to complex reliability improvement efforts aimed at satisfying a variety of business and regulatory-driven requirements. Others were motivated when industry moved from simply putting solutions in place to recognizing the need to change those who use the solutions and then sustain the change for long-term payback.

Jim and I have worked to satisfy these changing needs in a dynamic, constantly evolving business environment. I am not able to continue this pace for very much longer, but Jim is. I am passing the torch to him and have asked him to write this second edition of my original book and to share what we have learned with you. He has kindly agreed to take on this work, and this book is the result. Enjoy and learn.

John Dixon Campbell

Note: John completed this Foreword near the end of his long and courageous battle with cancer, only days before he passed away on November 11, 2002. His friends and colleagues have since created an award and scholarship in his name at the University of Toronto, where he studied.

Acknowledgments

The first edition of *Uptime* was based on observations of clients and other successful companies that were high performers in maintenance management.

The second edition of *Uptime* was born in discussions with John Dixon Campbell in 2000. The dust generated by Y2K was beginning to settle, and the consulting industry, which had done very well in the previous few years, was heading into a period of upheaval. Our maintenance management practice was doing very well and had grown substantially since *Uptime* was first published in 1995. Developments in computing technology and the explosive growth of the Internet had changed the landscape for management information systems dramatically, and that part of the book was clearly out of date. We had been using *Uptime* very successfully with a number of clients, made a few mistakes and learned a great deal about its application in the changing business environment. During the 2-year period preceding his death, John and I discussed these topics frequently, and thus, the first person to be acknowledged here is John Campbell—my good friend and mentor. Without his leadership of our practice, his dedication to excellence and his insights, the inspiration for the subsequent editions of *Uptime* would not exist.

All of the professional consultants and clients I have worked with have helped me learn and have had an impact on my personal and professional development. They are too numerous to be named here, but they know who they are, and they are all very much appreciated and thanked.

I remain indebted to Bev Campbell, John's wife, for her encouragement and support, and for helping me work with the publisher of this book. Bev, without your collaboration, John's legacy work, *Uptime*, would not be as fresh and useful today as it was when he first set pen to paper in the early 1990s.

I would like to acknowledge my wife, Aileen—a "nonmaintenance professional"—who read and commented on the drafts and helped me remain true to John's original intent of making the book an easy and informative read. Furthermore, she has provided encouragement to get and keep working on this when I was having difficulty focusing. She challenges me to reach far and has never faltered in her love and support. Aileen—thank you.

Author

James V. Reyes-Picknell is founder and president of Conscious Asset, a Canadian-based consulting and training firm specializing in asset management. James is a licensed professional engineer (Ontario, Canada), certified management consultant (international), certified maintenance and reliability professional (United States), RCM practitioner, member of the Institute of Asset Management, member of the Plant Engineering and Maintenance Association of Canada (PEMAC) and honors graduate of the University of Toronto with a degree in mechanical engineering (1977). He has done postgraduate studies at the Royal Navy Engineering College (United Kingdom), the Technical University of Nova Scotia and Dalhousie University in Halifax.

Before founding Conscious Asset in 2004, James was already recognized as a leading authority on the enterprise asset management practice of IBM Business Consulting Services (formerly PwC Consulting, PricewaterhouseCoopers and Coopers & Lybrand). He worked as a marine engineer afloat in the Canadian navy, as a specialist machinery engineer with Exxon Chemicals in Canada, as the maintenance and support planning manager for a large warship design and construction project and as logistics support manager for helicopter and microwave landing systems projects.

In his capacity as a maintenance management consultant, James has assisted numerous clients worldwide to achieve significant improvements in maintenance and overall business objectives. His extensive experience includes asset management; plant, fleet and facility maintenance management; strategy development and implementation; reliability management; engineering; spares and operating supplies; life-cycle management and analysis; diagnostic assessments; benchmarking for best practices; business process design; and enterprise asset management systems.

James has coauthored or contributed materials to several books and authored three. His articles on maintenance management have been published in numerous trade journals, periodicals and his online blog. He has taught physical asset management at the University of Toronto's Professional Development Centre in support of the programs offered by the university's Centre for Maintenance Optimization and Reliability

Engineering and taught the first module of PEMAC's maintenance management professional certification program, where the second edition of *Uptime* has been a major reference. The second edition of *Uptime* is used in several postsecondary institutions as a textbook on maintenance management and by many companies as the model framework for their maintenance management programs.

Contributors

This third edition of *Uptime* makes extensive use of input from several colleagues who have contributed a great deal of its new and revised content. *Uptime* now reflects a far broader and deeper wealth of experience and knowledge. All have contributed in one way or another to the entire book and extensively to specific chapters. Those contributing authors are as follows:

Dr. Andrew K.S. Jardine (Foreword)
Uri T. Wittenberg (Chapters 1 and 4)
Richard (Doc) Palmer (Chapter 3)
Larry Johnson (Chapter 7)
Carlo Odoardi (Chapter 8)
Dr. Ali Zuashkiani (Chapter 10)
Paul Picknell (Chapter 12)

Each of these contributors deserves special mention.

Dr. Andrew K.S. Jardine contributed the Foreword to this third edition of *Uptime* and, indirectly, through his leadership of the University of Toronto's Centre for Maintenance Optimization and Reliability Engineering (C-MORE). We first met in John Campbell's consulting practice, where Dr. Jardine was spending a sabbatical from his work at the university, and as we worked together closely, we became good friends. His friendship is highly valued and his professionalism has been an inspiration to me. He has always been willing to act as a sounding board for my ideas and offer his sage advice. Dr. Andrew Jardine is director of C-MORE. He is author of economic life software AGE/CON and PERDEC, the OREST software used for optimizing component preventive replacement decisions and forecasting demand for spare parts. In addition to writing software, C-MORE, under Dr. Jardine's guidance, has developed and commercialized two software packages: EXAKT for the optimization of condition-based maintenance decisions and SMS for the optimization of stockholding policies for slow-moving expensive capital spares.

Dr. Jardine is a prolific researcher and advocate of advances in maintenance decision making and reliability engineering. His views are sought after by industry, he has published numerous books and papers and he presents his work at professional seminars and conferences worldwide. His first book, *Maintenance, Replacement and Reliability* (1973), is in its sixth printing. He is coeditor with J.D. Campbell of *Maintenance Excellence: Optimizing Equipment Life Cycle Decisions* (CRC Press, 2001); the second edition was published in 2010 as *Asset Management Excellence: Optimizing Equipment Life-Cycle Decisions*. The second edition of the bestselling *Maintenance, Replacement and Reliability: Theory and Applications* (CRC Press, 2006), coauthored with Dr. A.H.C. Tsang, appeared in 2013.

In 1998, Professor Emeritus Jardine was the first recipient of the Sergio Guy Memorial Award from the Plant Engineering and Maintenance Association of Canada in recognition of his outstanding contribution to the maintenance profession and was elected a fellow of both the Institute of Industrial Engineers and the Canadian Academy of Engineering in 2013.

Uri Wittenberg has had extensive input to the material on strategy in Chapter 1, which has been substantially rewritten, and the material on basic care in Chapter 4. Uri introduced me and several clients to an extremely effective technique for strategy deployment (Hoshin Kanri). That technique has been instrumental in client success ever since meeting him; it has become a regular part of our firm's service offering, and it is now a part of *Uptime*. The crucial, yet previously missing, *deployment* component has been added to Chapter 1. Uri is an entrepreneurial business coach with extensive experience in strategic planning; policy deployment; Lean business and methodology deployment; the Toyota Production System; and benchmarking in the areas of operations, supply chain management and maintenance management, predominantly within the manufacturing industry. He has designed, developed and delivered organizational business process improvement and change management solutions for enterprise-wide collaboration fluidity, customized learning concepts and experiential tools. Uri's Lean-enterprise experience and knowledge have enabled his contributions and revisions to Chapter 4 on basic care, where he has also added considerable material on the 5S tools and how to deploy them successfully.

Richard "Doc" Palmer, another friend and colleague, is already well known. Even before retiring after a career of more than 25 years as a practitioner, Doc began helping companies with their maintenance planning and scheduling efforts. Today, companies worldwide benefit from his skills and expertise through his company, Richard Palmer and Associates. He provides consulting, education, guidance, mentoring and training for maintenance planning success with a strong theme promising that you can "increase your workforce without hiring." His *Maintenance Planning and Scheduling Handbook* (now in its third edition) is widely regarded as the prime reference for planners and schedulers the world over. Doc extensively revised and added to the material on work management in Chapter 3. His considerable insight reflecting contemporary issues and his extensive experience in deploying planning and scheduling in numerous companies are now major enhancements to *Uptime*.

Larry Johnson, another friend and colleague, extensively rewrote Chapter 7, "Management and Support Systems for Maintenance," effectively replacing the old chapter to reflect significant technology changes. This is the chapter that has provided the catalyst for both the second and third editions of *Uptime*. Technology has never slowed its pace, and there will always be a need to keep up with it. Larry is the founder and president of Fractal Solutions. He is an internationally known consultant, lecturer and trainer in asset management and equipment reliability programs. He is an expert in integrated maintenance programs, planning and scheduling and computer-based maintenance management system design. He has helped thousands of maintenance and operations personnel apply reliability improvement programs at their facilities. He has extensive maintenance experience in various capacities, having spent 25 years in consulting, management and training.

Larry has published numerous articles in the reliability field, including "Improving Equipment Reliability and Plant Efficiency through PM Optimization," and has made presentations at large international conferences such as the Society for Maintenance and Reliability Professionals Annual Conference and the Strategic Industry Research Foundation's industrial round table. He is the pioneering developer of the preventive maintenance (PM) optimization methodology, an alternative and complement to reliability-centered maintenance, now in use at many facilities worldwide. Larry designed PREMO XPERTS, PREMO PAS, the EPRI RCM Workstation and other computer applications in use by numerous organizations. He has worked on the application of reliability-centered maintenance at more than 70 sites in the United States and around the world, and trained thousands in reliability-centered maintenance through his interactive workshops.

Carlo Odoardi has been a long-time friend and colleague, working extensively with my firm for the past several years. He revised and rewrote large portions of Chapter 8, "Asset Reliability 1—Being Proactive," formerly "Asset-Centric Approaches 1—Being Proactive." He has added considerable material on reliability-centered maintenance (RCM), increasing the depth in this chapter and reflecting his years of experience implementing RCM. Carlo is a business reliability professional with a passion for helping asset-intensive companies achieve sustainable, world-class operational performance. For more than 25 years, he has provided consultation on industrial culture change management, business transformation, advanced industrial technologies' applications and management information system solutions. Carlo advises senior executives about what steps must be taken to achieve cost-effective business results and then implement an optimal mix of proven methodologies and technologies. He is a passionate teacher and an advocate of positive change through mentoring, adopting new organizational philosophies that result in clear direction, and business transformation initiatives.

Dr. Ali Zuashkiani has contributed the entirely new Chapter 10: "Evidence-Based Asset Management." Ali and I met at the University of Toronto's Centre for Maintenance Optimization and Reliability Excellence (C-MORE), have worked together on many occasions and have become good friends. His chapter introduces us to the new gold standard for asset management decision making. He introduces and provides considerable detail on evidence-based asset management (EBAM), life-cycle cost and various decision optimization methods and illustrates them with a number of case studies. Ali also presents *knowledge elicitation*, a technique that he has used successfully to deal with incomplete, inaccurate or missing data—a common problem that many struggle with today. Ali consults and trains globally in the area of asset management. He has given hundreds of seminars and workshops in national and international conferences and published a book titled *Expert Knowledge Based Reliability Models: Theory and Case Study*, and chapters in several other books and various articles. Ali was selected as a Young Global Leader by the World Economic Forum in 2013, and in 2008, he was awarded as a Young Global Leader by Asia Society. Ali is CEO of PAMCo and director of educational programs at

C-MORE at the University of Toronto. He is a reliability-centered maintenance (RCM) practitioner responsible for implementation throughout the Middle East.

Ali and I also acknowledge the University of Toronto and Dr. Jardine's firm, BANAK Inc., for their contributions. Most of the case studies presented in Chapter 10 were conducted by researchers at the University's C-MORE and BANAK's consultants under the direction of Dr. Andrew K.S. Jardine.

Paul Picknell has been known to me since he was born. He is my youngest brother, and by odd twists of fate on very different paths, we have come together working in related fields. Paul contributed another new Chapter 12, on asset information management. This chapter discusses the management of information and its governance as applicable to the broad field of asset management and is clearly needed in a world swimming in data yet information starved and clearly in need of help to make better decisions. Paul is a senior manager with extensive experience in program and project management. He is experienced in all aspects of the system delivery life cycle and highly skilled in managing a variety of information technology (IT) service functions. Paul excels in core project management functions, with specific strengths in risk and stakeholder management, strategic planning, budget and scope management, workshop and seminar facilitation and communications. Through his career, he has played a crucial role in delivering projects ranging in scale from the business unit to enterprise-wide.

In addition to the contributors there are three colleagues who carried out independent reviews of the draft material and provided valuable insights, corrections and suggestions that have been incorporated in this work. Thanks go out to Mick O'Sullivan, Marcelo Aliendre and Alun Roberts for all their help.

Introduction

WHY *UPTIME?*

Your operations run 24/7, generating millions in revenue every day. The markets are good, production is running flat out and your customers are happy. You have some minor stoppages, but they are fixed quickly—total loss of production is relatively minor. Then, late in the week, there is a major equipment outage. It takes several days to get a critical part and a few more days to fix the problem. Total downtime: 5 days. By now, customers are screaming for product. You resort to buying and repackaging a competitor's product for resale to satisfy your customers. Throughout this time, a good part of your production staff was idle. Your maintenance crews, already short staffed because you have not been able to find qualified tradespeople, worked around the clock at premium rates. You cannot make up for the lost production. You are backed up and already running flat out. This one incident has reduced annual revenues, taking more than 2% from your bottom line.

Only a short distance away, your competitors were able to ramp up production to help you make up for your lost production. They were happy to help—your situation generated more revenue for them and at a premium price! They do not have a problem with outages, and although they compete for the same labor pool as you, they do not seem to be short staffed. Their operations are similar to yours, their product is virtually identical, but they are more profitable. What is their secret?

You arrange a visit to the competitor's plant, hoping to find an answer. The plant manager is your host and gives you a tour. The plant is not new, but you are immediately impressed with how clean and orderly everything is. Much of the equipment is the same as yours but better cared for. You see operators using handheld device checklists and helping the maintainers while they do repairs. There is a crew of maintenance people who do nothing but condition monitoring—today, they are doing a combination of vibration checks, oil analysis and thermal imaging. The storeroom is tidy and manned only during the day shift. At night, it has a card access; bar code readers and radio-frequency identification (RFID) tags are used to record stock transactions. Maintenance performance statistics are posted alongside production; safety statistics are posted on boards throughout the plant, and they are current. You notice that the plant's recorded accident rate is 0.5 reportable incidents per 100,000 man hours; yours is 2. It is probably a given that their insurance premiums are lower than yours, too.

When you ask how they achieve this remarkable performance, the plant manager explains that maintenance is a critical business process and a key to the company's success. He knows his competition and knows that they do not have that same view—he considers it a not-so-secret competitive weapon. He views maintenance as an investment in productive capacity. You have been viewing it as a necessary evil—a cost center.

And it is precisely this scenario and these divergent views of maintenance that are the crux of the message of *Uptime: Strategies for Excellence in Maintenance Management*. What may, at first glance, be a seemingly trivial difference of opinion separates a successful operation from one beset by outages, staffing problems and a host of related costs and other irritants.

UPTIME'S HISTORY

Uptime: Strategies for Excellence in Maintenance Management was published in 1995. Since then, John Campbell and I, along with our colleagues, used it to help hundreds of companies move toward excellence. While applying the concepts and theories described in *Uptime*, all of us have learned a great deal more about them: where they work, where they do not and how to apply them. Maintenance managers, who made up the majority of readers, were asking for more detail on how to apply *Uptime*. That request, along with significant changes in technology that had occurred, led to our choice to produce a second edition.

By the time the second edition was published in 2006, our team had collectively gained more than 500 years of experience in a wide array of circumstances, industries and environments. Today, this third edition represents several hundred additional years of experience.

This third edition of *Uptime* is an updated and expanded affirmation of the premise promulgated in the first edition and expanded in the second edition, and it provides current insights and practical suggestions for implementing maintenance management as a viable and valuable asset for any industry seeking to improve its operating systems. This edition goes deeper into the how-to of *Uptime*'s model of excellence, adding considerably from experience gained since the first edition was published in 1995. Indeed, in doing so, this edition features material from six additional contributing authors, all professionals that John Campbell either knew or would have been proud to know.

USING *UPTIME*

John intended *Uptime* as a senior-level reference for both maintenance and nonmaintenance professionals alike. Both used it effectively. It was maintenance managers who made up a large part of *Uptime*'s readership—they would remark that it was the first book to ever describe their job to them. They loved it, and they asked for more depth on how to apply *Uptime*. Subsequent editions have included more material specifically in response to that request.

Uptime provides an overview of maintenance management and, in this edition, expands that overview, now introducing asset management—the next step in our evolution as a profession. It examines various elements that maintenance managers deal with and offers guidelines for maintenance success, specifically, useful information about *what* works well and *how* to achieve it. We have attempted to stay away from excessive details that are likely to be more confusing than illuminating. If you want to focus on only one topic, you can. Each chapter stands alone as a guide and each gives an indication of other *Uptime* elements you should take into account.

While this edition contains even more guidance on implementing *Uptime* and its elements, it is not a field manual. Keep in mind that you are likely to need help from experts as you implement some parts of *Uptime*, and for other parts, you will not.

We have provided enough information to help the dedicated maintenance professional make informed choices while also providing overviews for the nonmaintenance reader.

"*Uptime* Summary" sections were added to the second edition, appearing at the end of each chapter. These outline key points for executives and managers who want to focus on significant points without getting bogged down in minutiae. Feedback from readers was positive—they loved the summaries. This third edition has new versions of those *Uptime* Summaries. They were written as a single document, divided by topic to address each chapter's material and then placed at the end of each chapter. Readers who want to skim the book will get a great deal from those alone. Managers who want a quick start with *Uptime* are encouraged to read this introduction and then each of the 13 *Uptime* Summaries. In a very short time, you can gain a good understanding of *Uptime*'s breadth and depth without getting into the details.

CHANGES

The first edition was subdivided into four parts: "Leadership," "Control," "Continuous Improvement" and "Quantum Leaps." Those translated into four levels in the original *Uptime* Model of Excellence (Pyramid).

In the second edition, there were four parts, with new titles: "Leadership," "Essentials," "Choosing Excellence" and "Epilogue," but the pyramid was changed to include three levels as it does in this third edition.

The first three sections of this third edition discuss the model and its 10 elements. Section IV is entirely new material on asset management. It provides a bridge from the world of maintenance management into the broader world of life-cycle asset management, reflecting the emergence and popularity of international standards that are driving our profession to higher levels of achievement warranted by the significance of physical assets to businesses and the world today.

Section V covers implementation of *Uptime*—a much-needed addition that provides considerable guidance on how to implement the *Uptime* Pyramid in today's working environment. The advice in this part of the book is intended to help you get started and moving successfully and then sustain *Uptime* for years to come.

Section I, "Leadership," discusses strategy, strategy deployment, people, teamwork and managing change.

- Chapter 1 now includes material on how to deploy your strategy successfully with the addition of Hoshin Kanri. We also have emphasized and recommend a new approach to beginning your *Uptime* journey that avoids many of the initial change management challenges that an *Uptime* implementation can face.

- Chapter 2 reflects the increasing importance of teamwork in today's workplaces. The material on teamwork has been moved from the top level of the *Uptime* Pyramid and included in Chapter 2 on people in this first or foundation level (*leadership*).

Section II, "Essentials," discusses the elements of *Uptime* that must be present in any organization that delivers maintenance successfully while setting the stage for high levels of performance.

- Chapter 3 on work management has been reworked to reflect successful practices in today's working environments: plants, mobile workforces and shutdown situations.
- Chapter 4 on basic care has seen significant edits and changes. The detailed material on equipment failures has been moved to Chapter 8 and is covered with reliability-centered maintenance (RCM), where it is a better fit. Given the emphasis on teamwork (Chapter 2) we have also added a highly successful team-based approach to enterprise housekeeping—5S, taken from the world of "Lean."
- Chapter 5 on materials management has seen several edits, largely to remove material that is of little interest in the maintenance community. Materials management professionals will consider this chapter to be "basic," but maintenance professionals ignore the remaining material at their peril.
- Chapter 6 covers performance management, key performance indicators (KPIs) and benchmarking. It has been edited to simplify and clarify it from the second edition.
- Chapter 7 on information technology has been totally rewritten. Needless to say, since 2006, there have been substantial changes in the world of technology and what it enables.

Section III, "Choosing Excellence," discusses and presents three aspects of reliability that are keys to accelerating your performance beyond ordinary toward extraordinary.

- Chapter 8 on proactive methods is dedicated to RCM. RCM is covered in more depth now and adds considerable insights from the field on its implementation.
- Chapter 9 covers additional reliability tools used in getting started quickly, optimizing your existing preventive maintenance (PM)

program and optimizing your decision making. Rapid deployment of PM, PM optimization, root cause failure analysis, decision optimization, reliability modeling and simulations are covered.
- Chapter 10 introduces an entirely new topic—evidence-based asset management—the new gold standard in decision making in our field. This chapter also introduces a method, knowledge elicitation, for use where the data needed to make evidence based decisions are lacking.
- Material removed from this part of the book on teamwork and total productive maintenance (TPM) has been moved to Chapter 2. Material on process optimization has been removed entirely. It was primarily relevant to the processes described elsewhere in *Uptime*, and each of those chapters already addresses what is needed to optimize their respective processes.

Section IV introduces a new topic—asset management. While the second edition of *Uptime* was being written, this "new" field emerged, and global awareness began to grow. Since then, asset management has emerged on the world stage and is the subject of new international standards published early in 2014. Asset management is a much broader topic than maintenance management—indeed, the latter is a part of the former. It is the direction in which our profession is headed as we continually improve and consider all matters of the asset life cycle—thinking out of our traditional box.

- Chapter 11 is entirely new and discusses asset management, providing an overview of the subject, its various topics, the international standards and their voluntary requirements.
- Chapter 12 is also entirely new and covers the important topic of asset information management. Arguably we need this to be effective in maintenance management, but the topic covers a broader scope of information than what is used by maintainers. AIM is a good place to start with asset management, particularly if you are considering certification against the new standards, as it is central to providing the information you will need in all your efforts.

Section V is also new—implementing *Uptime*. Since the first edition was published in 1995, people have asked, "How do we do this?" The second edition (2006) answered some of those questions, and many companies have implemented *Uptime* successfully using advice found in its chapters. This third edition goes beyond that chapter-by-chapter/topic-by-topic advice and provides an overview of how to implement the entire *Uptime* Pyramid and sustain the changes in your company.

- Chapter 13 provides that advice on implementing the already successful *Uptime* Pyramid, with tips and considerations based on years of experience in applying the model in a wide variety of environments, industries and cultures.

Appendices supplement the book materials.

- Appendix A provides a discussion of maintenance assessments (the traditional approach to starting an *Uptime* implementation) and the newer approach that begins with training. It presents questions that can be asked in getting started and introduces a new online app—the *Uptime* Performance Assessment app that can be used as a handy tool in starting your journey.
- Appendix B is an expanded and slightly edited version of the glossary that was introduced in the second edition of *Uptime*. Edits largely reflect the changes in emphasis that appear elsewhere in the book.
- Appendix C is a guide for rapidly deploying a PM program for organizations that presently have none.

UPTIME IN YOUR BUSINESS

People and companies are a lot alike. For individuals, there is substantial evidence that physical and financial well-being are interrelated. There is a clear link between wellness and success—the healthier you are, the better you do. Conversely, failure is related to both physical and emotional distress. Those who take good care of themselves physically, emotionally and spiritually often do better than those who do not, and they sustain it for longer. They also feel more satisfied and are more likely to be seen as happy people. Companies are made up of people, and like people, if they are healthy and stable, they do well, and their people feel good about working there.

Keeping healthy both on the personal level and as a company means keeping all your systems and parts in proper working order. Neglect leads to breakdown, disease (dis-ease) and worse. We all know we should exercise, eat healthy and avoid overstressing ourselves. Nevertheless, many of us neglect our physical health and indulge, favoring short-term gratification over a long and healthy life. Many organizations are also like that, and the result is clearly negative. The human body and the corporate body suffer because we do not pay enough attention to physical health through maintenance.

Most businesses today are highly dependent on technology, automation and physical assets, decreasing their dependence on labor. We are witness to technological growth at a remarkable pace. As technology grows, it enables more. We can do more with less human intervention while becoming more profitable, safer and less vulnerable to labor shortages. At the same time, we become more dependent on our physical assets. Sometimes, new technologies are much more reliable than whatever they have replaced, but not always. For certain, they will be complex, and due to our emphasis on consuming less of our planet's resources, they will put their component parts under high stresses. Like the human body under stress, those highly stressed and complex assets can fail—they are dependent on effective maintenance, preferably delivered in a cost-effective way.

What we gain by maintaining our physical assets diligently is uptime—the capacity to produce and provide goods and services. We also expand our ability to produce high-quality goods and services quickly and satisfy our customers consistently. Finally, we provide a safe and controlled work or service environment, with minimum risk to the health and safety of our employees, our customers, the public at large and our environment.

Maintenance is treated, in the accounting world, as an operational expense, including repairs, proactive maintenance, consumption of parts and materials, labor and contractors. Some parts that are consumed in extending the useful life of assets may be treated as capital investments, but most will be written off as expenses. The largest cost associated with poor maintenance and operating practices is the "hidden cost" of downtime (lost revenue and damage to reputation). Fines or other penalties due to low quality or failures to deliver on time are more visible but often treated separately from maintenance costs. On the income statement, maintenance is often buried as a component of "operating costs," not even visible to senior management and executives, but its impact can be huge.

Though they vary in direct proportion to the capital intensity of a given business, budgeted maintenance costs can be as high as half of production costs (Figure I.1).

Sector	Percentage Direct Maintenance to Operating Costs
Mining	20 to 50
Primary metal	15 to 25
Electric utilities	15 to 25
Manufacturing	5 to 15
Processing	3 to 15
Fabrication and assembly	3 to 5

FIGURE I.1
Ratio of direct maintenance cost to total operating costs.

Although high enough, the numbers in Figure I.1 are not "total costs"—they do not include the sales value of lost production or the cost associated with rework, rejected product, recycled materials, fines or other penalties. Those costs can make the maintenance costs look small in some industries. Understanding the total cost of maintenance and its impacts enables rational decision making and can often justify increases in maintenance budgets. The result of this is often a lower total cost to the business relative to revenues generated—you become more profitable.

The more capital-intensive[1] a business becomes, the less it depends on operators, and the more it depends on maintenance. The costs associated with this dependence on maintenance grow as a direct result of our increased dependence on physical assets for production. But if we manage our assets well, those costs will decline, as will the cost per unit of output. It pays to think in terms of cost per unit output (effectiveness) rather than just cost (an input).

Maintenance is a complex business function, and getting it right is a challenge. A lot of questions need to be answered:

- What maintenance activities do we focus on? Can we become more predictable and less reactive? How can we do that?
- How do we attract and keep capable people to maintain sophisticated equipment systems?
- How can we get more productivity from a shrinking skilled workforce?

- What is the optimum level of inventory of maintenance parts, materials and consumables? Where can we get them?
- Can we extend the life of our aging assets? Is it worth our while to do so?
- Do we need specialist maintenance engineering support?
- What organization arrangements are most appropriate in our business?
- What should we contract out and how much of it?
- What are the risks associated with failures of our major systems? How can we deal with those?

The world is getting smaller. Global competition makes it more important than ever to get the answers right. Business is under enormous pressure to be financially productive. Maintenance is a major production cost. If it fails to deliver uptime cost-effectively, then plants can be shut down and production outsourced or moved offshore. Everywhere, the dictum is the same: Maximize the output of goods and services, and minimize input of resources—financial, human and physical. Provide the best value to both the customer and the shareholder, but at the same time, be safe and environmentally conscious.

Providing value clearly has to do with giving the best quality and service, quickly and at the lowest price. To satisfy customers, an enterprise must respond quickly to service its goods throughout their useful life cycle. In connection with this, we see "product life-cycle management" emerging as a new discipline closely related to maintenance management but focused on maintaining the products sold to customers. That same thinking has grown into "asset management" today as related to our physical assets that are used to deliver value for our companies. We also want to expose ourselves and our customers to minimal risk (whether financial, market, operational, environmental or safety related), so it follows notionally that

$$\text{Value} = \frac{\text{Quality} \times \text{Service}}{\text{Cost} \times \text{Time} \times \text{Risk}}$$

The higher the quality and service we can deliver for a given cost and response time, the more value the customer perceives. It is essential that the physical resources employed—equipment, fleets, facilities or plants—be available when needed and produce at the required rate and quality, at reasonable cost. It goes almost without saying that environmental and safety risks must be consistently minimized, but also business risks.

Today, we expect a lot, and we expect it at low cost. Getting it all right has its costs too. Those costs are truly investments in your capability to sustain your assets. The strategies described in this book will require some initial investment to implement. Like going to the gym, your improvement is contingent on a commitment to expend the necessary effort and finances, and the reward is a high payback.

New manufacturing and processing philosophies and cost-effective designs of capital equipment have spawned corresponding maintenance responses. For example, modular equipment designs are "maintained" by substitution: Entire modules are replaced, and electronics are designed to be increasingly fault tolerant. Some "smart" technologies are even eliminating maintenance through systems that have the ability to self-correct, but those applications are few and far between. Well into the foreseeable future, we will be depending on complex physical assets that can break down.

Managing failures and their consequences results in the delivery of uptime. *Uptime* enables performance that meets or exceeds desired levels of production, quality, speed, service, timeliness and consumption of resources.

Maintenance and asset management are now recognized as business disciplines with "learned societies" and educational programs, several at the level of advanced degrees, like those for other professions. Our field is no longer the realm of technologists or technocrats. It is a legitimate professional endeavor. At its heart are a number of activities that must be understood and executed well. Those activities are the elements of the *Uptime Pyramid of Excellence in Maintenance Management*—the subject of this book.

UPTIME PYRAMID OF EXCELLENCE IN MAINTENANCE MANAGEMENT

Figure I.2 is a graphic depiction of the structured framework used for applying these successful practices in your business. That framework is an overall strategy, or roadmap, that can be used to guide your choices about how you will manage maintenance in your business. Although it

FIGURE I.2
The *Uptime* Pyramid of Excellence.

is not necessary to follow a prescribed approach to climb the Pyramid of Excellence, it is important to embrace all the elements in the lower two levels, *leadership* and *essentials*. Achieving at least a level of competence in these improves your ability to survive as a maintenance manager in today's demanding business environment and positions you for continuous improvement on the top level. If you are striving for superior performance, then you will likely embrace at least one of the methods on the third level, *choosing excellence*, the key to transitioning from competence to excellence.

Consider three people with varying degrees of competence at swimming. One is uncomfortable in the water and cannot swim at all, one can swim well and the third is an Olympic champion swimmer. When dropped into the water, the first will bob to the surface, thrash about, make a lot of noise, get nowhere and eventually drown. The swimmer will quickly gain his composure, determine which way he needs to go and swim to safety. The Olympic champion will do much the same, but he will be better at it. He will make it look easy, getting to safety more quickly and maybe even helping the others along the way. Extend this to maintenance management, and you will find some interesting parallels: Some people do not belong in the process, some function or manage reasonably well and some excel.

Any company that has physical assets to maintain will, by default, apply at least some of the elements from the *essentials* at varying degrees of competence. Even if a company does nothing more than run everything in a totally reactive mode, it will manage a workforce and materials, comply with some minimal level of regulated maintenance requirements, monitor costs, and use some sort of technology to help manage at least parts of it. Do this badly, like the poor swimmer, and you will eventually drown in high costs fines for noncompliance with regulations, lost revenues, an inability to see your way out of the mess you are in and poor safety records. You drown! In all likelihood, this happens because no one has consciously applied the principles represented by the *leadership* part of the Pyramid of Excellence and described in Section I of the book.

Successful companies will consciously apply the *leadership* elements and may even achieve some level of excellence in executing the *essentials*. Doing this consistently dramatically increases profitability. Like the reasonably good swimmer, those companies will survive and may even do reasonably well, encountering only occasional problems along the way. High-performing companies will be consciously and consistently attentive to *leadership* and *essentials*, adding elements from *choosing excellence* into the mix. Like the Olympic swimmer, they will make the process look easy because they are so good at it. One measure of their success is that others will invariably attempt to emulate them.

How well a company executes maintenance using all or some of the elements presented in this work depends primarily on how well it motivates its people. This factor is a key determinant of how far and how quickly a company moves toward improvement, success and sustaining itself.

The *Uptime* Pyramid of Excellence is not a prescriptive "one-size-fits-all" approach to implementing successful practices. It is an underlying strategy, a framework, if you prefer, that provides many possible routes to achieving superior results. It works and can be found in one form or another, to various degrees, in many highly successful companies. It does not need to be followed in sequence from bottom to top, although that is a very practical approach. It is not necessary to excel at one level before attempting the next, and attempting to improve elements from multiple levels in parallel is achievable, provided you do not overload your people with too much at once.

Within the pages of *Uptime*, you will find practical and relatively easy-to-implement suggestions and methods. Little of it, until you get into parts of the top level, is complicated. But it does require commitment and effort sustained over an extended period—often several years.

It is hoped that the book will be of great interest to the general manager who seeks to understand more about maintenance and for the maintenance and engineering professional who wants to appreciate both the bigger picture and the details needed to excel in his/her job. Both will gain valuable insights into the various successful maintenance management techniques and methods available today.

ENDNOTE

1. *Capital-intensive* means that the company makes extensive use of physical assets, including plant, equipment, physical systems, fleets of vehicles, fixed assets, facilities, and utility infrastructure.

Section I

Leadership

Companies that choose excellence are setting out on a journey toward high performance. They begin with a clear appreciation of where they are, where they want to go, what they will do to get there, what constraints can hold them back, what enablers they can use, what policies they will adhere to and how long it will take. They also review these criteria regularly to ensure that the parameters set still match the needs of their business. They recognize that the key to success is people and being proactive. They know that change is sustained only by highly motivated people. Such people will execute a well-thought-out strategy if they have participated in its creation, if they take ownership of it, if they can work in a collaborative environment to implement it and if the results help them achieve what they want. Success in this journey means success for your company, your people and you—it is a W^3 (win–win–win) proposition. Any approach less than W^3 will result in less than the desired results.

Today, we have a new standard for asset management that encompasses *Uptime* and its various tactical elements. Chapter 1 on strategy applies to both maintenance management and the broader perspective of asset management in a corporate setting. Asset management in its entirety is beyond the scope of this book, but Chapter 11 introduces it and some key concepts that are highly relevant to the realm of maintenance.

1

Building a Maintenance Strategy

> The biggest risk is not taking any risk... In a world that is changing really quickly, the only strategy that is guaranteed to fail is not taking risks.
>
> **Mark Zuckerberg (Facebook cofounder)**

If you know where you are going and you have a basic idea of how you will get there, then you have a strategy. The various twists and turns, the route you choose, the method of transportation you use, how fast you go, whom you go with, etc. are all tactical choices. Strategy describes the general direction. It is no more complicated than that. Asset Management (AM)—the management of the physical infrastructure of a business—is all about execution of an AM strategy. Maintenance is an important part of that overall strategy. Tactics are represented by the choices you make to implement the strategy and manage the people, processes and physical-asset infrastructure that make up your business.

Regardless of whether or not you document your strategy, you are following one. Even if you have no stated direction, you will still be following a strategy—albeit not consciously. This lack of definition will often result in a totally reactive approach to problem solving—failure, as Zuckerberg says it. Because you have not chosen your own direction, you are letting events and others choose it for you, and you end up in a reactive mode. You will be operating on a run-to-failure strategy in maintenance, regardless of how your company, at a corporate level, defines its strategy. If you have a defined strategy that is known to everyone in your organization, you will be identifying, analyzing and solving both old and new problems, introducing new tools, innovations, approaches, resources and capabilities. You will not be relying on doing things the same old ways. If you do not have a sound strategy, you will benefit immeasurably from creating one, communicating it and then focusing on your tactical choices for how to achieve and sustain it.

It is important at this juncture to clear up a bit of confusion about the definitions of the word *strategy*. One definition applies to high-level business; the other is unique to the field of maintenance management. In this chapter, *strategy* is used in the business sense. It refers to an overall direction, goals and a high-level flexible plan that leads to good choices. An example is the choice to implement methods that will move a company from a reactive approach toward a proactive approach in maintenance—choosing that results in lower costs, more reliable and predictable operation, improved safety performance and environmental compliance. The practical choices of how to implement strategic direction are tactical in nature.

In the realm of maintenance management, *strategy* often refers to the tactical choices of how to manage specific physical assets. Decisions to utilize preventive or predictive maintenance methods are often referred to as "maintenance strategies" for the specific equipment to which they are applied. Here those are considered to be "tactical" (i.e., execution) choices as opposed to strategic.

Strategy need not be complicated—in fact, many of the most successful strategies are little more than simple guidelines or sets of rules. They do not prescribe details, but they suggest alternative routes or actions (i.e., tactics) to take as circumstances shift, all the while keeping the ultimate goal or destination in sight. Stephen Covey (1989), in his book *The 7 Habits of Highly Effective People*, describes the habit "begin with the end in mind." That is exactly what strategy does. A good example of this elegant simplicity is Sun Tzu's *Art of War*. Written in about 500 BC, it is nothing more than a collection of pretty simple rules that no one seriously challenges. Indeed, Sun Tzu's work has been translated and is used as a business tool even today!

To be practical, however, your strategy must go beyond its apparent simplicity. Maintenance strategy must support the AM strategy, which, in turn, must support corporate strategy. Successful organizations have both strategy (direction) and tactical plans (specifics) at each level—corporate, AM, site and departmental (maintenance). The tactical plans at one level often create the strategic direction at the levels below. It must be supported by tactical plans for how to implement it, and those plans must be executed. Without the plans, you will not have a clear idea of what you are doing or how. Execution is critical, unless you carry them out, you will have produced little more than an interesting intellectual exercise. Tactical plans address the short-, medium- and long-term activities; the human resource (HR) needs (people, skills, knowledge); the change management that will inevitably be required; and the investments and budgeting for getting it all done.

A good business strategy has the following elements:

- A solid comprehension of the business you are in and its current products and services, and a description of key external customers and what factors keep them as key customers
- An assessment of the regulatory/political, economic, social, technological (PEST) and financial environment, especially as companies are increasingly global in scale
- A description of your future business vision (the state of the business, say, 3, 5 or 10 years from now) generally supported by goals that are meant to motivate and galvanize employees into action
- A statement of mission (what you are there to do), guiding principles (the rules you will follow), major objectives to be accomplished (milestones) and the business plan to achieve them
- A comprehension of the company internal environment with its various constraints and enablers as well as a sense of what to do with and about them

Maintenance provides support to corporate strategy indirectly through an overall AM strategy (if it exists). Maintenance needs its own strategy, but that cannot be developed in a vacuum. Keep in mind that the corporate strategy is supported by various activities and analyses that helped develop it, justify it and provide a context for it. It is important to understand those and their potential implications. While not likely to be specific to maintenance, these can have an influence and impact on the maintenance strategy and must be understood. Maintenance impacts can show up in production levels (revenue generation), safety, regulatory compliance, environmental performance, product quality, insurance considerations, financing considerations and even whether or not warranties are worth managing. A discussion of the business of maintenance appears at the end of this chapter for those who want to dig more deeply into the interaction of maintenance with various other business functions.

FRAMEWORK FOR THE STRATEGY

There are several ways to build a strategy. Stephen R. Covey tells us to begin with the end in mind (Covey 1989). If you have a good idea of your current state (where you are now), create an overall vision (the end result you want to achieve), and then state what you will do to achieve it. If you do not have enough knowledge about your current state, it makes good sense to perform detailed analyses of this before launching into the vision and main tactical choices.

Maintenance strategy is based on the framework model depicted in Figure 1.1. Foremost in any business plan are the needs and wants of the customers, shareholders and other stakeholders. The key objectives for each function and element in the business strategy are drafted with them in mind. A successful technique for translating business objectives into functional or departmental objectives is Hoshin Kanri, discussed later in this chapter. Maintenance is likely to have goals and/or targets, somewhat like these examples (but specific to your own industry and business):

- Maximize the production rate of a particular product through high reliability (e.g., increase availability from 93% to 96%).
- Reduce costs per unit of output by doing only the safe minimum amount of maintenance (e.g., safely reduce maintenance costs per ton of concentrate from $42 to $35).
- Add productive capability for an additional plant by supplying advice to the design team (e.g., designate experienced engineers to work with the design and commissioning team for the expansion of the processing line with a goal of increasing line availability from 90% to 97%).
- Reduce stores inventories through vendor partnering (vendor-managed inventory), increased predictive maintenance and PM and drastic reduction of emergency work (e.g., reduce the value of stores inventory by 25% while maintaining stores service levels of 95%).
- Support quality improvement initiatives through the application of precision maintenance on all production assets (e.g., introduce laser alignment techniques to improve rotating equipment reliability by eliminating all quality defects due to installation or repair misalignment).

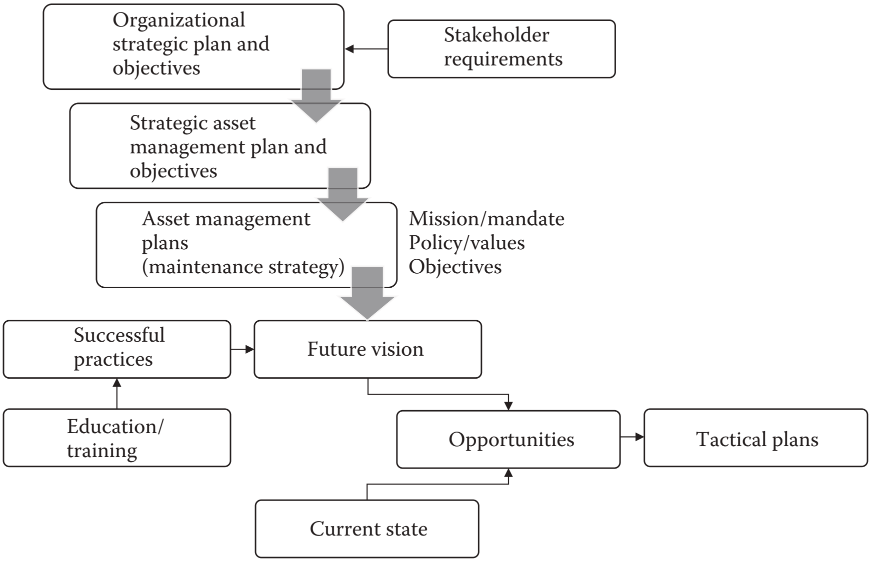


FIGURE 1.1
Maintenance strategy based on framework model.

A maintenance strategy must remain flexible. If the company's situation changes, so does the maintenance strategy. For example, if a business shuts down excess capacity, it makes little sense to continue to maintain plants that will be shut down.

Companies have a unique culture and values, and it is important to remember that these will come into play and may get in the way of change. If the company has always been highly responsive to market shifts, it is likely to have a reactive culture that demands rapid response to any event. A maintenance manager in such a company will have difficulty shifting from a reactive "fix it when it breaks" mode to a proactive mode that focuses on avoiding breakdowns. In such a case the company's strength (i.e., flexibility) has led to a reactive weakness in maintenance that is costly in any business environment.

Successful maintenance practices can be learned from both outside and within the company. Many companies create their own road maps based on benchmarking results and observing what their best plants or others are doing. Regardless of where you get your direction, the description of excellence as you desire becomes your vision.

Your asset environment is usually a given. Unless you are building a new facility or buying a new fleet of vehicles, the plant, the technology and even the people are already there. Your current practices, good, bad or somewhere in between, are also a given. If they do not match your vision, they need to be changed. When the gap between your present reality and your vision is understood, it can be closed. Closing that gap will require a plan that gets you there, and your plan must include all the people, behavior, systems, processes and other influencing factors that will be involved in the changes. Understand what drives behavior in your organization and what you can do that will influence changes in that behavior. Those activities are the performance drivers for making the change happen. They will require a high degree of attention and focus to ensure timely execution.

Stakeholder buy-in is also critical. Stakeholders are those who are most likely to be impacted by the changes you want to implement. This includes your own employees, contractors, suppliers, unions, and departments that interact with maintenance. Getting their input to future plans increases their buy-in substantially along with your chances for successful and sustainable deployment of your strategy.

STRATEGY COMPONENTS

Strategy is the basis for your tactical implementation. It provides a general direction, and it need not be complicated or lengthy. It includes the following components:

- Mission: a statement of what you are there to do. This statement should provide a simple common and clear purpose for the organization. One company's maintenance mission was "to work with production delivering needed production capacity, consistently and safely." The mission rarely changes over time, although the rest of the strategy may change annually.
- Vision: a simple statement of what you are trying to achieve with your maintenance strategy. If you want to improve, describe the standard you wish to achieve. Write the statement in the present tense as if you were already there. For example, "We are sought after as benchmarking partners of choice" indicates that your performance is so good that others want to copy it. Like the mission, the vision rarely changes.
- Tactics: the projects you will implement to put in place new or improved processes and practices. For instance, you may choose to

implement RCM or total productive maintenance (TPM). Those are tactical implementations intended to achieve a strategic goal. Those goals, their specific targeted objectives, and to some degree, the tactical choices are set using the Hoshin Kanri method (described later).

- Target timing: a statement of when you plan to achieve your vision. This does not need to be a complicated Gantt chart with milestones. A single realistic completion date is enough for your implementation teams to work toward. For example, to achieve benchmark-worthy performance, "all critical production systems will have RCM-derived maintenance programs within 2 years."
- Values: a statement of a few simple rules you will follow in implementing the tactics. These rules will reflect shared corporate values for behavior that will hold when the vision is achieved and guide how things get done along the way to achieving it. Your rules should be easy to remember and follow:
    - Take care of yourself.
    - Take care of each other.
    - Take care of the equipment.
    - Take care of business.

Putting a strategy together is a cross-functional team effort. Do not leave it all to the maintenance manager and his/her people. Operations, supply chain, HR, training departments, finance, accounting and plant management will all be affected. Include them in the strategy development team. Furthermore, the strategy must be linked to corporate strategy—without that, you are flying blind and potentially working at cross-purposes to the efforts of other functional areas. Because everyone at the table will have their own "agenda," use a third-party facilitator who is completely independent of the result and the various agendas that each party brings to the table. The person who performed the maintenance review for you is the best candidate because he/she will be knowledgeable about your issues and objectives. Once a maintenance review has been carried out, the strategy development effort requires only a few days of teamwork. Keep it simple. Avoid excessive detail. Implementation plans are needed to support the strategy, but there is no need to include them in the strategy document or statement. Manage those separately like any project.

Because the overall initiative could take several years to complete, do not preplan the details for it all. No plan is ever executed exactly as intended without change, so don't create work for yourself with plans that are very long. Plan for a year at a time, do an annual project review, determine what (if any) alterations to the original plan are needed and add in the details for the following year.

STRATEGY DEPLOYMENT

Without a clear linkage of corporate strategy down through the organization, departmental leaders are forced to interpret strategy and act in areas where they have control, often without collaboration from other departments. Many attempt to cut costs (and sometimes people), in an attempt to boost productivity and profit. But the improvements, as we so often witness, do not last. Many stand-alone initiatives never get implemented; instead, people cling to habitual ways of doing things. New ideas or state-of-the-art concepts do not spring forth from people at the front lines, because they are seldom consulted and too intimidated to stick their necks out. Energies are not released to create new tools or ways to better meet customer requirements, because people are too busy competing with each other to please their bosses. Sooner or later, new crises ensue, and the vicious cycle continues. A method to consistently deploy corporate strategic intent all the way to shop floor implementation is needed.

And this is where Hoshin Kanri strategy deployment comes into play. The name *Hoshin Kanri* translates from Japanese to mean "direction management" (Japanese: 方針管理). It is a method devised to capture and cement strategic goals as well as flashes of insight about the future and develop the means to bring these into reality while ensuring cooperation amongst company functional areas and team members. Corporate strategy, often devoid of asset specific direction, must be converted into meaningful initiatives and projects that, if properly deployed, will yield and provide the expected results to the overall organization.

Hoshin Kanri integrates *strategic planning*, *change management* and *project management* with the *performance management* methods that focus on delivering results. Some specific subprocesses include the following:

- Identifying critical business assumptions and areas of vulnerability
- Identifying specific opportunities for improvement

- Establishing business objectives to address the most imperative issues
- Setting performance improvement goals for the organization
- Defining change management strategies for addressing business objectives
- Devising project charters for implementing each change strategy
- Creating operational definitions of performance measures for key business processes
- Defining business fundamental measures for all subprocesses to the working level

Once a strategy has been set, the next challenge is to align the work that is being performed in the daily management system with the strategic direction.

Hoshin Kanri strategy deployment is be top-down as well as cross-functional. It promotes cooperation along the value streams, within and between all associated business functions. It is crucial to state here that when we address the notion of "top-down," we mean from the top executive floor. Keep in mind that the enterprise as a whole has a myriad of business requirements that must be met over the course of a year. The AM organization within this enterprise plays a key role in delivering performance and has a big impact on the annual outcomes.

The AM organization must consider and include two major inputs: what can our AM organization do to help with the achievement of the overall annual goals, and, more specifically, what are our maintenance goals needed to support those? We need to devise the right initiatives and projects and provide assurance they can indeed be met, yielding the desired bottom line.

Hoshin Kanri utilizes an eight-step process:

1. Identify key business matters facing the AM organization. Consider both inputs from executive-level business strategies as well as specific asset and maintenance management annual initiatives.
2. Establish succinct business objectives that deal with these unique challenges and will address them head-on. Team sessions begin by identifying these measurable objectives so that everyone knows exactly what they are there to achieve.
3. Define the overall vision and goals for the various principal AM value streams. The overall objectives, which may be somewhat vague, are translated into more specific objectives related to the various ways in which AM can contribute to the overall business objectives.

4. Develop supporting strategies for pursuing the goals. In the maintenance organization, this strategy will include projects that encompass the use of AM methods, techniques and tools.
5. Determine the tactics and objectives that facilitate each of the strategies. On each organizational level downward, this initiative becomes more detailed and tactical, reflecting the specific segment or elements of the maintenance management function for which they have been devised and deployed.
6. Implement performance measures (KPIs) for every supporting AM business process. The specific list of these KPIs has been defined under point 2 above. KPIs should demonstrate the following characteristics:
   - Clear
   - Concise
   - Time based
   - Verifiable
   - Measurable
   - Easy to document and chart
   - Have assigned accountability
   - Understood and adopted by stakeholders
7. Measure, display and communicate all related AM business essentials and results. A useful approach is the "Visual Enterprise," in which requirements and results are shown visually on graphs or other means for the entire organization to see. It makes progress visible to anyone and everyone, encouraging performance. Results must flow upward in the organizational chain, verifying that results are indeed supporting and contributing to higher-level objectives as originally intended.
8. Incorporate the Deming cycle (plan, do, check and act [PDCA]) promoting continuous-improvement principles. Ongoing review of progress and results should happen during the "check" phase, in accordance with the "plan" and "do" phases. Where results are less than desirable, corrections and corresponding action items are devised under the "act" phase.

The above process is repeated cyclically at successive levels through the organization using the "catchball" process. The word "catchball" denotes a simple game in which a circle of children throw a baseball around the circle. It metaphorically describes a participative process using iterative planning sessions to field questions, clarify priorities, build consensus and ensure that strategies, objectives and measures are well understood, realistic and timely toward achieving stated objectives.

Hoshin Kanri assumes "open-book" management with nothing hidden. One of its central features is a "balanced scorecard" of continuous process improvement targets that results from the use of cross functional teams in developing the tactical plans as the method cascades throughout the organizational layers.

In many unsuccessful change initiatives the failure to link the achievement of top management goals with daily management at an operational level is a major cause of loss of momentum. It is imperative to understand that perpetual examination and linking of results both upward and downward in the cascading chain is vital. KPI targets are allocated down and results accumulate upward through the various management levels.

Hoshin Kanri integrates planning and doing (execution) at all levels of the organization via an involved deployment process called catchball, cascading management ideas, from complex executive high-level strategic concepts into specific tactical initiatives and projects on the operational level.

Strategic Planning Level

Any organization generally has a small number of key long-range corporate objectives. They support the organization's mission and take it in the direction of its future vision. They are called breakthrough objectives and typically last 2 to 5 years with little change. They are directed at achieving significant performance improvements or at making significant changes in the way an organization, department or key business process operates. Those changes could be triggered by new market and customer expectations, new technology, innovation, government regulatory adjustments, business acquisitions and more. They are strategic and often somewhat vague, but they do provide a direction. They need to be formulated and redefined so they can more easily be understood at the next lower level, which will devise and deploy more tactical initiatives and projects aimed at achieving those objectives.

Management (or Day-to-Day) Level

At the management level, most of the time in an organization must be devoted to keeping the business running, carrying out the value-added activities of the key business processes, which fulfill the purpose of the organization. Examples of those could be operations, supply chain, AM, maintenance management and engineering. Supporting business processes that must be considered include finance, quality, HR, environment, risk, security, etc. These day-to-day business fundamentals must be monitored on a daily basis in all parts of the enterprise. Following PDCA enables process owners to take real-time corrective action for continuous process improvement whenever diminished performance levels, reduced quality levels, increased downtime encounters and duration, escalation in incidents of customer complaints, etc. are encountered. *Kaizen*, the Japanese term for continuous improvement, is built into the Hoshin Kanri approach.

Breakthrough projects deliver on the long-term strategic direction and achieve sustainable business strength while providing a tactical operating plan to achieve short-term performance. Policy deployment anticipates long-term requirements and focuses on annual plans and actions that must be met to accumulate long-term strength. Policy deployment begins when senior (executive) management identifies key issues or statements of vulnerability, where improvement will have its greatest impact on overall business performance. Communication of the focus area or theme for improvement provides direction. Hoshin Kanri assures alignment of the entire organization to that direction while encouraging consensus among the management team from all functional areas on business priorities.

Good practice of strategic management and the use of Hoshin Kanri to deploy your strategy provide the following:

- Focus
- Alignment
- Integration
- Timely execution
- Review

So, how do we do it?

Case Study Showing How Hoshin Kanri Is Used

A large mining company had a corporate strategy statement that contained four very-high-level goals:

- Financial: to consistently deliver superior shareholder value
- Business partners/community: to manage our reputation
- Internal processes: to safely achieve global benchmark practices and performance in all aspects of our business
- People, learning and growth: to attract and retain a talented, innovative, diverse and engaged workforce

Like all goals, these were high level and strategic in nature but, on their own, provided little insight into what must be done to achieve them. They did, however, have an accompanying set of specific targets (objectives) to be achieved to mark success in each of those four goals.

For example, in the area of internal processes the objectives (targets) were as follows:

- To achieve zero harm (with a specific "not-to-exceed" target for lost-time injuries)
- To achieve industry best practice for support to core "full-time-equivalent" staffing ratio of better than 2.5 (i.e., no more than 2.5 support role personnel for each "miner" active in the operations)
- To achieve industry best practice for support to core cost ratio of 20%
- To improve efficiency of loss prevention to 85%
- To be in the top quartile rating for global mining companies in the area of internal controls
- To successfully implement the expansion of mine B

The above goals and objectives were mandated by the company's board of directors and assigned to the CEO to deliver.

The first cycle of Hoshin Kanri was carried out with the CEO and his entire executive leadership team. It flushed out the strategic objectives for the next level in the organization (i.e., those who reported to the executives who were present in this first session) to meet each of the four corporate goals.

That next tier of the organization, in all cases led by one of the executives present, managed the various functional departments and processes.

The internal-process team session produced the following more specific objectives:

- Simplify and standardize policies and procedures
- Improve security inspection effectiveness

- Improve security physical prevention
- Create awareness of product issues
- Reduce product spoilage
- Implement rapid results
- Implement risk control guidelines
- Create health, safety and environmental awareness
- Improve the HR management operating system
- Improve support function management operating systems

Again, these were somewhat vague, but they allowed the team to see what sort of projects would be required. Each of those second-tier objectives was linked to specific "projects" falling under one or another of the original four main strategic objectives. Keep in mind that these senior executives have a good idea where the company had its problems, so the projects were aimed at addressing those problems to achieve the objectives. Those projects were as follows:

- Review policies
- On-the-job coaching and training
- Security inspection booklet
- Implement recruit training
- Develop loss prevention and education program
- Recover mine A spoilage
- Enhanced recovery project at mine B
- Identify and resolve high spoilage areas
- Create temporary facility for mine A motorized vehicle support
- Improve mine A vehicle workshops
- Blasting effectiveness at mine B
- Motorized vehicle availability/utilization improvement
- Roll out risk control action plans
- Implement near-hit and quality programs
- First-line supervisor program
- Train all mine trainers
- Implement competency development process
- Improve quality of HR master data
- Shorten "recruit-to-hire" time
- Automate supplier accounts-receivable process
- Review supplier supply-chain policies and procedures

These projects were quite specific and obviously meant to address known problems that arose in the discussions. Several clearly required changes in asset management and maintenance. Each of these projects was assigned to specific teams of “interested” or “affected” executive-level managers with a designated lead executive (sponsor). Each was also accompanied by specific time lines and measurable KPIs that would mark both progress and results.

That ended the top-level session. The output of that session, the final list of projects, became the input to the next-tier Hoshin Kanri session. That was carried out with the various senior managers and the executives of the senior-level team and was chaired by the team sponsor.

Again, a list of even more specific projects and actions was produced. Each of those subprojects, also with designed managers and KPIs, was the input to the next level down in the organization. In total, there were four levels of Hoshin Kanri sessions, each 2 days long:

1. Executive—corporate leadership (e.g., CEO and his direct reports, mostly senior vice presidents and vice presidents).
2. Functional executives (e.g., SVPs and VPs of operations, HR, finance, etc.) with their direct reports (directors/senior managers). There was one Hoshin Kanri session in each of the functional areas.
3. Operational management (mine general manager with their senior managers). There was one Hoshin Kanri session at this level at each of the large mine operations.
4. Mine and head office departmental levels—senior managers and their reports (e.g., mine engineering and maintenance manager with his section heads). There was one Hoshin Kanri session for each of the major operating departments (mining, ore processing and maintenance) and one for the remaining supporting departments.

Facilitation Is Key to Success

Hoshin Kanri leans heavily on team facilitation, and the teams are typically multifunctional or cross-functional. Like any facilitated effort, the maintenance organization and its supporting and supported functional areas will need to invest ample time away from the daily work environment so they can brainstorm, plan and chart future strategies, projects and plans. Hoshin Kanri sessions specific to maintenance will require participation from these other functional areas to be successful. Successful organizations put the effort in to ensure this happens and they use independent facilitators to avoid any conflicts of interest that can arise from using internal resources.

Team facilitation uses a variety of tools to enhance and accelerate team performance. Meetings, workshops, training classes or seminars can leave us feeling drained, demotivated and far from satisfied with the actual outcome. Competent facilitation is required to avoid such energy sinks as the following:

- Unbalanced distribution of participation efforts and input by group members
- Unmotivated participants who are bored or destructive, unless given enough opportunity to speak, or those who feel they are being ignored by the facilitator or other participants
- The facilitator taking center stage so that participants are only able to influence progress and results in a minor way
- Failure to capture, prioritize and record all ideas that are tabled, resulting in insufficient follow-up action being designated and taken
- Discussions that are not completely understood by all participants
- Chairpersons interested in their own agenda
- Endless discussions concerning minor points that result in the neglect of key items or issues
- Group work that ends unsuccessfully in chaos; goals and results not achieved, putting the entire future strategic and improvement initiatives in jeopardy

Good facilitation ensures that those taking part do not just listen but also actively participate by each making a contribution to the visualization of the subject matter at hand. This encourages a high level of willingness to participate so that the topics discussed are well received, successful learning and development are guaranteed and high levels of comprehension are achieved. To do that, good facilitation uses the following:

- Visual dynamics—All participants are expected to contribute: their ideas, problems, facts, questions, statements, fears, etc. All are documented and displayed, visible to all.

- Organization, clarity and tidiness—Similar or related statements are grouped together and given headings, simplifying follow-on tasks and initiatives.
- Priorities, evaluation and consensus—Specific areas of work focus, interests, opinions, estimates, etc. are discussed, evaluated, prioritized and voted on by the entire team.
- Method variations and breakout action teams—Working groups and learning partnerships are formed to handle individual subject matters and additional details.
- Highlighting views expressed—The use of special signs and symbols allows inconsistencies, points of agreement or disagreement, subjects needing further clarification, etc. to be easily portrayed and visualized.
- Gaining commitment and ensuring results—Lists of recommendations for action and associated plans are generated with detailed activities, deadlines and responsibilities assigned. This sets the group up for follow-up and the implementation of performance measures in the workplace.
- Complete documentation—At the end of each session, detailed photo protocols are generated, providing a very useful reference document to be used in follow-up meetings or team activities. Photographs eliminate the possibility of misinterpretation by the facilitator.

This approach allows for various communication and learning "channels," visual being the most prevalent. It encourages participation from all team members and ensures that their inputs are both heard and considered, thus eliminating potential sources of later conflict or resistance.

MAINTENANCE INITIATIVES

Your improvement initiatives, evolving out of the Hoshin Kanri process, will include activities as described in the rest of this book. The difference between the current reality and the vision is what your maintenance improvement plan will address. The plan will have a number of projects with KPIs, designated accountability and a lot of activity. It is useful to fully understand the major differences between successful practice and current reality. Two other items are critical: (1) ensuring that "successful practice" is a realistic vision for your industry sector and your particular operation and (2) setting priorities for the various activities.

Training and benchmarking are excellent ways to determine successful practices. Benchmarking, discussed more fully in Chapter 6, involves looking at how the leaders in the field achieved their performance targets and will show you what realistic targets really are. Once you know what is realistically achievable and how others achieved realistic targets, you can emulate their approach and work toward achieving your own performance targets. Note that benchmarking is not needed to set your targets; it is needed to learn how to achieve them. You are not looking to keep score; you are looking at others in order to learn how they got to be successful.

Understand your own strengths and weaknesses before studying how others manage maintenance. This is where your assessment results come in handy. When it comes time to compare notes with other operations, be sure to have a list of specifics. What you want to learn from them is how well they are really doing (i.e., the measures and statistics) and, more importantly, how they got their results.

In Hoshin Kanri at the departmental level, those who will be responsible for achieving the results are involved in developing the maintenance improvement plan. The group needs to include your managers, superintendents, supervisors, influential tradespersons and union leadership. You will need people from departments that will be affected outside of maintenance, such as purchasing and HR. An excellent way to do this is to bring everyone together for an off-site strategic planning session. Again, an independent facilitator is very useful. Giving participants the chance to help create the vision and plan will encourage them to pull together when it comes time to get it all done. Everyone feels more responsible for making it work if it is their baby.

MAINTENANCE REVIEW

Maintenance improvement fails when there is little understanding of the situation at hand. There may be a strong inclination in the department to retain the status quo, or there could be friction between production and maintenance. Technically, it may boil down to a lack of knowledge about automation or how to predict probable failures.

For instance, a city transit company wants to use RCM to become totally proactive so that it will have fewer breakdowns on the road. That goal will fail if the transit company does not establish a solid, systematic maintenance work management program—one that ensures that PM gets done on schedule all the time. It does not matter whether the goal or the program comes first, but both must exist to ensure good results.

Before embarking on an improvement program, assess thoroughly the strengths and weaknesses of the present system and which areas head the list for enhancement. A maintenance review can produce a clear understanding of the shortfalls relative to successful practices and let you see the necessary next steps to achieve the vision. It is comprehensive and covers strategic, procedural, technical, administrative and cultural issues. Never underestimate the impact of cultural issues. Experience shows that these are usually the biggest hurdle. The best time to do this is before the corporate Hoshin Kanri process moves to the site leadership level. Individual site assessment results will have no impact on corporate goals or objectives, but they can influence the decisions about what projects are needed when implementing those objectives at the site level.

A complete discussion of maintenance reviews is included in Appendix A. Alternatively, a quick assessment can be done using a Maintenance Performance Grid. A simple grid, measuring the elements of the Pyramid of Excellence against the current status, can give a qualitative score on a scale from "innocence" to "excellence." Table 1.1 provides an example of the grid. Each block contains an abbreviated description of the characteristics of a typical organization operating at different levels of development for each of the 10 elements of the Pyramid of Excellence.

Comparing the perceptions of one department to another can also be quite revealing. At one base metal extrusion plant, four groups evaluated the status of their maintenance function. Production, maintenance and front office management all scored their status at approximately the "competence" level. Project engineering, however, rated it well below, at "awareness." When the results were discussed with all groups together, it was clear that the project engineering team was remote from day-to-day activities and their opinion was driven by what they saw relative to other organizations not relative to results being obtained. This assessment not only shed light on a new strategy for maintenance but also highlighted the need for project engineering to become more involved on the shop floor and vice versa. Many companies still have well-defined functional boundaries that act as barriers to cross-functional information and experience

TABLE 1.1

Simple Grid Measures the Elements of the Pyramid of Excellence against the Current Status

	Strategy	People and Teams	Work Management	Materials Management	Basic Care	Performance Management	Support Systems	Reliability Centered Maintenance	Reliability Quick Start and Optimization	EBAM
Excellence	Maintenance programs clearly support broader corporate strategic goals. Programs and practices well established, documented and undergo continuous improvement.	Fully developed multiskilling, autonomous teams of operators and maintainers active. Specialist engineering support available.	Long-term planning cycles and extensive use of standard job plans. Planning is used to determine all support requirements for new systems based on RCM results.	Stockouts rare. Service level 98% plus. Inventory turns > 2 times.	Full regulatory compliance. PM program features extensive CBM. Operators do some minor PM. Equipment condition good.	Fully balanced score cards for teams. Improvement results evident in performance trends.	Full user acceptance and widespread use of integrated management systems sharing information across the enterprise. Information is widely used in EBAM and reliability work and performance management.	RCM being used proactively for new projects. RCM, maintenance planning and support analysis used before new equipment/ systems are put into service.	Reliability enhancements rely on use of advanced mathematical models and data. RCM results are continually being improved upon. RCFA used occasionally.	Data are useful. Any gaps are closed with a formal knowledge elicitation process to ensure that information is reliable. Decisions are regularly informed with trustworthy evidence.

(Continued)

TABLE 1.1 (CONTINUED)

Simple Grid Measures the Elements of the Pyramid of Excellence against the Current Status

	Strategy	People and Teams	Work Management	Materials Management	Basic Care	Performance Management	Support Systems	Reliability Centered Maintenance	Reliability Quick Start and Optimization	EBAM
Competence	Maintenance strategy and plans align with corporate strategic goals. Improvements in place. Maintenance is "under control."	Multiskilling and managed teams of maintainers and operators. Regular use of RCFA and RCM analysis teams.	Scheduling and planning well established for most work. Compliance high.	Inventory turns > 1. Service level 95% plus. Stockouts less than 5%.	Full regulatory compliance. PM program features some CBM. Operators help with PM. Equipment condition good.	Reliability measures in use and improvement programs monitored, trends being developed.	Extensive management systems in use with integration for sharing and reuse of important information. CBM and reliability analysis tools in place. EBAM in use.	PM program fully developed using RCM/PMO and improved using RCFA. RCM results evident in procedure changes, training, equipment mods.	RCFA used as complement to RCM program. Experimenting with more complex reliability tools/methods. PM optimization no longer needed.	Data gathering is reliable and good information is available for improvement efforts. There are information gaps that are being filled by experienced workers.

(Continued)

TABLE 1.1 (CONTINUED)

Simple Grid Measures the Elements of the Pyramid of Excellence against the Current Status

	Strategy	People and Teams	Work Management	Materials Management	Basic Care	Performance Management	Support Systems	Reliability Centered Maintenance	Reliability Quick Start and Optimization	EBAM
Understanding	Management defined strategy and plans. Improvement efforts are underway and working.	Some multiskilling. Mostly distributed maintenance teams with supervision. Task-based teams used as needed.	Scheduling established, compliance good. Planning for major work and shutdowns as work arises.	Inventory turns > 0.7. Service level 90% plus. Inventory analysis being performed.	Partial regulatory compliance. PM program based on fixed interval tasks with little CBM. Equipment condition fair.	Basic maintenance performance measures in use.	CMMS, EAM or ERP is in use with report generation and analysis. CBM is supported with specialized systems. Documentation, financial records, maintenance, stores, etc. not integrated.	RCM program in use for critical equipment. PM program blends manufacturers' recommendations with experience and RCM results.	RCFA used for more than just critical failures. PM optimization applied to "clean up" the existing PM program.	Data are being used in problem solving (RCFA) but data problems are evident. Decisions still require mostly experiential inputs.

(*Continued*)

TABLE 1.1 (CONTINUED)

Simple Grid Measures the Elements of the Pyramid of Excellence against the Current Status

	Strategy	People and Teams	Work Management	Materials Management	Basic Care	Performance Management	Support Systems	Reliability Centered Maintenance	Reliability Quick Start and Optimization	EBAM
Awareness	Documented goals but no objectives or plans to achieve them. Attempts at past improvement programs have failed.	Maintenance organized by shops. Some area maintainers assigned. Conventional supervision. Occasional teams used for RCFA.	Scheduling with about 50% compliance. Plans for shutdowns only.	Inventory improvement plans in place. Measurement of stores performance started.	Poor regulatory compliance. PM program under development using traditional methods. Equipment condition fair.	Financial measures used to analyze spend patterns. Some downtime records.	Management systems use is spotty and providing little valuable output. CMMS is in place and operating independent of other systems. A number of ad hoc systems are in use.	Downtime analysis is performed and some improvements are implemented. PM program is being followed.	RCFA used for highly critical/ visible failures. It is the primary reliability tool.	Data collection is done but generally data are in poor shape/ useless for reliability purposes.

(*Continued*)

TABLE 1.1 (CONTINUED)

Simple Grid Measures the Elements of the Pyramid of Excellence against the Current Status

	Strategy	People and Teams	Work Management	Materials Management	Basic Care	Performance Management	Support Systems	Reliability Centered Maintenance	Reliability Quick Start and Optimization	EBAM
Innocence	No documented strategy. Maintenance is largely reactive to breakdowns.	Centralized organization based on trades demarcation. No sign of teamwork. Operations and maintenance do not collaborate.	No planning, little scheduling and poor compliance to schedule	Frequent stockouts. Service level poor. Jobs frequently waiting for parts.	Poor regulatory compliance. Minimal or nonexistent PM program. Equipment condition poor.	Only financial measures being watched but no analysis of costs performed.	Little to no use of management systems. May be using variety of ad hoc systems with little to no sharing of data and information among them. Maintenance is operating its own isolated information island.	Plenty of downtime but no analysis of causes or attempts to improve. PM program missing or not followed. Production complains about how badly maintenance manages its assets.	No effective reliability improvement efforts being made. Reliability poor and stays there. Production complains about how badly maintenance manages its assets.	No use of data/ information as evidence in analysis of systems, problems, failures, etc.

sharing. A diagnostic review helps to reveal those barriers so that choices can be made about whether or not to keep them in place.

CLOSING THE GAP—IMPLEMENTATION

With the maintenance review completed, the Hoshin Kanri processes completed, projects defined and a vision established, you must now do the hard work of implementation.

Deployment of these plans is far more than a technical undertaking. It will require a great deal of human change, and that is the hard part. Do not shortchange yourself by ignoring change management at all levels in your organization. Chapter 2 deals with the human elements—the truly challenging aspects of making your improvement initiatives a success.

One business with a solid history of reliability and profitability developed an overall physical AM strategy that dealt with most of the asset life cycle depicted in Figure 1.2 and included company-wide objectives for fixed-asset accounting, economic evaluation of projects and maintenance management. Because of the high average age of the company's assets, there was an increasing demand for refurbishment in an environment

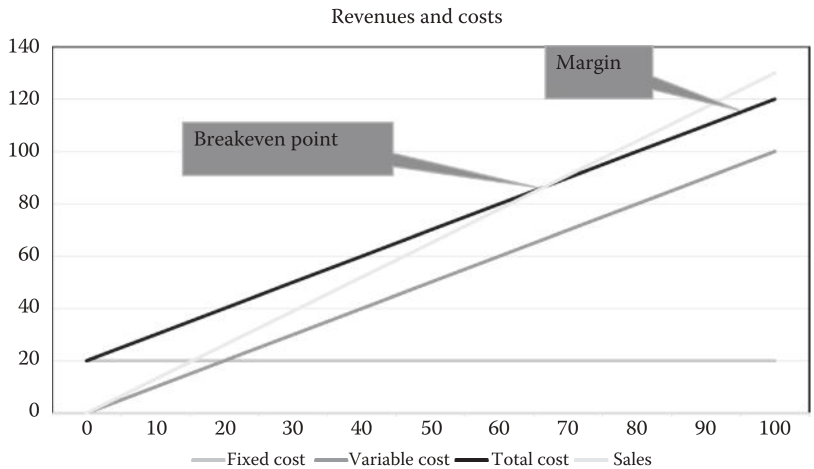


FIGURE 1.2
Fixed and variable costs.

of cost reduction. One key operating division developed its maintenance strategy based on this companywide strategic direction:

- *The mission.* "To maintain assets to meet customers' needs cost-effectively, to continuously improve skills and processes to optimize asset life, using best-fit methods and technologies; to work safely and be environmentally responsible." Each word was crafted after tedious but heartfelt debate by those who had to live with the finished statement.
- *Objectives.* A vision was set by looking at the current situation—challenges in structure, planning, methods, skills, applied technologies and measures—and by coming to a consensus of what was possible over a 3-year period. Five long-term "breakthrough" objectives were selected to fill the gaps between the reality and the vision. The focus was on having higher equipment effectiveness than the industry average at a lower maintenance cost based on the replacement value of assets employed.
- *Action.* Each objective was "owned" by those responsible for ensuring successful completion and a champion, who committed resources, developed a timetable and structured a detailed implementation plan. Orchestration of these plans was key to overall success. Monthly progress review meetings were held to share successes, determine how to overcome obstacles, and manage frustrations.

The company stuck to its strategy, making measured steps to improvement in a tough business climate, and succeeded at making the desired changes.

BUSINESS OF MAINTENANCE MANAGEMENT

Maintenance management supports a business by keeping its productive assets (plant, equipment, vehicle fleet, etc.) available for use. The product that maintenance delivers is "availability"—uptime. It also provides, indirectly, improved yield and process rate, quality, safety and environmental performance.

Downtime is usually (but not always) unproductive time. It may be caused by lack of market demand, repairs or scheduled maintenance.

We can minimize the amount of time spent on scheduled maintenance by doing only the right maintenance. We can minimize the unscheduled maintenance downtime by being more reliable—that is, by consistently and conscientiously performing the right scheduled maintenance. Even where market demand is low, we can idle spare or excess capacity, cutting costs by idling less productive assets and reducing shift requirements. The role of maintenance must be fully integrated with production and sales strategies so that the company can meet its production targets to meet market demand. This means optimizing our asset availability and capacity for the business.

Maintenance and plant managers have often been too technically focused. This shows whenever they try and fail to get improvements funded often because they cannot show the relevance of their ideas to those who will finance them. They need to understand the business as a whole and their role in it and get away from thinking only of technical matters, getting things fixed when broken or keeping them running to the end of the day or end of the shift. Ron Moore (2002) provides an excellent discussion of this integration of key business functions in his book *Making Common Sense Common Practice*. *Uptime* focuses primarily on the maintenance aspects of that integrated manufacturing strategy.

Maintenance keeps an asset performing to the standard that is required by a business to achieve its objectives. This is a rather straightforward statement, but its full meaning relies on an understanding of the term *objectives*. One obvious objective is a healthy bottom line. From a purely financial perspective, maintainers can have significant influence on a company's bottom line. In any capital-intensive industry, so long as production rates can rise to meet demand, production costs (i.e., the total of operations and maintenance costs) and revenues both rise and fall in response to the volume of sales. As Figure 1.2 illustrates, there are substantial fixed and variable costs that must be recovered before a company makes any profit. Note that this is a simplified representation—fixed and variable costs are rarely as linear as shown. What should be obvious, however, is that all companies want to maximize profit and increase the slice of the diagram labeled "margin."

Increasing the margin can be done in a number of ways. You can increase sales revenues if, in your competitive market, you can increase either the price or the volume of production, or you can reduce fixed and/or variable costs. Maintenance can have a significant impact on these business results by focusing on doing more proactive maintenance, reducing spares inventories, planning and scheduling work more effectively. Good housekeeping (an underrated maintenance activity) can have a direct impact on quality of production, reducing scrap, rework and other non-value-added activities, improving employee morale, in turn reducing costly mistakes.

Price is often set by market conditions, and maintenance is unlikely to have any impact on it at all. It can, however, have a profound influence on production volume. If your product or service is in demand and the market will buy more, then this is of value to your business. Additional or supplementary uptime increases your production capacity so that you can produce and sell more, generating greater revenues at higher margins. A cautionary note that must be considered is that if your business is market (or externally) constrained, you will be unable to sell the additional product, and increasing production output overall will not help. In fact, in this situation, you may already have excess production capacity, and increasing uptime seems valueless. Increased uptime, however, has other advantages.

If you can increase uptime substantially, then it may be possible to meet the market demand using only a portion of your fixed-asset capacity. In this case, you can shut down and idle excess capacity, reducing both fixed and variable costs. For example, an aircraft parts manufacturer was able to meet demand using two production shifts instead of three. While the company's fixed costs remained the same, its variable costs were cut by one-third.

Another case demonstrates how uptime can be used to alleviate a different problem: capacity constraint that may be related to a bottlenecked production process. In this example, a large open-pit copper mine was operating a fleet of 100 haul trucks, but capacity was constrained by the shovels used to load them. By increasing truck reliability, the company was able to increase overall haul truck availability by 3%—97 trucks could now haul the needed capacity. The mine removed three trucks from service, reducing both fixed and variable costs. In a similar case, the mine sold its extra haul trucks and recovered some of its capital investment.

One newspaper printing plant is selling its spare printing capacity to other newspapers. The growth of online readership has decreased demand for hard-copy newspapers so excess capacity could be turned into a new line of business—contract printing.

Of course, you can also perform maintenance more effectively (doing the right things) and efficiently (doing them well) overall. This has the effect of reducing both fixed and variable costs. Even an idle physical plant requires a minimal amount of maintenance in order to preserve it for potential future use or resale. That is a fixed cost. If maintenance demand increases or decreases, it is evident that the cost of parts and labor will also fluctuate in unison, but the cost of managing them will not. Management costs are more or less fixed in most businesses, regardless of the variable demand. Changing fixed maintenance costs requires a reduction in the physical plant itself or a reduction in the management effort. Reducing the physical plant will also lower the financing component of fixed costs. If this can be done at the design stage of the assets, it has a substantial positive business impact. That is one element of AM that requires experienced maintenance input, or the opportunity can be lost. Management effort can also be reduced through increased dependency on self-managing teams as described later in this book.

Direct maintenance labor and parts costs are variable. The more maintenance we do, the more labor we expend. In most cases, that also requires the use of parts, materials and other supplies. For example, as a rule of thumb, direct maintenance labor and parts costs are roughly equal in most industries in North America. If a company spends $5 million per year on maintenance labor, it will be spending close to $5 million per year on parts and materials consumed in maintenance activities. It makes little difference whether that labor cost is paid to a company's own employees or contractors unless those contractors are paid less, trained less and receive fewer benefits than employees. Outsourcing is a complex strategic decision that must be addressed not only from a cost perspective but also from the perspective of the quality of workmanship received and the incentive to a contractor to deliver value in the long term as opposed to capturing only short-term profits.

Direct maintenance (variable) costs can be reduced. An effective maintenance effort results in higher asset reliability, increased uptime and more productive capacity for the effort and cost expended. An efficient maintenance organization delivers its maintenance program (and hence, the results it obtains) at a lower cost. The objective is to combine these two seemingly diverse matters and thus improve the overall system. The results can be very impressive and rewarding. One government report in the United Kingdom, for example, showed that a 10% improvement in maintenance performance could create a 40% increase in bottom-line business performance.

Quantifying both the direct and indirect costs of maintenance to your company (including costs of downtime, rework, scrap, lost sales, penalties, etc.) provides a tool for prioritizing maintenance activities and justifying maintenance improvement expenditure. An investment in maintenance can reduce downtime and its associated costs. Your business may also benefit indirectly as a result of an effective maintenance program. Regulatory compliance, compliance with quality programs, insurance, ability to borrow and the elimination of extended warranty costs can all be of value.

Regulatory Compliance

Extensive regulation has had a profound impact in the financial industries as well as on executives of major corporations—some of whom have been prosecuted and/or jailed for their roles in financial meltdowns, such as those that occurred at Enron and WorldCom. It will not be long before similar legal action is taken against executives whose management systems have failed to prevent deaths due to industrial accidents. Legislation on this has already been enacted in the United Kingdom and will likely be followed by similar legislation in Canada, Australia, Europe, the United States and elsewhere.

Most companies are doing all they can to comply with pertinent regulations about safety, the environment, maintenance of lifting apparatus and so on. Not following regulations that pertain to your industry, be it mining, food and drug, nuclear, chemical handling, workplace safety, etc., you are liable to be caught, fined, lose any AM certifications or even face jail time. Your company can lose its license to operate and risk being shut down, throwing many out of work. Even if this worst-case scenario does not occur, being cited for noncompliance can severely dent your company's financial forecasts and damage its reputation. Consider, for example, how Exxon's reputation suffered after the *Exxon Valdez* oil spill and, more recently, how BP's reputation suffered as a result of the Deepwater Horizon spill in the Gulf of Mexico.

At a bare minimum, then, your maintenance program must be compliant with regulations. Inspectors from various government regulating bodies are very good at spotting areas of noncompliance; they are also diligent about warning companies to change things before accidents happen. It is wiser to view these agencies as friends rather than as foes and heed their advice. But while getting a "clean bill of health" from your inspectors is certainly welcome and laudable, it indicates only that you are doing the minimum. To be truly successful, you must reach higher. One way to do this is to be scrupulously attentive to maintenance management.

Quality Programs

Quality programs have two major components—quality management, which provides the strategic philosophy for the company's quality program, and quality assurance, which includes the daily tactical activities to ensure quality of output. Many companies follow rigid quality programs and are certified to standards such as ISO 9001-2000, which requires that you document what you do, follow it, and be able to demonstrate that you are following it.

Quality management includes elements such as a charter (philosophy), requirements for standardization, supplier performance, standards, etc., and requirements to meet both internal and external customer expectations and requirements. Independent International Organization for Standardization (ISO) auditors verify compliance and certify the company.

Maintenance has its role to play. In addition to meeting the requirements of its internal customers (operations), it must ensure that the physical plant is capable of delivering to meet external customer requirements. This means keeping the plant reliable so it can meet production volumes and keeping it running well so it can produce quality output. Machines that are no longer producing within specified tolerances are creating waste and, ultimately, low-quality products.

To do its job effectively, maintenance can use methods like RCM (Chapter 8) to define the optimum maintenance program required to meet quality standards.

Insurance

Your company's insurance will stipulate that you comply with all the applicable regulations. Your premiums will depend both on your performance relative to your industry and on your industry's performance overall. Industrial insurers also have inspectors who can help to identify risks that could lead to future claims or potentially higher premiums. These inspectors serve two masters—they help you identify risks so that you can take appropriate action, and they also help their own companies minimize their exposure to excessive levels of risk. If they deem your operation to be unsafe or excessively risky, you will either pay more for your coverage or become uninsurable. By managing an effective maintenance program, you reduce risks to your business, making it more "insurable" and possibly even reducing your insurance premiums.

One insurance company in Canada offered its client, a global mining firm, reduced annual premiums if the company agreed to use analytical approaches like RCM to determine its maintenance requirements and could show compliance with the maintenance program developed that way. RCM was instrumental in highlighting potential risks and defining appropriate mitigating strategies while providing a well-documented and defensible decision process. The company saved over $2 million per year, easily paying for the analysis work in the first year.

At the time of writing, the California Public Utility Commission (CPUC) and the US Federal Energy Regulatory Commission are moving away from compliance-based regulatory schemes toward rewarding utilities for proactively managing their risks while penalizing those that do not. In Ontario, one utility was recently dropped by its insurers when the Ontario Energy Board rejected their application for funding the renewal of aging equipment.

Banks

Many companies borrow money to buy capital equipment or lease equipment for operations. That equipment will have a resale or disposal value at the end of its forecasted useful life and will depreciate in value over time. It will also have ongoing maintenance costs associated with its upkeep. Banks realize that a well-maintained asset will last longer, run more reliably, generate more revenue and have a higher resale value down the road. Like the insurance companies, banks want to reduce all potential risks associated with loaning your company money. Banks want you to repay your loans or keep current with your lease payments. If your business risk is minimized, so is theirs. Increasing asset reliability reduces your business risk. Higher utilization increases your profit potential, making your business more attractive to investors and lenders. Some banks will consider what you are doing to manage your assets and give you more favorable terms on loans and leases if you are doing things well.

Warranties

Warranties are a form of insurance. You pay for them up front, and you pay to keep them in force. You must then follow the instructions of those who do not own or operate the assets and have no material concern in your costs or business results. The warranty provider has interest only in reducing its own risk.

RCM analyses often reveal that manufacturers' recommended maintenance is overkill while missing important failures that are unique to your operating environment and context. Consider that the manufacturer rarely operates their own product—they sell it to others. Many do not even maintain their products, so they have limited ability to learn about their own products' failures and how they impact your business. They are rarely in a good position to recommend anything more than the most basic maintenance. Why tie your success to a requirement to follow their recommendations?

Consider the cost of warranty. Typically you will pay 2%–3% of the capital cost to obtain warranty coverage. You are paying for your suppliers' insurance coverage and then, should something fail, will battle with them for every claim! A thorough RCM program will cost about the same amount; when something fails, you still need to repair it, and you avoid the hassle of haggling with suppliers. In most cases, you are better off investing in RCM rather than warranties. Warranties are rarely worth the investment and effort, and they only provide limited coverage for a limited time. RCM, for roughly the same cost, will provide benefits that far exceed the value of any benefit paid under warranty, and those benefits continue for as long as you own the asset.

A good AM strategy considers all of these factors and their potential to help or harm your business.

Until recently, many maintenance managers came from technical or trade backgrounds, and they seldom thought in terms of return on investment. Although they understood the concept, they did not live it. Today's maintenance manager cannot afford this luxury. He/she must understand and live the concept and pay strict attention to the business aspects of his/her role.

Maintenance management deals with the tactical planning, organizing, directing and use of the resources necessary to keep your physical assets running well and contributing to your customers' as well as your own business success. Several questions can help you determine whether this is being done effectively and reveal where a more holistic AM regime (Chapter 11) may help your business:

- Can the assets be designed for better maintainability and higher reliability? Will the added investment be worth it?
- What is the impact of financing on the capability of new assets? Does the payback cover at least the cost of capital?

- How do operating expectations, procedures and practices affect asset performance?
- How do the efficiency and effectiveness of our maintenance efforts impact asset life-cycle costs?

Clearly, maintenance is only one part of the overall asset life cycle, which covers everything from the time when the productive capacity needs of the asset (e.g., a vehicle, press or pump) are determined until the time of its disposal (Figure 1.3).

On a linear time scale, the "operate, maintain and modify" cycle takes up most of the "life" of the asset. Modifications are made if the asset no longer meets the demands of the business or in response to continuous-improvement initiatives. Today, many organizations are rethinking their approach to managing this asset life cycle, often triggered by continuous-improvement ideas and adopting a different approach: physical AM (often abbreviated to AM, as discussed later in this book). This approach goes well beyond the traditional boundaries of maintenance and engineering

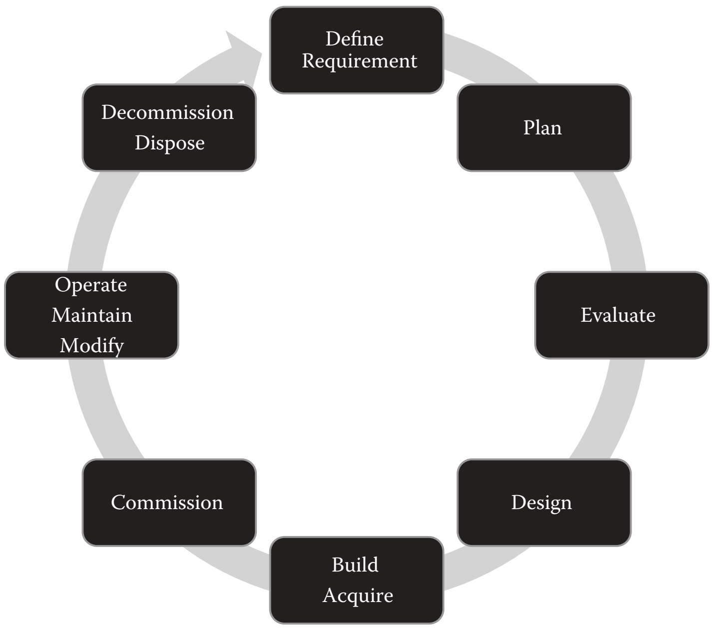


FIGURE 1.3
Asset life cycle, which covers everything from the time when the productive capacity needs of the asset are determined until the time of its disposal.

by embracing financial considerations, market realities and the human capital necessary to make it all happen.

Traditionally, most businesses were organized to think and act in functional silos—"I design, you operate and someone else fixes." Many companies still operate this way. Within this framework, however, it is often easy to miss the overall business process. Those who subscribe to this mentality often miss out on insights that others in the organization can contribute. Those insights can often make a tremendous difference in the way assets are perceived, managed and maintained.

Successful Lean[1] manufacturers get away from functional silos. They rely heavily on teams of operators and maintainers working together. At the production-floor level, they combine their ideas and insights, making continuous improvements that relentlessly reduce levels of waste and improve productivity. Managers still have their role, but they, too, participate in the teams and contribute insights that often lead to improvements. Anyone's ideas, even those of casual observers who may notice something as they tour the plant, are treated as valuable inputs.

Electric power, transmission and distribution utilities were once publicly owned monopolies charged with providing uninterrupted services. To ensure high reliability (i.e., uninterrupted service), they built in a great deal of hardware redundancy and usually overdesigned their systems. Costs were simply passed on to users and/or the taxpayers and justified on the basis of a need for high reliability. Now deregulated, these utilities are learning to compete in markets where overdesign reduces profitability. They already knew that reliability can be bought; they are now learning that it cannot be bought at any price. They are recognizing the need for more economical approaches to keep asset investment costs and operating costs down and reliability and service levels up. Their business has changed, and so has their approach to managing their physical assets.

Good AM begins by asking why the asset is required and how it impacts the business strategy and plans. Once this has been established, the purpose, function, standards of performance and key performance indicators (KPIs) must be set. Costs and benefits are evaluated; the asset is justified and ranked as an investment option by the company. Well run organizations ensure that lessons learned from past use of similar equipment are incorporated into the design and selection choices. The new asset is constructed or procured and installed. Once it gets a thumbs-up in testing, it is operated and maintained (and often modified as requirements change and as time goes on). A key to providing valuable decision-making knowledge during the life cycle of the asset and input to the next cycle is the documenting of experience so that better decisions can be made for the next generation of assets. When the asset's economic usefulness ends, it is disposed of, and its valuable past history is retained.

Reaping the cost benefits of an asset rests on all steps in its life cycle. Ideally, maintenance, operations, engineering, materials, accounting and any other related departments can and will be involved each step of the way. Even before the systems are built, the decisions about what to build, how to build it, how to operate it and how to maintain it will have an impact on the business for years to come. Capable engineers must design the systems. In truly Lean environments, the concept of concurrent engineering is used. Operators, maintainers and even suppliers contribute during the design phase. An axiom related to this approach is that 95% of operating and maintenance (O&M) costs are determined in the design phase, the first 5% of the asset life cycle. Once the systems are in place, capable maintainers and operators must keep them running.

It is almost paradoxical that the operators who run the systems and the maintainers who care for it often have very limited potential to influence the asset or system's total life-cycle costs. Those costs are often driven by design constraints and limitations that they must simply "live with." It is at the design stage that most decisions that have an impact on total life-cycle costs are made. Figure 1.4 illustrates the commitment and spending patterns during critical phases of an asset's life cycle. As the figure illustrates, maintainability and reliability considerations have the greatest impact early in the process, during the design phase. Almost as soon as the asset is built and deployed into service, the flexibility to deal with maintainability and reliability problems is dramatically reduced, yet those same problems become far more visible and their impact on the business more apparent. Costs continue to accumulate, and the rate of that accumulation is largely driven by decisions made before the assets were commissioned.

The operations and maintenance stage of the asset life cycle is dramatically influenced by the reliability of the design. If you are running and maintaining a system that is inherently unreliable, no amount of maintenance effort will improve it. Too often, there is no time to do it right the first time but plenty of time to do it over and over again later. You will need costly design modifications. Using the practical knowledge of experienced maintainers and operators at the design stage can result in significant savings in O&M costs. These individuals can provide excellent insight into issues that are best dealt with before the design and construction begin. In

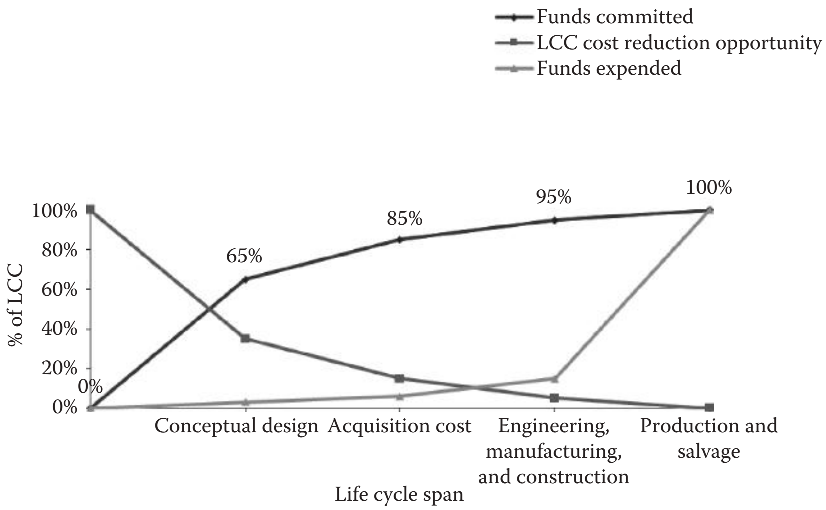


FIGURE 1.4
Commitment and spending patterns during critical phases of an asset's life cycle.

some cases, they may even help avoid excessive capital costs. For example, by including high reliability and design for maintainability as considerations for choosing among options for a fleet of buses, it is possible to get more available service time from individual buses. This, in turn, affects the desired overall fleet utilization as fewer buses will be required. Because fewer buses are required, less capital is spent up front. An excellent tool is RCM, which can be deployed at the design stage, often yielding very effective design insights. RCM is described later in the book.

In the United Kingdom, the privatization of the electricity industry led to a tremendous improvement in performance. This occurred because risk in AM was explicitly acknowledged, and this led to the development of decision-making models that consciously traded off cost versus risk versus performance. The net result was a 30%–40% across-the-industry reduction in cost (and manpower) with a simultaneous improvement in asset performance, which was measured as a reduction in customer outage duration. Financial values were placed on customer service levels, image, environmental compliance or breach and regulatory compliance or breach, allowing optimization of the total picture.

Most people tend to think of the steps in the asset life cycle as being sequential, but this is not always the case. The design, procure, build and operate phases may actually overlap. Operate and maintain certainly overlap during the entire life cycle of an asset. When the need arises, both of these are overlapped by modification. Complex systems take years to design and build and are rarely built exactly as designers originally envisioned them. Compare any "as-built" drawings to the engineering drawings, and you will observe that. Design of the maintenance program ideally overlaps with the design of the asset. Up-front definition of the right maintenance through concurrent engineering and early deployment of RCM can lead to substantial benefits in life-cycle cost reduction. Design flaws are often found when this up-front analysis is performed—they can be corrected on the drawing board instead of in the field. Maintainability issues can become apparent and can be rectified so that downtime is minimized once the asset enters service. Knowledge of maintenance requirements can drive the identification and purchase of spare parts. Often, spares are bought at the recommendation of manufacturers, not maintainers. But ask yourself who benefits from this, and you will discover that having available the spares that maintenance says are needed when the asset starts can help avoid unnecessary downtime. If that seems too expensive an approach, then consider that the cost of those spares is very likely much less than the cost of the downtime avoided.

Today, demographics are a critical issue for all industries. As the baby boomers retire, a massive succession problem has grown. The generations that follow are not smaller in numbers, but they have different work ethics and values. Postboomers (generation Y and millennials) grew up (and are growing up) in the Information Age. They learned far more about computers and high technology than about skilled trades. Few children or grandchildren of the baby boomers have shown an interest in learning a trade; their parents and grandparents have encouraged them to get college degrees and become "professionals." Two strategic issues arise from this state of affairs. Just who will replace the retiring boomers who are trade skilled? And how will we capture the knowledge that is leaving as seasoned workers retire? This problem began to materialize more than 10 years before the publishing of this edition of *Uptime*, when the boomers began to retire, and it is still unresolved. Economic conditions in late 2008 devastated many boomers' retirement funds and plans, so there is a temporary reprieve as they delay retirement. However, that will not last forever, and it is keeping the door shut on job opportunities for the younger workforce.

Dealing with these issues will be challenging, and solutions will not be quick fixes. Immigration, an old and reliable solution, will not work on its own. Other countries are facing the same problems or do not have the ability or resources to train people in trade skills. Outsourcing is an option, but even the outsource service providers are facing similar challenges. Part of the solution lies in doing more work with fewer people—in other words, becoming more efficient. Another part of the solution is working smarter—becoming more effective. Two particularly good ways to do the latter are through the proactive maintenance programs discussed in this book and through designing for reliability. Providing trades training and apprentice programs is also part of the solution and can be applied to newcomers from overseas who lack skills but are willing to learn them. Sadly, shortsightedness in government and industry has resulted in a dearth of these programs. Industry and government have not collaborated effectively in this area. Both have failed to see the strategic importance to both industrial success and national well-being.

Contract Maintenance

Many businesses contract out some form of maintenance, whether specialized technical work, like nondestructive testing, or overflow fabrication and machining work. Some contract out the entire maintenance function, while others contract out all operations and maintenance. The practice of outsourcing maintenance is common around the world (more so in Australia, Asia and Europe than in North America, but it exists everywhere). In fact, several very large contracting firms look after maintenance for hundreds of plants worldwide.

There are many reasons for contracting out or outsourcing maintenance. The most common is that a contractor can do the work more cost-effectively than you can. Some companies use outsourcing to transfer risk. By having a contractor take full responsibility for maintaining lifting equipment, elevators and hoists, for example, you eliminate (or substantially reduce) an element of risk and potential liability from your business. In other cases, the work requires technical specialties that are not available (or wanted) in house. Heating, ventilation and air-conditioning (HVAC) maintenance is very commonly outsourced for this reason. Occasionally, there is simply not enough work to justify having your own talent do it (e.g., some companies outsource their oil analysis work). Some companies look to outsourcing as a means of alleviating the demographic problem of finding enough skilled tradespeople, not realizing that the outsource service providers may have the same problem.

Contracting maintenance has many benefits, including labor leveling for shutdowns and cost and capability factors. It also has some drawbacks, such as the difficulty in controlling quality and getting the labor experience needed. To answer the strategic questions of whether to consider contracting significant portions of your planned and preventive maintenance, first, understand the concept of competitive advantage. Your business has one or several core products and services that you provide to customers. There are a few core processes and physical assets that allow these processes to happen, but no one, when asked, would consider their part of the business to be "noncore." Can your cost-effectiveness and capabilities in maintaining these assets be considered a competitive advantage, something that allows you to compete and win in the marketplace? If so, contracting out maintenance of these assets may give away or diminish some of your competitive advantage.

Many believe that maintenance is a core capability that cannot be contracted out. Rather than think in terms of core versus noncore activities, it may be better to think about "uniqueness." If what you do in maintenance is unique to your business, then it is something you probably want to hang on to because no one else is doing it and it may be difficult (if not impossible) to find anyone to take it on. If it is something that is commonly done by many other companies or service providers, then it can be considered appropriate for outsourcing. Something that is not unique is unlikely to give your company any competitive advantage. In fact, that sort of work may even be done better by another company since that company will focus on the work as a business instead of treating it as a "necessary expense item." For example, an electrical rebuild shop that services several dozen customers may do a better job at rebuilding motors or switchgear than your own electricians, who also have many other, more pressing tasks to perform. The diagram in Figure 1.5 can help you determine whether outsourcing is a good option.

	Strategic	**Not strategic**
Competitive advantage	Keep work in house	Consider outsourcing (evaluate)
No competitive advantage	Rework to provide advantage	Outsource

FIGURE 1.5
Is outsourcing a good option?

Ask yourself if the maintenance activity is of strategic value to the business. Is it unique to your business, or does having the capability in house result in some other advantage in the market? For example, if maintenance costs are typically high in your industry, you may want to keep it in house, where you can have better control over those costs, unless you can find a credible contractor who can promise better cost control or take it on for a fixed cost. On the other hand, a contractor who is more skilled at maintenance may deliver the greatest uptime. Which is more important, cost or results? Generally, if you can get more uptime, your costs will drop, and output will increase.

The competitive dimension row in the diagram helps you determine whether or not you are already providing cost-effective maintenance compared to what is offered at what price by external service providers. If maintenance is of strategic value to your company and you are providing it cost-effectively, maintain the status quo. If what you are doing is not cost-effective but it is of strategic value, then consider an improvement program for your maintenance function so that you can deliver it more cost-effectively.

If you do plan to contract maintenance, your key concerns will be contractor productivity and performance. Ideally, the contractors will be subject to a thorough review, appropriately trained and not subject to high turnover. Contract out specific, well-defined projects or responsibilities and ensure that performance standards are set and closely monitored. "Service-level agreements" based on minimum acceptable standards of performance results have proven successful. Do not specify how to do what you want done; do specify the results or performance outputs you want. Leave the "how" to the service provider but give that provider an incentive to do the work well. Remember that providers expect to make money too; if they save you money, it may mean they are earning less. Successful outsource agreements stipulate that a contractor can earn more if savings are realized.

Clear lines of demarcation should be drawn between in-house and contract involvement. Contracting can bring a lot of flexibility to your business, but it requires assertive management and control. Managing contracts is not the same as managing your own people—it requires a different skill set and approach and may require new people or additional training for your existing staff.

An example that illustrates the broad concept of outsourcing centers on some interesting challenges facing a global mining company that is choosing excellence. The company has chosen TPM[2] as a preferred method for improving performance at all its global operations. Several of its mines are already using outsourcing under Maintenance and Repair Contract (MARC) agreements. These were originally put in place using the manufacturer's recommended maintenance practices as a basis for pricing. There was no provision to encourage reliability and availability improvements, so performance remained relatively flat. There was also no mechanism to encourage teamwork between maintenance, which was outsourced, and operations, which were performed in house. Another problem can arise where the contractor refuses to accept input/guidance/direction from the contracting company. While you can outsource activities and risks, you cannot abdicate all responsibility. Contracts must allow for communication and dialogue.

In one mine, the company chose not to renew the MARC agreement and brought all the work back in house. Within a year, reliability and availability at the particular mine were up, and costs were down dramatically. The company is now seeking to challenge its other MARC service providers in ways that encourage similar improvements by using asset- and team-based approaches so that both the customer and the outsource contractor benefit in a win–win arrangement. Service providers not interested in such an arrangement may lose the company's business. An alternative solution is to outsource operations along with maintenance. Another is to perform all the work in house (as the mining company did). If the work is outsourced, gain-sharing[3] provisions in the contracts can be used to encourage reliability and availability improvements using reliability methods.[4] This might also work for team based methods like TPM, although management of a joint program involving employees from two companies could prove challenging. There is no easy answer to this issue, but the onus is on the contractor to convince company decision makers that the work should be outsourced. Because many companies are becoming increasingly more selective about whether and to whom they should outsource, it is up to service providers to come up with attractive proposed solutions for their customers.

UPTIME SUMMARY

Uptime's Model of Excellence has three parts: leadership, essentials and choosing excellence. Having a clearly defined and achievable strategy with a vision of your future state and goals is a big part of good leadership.

In choosing excellence, you will be choosing a path of constant change and improvement, but remember that excellence demands leadership. Leadership is about vision and direction (strategy), its effective execution and your people—arguably the most critical element. Taking your organization from ordinary to extraordinary requires an idea of what extraordinary looks like, a sense of where you are now and a plan to close the gap. Making those changes can be a complex process, and it will not come without some angst and pain. Good leaders are there to rock the boat, and managers keep it stable—this dichotomy sets you up for conflict. It must be managed.

Maintenance is a critical business function. It sustains your productive capacity, contributing to both fixed and variable costs. Reducing maintenance costs through efficiency gains (doing maintenance the right way) and effectiveness (doing the right things) increases operating margins. Maintenance also contributes substantially to the company's safety and environmental performance and its overall risk profile as viewed by financial and insurance institutions.

Well-maintained assets meet production commitments easily and at low risk, something that lenders and insurers like to see. When building a new plant, consider the importance of maintenance and reliability decisions at the design stage, when you have the greatest opportunity, by far, to reduce total life-cycle O&M costs. Maintenance strategy is easily set in these "greenfield" scenarios but more difficult in an existing operation with all its habits.

Strategy should be kept simple. Your business objectives, the asset environment, its present state and the state of maintenance management practices are your starting points. Understand what it means to be a high performer and using successful practices—training in *Uptime* is an excellent starting point. Bear in mind, though, that whatever is best for your company is what works best for your company—while there are successful practices, there are no best practices. Based on your organization's strategic direction, decide what you want to achieve—that is your vision. Look at performance and practices today—they are good indicators of your ability to achieve your vision. Consider what successful practices, such as those described in *Uptime*, will be best to help you close any gaps. Develop a plan of action to implement those improvements. Plan the broad brush strokes for the entire initiative. Do not be surprised if it takes many years to complete. Detail that plan for the first year and begin implementing. Execution is what matters.

Good governance of your improvement initiative and integration of it with other improvement programs is essential. To avoid conflicts and competition for resources, use Hoshin Kanri to deploy your strategy. Ideally, that process begins at the corporate level so that your maintenance vision is driven by a clear sense of where the organization is going and how it is going to get there.

In some cases, you may choose to outsource maintenance. Do it for the right reasons. It is not a way to unload responsibility, and transferring a "problem" to someone else may not be the answer. If done poorly, it can even be harmful. If maintenance is of strategic importance or if it is unique to your business, you are probably better off keeping it in house.

Once you have embarked on making improvements, it is important to sustain them. Excellence as described in this book is a journey, not a destination. Do not rush it, sustain the pressure to improve and never let up. Annual reviews of your strategic plans, tactical deployment activities and progress are essential elements to keeping on track with your journey. You will know it is working when you find yourself dealing with new challenges every year and not revisiting the same ones.

ENDNOTES

1. Lean manufacturing refers to a business model and collection of operational methods that focus on eliminating all forms of "non-value added" activities (waste) while delivering quality products, on time and at the least cost.
2. Total productive maintenance (TPM) is discussed in detail in Chapter 10.
3. Gain-sharing concepts are described more fully in Chapter 2 as related to people, but they can be applied equally well in contracting situations.
4. Asset-centric methods are described more fully in Chapters 8 and 9.

2

People and Teamwork

Talent wins games, but teamwork and intelligence wins championships.

Michael Jordan (basketball star)

At the time this edition of *Uptime* is being written, approximately half of the baby-boom generation is 60 years or older, and many are already retired. With them goes a lot of corporate knowledge that is contained in their heads. Many of them, particularly the older ones already gone, were not the best with computers, and they did not do a good job of recording what they knew for their successors to learn. That loss of corporate memory is exacerbated by several factors:

- The widespread inability of many organizations to deploy computerized systems effectively so they can make up for the shortfall in providing valuable input to inform decision making. Technology has enabled a great deal, but we have been largely incompetent at harnessing that capability and leveraging it to its fullest extent.
- The erosion of apprentice training programs that are government funded and provided through educational institutions puts the onus on industry to train its own. There is a recent trend making up for this, but so far, it is producing far fewer recruits than industry can use.
- The failure on the part of industry to protect its own interests and run with the ball on apprentice programs whether in partnership with colleges or on its own.
- The generally accepted drop in educational standards overall that make hiring someone who has not at least graduated from high

school and preferably from some form of postsecondary education or training unattractive, thus limiting the available talent pool.
- The high level of interest on the part of the baby boomers' successors in computers and their capabilities has meant that fewer people are pursuing the trades and those jobs that are being vacated are becoming increasingly difficult to fill with someone who has the same level of skills.
- The changing values that people hold today. While baby boomers tended to "live to work," their successors "work to live." Some lament that work ethics have eroded, but they have not—they have just shifted and arguably in a direction that anyone would want for his/her own children!
- The desire for instant gratification that has been fostered by our growing familiarity with technology and the quick answers and pleasures it can provide. All of us, young and old alike, are now used to getting what we want from technology more or less always on demand, and we tend to forget that in "real life," things do not happen that fast. Our expectations on what people can and will do in the business setting are often unrealistic.

Increasingly, we are being asked to "do more with less," but what we really want is "more result with less effort." Working smarter, more effectively and more efficiently are keys to success. In the dimension of human resources, we are especially challenged because increasingly, we have less to work with. We need increased productivity from fewer people. As our people adapt to the only constant we can count on, change, we gain security and competitive advantage. Getting the most from your people by adapting to change, responsive team-based organizational structures, multiskilling, learning, training, development and compensation schemes all aligned with business goals is what this chapter is all about.

PEOPLE REALLY ARE YOUR MOST IMPORTANT ASSET

There are three things that make up any business: its assets (financial, intellectual and physical), its processes (what it does and how it does it) and its people. The business itself is an extension of its people—whatever they bring to the business becomes a part of that business. Change only one person, and you change the business. Without your people, nothing will happen. Maintenance is a complex business process with many sub-processes. It exists to ensure that your physical assets do what you want them to do, but it is the people in your maintenance group that makes this happen. Leading companies recognize how important their people are and put them first.

Excellent companies that truly recognize the value of their people keep their turnover costs down and provide consistent service to their customers. When motivated and inspired employees remain with a company, they help it grow and expand. These employees constantly look for ways to improve things and are always adding value. They know what needs to be done, and they do it, often delighting the customer in the process. Motivated maintainers keep operations happy, much like frontline sales staff does when dealing with customers. Employees who are demotivated, uninspired or unhappy will not expend that level of effort, and many will leave. Employee turnover is expensive—recruitment, replacement and training costs are measured in multiples of annual salary or wages. A hidden expense is lowered productivity while a new employee learns how to do a job an experienced employee has left. This is exacerbated now that seasoned baby boomers are retiring in large numbers and replacement generations are showing up with different values and skill sets. Managing this transition to take advantage of the new skills and values is proving a challenge as conventional management models and ways of thinking still dominate in management today.

There are significant changes in the social landscape we inhabit. Fewer young people embrace trades, seeking careers in the technology sector, which are perceived to be more challenging and rewarding. Many of these young people have a social awareness about things that did not concern previous generations. They value social responsibility, personal growth and development. At the same time, they want autonomy and a great degree of self-actualization. They make extensive use of social media and electronic communications to remain connected and value team collaboration. Managing them successfully is different from managing baby boomers.

The baby-boom generation was not as prolific as its parents, and it is fast retiring. This is leaving businesses scrambling for fewer available workers having the right skills to do an ever-increasing amount of work. Replacing the aging baby boomers and capturing their knowledge is going to be one of your most significant strategic challenges.

Demographics have always been a driving force for change in society and in business. Today, perhaps the greatest demographic concern to industry is the dwindling number of skilled tradespeople. There simply are not enough qualified tradespeople to do things the way we used to do them, and our most seasoned tradespeople are retiring. With them goes considerable "corporate memory." Simply capturing and storing their knowledge is not enough. You must be able to use it too. For example, you can easily get hold of your supervisors' contact lists, but can you get their contacts to call you back when you use it? Replacing these people is difficult because the pool of skilled workers is smaller. Government skill training programs, which were once numerous and reasonably effective, have all but disappeared. Successful companies realize that they must tackle this problem themselves. Many others are struggling, and this is no simple challenge.

Although the replacement workforce may be highly skilled, the skills younger workers have do not always match what a company might need, and there are far fewer of them. As noted in the previous chapter, immigration is not keeping pace with the demand for new workers, and this presents an additional problem. In some companies, this has already reached a truly critical stage, and work management looks like emergency room triage. Confronting these problems, companies are forced to rethink what it is their people are doing and create viable solutions that are often radically different from the old labor solutions. (Some of these are discussed later in the chapter.)

To deal with the problems of a shrinking labor pool and an environment that is unpredictable and sometimes chaotic, the successful maintenance manager must be far more than a competent technical person. In addition to management skills, this individual must have consummate "people skills." He/she is a coach and a nurturer who enables people to get their jobs done by clearing away barriers and providing resources. The astute maintenance manager does not control people tightly but, rather, tells them what needs to be done and then gets out of their way. This person encourages reasonable risk taking, rewards success and attacks problems, not people. These "soft" skills are the hallmarks of the modern maintenance manager, indeed, of any successful manager. They are critical in dealing with today's biggest challenge.

Individual workers may or may not rise to the challenges when told what is expected of them without clear guidance on how to do it. Teamwork addresses this challenge. Successful organizations are increasingly structured around self-managed teams. Teams leverage the creativity and collective talents of their members, unleashing potential that is otherwise bottled up in conventional, command-and-control organizational structures and approaches.

TEAMS

The dominant methods used by companies that strive for superior results are team-based. There is a simple reason for this: These humanistic approaches work well. Reliability-centered maintenance (RCM), root cause failure analysis (RCFA) and preventive maintenance optimization (PMO) are all team-based methods that focus on physical assets. Developing an effective strategy and then following it also depend heavily on teamwork among maintainers, operators, finance, human resources and supply chain. Multiskilling enables maintainers to work in smaller teams and sometimes even alone, but it also enables maintainers to work closely with operations, satisfying many of their immediate needs as important contributors to the production team. Work management (Chapter 3) also requires a form of teamwork because operations and supply chain both play critical roles in the process along with maintenance. Basic care and 5S (Chapter 4) utilize a team approach—operators can do simple maintenance tasks and help maintainers while they do more complex work on systems that are shut down. Total productive maintenance (TPM), a component of the highly successful Toyota Production System, is a team-based method. Teamwork is clearly important, but so are team size and structure.

In *The Tipping Point*, Malcolm Gladwell describes Robin Dunbar's 1992 anthropological work relating the brain size of primates to the number of group members in the primates' groups. Bigger brains are needed to handle larger groups with many more relationships. Humans are at the top of the list for brain size and for the size of the groups we interact with. And size matters. The number of people in a group with whom any one person can maintain genuine social relationships is approximately 150. Several organizations use this rule of 150 to determine maximum group size. Hutterite colonies are limited to 150 members before they split to form two colonies. Gore Associates (makers of Gore-Tex) limit their plant sizes to 50,000 square feet and their parking lots to 150 spaces. Once these are full, the company builds another small plant. We have seen many instances where smaller organizations work very informally yet produce superior results. In military organizations the world over, the basic fighting unit is the "company," which typically has between 120 and 150 soldiers.

A company commander and all of his/her troops will know everyone else in the company, but a battalion command (a battalion contains several companies) will not. What these organizations have found is that small groups develop a form of group memory and the ability to transfer knowledge easily. They can work toward common goals quite naturally. Within these small groups, informality works best. But larger groups, with more than 150 people, begin to need more formal structures simply because the relationships within those larger groups are less well developed. Smaller teams are quicker at decision making than larger ones, and the quality of their decisions, as measured in results obtained from implementing them, is often better. They do not get bogged down in analysis paralysis, and they are less worried about company politics. These teams simply work!

In *Finding Our Way: Leadership for an Uncertain Time*, Margaret J. Wheatley describes living organizations in their own right, and they are, simultaneously, made up of many other living organisms: people. If command and control are removed from these organizations, they (and the organization they inhabit) become self-organizing. Each self-organizing unit creates for itself the necessary aspects of organization used to achieve its goals, including communication networks, structures, values and behavioral norms. Research shows that self-managed teams are far more productive than teams formed or organized in other ways. There is a clear link between participation and productivity, and productivity gains of up to 35% have been documented. Unfortunately, many organizations are designed to accommodate command and control by their leaders, often harming productivity. Teams and the benefits they can generate are stifled in such organizations.

Leaders of highly structured organizations argue that control is needed to manage the risks inherent to turbulent times. Those leaders give far too much power to their fears of failure. In military organizations, however, commanders learn that the greater the risk, the more they benefit from everyone's commitment and intelligence. By controlling too tightly, leaders stifle creativity and prevent intelligent work. In April 1992, Argentina invaded the Falkland Islands (Islas Malvinas) in the South Atlantic. British junior officers were given unprecedented authority to make decisions and simply get things done. The result was a rapid and very efficient mobilization of a large fleet sailing a long way from home on very short notice. As Wheatley noted, effective leaders are better at relying on their people and not controlling every detail themselves. Machinery needs structure; people do not. Machines cannot adapt to change; people can.

Running an organization like a machine might maximize control, but it suboptimizes performance.

Team-based methods for maintenance use small teams: groups of people who have a common mission develop relationships and create highly productive output. To confirm this point, just observe the results generated by teams of various sizes working on problems of any sort. Smaller teams will generally be far more productive. The cautionary note here is that quality suffers if a small team lacks diversity in experience and knowledge. Striking a balance between team size and composition also matters.

We all know that the only constant in life is change. Today, change is faster than ever, and it is largely unpredictable. Many businesses are left scrambling, uncertain how to catch up. Mergers, acquisitions, divestitures, strategic alliances, increasingly stringent regulatory requirements and deregulation are all driving substantial and often unexpected change. Such a charged atmosphere demands quick reflexes and well-thought-out approaches to remain competitive.

MANAGING CHANGE

In this ever-changing environment, companies and individuals alike are subject to challenge. Even if you think you are static, you are really undergoing some form of change, albeit slowly. Things around you are always in motion—technology, processes, people, etc.—and you must keep up with this motion and these changes to stay ahead of competitors. As the opening quote of this chapter implies, change is necessary for survival in today's business world.

History teaches us that dogmatic approaches to change tend to produce mixed, short-term results at best. Today's workers simply do not buy into this approach—you cannot just direct them to change and expect that it will happen. It will not. Even your older employees are likely to balk at such directives. Although they might have responded to them in the past, they are no longer receptive to many changes. Most are looking forward to a smooth and predicable transition into retirement. They do not want change, and they especially do not want change by coercion. A simple truth shines through all of this—none of us likes to be changed, but we are all very good at changing on our own terms. It is like shopping—many people enjoy shopping so that they can buy something they want, but they do not enjoy it when salespeople approach them and try to sell them something that they may or may not want. Some people will even resist being "sold" when they actually want what the salesman is pushing—the experience of being sold is so abhorrent to them that they look for an excuse not to buy from that pushy salesperson. The idea that something is needed must be theirs, and the buying choice must be theirs.

Today, for both younger and older workers, change must be driven from within. It is human nature to change if there is benefit to be gained. New initiatives must grow from your own ideas, not the recommendations of others, even if others are used to help move those changes forward in areas where you lack sufficient expertise to teach or implement them on your own.

Successful organizations steer their own courses in an organized fashion toward a predetermined goal or vision, navigating among many challenging constraints. Change can be described as a movement from one state to another, through various transitional forms, to some final state. For plant engineering and maintenance, the main objective is usually to boost equipment productivity. There are many factors involved, all of which can be in a state of change simultaneously:

- Increasingly complex technology in every aspect of work.
- Integrated information and data management systems for employees, fixed assets, costs, performance and virtually all business activities.
- Advancing process automation and robotics requiring fewer operators but more highly trained technicians.
- Tighter design tolerances for higher-quality products and less maintenance intervention.
- Shorter obsolescence cycles as time to market for new products, especially in the area of high technology.
- Larger scale of plants with increasing flexibility to serve today's demands for mass customization.
- Increasingly prevalent use of modularity in designs allowing for automated troubleshooting and then replacement of whole modules rather than repair of components.
- Higher targets for return on investment and profit margins in the new global economy with few business boundaries.
- More rigorous health, safety and environmental standards in all jurisdictions. Failure to meet standards can cost your company dearly, shut it down or, in some countries, send your executives to jail.

- Increased degree of contracting as businesses stick with their core competencies and contract out the rest.
- Product liability law changes.
- Workers' expectations for self-realization in their jobs, especially among younger members of our workforce. Skills and knowledge are highly portable, workers are highly mobile and many do not mind moving. If a company provides a terrific working environment and interesting people to work with and for, people will stay. If it does not, they leave.
- Workers' expectations of their bosses. A good boss helps attract and retain good people; a bad one causes them to leave.
- Less emphasis on loyalty both to and from employers and employees alike. The security of having "jobs for life" is largely a thing of the past. Changes like the demise of defined-benefit pension plans have made staying in one company for an entire career less attractive.

For maintenance managers, these changes represent a great challenge. It can be met in part by having a strategic direction, as described in Chapter 1. Within this strategic direction is a successful vision, which is embraced by every employee at all levels. This is a tall order. Anyone involved in maintenance management or any management knows that a project can be derailed by employees unwilling to execute it. Thus, achieving your maintenance strategy will require change on the part of everyone in your organization. All employees must understand, accept and, most importantly, internalize the inevitability of change in order to improve.

Organizations are ultimately altered and shaped by the individuals involved in the change process. Getting them involved requires a compelling case that drives their desire to change and move toward a shared vision of the desired future state. The process also requires the means to make it happen. We cannot expect new processes and methods to happen without investing time, energy and money. The major steps in the process are as follows:

1. Identify the need. What is the business case that calls for a change?
2. Identify a champion for the change initiative. Who is accountable for the results?
3. Enroll the team that will lead and execute the change. Who is going to make it happen?

4. Define the change. What is it you intend to do?
5. Demonstrate that the specific change is really the best option. What are the alternative solutions? Which alternative is best? Who needs to know?
6. Plan the change activities and plan your work. What are the specific objectives or goals, approach, timeline and boundaries?
7. Communicate the plan. Does everyone affected understand what is going to happen and why?
8. Carry out your plan. What gets done?
9. Measure and communicate results as you implement. What has been done? Did it produce the right results? Who needs to know?
10. Foster continued engagement and development of the people affected to support the change. Involve them to the extent practical in defining the change. What will sustain the change?

To ensure success, include detailed change management assessments and plans with your primary plans. These need to be worked into the plans for any technical change not managed separately. Managing the change entails considerable emphasis on the human element, which is often overlooked in technical projects. Implementing improvements in maintenance and engineering often entails a number of technically oriented activities. Do not forget that the improvements are carried out by real people who have feelings, judgments, fears, ambitions and emotions. If they are not fully onboard with your program, it will not work the way you intended.

Change is difficult in any organization. There are several things that make it easier, more successful and faster.

Have a Compelling Reason

The most difficult aspect of change is usually convincing those concerned that there is good reason to change. That is not easy, especially when it means destabilizing the entire organization. Any sane person will ask, "Why put ourselves through this pain?" The impetus for organization-wide change can take many forms: the threat of business closure, the desire to remain competitive in a changing market, the desire to avoid being outsourced or the need to make up for natural attrition in the workforce. These are reactive reasons. There are also proactive reasons to want a program of change. For example, customer satisfaction surveys can provide information on how the organization is perceived by its clients. In maintenance, this can be an internal customer survey.

Regardless of the reason for the change, any change means shaking up the status quo, encouraging employees to think of better alternatives and allowing the organization to move forward. Unfreezing old thinking is usually the best place to start. New concepts will often clash with old ideas and perceptions. Challenge the old methods, show more logical alternatives that work and give people a chance to accept those new ideas. Education and training are usually the most effective ways to do this. Do not just train the people who will be directly involved in making the change happen. Train those who are also going to be affected by the change, and provide some sort of informative overview for others so they are kept abreast of developments in their company. Ideally, the change will make work more interesting and satisfying. You want your employees to endorse the new methods, but more importantly, you want them to play a large part in designing them. If they are not involved, resistance will be high, ownership will be low, the present situation will not improve much and the organization may even be harmed. The most successful organizations at making change "stick" are those who involve the entire workforce in the decisions about what and how to do things in the future. These organizations are great at execution because they embrace a culture of change.[1] The Hoshin Kanri strategy deployment methodology described in Chapter 1 involves those who are involved in leading and implementing the changes at each level in the organization. One of its objectives can be seen as the minimization of resistance to change.

Make It Theirs

Reliance on outsiders to perform assessments, as discussed in Chapter 1, can result in resistance to the changes recommended. Everyone on site knows his/her own job to one degree or another. They know what works and what does not. They know what gets in their way and what helps them. They have creative ideas about how to make it work better. Those ideas are seldom captured, and even if they are, they are often not acted upon. Failure to act on ideas or to explain reasons for not acting will quickly shut down the source of those ideas, and everyone just accepts the status quo as a given and stops caring.

Getting those creative juices flowing will generate excitement about making positive changes. Education in successful practices, as discussed in Chapter 1, will generate discussions and dialogue. That will lead to those ideas flowing. Capture them and turn them into your improvement program, and you will have their hearts and willingness to change. They will "own" it.

Deal with Fears

People resist change for many reasons. Chief among these is fear: fear of the unknown, of losing skills and status and of not being able to cope in a new environment. Some employees may see a proposed change as implied criticism: "It's been working well for years. What do you mean we had it wrong all along?" Others may criticize those introducing the change: "What do they know about our business?" "Our business is unique. How can someone from outside possibly know what's best for us?" This is where externally led assessments run into trouble. (Note: It is never a good idea to have an outsider lead the change for you.) Still others may not agree with the targeted end result, especially if they have had little or no input or they believe that the new plan is being foisted upon them from outside (including changes coming from the "head office") and especially if the change will lead to some perceived or real pain. Managing change requires that these people be allowed to choose. Let them choose to come onside and make the change theirs. All of this is far more complex to manage than simply giving orders, but it works.

When introducing significant change in people's lives, it helps to understand what psychologists refer to as the change cycle depicted in Figure 2.1. Whenever we undergo a radical change, we go through six identifiable stages: loss, doubt, discomfort, discovery, understanding and integration. The change that triggers this is anything that will be seen as losing something people are familiar and comfortable with. We all experience this with any change that is imposed on us from outside, and we all go through it at different paces.

- Loss: It generally takes people time to adjust to the news of a change. The feelings are fearful, and we get cautious about what is happening. Not much can be done at this time, and we feel paralyzed to some degree—we just do not know at this point what the change will mean to us.
- Doubt: We commonly react with "this doesn't apply to me" (or my department). This is a form of denial where we feel some resentment,

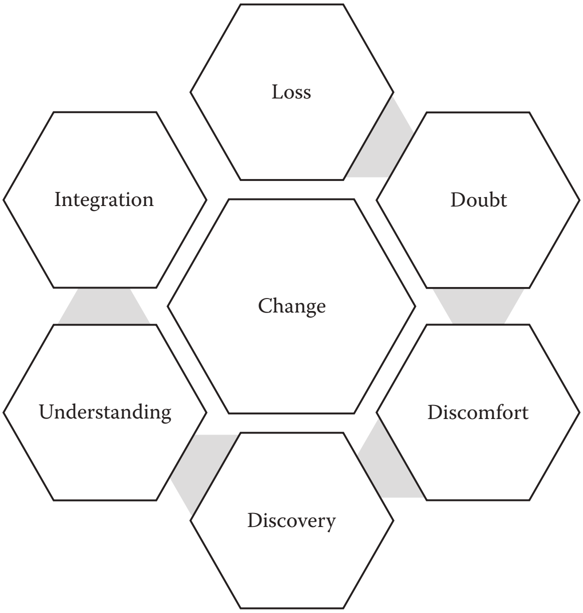


FIGURE 2.1
Change cycle.

we are skeptical that it can work and we are likely to resist the change. For example, it is difficult to accept contracting out much of what was perceived for many years as core work. We doubt that it can be successful, and we will do whatever we can to avoid the change, including improving performance using the old methods. Of course, those improvements are short-lived unless the change is quick and new ways simply sweep away the old.

- Discomfort: We are starting to learn about the new change, and we have not quite let go of the old ways. We are anxious and confused. Productivity usually sags. We see the new way of doing things as somehow worse than the old way. Some people may actively resist or attack the change. Discomfort can lead to anger and more fear. If we do not deal with this effectively, we will struggle to embed the change.
- Discovery: At this point, the change has not gone away on its own, and efforts to stop it have failed. There is a resignation to the new order, and some learning takes place. With that comes anticipation of improvement, and we start to look at ways to leverage and even improve on the change. The mood is more upbeat, and people are energized.

- Understanding: As learning spreads and familiarity with the new order grows, there is more ease. People feel more confident in their success with the new ways, they are very practical about what it can do for them and they become more productive.
- Integration: The new order is producing results, and those are visible. Confidence grows into satisfaction, and people are focused on doing things well using the new ways. The anxieties are gone, and people relax as the change has now become just another part of the way things are done here. The metrics you've implemented are showing sustainable results. This is success.

Be aware that this cycle affects everyone, though not at the same pace. Some people go through it quickly, and others never quite make it to the end. Some people embrace new ideas immediately, some accept changes slowly and some never will. In every population, there are innovators, early adopters, a majority that comes along eventually, laggards that come aboard long after everyone else has and those that simply refuse to budge. Recognize that your workforce comprises all of these. The innovators and early adopters can help bring the majority along. If the laggards and those who refuse to budget don't get onboard eventually, they may be better of elsewhere. Geoffrey A. Moore (1999) describes how to use this concept in marketing and the selling of high-tech products to mainstream customers, but it is just as applicable to entire organizations and to maintenance management.

Figure 2.2 depicts another concept: a force field showing that change occurs only when there is an imbalance between the sum of restraining

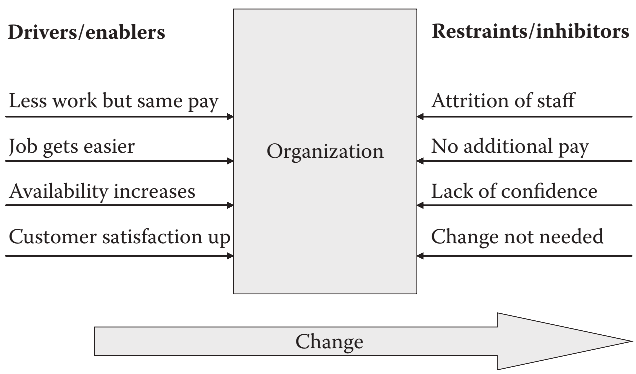


FIGURE 2.2
Force field shows that change occurs only when there is an imbalance between the sum of restraining and driving forces.

and driving forces. The premise behind this concept is that there are three basic strategies for achieving change: (1) Increase the driving forces, (2) decrease the restraining forces and (3) a combination of 1 and 2. Another way to look at this is that change will occur when the status quo becomes so uncomfortable that the future state is perceived to be more comfortable. People will go with the least discomfort even if that means changing. When a steering group, study team or task force is inaugurated, consider conducting a force-field analysis. Document the key drivers and restraints to change in the organization. The challenge, of course, is to estimate the relative strengths of the driving and restraining forces. Recognize that this is not an exact science, but it will provide some interesting insights!

As humans, most of us naturally resist change because we want to remain comfortable. Change means facing the unknown, and fear of the unknown is usually greater than our fear of any discomfort associated with the status quo. People often resist change even if they are shown the benefit of change. They tend to evaluate from a present frame of reference, which means staying with what they know. Eventually, however, discomfort with the status quo becomes so great that the change begins to look like a more comfortable option and becomes desirable. That is when people choose to change. Interestingly, discomfort is the mechanism that makes them accept change. Rather than being proactive and choosing to benefit from a changed state, they wait to experience discomfort before accepting change and whatever comes with change. The pattern is to defer the inevitable in hopes that the unknown will become known before they are compelled to choose.

Communicate

By providing information through communication, education and training, you will greatly improve the odds for success by reducing the fear factor. This can help employees understand the driving forces behind complex business imperatives and to see the benefits of a proposed change. By providing relevant communication, education and training, you also enable your employees to participate more meaningfully in the design and implementation of the change process. By trusting them to provide their input, you also empower them. Instead of having to accept a change that is entirely directed from the top, employees can participate in the makeover, be given the time to get used to it and even have a stake in the process of making it happen. Your chances for success with this kind of participation are high. Successful organizations use all available channels to get through to both their employees and others who are likely to be impacted by any change, including the employees' families.

When deploying strategy as described in Chapter 1, communication can be accomplished by the people who determined what change initiatives are needed. Each level of decision making can explain the changes and challenges to the level below. The more participation that can be accomplished in the decision making processes, the easier the communication challenge becomes to resolve.

Show That It Works

Nothing succeeds like success. When you plan a change initiative such as improvements in plant maintenance and engineering, you might turn to benchmarking for support. The benchmarking of indicators, processes and organizational structures can also help you determine the direction and rate of change that have worked elsewhere. That can serve as a useful guide and as a showcase for skeptical employees. It is particularly valuable if the organizations studied are the best in their field. Field trips for key employees (i.e., those who have a great deal of influence) can be incredibly valuable in showing the organization what it takes to succeed. Those influencers return from seeing it firsthand to spread the word, often through informal communication channels.

Benchmarking companies that have been successful at transforming themselves reveals some noteworthy patterns of how change came about:

- It was directed strategically and led by a clearly recognized leader (Kotter 1996).
- It was participatory. Employees understood what was going on and were deeply involved.
- It was well planned.
- It was developed from previously established principles and precedent, not from personal edicts.
- A team approach was used. Teams were used for projects, subprojects and tasks and were empowered to make decisions. They were also held accountable for results.
- It was balanced in functions, not one sided or targeted only at one group. For example, a change to plant maintenance performance did not target only the maintenance trades—it included maintenance,

repair and overhaul (MRO) supplies; purchasing; human resources; etc.

- It was flexible—one size does not fit all.
- It was integrated (not simply interfaced). For computer system implementations, tight integration among different systems often works better than leaving data interfaces to manual and batch processes.
- There was excellent communication; timely and meaningful messages were sent and heard. All communication had content relevant to the audience, not just the sender.
- The participants in the change benefited from its implementation. There was something beneficial for everyone involved, and there was no threat to financial or emotional security.

Leadership

"If your actions inspire others to dream more, learn more, do more, and become more, you are a leader."[2] Leadership style is another key to implementing change. If leaders are not fully committed, if they vacillate, subtly or overtly question why they are doing what they are doing or have more pressing priorities, then chances for success will be severely diminished. On the other hand, if leaders dominate the change process with a personal vision or agenda, others can resent it and become inflexible. Leadership is often walking a fine line between too much and too little. Micromanaging is not leadership, and neither is allowing others to do whatever they want. The trick is to find a balance, and that means motivating without browbeating, nurturing without excusing and giving direction without hamstringing.

Leaders will lead by example. They communicate through their actions as well as their words. People will follow the way they are led, so it is important to set the example of the behavior you want to achieve. Ideally, you want people you are leading through change to want the change. As Dwight Eisenhower said, "Leadership is the art of getting someone else to do something you want done because he wants to do it." Change your own way of doing things, and you will change the way that others around you work. Say one thing yet do another, and you will get results that match your actions.

In organizations where change is embraced, it is often implemented quickly, and the changes stick. A culture that focuses on execution (Bossidy and Charan 2002) is successful. A corollary to this is that when organizations make significant changes, one of the things that must change is the organizational structure. If you set out to do things differently, you often find that the current structure simply will not work or even gets in the way of execution. Structure follows function. Note that if you are implementing changes that will result in a reduction in staff sizing, you may find a great deal of resistance. In those cases, function (the changed processes) may best be implemented after the structure is changed provided that the new processes can be implemented immediately.

ORGANIZING THE MAINTENANCE STRUCTURE

Building on the earlier topic of teamwork, today's successful maintenance organization has abandoned Industrial Age command-and-control concepts and replaced them with looser, self-organizing structures that allow autonomy for small but effective service delivery teams. Autonomous teams are relied upon to meet or exceed agreed-upon expectations for performance. These organizations are tapping into the power and creativity of motivated and inspired individuals to truly add value to the companies they work for.

Traditionally, many maintenance organizations were centralized through the maintenance manager, who was often an experienced tradesperson with good management skills. Typically, this person was responsible for management and centralized dispatch of all aspects of plant and facility support and services, while all spares and materials were regulated from the main or central stores.

The strength of this system was threefold: (1) It ensured control over policy, procedures, systems, quality and training; (2) leveling of the workload across the operation was guaranteed; and (3) it worked well when decision making was needed at the top. This still works well in smaller organizations, but its major disadvantage is inflexibility, and this was felt in many ways, particularly in larger organizations:

- Sluggish response time to production requests.
- Workers' lack of familiarity with specific equipment in the plant and difficulty matching the skills to the job.
- Workers who felt unappreciated.
- Rigidity in approach, procedures and policies (what worked in the past was expected to work today and for the foreseeable future). It is also highly dependent on the personality, knowledge and skills of the central leader—change the leader, and it can all fall apart.

- High charge-out rates reflecting bloated management infrastructure and bureaucratic processes.
- Customer dissatisfaction over allocation of resources.
- Strict demarcation among trades, which complicated even simple jobs and often created turf wars.
- Focus on process efficiency rather than process effectiveness. Emphasis was on doing things right, not on doing the right things.

Today, only small maintenance organizations (i.e., those with fewer than 50 people) seem to be able to overcome these drawbacks, and successful centralized maintenance organizations are found only in small companies. Elsewhere, different approaches were needed and emerged.

In large organizations, production became the responsibility of area or product managers, who must react quickly as economic conditions change. Management participation and job enrichment for frontline workers improved productivity and effectiveness. Especially in larger organizations, structure shifted toward decentralization, and maintenance moved into the mainstream of operations. In some organizations, the maintenance manager completely disappeared and was replaced by production area superintendents. In Japan in the 1970s, the Toyota Production System emerged and was enhanced by the teamwork concepts embodied in TPM.

Despite its popularity, decentralization was not a panacea either. It was difficult to manage risk and maintenance engineering consistently from one production department to another. Often, neither was handled very well. Some production areas ignored proactive maintenance, and pockets of chaos coexisted with plant areas that were well run. Standardization became attractive to senior management, but decentralized groups preferred to go their own way, and in the absence of standards, conditions often deteriorated. When standards were applied and enforced, decentralized organizations worked very well. TPM builds on this concept very successfully, but it does not work well everywhere. Clearly, there is no one approach that is best for all.

There is no one correct organization structure that can be transferred from a book to a real-life situation. There are only options that can be applied in specific situations. Usually, the best solution in larger organizations is to restructure for maintenance as a hybrid of centralized and local area functions that have close, regular and formal liaison with operations and engineering. This hybrid model was implemented in a plant in the

Midwestern region of the United States. A brief look at what was done and why is in order.

The 2-million-square-foot plant of a microelectronics operation was divided into four focused factories producing different products: chemicals, components, hybrid electronic circuits and capacitors. After the introduction of the just-in-time manufacturing philosophy, these focused factories were further divided into 60 production cells. This new arrangement was supported by a centralized maintenance group and suffered from unacceptably long response times and less-than-satisfactory customer service. Within the focused factories, it was rare to have the same maintenance technician dispatched to the same cell on different days, so the learning curve for technicians exacerbated the delay time. After much soul searching and debate, maintenance and production managers agreed to try a new structure for maintenance:

- Central maintenance for facility maintenance (heating, ventilation and air-conditioning [HVAC], etc.), parts inventory warehousing and control, fabrication and machine shops, tooling, information database control and specialized trades training
- Focused factory maintenance for workshops, planning and scheduling, operator training in maintenance and maintenance engineering
- Cell maintenance for multiskilled teams (sometimes covering several cells), urgent maintenance, PM and consumable and free-issue parts and supplies

Before investing time and resources into the change in structure, plant management considered the implications and weighed costs and benefits. The new, hybrid model satisfied the ultimate objective of the maintenance function admirably, providing rapid response and equipment uptime safely and at a reasonable cost.

Today, we are focused sharply on corporate responsibility to various company stakeholders as well as to society at large. As a result, another organizational shift has begun and has precipitated an increasing awareness of the importance of physical assets to business. Compared with past changes, this shift has been rather subtle, but it is getting an increasingly higher profile with the advent of international asset management standards, specifically ISO 55000, 55001 and 55002—the subject of Chapter 11.

At the shop-floor level, for example, the focus on stakeholders is almost imperceptible because most of the changes are happening at the most senior management levels, where physical asset management is becoming a hot topic.

In highly automated systems, poor design, poor execution, unsafe practices and equipment failures of all kinds can result in safety and environmental problems and severe business losses. These events are bad enough, but their consequences are worse. Because executives are increasingly being held liable for these consequences, they have begun to take a hard look at how to fix the underlying causes. What they have discovered is that businesses need competent professional support in managing the technology and physical assets for which senior executives are ultimately responsible. This is, in large part, what has given rise to the advent in 2014 of the international standards for asset management.

In large global organizations, there is a trend toward standardized models for maintenance and engineering that requires corporate-level leadership but allows for execution at the local level. At the same time, as businesses automate more and rely more heavily on computerized controls and systems, they put less emphasis on the operator and more on the maintainer. And while maintenance is still viewed as an engineering function, in most organizations, it is often located in a separate department. All of this points to the real nature of the current shift—the emergence of physical asset management as a new paradigm and the new international standards.

With so much efficiency already built into management processes and systems with complex networks connecting suppliers and customers, it is apparent that meeting today's standards and demands means working smarter, not just harder and better. Physical asset management encompasses the entire spectrum of asset life-cycle management, from conceptual design to disposal. It includes traditional engineering and maintenance functions and recognizes that operations contribute to asset integrity by operating the assets correctly.

Slowly but steadily, maintenance management, once relegated to a corner of the shop floor or the warehouse, is being elevated to the executive suite, often with engineering in newly emerging asset management roles. Many companies now have VPs or directors responsible for physical asset management, and corporate standards are being set and applied to maintenance, engineering and operations in much the same way as they are applied to any manager who incurs expenses or any manager who hires and fires employees. Like the hybrid organization, the physical asset management organization manages some services centrally and others at a local level. Responsibility for execution of the work is separated from the responsibility

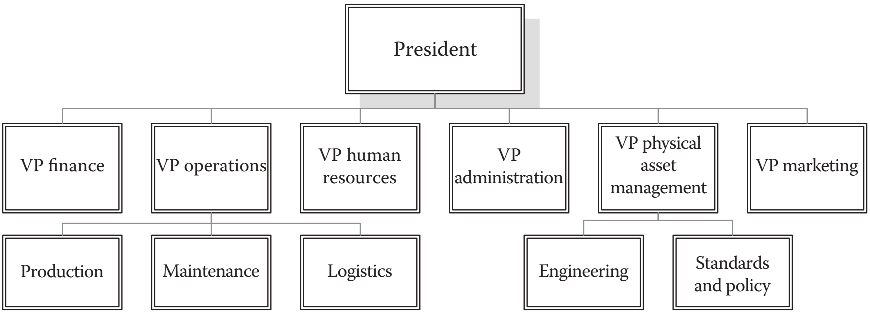


FIGURE 2.3
Typical organizational chart.

for creating and maintaining the standards. The VP manages the latter and focuses on compliance. The maintenance, engineering and operations managers are responsible for doing the work and for complying with those standards. Figure 2.3 shows a typical organizational chart for this model.

What this figure and the previous historical analysis of organizational infrastructure suggest is a shift away from dogmatism and toward a more flexible approach better suited to the behavioral complexities of today's workplace. As previously noted, Industrial Age solutions do not work for children of the Information Age. Margaret J. Wheatley (2005) points out that command-and-control structures do not work well anymore—they hold us back from progress. Particularly in dealing with the challenges of replacing an aging workforce, anything that holds us back is clearly unwelcome. The new model to embrace involves greater reliance on people who are free to choose their own paths and respond to their environment within a self-organizing team-based system. Although this may sound chaotic, this model has the potential to unleash latent talent and capability that can solve some of our most pressing problems. Studies (Wheatley 2005) show that productivity gains in truly self-managed work environments are on the order of 35% greater than gains possible in traditional organizations. One proven practice that unleashes some of the latent talent in a workforce and illustrates the ability of individuals to expand is multiskilling.

MULTISKILLING

As decentralization took hold and flexibility increased, it became essential to improve labor skills, planning and scheduling. Managers had to offset the inevitable duplication of talent that arises in a decentralized system with higher asset performance and labor productivity. One highly successful option was to train workers in multiple skills or multiple trades. Initial attempts met resistance from trade unions guarding against encroachment on their specialties. In response, many organizations collaborated with their unions to help enhance skills and pay extra for their use. Today, multiskilling has become a staple of many organizations and is one of the solutions to the current problem of reduced availability of skilled trades. It is a viable option but not always easy to implement. Multiskilled employees possess all the skills necessary to do their tasks safely across traditional disciplinary boundaries. In some companies, tradespeople hold more than one recognized trade certification or are “ticketed” in more than one trade. Generally, the multiskilled worker may not necessarily have all the skills to qualify in multiple trades but does have the skills needed for his/her particular job. Multiskilling works best where jobs are relatively simple and of short duration. For example, it is ideal for jobs like changing out a small motor but is not as well suited for calibration of a variable frequency drive. The objective of multiskilling is not to have everyone do everything, eliminate specialist skills or loosen the standards for quality work. Specialists are still important. A secondary, but equally important, function of multiskilling is flexibility. Multiskilling can help reduce costs because increased flexibility reduces the number of jobs for which you will need multiple people with multiple skill sets. A cautionary note to this is to avoid approaching multiskilling simply as a method to slash costs, because the most significant long-term benefit is improved productivity.

In organizations in which multiskilling was used primarily to reduce workforce size, it has failed, sometimes miserably. Usually, those organizations had more to do than they could handle, and reducing the workforce through multiskilling failed to address the basic problems of too much work, poorly managed workforce deployment (planning and scheduling) or both. One example serves to illustrate what can occur if multiskilling is implemented with the sole intent of reducing the workforce in a facility overburdened with too much work. Multiskilling was instituted over a 3-year period by an aluminum industrial product manufacturer in central Canada. In the first year, training was provided to increase workforce skills. The excessive backlogs of work were gradually reduced. Late in year 2, following a downturn in the business, the workforce was cut. Backlogs gradually returned to previous levels, and the workers who survived the cuts, now demoralized, gradually stopped using their multiple skills. By the end of year 3, the backlog exceeded previous levels, and multiskilling was all but forgotten. The workload required more people than ever before, but there were fewer to do it. The situation deteriorated, and a once-proactive maintenance organization became reactive.

In all cases, introducing multiskilling has it challenges: boundary disputes and communication difficulties, workload leveling among the various distributed work areas, demands for job enrichment and variety, unequal opportunities for overtime and general management career path planning and trade union resistance. There is also a need to ensure the skills are used—if tasks requiring the new skills occur infrequently, the skills are lost. Make sure that multiskilling is applied for frequently occuring tasks. Some organizations contract work out in order to smooth workload peaks. Others have centralized floating teams for shutdowns and major overhauls. Maintenance and production duties are sometimes shared, increasing the know-how of the decentralized maintenance and operations teams.

Multiticketing, where a tradesperson is fully qualified and recognized (ticketed) in more than one trade, is an excellent way to introduce multiskilling. Union resistance to this approach is usually less strident than it is to the less formal multiskilled approach. Multiticketed tradespeople are very well compensated with premium wages. In some cases, unions actually support the practice as it has clear benefits for their members.

On the other hand, organized labor's resistance to multiskilling in general remains rather strong. There are several legitimate concerns about the practice:

- There may be no marketable, generally recognized skill certification that can be transferred to other organizations or jurisdictions. Multiskilling programs can lock employees into an organization because their skills are unique to that organization. This is becoming less of a concern as more companies, in response to challenges in replacing experienced workers, are seeing the value in multiskilled as well as multiticketed workers.
- Training programs can be poorly conceived or inadequate. Often, a lack of up-front definition of the work is the culprit. Simply throwing together a training program without adequate analysis and without training follow-up does not work. A great deal of effort is required in training needs analysis, training development and delivery.

- Multiskilling ignores traditional career patterns, in which long or valuable specialist experience often leads to promotions into management. With multiskilling, those who are the most capable can now move forward more quickly. Seniority or tenure is no longer enough to ensure advancement or promotion, and workers with more seniority, a pillar within many trade union arrangements, understandably resist the shift. Increasing pay with increases in skills that are utilized can help overcome this resistance while encouraging workers and their unions to participate rather than resist.
- Some organizations attempt to generalize skills to meet immediate needs. This reduces mobility and is a shortsighted approach that unions are right to challenge. Over time, workers become bored, and turnover rates increase. This presents a new, high-cost problem. Turnover results in lost knowledge (equipment history, organizational issues, human issues and technical knowledge); additional recruiting requirements; cost of getting recruiting wrong; and lost time associated with learning curves and errors that occur while new employees learn and gain proficiency in their new jobs.
- Multiskilling is sometimes viewed as a precursor to contract maintenance, making the workforce more attractive to a potential contract service provider under an outsourcing agreement. This appears to be a legitimate concern, but in practice, few companies have prepared themselves very well for contracting out the maintenance function.
- Often, organizations introduce multiskilling programs with staff reductions and inappropriate compensation schemes. The desire to cut costs quickly leads to rapid cuts, usually before the payback of multiskilling is realized. As in the example above, it harms the very people needed to pull it off successfully. The emphasis needs to remain on productivity gains, not on cost reductions.

To foster employee commitment to multiskilling, it is important to encourage their involvement in addressing these issues openly and early in the process. If the process is thrust upon them without adequate notice and preparation, you have a recipe for disaster.

Planning and training for multiskilling centers on a “training needs and tasks analysis.” What tasks are currently being carried out and by which tradespeople? Is the current skill level appropriate? What are the most frequently performed tasks of some typical jobs or work orders? What tasks will be performed in the future? The concept of “natural work” applies here. Tasks that may entail a variety of different trade skills that are relatively simple are appropriate for multiskilled workers. Tasks requiring very complex skills in one or more trade areas will demand a multiskilled worker with a great deal of training in several trades. It is often not cost-effective to provide all that training. Moreover, multiskilling does not replace truly unique specialists. They have and likely always will have a valuable role to play.

To perform the training needs and tasks analysis you can search for task requirements in work order histories, industrial engineering studies, maintenance manuals or employee questionnaires and surveys. Organizations that use RCM have an excellent source of defined task requirements. Figure 2.4 shows an example of the relationship between various trades and some of the tasks performed.

Through the needs and tasks analysis, you can develop an overall education and training approach. Because high school dropout rates remain high, and schools have deemphasized basic and trade skills, many organizations find that this process requires basic education before skill training can start. New employees today often have a better formal education; that education is rarely focused on useful trade skills. Hiring practices may attempt to weed out the less-well-prepared, but in tight job markets, those standards are dropped. In those cases, new employees may actually be less educated than their predecessors. Some senior employees who have “learned on the job” may have failed to keep up with developments in

Trade/task	Blueprint reading	Requisitioning	PLC programming	Vibration analysis	Pneumatics	Hydraulics	Drilling	Sawing/shearing	Measuring	Welding	Rigging	Framing	Troubleshooting	Lubrication	Balancing	Alignment	Thermal cutting	Bricklaying
Mechanic	√	√		√			√	√	√				√	√	√	√		
Electrician	√	√							√				√					
Instrument technician	√	√	√		√				√				√					
CNC machinist	√	√	√		√				√				√	√				
Pipefitter	√	√			√	√			√		√							
Welder	√	√							√	√							√	
Rigger		√			√	√					√						√	
Stationary engineer		√											√	√				
Machinist	√	√					√	√	√					√			√	
Millwright	√	√		√	√	√	√	√	√	√	√		√	√	√	√	√	
Mason	√	√							√									
Carpenter	√	√					√		√			√						√
Painter		√																
Mobile equipment operator		√											√					

FIGURE 2.4
Relationship between various trades and some of the tasks performed.

computing technology. In today's world of pervasive technology, tablets, fablets and smartphones, the technological laggards are fewer and farther between, but where they exist, they are now working alongside younger and more tech-savvy workers. Depending on your workforce demographics, the first priority may be upgrading employees' literacy, facility with numbers and basic computer skills. All employees will benefit from a clear understanding of the company's markets, customers, products, services and overall strategy for success. Never assume that just because people have worked in your organization for many years, they really know the business. Recognize that employees who understand the basics of your business are more likely to make meaningful and rewarding contributions to its success.[3]

Other general knowledge that will benefit employees includes basic statistics, modern concepts and methods in maintenance management and quality management. Try alternating classroom and on-the-job experience, including job rotation. There is a vast array of training methods and tools. Classroom-based training is still useful where it is important to learn how to put what is studied into practice, particularly in team-based methods. Computer-based training, simulations, gaming and electronic manuals, documentation and testing and study guides are all available. No matter what media is used, case studies are always useful to drive home the points being made. Games combine classroom learning with hands-on practice, often using simulation techniques that appeal to the visual and tactile learning styles common among maintainers and operators. The results of the detailed needs and tasks analysis will, of course, set the agenda.

It may help to segment the many tasks performed by maintenance into skill modules. Clusters of these modules are then linked for logical multiskilled groupings and progression. Common groupings are fairly obvious: mechanical, electrical, control. For example, the new "industrial mechanic" skill set includes the traditional skills of fitting, pipe fitting, rigging, welding, millwright and mechanics. Increasingly prevalent robotics has led to specialists in mechanical and control systems. Engineering schools now have degrees in "Mechatronics." Multiskilling will clearly blend these skill sets.

Implementing multiskill training in tandem with changes in compensation works best. Employee representatives can help design pay-for-knowledge systems, in which workers are paid for learning and using new skills. To be eligible for the extra pay, they will use a skill when and where called for. Make sure you can measure the output and reward improved performance and teamwork with bonuses and other benefits. Setting up a pay-for-knowledge system can necessitate changes to existing collective agreements and to the less formal but traditional expectations that make up your corporate culture.

If you need to hire new employees and train them to become multiskilled workers, you will need to be picky even though the available talent is limited. A study of candidates for multiskilled positions in the United States revealed that only 37% had multiskill aptitude. Only 6% of electrical trade applicants met entry requirements, 18% of mechanical trade applicants met entry requirements and less than 1% were able to perform multiskill tasks.

Multiskilling has its costs, and it helps to be aware of these before you begin multiskill programs. To the direct cost of increased compensation, add significant investment in training and facilities; management time; and changes to existing systems, methods and labor agreements. The company will also pay, at least initially, for some of the time used for training, either directly (paying for your employees' training time) or indirectly (a larger workforce to get the work done while your core workers are out being trained).

Many colleges and trades schools are now producing multiskilled graduates, and many of today's new hires are already multiskilled to a degree. What they lack, however, is job-specific experience. Apprentice programs ensure that this experience is gained while the knowledge is fresh—avoid the traditional approach of starting too slowly because a new hire needs to "get adjusted." The best adjustment comes with appropriate training. Do not use your most junior tradespeople for predominantly menial tasks. You will lose them. Younger workers today want to be challenged intellectually, not just physically. They have invested in their own education up to this point and expect you to continue the process. Minimize their value, and they will go somewhere else.

The long-term benefits of multiskilling are worth the investment you make. You can expect the following:

- Increased flexibility in scheduling workers
- Shorter response times
- Reduced supervision
- Greater labor and asset productivity
- Higher morale among workers

- Improved scheduling, communication and integration among departments
- More stable employment
- Greater job satisfaction

Case Study

The following case study shows how one consumer goods company, Lever, dealt with severe business challenges by using an extensive multiskilling program. Lever, a Unilever company, manufactures soaps, detergents and other laundry and personal hygiene products, and operates several plants in the United States and Canada, one of which is located in Toronto. The North American Free Trade Agreement (NAFTA), signed by the United States, Canada and Mexico in January 1994, was about to increase the competition for the rights to manufacture various products among the various Lever plants. Unless the Toronto plant could find a way to produce at lower costs, all of its products could be manufactured at other plants and imported as tariffs began to fall. Responding to this perceived threat, the Toronto plant increased the productivity and flexibility of its maintenance workforce through multiskilling. The overarching philosophy was to achieve "one job–one person," and the overall objectives were as follows:

- Broaden the scope of skills for each tradesperson
- Reduce the complexity of trade demarcations
- Provide new career paths
- Increase the skill level of key tradespeople

Working closely with two local community colleges, Lever designed a series of courses that enabled millwrights to acquire basic electrical skills and electricians to become skilled at alignment and vibration. A career progression plan was developed so that millwrights and electricians could achieve a supertrade category, earning skill-based incremental pay as they progressed. Figure 2.5 summarizes the training modules required for the multiskilled trade designation at Lever.

During the first round of training, about 80% of the tradespeople participated in upgrading or expanding their skills, with 95% of these eventually passing their courses. Each participant's record of the various modules completed and those yet to be achieved was documented. The company

Module/skill	**Millwright/industrial mechanic**	**Packing mechanic**	**Electrician**	**Instrument technician**	**Supertrade**
Safety	√	√	√	√	√
Communications	√	√	√	√	√
Trade science	√	√	√	√	√
Blueprints	√	√	√	√	√
Hand and power tools	√	√	√	√	√
Machine tools	√	√	√	√	√
Measurement	√	√	√	√	√
Fasteners	√	√	√	√	√
Lubricants	√	√		√	√
Rigging	√				√
Materials handling	√	√		√	√
Power transmission	√	√	√	√	√
Compressors and pumps	√	√			√
Prime movers	√	√	√	√	√
Weld, braze, solder	√	√	√	√	√
Bearings, seals, packing	√				√
Valves, piping	√			√	√
Fans, blowers	√				√
Electrical controls	√	√	√	√	√
Pneumatics	√	√		√	√
Hydraulics	√	√	√	√	√
Predictive maintenance	√	√	√	√	√
Milling, grinding	√	√			√
Lathe work		√			√
Packing machines		√			√
Electrical circuits		√	√	√	√
Electronic systems		√	√	√	√
Electronic power distribution			√		√
PLCs			√		√
Drive systems			√		√
Microprocessors			√		√
Process equipment				√	√
Process control systems				√	√

FIGURE 2.5
Multiskilled trades at Lever (Toronto).

is continuing its multiskilling process, with management and the local Teamsters union negotiating the fine points and implications for workers.

The provincial government approved the trade of "multiskilled industrial mechanic," with the requisite skills and training requirements. This recognition increased the marketability of participants. Lever and the union worked toward the development of a supermultiskilled technician, with expanded troubleshooting and technical training skills.

Multiskilling has been a major factor in the decentralization of the Toronto plant's maintenance organization structure. Now the multi-skilled tradespeople are an integral part of the area operation teams. The plant survived its NAFTA challenge and is thriving despite a change in ownership in 2002, ample proof that the approach was sustainable. Central to Lever's success with multiskilling was their commitment to learning, training and employee development.

LEARNING, TRAINING AND DEVELOPMENT

Today's business environment is highly competitive and constantly changing. Knowledge is no longer static, and information is readily available online. Knowing how to use that information most effectively requires constant learning. A key feature of organizations as they move toward physical asset management from older maintenance models is that they are learning and developing their people. They have a technical/managerial career path that embraces learning and continual development.

Learning is constant, a way of life. Those who value knowledge do not hesitate to investigate what they suspect is a more productive way of completing a task. If they find that their assumption was correct, they adopt the practice and let others know about it.

Despite the trend toward continuous learning within companies, there are variations in performance from plant to plant and even within plants and among departments. Productivity can vary greatly from one plant to another. Even in large plants, an innovative practice that has been skillfully adopted by one department is often ignored by another. Inconsistencies occur in integrating operations and maintenance, cross-training or multi-skilling tradespeople and empowering supervisors. Making employees (whether they are salaried or paid hourly or on a contract basis) responsible for productivity and profits will not necessarily produce the desired results.

Finding the most productive methods has a great deal to do with access to information of several kinds and sharing ideas and innovations. Having an open pipeline to the best practices in other, similar industries is also important. Much also depends on the attitude, knowledge and skills of employees. People have to want it, or it will not happen.

In *The Age of Unreason* (Handy 1991), Handy describes the learning process as a wheel divided into four parts. It starts with a *question* or problem to be solved. Then it moves on to *speculation* or theory. Next comes *testing* the theory, and finally, *reflection*. This sequence is used extensively in setting up benchmarking studies—formalized learning by the corporation. The learning wheel runs on the "lubricants" of self-responsibility, perspective and forgiveness. A well-oiled attitude includes accepting ownership for the future, being able to view events from many angles and being capable of living with uncertainty and mistakes. The underlying premise is that people learn from their mistakes and improve. If they are not making mistakes, they are not trying hard enough.

Employee education and training is the starting point for fostering a learning environment. A good education and training strategy includes the following:

- A clear objective
- A review of the training requirements
- An understanding of the unique work culture
- An implementation plan addressing both training and the work culture
- A budget for the associated costs and expectations of where the benefits will be captured
- A method for continual assessment of whether the objectives are being met

Training can range from basic literacy (so employees can at least read the employee suggestion form) to the latest methods of managing technical people, and just about everything in between (Figure 2.6).

Here, it is important to point out the distinction between education and training and examine why each is important in a different way. A simple example explains. Most people would probably agree that teenage children benefit from some form of sex education; education, after all, enables intelligent decisions. A more debatable subject, however, is the benefit of training in sex—does any parent really want their children to become sexually competent at their age?

As the example above suggests, the objective of education is to expand knowledge of a topic, to bring an uninformed individual through stages of awareness to understanding and to enable the right decisions. The aim of training is to upgrade a person's skills so that he/she acquires proficiency in a given job or task.

To define education and training requirements, you match tasks with the skills required to execute them. In a greenfield operation, this bottom-up

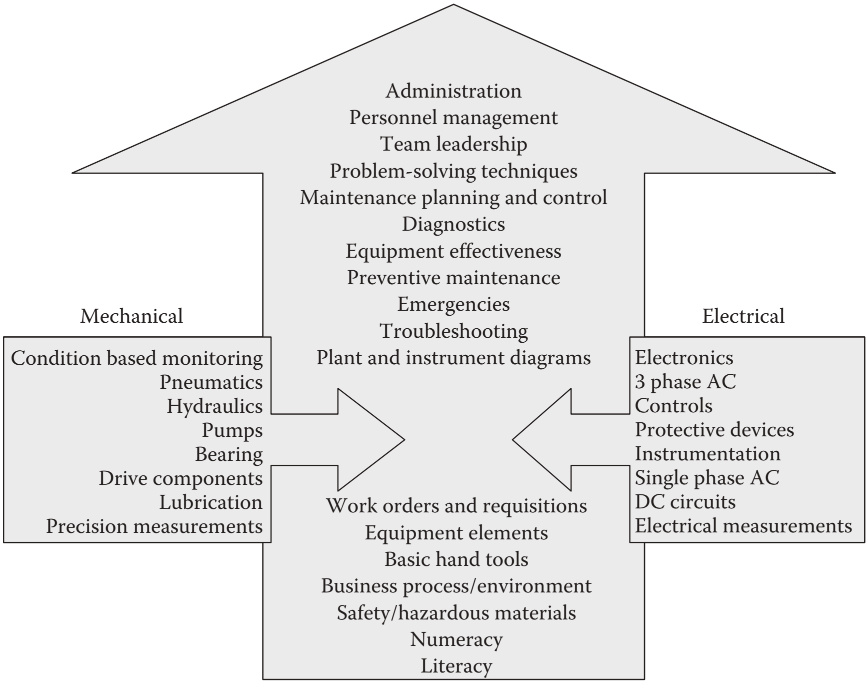


FIGURE 2.6
Scope of training requirements.

approach works well in combination with the use of RCM (Chapter 8). RCM produces task requirements that are easily translated into skill and knowledge requirements that feed training definition.

For an existing operation, you should look from the top down and review plant and equipment performance against performance and output requirements or expectations. You will invariably see thorny areas. Many of these are caused by gaps in knowledge or skills. Recognize what work can be done and the skills required to do it. Then look at the training needed to deliver the necessary skills and competencies and provide it. When planning a training program, you should obviously factor in the skills and competencies that need to be learned, but you should also give some thought to the following:

- *Who*—to optimize the costs and impact on the available workforce
- *When*—considering plant schedules, cultural issues, after hours
- *Where*—on site, off site, at home, out of town
- *By whom*—community college, supervisors, vendors, consultants

- *How*—mix of classroom and on the job, lecture, audiovisual, computer based, web based, home study
- *How much*—standards, evaluations and certifications

Managing others is as essential a skill as expertise in the maintenance trades. Too often, however, very little thought is given to training people how to manage. The typical first-line supervisor is promoted for being technically adept and a team player. He/she may not have any inherent ability to manage, and all too often, technically oriented people lack the interpersonal and leadership skills to be effective as managers. Technical skills reside in the left side of the brain; interpersonal and leadership skills (which are more art than science) reside in the right side of the brain. Most of us have a preference for one or the other, and your best technical people may prefer left-brain functions and knowledge that does not give them the right skills for supervisory and management roles. They may also lack formal training in business. Promotion of your most competent technical people can, in some cases, result in a double negative—you lose an excellent technical resource and gain a poor supervisor.

A maintenance manager with no understanding of leadership, administration, budgeting and productivity control can be a liability. In *The 108 Skills of Natural Born Leaders* (Blank 2001), Warren Blank writes that no one is a born leader but that we all have the potential to become leaders. Somewhere along the way, we learn and develop the skills to make this happen. Self-awareness, self-management, social awareness (empathy) and relationship management are skills required to be "emotionally intelligent," and they are key to leadership (Goleman et al. 2002).

Many planners act solely as parts chasers, clerks or data entry personnel. Because they sometimes have little shop-floor experience, their credibility is seriously questioned by the tradespeople and supervisors they serve. They end up dissatisfied with their roles and rarely make valuable contributions that planning can make if it is executed well. Planning is a valuable skill, and a well-trained planner is probably the most highly leveraged employee in maintenance. A good planner can keep up to 40 tradespeople very busy, but planner training, like management training, is often inadequate (in some cases, nonexistent).

When change in an organization occurs, old paradigms are shattered or unfrozen; new ideas are planted and allowed to grow. For people to learn to handle change, education is key. Encouragement is also important, and the best way to encourage people is to acknowledge and share positive results, ensuring more of the same. Nothing succeeds like success, and public recognition will motivate others while expanding and extending knowledge.

Another element in Lever's success was their tying of compensation to the demonstrated use of new skills. Compensation in a variety of forms is important if you are to attract and retain the best workers.

Career Development

Too often, we hire and fire people as if they are commodities. We expect new hires to have the knowledge and skills required for their jobs—particularly if we hire into senior positions. Many people will change jobs because they see opportunities for advancement and end up in positions with responsibilities and authority that they have not had before. They are learning on the job, and sometimes, they make costly mistakes—that is part of learning.

When someone leaves to go elsewhere, you lose a knowledgeable and skilled asset. It will be expensive to fill the gap left—recruiting, hiring and training all take time and money. This hurts companies in a financial sense as well as impacting on productivity overall. When someone leaves, particularly someone in a key position, the impacts are often negative. Why not keep those people happy so that the opportunities where they are today outshine the apparent opportunities elsewhere?

One large mining company developed a model for career progression for its "engineering" staff (which included maintenance as well as project, mine and ore processing engineering). They defined the various levels at which their "engineers" could work all the way from apprentice up through senior manager at the mine and on to corporate-level asset manager. At each level, they defined the sort of responsibilities the individual could have along with the skills and knowledge they needed. Some of these were defined from their own experience, and they enhanced it with external information, including the Institute of Asset Management's "Competences Framework," which defines seven asset management roles along with specific activities that the individual must be capable of demonstrating at increasing levels of competency. This broadened their perspectives on what they could be expecting and provided an excellent framework on which to develop their talent in house at each level.

For each level, they went on to define the specific learning requirements and how they were to be achieved—classroom work, on-the-job experience with demonstrated task accomplishments and any formal testing or certification requirements that would enhance learning and capabilities. This also proved very useful in helping them define the job requirements for positions within their organization and for recruiting purposes.

Needless to say, they are developing some amazing talent and have become somewhat of a target for recruiters. Their compensation schemes have kept pace, and few have reason to want to leave. For their efforts and investment, they are getting a top-notch workforce with top-notch management, retaining employees, and seeing savings in costs to recruit and replace employees due to the low attrition.

Total Productive Maintenance and Lean Operations

TPM is a team-based approach to organizing and working that has proven highly successful in a variety of industrial environments such as automotive, light manufacturing, brewing and chemicals. It is a feature in many "Lean" manufacturing operations. Similar to quality approaches, it emphasizes the importance of integrated teams of operators and maintainers who work together, care about their work and are committed to team success. From that flows the overall success of the organization. The small team is one of the distinct features of TPM. Operators and maintainers work together toward the same goals with common performance measures and methods. The traditional work boundaries tend to blur between them, and extensive training is used to help maximize flexibility and capability while retaining safety. The teams are allowed to operate autonomously, are responsible for their own decisions and support overall plant or operational goals.

TPM's three distinct features are reflected in its primary objectives:

- To maximize equipment effectiveness and productivity by eliminating all machine losses
- To create a sense of ownership in equipment operators through a program of training and involvement so they can perform autonomous maintenance
- To use small-group activities involving production, engineering and maintenance to promote continuous improvement

Each enterprise has its own unique approach and vision for TPM, but in most cases, there are common elements:

1. Asset strategy—take a hard look at the physical configuration of equipment and systems to reduce waste in all forms to optimize operability, maintainability and ergonomics.
2. Empowerment—autonomous teams making their own decisions and acting on them within broader guidelines and management direction to achieve well-defined goals.
3. Resource planning and scheduling—to ensure maintenance resources are utilized effectively with operators who may be working in tandem on manufacturing cell-based teams.
4. Systems and procedures—to document successful practices as they are implemented so that they may be sustained.
5. Measurement—to demonstrate results and progress toward goals, often using visual management methods so the results and progress are well known to all team members.
6. Continuous-improvement teams—to identify chronic problems and address them with design and implementation of solutions on an ongoing basis. Improvement is intended to be gradual and continuous.
7. Processes—a new definition of the working processes is needed as they replace more traditional maintenance processes such as planning and scheduling and the management of PM.

Teams optimize the value of employee input into your company, and TPM is an excellent approach that works well in the production environment. With blending maintenance and operations into autonomous self-directed teams achieving superior results, TPM provides a framework for exceptional team achievement.

Various models of TPM can be found. Here, it is considered to be the effective implementation of all the elements of the Uptime Pyramid of Excellence in a collaborative, team-based environment with considerable autonomy being granted to a well-informed and knowledgeable skilled workforce.

A Word about Lean Manufacturing

The term *Lean* has been overused and abused by many. Lean manufacturing and all that it entails is all about eliminating waste. Unfortunately, many companies, likely driven by a hyperfocus on costs, have tended to focus on cost reduction. In asset maintenance and materials management, that means eliminating the use of people and materials. While that may, in fact, be one result of Lean efforts, it is not the objective to eliminate anything as specific as people or materials unless they can be shown to be "waste." Eliminating them implies that either they were not needed before or the way they are utilized can be replaced with some more cost-effective means.

It is that search for the more effective means that triggers the elimination of waste, not the reverse. Programs that focus on elimination of headcount or arbitrarily reduce levels of inventory without consulting the users of that material are ill-advised and doomed to failure.

In many ways, this entire book is about Lean operation without really calling it that. We are searching for the most cost-effective, safe and environmentally sound ways of caring for our physical assets so that they can continue to produce or provide the services they are intended to provide without wasted (nonuseful) downtime. The use of *Uptime* will not necessarily result in lower headcount or reduced inventory of spares. It could easily increase those if, in fact, the current maintenance programs are not achieving their objectives. As a rule, the cost of downtime is far more than the cost of maintenance or spares held in inventory. Reducing maintenance resources or the support they need to be effective is often a false economy.

In one sawmill far into northern British Columbia, increasing the size of the maintenance department by four trades persons enabled the mill to reduce its breakdown maintenance by over 80% and reduce overtime that was running at well in excess of 20%, and had a secondary benefit of reducing on-the-job injuries because the workforce was less fatigued. That 20% level of overtime was waste. It actually cost them the equivalent of 10 full-time employees to sustain that. Adding four persons enabled the performance of their proactive maintenance program. Overtime dropped to only 5%, so the net gain was 12% of their maintenance labor costs. That dropped operating costs sufficiently to improve profitability and sustain operations in that location longer than they had previously forecast.

Being Lean is not about becoming "cheap." Reducing staffing and other resources without taking the steps to truly operate more efficiently and effectively is a false economy that will backfire every time. Eliminating waste may entail an increase in costs if it means greater effectiveness and more uptime. Avoid the temptation to slash costs directly—you will not create a Lean organization that way; you will create one that is anorexic and incapable of functioning well.

COMPENSATION AND REWARDS

The younger generation of workers has a different set of motives and values than their predecessors, and money is not always at the top of their list. Money, in fact, is a motivator with hidden defects. If you pay only by the hour plus overtime, you encourage inefficiency. If you pay a straight salary, you discourage overtime and do little to encourage efficiency. Various schemes exist for compensating the workforce, but the bottom line is that money is only one of many rewards that make people want to work in any given company.

The best way to *attract* qualified, enthusiastic technical employees to challenging careers is to offer generous financial incentives. If you do not pay well or provide attractive benefits, the talent you want will go elsewhere. Even the prospect of a major commitment to education and training will pale without a direct payoff because even though increased skills can bring long-term rewards, most people want to see something more immediate. The best way to *retain* employees is to create an environment that they want to work in. Without such an environment, people turn off their brains or go elsewhere. If they stay, they do so only for the money. A team-based environment where individual and team contributions are valued is highly effective at retaining talent. Another successful practice is to help your employees develop their full potential in a meaningful way, even if it means you might be helping them create a more attractive resume.

One major supplier of industrial equipment had about 20 apprentices in one of its maintenance shops. The manager went to extraordinary lengths to get them the required field experience so they could become ticketed quickly. The apprentices appreciated the effort, and they were compensated for the additional experience they gained—the maintenance shop had the best employee retention record in the company.

Your compensation program is best linked to your organization's overall objectives as well as to your maintenance strategy. One or more approaches may be appropriate. The following categories of compensation can be mixed and matched to make up the total compensation package:

1. *Base pay*. In any compensation system, base pay is competitive and guaranteed. The technical trades employed in maintenance work are in great demand, and the supply is shrinking. If you want low turnover, begin with an appropriate base pay. It is normally related to an employee's position, grade or seniority, skills and the tasks or duties required in the job description. In the case of multiskilling, tie base pay to the knowledge or skill level demonstrated and applied by the employee. Ideally, your base pay is sufficient, precluding the need for overtime payment.
2. *Overtime*. Base pay often covers only a specified number of working hours per day. If more effort is required, overtime is paid. Unfortunately, overtime provides a disincentive to getting work done during the normal working day. It puts more pay in the employee's pocket and increases maintenance costs. Overtime pay can also become addictive to employees, especially if it forms a substantial part of their compensation. It encourages reactive working environments and provides a disincentive to do any proactive maintenance. This results in plenty of extra overtime, call-ins and unplanned shutdowns. If you find yourself in this situation, considering making the average overtime payment a part of the base pay and eliminating overtime altogether. This will require a concurrent effort to improve planning and scheduling, as described in Chapter 3. It does not raise labor costs, and it provides plenty of incentive for the workforce to become proactive. Workers are paid as much as they were paid when they were working more, and you get improved reliability and performance.
3. *Profit-based incentive pay.* Incentive schemes can be designed for either individuals or groups. These schemes pay out a share of profits based on gains made by the company, equity or stock options. Incentive pay can be decided at the discretion of the manager using some formula based on time worked or piecework achieved. Some programs offer incentives for suggestions that are implemented or compensate for sick and vacation time not taken. With increasing emphasis on teamwork, there is a trend toward group rewards as opposed to individual awards. Such plans reinforce desirable team behavior and employee involvement. Individuals in these schemes are under pressure from their peers to perform for the benefit of the entire team. Productivity gains are shared between the company

and the employees, according to a predetermined schedule. These schemes are often very effective at achieving their goals.

4. *Gain sharing*. This is a form of incentive pay that is not tied to profits. Incentive payments are based on the attainment of specific goals, regardless of profit. The goals might be related to production levels, availability or reliability targets. This has an advantage over profit-sharing schemes because payout is not tied to profits, which employees often feel are beyond their control. It also avoids the inevitable disappointment and disillusionment with the profit-sharing program that arise when goals are met but profit expectations are not.
5. *Benefits*. Traditionally, benefits have comprised a social safety net and basic life and disability insurance. In many jurisdictions, some of the basics, such as unemployment insurance and pensions, are legislated. Beyond those, however, most companies provide additional paid benefits. These packages have become expensive, and in some cases (e.g., the steel and automotive industries in most of North America), they have led to severe financial hardship for companies. With cost cutting aimed at remaining competitive with offshore companies, there is a trend toward contracting with insurance and other providers for the management of these benefit packages. Some enterprises are offering a menu of benefits, usually grouped into packages that are carefully tailored to cater to various employee desires (e.g., single employees vs. married vs. married with children vs. nearing retirement etc.). Each is priced so employees can select the most appropriate cluster of benefits up to a preset dollar limit. These can include participation in pension programs, savings programs, medical and dental programs, drug programs, etc. The best packages offer a lot of variety and individual choice.
6. *Perquisites*. Perks are popular when the economy is expanding and competition for highly qualified employees is keen. In maintenance management, the most common perks are subsidized personal work tools and equipment, education leave and financial assistance. Other perks include car allowances, free parking, cell phones, work clothing, education and day care, fitness clubs, social clubs, cultural and recreational activities and employee discounts on purchases of company products or shares. Beware of the temptation to pull the perks when times get tough. Companies tend to view perks as a privilege,

> but employees tend to view them as an entitlement. Eliminating these perks, once they are established, can be a challenge. If a perk is "lost" by the workforce and is not replaced with something else, workers are likely to resent it. (Overtime is a good example of a business requirement that has become a perk and an entitlement.)

Non-monetary rewards are another way to compensate employees. Besides base and incentive pay, you can recognize individuals and groups for a job well done. There is usually no set pattern for these rewards, which vary greatly depending on the organization. Most companies that offer such rewards began to do so as a form of thanks to employees for their achievements in throughput, safety or project management, or for completing formal training courses. Now, they are also offered for significant contributions in quality service, cost and time improvements and advances in job-based knowledge or competence. Awards can range from certificates, medals and trophies, to dinners and getaway weekends. Make sure you reward the desired behavior. Avoid the temptation to reward the white knight—the one who rescues you from a major failure situation—while ignoring those whose efforts helped to prevent other such situations. Also be aware that some individuals do not want public attention drawn to them. In such cases, public recognition would be counterproductive, so keep it private and personal.

Today's trend in compensation is moving away from pay for a single trade skill toward pay for demonstrated knowledge and multiple skills. An excellent practice is to have all employees on salary with specified annual hourly contracts. Incentives are paid based on business results or outputs rather than individual or departmental results alone (for example, increasing production levels by x% or reducing unit production costs, which include maintenance costs, by y%). This encourages interdepartmental cooperation and helps break down the old maintenance/operations barriers. Additional incentives based on individual or departmental results are kept to a minimum to encourage teamwork. Incentives are paid regardless of profits because profits can be impacted by market conditions that are completely out of employees' control. This also shows that management appreciates employees' efforts to improve the business, even if external factors negate their efforts.

This chapter began with a look at the extent of change in the marketplace and the business imperative to respond quickly and effectively. Handling change really boils down to managing people well. Doing that is not only something you teach now and again; it is a lifelong learning process. Your own workplace version of the three *R*s—reassess, recognize and reward—will earn you top marks for your efforts. Best of all, you will make change work for you.

Managing people is a huge challenge, but an astute leader will have a workforce motivated by free will and people who choose to work toward common goals. People make all the difference between companies that are good and those that are great. If you get the people part wrong, other goals will suffer.

UPTIME SUMMARY

Good strategy deployment and ongoing execution of your maintenance or asset management system (and we do not mean information technology) require the right quantity of the right people, suitably motivated and rewarded to achieve your strategic goals. It only happens through people—nothing else. People are an important, arguably the most important, strategic asset you have got to work with. You cannot provide solid leadership without people to lead.

An organization is an extension of its people. It stands to reason that we need to focus on people if we want our organizations to thrive and change. Your people truly are the most important part of your business. Both you and your people need to make the choice to take this journey together and for each other's benefit, not just for the company or profits or shareholders. Narrow vision focused only on the business will cripple your efforts to improve.

Managing the change is critical to success, but it should not be a separate project work stream running in parallel with your improvement efforts. It must be an integral part of all you do—built into every activity and communication. Excellence is a journey where change will be constant—you need to be good at managing people and managing change.

Purely technical approaches, the long-time favorites of engineers and technical people, no longer work well on their own. Installing a new computerized management system is not a solution, nor will it guarantee success. View technology as a tool, do not put it on a pedestal and look to your people for the answers you need, and you will do well.

Today's effective managers are less likely to be purely technical people. Rising through the ranks on the basis of technical merit alone is a recipe for poor management. Choose your managers on the basis of their suitability for the role they are heading into, not on the basis of past performance or technical merit alone. You need a balance of technical, managerial and human skills. Promoting a good technician purely because of technical merit or skill on the tools ensures that you will lose a good technician and gain a poor supervisor.

Organizational designs continue to evolve. Centralized, military-style organizations have given way to more responsive decentralized structures. To deliver maximum business benefits, traditional maintenance, engineering and operations departments are working together under the umbrella of asset management. Increasingly, they are becoming single-delivery organizations. Traditional departmental boundaries are blurring, and the focus is shifting to the delivery of business results, not departmental results.

There is an old saying that "two heads are better than one." Teamwork has been proven time and again to produce superior results. It is the basis for many successful methods like RCM, PMO, RCFA, TPM and even the highly technical evidence-based methods as described in this book. While your people are truly important both individually and collectively, it is organizations that make extensive use of teamwork, especially self-directed teams that truly see exceptional performance. Self-organized teams bring out the best in people. They encourage creativity, participation and innovation. They use team/peer pressure (ever so subtly) to ensure that people are all working toward the same goals. In turn, these teams deliver enhanced productivity and superior results.

Smaller teams tend to be more effective than larger teams, provided they have sufficient breadth and depth of knowledge to handle assigned tasks. When teams grow into large groups or departments, they begin to need more formal management structures and processes in order to remain effective. If you have a group with more than 150 people, you will find formalized approaches necessary. In groups with fewer than 150 people, such as a small manufacturing plant, a degree of informality works well. Keep this in mind when looking at organizational arrangements. Smaller groups and less formal organizations do not need or rely on command and control to get things done—management becomes easier. Command and control stifles initiative and creativity and harms productivity, especially in today's well-educated, socially aware and tech-savvy workforce.

Learning, training and development are critical to companies that strive for excellence. Our educational systems are no longer geared toward industrial careers, and the onus is shifting to companies to foster their own talent. Without a focus on developing people, companies will become victims of the demographic realities of our times. Attracting, retaining and rewarding talent is critical. There is no point spending a great deal on recruiting and developing people in house if you do not retain them through a competitive and attractive compensation program that recognizes their individual and team contributions and successes. Encouraging career and personal development and then paying for new skills that get used at work are excellent ways to motivate and retain talent. Multiskilling continues to grow in popularity as a means of developing workforce flexibility and enabling more efficient deployment of maintenance resources.

ENDNOTES

1. Larry Bossidy and Ram Charan discuss this at length in their book, *Execution: The Discipline of Getting Things Done* (New York: Crown Business, 2002).
2. John Quincy Adams, sixth president of the United States, 1825 to 1829.
3. This concept is described as "open-book management" in *The Great Game of Business* by Jack Stack with Bo Burlingham (New York: Currency/Doubleday, 1992).

Section II

Essentials

This section of the book describes the core elements of maintenance management, which all companies use, albeit with varying degrees of competence. High-performing companies make it look easy, but even those companies that perform poorly find that they provide at least some level of consistency and stability. For companies that are underperforming in maintenance, building a conscious awareness of strategy and managing people more effectively (as discussed in Chapters 1 and 2) will help spark improvement. For companies that are performing well, these issues may be less of a concern, and the greater focus may be on moving from good to great (as discussed in Section III). In either case, mastering the essential core elements discussed in this second section of the book is a step on the road to success.

3

Work Management

> So much of what we call management consists in making it difficult for people to work.
>
> **Peter Drucker**

Perhaps the most important process that maintainers "own" within any business is "work management." It is all about getting needed work done. The work itself is dictated by preventive, predictive, detective, and run-to-failure strategies, and it may include execution of projects that modify the plant. Getting all the work done in an effective and efficient manner is what work management provides. If that is achieved, operations experiences the least disruption to their operating cycles, they can then produce more, maintenance costs are minimized and equipment operates well, producing good-quality outputs with the least input of energy and the least generation of pollution. Good work management gets the most productive effort out of your workforce, keeping them busy doing meaningful work and getting the work done that keeps production running. Arguably, if you achieve this last goal of getting the most productive effort from your workforce, you will achieve the other goals much more easily.

WORK MANAGEMENT CYCLE

Drucker's observation above does not apply to those few companies that are truly high performing in maintenance. Making it easy to do the right work the right way and in a timely manner is what work management is all about. At the heart of the maintenance function are work planning

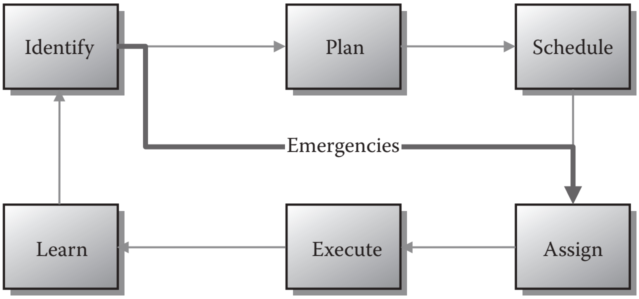


FIGURE 3.1
The work management cycle.

and work scheduling, but these tell only part of a complex story. Work management includes planning and scheduling, but it also extends to other activities that, together, comprise a six-step work management cycle, depicted in Figure 3.1.

As the figure illustrates, planning and scheduling are two important steps in the cycle. Planning defines what gets done and how; scheduling defines when. The problem with focusing only on these two segments of work management is that this presumes that operations always proceed without problems or variations, and that is rarely the case. For this reason, the material presented in this chapter deals with the entire work management process, including an emphasis on shutdowns and on managing a mobile workforce.

What every plant or fleet manager wants most is to sleep soundly—to turn off the office light at night confident that the equipment will be running reliably and efficiently the next morning. Unfortunately, such peace of mind is rare. Breakdowns, emergency repairs, unplanned and unscheduled downtime, overtime, and maintenance stores' stock-outs all rob a business of capacity and profits. Avoiding these pitfalls requires effort in four areas:

1. Having the materials you want available at the time you want them. Materials management is covered in Chapter 5.
2. Doing the right proactive work that eliminates or at least minimizes the disruptive consequences of equipment breakdowns. Reliability-centered maintenance is a technique for identifying the most appropriate work in a systematic way and is covered in Chapter 8.

3. Having the skills and abilities available to do the right work efficiently. This has been covered in Chapter 2, People and Teamwork.
4. Getting maintenance work done the right way through effective work management practices.

Let us begin with the assumptions that you have good materials management support, you have the right people with all the right skills and ability at your disposal, and you have a well-defined maintenance program. It is the maintenance work management process that pulls these elements together so that the right work gets done by the right people using the right materials at the right time. The six-step work management process depicted above is the framework that enables that to happen:

- *Identify*. Preventive, predictive, and failure-finding work orders are usually generated from your proactive maintenance program schedules. Repair work arises as a result of failures that are reported, usually by operators, using your work management support system.
- *Plan*. This describes what work is to be done and how. A sequenced, documented plan is made, with descriptions and drawings, as necessary, of what has to be done for each job. All known materials are made available, and repair manuals are reviewed to get any needed relevant information. The job is not scheduled to start until all the right parts are on-site.
- *Schedule*. Once materials and labor availability has been confirmed, the job can be put on a schedule for execution. Jobs are scheduled for the best production window with the least disruption to customers. For maintenance not requiring special shutdowns (discussed later), there are two schedules, weekly and daily. Advance scheduling is best performed for a weekly cycle, which means identifying next weeks' work before the end of this week. The scheduler (usually the planner) creates the weekly schedule as a batch of work as a goal to focus the supervisors. The crew supervisor creates the daily schedules usually a day or two in advance as the week then progresses using the weekly batch and working in new emergencies and other urgent work that cannot wait until the next week. The best practice is not to allow any portion of the weekly schedule for "break-in" work but, rather, allow the supervisor the freedom to break the schedule. The goal-setting aspect of a full-capacity schedule focuses the crew

and leads to completing more work than normal. The compliance to the schedule also leads to management focus on areas to improve because it clearly identifies the gap in labor capacity versus schedule accomplishment. Because extra work completed is usually proactive, the increased productivity allows your proactive maintenance program to take effect and eventually reduces the number of emergency and urgent work situations you experience. This improvement is also reflected in eventual higher schedule compliance.

- *Assign*. Maintenance supervisors assign the various tradespeople under their direction to the various jobs on the weekly schedule, given the planned work package and any additional instructions the supervisor deems appropriate. There is a blend of scheduling and assigning work. The daily schedule essentially is the supervisor assigning the work a day ahead of time and ensuring that operations will support having the equipment available. On the day of the work, the supervisor may shift actual persons among jobs depending on any absences and new emergency or sometimes urgent work that should not wait. Assigning persons to work is a skill for supervisors considering many factors, including risk and human nature. Among these considerations are who works well together versus who works best alone, who gets along with certain others versus who does not, who is the most highly skilled for a certain task versus training less experienced persons, and how important the timely completion of the work is versus who and how many persons should be assigned. The supervisor properly assigning persons to work is a critical part of supervision. The supervisor should make thoughtful assignments rather than simply assign whoever is available or whoever will stay on overtime.
- *Execute*. In successful companies, work crews do the work as best they can, and this is where trade skills, multiskilling, and training pay off. Do not rush the work. Be careful with slogans such as "do it right the first time." This statement should mean that if something does not go exactly as planned, correct it. Do not try to work around it just to meet the schedule. Too many people, however, take that statement to mean that everything should go perfectly as planned and management punishes imperfections. Such punishment leads to hiding mistakes and shooting the messenger. No, do the job the way it needs to be done, and then report any problems with the plans and the execution so we can do a better job next time.

- *Learn*. When the work is completed, inform operations. Typically, Maintenance reports to Operations that the work is complete and the equipment may be operated. Many times, operations does not want to immediately operate or test the equipment, and maintenance should not simply wait around for operations. However, if either maintenance or operations is ready and wants to test the results, operations should test the equipment as soon as practical while maintenance is conveniently available. If operations is satisfied that the work is indeed ready, the equipment will be deemed ready for production. The work crews record the parts used, materials used and other relevant data on the work order along with any feedback to the planners. The planners close the work order by making any necessary improvements to standard job plans and making the job history data available for reliability. Closure of a work order is a learning step in which the organization learns from each job as it is executed so that the next time the job is done, it will be done better.

As with every complex business specialty, maintenance has a language of its own—terminology that describes conditions, processes, tasks and practice. A few definitions will facilitate comprehension of maintenance management concepts and protocol:

- *Break-in work*. Work that is added to a weekly schedule for execution after the weekly schedule has been finalized.
- *Corrective maintenance*. More commonly known as *repairs*, this is work done to correct a defect or restore a failed device to working order. Generally, corrective maintenance will be less urgent than so-called reactive work. It would be a defect or failed device that can be corrected before it significantly bothers operations.
- *Detective maintenance*. Also known as "failure-finding tasks," this form of proactive maintenance is work done to detect failures that have already occurred but remain undetected because the functionality that has been lost is normally not used or dormant. This work is most often done on backup, standby, protective or safety systems.
- *Emergency maintenance*. Work that is treated as if it were truly an emergency, whether or not that treatment is warranted. Emergency work gets top priority regardless of other work that is being executed. Emergency work always "breaks into" an existing daily schedule and displaces other scheduled work if encountered during a workday or

shift and justifies calling in someone outside of the workday or shift. Every effort is made to hasten work execution, including but not limited to expediting missing parts, use of overtime, use of contractors on callouts, etc.

- *Planned maintenance*. Work where a planner has considered the job in advance of it being scheduled and assigned to work crews for execution. Planning is used to increase work effectiveness, ensuring that the work is done to the best of the company's institutional knowledge and can be scheduled. The planner usually creates or uses, sometimes with modification, an existing "standard" plan. The planner also assigns required craft skills and estimated labor hours. The planner has deemed that all known parts and tools are available. Work is not "planned" if it has not first gone through the hands of the planner, where the planner sees about attaching a standard job and estimating hours. The standard job holds the company's institutional knowledge learned in the past, and the estimated hours support scheduling. If some workaround was later needed, the plan obviously could be improved in some way. Capturing this knowledge via feedback and improving the standard job is essentially the very reason for planning.
- *Planned job*. A single maintenance job that is fully planned, as described above.
- *Planned work*. Work on planned jobs, as described above.
- *Predictive maintenance*. Also known as "condition-based maintenance" or "on-condition maintenance," this form of proactive maintenance is work done to look for signs of impending failure so that corrective maintenance can be done before equipment functionality is lost. There are two stages to predictive maintenance: "condition monitoring" and "inspections" (also known collectively as "condition-based monitoring"). These are used to determine the condition of the equipment followed by corrective maintenance performed only when that condition is deemed to be unsatisfactory. High-performing companies monitor the success of their condition-based monitoring closely by tracking the corrective work that arises from it on separate work orders. Usually, predictive maintenance employs some sort of high technology, such as vibration monitoring or ultrasound.
- *Preventive maintenance*. This form of proactive maintenance is work that is scheduled and executed to replace components or restore

them to original condition regardless of their apparent condition at the time. This work is done for failures that are age or usage related, and it is done before the failures manifest. This type of work is considered planned work because it has a standard job plan and time estimates, although the planning was done not necessarily for the current work order but in the past, when it was first created or later revised.

- *Proactive maintenance.* Work that is done with the intent of avoiding the consequences of failures. This includes preventive, predictive and detective (failure-finding) work.
- *Reactive maintenance.* Repair or corrective work that is done when something fails. Distinguished from corrective maintenance (above), reactive maintenance is usually more urgent and a current bother to operations.
- *Scheduled maintenance.* Any work that is committed to a time schedule for execution before the scheduling cycle in which it is to be executed. Work added to a schedule after it has been committed is known as break-in work. Scheduling is done proactively to increase the efficiency of use of the workforce and materials. Work is scheduled if it is carried out or started within the scheduling window as scheduled. If scheduled work is started outside the intended scheduling window, it is effectively unscheduled.
- *Unplanned maintenance.* Work that is not planned before execution because it did not first go through the hands of a planner for adding any instructions or attaching a standard plan or a time estimate. It is difficult to properly schedule unplanned work because it does not have a planner-supplied time estimate.
- *Urgent maintenance.* Work that is prioritized so that it may require break-in to the current weekly schedule, but the situation is not so serious as to demand that the work be done immediately. There is some time for preparation before the job is executed. Planners might be able to quickly plan such work even though it might be executed before the next weekly schedule.

Studies done by several research teams, including Alcan, General Motors and the author's own consulting team, have shown a clear link between planned maintenance and reduced costs. When work is planned, it is easier and less expensive to execute than work that is unplanned. This is not only logical but also statistically sound. A conservative rule of thumb is that unplanned running repair work will cost at least 50% more than fully planned and scheduled work and that emergency work will cost 3 or more times as much. A ratio of 1 to 1.5 to 3 times can be used to estimate the breakdown of work costs if you know the ratios of planned and scheduled, unplanned and emergency work. Estimates of 1 to 3 to 9 to 14 are also fairly common—the actual ratio will vary considerably from industry to industry and from plant to plant. One underground mining manager estimated his emergency repair costs to be 14 times the cost of planned work. A large nickel refining operation had estimated ratios of 1 to 3 to 5.

Planned and scheduled work is both effective and efficient. Planned work may be effective from the perspective of those carrying it out, but it is not cost-effective unless it was scheduled as well. It is possible to carry out planned work using parts that were flown in from far away at great expense in order to meet a hastily prepared or ill-conceived schedule. It is more cost-effective to get both planning and scheduling right.

Some work is very simple to execute, requires no parts and needs only minor hand-tools to be completed by a single, trained tradesperson. Clearly, not every running repair warrants *detailed* planning and scheduling—that would be going overboard—but it is clear that jobs involving complex procedures, specialized skills, multiple trades, replacement components and parts certainly do. Nevertheless, simply running even "simple" jobs through the hands of a planner allows the planner to help the tradesperson avoid any time-consuming delay encountered in the past and also allows scheduling. More work that does not get planned encourages the abandonment of full-capacity scheduling, a huge key to productivity. Furthermore, companies frequently find that when they allow so-called simple jobs to bypass planning, many major jobs bypass planning as well. Under most circumstances, leaving the work planning to the tradesperson who will also execute the work is inefficient.

SIX KEY STEPS

Effective maintenance work management comes down to six key steps that are the same regardless of the industry or circumstances. The process starts with identifying what has to be done and ends with analyzing why you had to do it in the first place (Figure 3.1).

Identify

Maintenance work can spring from something as simple as a noisy bearing or pushing a "test" button to something as complex as interpreting trends in vibration signatures. These are examples of using the equipment condition to trigger the repair work and are considered to be "proactive." Random observations have a low probability of catching a problem before its condition becomes unacceptable. The most effective observations are those that are both disciplined and regular. It is also much better to program inspections by operators or maintainers who are equipment sensitive and know what they are looking for. It is not good enough to tell someone to "check it"—you must specify what to look for, what is acceptable and what is not.

Like your family car, your equipment will benefit from regular cleaning, lubrication, adjustment and observation for signs of abnormal performance. These are important checks that give us early signs of problems, and they can help you decide where in the "repair queue" a job might be positioned. Work prioritization determines what gets repaired soonest.

Waiting for equipment to fail is one way to be certain you are repairing it without wasting "useful running life." However, this may also bring unacceptable consequences, such as loss of production or interruption to customer services. This approach of waiting for failures is known as reactive maintenance. Organizations that are highly reactive plan less of their work than proactive organizations—some even plan none of their work in advance. Unfortunately, the cost ratios still apply to them, and they are choosing the most expensive approach. These organizations are also easy to spot but not so easy to change.

Plan

Planning is ensuring that all the known resources necessary to do a job are accounted for and available. Scheduling (discussed later) is a matter of when to do the job. In many organizations, people refer to planned maintenance when what they are actually doing is scheduling their work. The two are quite different.

The most obvious planning tasks are to determine what has to be done, in what sequence and with what skills. Parts, materials and components are usually necessary and sometimes not immediately at hand. Sometimes, extraordinary items or resources may be needed, including engineering drawings, outside contractors, special tools or mobile equipment. Safety reminders or regulatory direction may also be required. Some tasks will need work permits, locking out and tagging out of equipment. All of these should be identified and included in your job plans. Miss even one item, and the tradespeople who are trying to do the work will be spending their time looking for whatever is missing—and driving up the costs. Nevertheless, the level of detail a planner places in a job plan depends on how much work there is to plan. A planner must plan all the incoming work. This work excludes only emergencies and urgent work where the supervisor has said the crew has already completed it or will start almost immediately. In emergencies, planners help chase parts as requested, and on urgent work, they quickly add plan details and time estimates within a few hours. Rather than plan each job perfectly (which cannot be done), the planner's objective is to put all the work through the Deming cycle of continual improvement. The planner's objective is to plan all the work in as much detail as possible subject to the constraint of planning all the work. The only way the planner can accomplish this feat is through counting on the existing skill of the tradespeople for current plans knowing that in the future, plans might one day be developed to the point where tradespeople new to the site can easily use them. Even then, the plans should be seen as continually improving and never perfect. So the planner tries to plan around all the delays that might impact a tradesperson but knowing that problems that are encountered will be reported as feedback for future avoidance. These job plans are called standard plans, but they are never really ever standard or settled.

Getting the plan off to a good start and then continually improving requires a planner protected by management to plan. Current best practice shows that a planner can plan work for 20 to 30 tradespeople, although depending on circumstances, such as the proactive nature of the plant or the maturity of the planning program, the number of tradespeople per planner could be much higher. On the other hand, a single planner planning for multiple trades, a plant that has poor support systems (such as stores), or a plant that is geographically situated with only a few tradespeople might dictate a planner planning for fewer than 20 tradespeople. In some such plants with fewer tradespeople, a planner might also be allowed a role in helping chase parts for jobs in progress (usually not a planning duty).

Selecting capable people for planner positions is critical to making planning "work." The planner should have technical skills and plant-specific experience to be credible to those executing the plan. The planner should also possess skill in collecting and organizing data. The planner should also be a good communicator. Of these three skill areas—technical, data, and communication—the planner could be weakest in the technical area because the planner will never be as knowledgeable as the cumulated wisdom and experience of 30 tradespeople. Nevertheless, considerable craft skill is desirable. The planner uses field inspections, his/her own knowledge of the equipment and systems, and all additional available information to lay out a job and estimate how long it will take. Finally, the planner often estimates the overall cost, which facilitates cash flow projections and repair-or-replace decisions. The estimated time to do the job is used together with "net capacity" in the scheduling process.

Again, it is worth noting that not every job requires planning *in detail*. There are many jobs that can be done in just a few minutes by one tradesperson, using standard-issue hand-tools and no parts. These simple jobs are well within the tradesperson's skill set and require little to no preparation in advance. One mining operation claimed that up to 60% of its work fit that description. We still want that job to go through the hands of a planner whenever possible. A planner can simply check the equipment records to avoid past reported delays and set time estimates to allow scheduling. Try to avoid work charged to blankets or standing work orders that cannot be scheduled. Blankets also get abused. Obviously, it makes no sense to plan such simple work in detail, but a planner can simply say, "Do this or do that, and it should take one mechanic 30 minutes." Now the work can be scheduled, and there is a discrete work order in which to capture feedback. It is not just that we want to schedule that one work order. It is more that if too much of the work is not on work orders, we have lost the ability to schedule to fill the net capacity mentioned in the preceding paragraph. Even so, the planner should not get bogged down putting in too much detail on such work and should spend more time working on more challenging jobs.

Parts availability is a matter of checking the on-hand status of the maintenance stores or the lead time of any items ordered directly from suppliers. In many cases, there is a gap between what the stock records indicate and what is actually there. "Open stores" where there are few controls on issues and returns are usually the worst, especially if they are in a reactive maintenance environment. Maintainers in a hurry are not usually good record keepers. Visual confirmation of parts availability is highly recommended until you gain confidence in your stores and your inventory control system. Most maintenance management systems will do this check for you using their integrated inventory and planning modules. Of course, the data they supply must be accurate, and you want to ensure that it stays accurate, or you will find yourself resorting to manual checks. "Kitting" or "staging" of parts and special tools is usually recommended for shutdowns but can also be almost necessary if you have a poor storeroom. The industry traditional definition of a planned job that mentions all parts should be kitted is false. If you have a good storeroom, many times, kitting will only be taking a chance on losing or damaging the parts because you got them out before you needed them. Kitting parts is not the answer to productivity anyway; scheduling is the answer, as discussed below.

Schedule

Scheduling determines *when* the work will get done and is a matter of resource and asset availability. Because the work has been deemed planned, you should have the parts and have the strategy of the job determined. When is the equipment available to be worked on? When can you coordinate the people who have the right skills? Do you have the agreement of the production department to release the equipment? Only when all of these conditions are in place can the work progress smoothly. If your tradespeople have to wait for any of these, they are being paid but underutilized. We will consider the weekly schedule to be the schedule. The daily schedule will be considered in the following section on assigning work.

To schedule the resources of your tradespeople, first look to see who is scheduled to be at work, sick, on vacation or on a training course for the following week. This gives you a pool of labor to draw from.

Bear in mind that the estimated time to do a job considers not only productive working time but also nonproductive working time. There is also a lot of nonproductive working time, including time spent on breaks, waiting for parts, waiting for instructions and permits, travel time between the shops and the job site and cleanup time. In planning individual jobs (as discussed later), the planner takes into account breaks and other plant circumstances to include in the overall time for jobs longer than a few hours. The planner considers how long the job would take if a tradesperson was available (not in training, vacations or special meetings) to the supervisor. When you take away all of the time spent on vacations, known sick leave, safety meetings, training, etc. (but paid), you are left with net capacity. In many organizations, net capacity can be less than 60% of the time for which you actually pay the workforce. Much of your lost capacity is used in vacations, sick time and mandatory meetings. That time reduces the availability of the workforce to perform work. Planning and scheduling eliminate many of the delays and help to increase your ability to do work within the net capacity you have. Furthermore, within that net capacity, the actual time of tradespeople doing productive work (wrench time) is only about 35% in most companies. If you have 50 tradespeople and an estimated net capacity of 70% and a wrench time of 35%, you are getting the productive effort of the equivalent of only 12 tradespeople full time, taking no breaks and wasting no time in unproductive activities like waiting for anything. You cannot increase the net capacity without modifying your training or leave policies, but you can increase the wrench time with planning and scheduling. Increasing the wrench time to 55% (a realistic target) will add another 57% (55/35 = 1.57) to your equivalent labor effort—you will have the equivalent of 19 (12 × 1.57 = 19) tradespeople full time in a productive effort (pure wrench time). You will still be paying 50 because you cannot eliminate all the nonproductive time (breaks, lunch, etc.), but you will be getting more value from your workforce. As for the 50 original people, they would be worth 78 people (50 × 1.57 = 78). So the improvement to the workforce is really 28 extra persons. You are paying for 50 people, but you have the effort of 78. You have gained 28 persons for free to come to your plant to do proactive work.

Nevertheless, none of this productivity improvement happens without scheduling, because of Parkinson's law. Parkinson's law states, "The amount of work assigned will expand to the time available." The traditional view of planning and scheduling is that planning reduces delays during jobs and scheduling reduces delays between jobs. But because of Parkinson's law, simply planning work does not improve productivity, because crews then "take their time" accomplishing that work. Therefore, the true purpose of scheduling is to assign enough work, not just to say when the work will be done.

Traditionally, the weekly schedule was made up of daily schedules for each of the days covered in the coming week. The thought was that if the maintenance workforce was really well organized and could tell operations when to have all the equipment ready, the crews could complete more work. Added to this thought was the commitment of management that "if we are going to do scheduling, let's do it right!" And furthermore, most computerized maintenance management systems (CMMSs) naively think that maintenance time estimates are very accurate. However, the uncertain nature of many time estimates is a reality as is the significant amount of urgent work in many plants. Therefore, trying to predict exact days and hours of work nearly a week in advance in a weekly schedule leads to frustration.

Instead, current proven best practice is simply to start each crew with a batch of work that matches their net capacity (or labor available) for the next week. This batch of work must be acceptable to the crew supervisor and operations, who then both use it as a focus for the next week to later create daily schedules as the week progresses. This strategy, in line with this book's overall philosophy not to overcomplicate and not to take away lower-level freedom, remarkably empowers first-line supervisors. It focuses them on this week and frees them from having to continually comb through the backlog (if there were no schedule) or constantly revise entire schedules (if there were a series of daily schedules in advance). Even if there were a scheduler to constantly revise advance multiple daily schedules, the supervisor would have to constantly communicate with that scheduler because the supervisor is the only person involved enough with the crew to know the status of all the current work in progress. Instead, the simple batch of weekly work frees the supervisor to check on the current work for the day and figure out what to do tomorrow. Actual plant results of such simple scheduling demonstrate its effectiveness in increasing productivity.

In creating the weekly schedule (the batch of work), the planner now has the labor hours available but must organize the backlog of work orders that are already planned into a suitable order to consider them for inclusion. There are also mandatory jobs that will have priority. These include regulatory compliance work; some proactive maintenance; urgent work that, for some reason, was not started; and carryover work. Many times, plants have urgent work that was not started even though operations has tried not to abuse the ranking system. Somehow, during the week, however, the maintenance supervisor and operations group decided not to work overtime or on the weekend to finish it. This is why it is so crucial for planners to knock out quick plans including time estimates for as much urgent work as possible. Not only do these quick plans allow the use of previous feedback to avoid new delays; the jobs can now be easily included in the new schedule. Carryover work (work that already has been started yet will not be finished) can be handled in various ways, such as rescheduling the remaining hours or simply taking those hours out of the labor availability for the next week. Considering the normal load of emergency work that is expected to occur yet again the following week, this work is *not* considered for the schedule. Many plants schedule for only, say, 90% of the available labor capacity for the next week knowing that they usually experience 10% emergencies. Or they may only schedule 70% knowing they usually get 30% schedule breakers. Experience has shown that these plants usually lose both the goal-setting aspect of scheduling and management's ability to recognize the extent to which the plant is acting proactively. In goal setting, if the goal is set too high or too low, it does not affect performance. The objective of scheduling is to focus the supervisors to complete more work, not simply to meet a schedule. If the latter were the objective, the extreme would be simply to schedule the work you know you will do and achieve 100% schedule compliance. And your wrench time would remain at 35%, no improvement. Management also has a better opportunity to recognize the extent of reactive work if the schedule provides a standard. For example, are we completing 400 hours' worth of work with the 400 hours' worth of labor available? If not, why not? The extent to which a crew does not complete all the work in a fully loaded schedule is usually due to the extent of reactive work. So, in filling this 100% of the labor available, the planner considers the mandatory work along with the priorities of the other work in the backlog. The scheduler can provide a valuable service to the supervisor by constantly looking to group lower-priority work with the higher-priority work that must be done. Identifying and grouping work that could be done under a combined locking out and tagging out for systems or at least work in the same area can be a real time saver for maintenance, and not just mobile crews that travel to various areas outside a single plant's boundaries.

It is essential to make sure that operations agrees to make equipment available before it is scheduled for maintenance and that any production operation knows when the work will be performed. Coordinating maintenance and production schedules requires a close working relationship among maintenance planners, production planners and shop-floor leaders. The exact coordination between maintenance and operations occurs in two steps. In the weekly step, the scheduler has a backlog of work that has been coded to identify whether it does not require any outage (or other unusual circumstance), so it could be done during a normal week. The scheduler sorts this work into a preferred order as described before and then allocates all of the available labor to as much preferred work as possible. The scheduler might also first check with operations and the maintenance supervisor for special work they simply feel should be included.

Then the scheduler meets with operations and the supervisors to present the schedule. Operations is asked, "Is this work for which you could reasonably make the equipment available, given a day's notice, or is there any special notice you need?" Then later, in the daily step of scheduling, the supervisor continually monitors the crew's progress on current work and talks with operations about what should be made available for the next day or two.

Except for emergency work, no job escapes scheduling. As discussed above, even jobs that require no planning can and should be scheduled by someone simply adding estimated hours. But where we can, we do want to plan even those small jobs to take advantage of the Deming cycle improvement and to avoid possible abuse of blanket standing work orders where possible.

In one large paper mill with a highly reactive culture and an almost chronic state of chaos, one remedial activity used by the author's team was to schedule all work. Using rough time-slot estimates, the team even scheduled work that was not planned. The schedules were posted where the work crews, shops, materials people and production people could see them. At the end of each week, the team marked up the schedules to show which jobs were done and which were outstanding and then posted the following week's schedule. Initially, slack time was built into the schedule to allow for 20% break-in work. The graphic depiction of performance inspired the workers involved to improve schedule compliance, even in the absence of planning. Within a few weeks, they achieved 75% schedule compliance. Furthermore, they maintained this percentage and even increased it once they introduced planning and were able to reduce their break-in work. Their backlogs began to drop, and most of the chaos dissipated.

Assign

The assignment of a job depends heavily on organizational structure. Autonomous, self-directed work teams do all but the most specialized maintenance diagnostics and repair work themselves. More traditional organizations usually delegate the day-to-day work assignment for a particular area to the area foreperson or to a supervisor. In either case, it is very important to start the team or foreperson with a week of work planned and ready in advance (that is, the weekly schedule). The schedule does not dictate specific days for the vast majority of the work. Giving the crew a batch of work, but not specifying the days, gives the crew focus but also allows for the flexibility to deal with emergencies and urgent work, jobs that run over or under their estimates and crew changes where there might be sudden absences or other problems. The job of work assignment falls to the first-line supervisor or the self-directed work team. These are the people who know the skills and abilities of the tradespersons the best. A few organizations leave work assignment to planners. This is not a recommended practice, because the planners provide the most value to your company if they are focused on future work—not today's. Getting the planner involved in today's problems detracts from the proactive approach you are creating by having planners. Planners are not supervisors, and they are not parts chasers. Both of these roles drag planners into the daily churn and compromise planning.

Execute

This is where "the rubber hits the road." Well-trained, motivated team players keep the maintenance process revolving. They add real value: quality and service that is cost-effective and timely. They reduce risk by getting the job done as best they can. All of this happens if the maintenance team is supported by effective management systems, treated fairly and allowed to proceed with proactive and planned work.

Effective work execution requires that the skills and abilities of the tradespersons be matched to the work at hand. That, in turn, requires that qualified people be hired, trained, retained and motivated. Your work crews have to want to do what they are assigned to do. A poorly motivated crew is more error prone and less efficient. Not only can that cost you more; it can also result in rework or in equipment that is not maintained at the "as good as new" standard.

Learn

Gathering good history is critical to plant improvement. The planner plays a key role in making sure the work history is valid for use in reliability decisions and standard job plan improvement. Closing the job entails far more than changing the status of a work order from "pending" to "completed." Of course, no job is truly finished until the paperwork is done.

Reliability engineers count on good equipment history. Their thoughtful analysis of the work history, their response to it and whether or not failures could have been avoided will lessen the chance of repeating the same mistakes. If maintenance work was significant, for example, a plant might consider redesigning preventive maintenance and operating procedures so that the related failure does not recur. Feedback about why or even whether the equipment failed in service is also very important. This information is invaluable to both the standard jobs and the reliability engineers who may be looking at the repair history 2 years from now, so the tradespeople and the planner must carefully document actual conditions and history. It is quite common for equipment to be removed from service for repair work only for it to be discovered that nothing was really wrong with it. But if the records do not reflect that, decisions made later may be compromised. The reliability engineer depends on your accurate and complete maintenance records to preclude future problems.

From a purely planning perspective, the planner also uses the work history to improve standard job plans. Careful collection of information—parts used, the condition of parts removed, tools used (if different from what was indicated in the plan), skills used (if different from what was indicated in the plan) and the amount of time the work took—pushes the quality of maintenance job plans ever higher through continual improvement. This feedback enables the planner to do his/her job most effectively. Closure is a never-ending process of good data collection and usage, not simply an event for a single work order.

At the very least, any maintenance work should be part of the equipment history. Only by collecting this history can it be work that leads to improvements.

The six steps presented above comprise the core maintenance management process. Many enterprises, however, seem to be programmed to hit only the *execute* button (shown as the shortcut line from "identify" to "assign" in Figure 3.1). Firefighting is certainly exciting, and people feel a tremendous sense of accomplishment when the fire is put out. But this method of managing maintenance leaves less and less time for sober thought and careful planning. People get hooked on the adrenaline rush while the fire rages, and some enjoy the "dragon slayer" status of getting it under control. See this behavior for what it is. Give praise to those who prevent the problems and counseling to those addicted to the crises.

Organizations that choose not to deal with this addiction to firefighting are inadvertently choosing high maintenance costs along with unreliable operation and the business consequences that arise as a result. Failure to get this under control can result in unreliable delivery to customers, and that can result in contract penalties that can sometimes be fatal to a business. In one large tissue paper converting plant in the eastern United States, this kind of reactive maintenance was leading to delivery problems with a major retail customer that was buying up to 80% of the company's production. The result was a new supply agreement with that customer, which included a penalty scheme for late deliveries. After the first late delivery, the plant received a warning. After the second late delivery, the plant lost $100,000. After the third, it lost the contract. Eight hundred people were laid off, and the plant was sold.

PLANNING HORIZONS

Issuing a work order to repair a faulty circuit breaker is clearly a different undertaking from maintaining the civic-run power scheme that supplies it with electricity, yet these are related. All types of fixed assets, from a switch to a power station, require at least three kinds of planning: (1) life-cycle and long-range plans; (2) an annual plan and budget, which includes projects and major shutdown work; and (3) work orders for specific jobs (Figure 3.2).

Life-Cycle and Long-Range Plans

This type of planning is closely associated with strategic planning for maintenance, as discussed in Chapter 1. The planning process involves creating a vision of future performance, including human, financial and physical resources. It also includes action plans to achieve the vision.

Life-cycle planning for the physical plant, equipment and fleet means getting the most from maintenance and operating activities and doing it economically. Because most failures are caused by random events, age is not the best indicator of pending failures in most complex equipment systems. It is usually helpful to develop a long-range forecast of major project and maintenance costs, based on past experience and/or the output of a thorough reliability-centered maintenance analysis. Besides studying history, scheduled work for age-related failures, such as painting (to avoid corrosion); restoration of deteriorated roads, civil structures and roofing; restoration of worn mining equipment working surfaces; and replacement of fatigued cyclically loaded components like aircraft landing gear all contribute to the plan.

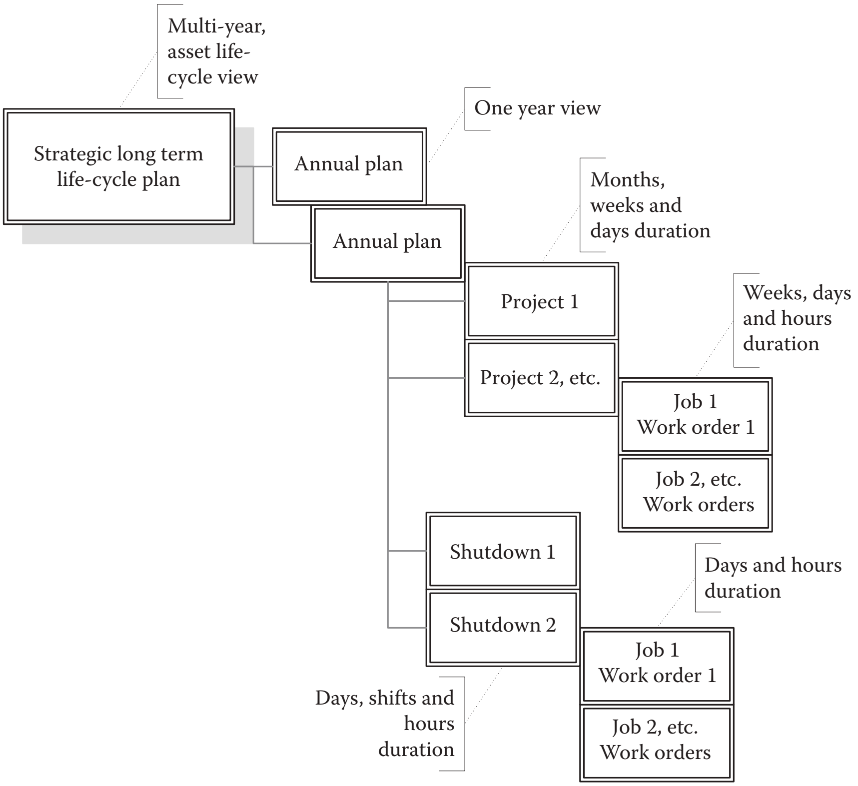


FIGURE 3.2
Planning horizons.

Equipment and system life-cycle plans are geared for major or significant work. They can fit neatly into the operation's overall business strategy. For example, aircraft have long-term overhaul schedules based on flying hours; naval ships have 4- to 6-year refit cycles to accomplish major restoration and replacement work; metal presses have a fixed number of cycles between die changes; steel mills have scheduled furnace relines; and buildings have a roof replacement schedule based on age. Keep in mind that any new or replacement capital purchases will have a direct bottom-line impact on maintenance requirements of all kinds. There is an optimum age at which replacement achieves the lowest equivalent annual cost of ownership for any asset.

Long-term plans help your finance department arrange for suitable funding for big-ticket items. They also facilitate decisions about other significant expenditures, such as those associated with plant expansions.

Annual Plan and Budget

If you do not plan and budget, you jeopardize all of your efforts to improve maintenance quality. A poorly crafted budget will be scrutinized by finance and plant management and is likely to lead to demands for cuts. Sadly, those cuts usually impact training, equipment upgrade funds and, in extreme cases, your workforce.

The maintenance budget is created from your maintenance plan for the next year. This plan includes all the elements from your long-range plan that are coming due along with anything that has arisen and been deferred this year. It also includes all your planned maintenance with allowance for breakdown work and improvements. Inputs to this plan include accurate equipment histories, results of periodic inspections, condition-based monitoring and an emphasis on continuous improvement. Plant shutdowns, equipment overhauls and major inspections are forecast by month, priced and incorporated in the plan. New technology, systems, procedures and organizational changes that affect capability are also factored in. The plan is then converted to dollars, item by item, to create the budget.

This type of zero-based budgeting and planning is more challenging than relying on last year's budget, plus or minus 5%, but it is far more useful for scheduling staff, long-lead-time parts and material and cash flow. It commits everyone to the concept of planned maintenance throughout the year. In addition, a zero-based budget sets the expenditures to match resources required to deal with specific events both planned and reasonably likely to occur. Items can be deferred or excluded if the consequences of doing so are fully appreciated and accepted. Knowledge of the cost of downtime and the total costs of maintenance is essential to this process.

Budgeting solely on the basis of historical costs is a mistake. Like most organizations, yours is probably adding equipment, controls and more automation to address demands for greater environmental integrity, safety, production capacity, customer service and quality. That new equipment means there is more to fail, and that drives more maintenance. Allow for it—failure to plan is planning to fail.

If you have used the zero-based approach, defending your budget from the inevitable attacks and requests for cuts becomes much simpler. Remember that those requests often come from accounting and financial people who do not really appreciate what you are trying to accomplish. Answer requests for cuts with "what don't you want me to do next year?" Recognize that giving up budget is also giving up work scope that you can execute—customers who would have received the benefit of that work may want to be involved in the decision to cut it out. Making the pain theirs will help fend off these requests for cuts so you can achieve your long-range vision. Perhaps they will not mind the rain and meltwater ingress in their administration building when their roof replacement is deferred!

Work Orders and Specific Jobs

Top-performing organizations use work orders for all their maintenance work, regardless of who does the work: their own maintainers or contractors. Maintenance work, like purchases and sales, comprises a large number of separate "job" transactions that can be tracked. Similar to the purchase orders used by purchasing and order fulfillment functions, the record of these maintenance transactions is called a work order. The basic maintenance work order specifies what work is to be done, authorizes its execution and serves to collect information about the work. Today, most work orders are computerized documents. Paper copies are sometimes used by maintenance supervisors assigning work to their crews and by tradespeople recording information in the field. The various functions of a work order are as follows:

- To identify and authorize work to be done.
- To facilitate planning and scheduling for complex jobs and subsequent improvement.
- To facilitate planning and scheduling for simpler jobs and subsequent improvement.
- To record what work is assigned to individuals, contractors, work centers, etc. for execution.
- To collect cost information for labor, stores requisitions, purchase orders and services to charge against a piece of equipment or production cost center.
- To record the "sign-off" or approval of work that has been done, accepting the equipment for production use.
- To capture information about work duration and maintenance-related delays to use in measuring productivity. (Reported delay information can be helpful, but proper wrench time studies take independent observations.)
- To provide work estimates to create schedules, make assignments and determine and manage work backlogs.

- To provide a means of acquiring equipment and work history data to be used in improving standard job plans, analyzing failures and determining the effectiveness of preventive maintenance efforts.

Without work orders, your maintenance records are incomplete, and your maintenance work will not be managed as well as it could be. Without records, you will never know for sure.

There are hundreds of different computerized maintenance management software packages available on the market today. These packages range in scope and price from simple and inexpensive to complex and expensive. They can range in scale from single-purpose work order systems to highly integrated systems that provide other enterprise management functions like human resources, accounting, purchasing and timekeeping. The trend today is toward large integrated enterprise management systems, but even companies with these massive computer systems often rely on simpler maintenance-specific software packages that are easy to use. These are discussed further in Chapter 7.

PROJECTS AND SHUTDOWNS

Maintenance departments are often involved in capital projects: improvements to the plant and equipment. Strictly speaking, these are not maintenance jobs, because they are not maintaining existing capability or capacity; they are extending, enhancing or expanding it in some way. Usually, these jobs are overseen by a project engineer who is not otherwise associated with maintenance work. Maintenance tradespersons have most, if not all, the skills needed to execute many projects successfully. Top performers segregate capital work from maintenance work, even though they manage it all using work orders. They know how much real maintenance work is being done and how much project work. Knowing this allows them to measure maintenance productivity without clouding their figures with project workloads.

What maintenance departments lack in capability or capacity can be contracted. Contractors can be less expensive, but when contracting project work, take care not to violate any agreements with your trade unions or employee associations. Many of these agreements prohibit the use of contractors except in very specific circumstances.

Shutdowns are disruptive major maintenance activities that are normally characterized by many small jobs being done at the same time while a production unit is out of operation. They are similar to projects in how they are managed, but they are purely maintenance work.

Both projects and shutdowns are labor intensive and entail some shutdown of production capacity. Fortunately, most of the work in many projects can be done without disrupting existing operations, but the final tie-ins and connections to any existing plant will normally require shutdown of at least part of operations. Shutdowns, being major maintenance jobs, inherently take production down. They cost a great deal, and as they are executed, your capacity to generate revenue is zero. That is a great incentive to end shutdowns as quickly as possible. Like it or not, however, shutdowns are a normal part of most plants' operations. They are needed to clean, overhaul or inspect equipment at predictable intervals. In successful operations, they are forecast in both the long-range and annual plans and budgeted accordingly. Projects are also part of long-range plans, but those plans are generally managed by engineering rather than maintenance. Successful organizations coordinate the budget activities of maintenance, engineering and operations to ensure that everyone is aware of the need for downtime and project-specific resources. For example, maintenance needs to know if a project is going to require 100 tradespersons during a planned maintenance shutdown to ensure that enough skilled people are available for all of the work to be done.

Projects can arise as a result of changing market demands that are not always predictable over the very long term, so they may not be part of an overall strategic capital plan. If projects are not planned as far in advance as practical, they can be very disruptive to normal operations and the normal maintenance function. Successful organizations maintain regular communication about project, shutdown and production requirements among the engineering, maintenance and operations groups.

Shutdown Management

Top performers avoid shutdowns whenever possible; if a shutdown occurs, they minimize the downtime required to handle what caused it. From the perspective of the production manager, downtime for any reason is a bad thing because it detracts from the ability to produce and generate revenue. Shutdowns come in two flavors: planned and unplanned. It is best to avoid the latter as much as possible, and that is a major reason to perform proactive maintenance. Planned shutdowns are useful from time to time. They can, for instance, facilitate planned maintenance activities or allow for cleaning of process equipment to maintain product quality standards. Regardless of the reasons for the shutdown, there is much that can be done to minimize the downtime periods and maximize the time between them.

Unscheduled shutdowns are a result of failures of critical equipment that an organization has failed to prevent, predict or design out. When a shutdown occurs, it creates a business emergency. Production is down, and revenue is not being generated; yet many of the operating costs of labor are still being paid. Moreover, maintenance will probably be working overtime to fix the problem. In any case, costs are up, but revenue is zero. The best way to avoid this situation is to institute an effective proactive maintenance program, and that is what successful organizations do.

Even the most successful enterprises cannot always prevent unplanned outages. They do not, however, allow these events to become crises. Instead, they see unplanned outages as a window of opportunity for other planned but unscheduled work to be done. Top performers never extend these unplanned outages to get other work done; they squeeze in what they can without lengthening the downtime period. This opportunity allows them to clear at least some backlog, but this is not done haphazardly. For it to work well, jobs that are squeezed in must have been fully planned, and all necessary resources must be available for execution on very short notice. If you expect such opportunities to arise, use a separate work order classification to make identification of those opportunity jobs easy.

One plant called these planned and unscheduled jobs that require shutdown "if down, do" jobs, or IDD. The maintenance and production shifts always knew what jobs were on the IDD list so they could be done during production changeovers or setup adjustment times when the equipment was down anyway. However, it is never a good idea to stay down any longer than you have to, so avoid the temptation of trying to get too much done. Do not add any workload that will extend downtime. Avoid adding big jobs to your unplanned shutdown and avoid adding jobs that could possibly interfere with the critical-path job. Always remember that top performers have all the needed materials and other resources available at short notice for these IDD jobs. If you do not follow suit, you run the risk of lengthening the duration of the downtime and increasing your costs.

If your critical-path job is missing materials or a plan or other resources, there is little you can do besides get them—expeditiously and at any cost necessary. If you are already down, you are in an emergency situation;

inaction hurts business. The best you can do is to minimize the damage. Noncritical jobs, jobs that are not yet planned or for which parts or materials are missing, should not get priority during a shutdown. Do not create an opportunity for some logistical glitch on a noncritical or secondary job to extend shutdown time.

Today's maintenance management systems can quickly pull up a list of outstanding work from a backlog file. A quick check of work order status to identify the planned and ready-for-scheduling jobs will tell you which can be executed with the materials that are available or near to hand. Those jobs are planned already, so you can move to scheduling them within the anticipated shutdown window. Allocate your net capacity available in a way that allows you to deal with critical-path jobs first; then execute secondary shutdown jobs as expeditiously as you can.

Successful organizations plan shutdowns beginning with forecasts years in advance so that a window of time is planned into the production schedule and the financial resources are available when needed. That shutdown window is your planning and scheduling constraint. Avoid jobs that will take longer.

Preparing for a planned shutdown requires lead time, and industries that deal with planned shutdowns exceptionally well have long lead times. In oil refining, for example, preparation can take up to 18 months. Needless to say, budgeting for a planned shutdown can easily span 2 budget years. Because of the nature of shutdown work (the jobs are usually large and complex, the materials are rarely held in stock and may take a long time to procure), preparatory lead time is essential. This lead time, in fact, is the primary reason for the long planning cycle. In successful organizations, the work scope for the shutdown is fixed or "locked down" well in advance of the shutdown date to allow for long-lead-time items to be procured. Remember to allow time for your normal procurement approval processes, vendor lead time and, if the materials fit your criteria for capitalization, enough time for your capital expenditure approval process.

Well-planned shutdowns focus only on those jobs that absolutely require equipment shutdown. Each of the jobs approved for the shutdown period is planned in detail, as described earlier. All job plans are then integrated into a master schedule for the shutdown. That schedule is essentially a project plan, and it is managed the same way. For top performers, break-in work is not added after the official lockdown date for work scope without careful consideration of the ramifications and very-senior-level approval.

The plan also includes all the work that will be required of any contractors as well as operators to shut down, isolate, lock out, drain and prepare equipment for work and their start-up activities.

Minimizing downtime entails doing as much work outside the down period as you can. Successful companies prepare the work areas prior to the shutdown (as long as this does not interfere with normal operations) by erecting scaffolding, removing roofing or wall panels to facilitate equipment access, renting cranes and other lifting equipment and moving them into position, staging and prepositioning parts near targeted equipment, prepositioning tools and rehearsing procedures for critical jobs that will be performed. Rehearsing the work steps is particularly important because practice improves job performance. (A good example of this is the planned and practiced work execution performed by racetrack pit crews.) Generally, the more you can do in advance, the less you risk extending your downtime.

When the shutdown begins, your plans are put into motion. If there is a great deal of work to be done, as is often the case, you will probably have contractors supplementing your workforce. They will require supervision by knowledgeable supervisors or senior tradespeople from your own staff. If the shutdown is extensive, you may even have all of your own staff, supervisors and tradespeople serve in supervisory roles for teams of contractors. By this time, you have a plan for all the work; all you do now is work the plan.

When machines are opened up for inspection, there are often surprises, and these lead to new work. If there is a likelihood of this happening, it is best to anticipate this contingency and to plan for it. Top performers, for example, predict what may happen and keep relevant parts on hand and other resources available so they are not caught off guard. They rarely have surprises because they have done an excellent job of forecasting all maintenance requirements that might be associated with a shutdown.

But even this level of preparation is not foolproof, and despite rigorous efforts, some surprises do arise. Some may require emergency measures. Others may not be critical in nature. If this is the case, deferring the work until the next shutdown may be the best option. You must determine whether the surprise is critical or not and decide what to do about it quickly.

Throughout the shutdown, have a series of shutdown management meetings to update status and discuss problems that have arisen and how to resolve them while maintaining tight coordination over needed resources. Keep track of work completed, work in progress and its status. Use checklists to ensure that everything is done—do not forget to inspect the job for completion, deisolate the equipment, remove locks and tags, close work permits, etc. As work is completed, close it off just as you would for running repair work orders. Do not waste time moving work crews to their next jobs. If they are done, send them home. Extra people get in the way of those who are still working.

When all of the work is completed, turn the plant back over to operations for start-up. It is an excellent practice to keep a maintenance crew on hand during start-up to handle any failures or surprises that crop up while equipment is coming back on line. Your plan should also include the time it takes to ramp production back up to normal once the maintenance work is completed. Another successful practice is to plan production output at reduced but gradually increasing levels to allow for glitches during start-up. (For example, a company may expect 25% of normal rates from the first shift, 50% from the second, 75% from the third and full production by the fourth.)

Progressive Shutdowns

Most production processes[1] can tolerate some minor production disruptions, and the operators are usually very good at managing these. These often occur due to the loss of feedstock or other non-equipment-related causes and contribute to less-than-ideal production rates. In a progressive shutdown, you can make use of the ability of the operators to handle minor disruptions to create windows of opportunity on parts of the production line while it is still operational.

In a batch process where you have the capability of building up some work in process (WIP) between the batch steps, you can take parts of the process down fairly easily without disrupting overall process flow. The duration of the downtime window is dictated by the time it takes for downstream processes to draw down the WIP between the steps. Needless to say, this takes careful planning and preparation. The advantage of this highly successful technique over a full shutdown is that production only slows down for a period of time—it does not come to a complete stop. Production levels are sustained, albeit at slightly lower levels. Avoiding a complete shutdown also avoids the time it takes to ramp back up and the inevitable start-up glitches that occur. On the other hand, the just-in-time (JIT) philosophy is a production technique that wants as little WIP as possible between batch steps. This theory wants to identify line problems as soon as possible by not allowing potential defects to accumulate in WIP between steps before it is used. JIT makes maintenance very difficult simply by adding a level of pressure to deliver rapid response to virtually every problem that arises and limiting the ability to benefit from planning and scheduling.

In a continuous process, production flows do not normally stop, and there is often little or no capacity to store WIP between process steps. In these processes, the feed is shut down to a part of the process, and the production line downstream is allowed to empty. Areas where equipment is empty can be shut down for work for a short duration. When the work is completed, the feed is turned back on, and the empty portion of the production line moves downstream. In this way, the portion of the production line that is down for work moves in the direction of production flow. The next section can then be shut down for work, and the maintenance crew moves to that area. The process requires careful coordination of activities, but the payoff is that you do not need to take production all the way down and incur only minor slowdowns. Operators are very good at handling these situations and can ramp up shutdown sections to full production without difficulty. It is simpler and far less disruptive than restarting the entire plant after a complete shutdown.

A good example of progressive shutdown in practice is Molson breweries in Toronto, which is using this technique successfully on sections of its high-speed bottling lines. The decision to go with a 2-hour time frame for this was based on the resources the company had available to work on line sections and a realistic assessment of how much work could be managed in a single fixed window. Molson gets 50% more productive effort from the maintenance workforce using this system because those involved are fully engaged during the shutdown windows on those sections of production line. The company has also experienced improved compliance with its proactive maintenance schedule, enhanced operator involvement in doing "soft maintenance"[2] tasks and increased levels of production.

PLANNING AND SCHEDULING TOOLS

The most effective tool for managing work orders is the CMMS. Most commercially available systems have comprehensive modules that include work order management, equipment records and history, preventive maintenance tasks, interfaces to external scheduling systems, costing and budgeting, materials management and labor skills capacity planning. Because of its importance, Chapter 7 deals with this tool in detail. This chapter provides an overview.

Gantt Chart

Successful shutdown and project managers use the Gantt chart to manage activities, sequences, duration and dependencies among the various jobs that make up the total work scope. It is a useful yet simple tool for planning and scheduling, first introduced by Henry T. Gantt at the beginning of the twentieth century (Figure 3.3). Gantt charts list key steps and activities required to complete a job in a vertical column and depict the time to accomplish these activities with corresponding horizontal bars. When properly constructed, a Gantt chart shows the following in graphic format:

- The sequence of tasks (events)
- The duration of each task
- The start and end times of each task
- The overall shutdown or project start time and end time
- The dependencies among tasks (e.g., showing that a machine must be disassembled before it can be repaired)

The chart also provides information (for each task), such as the resources required, costs and any interdependencies among the tasks that make up

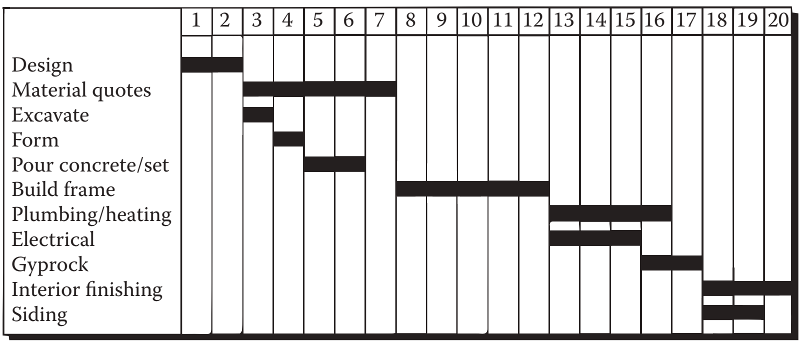


FIGURE 3.3
A Gantt chart.

the entire job. The job being planned can be a single repair to a piece of plant equipment, it can be a major plant shutdown with many jobs or it can be a capital project that uses contractors as well as maintenance and operating personnel. It is highly versatile, and because it is a visual tool, it can make the job of planning and scheduling quite easy.

It is particularly useful for events that are either strictly sequential or independent. It does not, however, clearly show interdependence among different projects unless it is linked with the other projects where the dependencies exist. Today's better-computerized project planning tools enable this complex integration of multiple projects. They include features that allow individual resource calendars to be considered so that holidays can be avoided and calculate cost automatically. They are easy to use once the planner understands the project management basics on which they are developed. Successful planning organizations use the Gantt chart, usually in computerized form, to plan, schedule and manage shutdowns, projects and large single jobs.

Critical-Path Method

A critical path is the sequence of tasks that must be completed when working through a project or shutdown and determines the length of the overall shutdown. Any job that is on this path is known as a critical-path job. Organizations that successfully stay on schedule in their shutdowns and projects are very good at managing these critical-path jobs. They are also very good at managing work arising during the shutdown—they avoid adding anything to the overall plan that would increase the duration of any critical-path job, add to the critical path or change the critical path.

Critical-path jobs can be shown on a Gantt chart, often in a different color from other jobs. As Figure 3.4 illustrates, critical paths are usually shown as a network of activities that resembles a flow chart.

Once the entire network of jobs is plotted, the path with the longest duration is highlighted on the critical path, usually in a different color or different style. In the figure, the jobs in double "bubbles" are on the critical path. This path is the sequence of tasks that are related to each other that requires the closest scrutiny during work execution in order to ensure that the entire plan is accomplished on time. Other jobs can generally tolerate a small amount of schedule overrun if it occurs without lengthening the overall duration. However, large schedule overruns on other jobs can change the critical path. For example, if the material

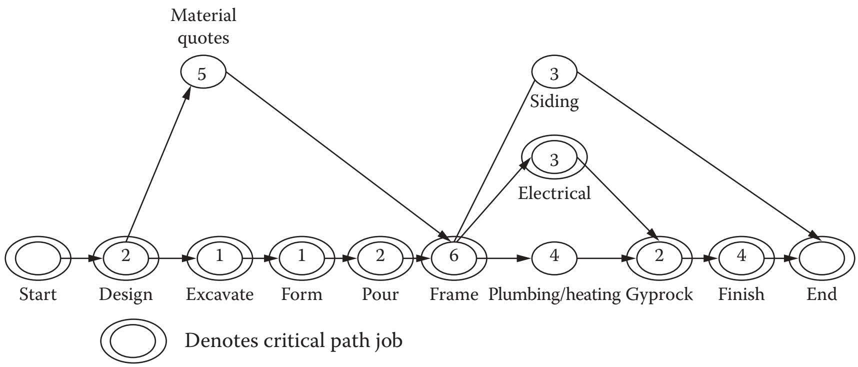


FIGURE 3.4
A critical path.

quotes take much longer than expected, they may become a critical-path job and lengthen the whole project duration. In that case, excavate, form and pour would no longer be critical-path jobs. There are several software packages of varying sophistication available to help determine the critical path. They can also plan and schedule the resources necessary to execute the plan. These packages can often switch back and forth between Gantt chart and critical-path views to suit the user's preference. (Note that both the Gantt chart and the critical-path method are best used for shutdowns or projects. They are overkill for most routine weekly maintenance work and schedules.)

Planning Standards

The term "time standards" is not well received in maintenance. It conjures up images of a dogmatic, authoritative organizational culture with everything being measured and tightly controlled. It is a reminder of the days when techniques such as Universal Maintenance Standards, Methods-Time Measurement and engineered performance standards kept employees on a tight leash. These methods were almost universally despised by the workforces being managed. The lesson learned from that experience is that you cannot motivate people to do better if you are constantly irritating them. As Dwight D. Eisenhower said, "You do not lead by hitting people over the head—that's assault, not leadership." Frederick Herzberg's *motivation–hygiene theory* recognizes that unsatisfied "hygiene factors" can act as demotivators. Recognize that people work first and foremost for their own self-enlightened interests—they are truly happy and mentally healthy through work accomplishment. Because draconian management techniques demotivate the workforce, they undercut improvement efforts.

Consequently, these techniques are of little value in today's workplace. If you believe in a team approach to continuous improvement and an environment that truly values the total employee, you will see no benefit in time standards that measure and control individual productivity. These techniques attempt to cure a symptom, not root causes. A motivated individual will perform; an unmotivated individual will not. And in the best of all worlds, the ideal workforce is not only motivated but also self-motivated.

Planning standards, then, begins with the understanding that the people affected by those standards and related processes will not respond well to time standards like those described above. Nonetheless, it is still important to know approximately how long a job will take in order to schedule it. To do this, you estimate its cost, schedule it along with other jobs and determine the equipment downtime necessary to complete the work. In a broader sense, you can apply useful standard-quality, operating, and maintenance procedures, as well as benchmarks for equipment performance and cost. Then you seek the input of the workforce in refining these with the objective of improving scheduling, not with the objective of making them "work better."

Pareto Diagram

The Pareto diagram (named after the Italian economist Vilfredo Pareto who, in 1896, noted that 20% of the population of Italy owned approximately 80% of the land) is a simple tool for determining what work should have the highest priority. In successful organizations, it is used by planners, maintenance engineers and total productive maintenance (TPM) teams to determine what equipment merits the most attention. Planners use it to determine where they should put their planning efforts. By determining what equipment requires the most downtime for repair, planners can look for innovative ways to shorten the duration of downtime by modifying the job plan. They can also use Pareto to determine which equipment causes the greatest downtime or greatest maintenance cost in order to identify improvement effort priorities for maintenance engineers. Another technique, known as log scatterplots (Knights 2001), can be used to highlight failure frequency and mean time to repair as well as the downtime and cost factors, making prioritization of the problems to be tackled even easier.

Backlog Time Standards

When maintenance work is planned, successful organizations will estimate the duration of the job to facilitate effective scheduling of work. For complex jobs requiring more than one trade skill, the task duration is also estimated to facilitate the coordination of arrival and departure times for the tradespeople involved in the job. This helps supervisors assign work more efficiently and increase actual hands-on-tools time.

For many maintenance jobs, a planner's judgment is adequate provided the planner has planning experience and, even more preferred, extensive trade experience and skill, as well. The planner simply views the job and considers how long a tradesperson that generally knows what to do would take if the job does not encounter any unusual surprises. A qualified planner can easily make judgments to estimate many jobs in a single day that are as accurate as more "scientific" estimates. The planner can also compare the estimate with historical times for the subject equipment or a similar job. The accuracy of such maintenance estimates has a great variance in that they might be plus or minus well over 50% accurate. But experience has shown they have a very normal distribution, where as many are under as they are over, allowing the estimates to be used for creating quite-accurate weekly schedules and generally assigning work. The problem with simply using historical data is that many times, past work orders were completed in an environment without proper scheduling to increase wrench time, and past work orders may have been assigned to tradespeople of varying degrees of technical competency. Instead, we would like a "standard" of what the job requires of a competent and motivated tradesperson operating under a weekly scheduling program.

With that said, we do want to consider two practical methods for estimating how long a job will take, which are equipment history work-order file times and time-slotting; these can be used by the planner as aids as necessary. Top organizations record the work completion time on their work orders, which can be used to determine the average time it takes to do any job. This average time, in turn, can be used as a standard, but only when adjusted by the planner's judgment.

If you do not have such records, or if the plant or equipment is relatively new, time-slotting may be a better solution. Time-slotting is a simple comparison method. For example, it takes less time to change a tire than brake pads and less time to change the pads than the master cylinder. Standard time-duration ranges are assigned to these tasks. The tire and brake-pad jobs may fit in the 1- to 2-hour range while the master cylinder fits in the 2- to 3-hour range.

Typical time slots used in industry are 2 hours or less (the time between subsequent breaks), 4 hours or less (half a day or shift), 8 hours or less (a single shift or day) and numbers of days. One major newspaper uses a 2/4/7 concept—jobs are slotted into 2-, 4- or 7-working-hour periods. All of those fit into a normal working shift. An integrated steel mill used operational time windows: 30 minutes to change a work roll, 4 hours for a backup roll and 12 hours for a shutdown. The mill used 30-minute, 4-hour and 12-hour slots for any work requiring equipment downtime.

The planner selects several common jobs of varying duration and complexity and then times them, using observation, time cards or expert opinion of those performing the work. The timed jobs are grouped into categories and used as benchmarks for similar jobs (Figure 3.5).

If an average of the actual time taken is kept, that number can be used for the planned time. For example, the jobs slotted in D will likely be of the same repetitive type in that particular area over which the planner has responsibility. Organizations using CMMSs often use the average times, but, for ease of scheduling, slot them into convenient time slots. This usually allows for a little bit of extra time in case something goes wrong or allows tradespersons to move on to the next job a bit early, although as a rule, planned estimates generally count on a job without "extra time just in case." Not automatically giving extra time promotes full-capacity scheduling and also encourages better feedback when problems do arise that delay jobs.

Slot	Time range	Plan time	Actual average (6-months moving)
A	0–3	1.5	2.2
B	3–6	4.5	3.8
C	6–12	9	9.1
D	12–24	18	21.7
E	24–48	36	35.4

FIGURE 3.5
Time-slotting method.

Quality Standards

It seems ironic that while the quality standards on products and the techniques used to produce them are becoming more uniform and precise, the work environment from which such standards spring has become less rigid. There is, however, a logical underpinning to this irony.

Many successful companies, in their relentless quest for lower costs, are reinventing themselves into lean, flat organizational structures. Often, employees now operate in autonomous, self-directed work teams. There are many examples of this throughout the automotive industry and its suppliers, where cost cutting has become an art form. Working in teams has freed people up to develop the best processes and procedures to achieve near-perfect conformance in their work area. The now-popular Six Sigma method is aimed at eliminating defects through fundamental process knowledge. It integrates business, statistics and engineering to achieve its results. This self-directed, integrated move toward leanness can also be applied to maintenance procedures, particularly to repetitive tasks such as preventive care and tool and die maintenance. Overall, there is little reason today for getting these wrong.

Quality standards are not a matter of employees having the freedom to do what they want. It is, rather, a matter of excellence that results when everyone involved is responsible for developing the delineated best practice and is accountable for carrying it out. In our case, for planning and scheduling, we plan for the best we know and improve it over time, and then we schedule for the best we can and then look for opportunities to complete more of the schedule in the future. Six Sigma is implemented through extensive education and then facilitated through design experiments to identify factors that cause waste, which are then eliminated in a controlled environment. Once the best practice is determined, the time standard can be determined using actual time averages or the time-slotting techniques. Nevertheless, we know that even the best practice is subject to improvement.

MOBILE WORKFORCE MANAGEMENT

Industries with physical assets or service points spread over a large geographic area are likely to have mobile workforces. These pose unique challenges for work management. The crews, once dispatched to their initial jobs, can be away from their supervisors for an entire shift. In some cases, mobile workers may not go into their depots or shops or see their supervisors for days. Work management practices for the mobile workforce are basically the same as for workers in a plant, but there are a few exceptions:

- Communications with your workforce during the day may be challenging; however, today's communication technology is rapidly making this a problem of the past.
- Normally, planners consider travel time in job plans, and that is taken into account by full-capacity scheduling. However, the net capacity of your mobile workforce to get work done will be lower than it is in a fixed-plant environment because of the travel time between jobs. Scheduling should consider this travel time to some degree either by reducing the net capacity or not scheduling fully 100% of the available labor. To maximize workforce efficiency, schedule jobs geographically close together.
- On the other hand, balancing that lowered net capacity is a tendency of mobile workers to be more efficient than their plant counterparts. They do not have many distractions while working on-site, and they often prefer to get the work done quickly to avoid overtime or having to return to the same site the next day.
- The provision of parts and materials can be handled differently because the mobile workforce is usually deployed in light trucks that can carry many of their own supplies. This can actually simplify the planning required for many jobs.

Mobile workers have a special need to have their work assigned and to communicate job status back to the dispatch office while they are in remote locations. There are many ways to handle this:

- The worker can phone or radio in at the end of a job to get his/her next work assignment.
- The supervisor can visit the work sites of all crews and assign work personally.
- Enough work can be assigned for an entire shift. This can minimize communication throughout the shift unless there is an emergency that requires you to break into the mobile worker's schedule for the day. Pagers, radios, cell phones or tablets can be

used for that purpose. The work orders assigned can be tracked using paper documents or with portable computing devices that store data collected throughout the day and download it when the crew returns to the shop, if not sooner, on a wider area or even a mobile phone network.

- Handheld computers with built-in communication systems can be used to receive, update and close work orders while remote from the office. Some of these are very sophisticated and can access databases of repair information such as spec sheets and drawings.

Communications used to be a great time waster for mobile work crews, but today, that is no longer the case. Technology today has resolved many of the problems associated with communication. Cell phones, pagers, personal digital assistants, handheld computers, data-logging devices, Global Positioning System (GPS), geographic information systems (GISs), etc. have all come to the rescue.

Traveling between jobs reduces the net capacity of the mobile workforce, but this is balanced by efficiency. The key to increasing the net capacity of mobile workers is to schedule the work so they do the least amount of traveling. Linking asset locations to a GIS will help the scheduler to pick jobs that are physically close to each other and balance relative job priorities, locations and duration of work.

GPS can be used in the mobile trucks to pinpoint and report their location. This enables dispatchers to see, on a map, where their work crews are located relative to the assets that require work. When work arises, this location information is useful in selecting which mobile crew to dispatch to the job.

Parts and materials are often stored and carried around in the vehicles used by mobile work crews. Materials that are commonly used are usually in stock on the truck, so the work crew can simply pick what they want for any given job directly from the truck. Trucks can be restocked during the off shifts. Oftentimes, mobile crews do more or less standard jobs, so provisioning their vehicles for those jobs is relatively straightforward. Odd jobs or jobs requiring parts and materials that are too large to be carried or manhandled off a truck by the work crew will require special handling. Special vehicles provisioned for transporting and unloading these materials can be dispatched as needed. These jobs will require the same degree of work planning that would normally be applied in a fixed plant; the more common jobs will not.

Some mobile work crews are assigned to specialized vehicles, for instance, cable vehicles in municipal utilities. These vehicles and their crews may be required in conjunction with other crews for some jobs. One electrical distribution utility was engaged in jobs such as underground vault transformer replacements that required upward of six separate crews to cover all the skill, material, special-purpose and lifting requirements. Coordinating those crews required excellent planning. Timing the arrival of the various crews so that they arrived when wanted and spent as little time as practical waiting for their role was a challenge for the schedulers. This difficulty is what usually accounts for the times you see several vehicles from the same company at the same location with workers standing around idly—they are usually waiting for their turn to work.

UPTIME SUMMARY

The essentials are the activities, processes and tools you use to deliver the most visible aspect of Maintenance—people working in the field, efficiently doing the right work. The essentials consist of those things you cannot do without if you are to be effective and set the stage for continuous improvement. Work management is supported by a reliable source of parts and materials. The work you do (basic care) goes beyond compliance with regulated requirements; it delivers basic reliability and sets the stage for improvements. Your department is managed using an effective set of key performance indicators using information that is gathered and stored in a maintenance management system to support decision making.

At the core of the maintenance function is work management: a six-step process for getting maintenance work done—identify, plan, schedule, assign, execute and learn. Without a good process, workforce deployment becomes reactive to emergencies, and maintenance costs will be high—much higher than they need to be. Work done in those reactive situations is anywhere from 1.5 to 3 times as expensive as fully planned work that is carried out to a schedule considering availability of materials and other requirements for the work. In some industries, the cost of emergency work is even higher—consider lost production, fines and other penalties when your equipment fails. Choosing excellence means mastering the work management process.

The simple six-step work management cycle is something that highly effective maintenance departments do well. Scheduling, using nothing more than reasonable estimates of job duration and a rudimentary check to make sure materials are available, is a great first step to enhanced productivity. Over time, more thorough planning will enhance the gains. Not only will work be less expensive to execute; good work management will free up craftsperson time to do more work. Individual tradesperson/artisan productivity can nearly double. This improved efficiency opens the door to enhanced effectiveness through a variety of reliability improvement initiatives.

There are planning and budgeting cycles to consider. These range from detailed job plans through project, shutdown and annual cycles, to strategic multiyear and asset life-cycle focus. The basics of planning and scheduling apply to all work. Individual jobs, projects and shutdowns are all managed the same way, the only difference being the scale and scope of work. Shutdowns, in particular, are high-cost, intensive activities that occur when revenue generation through production is zero. It is important to get it right and avoid the temptations to do too much unplanned or poorly planned work in the available time windows. Good use of predictive maintenance techniques helps identify work scope and reduces the volume of work arising during shutdowns.

Mobile workforce management differs from fixed-plant management. Communications are challenging, and a variety of technologies have been developed to deal with that. Work order and work reporting via tablets, laptop computers, smartphones and other ruggedized handheld devices are becoming common in mobile workforces and even in larger plants.

Scheduling plays a big role in efficiency because of the need for travel from job to job. Technologies like GPS coupled with GISs help keep mobile workforces productive while meeting the demands of far-flung customers. Mobile work crews are autonomous by nature and carry much of their own support parts and materials with them, but those must be replenished regularly, or excessive travel time will result. Planning and scheduling to accommodate geographic considerations is a key to success in managing a mobile workforce.

Work management is the most important maintenance process. Paying attention to it provides substantial benefits.

ENDNOTES

1. This technique was developed in and works very well in nonproduction environments. It is commonplace in building, railway and other infrastructure maintenance programs. It has also been adapted to batch and continuous production processes.
2. Soft maintenance includes work that requires little training; the use of no parts; and few tools such as lubrication, cleaning and minor adjustments.

4

Basic Care

"Institutional paralysis" and "lamentable failure."

Two of Lord William Douglas Cullen's comments in his report on the Ladbroke Grove rail crash that killed 31 people in 2001

THE MINIMUM IS NOT ALWAYS ENOUGH

Many business-related regulations that exist today are the result of past failures by companies to do even the minimum to protect their workers, the public or the environment. Those failures have led to horrific accidents, and regulations are society's way of setting minimum expectations for its citizens and companies. They are often written in vague and legalistic language—open to interpretation and, more importantly, to misinterpretation. Despite those efforts to minimize, eliminate or contain harmful events and their consequences, bad things still happen.

Recently, we have seen a spate of rail accidents in North America in which trains carrying hazardous materials have derailed. In the case of Lac Megantic, Quebec, derailment of a runaway train caused serious loss of life and destroyed the center of the town. Incidents like this trigger reflection, massive investigation and analyses often bringing on changes, only because we have not been proactive or used all the technologies and techniques available to use. Some examples are as follows:

- The proliferation of process safety management regulations and standards since the 1984 accident at Bhopal, India

- The widespread acceptance of Lord Cullen's far-reaching safety recommendations following investigations into the 1988 explosion of the offshore rig Piper Alpha
- The comprehensive reforms to the offshore oil and gas regulations by the US Bureau of Ocean Energy Management Regulation and Enforcement (BOEMRE) in the wake of Deepwater Horizon in the Gulf of Mexico
- The reviews and changes to regulations for the rail shipment of hazardous substances in the wake of a spate of derailments, fires and deaths in North America in early 2014

These illustrate how regulations are spawned by disasters. Australia, India, Britain, Canada, the United States and other countries now have laws that hold employees, supervisors, managers, business executives and directors of their companies liable for accidents that seriously injure or kill people. All these laws and regulations have one thing in common—they were put in place *after* the fact.

After mistakes were made and lives lost, regulators stepped in to protect the public, the workforce, the environment or other stakeholders. These regulators, who are representatives of governments or government agencies, appeared on the scene because businesses were seen to be remiss in protecting people or the environment and deemed incompetent or unwilling to regulate their own behavior. Sadly, they only respond when the head count of casualties is already excessive. They are not proactive. Businesses often complain of overregulation, sometimes with good reason, but we cannot deny that regulations are often a reflection of our own failures to manage our businesses responsibly.

The volume of rulings and rules we are asked to follow is almost impossible to digest, let alone adhere to. In some cases, regulators have almost surely gone too far. Noble intentions have sometimes led to unduly restrictive, prescriptive, overwhelming, inappropriate and often costly new requirements that must be met. All of those constrain business and productivity, ostensibly for good reason but often through misinformation or poor understanding of technical issues by legislators. At the same time, it can be argued that without all this, many companies would not do enough to reduce risks and consequences; some would have failed to take even minimum precautionary measures. Despite all the corporate rhetoric about safety being a priority, the truth is that it is profits that are driving most decisions, with safety and environment as secondary considerations.

Following regulations is not enough if we are to be responsible corporate citizens. Recognizing potential risks and their consequences and managing them is the most important function and priority of the maintenance manager, and it is central to the thrust of today's international standards in asset management. It is a great responsibility and requires consummate attention.

Arguably all of those disasters resulted from running something to failure, but that does not mean that doing so is wrong unless, as in those cases, the consequences were unacceptable. Running equipment to failure is a legitimate maintenance strategy when the consequences of failure can be tolerated—if safety is not compromised, the environment is not compromised, product quality is not jeopardized, regulations are not broken, the business can tolerate the costs and the choice is made consciously with adequate deliberation. But this choice must be conscious. Allowing everything to run to failure is clearly unacceptable. Most companies lie somewhere between these two extremes, consciously allowing some failures, preventing some, and all the while remaining unaware of the potential consequences of others that have not been examined thoroughly. In our increasingly litigious and heavily regulated social environment, errors and omissions are seldom tolerated. We all pay the price for others' errors with increased regulation, higher workers' compensation insurance premiums, high liability insurance premiums, environmental taxes and loss of business. Those who are not diligent invite litigation, more regulations, punitive fines and jail time and can have their operations shut down.

Lord Cullen, one of Britain's most respected judges, led formal inquiries into several disasters, among them Piper Alpha (July 6, 1988) and the Ladbroke Grove train tragedy (October 5, 1999). His criticism of management, particularly in the case of Ladbroke Grove, was especially bitter and included the quote at the start of this chapter. The report of the US Chemical Safety and Hazard Investigation Board on the 2005 refinery explosion and fire in Texas City, which resulted in 15 deaths and 180 injuries, noted individuals' errors, misleading and inadequate safety performance metrics, cost cutting that left much of the refinery equipment and infrastructure in a state of disrepair and vulnerability and cutting of operator training and staffing. Management was certainly neglectful in its tolerance of those situations. Following the 2010 Deepwater Horizon disaster, the US presidential administration launched the most aggressive and comprehensive reforms to offshore regulation and oversight in US history.

Similar investigations have followed the 2014 spate of rail disasters in North America involving the shipment of hazardous hydrocarbons, previously shipped largely by pipelines. Interestingly, it is the increasingly restrictive environment for building pipelines (i.e., environmental regulations, safety considerations, First Nations' objections, "not-in-my-backyard" syndrome) that have led to the use of rail as an alternative, arguably self-defeating the intentions of all those special interests.

No business wants to be the trigger or subject of such a report. No manager wants to be held responsible for environmental disasters, deaths or business failure. Nonetheless, accidents happen because not everything can be predicted. So how can companies avoid these situations and consequences?

The simple (possibly naive) answer is to do everything possible to avoid endangering people, the environment and the businesses. Be aware of the risks, take conscious steps to avoid the dangers and mitigate the damages. Even with the best intentions and follow-on efforts, not every possible risk is likely to be identified. However, being able to say under oath that you have done all you knew you could at the time will certainly help you feel better if something does go wrong.

Basic care is about following the rules and taking incremental steps to improve what needs to be improved. It is not about doing all you can; it is about getting started and then taking reasonable steps beyond the minimum. It is about doing what we can to avoid failures, and it is about looking for warnings of pending failures that could lead to disaster before they occur—it is about being proactive.

BEYOND THE MINIMUM: BASIC CARE

Basic care goes beyond regulatory compliance. It includes having some form of proactive maintenance program, participation by operators in basic maintenance activities (i.e., cleaning, lubrication, inspections) and enterprise housekeeping (5S).

The minimum your business must do is to comply with regulatory requirements. Sadly, we do not need to look far to find examples of companies that have suffered some sort of failure that's impacted employees, the public or both as a result of failure to comply with regulations, and worse, some have not even heeded good common sense. Start there—identify and then follow the rules. But putting blind faith in those rules is demonstrably wrong. As already described, the rules are inevitably created after the fact, are often flawed in some way (technically) and rarely anticipate failures that have not yet occurred. They are almost always put in place reactively.

There is more that you can do that will reduce risks further, potentially lead to better business performance and help you sleep better at night.

Basic care entails taking care of equipment at a basic level as the name suggests, but it is also about behaviors and habits around that activity. It will not eliminate all possible causes of failure or eliminate all failures, but it will keep you running in reasonably good order and provide more productive uptime. Top performance comes into reach when you begin to apply the reliability methods described later in this book.

Think of your plant or fleet of vehicles as if they were your brand-new family car. Regulations require you to keep it in safe working order and get exhaust emissions checked regularly. Beyond that, you probably make sure the oil and fluid levels are maintained, the windshield wipers are in good working order, the brakes work, the tires (including the spare) are fully inflated, tire treads are still deep enough to provide traction, the upholstery is clean, the seat belts are working, the child restraints are secure and the lights (including brake lights) work as they should. Periodically, you wash the car. When you wash it, you may find chips in the paint, small cracks in the windshield or leaks in the door sealing systems. You may notice that oil, coolant or transmission fluid leaks on your driveway. When you find those minor defects, you are fairly likely to correct them, especially if they are still under warranty. Over time, we begin to take our family car for granted, and our interest in caring for it wanes. As the car ages, you are likely to become less inclined to look after the aesthetic features but retain focus on the safety- and operability-related features.

Companies are collections of people just like us. These companies treat their physical plants as you might treat your old family car. The older the physical assets are, the less mindshare and overall attention they are likely to get. Yet these physical assets still generate revenue, keep people employed and produce products that are used by your customers. If the family car breaks down, you can always take a bus or a taxi or hitch a ride with a friend. If the old plant breaks down, work-around plans may not exist, the problem is not as easy to fix and business suffers; conceivably, if it is too expensive to fix, it jeopardizes the company's (or at least that site's) future.

Basic care helps to get the plant to a condition of safe and reliable operation that can be sustained and improved. Reliability-centered maintenance (RCM; Chapter 8) and Optimization Techniques (Chapter 9) will move you from mere compliance to truly doing all that you can. These are the most comprehensive approaches you will find. But are you ready for them? You may be just starting your improvement program, reliability may be poor and most of your organization's approach to maintenance very possibly follows the mantra "if it isn't broken, then don't fix it." Organizations like this demonstrate a low level of competence in managing maintenance. They are not yet ready for RCM, and any attempt at it will fail to achieve desired results. There are, however, basic approaches that will serve you well, delivering quick paybacks on your efforts and investment, eventually paving the way for advanced methods like RCM. These will help you design a basic maintenance program that works for you in your present operating environment.

Doing the right maintenance matters—you need to determine the most appropriate maintenance tactics, or you will be wasting time and effort doing things that do not work or possibly even leading to other failures. Every time you interfere or intervene with something, there is a risk of making a mistake or triggering a failure mechanism. Once you know the "right things" to do, start doing them the right way. Planning and scheduling helps you get things done more efficiently. Create an environment that screams "continuous improvement," and embed that attitude or mentality into your culture. Basic care and specifically 5S (enterprise housekeeping) can do exactly that.

Maintenance practices recommended by your equipment manufacturers are one place to start, but be cautious. Manufacturers may not know your operating environment, and they may not know how you are operating their equipment. Their recommendations may not always be entirely appropriate.

You cannot trust manufacturers' recommendations blindly. They make and sell parts. They do not know or cater to your specific operating climate, operating condition and level of workforce skill or experience. They rarely operate and maintain their machines. Blindly following manufacturers' recommendations, or worse, their sales representatives' recommendations, is risky. Basing your maintenance program solely on their recommendations is usually a mistake.

Your existing maintenance program (assuming you have one) may be preventing some failures already (let us hope so). On the other hand, it may also be causing some. A good indication of that is breakdowns or failures very shortly after you have just worked on the equipment (or its components) and started it back up. Regardless of where you get your ideas about what to do, your basic care program will comprise the proactive maintenance tasks (and sometimes operator tasks) that make the most sense in your operating environment and context. Some examples of basic programs that you might choose are listed below:

- Operators perform inspection "rounds" with regular checks of oil levels, to top up lubricants and to look for obvious signs of machinery distress. This is often called "autonomous maintenance" in Lean and total productive maintenance environments.
- Checklists for use when operators take over operation of equipment to make sure it is in good working order and set up and started up correctly.
- A regular set of maintenance inspection rounds during which an experienced maintenance supervisor or tradesperson walks around and visually looks for signs of trouble.
- A vibration analysis program for critical and general-purpose rotating equipment.
- An oil sampling and analysis program to look for lubricant deterioration in major equipment.
    - In one US automotive supplier, there were 15 large plastic molding machines, each with small oil analysis units on their 800-liter oil tanks. Those units perform periodic oil viscosity analyses and, based on the findings, perform automatic oil dialyses.
- A thermal imaging program to look for loose electrical connection "hot spots," signs of deterioration in thermal insulation on static equipment, misalignment of rotating shafts and other defects that give off abnormal heat.
- A cleaning program (with instructions for how to clean specific equipment) that is used to clean up spills, remove contamination sources, reveal where leak sources are before they get out of hand and keep heat transfer surfaces clean.
- Permanently installed monitoring equipment for vibrations, temperatures, flow, electrical current/load and other equipment condition parameters on critical process equipment.
- Ultrasonic surveys to look for leaks, abnormal sounds undetectable to the human ear and other defects that give off high-frequency sounds.
- X-ray analysis of devices (e.g., valves and pipes) to look for defects in metal thickness, blockages, internal parts that may be dislodged or stuck and so on.

This is not an all-encompassing list—there are literally hundreds of techniques and technologies that can be deployed—but it covers many of the activities that companies use to go beyond the minimum required by regulations. In striving for higher predictability and reliability, these companies ensure that equipment runs longer (increased uptime) so it can continue to generate revenue. These activities are all relatively easy to deploy and low cost to put in place without a great deal of analysis needed for their justification. As a rule, the problems they can detect will help avoid costly failures and even more costly downtime. They will go a long way in the right direction, but they are sometimes overdone or executed with flaws. Chapter 9 and Appendix C contain suggestions on putting together a basic proactive maintenance program based on RCM concepts. It must be used with caution as it is generic and not specific to any particular circumstance. Ideally, you apply it only after having some RCM training. Refining your initial PM program with a thorough RCM analysis (Chapter 8) or PM optimization (Chapter 9) can minimize errors, trim the program to only what is needed and most effective and avoid costly overmaintaining.

Once you are confident that you have identified the relevant regulations, you are following them and you have started a basic proactive maintenance program, you are ready to go that extra mile in basic care—5S.

5S ASSET MANAGEMENT HOUSEKEEPING EXCELLENCE

Competition is fierce and continuously getting tougher. The companies that will survive and thrive are those that reduce costs and produce their products at the lowest cost per unit. They have declared an all-out war against non-value-added activities, improve responsiveness, increase flexibility, improve quality and focus on customer needs.

Key to achieving all these objectives is the use of 5S techniques to attain the visual workplace. 5S is about good housekeeping, common sense and self-discipline, and these are the very reasons why it's difficult to implement and maintain.

5S is a system to reduce waste and optimize productivity through maintaining an orderly work environment and using visual means to achieve more consistent operational results. The implementation of this method cleans up and organizes the workplace around its existing configuration, and it is typically the leading Lean step that many organizations deploy.

The 5S pillars are as follows: sort, set in order (systematize), shine (sweep), standardize and sustain (self-discipline). Their original Japanese names are *seiri*, *seiton*, *seiso*, *seiketsu* and *shitsuke*. They provide a methodology for organizing, cleaning, developing and sustaining an increasingly productive work environment. Specifically in the daily activities of the maintenance department, routines that maintain organization and orderliness are essential to a smooth and efficient flow of all daily activities. This Lean method encourages maintenance team members to improve their own working conditions and helps them to reduce waste and unplanned downtime and improve levels of customer satisfaction.

The successful deployment of the 5S principles results in the organization of tools, spare parts and supplies into labeled and color-coded maintenance storage locations, as well as maintenance job kits that contain just what is absolutely required for the job at hand.

In the rest of this chapter, we cover the following:

- Why implementing 5S is critical to your company's success
- How 5S is a cornerstone of the Lean enterprise system and lays the foundation for all other Kaizen (continuous-improvement) activities
- Prerequisites to implementing a successful 5S program
- Goals, activities, and checkpoints for each of the five *S*s
- A strategy for implementing and sustaining 5S in your organization

Maintenance inspections, PM and breakdown maintenance repairs make up the lion's share of the daily functions of any maintenance department. Let us take a look at some of the typical challenges facing the maintenance team attempting to perform their daily duties in the most efficient and effective manner, especially if they are just embarking on a maintenance improvement initiative.

- Tools and repair equipment are not working properly.
- Tools and repair equipment are misplaced and difficult to find.
- Spare parts are not in their designated locations.
- Spare parts are damaged or contaminated.
- Maintenance supplies run out or cannot be found.
- Workbenches are cluttered and not conducive to smooth work flow.
- Production equipment is obstructed.

- Maintenance manuals are not up-to-date, incomplete or missing.
- Data entry equipment/devices are nonfunctional or obstructed.

Does any or all of that seem familiar? Let us face it: Most operations and maintenance organizations suffer greatly due to poor housekeeping practices and the lack of a true visual workplace.

Lean enterprise management systems focus on the eradication of eight categories of waste. Is this not something that every organization, even at a basic level, should be working to achieve?

1. *Overproduction*—impediments to doing the job right the first time often result in doing it over.
2. *Waiting time*—valuable time is lost if paperwork, tools, parts and supplies are not readily available or in a state in which they can be used as originally intended. We are left with little choice but to waste time looking for, locating, repairing and waiting for them.
3. *Unnecessary transportation*—many hours are wasted due to miscommunication of what is to be done and where, poorly planned travel routes and obstructions requiring detours.
4. *Redundant processing*—missing tools or parts, miscommunicated instructions and out-of-date manuals and drawings can all add to the time required to do any job right the first time.
5. *Inventory shortages and parts overconsumption*—lost, misplaced or missing parts will result in duplicate ordering and delays in repairs that can lead to lost or low-quality production.
6. *Unnecessary motion*—performing work steps repeatedly, visiting a work site more frequently than originally planned or intended or having to take unnecessary detours are all wasted motion and time for which we pay in wages, fuel and delays to efficient work execution.
7. *Product/service defects*—waste due to poor housekeeping will have a direct bearing on the levels of quality of both products and service levels. This adversely impacts both internal and external customer service levels, leading to a negative perception of the organization. Poor quality results in product wastage and/or rework.
8. *Underutilized talent*—wasting our precious time on a myriad of non-value-added activities increases frustration levels, reduces morale and has a direct and negative impact on one's ability to concentrate on the generation of productive ideas and actions. No one wants to feel that his/her time is being wasted!

If you could eliminate these, how much benefit would come to your organization?

Eliminating these forms of waste will require some changes to attitudes and perceptions. Approaches that work are as follows:

- Thinking outside the box (encourage creativity and new ideas)
- Making revolutionary changes (take risks)
- Combating waste (make it a campaign)
- Streamlining processes
- Being relentless about improving continuously
- Empowering employees (let go of control)
- Leading by example (be the change you want to see)

5S produces measurable benefits that can be tracked using metrics. For example, measure the time required to locate items in the workplace before the 5S deployment, and then measure the time required after the workspace has been improved. Longer-term benefits can be measured by monitoring workplace injuries after 5S has been implemented. Lead times for inspections, PM and repair will be reduced manyfold in a work environment that is orderly, clean and well marked. 5S is an excellent complement to good planning and scheduling and an enabler of efficient work execution.

A popular and very successful technique is to make the improvements visible to everyone. Take "before" and "after" pictures. Images are very effective at highlighting the improved appearance and orderliness in the workplace. Concrete measurements (5S audit result charts or graphs) are a complement to the pictures, fueling the momentum needed to sustain 5S and to expand those to other areas in the organization (Figure 4.1).

The five *S*s are implemented in corresponding steps (Figure 4.2):

Step 1: Sort—clearing up; "when in doubt, throw it out!"
Step 2: Set in order—organizing
Step 3: Shine—cleaning
Step 4: Standardize—standardizing housekeeping routines
Step 5: Sustain—audits, visualization, discipline and accountabilities

1S—Sort

Sort is focused on eliminating unnecessary items, tools and spares from the workplace. An effective visual method to identify these unneeded items is

FIGURE 4.1
Before (top) and after (bottom) photos showing improvement.

red tagging. Evaluate the necessity of each item in the work and repair area and then determine its best disposition. A red tag is placed on any item that stakeholders are not sure about. Tagged items are entered into a red-tag log, with a unique identifying number, identification of the location they were removed from, removal date and their central red-tag location. This red-tag area is delineated by red tape and is off-limits for anyone who is not closely

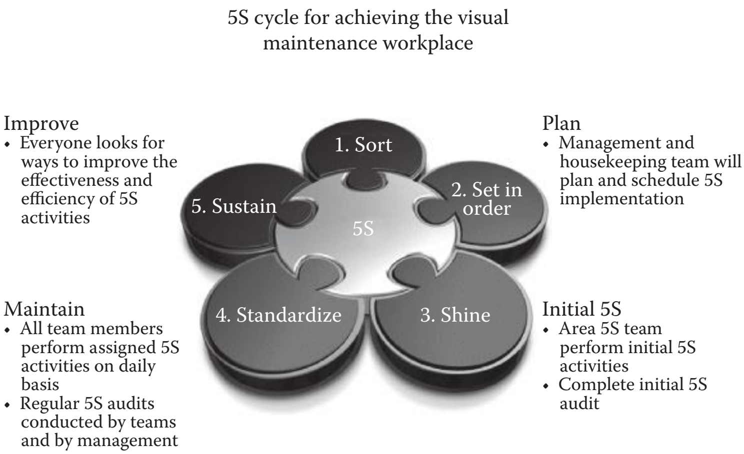


FIGURE 4.2
5s: sort, set in order, shine, standardize, sustain.

associated with the red-tag process. The area may be fenced and locked. A designated red-tab team reviews all red-tagged items weekly, and items that are not moved out of the red-tag area after a predetermined time are discarded. Occasionally, other individuals will supplement the red-tag team as needed to help in decision making. Items deemed as needed will be replaced in their original locations and taken into consideration during the set in order step (2S).

2S—Set in Order

Set in order means that there is "a place for everything, and everything in its place." Focus here is on creating efficient and effective storage for everything we utilize during a regular workday. This includes all work areas and benches, equipment, machines and tools, spare parts, safety apparatus, documentations, office equipment, supplies, etc. Organize all these items so they are visible, easily accessible and easy to find and put away again. Set in order is implemented after the 1S work environment, so the coast has been cleared of all unwanted tools, items and parts. Strategies for effective set in order include, but are not limited to, painting floors, marking floors with tape to denote move and work areas, affixing labels and placards to designated proper storage locations, outlining work areas and locations, designing and preparing signage and shadow boards for tools and installing shelves and cabinets.

Two helpful implementation tools are the value stream map (VSM), to better illustrate and understand the most optimal flows for specific work and repair routines, and the 5S map. They help in defining ideal storage locations for designated items. The 5S map is a planning and working document providing a good overview of the final destination for various parts, supplies and tools, prior to moving them around. It helps save a lot of non-value-added movements and frustration with multiple iterations leading to the final result. Like the old carpenter's saying, "measure twice, cut once."

A few helpful tips are as follows:

- Locate items according to their frequency of use:
  - Frequently used parts, tools and supplies should be in close proximity to their point of use.
  - Infrequently used items are stored away from the immediate work and traffic areas.
- Store items and tools together if they are used together, and define their storage location based on the sequence in which they are utilized.

- Plan your storage areas to be large enough for ease of removing and replacing of designated items.
- Standardize by eliminating the variety of tools, jigs and equipment to reduce the number of instances they have to be exchanged. Note that this might require some engineering intervention.
- Store tools and equipment according to their function:
  - Repair function–based storage means storing tools, equipment and possibly spare parts, when used for a particular and unique repair or replacement function.

Having an organized facility marking program (defining standards for markings, color coding, etc.) is integral to 5S success. Otherwise, each 5S team does its own thing with haphazard results and little real change.

3S—Shine

The third *S* is shine. Once working areas are decluttered, down to the minimum of tools, equipment, parts, supplies and furniture that are truly needed, and they have all found their optimal "home," we are ready for some "shine and pretty." This goes beyond just cleaning. We repair, recondition, adjust, tune, paint and bring the entire work environment to a shine and proper operating condition, including all of its components.

There are three primary activities, which include getting the workplace clean, maintaining its appearance and using preventive measures to keep it clean (i.e., we are preventing it from deterioration).

Eliminate dirt, dust, fluids and other debris. You will need adequate cleaning supplies that have been tested to make sure any solutions will not harm any equipment or work areas. Teams clean equipment, tools, work surfaces, desks, storage areas, floors, lighting and anything else that is visible or used by anyone in the course of their work. You may also paint or coat work surfaces, equipment, floors and walls to help sustain the shine and make future sources of contamination readily visible.

Cleaning is inspection! Treat cleaning as an inspection process. Use it to identify even tiny abnormal and prefailure conditions. Working in a clean environment enables workers to notice leaks and other defects, including the effects of vibration, breakage and misalignment. The shine process should not be left for a special janitorial crew. It is important that the team that normally works in the area carry out the shine process. In order to make sure everyone participates and works together, each team should establish a regular schedule for routine cleaning as well as deep cleaning.

One of the more obvious purposes of shine is to turn the workplace into a clean, bright place where everyone can focus only on the value-adding elements of their work, do things right the first time ("you don't get a second chance to leave a first impression!") and truly enjoy their contribution to overall company success. Another key purpose is to keep everything in top condition so that when something is required, it is indeed ready for use. Abandon the inadequate tradition of an annual year-end or spring cleaning. They have little practical effect. Cleaning should become a deeply ingrained part of daily work routines and habits, so that tools, equipment, workbenches, storage rooms and areas will be ready for use and presentable at all times.

4S—Standardize

Once the first three *S*s have been deployed and completed successfully, you want to establish a consistent approach to task and procedure execution. Standard methods result in standard results. During this phase, the team identifies ways to establish the improved workplace practices as a standard. The goal is to create best practices and to get each team member to use the established best practices the same way.

Standardizing entails assigning the job responsibilities for the first three *S*s, integrating those duties into regular work duties and checking on the maintenance of the first three *S*s. You can use job cycle charts; visual prompts (e.g., signs, placards, display scoreboards); scheduling of "5-minute" briefings; and checklists. The second part of standardize is prevention. Prevent the accumulation of unneeded items, preventing your established procedures from falling into disuse and preventing equipment, materials and markings from getting dirty or damaged.

Neglecting standardization produces unwanted consequences and challenges:

- Work area conditions will slide back to their old unacceptable levels even after a successful implementation of an organization-wide campaign.
- At the conclusion of work shifts, piles of unneeded tools, parts and supplies will lie scattered around workbenches, equipment and other activity areas.

- Tools and spares storage sites become disorganized and must be brought back to an acceptable appearance at the end of each day.
- Experience shows that even after the successful deployment of sort, set in order and shine, it does not take long for maintenance, operations and office personnel to start accumulating superfluous materials, tools and supplies. Old habits die hard!

In order to standardize, roles and responsibilities must be clearly and consistently introduced and applied. This can be accomplished through visual controls such as color coding, flowcharts, checklists, shadow boards, 5S maps and labeling to help reinforce the standards.

Managers and supervisors need to commit to the initiative and provide guidance and general support to the team. Team members, in return, must embrace 5S principles and practices in order to help implement these changes into their work area and embed them into their daily routines.

As 5S standards are adopted into each individual work area, each will develop unique approaches and methods to accomplishing the specified tasks and goals. A valuable tool that results from this is the newly developed and deployed standard cleaning schedules across all areas that have undergone the first three of the five *S*s. Any team member working in that area must receive training in that area's specific and agreed-upon approach and method of work. Where possible, the tools used to standardize and sustain the 5S effort should be unified across all areas of the plant. This is intended to enable quick understanding and consistency as people are moved between departments and areas.

5S—Sustain

Commitment means doing the things you said you would do, long after the mood you were in when you said you would do them has left you!

Once you have implemented the first four *S*s, things look and feel good. But now, the challenge is to sustain the progress and make it a new way of life. Commitment is paramount! Everybody involved must maintain their commitment to the 5S journey and its great accomplishments thus far.

The sustain step is intended to systematize maintaining the momentum generated during the initial deployment of 5S with a goal of keeping it alive, forever. Sustain entails making a habit of properly maintaining standard procedures and periodic cleaning schedules, introduced as part of the standardize phase. In many organizations, this is the most challenging and difficult *S* to implement and realize. Organizations with a relentless focus on "this quarter's numbers," meeting short-term obligations or always struggling to achieve a new stretch target for production will often struggle to sustain anything long term, including past accomplishments of the 5S initiative.

Entrenched behaviors are difficult to change. There is a tendency to return to the old status quo and the comfort zone of the "same old way" even after seeing the benefit of the new way. Sustain requires the organization to focus on defining a new status quo and establish new habits and a new standard of workplace organization. Without sustain, the achievements of the other four *S* building blocks will not last long.

Tools for sustaining include signs and posters, newsletters, pocket guides, team and management check-in, performance reviews and 5S audits. Successful organizations typically seek to reinforce 5S messages in multiple formats until it becomes "the way things are done."

Proper discipline and accountability are paramount for keeping 5S in place and alive. A 5S auditing process (like any audit process) is used to ensure continued adherence and success. It reinforces the importance of 5S to all stakeholders so they appreciate that maintaining the level of workplace organization and housekeeping excellence is a top priority. It encourages their full commitment. 5S audits should focus on ensuring that the routines and periodic cleaning schedules devised in S4/standardize are being properly followed. The audit provides an excellent opportunity for asking questions and providing suggestions that stimulate further improvements. Results of individual audit achievements are posted on an ongoing basis as part of the visual enterprise system. It serves as a beacon for a company-wide continuous-improvement and business excellence philosophy.

5S AUDITS

With 5S, your organization will have devoted a lot of energy and resources getting things to the way they should be. To sustain these housekeeping excellence gains, you need periodic (weekly to start and monthly once stabilized) 5S audits. An audit should always be led by team members from other areas (peer review). You could try having people from the office and admin areas conduct the audits for the operational areas and vice versa.

The audit validates the accountability of the 5S target area owners for compliance with 5S plans and targets. Without the audit, experience shows that the 5S initiative will slowly fade away and become ineffectual. Do not cheap out by eliminating the audit—it will result in a short-term gain but long-term failure.

The 5S audit is a form of a quality assessment. It is a planned, independent, documented appraisal supported with graphs and evidence to determine if 5S procedures and guidelines are being met. The five reasons for a 5S audit are as follows:

1. 5S system compliance
2. 5S guideline and routine adherence
3. Measuring what matters
4. Effectiveness of the overall 5S initiative
5. Gauging opportunities for improvement

5S System Compliance

The 5S audit answers two key questions: Have you devised and deployed written documentation (work plans), and are you following them? Compliance means that the plans are being kept in focus and followed by all respective stakeholders. An auditor reviews the plans and the records generated by the individuals accountable for these plans. The records are the evidence that the plans are being followed.

A 5S audit differs from the traditional audit, in that it requires not only verification of compliance to the plan but also verification that the plan is producing the intended results. Are those plans effective in fulfilling their strategic intent?

5S Guideline and Routine Adherence

5S will generate a number of routines and guidelines specifying how areas should be maintained and kept. These routines and guidelines spell out what is required to ensure a sustainable and consistent result. Accordingly, the audits outline the elements to be inspected and audited, and the benchmark standards to which they are compared and measured.

5S routines and guidelines identify and communicate the conditions you want to maintain for each of the respective 5S areas. They are intended to ensure that everyone knows exactly what they are responsible for doing, when, where and how to do it. Without such standards that produce a consistent perspective, sort, set in order and shine lose their meaning. It is essential that people be given clear guidelines based on their own workplace needs and requirements and that they follow those procedures and guidelines.

Measuring What Matters

The audit form outlines those areas where we want to demonstrate a given level of cleanliness, organizational character and benchmark. They note the proper attributes to help achieve the highest-quality standards of output and service delivery.

Sufficient time should be dedicated to plan the scope and design audit forms for each area. Best results are realized when selected individuals shadow the entire 5S process from inception, through deployment of the first *S* (sort) and onward. Keep transcripts to serve as input to the outline of each area's audit forms. This process helps to ensure that no detail is missed and that all discussion points raised during the first four *S*s are considered.

Final audit forms are customized to address specific and unique requirements by area, and should be approved by the process owners prior to their deployment.

Monthly audit results by area are graphed and displayed on visual boards, either in paper form or electronically. Quarterly organization-wide results are tabulated and used by management during quarterly, semiannual and annual company performance reviews.

Effectiveness of the Overall 5S Initiative

Audits determine the effectiveness of the 5S initiative and ensure that follow-up activities include verifying the effectiveness of any corrective measures already taken. This compels the auditor to examine progress toward the goals outlined in the 5S strategic plan. They also require the auditing team to verify that corrective actions actually solved the problems for which they were created.

Every routine and guideline includes a defined scope and tangible objective. When reviewing the documentation, the auditor should ask three questions:

1. Does the purpose contribute to quality, cost and delivery requirements spelled out in the 5S strategic plan?
2. How is the area measuring up?
3. Does the scope cover everything necessary to fulfill the purpose?

In asking these, both the results and the process are challenged and verified. A good evaluation of the value of the auditing process will tell the auditor how well the form works. Periodic brainstorming sessions provide feedback to consider as ongoing updates to the form's scope and content.

Gauging Opportunities for Improvement

5S auditors must be objective in their evaluation; this allows them to find opportunities for improvement as it relates to the areas maintained, results obtained, as well as overall compliance to the 5S goals.

The auditor looks for ways to improve 5S routines and discuss potential shortcomings and recommended changes with the responsible area managers or supervisors. It is a good idea for the auditors to further document any ideas or recommendations agreed upon in the audit report so they are not forgotten, lost or ignored.

Recognize that audited areas will change in character over time and should therefore be scrutinized for respective improvements in the various 5S activities.

5S Audit Form

Audit forms should have the following characteristics:

1. *Be customizable*, to suit various auditing activities by area. It should provide for periodic updates. Consider the following areas considered for customization:
   a. Team designation
   b. 5S area designation
   c. Respective auditing specification by area
2. *Have an algorithm for the tabulation of monthly results*. A formula should be provided to calculate levels of performance by line item and totals per area based on performance level entered into the form.
3. *Have or allow for graphing capabilities*. If using software, it should be able to convert numerical result values into bar graphs.

4. *Allow for the display of monthly results.* Bar charts should be printed monthly and provided on display boards as part of the visual enterprise. Results could be displayed in paper form, but preferably in electronic form, guaranteeing that the same monthly values are displayed across the organization.
5. *Provide for specific feedback by area.* A comment/feedback field is utilized to provide input into analysis sessions, potentially triggering necessary improvement changes resultant from audits.
6. *Provide for noting successes.* Recognizing the hard work and investment in time contributed by all stakeholders is vital for motivation and morale. Areas achieving outstanding results should be recognized and celebrated from time to time.

5S Audit Form Example

Figure 4.3 illustrates part of an audit form. Both the category as well as the item description are fully customizable. Here, we show the Japanese equivalent definitions of the various 5S categories, familiar to Lean enterprises. For each of the five items in each of the five categories, the auditor does his/her inspections and records a result, placing an "X" in the column corresponding to the number of "defects"/"nonconformances" found. The spreadsheet calculates a score, which is higher as there are fewer defects. These are completed monthly and compared over time to see improvements or areas where slippage is occurring.

Audit Instructions:

1. Print the audit sheet for each audit area for the month. Use this sheet to conduct your respective area audit.
2. Score your audit area as follows: Record an "X" in the appropriate column.
   a. 5 or more problems found
   b. 3–4 problems found
   c. 2 problems found
   d. 1 problem found
   e. 0 issues found
3. Once your audit is complete, update the electronic spreadsheet audit file for the corresponding area.
4. When you update the audit sheet, the total audit score for each of the five *S*s will be tabulated automatically and a corresponding audit

Monthly 5S Audit

Year 2014
Month January
Team Acme III

Indicate the number of problems by placing an "X" in the approriate column for the item.

Click for monthly audit graph

Click for year to date audit graph

Click for instructions

Category	Item	5+	3–4	2	1	0	
		Number of problems					
Seiri = S1	**Distinguish between what is needed and what is not needed**						
	Are unneeded equipment, tools, furniture, etc. present in the area?		x				**Total responses**
	Are unneeded items on walls, bulletin boards, etc.?		x				**5**
	Are any Red Tagged items more than 3 weeks old?			x			**Total score**
	Are personal belongings properly stored?				x		**Seiri = S1**
	Do safety hazards (water, oil, electrical, chemical, machines) exist?			x			**9**
Seiton = S2	**A place for everything and everything in its place**						
	Are aisle ways and workstations clearly indicated?	x					**Total responses**
	Are jigs, fixtures and tools etc. in their correct places?			x			**4**
	Is all inventory and W.I.P. in its correct spot?						**Total score**
	Is equipment clearly marked?			x			**Seiton = S2**
	Are items put away after use?		x				**5**
Seiso = S3	**Cleaning and looking for ways to keep the workplace clean and organized**						
	Are cleaning materials easily accessible?			x			**Total responses**
	Is equipment kept clean and free of dirt, oil and grease?		x				**5**
	Are floors, walls, stairs and surfaces free of dirt, oil and grease?				x		**Total score**
	Are lines, labels and signs clean and unbroken?					x	**Seiso = S3**
	Any other cleaning problems (of any kind) present?					x	**14**

FIGURE 4.3
Monthly 5S audit form.

graph for the respective month generated. In addition, the year-to-date graph will also be updated to show trends.

5. Print the monthly graphs and display them on the corresponding visual dashboards.

Figure 4.4 shows how audit results can be shown in each area for each month.

Figure 4.5 shows how bar charts can be used to show successive months' comparative results.

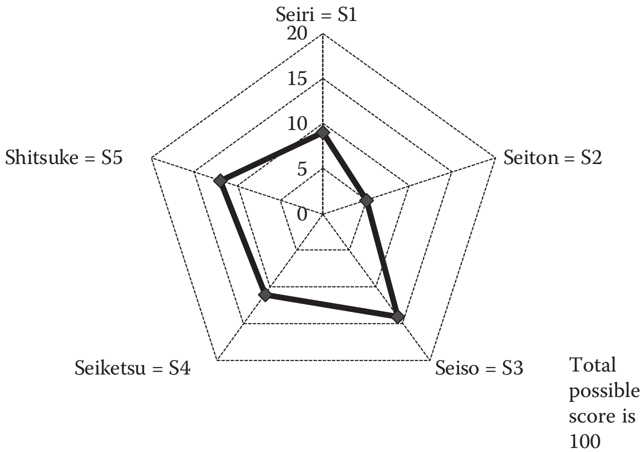


FIGURE 4.4
Graph depicting audit results.

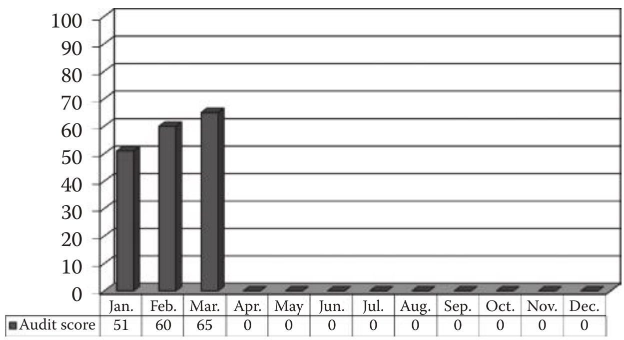


FIGURE 4.5
Bar chart depicting successive months' comparative results.

5S + 1

5S is long established and successful. In the interests of continuous improvement, there is even more that can be done. Recently, we have seen the addition of a sixth S—safety. In many instances, if the first 5S's are truly in place, then many if not all of the workplace safety hazards will have been dealt with, at least those that are not inherently built into your manufacturing processes. Those will require a more in-depth safety oriented analysis like RCM (Chapter 8) or hazard and operability studies (HAZOP).

By adding the sixth S (safety), we actively look for workplace safety hazards that may have been overlooked in the 5S implementation, and we make sure we have all the safety equipment that is needed, that it is maintained using 5S and readily available if needed. You would have a tag system to identify any unsafe conditions so they are dealt with, controls and procedures to ensure safety equipment is identified and put in place and a "job safety analysis" (JSA) that becomes a part of every job plan, and all safety equipment will be in good condition, readily accessible and unobstructed.

To achieve the sixth S, you would do what you can in the way of training and awareness building to heighten awareness of safety (Chapter 2), and use good planning and work management practices that include JSA (Chapter 3). You would critically examine what could go wrong and put in place steps to minimize or eliminate the consequences of those failures—that is what RCM does for you (Chapter 8).

BEFORE YOU START 5S

Recognize that 5S is an ongoing journey—it is not a destination, although there are milestones along the way. All stakeholders should be encouraged to continue making improvements to their workplace on a regular basis. Each work area that has deployed 5S should undergo a monthly audit verifying that results are maintained. Continuous improvement must become part of the routine expectations and activities of the workday. When improvement stops, there is a likelihood that a workplace organization will not just stagnate but actually deteriorate. After all, that is very likely what happened before you started 5S. To avoid that, keep everyone continually looking for ways to improve their work conditions.

Before your organization commits to the introduction and deployment of a 5S initiative, it is important that you ask and answer the questions presented below. If you are not sure or clear about the answers, and whether they might put your success in jeopardy, then it is advisable to take the time to pave the road to a more 5S-conducive environment. As described in Chapter 2, change will always be a challenge for any initiative; take the time to do it right and you will not need to do it over or give up.

1. Does forming teams present a challenge?
2. What aspects of your organization will make it conducive to a successful 5S implementation?
3. How have your past team endeavors and productive interaction worked out for your organization?
4. What needs to work differently this time?
5. "The same things, done in the same way, yield the same results." How might you do things differently this time around? What will be the effect?
6. Do you have the right team members who are willing to work with you and do what it takes to make this initiative a resounding success?
7. Do you have the right measurements in place that will help guide you to the desired outcomes and a successful deployment?

UPTIME SUMMARY

This chapter is about doing the minimum you need to do to ensure legal and regulatory compliance and then going beyond that to generate true value for your organization. Regulations, no matter how excessive, ill conceived or intrusive they may seem, must be complied with.

Beyond that, you want to make sure your maintenance efforts are fit for their purpose. Following manufacturers' recommendations is not necessarily the best approach, and strict compliance to them could cost you more than necessary and even induce failures. Putting a PM program in place quickly will be beneficial, but use your own judgment and experience along with suggestions from Appendix C as a guide.

Once you have a basic PM program in place, you should be seeing some benefits of being proactive. You can always return to it later and refine it using PM optimization or RCM.

Once you are doing the regulated work and have a PM program in place, you want an environment conducive to getting it done well and efficiently. 5S is a well-proven approach to creating a highly productive work environment for maintainers, operators and even office workers. The 5S pillars—sort, set in order, shine, standardize and sustain—will simplify, condition and make your workplace far more effective while helping to eliminate a variety of wasteful practices and old habits.

Implementing basic care is one of the first steps in getting an out-of-control work environment under control and functioning both effectively and efficiently. When implemented in parallel with planning and scheduling, you can realize some amazing gains in your workforce productivity.

5

Materials Management

> Bitter experience in war has taught the maxim that the art of war is the art of the logistically feasible.
>
> **Admiral Hyman Rickover, US Navy**

When you ask maintainers what the biggest problem standing in the way of doing their job is, you often hear complaints about materials. The answers come in many forms:

- Stores do not have the parts we need.
- It takes too long to get what we need.
- Purchasing keeps buying the wrong parts.
- We tell purchasing what to buy, and they go buy something else.
- Lead times for needed parts are way too long, and so on.

Discussions of spare parts, inventory/materials management and purchasing are almost always emotionally charged. Interestingly, if you go ask the materials/stores managers about what is wrong and why you hear so many complaints about materials, you often hear that maintenance never says what they need in a timely manner. The experience in dealing with this in hundreds of operational sites the world over is that both complaints are valid, but the root cause of the problems often lies in poor (or no) planning within the maintenance department.

Although no one is actually fighting a war in our maintenance departments, there are certainly times when it feels that way. Almost always, the worst battles are over critical parts or materials that are needed immediately but are not where they need to be. Maintenance managers tangle with suppliers to find out about material availability, with their own purchasing departments to get the paperwork done, with plant managers to get the approval for premium pricing and so on. It is no fun, and it almost never has to happen.

Detailed planning efforts are for naught if work is scheduled without having materials available. It is critical to keep costs under control and balanced—something that most operational and maintenance managers do not care about when equipment breaks down. Excessive investment in parts and materials ties up working capital. Too little investment will fail to serve maintenance and business needs when failures occur. Moreover, to ensure that their accounting statements are accurate, accountants want to book the investment in material inventories as visible assets, not as hidden costs. With today's tight financial controls, managing inventory becomes more important than ever; however, if that inventory is properly managed, it will be used two or three times a year and help keep maintenance costs down.

Consider the cost of downtime. When production equipment fails, production (or some portion of it) stops, slows down or begins to produce off-spec product. That means loss of revenue generation potential and profitability and risk to reputation among customers. What does that cost in your situation? Downtime is a lost opportunity (as opposed to a direct financial loss), but it is almost always very expensive. Because it is a lost opportunity, though, it will not show up as revenue, nor as an expense. To your accountants, that cost does not exist.

Now consider what steps are typically taken in your plant/environment when that equipment fails and you are down. Do you rush around looking for parts, find them from whatever supplier may have them in stock and pay a premium to get them and to get them delivered quickly? If you do, then those parts are very expensive, and your accountants will see a very high material and maintenance cost all showing up as expenses. At this point, any past savings from buying from a low bidder or stocking fewer parts are probably negated.

Now, balance that against the cost of having more parts and materials available on-site so that breakdowns can be repaired quickly. Later in the book, we will discuss how to have fewer breakdowns, but for now, assume you can shorten the duration of that breakdown. If you have the parts you need on hand, the repair will be quicker (less downtime and lost opportunity), and you will avoid the high costs of excessive overtime, premiums paid on parts and higher costs for rush shipping.

As maintainers, we know all of this intuitively, and it is brought to our attention in gory detail every time we suffer a breakdown without having parts on hand. Our response is often to take care of our own destiny and stockpile critical parts in our desks, file cabinets or shops. All of that unofficial inventory adds up in cost, and none of it is tracked. Operations people are typically aware of this too, but they rarely have any say over it, so they have grown used to accepting it as a poor state of affairs, or they point fingers—either at stores (for not having the parts) or maintenance (for not anticipating the problem in the first instance), or both. In response, maintenance's unofficial spares (sometimes called squirrel or magpie stores in honor of little critters that stockpile) grow in size and importance while the official spare-part stores diminish.

As this problem spirals into chaos, the official storerooms increasingly hold less relevant stocks of parts and materials—the ones that no one wants or uses—and the cycle only gets worse. The solution is not to eliminate unused spares from the warehouse—that does not even come close to addressing the real problem. Likewise, the solution is not to tighten up purchasing processes to curb the growth of unofficial spares. That only exacerbates the downtime and increases the costs of lost opportunity. Gathering up the unofficial spares and putting them all into the official storerooms will not help either. If distrust in stores is high, you will not get them all anyway, and maintenance will simply find ever-more-creative ways to get and hide their own unofficial spares stocks.

The answer is to fix the broken planning, scheduling and materials management processes and, more specifically, how they integrate with each other.

In Chapter 3, the planning and scheduling processes are covered. Scheduling work without identifying that the parts you know about are, in fact, on hand is an invitation to create a rush to find parts. If plans identify the parts you are likely to need, then make sure those are on hand before scheduling the work. Some successful organizations employ a "materials coordinator" to take care of this and alleviate some pressure from the planners and schedulers. If the job is of an emergency nature (i.e., you cannot wait on the normal planning and scheduling cycle), then find as much of the material as you can in parallel with the supervisor's efforts to get his/her work crews ready to carry out the emergency repairs.

PLANNING, SCHEDULING AND MATERIALS MANAGEMENT

A key to success in work management is the timely provision of the materials and parts for maintenance work. The lack of even one part can delay the job, add to the cost and increase total downtime for the asset itself and possibly for the process it belongs to. It increases business risk even if the item being repaired has a backup.

The consumption of maintenance, repair and overhaul (MRO) supplies—spare parts, components, consumables, lubricants, fasteners and all other maintenance materials—typically accounts for about one-half of most companies' maintenance budget in North America. As more and more of our industrial equipment and fleets are designed for increasingly more expensive modular parts replacement, those material costs can devour an increasing portion of the budget. Yet, despite all these important considerations, management of materials is neglected in many companies. If the interrelated maintenance planning, scheduling and materials management processes are not working well together, you have a problem.

Maintenance supervisors often react by creating their own unofficial stockpiles of inventory—off the books. If the stores keepers are not getting input from maintenance, they start decreasing inventories based on the aging of the parts in inventory; the longer inventory sits collecting dust, the more likely it is to be scrapped or sold off. Of course, these two reactions set up the conditions for a downward spiral, which satisfies no one.

In one very large North American integrated steel mill, there was an estimated $108 million in spares and materials on-site, but only about $18 million could actually be accounted for in controlled inventories. The rest was expensed as part of past job costs, hidden and squirreled away by maintenance supervisors and tradespersons at various stashes around the mill. This inventory was not in the books and generated a big accounting headache when eventually, auditors found it. Parts that are hidden away like this are rarely available to anyone but the person who has hidden them, and that leads to duplication of parts among various stashes and with the stores. In a large postal operation, the estimated value of total inventory of spares and materials (including the unofficial stashes that had been found) was over three times the official book value (ignoring depreciation) that their accountants could track.

The practice of keeping stashed parts inflates operating expenses, bloats inventory and ties up working capital—none of which is good for business. Maintenance managers, supervisors and tradespersons will argue with some validity that if they do not keep these stashes, they cannot do their jobs. If this is indeed the case, the materials management system has let them down. What they often fail to see, however, is that they have had a hand in creating the problem by working around the system instead of working with it or fixing it. They have also exacerbated their own materials headaches!

Often, if there is a problem with maintenance getting its job done, there is also an underlying problem with MRO materials management. To get it right requires the following:

- Good communication between maintenance and materials people
- Well-defined and working linkages between work management and MRO management processes
- Discipline to follow the processes and not to work around them
- A clear delineation of who is responsible for what work when it comes to materials procurement (maintenance and engineering provide the specifications, and materials management handles the supply chain)

The basic processes of purchasing, stores and inventory control are shown on the right-hand side of Figure 5.1. As the figure shows, this process has several links with the work management process. If one or both of those two processes are not working properly or if any of the links are not working properly, then maintenance and materials costs go up. The following sections describe each of the materials management process steps.

Specify (Identify)

This first step is simply defining what is required, and the best people to do this are maintainers and engineers because they know what they want. Specifying the correct parts is facilitated if there is a good equipment register—an accurate, updated record of the equipment configuration. In the register, each major equipment assembly or system is broken down into the smallest component or part that can be bought as a unit. For older equipment, you may have lists of all the individual parts. Newer equipment, particularly electronic or instrumentation, tends to have several integrated components that are changed out and returned to the

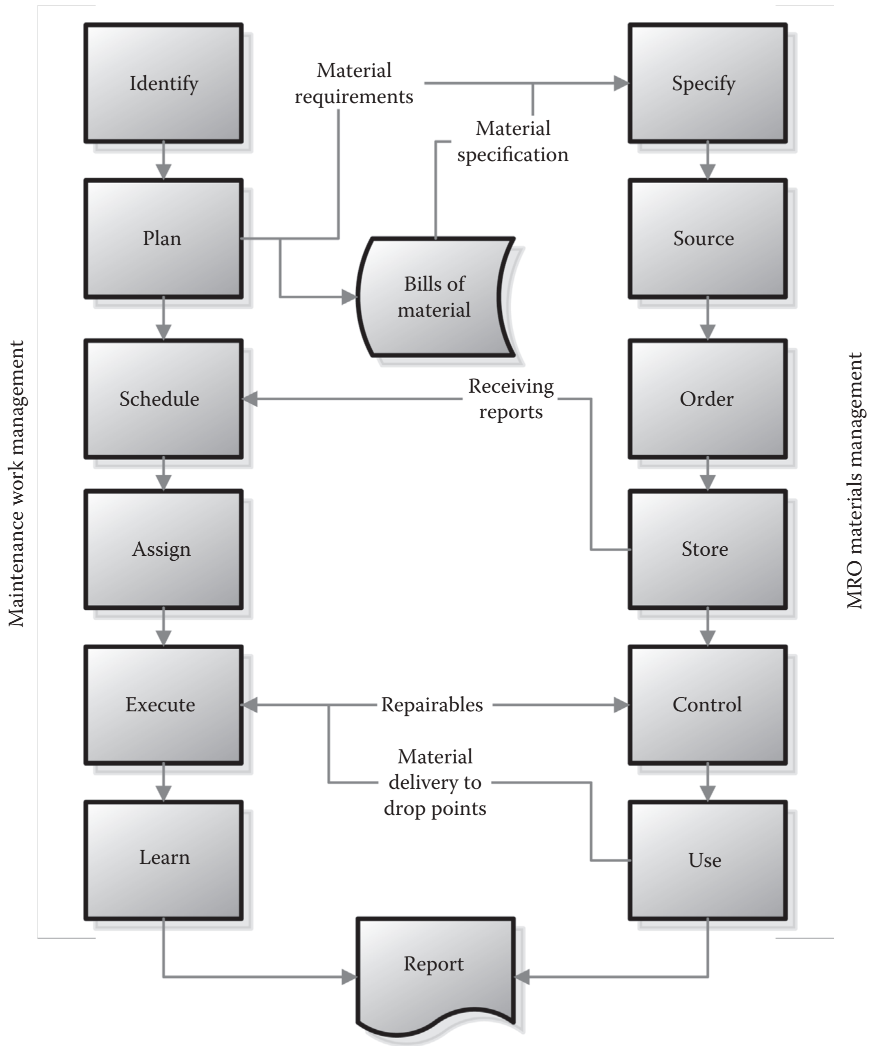


FIGURE 5.1
The linked materials and work management processes.

manufacturer for repair or simply discarded and replaced. If your records are accurate, the rest of the materials process will be simplified. This topic is covered in depth later in the book in Chapter 12 on asset information management.

Of course, not all the materials are found on parts lists. Bar stock, fasteners, lubricants, adhesives and a host of other materials are generally not listed but should be considered necessary materials. In either case, specifying precisely what you want is a critical first step. If you specify the wrong or substandard materials, you are likely to shorten the useful life of the equipment.

The specifications for parts and materials should be clear and unambiguous so that your supply-chain staff (buyers, stock clerks and suppliers) will know what it is you really want. Specifying a "drive end bearing for motor M-33" will only invite questions or, worse, generate guesswork, and then you will end up with the wrong bearing. If you want a certain part or material from a specific supplier because of quality requirements or unique tolerances, then make sure your buyers are aware of that. If you do not, buyers will tend to shop around for the best deal and invariably end up buying the wrong parts because they get a better deal. Those better deals are usually just better prices, and they are lower for a reason. If equivalent parts from various suppliers are acceptable, use the words "or equal" when specifying any particular vendor's parts identification—a sign to your buyers that it is OK to shop around. The onus here is on maintainers (or their parts coordinators) to be very specific. These days, most procurement processes will demand multiple bids and quotes. Those processes, all put in place with good intentions, are an opportunity for parts suppliers who want more business to simply play the pricing game and provide higher volumes of substandard parts at low cost. Maintainers must be more specific in identifying materials they need, and they must avoid identifying the supplier to buy it from (that only generates suspicion in the mind of a good purchaser).

Your MRO inventory contains the parts and materials you anticipate using on an ongoing basis at some time in the future. That includes fast-moving parts and materials as well as some very-slow-moving but critical items. Over time, inventory holdings go "stale." This happens when the equipment certain parts are used for has been removed and the parts for it remain in stores. It also happens with some parts that actually have shelf lives (e.g., elastomers, O-rings, solvents, gaskets, etc.). A disciplined process is required to control those shelf-life items. In the interests of keeping inventory holdings (and their costs) down, you want to eliminate those items from stores and minimize the slow-moving inventory. That inventory, however, will often also include hard-to-get parts that are being held as insurance against major failures. Some of those *insurance parts* may be critical to your operation but are no longer being produced. It is important that those items be identified to the inventory management staff so they are not discarded or sold during regular inventory cleanup efforts.

Classification of your inventory as critical and noncritical is also useful, critical spares being those items required for your most important equipment and systems or items that, if missing, can keep you down for a long time. If you have not identified those exceptions that are worth keeping on hand, then your materials management staff will be tempted to eliminate them.

Periodically, your stores personnel will carry out a purge of these materials. They usually do not do it without input from maintenance, but, despite asking, they often do not get the information they really need from maintenance. Simply sending a long list of parts to maintenance and asking them which of those they really need rarely gets a useful response. Cleaning up these messes is a difficult task and one that no maintainer really enjoys. It is far better to avoid the situation in the first place.

Knowing what parts are required to support your installed equipment and systems is sometimes much easier said than done, but the tools exist—we just do not always use them very well. Typically, our inventory management and asset register systems are somehow integrated, and the identification of "where used" is accommodated in our stores management software. However, if that is not completed, is inaccurate or is not up to date, or if the asset register is not kept up to date, those fields cannot help. This is often a very big problem in most organizations unless they have put in the effort at good "configuration management" as discussed in Chapter 12 on asset information management. Some industries typically do a good job with this: Nuclear power, aircraft maintenance and the military are all good examples.

Source

This book is not about materials or supply-chain management, but it is intended to help those in the maintenance and production/operational fields understand key interactions and relationships that need to work well for them to do their jobs. The relationship with supply chain is one of those areas.

Once materials are specified, the request to acquire them is turned over to your supply chain to handle the acquisition process. Supply-chain staff will get what you asked for (assuming they are satisfied that there is a legitimate need), and attempt to get the best pricing available and to do it all within the time frame you require, if that is possible. It is the time frame that gets a lot of material requests into trouble if there is poor planning and scheduling. It is not possible to negotiate good prices in a rush situation—the vendor has the advantage and knows it. Maintenance does its budget no favors by asking for materials at the last minute or in a panic. The better the forecasting of spares, the more time purchasing will have to fulfill the orders at a good price.

Vendor management can often be a win–lose situation, and confrontations between buyer and seller are commonplace. Buying strategy often dictates going for the lowest price of three or more bids for each purchase. Today, this can be an expensive process, especially when you consider that maintenance supplies typically generate a large volume of small-value orders. In some cases, there is latitude, but in others, there is none. As corporate auditors get pickier and companies focus more and more on costs, there is less latitude. Quite arguably companies are getting more and more "penny-wise and pound-foolish."

In most production plants, MRO inventory accounts for less than 2% of the spending but 80% or more of the buying activity. An example of how costly this can be is what occurred when a purchasing agent at a public board of education was required by policy to send out a request for proposal for a $2000 project to all qualified vendors—63 of them! The cost of the "politically correct" bidding process far exceeded the cost of the project—clearly an unintended consequence of poorly informed public policy. This is a flagrant waste that few companies can afford. Fortunately, most owners and shareholders, unlike taxpayers, generally have the option of refusing to engage in such practices.

A much more productive approach is to develop a supplier partnership, and many companies have these in place, at least for fast-moving or large-volume purchasing of parts for specific machines, production lines or material categories. In these arrangements, you lock yourself in with a trustworthy supplier for one or more years and work together to improve the overall value of the transaction for you both. You gain lower cost overall, higher quality and better service, while your supplier gains a relatively long-term arrangement with a stable business. In many of these relationships, the price you pay for some parts may not be the lowest possible price, but you can negotiate lower overall costs, and do not lose sight of the fact that this is offset by the overall value of the contract and its administration. High service levels from your suppliers reduce your order lead times. In turn, this reduces the inventory levels needed to obtain the same level of spares availability and your inventory and carrying costs, and ties up less working capital. A supplier that has a strategic supply partnership with a major customer will be willing to carry the inventory levels necessary to maintain that relationship and service.

This approach has been highly successful for many North American industries. Today, for example, North American automotive companies compete globally on a cost, quality and time-to-market basis with Asian and European manufacturers. A great deal of manufacturing has been moving offshore to low-cost labor markets in order to drive costs down. Many automotive parts for US- and Canadian-built cars are supplied from plants in Mexico, although the quality of the parts supply has been problematic, and some of those arrangements were reversed. Lower cost is not always best. Electronic components are increasingly being manufactured at lower costs throughout Asia.

Utilizing a few major suppliers who provide most of your MRO supplies is known as "strategic sourcing." With this approach, you have a relatively small number of contracts with those strategic suppliers. Today's enterprise management systems can get tremendous value from these arrangements. A global pharmaceutical company, for example, cut 17% from its materials costs by using this approach. The company aggregated many of its material requirements from several production facilities in the United States and Puerto Rico and purchased them from only a few key suppliers through a central purchasing group. Some items were indeed more expensive than those available locally, but the overall savings were substantial. Not only did materials costs drop, but also, the cost to purchase them dropped since there were fewer transactions and fewer buyers to manage. Other savings showed up in better forecasting of demand, reduced shipping and handling costs, fewer damaged shipments, more consistent forecasting, shorter lead times, reduced stock levels, fewer short orders, fewer returns and fewer warranty issues.

Order

Once the specifications and the supplier are known, the part can be ordered. Items kept in an inventory holding account (a balance sheet account as opposed to an income statement account) are normally ordered once the minimum or order point has been reached. The final user is not involved, because the inventory management system creates the order automatically as soon as the stock holding drops to a preset level. Because the authority to order was established when the order point was approved, circulating paper order forms for approval signatures becomes redundant.

Indeed, many computerized inventory management systems allow and enable automated ordering at preset trigger levels (usually a minimum stock level), ordering of preset economic order quantities and replenishment of stock to maximum levels. Of course, for that to work, the forecast of demand and stock levels must be set correctly. Doing that requires accurate usage/demand information, and that, in turn, can be distorted if the stores are not used and their inventory management systems updated accurately with each transaction or issue of materials to maintenance.

Many maintainers make the mistake of assuming that catalogue items are also stock items—they are not. Inventory items are stock items that are actually held in stores. Catalogue items are items that you probably purchase, or anticipate purchasing, on a regular basis. They are specified and given stock numbers, and their suppliers are known and possibly even under contract so that purchasing can acquire them easily, but the items are not always stocked in your stores. For catalogue items, most of the buying paperwork is already done, so they are quicker to acquire than noncatalogue items. Stock items are always catalogue items, but catalogue items are not necessarily stock items. For example, items you want for planned shutdowns may be catalogue items but not held in stock as inventory because your shutdowns have long lead times that are sufficient for the ordering and delivery cycle. Do not assume, when scheduling work for execution, that just because a part is in your company catalogue, it is also in stock. You always need to check on stock levels and either order them for issue or reserve them for your work/job order.

Items not kept in the maintenance stores can also be ordered by the user and are known as direct-purchase items. Some of those will be catalogue items, and some will not. Your buyers will often ask for approval before adding noncatalogue direct-purchase items to their catalogue. If you anticipate ordering these items again, it is a good idea to say *yes* and get them added to the catalogue. If you expect that they will be used in significant quantities on a regular basis, you may also want to add them to stock. To simplify ordering, many businesses have only one or two maintenance people (often your planners, but it is better to use dedicated parts coordinators) placing requisitions with the buyers to avoid duplication and to allow for grouping of requests. Today's integrated enterprise management systems have direct links from maintenance planning to requisitioning from stores and from suppliers (via the purchasing process) to facilitate this sometimes complicated process. Even with those integrated systems, however, it is often incumbent on maintenance to make sure that the supply chain is indeed acting on its requests. A parts coordinator is recommended for this role if the volume of work justifies someone more or less full time because planners have a far more important role to fulfill with planning, as described in Chapter 3. Chasing parts is not the best use of their time.

The need for maintainers to do direct purchase of materials usually reveals flaws in the inventory management system and/or the maintenance planning links to it. This may also reveal weakness in the initial identification of parts to be catalogued and stocked. Direct-purchase items effectively bypass inventory management going directly from source to user. Watch the volume of direct purchases. If it is high, you probably have a bigger problem in forecasting and/or managing inventory requirements.

Some organizations resort to purchasing cards (P-cards) or standing orders with suppliers for purchases by maintenance supervisors or tradespersons. This seems convenient, and it does help if unplanned material requirements arise at odd hours. It is not necessarily a reflection of poor planning, because plans can only reflect the best efforts of planners and the feedback they receive from completed jobs in a continuous-improvement cycle. These transactions are usually difficult to trace back to a work order (unless identification of the work order is required on the purchasing agreement by the supplier), so the history of materials used for these jobs is at risk of being lost. That is unfortunate because these jobs were probably important enough to justify the use of the P-card in the first place. Generally, the widespread use of P-cards is a symptom of underlying problems in the basic maintenance management processes. As a general rule, they are not recommended.

A practice that fortunately is becoming increasingly rare is to allow maintenance supervisors to buy directly from suppliers, bypassing the purchasing process altogether. This is very convenient for maintenance but is not recommended. Although it can be a big help in emergency situations, it can easily lead to the same sort of problems that arise with P-cards, and it is a process that is entirely open to abuse. This practice requires a high degree of cooperation between vendors and maintainers because they are supplying goods on the basis of a handshake. Again, it is a clear signal that other problems exist.

Store

The core job of maintenance stores is to receive stock and issue MRO materials for use. They also receive returns of unused materials, dispose of scrap, arrange for the repair of repairable items and, in some cases, even maintain inventory items on the shelves. Numerous factors affect the efficiency of the stores, from layout to the use of enabling technologies. Many storerooms have quarantine areas for newly received materials, warranty items and parts awaiting receipt inspection. If the sourcing is done correctly, much of the receiving inspection work can be eliminated. One company's solution to a 35% rejection rate of incoming maintenance supplies (by maintenance) was to add receiving inspectors in stores. That dealt very well with the problem as maintenance saw it, but it did not deal with the sources of the problem—poor specification of material requirements by maintenance and poor compliance with specifications by suppliers.

In addition to normal receiving, there is also a direct-order receiving area, for parts ordered by the users from suppliers. As previously noted, direct orders reveal potential flaws in your inventory management processes and keep inventory off the books. These special receiving areas only serve to institutionalize the problems rather than solve them. Paradoxically, the area must be managed aggressively to ensure that direct-purchase items are given to those who ordered them for imminent use. Without this sort of aggressive management, parts and materials can become obsolete before they are unwrapped.

Many poorly run stores have shelves full of direct-order materials with no work order tag or other identifying information. That information is used to ensure that parts get used and to avoid the risk of double ordering by the maintenance planners. In some organizations, these materials make their way to the maintenance shops or some other plant area where they end up being stored for use "just in case." They are often forgotten or discovered only after they have been reordered. In one steel mill, a large roll intended for use in a press during an upcoming shutdown was received and left outside in a large materials lay-down area without proper documentation. Winter came, and the roll was buried in snow. Several weeks before the shutdown, someone in maintenance noticed that a roll was needed and could not find the one that had been ordered. The mill rush-ordered a new one at a cost of $250,000. A couple of months later, the snow melted, and the stores people, wanting to make space in their lay-down area, decided to scrap the original roll. One alert mechanic, who just happened to be in the area on the day it was being lifted onto a flatbed, recognized it and asked the stores people what they were doing with it. His inquiry saved the roll, but it still sat for another year and half, tying up all that working capital, before it was eventually cleaned up and used. Even very expensive parts that sit long enough in direct-purchase receiving areas without good management may end up being thrown out as scrap.

Storage conditions are also important for many items. Items in stores should always be stored properly in a clean location. In some cases, temperature, humidity and exposure to light must be controlled to ensure a long shelf life. In addition, some items are not shipped the same way that they should be stored, and this must be dealt with so that the items remain in usable condition. For example, rechargeable batteries should be kept on a trickle charge, some electronic devices should be kept powered, electric motors should be stored where they can be easily turned by hand once a month (or so), large rotating assemblies are best stored "hanging" vertically to avoid shaft sag and bearing brinelling and so on. Storage conditions should be specified for all inventory items, and the specifications should be rigorously applied.

Control

As a rule of thumb, in North America, the value of your maintenance material usage will be roughly equal to the unburdened cost of your maintenance labor. In regions of lower labor costs, this ratio may be skewed toward higher materials costs unless labor is typically less productive. Similarly, in regions that are very remote where shipping costs are high, the ratio may be skewed the other way. Like any investment, you want the money you spend on materials to be spent wisely. That means that you want inventory to turn over quickly (i.e., be used). You do not want it sitting around unused or, worse, being scrapped after a long time of disuse. If it is fast-moving inventory for maintenance, it will turn over twice per year or better. That means that your inventory level (not including capital or insurance spares) will be about half your unburdened annual labor budget.

On the other hand, your inventory may comprise many insurance spares, with one-third or more of the investment still parked (no issues) after 24 months. Because depreciation rules vary widely and there is no general rule about which insurance spares to carry, there is no rule of thumb for insurance spares value. Moreover, they are a sunk cost, and their book value is irrelevant anyway. Their value to the company is driven by their potential operational value (as insurance against potentially costly downtime for failures that are expected to happen only rarely), the cost of carrying them versus their salvage value. Consider these facts before you decide whether you really want them in your inventory.

Your inventory of spares and materials is normally measured and managed rigorously. It deserves the same scrutiny as your production raw material, work-in-process and finished-goods inventory. Well thought-out stores management processes with strict process discipline are critical for both your stores and maintenance personnel to follow. Although shrinkage is not normally a major issue, free access to the storeroom, something the maintainers will want in order to help them get work done faster, is not advantageous. It is easy to lose track of what is actually in the stores. Maintainers are often in a hurry to do their jobs, so accurate reporting of issues and returns is not their priority. If they can walk in, grab what they want and walk out with it, they often will. The paperwork gets ignored, and the result is invariably a high level of stock adjustments and stock-outs. Your inventory records will not accurately reflect what you actually have in stores, and faith in the entire system may be shattered. Free access should be granted only to fast-moving, low-value, common items such as fasteners, piping, steel fittings and the like, and ideally at the workplace where they are used. The cost of managing these items closely often exceeds the cost of losses such as shrinkage due to spoilage (dirt accumulation, rust, aging of elastomers), so free-issue management is warranted. Note that spoilage of some items (e.g., elastomeric O-rings) can result in hazardous consequences if the items are used in a critical service. Be especially wary of managing these items as free issue. Many companies today are having success with vendors managing these ready-use inventories for them. This practice, known as "vendor-managed inventory," entails paying only for what you actually use on one monthly invoice, and the vendor worries about the details of what to stock and how much.

Some companies have concerns about their vendors, fearing that they will be ripped off by overinvoicing and inflated reports of actual usage. If you have chosen a strategic vendor well, then this sort of risk is low, and your vendors are highly unlikely to cheat. Fear of getting caught and having the word spread among other customers is a very good incentive to avoid such practice because that sort of reputation can destroy a business overnight. If you do not trust a particular vendor for some reason, the best solution is to find a vendor you do trust. There is little value in entering into vendor-managed inventory contracts to save your own stores and administration time if you end up spending time checking up on the vendors. Observe, too, that if you are afraid of attracting vendors that would cheat you, it is because you know that if the opportunity arose, you, too, might take advantage of them. Change that willingness on your part, and you will notice a remarkable shift in the business relationships you create with others.

Repairable items, components taken out of service, rebuilt and returned through the inventory control system, can be a headache to manage. There are as many ways of handling these items as there are plants that have them. Usually, the problem is the cost accounting of repaired components. To capture the cost of the repair on the correct work order, some companies make the mistake of letting maintenance manage the repair cycle. Of course, maintenance staff will only get to repairing these when they can—usually too late. Thus, the repairable items do not get repaired in time, the work order remains opened for a long time and this drives up the cost of managing many inactive but open work orders. When an emergency arises and the item is needed, a rush order to a happy supplier is usually the unhappy result, and inventory values grow. Free or no-value issue, with a charge-back of the actual repair cost to the last user, is often the easiest way to handle this situation. Another approach is to close the work order, accrue the repair costs in an inventory account, and charge them as a cost of the item to the next user of the item. This can all be complicated even more if accounting decides to track the costs as a capital expenditure (after all, you are extending the useful life of the asset). Although today's integrated enterprise management systems make this easier to control than it was in the past, the basic process must be right—fixing the system or part of the system does not solve the underlying problem. The process is determined and defined before the system is set up.

Use

One of the biggest wastes of tradespersons' time is the time spent waiting for tools, parts and materials. (A time study performed on North American plants revealed that this ranged from 17% to 22% of tradespersons' time.) This is a highly unproductive use of time, and it is not a labor problem but a management problem. Some work order management systems, in fact, have a stage in the work order cycle for work orders that are "awaiting materials." That is fine if it means the work orders are not yet scheduled for execution, but it sometimes means that your scarce tradespeople are doing the waiting and your equipment is down.

Good planning integrated with an effective supply-chain process is the key to minimizing this unproductive time wasted by tradespeople who are waiting for materials. The time expended while a part is looked up, requisitioned, spotted, issued and brought to the workplace can be considerable. If the part is not in stock, lead times can be long. (Remember that suppliers are also trying to keep their inventory values under control; they prefer not to stock more than they think they will sell based on historical usage rates and the delivery time promises of their suppliers.) Once the parts arrive, installation is usually speedy, but the time spent waiting is lost forever.

One excellent solution to this problem is the "kitting" of parts by work order, but it can be overused and abused. This is especially effective for major planned work like shutdowns and for repetitive work like preventive maintenance (PM) and other planned repair jobs that should make up most of your labor budget hours. Parts delivery to the site may sound expensive, but compared to lost tradespersons' productivity and extended equipment downtime, it can be very cost-effective. (Remember that tradesperson productivity is becoming a critical strategic issue due to the difficulties that many companies are having in finding skilled trades labor.) One unskilled delivery person can service many skilled tradespeople at many jobs. If you do this for 80% of your total workload (not a bad initial target for planned workload) and you save 10% of the total tradespersons' time for additional work, you will increase your labor productivity and save yourself higher overall repair costs. One consideration, as noted in Chapter 3, is that kitting does expose the parts to an additional handling step that risks damage or loss. With knowledge of your own stores and how well they handle materials, weigh that risk against the possible gains when determining your preferred policy.

It is not rare for materials and parts to be left over when work is completed. The repairable or reusable parts are returned to inventory, the appropriate credits made to the work order charges, the inventory entries adjusted and in some cases the parts can be returned to the vendor. It is pointless to return parts like bearings that have been opened and subjected to contamination that will render them prone to premature failure and unusable. To avoid scrapping these parts, it is best to leave them fully wrapped and unopened at the work site until they are actually used.

Analyze the Data (Learn)

One of the simplest ways to judge the effectiveness of your maintenance planning is to review the number of urgent or emergency requisitions received by your buyers. If your work is planned properly, then these will be relatively few. Another is to check the number of stock-outs in the stores, to see if inventory control is working. Again, you are looking to find only a few at most. By counting stock-outs, you are looking at historical performance only. How many stock-outs have not yet happened? Measuring inventory accuracy and managing stock levels, order points and order sizes are proactive ways to obtain and maintain high service levels. How many direct-purchase items are being ordered repetitively by your planners or parts coordinators? Consider adding those items to inventory to reduce ordering costs and to save the planners and parts coordinators valuable time. Similarly, look at purchases made by maintainers using P-cards, emergency purchase orders or purchase orders issued after the parts have been used. These are all indicators of opportunities to improve the service that MRO inventory provides to maintenance. The objective of MRO materials management is to balance the investment with value. Look for ways to continuously improve this ratio.

There is a great deal more to managing inventory that goes beyond the scope of this book; however, be aware that the determination of the quantity of each part to hold in stores, the reorder points, the minimum and maximum stock levels, the usage rates, variance from job plans, etc. are all a part of the big picture. Managing inventory is an important process, second only to work management, in keeping maintenance costs under control. An excellent source of additional information on this subject is *Maintenance Excellence: Optimizing Equipment Life-Cycle Decisions* (Campbell and Jardine 2001). We also present examples pertaining to spares management later in Chapter 10 on evidence-based asset management.

E-BUSINESS

E-business, also known as e-commerce, is a term that refers to business transactions conducted over the Internet. It is the most cost-effective media for many business transactions, and e-commerce is now a principal means of doing business. Today, many people and companies consider e-business to be business as usual, yet many companies, often in older facilities, fail to take full advantage of it. Other companies, even those with small pockets of automation, are making the shift as the benefits of lower-cost e-business become more evident.

In 2000, retail e-commerce in the United States was estimated at $28 billion (not including food).[1] By 2004, that rose to $69 billion, in 2013 to $263.3 billion with forecasts for 2014 and 2015 at $304.1 billion and $347.3 billion.[2] E-commerce is growing by an average of more than 12% per year, and it is showing few signs of slowing. For business-to-business transactions, the volumes are 14 times higher for manufacturers and 19 times higher for merchant wholesalers. Given these statistics, it is safe to say that e-business is here to stay.

The Internet has become an information highway; desktop computers, laptops, tablets and smartphones provide us with the on-ramp. Computing is just about everywhere now, and it offers near-limitless access to information, services and entertainment. Top-performing companies use technology to generate savings, speed up business transactions, enhance the accuracy of those transactions and manage their mobile workforces.

Arguably, in some ways, technology is well ahead of our ability use it, but enterprising companies are making optimal use of it in many ways. The days of paper purchase orders and requisitions are nearing an end. Only auditors, those obsessed with micromanaging, and companies unwilling or unable to invest in today's software packages seem to require paper anymore.

Today's successful management systems automate most of the day-to-day business transactions associated with maintenance and materials management. Within the inventory management system, a requisition for an inventory item by a maintenance planner can trigger a reservation in an inventory management system (very likely an inventory module within a larger enterprise system). When all materials and other resources have been confirmed as available, a job will be scheduled and a work order issued for execution. That triggers a stock issue for all materials linked to the work order. A pick-list is generated (usually on a handheld device now or on paper), and those parts etc. are then kitted into a package and identified by work order number, for delivery to the maintainer at the job-site. That same stock issue from stores may drop inventory holdings below the reorder point. Because the item is an inventory item, this triggers an e-business transaction. An automated order for the part is sent electronically to your supplier. The order is filled and shipped. On receipt, the packing slip (possibly on an electronic tablet or another piece of paper) will be signed off as received, and the order receipt will be entered into the materials management system, which will update the inventory records. The only paper document required in the entire process is probably the packing slip, used by relatively unskilled labor as a checklist. E-business allows the customer to identify, order, specify shipping of and pay for items online on the supplier's website. Efficient systems working in tandem with e-business substantially reduce the transaction costs associated with these purchases.

The availability of the Internet and e-business globally has changed many business models. Purchasers spend their time sourcing suppliers, negotiating and managing fewer large contracts for many goods and services. There is a trend toward large companies merging with each other to form massive global conglomerates. As these companies merge, the value of flexibility in these systems is highlighted, but the inflexibility of some enterprise systems can be revealed. Information exchange can be enhanced, transaction processing sped up and costs reduced. Most purchasing is automated since inventory items are preapproved for purchase with specific set order points and economic order quantities.

Setting up for e-business is no longer a lot of work. It is easy and often the only way to go now. Larger companies with more entrenched information technology may have some challenges, largely around data security, but few fail to take advantage of what e-business offers. When you engage in e-business, not only do you rely on your own management systems, but you also rely on their ability to interface with the Internet and the systems set up by your suppliers and customers. You still screen and manage your suppliers, negotiate the contracts and ensure that contract terms are met. An advantage of e-business is that it gives your company the flexibility to manage all its procurement through one organization, and indeed, some companies now outsource the whole purchasing function. Of course, many companies still prefer to keep things divided up by region or country, but even these choices can be facilitated by the capabilities of today's advanced systems and global-scale suppliers.

MRO IMPROVEMENTS

There is a lot that can be done to improve the performance of MRO stores in support of maintenance. Table 5.1 describes 12 activities that can contribute to enhanced stores performance, lowering of inventory costs and improved performance by maintenance. Companies that achieve high service levels to maintenance along with low inventory purchasing and carrying costs have done this work. This achievement requires the efforts of stores, maintenance and procurement to varying degrees and may additionally require upgrades to systems capabilities. These activities are presented in a logical but not necessarily fixed sequence, amenable to implementation.

TABLE 5.1

Stores Upgrade Activities

Activity	Requirements	Benefits	Costs	Comments
Physical spares management: implement basic practices	• Accurate listing of stores • Standard part descriptions • Warehouse organization—aisle-shelf-bin numbering • Parts identification and tagging • Receiving and issuing data collection • Regular cycle counts • Material requirements on work order • Pick-list preparation from work order	• Planners and technicians have parts when and where they need them • Reduced job delays through no parts and wrong parts • Reduced repeat parts collection trips to and from warehouse • Faster picking • Reduced parts duplication • Reduced stock-outs	• Initial data cleanup and recording costs • Physical setup costs • Training costs • Possible additional stores staffing costs	• Extra stores staffing will be offset by reduced maintenance hours • Not all warehouses need to be staffed

(*Continued*)

TABLE 5.1 (CONTINUED)

Stores Upgrade Activities

Activity	Requirements	Benefits	Costs	Comments
Physical inventory management: kit-ups prepared by stores	• Pick-list printing in stores • Earlier pick-list printing • Planners identify parts by work order	• Faster picking by staff who know the layout • Picking by stores keepers, not maintenance technicians • Reduced pick and wait time by maintenance technicians	• Requires stores staffing	• Extra stores staffing will be offset by reduced maintenance hours
Physical spares management: stores cleanup and obsoletes	• Parts "where-used" listing • Definition of obsoletes • Knowledge of what it is • Disposal of obsoletes • Help from maintenance to identify "where used"	• "Got rid of the junk" and "cleaned up warehouse" are big morale boosts—show that the company is serious • Cash for junk • Frees up space • Reduces stores management time	• Time consuming • Cost of physical removal	• Revenue from the obsoletes cleanup can pay for additional activities

(*Continued*)

TABLE 5.1 (CONTINUED)

Stores Upgrade Activities

Activity	Requirements	Benefits	Costs	Comments
Physical spares management: jobsite delivery and staging	• Earlier pick-list preparation • Earlier work order planning • Regular stores delivery routines • Emergency backup procedure	• One-stop stores responsibility • Less travel and time for maintenance technicians (large potential savings) • Substitutes costly maintenance technicians' time for less costly stores deliveryman's time	• Delivery staff	• Stores delivery route reduces overall travel • Requires change in operating philosophy/improved planning • Will not eliminate emergency spares collection • Security at parts staging area can be a problem
Inventory optimization: establish inventory levels, min–max. Economic Order Quantity (EOQ), lead times, stock counting, P-cards	• Consumption records • Vendor records • Requirements forecasts • Criticality and value analysis (ABC) • Regular stock counts and reconciliations	• Reduced inventory levels • Reduced spending on spares	• Analysis cost • Disposal costs (may be offset by scrap value)	• Levels generally set too high in the early stages; need to review periodically • Regular stock counts plus introduction of P-cards raises confidence • Use of P-cards can reduce accuracy of maintenance cost reporting by work order

(*Continued*)

TABLE 5.1 (CONTINUED)

Stores Upgrade Activities

Activity	Requirements	Benefits	Costs	Comments
Inventory optimization: parts standardization	• Policy and procedure on materials specification in maintenance, design and engineering	• Faster parts lookups • Time saved by planners • Fewer duplicate parts • Better parts pricing	• Analysis cost • Adds to design time	• Design engineers love to invent new things • Vendors have little influence over manufacturers and their designs
Physical inventory management: warehouse rationalization and regular cycle counting	• Records visibility • Interwarehouse policy and procedure • Interwarehouse delivery process	• Reduced inventory levels overall • Reduced spending on spares overall	• Analysis cost • Interwarehouse delivery costs	• Does not mean staffed warehouses everywhere • "Warehouse" may equal a field maintenance truck
Procurement: vendor optimization	• Negotiations with vendors	• Fewer vendors • Higher spend per vendor • Better parts pricing overall • Better vendor service	• Analysis cost	• Buyers' resistance to striking off vendors • Some part prices may rise, but overall costs go down
Procurement: automatic requisitioning by maintenance	• Procurement approves contracts	• Streamlined buying process reduces administrative cost	• MRO inventory and procurement systems must have capability	• Perceived loss of control offset by approval procedures

(*Continued*)

TABLE 5.1 (CONTINUED)

Stores Upgrade Activities

Activity	Requirements	Benefits	Costs	Comments
Procurement: e-procurement by maintenance	• Procurement approval of replenishment practices	• Streamlined buying process reduces administrative cost	• Systems capabilities upgrades may be needed	• Perceived loss of control offset by smart approval procedures
Physical inventory management: Just-in-time (JIT) supply by vendor	• Requirement forecasts • Performance targets for vendors	• Vendor owns inventory until shipped and can optimize supply • Vendor part of materials planning process	• Possible higher prices	• Perceived loss of control by procurement • Higher prices may be offset by longer and more secure supply contracts, plus performance targets
Physical inventory management: vendor-consigned inventory	• Requirement forecasts • Performance targets for vendors	• Vendor owns inventory until consumed • Lower spares investment • Lower carrying cost	• Possible higher prices	• Perceived loss of control by procurement • Higher prices may be offset by longer and more secure supply contracts, plus performance targets

Like maintenance, improving performance of your supply of MRO materials to maintenance can be a big undertaking. The biggest challenge is the integration of information flowing between maintenance (planning) and materials management groups. Successfully transforming underperforming stores into a streamlined operation that delivers what is needed, when and where needed, can be planned and executed in the same way recommended in Chapter 1. It is best tackled as a single project together with maintenance as no one department holds all the keys to success. Table 5.1 provides a list of things that can appear in your MRO improvement strategy and plan. Selecting what will deliver the most value for the effort depends heavily on where you are today. An assessment can be used to identify which areas need improvement, but many of the underlying problems are easily identified by looking at the evidence in the field.

UPTIME SUMMARY

Good materials management is another essential—without the right spare parts, many jobs cannot be done. There is no point planning and scheduling work if you cannot rely on materials management to provide the parts when you need them. If you want excellence in maintenance, you need excellence in materials management. Your work management and materials management processes must be integrated closely, or you cannot achieve the benefits that work management can deliver.

Top performers do not delay or halt work because of unavailable parts. That happens as a result of the work management processes failing to communicate material requirements in a timely manner to the supply chain and failures of the supply chain to deliver on time. Of course, the lead times for materials are a major consideration. Even an excellent plan that is communicated to materials managers only a week before a long-lead item is needed will fail.

Availability of spares is important, especially for critical and longer-lead items. MRO materials usually make up a small portion of most companies' material inventories but the bulk of the inventory transactions. These parts and materials usually represent a small portion of your inventory investment, but they can be critical to running your plant. Individual parts can be of any value, they are purchased and used in small quantities, they are often slow moving and they can be difficult to source; yet they are essential to getting planned work done as planned and on schedule. Managing MRO materials is a big and very important job. If MRO materials processes are not improved in lockstep with maintenance, your ability to deliver *Uptime* will be seriously limited.

Integration of materials management processes such as stores issues and returns, receiving notifications and purchasing with the maintenance planning and scheduling parts of the work management process must happen. There is no point ordering materials for a rush job if the parts arrive only to sit on a shelf because maintenance does not know they are there. This becomes even worse if the job is urgent and maintenance works outside the normal procurement processes and double orders to meet production demands. Such "out-of-process" purchasing activity undermines good materials management practice as it becomes increasingly difficult to forecast maintenance needs if the material requirements do not flow through the channels that collect usage data and forecast demands.

Of course, the maintenance parts storeroom is the focal point for your maintainers. There is much that can be done to make it efficient and cost-effective. Keep in mind that if you are experiencing trouble in this area today, you probably need to work on both your work management and materials management processes together. Do not be penny-wise and pound-foolish by tackling inventory problems in isolation. The key to success here is to have maintenance, inventory and supply-chain management working together.

ENDNOTES

1. US Department of Commerce, Census Bureau, February 24, 2005.
2. E-Marketer.com. Available at http://www.emarketer.com/Article/Total-US-Retail-Sales-Top-3645-Trillion-2013-Outpace-GDP-Growth/1010756, April 10, 2014.

6

Performance Management

> What gets measured gets done.
>
> **Tom Peters**[1]

> A crude measure of the right thing beats a precise measure of the wrong thing.
>
> **John Carver**

Tom Peters, coauthor of *In Search of Excellence* and *A Passion for Excellence*, emphasized the quantitative aspects of running a business. He observed that organizations, including his own, that focus on a set of goals (sometimes lofty goals) and measurement schemes to watch progress generally do well at meeting or even exceeding those goals. Measurement influences behavior, and people whose performance is being measured generally respond by performing better. The objective of performance measurement is to influence behavior in a way that helps achieve organizational goals.

In implementing *Uptime*, we have learned important lessons about performance measures and performance management. Most importantly, measuring it is not sufficient to create a change—at least, not the change you might expect. There is a strong tendency for people to strive to meet the numbers and then stop. If they can move beyond the targets, they will not necessarily do it unless sufficiently motivated to do so. They may also play games with the numbers to make sure to meet their targets, and this is where performance measurement can fall off the rails. People are meeting their numbers, but results are just not showing. Another challenge is that simply picking a suite of measures to use for management may result in unwanted behaviors (whether or not anyone fudges the numbers). Seemingly good and sound measures can generate surprising results, both good and bad. Underlying Tom Peters' work had to be an assumption that people would be motivated to actually meet their numbers and not to play with them simply so that numeric targets could be achieved regardless of actual results.

Companies have been under incredible pressures to generate profits from increasingly tight margins. They cut costs relentlessly and, in many cases, use the "Lean" label as a banner for downsizing (or rightsizing, as it is often called now), totally perverting the whole Lean concept. People, despite how important they are (see Chapter 2), have often been treated as a commodity, one that can be hired and fired with swings in capacity. Admittedly, in some forms of very labor-intensive low-skilled work, that may be justifiable, but that is not generally the case with maintenance and production workers. Both require skills and training that do not come cheaply. In the case of maintainers, they can be very difficult to replace due to the dearth of skilled trades available on the open job market. Yet companies have treated them as commodities. Loyalty to companies is probably at an all-time low. Resistance to change is high, resistance to being measured is high and any games that need to be played with numbers to protect the job will be played. The fact that it may hurt the company is seldom an important, immediate and very personal concern in the minds of many in our workforce today. Getting performance measures to work in this environment is challenging but not impossible.

Customer satisfaction was Tom Peters' best indicator of future health of a company—more so than market share or profitability. He encouraged companies to use customer satisfaction as the primary basis for bonuses or other variable-pay components and for annual performance reviews and to do so at every level in the organization. He also encouraged monthly monitoring of key quality measures, posting progress in highly visible locations in every workspace and making it topic #1 at every staff meeting. His teachings can be applied to any part of an organization but work best when applied company-wide. Organizations with a highly motivated workforce will indeed respond well to these sorts of measures.

In the 1990s, Kaplan and Norton (1992) conducted extensive research on benchmarking and published their findings in the *Harvard Business Review*. They introduced a scheme for managing performance measures that would extract the greatest performance from an organization and drive strategy decisions through the use of measures in a balanced scorecard. The concept was simple enough—the right measures in four dimensions (financial, customer, learning and growth and internal processes) would be optimized. Of course, instituting these measures requires considerable thought and coordination. It is quite possible to maximize performance in one area while suboptimizing it in another. An example of suboptimizing from the world of maintenance is minimizing maintenance, repair and overhaul (MRO) inventory holdings, which then results in poor service levels for maintainers who cannot get the parts they need in a timely manner.

For businesses that run on large, sophisticated equipment and facilities, maintenance performance has a dramatic impact on overall capacity and cost. Measuring that performance, however, is often based solely on the cost of tradespeople and materials or wading through a muddle of terms like *mechanical availability* and ratios like *maintenance costs over plant replacement value*. Maintenance costs are often seen by cost accountants[2] as some sort of necessary evil that should be minimized. Beware of that perception! While there is truth to it from a purely cost accounting perspective, shortsighted cost cutting in maintenance has led to many production, safety and environmental problems in many companies worldwide. Recognize that those costs are directly linked to the generation of revenue—without maintenance, your plant will not run, and you will produce nothing.

If you want productive maintenance, measure maintenance productivity and do it from the perspective of the customer. If you want to achieve your maintenance strategy, constantly review your strategic objectives and master plan. If you want to be competitive, compare what you are doing to what others in the field are doing. Learn from your most successful competitors.

MEASURING MAINTENANCE

Productivity

Productivity is an expression comparing what you get to what you put in. A figure greater than 1 means that you are productive. A figure less than 1 means you are putting in too much or getting too little out. Either way, something is amiss. With maintenance, what you get is better equipment performance, usually measured in production output terms. What you put in is money, generally measured as dollars spent on maintenance. A simple ratio of output to input, or its inverse, is an easily understood measure that quickly shows if you are getting more or less bang for your buck. Looking at costs per unit of output instead of using absolute or total costs gives you an excellent basis to trend. A trend line showing maintenance cost per ton of production tells you quickly whether the maintenance function is improving, getting worse or stable. Adding physical assets invariably adds the need to do more maintenance. When you add physical assets to your plant or fleet in the form of additional automation, computerized control systems, larger and higher-capacity production equipment, etc., you can expect maintenance costs to go up. If you look only at costs, you will see a negative trend; however, if you look at the ratio of output to input, you should see that output is climbing relative to costs, indicating that productivity is actually rising. If you do not see that, then you have some problems to solve.

Equipment performance is a key to delivering productive output, but it is not the goal that maintenance is striving to achieve. Many maintainers believe that they have done their job once they have delivered working equipment. In one sense, this is true. In a broader sense, however, these maintainers are missing the real purpose of their work. Their role is to sustain productive capacity so the company can earn revenue at a reasonable cost—the delivery of working equipment after a breakdown is but one part of that. They sustain the *function* of the equipment, not the equipment itself. A great deal of maintenance money is often spent in "emergency" situations, on restoring equipment to working order even though its function has already been restored by backup or standby equipment. While this reduces the risk of loss of functionality if the backup fails, the risk reduction may not be worth the cost. Most companies make no attempt to quantify this and go with old habits. A successful practice is to quantify those risks and make informed trade-off decisions.

Equipment Performance

How do we measure equipment performance? The most obvious parameter is whether equipment is running or not, but the answers to the follow-up questions tell much more. Is it available for use? If it does run, how long do you expect it to keep chugging along before the next failure?

What is the average time it would be down for repair and maintenance? How fast can it operate, or how much can it produce compared to what it was designed for? How precisely does it run? Does it always produce the quality required? Is its performance improving or deteriorating? There are commonly accepted terms and definitions to answer each of these performance questions:

- *Availability*[3]—a measure of uptime, as well as the duration of downtime. It is calculated as follows:

$$\frac{\text{Scheduled uptime} - \text{all downtime}^{4}}{\text{Scheduled uptime}}$$

- *Reliability*[5]—a measure of the frequency of downtime, or mean time between failures (MTBF). It is determined by the following:

$$\frac{\text{Total operating time}}{\text{Number of failures}}$$

or

$$\frac{\text{Total operating cycles (kilometers, tons)}}{\text{Number of failures}}$$

- *Maintainability*—a measure of the ability to make equipment available after it has failed, or mean time to repair (MTTR). It is determined by the following:

$$\frac{\text{Total downtime from failures}}{\text{Number of failures}}$$

- *Process rate*—a measure of the ability to operate at a standard speed, cycle or rate. This is calculated by the following:

$$\frac{\text{Ideal cycle time}^{6}}{\text{Actual cycle time}}$$

- *Quality rate*—a measure of the ability to produce to a standard product quality, or

$$\frac{\text{Quality product produced}^{7}}{\text{Total product produced}}$$

- *Overall equipment effectiveness (OEE)*[8]—an overall measure that considers uptime, speed and precision. It is measured as a product of

$$\text{Availability} \times \text{process rate} \times \text{quality rate}$$

The value of any of these measures has a lot to do with how the equipment was designed and built. Thus, a successful test of equipment performance is often its performance trend over time. This will provide you with feedback about changes in operating and maintenance practices.

One cautionary note about equipment performance and benchmarking is that comparisons of equipment performance in one organization or even in one operating environment with another can be misleading. Even identical equipment that is operated under different conditions, at different rates or under different loads can provide dramatically different performance results. For example, a pump used to pump lubricating oil will perform differently if it is used to pump water, fuels, caustic soda or acids.

Cost Performance

In many companies, it is extremely difficult to obtain accurate and relevant maintenance cost information. Labor is often charged through cost centers, and only significant materials expenditures are charged to the equipment. Labor may be charged against work orders and, hence, to the equipment, but it is often misreported or inaccurate. Overhead costs are often allocated on the basis of direct labor, whether those overheads are related to maintenance or not. Most organizations track costs in a way that is conducive to accurate accounting but not against specific pieces of equipment in the asset register. This lack of accounting for specific activities makes determining the value of reliability improvement efforts very challenging. By aggregating costs so that they are convenient for accounting but not for maintenance, companies can severely hinder their ability to make meaningful equipment-specific decisions.

Accurate maintenance information is useful for two reasons: (1) Maintenance productivity can be measured and, therefore, managed, and (2) it promotes rational equipment decisions, such as whether to repair or replace. Maintenance costs are usually segregated into the following categories:

- *Labor*—all the wages and benefits of the tradespersons and temporary helpers
- *Materials*—all the supplies, parts, components, repairable items, consumables and other items used by maintenance
- *Services*—all shops, utilities, facilities and stores warehousing
- *Outside services*—all contracted services for heating, ventilation and air-conditioning (HVAC) or other specialty services, training and consultants
- *Technical support*—engineering, supervision, planning, materials coordination, clerical and data entry
- *Overhead*—other support functions, such as accounting and management information systems (MIS) personnel, general utilities, facilities, taxes, rent and other general expenses

These categories are broad and rather generalized. A more useful way to consider maintenance costs is to break them down in the following way:

- Specific areas, such as labor, materials, services and technical support—all of which are influenced by area management and staff
- Job or work order for labor, materials and services, so the costs can be designated to a particular piece of equipment
- Expense type for labor and for materials and all services to monitor trends in key parts, consumables and services

As with equipment performance, tracking cost trends is more sensible than looking at individual numbers or single averages.

Many companies want to know if their overall maintenance costs are in line with those of other companies in their industry. One of the successful measures is cost per unit of production; however, that is a difficult measure to obtain from competitors, and everyone seems to measure costs a bit differently, so accuracy is questionable. A commonly accepted measure is the overall cost as a percentage of replacement asset value. Here, too, the same problem exists with ensuring that costs are measured consistently. Replacement asset value, particularly for fixed plants, is often no more than an educated guess, sometimes based on the insured value of the plant or an inflation-adjusted initial capital cost.

Process Performance

Maintenance management is a business process with inputs and outputs. The inputs are costs; the outputs are equipment performance and productivity. Between the two comes the complex job of making sure the equipment works at top performance. That job can vary dramatically from industry to industry and from product line to product line, so there is no single set of measures that is ideal for every situation. Many books on this subject suggest measures for maintenance under different circumstances. Additional suggestions are provided below, along with some performance benchmarks[9]:

- *Maintenance spending as percentage of capital replacement cost.* This gives an indication if the maintenance spending is in line with your industry sector. Coopers and Lybrand performed a study in the early 1990s, which revealed that maintenance spending in manufacturing companies ranged from 3% to 8% of capital replacement cost, with the majority falling into the 4%–7% range. They also found a correlation between this value and how satisfied people were with their overall maintenance performance. Companies spending less than 4% or more than 7% were least satisfied, a clear indication that underdelivery is possible with either underspending or overspending. It can be difficult to get an accurate figure for capital replacement value, so comparisons made using these percentages can provide only a rough idea of how you are doing, particularly in industries with unique variables. (For example, the oil and gas industry fell in the range of 1.5%–2% due to the capital investment tied up in static assets like pipelines that require very little maintenance.)
- *Emergencies.* If something immediately and negatively affects the safety, environment, profitability or customer service and automatically necessitates overtime to restore service and eliminate the consequences of the failure, then it is a true emergency. Both the amount and impact of emergency maintenance can be measured. Anything over 2% of your maintenance workload (labor hours) strongly suggests there is room to improve.

- *Planned versus unplanned*. Ideally, you will have very little unplanned work. With a well-designed maintenance program, you will know what to expect so it can be planned in advance, particularly for critical equipment. Having 95% of total maintenance labor hours planned is considered top-quartile performance. Of course, there is often a great deal of discussion around what work is considered to be planned and what is not. A useful and workable definition is that it is work that has been analyzed by a planner and at least had an estimate of the time required for its execution.
- *Schedule compliance* (or, stated more positively, schedule success). A good indicator that your plant and organizational discipline is in a firefighting mode or having success keeping out of it. Schedule compliance is measured by dividing the total labor hours for all work completed as scheduled by the total number of labor hours for all work scheduled in the same time period. For example, if you have scheduled 1600 hours of work for next week and completed 1000 of those during that week, compliance is 62.5%. If compliance (success) is high, then you are operating in a controlled manner. If it is low, then you are likely to experience excessive amounts of emergency work and higher costs than necessary. 70 percent is considered top-quartile performance, but you can do far better than that. The keys to obtaining high performance and avoiding firefighting are excellent planning, accurate scheduling, disciplined work assignment and execution and a maintenance work program that is mostly proactive. A note of caution about this measure: While it is highly useful, it can backfire if used as a target, and people begin to fudge numbers in order to meet their target.
- *Preventive maintenance (PM) schedule compliance (success)*. Doing the right proactive[10] maintenance activities when they are scheduled is probably the easiest and most effective way to improve equipment performance. This is measured as above but using only PM work for the measure. PM compliance should ideally be 100%, but there are times when breakdowns dictate the execution of repairs that take people away from doing their PM work. It is important to allow that while investigating whether or not PM could have been used to avoid the breakdown that caused the variance.
- *Work orders generated from PM*. This can tell you a lot about the thoroughness and effectiveness of the PM program. When an

inspection is carried out, you can expect some work to be identified some of the time—but not always. If your inspections are always turning up work, then you are very likely inspecting too infrequently and incurring more breakdowns than you want. If your inspections are too frequent and you find very little, then you are probably spending too much. Your task frequencies can be adjusted up and down, respectively, in those cases. There is no benchmark for this measure. It will vary depending on your PM program effectiveness, which can be monitored indirectly by observing a drop in emergency work and increases in planned work and schedule compliance (success). Note, too, that predictive maintenance is a part of your PM program. While PM should result in physical changes to your equipment (repairs, replacements, resurfacing, changes of fluids, etc.), the predictive maintenance is just a check of operating and other potential failure indicators. Most of the time, it should reveal only that the equipment is running well. If you are finding problems every time, you are probably checking too infrequently, and if you are also avoiding failures, you are incredibly lucky.

- *Urgent versus normal purchase requisitions*. Another test of maintenance planning, MRO inventory management and the appropriateness of equipment maintenance tactics. If the planning process is working, maintenance knows ahead of time what parts are required and can check on their availability before scheduling work, and urgent requests will be minimized. However, if inventory management is not working well, then no amount of maintenance planning and checking before scheduling will help. If your maintenance tactics are inappropriate, they will be ineffective at preventing, predicting and detecting failures, and you will experience a greater number of breakdowns requiring emergency response.
- *Stores inventory turnover*. Dividing the value of annual issues by the on-hand value of stores provides an indicator of the activity in your inventory. Specifically, this is measured by dividing the total value of stores issued to maintenance over a year by the value of the stores held in inventory at the end of that year. Anything over 2.0 is good. If turnover is low, you are carrying too much inventory or the wrong inventory and tying up working capital. Correcting this is not a materials management problem alone—it requires collaboration between maintenance and materials, as described in Chapter 5.

- *Stores stock-outs*. The percentage of inventory requests filled on request indicates what you are stocking and the service level provided for the investment. Ninety-nine percent is often considered top-quartile performance but may also indicate overstocking. A more practical target for stock-outs is 95%. It is important to remember that many stocked items[11] have little impact on safety, environmental or operational performance, and it does not matter much if they are unavailable. Aim to achieve the highest levels for the most critical spares. Note, too, that it is better to err on the side of caution here. While holding excessive levels of stock on hand is costly, it is probably less costly than the opportunity cost associated with equipment downtime if those parts are unavailable when needed. Organizations with a lot of breakdown maintenance often have high levels of inventory to help them reduce time to repair. If they have high levels of downtime, they often have excessive stock-outs, which result in long repair times. Trying to reduce inventory in these cases, without addressing the work management and reliability problems that are leading to excessive breakdowns, will only exacerbate the problem.

For the greatest value, tailor your process performance measurements and evaluate your results based on the unique circumstances of your situation. For example, if cost overruns and poor equipment performance are the effects, what are their root causes? The answer could be excessive overtime, but the reasons for this can vary. It could be anything from emergencies that resulted from poor PM compliance to quality problems arising from a lack of trade skills training or other causes.

Customers can also provide valuable insight into your maintenance performance. In a large Toronto hospital, nursing staff (the customer) were generally happy with the work that maintenance was doing but very unhappy because they never got feedback about when their requests would see action. It was important for them to know when things would be done. Once the hospital maintenance department centralized its dispatching system and started communicating estimated dates for the work to be completed, the concerns all but disappeared.

Response time can also be an issue for your customers, who typically want to know that you are taking care of their needs—they want the confidence that you will solve the problem in a timely manner. Response time is affected by the organizational structure (centrally dispatched versus area-based crews, for example). A big stumbling block for maintenance departments that are highly reactive to customer demands is the difficulty of getting the right parts from the warehouse. The lack of planning in these environments makes it very difficult to provide an inventory that matches demand, but another problem is the lack of equipment reliability—that must also be addressed.

BENCHMARKING MAINTENANCE

Benchmarking is a tool with which an organization compares its internal performance to external standards and then acts to close whatever gaps exist. The objective is to achieve and sustain best-in-class performance through continuous improvements.

Contrary to popular belief, benchmarking is not just appraising how your performance compares to that of direct competitors or others. Rather, it is looking behind those measures to the practices that produce them and learning what you can from them. It is about understanding which measures and practices are critical to your success; finding out who performs best, regardless of industry sector; and then learning how they do it so that you can emulate their performance.

Consider the case of one mining company that wanted to benchmark its truck engine overhaul practice. It first looked at critical success factors and concluded that the most important of these were reliability (having long periods between failures) and shop cycle time (reducing the size of the queue and, therefore, the capital cost).

Then maintenance documented its own procedures, measured reliability and cycle time and set about looking for benchmarks. The company's sister mines had similar practices and poorer results. The direct competitors were not much better. Some of the other mining operations in different commodities were improving reliability, but this was being done through expensive, contracted overhauls by the original equipment manufacturer.

Finally, the mining company discovered an engine rebuild shop with a flawless reputation for reliability. Using just-in-time manufacturing techniques, the shop ran with remarkable cycle times and short queues. Although it was an airline's jet engine rebuild shop, its planning, scheduling, execution and control procedures were directly applicable to those at the mine; after all, both were overhauling engines.

High reliability and short downtime produced higher mechanical availability that translated directly into higher fleet production availability. That meant that fewer trucks could provide the same level of production support. Some trucks could be parked and their maintenance costs reduced. When it became time to replace the fleet, the company was able to replace it with fewer trucks and saved themselves millions in capital costs.

As the mining company discovered, looking beyond your own limitations can provide substantial benefits. They learned from a successful company in an entirely different industry that happened to be doing what was essentially the same thing, albeit to different engines. It is not enough to improve just incrementally from your past performance or that of other company divisions. To compete globally, look everywhere you can to find and learn new methods. Becoming a student of the best, particularly of the best in unrelated business sectors, can be valuable. The basic approach to benchmarking is as follows:

- Know your own operation, both its strengths and its weaknesses. This may require some form of assessment to identify the areas you want to improve. Simply asking your employees where they see a need for improvements may be enough. As described in Chapter 1, they probably have lots of ideas and are just waiting for you to ask.
- Understand the key success factors that drive you to high performance. These are usually beyond your control but may require your response. The better you respond, the higher your performance. For example, customer demand for rapid response and problem solving on the first visit can drive your efforts to achieve excellent work management practices and high skill levels in your maintenance service delivery staff.
- Know those industries and companies that excel at the maintenance processes used in your operation, including competitors, industry-sector leaders and others from different industries with similar success factors.
- Compare your measured performance with theirs and learn how they are performing better than you. Pay attention not only to what they are doing but also to how they got there. It is almost certain that they encountered problems and resistance along the way. You can benefit from the lessons they learned through the transition process.

- Set realistic but challenging targets. Incorporate the successful practices with appropriate consideration for the changes you are imposing on your organization. Remember that what works well in one circumstance may not translate into yours, at least not as an exact copy.
- Measure results and strive continually for superior performance. Best can always become better.

A European microelectronics company manufacturing computer chips for calculators set what seemed an unattainable goal—doubling a production line's reliability (MTBF) from 24 hours to 48 hours within 1 year. The process could tolerate a few extended production shutdowns but not frequent interruptions, as there were quality losses both at shutdown and at startup. Availability, or the duration of shutdowns, was less significant than how often they occurred, or the reliability factor.

The company thought it faced a tall order—its equipment capability was to be doubled. But when it benchmarked similar process lines in Japan, it found that reliability there (MTBF) was at 200 hours! The original goal of 48 hours suddenly became irrelevant. Even if the goal were achieved, the company would not attain parity, let alone competitive advantage!

Benchmark what is critically important to customers: the value chain that affects the organization's success. In all cases, remember that the benchmarking process is exhaustive and that the improvement plan at the end of it will cost significant time, effort and resources. Benchmarking maintenance makes sense only if it will bring real gains to the company. Moreover, do not make the mistake of thinking that benchmark performance data are readily available in the public domain—they are not. Benchmarking data are usually acquired at great expense through commissioned studies, benchmarking projects, extensive visits and interviews. Those who have gone through the pain of gathering benchmarking data seldom want to give it away to others. Above all, do not benchmark with the expectation that simply measuring performance will cause it to improve—it will not. Having realistic targets will help drive performance, but achievement requires training, guidance, new equipment, change management and potentially a host of other things that you will discover through the benchmarking results. None but the simplest of changes is free. The following are examples of productive benchmark activities and processes for maintenance:

Strategic

- Creating and fostering a service or a partnering attitude toward production
- Creating and implementing strategic improvement plans
- Contractor service-level monitoring and performance management
- Measuring and managing performance of the maintenance function

Management

- Training needs analysis and program development for maintenance
- Organizational structures and management techniques
- Incentive programs
- Individual and team performance management
- Encouraging participation in continuous-improvement activities

Systems

- Computerized maintenance management system (CMMS) selection and implementation
- Encouraging use of the CMMS at all levels
- Getting value from the CMMS once it is installed and working
- Elimination of duplicate and ad hoc management systems
- Keeping users abreast of system upgrades and changes
- Maintaining maintenance and engineering technical documentation
- Reviewing new technology and deciding which to choose

Choose the businesses you want to benchmark with, keeping several factors in mind. The required information must be available, and the benchmarking partners you choose must be willing to share it. Benchmarking for information that is already available in published annual reports or on websites will not be especially valuable, nor should you ask someone for something you can find without their help. Determine whether you can glean enough from others' innovations to help your competitive position and whether they will even let you look. A great deal of up-front research is helpful to ensure you get the greatest value from your benchmarking efforts. Internal divisions and sister companies are easy benchmarking partners because accessing their data is simple, but it is unlikely that you will find many new, innovative processes unless the sister company or division you choose also happens to be a world leader.

Information from direct competitors will be difficult to come by—legally. Most countries have antitrust and competition-avoidance laws to prevent the sharing of information that could impact its markets, but industry-sector leaders and businesses in other industries who have mastered specific processes can make excellent models. Across-the-board comparisons with these companies may not be relevant, but they can inspire you to quantum leaps in selected processes. (Remember the mining company that reached new heights following an airline's model of reliability.)

As interesting as the quantitative comparisons will be, the most important part of the benchmarking process is putting the information to use. It can become a driving force behind your plan to improve maintenance continuously. You can use it to help your firm achieve a shared vision of excellence based on the proven successes of others. Several companies and associations have accomplished just that. E. I. Du Pont de Nemours & Co., for example, has been benchmarking maintenance performance since 1987. The company investigates maintenance practices of competing companies in the petrochemical field as well as in industries in other sectors. Du Pont believes that benchmarking sharpens its focus for improvement and quantifies its goals. Maintenance management in the company has been elevated to the importance it deserves. Benchmarking has found the following:

- Japan and Europe use substantially more contractors than the United States.
- Japan spends less to maintain its investment, and its productivity is higher.
- Japanese companies have less stores investment with higher turnover than European and US companies.

The General Motors Advanced Engineering group is another example of a company committed to benchmarking and has conducted a maintenance benchmarking study in several industries, including assembly, distribution, manufacturing, processing and consulting/academic. The objective was to determine both the average as well as the world-class measures for key parameters. Some of the more interesting findings of this study were the following:

- More than half of all maintenance performed by those surveyed was reactive. Eighteen percent was considered an acceptable reactive maintenance level for world-class organizations.

- PM averaged about one-third of the effort, with world-class levels at just under 50% of all activities.
- Predictive maintenance—using machine condition data to warn of impending failure and identify defective parts—averaged only 13% of the total. Perceived world class was 35% predictive activities, representing another major gap from actual performance to a vision of the world's best.

The International Iron and Steel Institute (IISI) produced another interesting benchmark study involving 17 of its members. It concluded that maintenance in steel industries is the third-highest cost item after raw materials and labor, representing between 8% and 15% of steelworks sales and between 13% and 25% of liquid steel costs. Key recommendations to reduce these costs and improve effectiveness, based on successful practices found in the study, were as follows:

- Apply CMMSs to control and analyze all aspects of performance.
- Ensure full and active participation of maintenance people in the design, selection and installation of new equipment.
- Set higher maintenance standards for all work.
- Institute comprehensive condition-based monitoring and analysis.
- Employ a well-trained, multiskilled workforce, following systematic planning and control of work.
- And considering the advancements in technology since this report it is also important to ensure a continuous training program so that maintainers remain current.

An early Coopers and Lybrand study of the hydroelectric-generating industry in North America provided benchmark statistics based on 30 utilities. Like the IISI study, it averaged results and subtracted 1 standard deviation for the benchmark. Among the top five utilities, the average for each parameter shows the following:

- Maintenance costs of $1500 per megawatt of installed capacity each year (in the year of the study)
- Generation availability of 95%, with forced outage at 2% and planned outage at 3%
- Emergency work at less than 3%, with preventive work at over 60%

A leading eastern Canadian forest-products company participated in a maintenance benchmark study that was commissioned by a smaller pulp and paper company (not a direct competitor) and discovered that among the various participants, overall productivity was the best at one of its own mills. Previous internal comparisons contradicted this finding, and the company commissioned an internal benchmarking study to determine what practices were driving its top performers and then disseminate this information to all its mills and improve overall company performance. In the process, the company discovered several key characteristics that were driving success, and the findings were shared with each company mill. Nearly 18 years later, the company still consistently leads the forest-products industry in productivity and profitability.

Fluor Daniel (Humphries 1998), a large maintenance outsource service provider to hundreds of plants, carried out its own study of maintenance performance among 148 top-quartile companies. Published in 1998, the study examined various measures and provided a range of benchmark performance for each of them. Although the study does not explain how the top performers got where they are, it is very helpful in providing realistic targets for performance among a variety of industries. Table 6.1 shows some of those measures. Refer to the original article for definitions of the terminology used to avoid misinterpreting the various measures.

In 2005, Reliabilityweb.com and Genesis Solutions completed a year-long, online benchmarking survey of over 800 companies. Based on Terry Wireman's book, *Benchmarking Best Practices in Maintenance Management* (Wireman 2004), it shows strengths and weaknesses in maintenance practices in 16 different areas. While the survey does not elaborate on what to do or how to do it, it is an excellent place to start to see just where you are in comparison with hundreds of other companies.

More recently, the Society of Maintenance and Reliability Professionals (SMRP) in the United States published a number of performance metric definitions associated with its five pillars of success as described in their "Body of Knowledge." Each metric includes a definition, how to calculate it and best-in-class benchmark figures (targets). These are available to all SMRP members at a nominal cost.

What all of these illustrate is that benchmarking produces impressive results and has generated a great deal of information on what and how to improve as well as what to expect in terms of results. Apply it and you can achieve performance breakthroughs.

TABLE 6.1

Selected Performance Benchmarks

	Quartile			
Benchmark	**Bottom**	**Third**	**Second**	**Top**
Results Metrics				
OSHA injuries per 200,000 hours	>5.5	5.5–3.1	3.0–1.0	<1.0
Stores/replacement value percentage	>1.3	1.3–0.8	0.7–3	<3
Maintenance/total sales percentage	~8	8–~7	6–~3	~3
Maintenance cost/replacement percentage				
Discrete	>5.0	5.0–3.2	3.2–2.0	>2.0
Batch process	>3.5	3.5–3.2	3.2–2.4	<2.4
Chemical, refining, power (continuous)	>4.8	4.8–3.0	3.0–2.5	<2.5
Availability				
Discrete	<78	78–84	85–91	>91
Batch process	<72	72–80	81–90	>90
Chemical, refining, power (continuous)	<85	85–90	91–95	>95
Overall equipment effectiveness	Not measurable	<48	48–78	>78
Process Metrics				
Mechanic wrench time	<31	31–41	42–52	>52
Percentage planned work	>65	66–78	79–94	>95
Request compliance percentage	<68	68–77	78–90	>90
Schedule compliance percentage	<15	16–35	36–70	>70
Work order discipline percentage	<54	55–83	84–95	>95
PM percentage by operations	0	0.9	10–24	>25
Replacement value ($M) per mechanic	<3.2	3.2–5.0	5.0–7.5	>7.5
Suggestions per mechanic per year	Not measurable	~0.5	0.5–4	
Stores turnover	<0.5	0.5–0.7	0.7–1.2	>1.2
Stores service level	<93	93–96	97–99	>99
Contractor cost percentage	<8	8–19	20–40	>40
Stores issues/total material percentage	>82	82–68	67–20	<19

(*Continued*)

TABLE 6.1 (CONTINUED)

Selected Performance Benchmarks

Benchmark	Quartile Bottom	Third	Second	Top
Training and Staff Ratios				
Span of control	<9	9–17	18–40	>40
Mechanics per effective planner	<25	25–59	60–80	>80
Replacement value ($M) per maintenance and reliability engineer	<50	50–200	200–250	>250
Mechanics per plant worker percentage	>32	32–21	20–10	<10
Total craft designations	>7	7–6	5–3	2
Training hours per mechanic	>80	80–70	69–40	<40
Training cost per mechanic	>3000	3000–1800	1800–500	<500

BALANCED SCORECARDS

Kaplan and Norton's balanced scorecard (Kaplan and Norton 1992) was compiled from a study of 12 companies at the leading edge of performance measurement. The balanced scorecard contained a set of measures to give top managers a quick but comprehensive view of their respective businesses. The measures are in the areas of financial performance (how do we look to the shareholders?), customer satisfaction (how do our customers see us?), internal process performance (what do we choose to excel at?) and innovation and improvement (can we continue to improve and create value?). The scorecard prevents information overload for the managers by providing only a few truly meaningful key measures.

The advantages of the scorecard are that it brings together measures from seemingly disparate aspects of a company into one coherent picture. Balancing the measures against each other safeguards against suboptimization in any one area.

The original balanced scorecard was devised for use by an entire company, not just a single department. Each department, however, can also have its own scorecard that feeds the numbers at the higher levels all the way up the corporate ladder. Ideally, the entire company is using the technique, but even individual departments, including maintenance, can use it to their advantage. To build such a cascading hierarchy of measures, you can use the Hoshin Kanri technique for strategy deployment, as described in Chapter 1. Each activity that arises in the Hoshin Kanri strategy deployment process has both progress and performance measures so that change and performance can be monitored during execution. Given the multidisciplinary nature of the Hoshin Kanri process, the resultant measures are inherently balanced among the disciplines.

For maintenance, the scorecard is applied to the four dimensions: financial, customer satisfaction, internal processes and human (employee) development. The financial dimension focuses on productivity and costs. Customer satisfaction focuses on the concerns of customers: reliability, availability, response time and resolution time. Internal processes look at your work and MRO materials management process measures (how efficient you are) and your reliability results (how effective you are). The human development (improvement) dimension looks at internal processes such as the application of formal methods to improve equipment reliability and availability and proactive maintenance coverage as well as development of employee skills, knowledge and proven abilities. Figure 6.1 shows an example of a balanced scorecard for maintenance.

Targets for the performance measures are set using benchmarks or realistic internal goals. Those targets are set so that achieving any one of them does not result in a drop in performance elsewhere. For example, MRO inventory cannot be allowed to drop to zero, or there will be no parts available for emergency work, so there is a balance

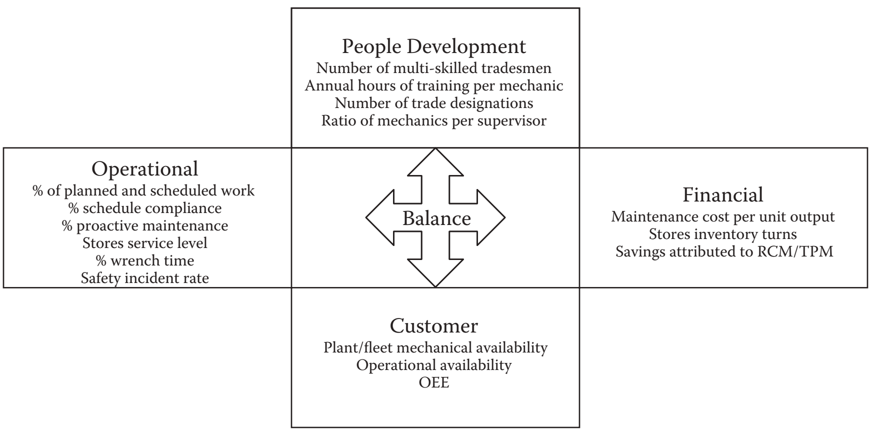


FIGURE 6.1
Maintenance scorecard.

between inventory turns (a financial measure) and stores service level (a performance measure). The percentage of proactive maintenance is also unlikely to reach 100% due to its high incremental cost beyond some point of diminishing returns that pushes the maintenance cost per unit of output up. The key to success with balanced scorecards is to maintain balance.

One approach for doing this is to make all the groups that can impact or be impacted by any particular measure responsible for its result. For example, maintenance has a huge influence on inventory success measures through the effectiveness of its planning. Make maintenance a partner in responsibility for stores measures. Likewise, parts availability has a big impact on times to repair, so make stores partially responsible for measures of repair time improvement. Maintenance cannot execute its PM program effectively if production refuses to allow access to equipment for its execution. Make operations responsible, in part, for PM program success. As a balance to that, make maintenance responsible, in part, for production utilization of physical assets. They must be available in order to be utilized. These sorts of shared metrics are intended to generate a team mentality and collaboration. Ideally, to gain the greatest results, you should not only make people responsible and accountable but also reward them based on the results they get jointly.

Tom Peters said, "What gets measured gets done." Take this premise a step further, and you will recognize that what gets benchmarked, measured, optimized and executed gets done best.

UPTIME SUMMARY

If you are going to manage effectively and influence behavior to achieve higher performance, an essential tool is the measurement and use of key performance indicators. Performance management is another critical element for maintenance management. Costs are important, results are important and so are the processes you use to turn costs into results. Keep that input, process and output model in mind. While you may want high reliability (and output) at low cost (an input), you can only get there by improving the processes that turn that money into results. Performance management is central to seeing problems and managing those processes in order to deliver greater cost-effectiveness. Striving for low cost alone is a dangerous game to play.

Good maintenance is about sustaining performance, not repairing what is already broken. When you are experiencing fewer breakdowns and repairs, it is a sign that maintenance management is doing well. It is not a signal to cut proactive maintenance costs. That proactive spending is entirely discretionary but absolutely essential to the results you most likely want to achieve.

Being effective in managing maintenance performance entails management of a number of measures that tell you about the work management process, materials management, training tradespeople, reliability improvement efforts and so on. What you measure, how you measure and how often you measure are all important. Having realistic process performance metrics and targets for performance helps, but beware of the gaming that gets done to make things look good. Measuring the wrong things, fudging the numbers and twisting definitions of what is measured all to meet arbitrary performance goals are all ways of fooling yourself into thinking you are doing better than you really are. Using the wrong or only single measures can result in unexpected and often wrong behaviors that generate sometimes surprising and very negative results. Never rely on any single measure taken in isolation.

Benchmarking has its place in helping you set realistic and achievable performance targets as well as learning about the practices that high performers use to achieve their performance. When talking about benchmarks, make it clear whether you are talking about numbers and targets or good practices. A number of widely used numeric benchmark standards are available for use if all you want is hard targets. You do not need an expensive benchmarking project to set targets. Benchmarking visits to see how others work are very helpful. If you do not have the budget for those extensive studies, though, you can always fall back on experienced consultants who have been around and seen both good and bad practices.

Balanced scorecards provide an approach to tracking performance measures so that you achieve a balance between (or among) competing priorities. Trade-offs are inevitable, and a classic example of this is the trade-off between inventory cost reduction and maintenance service levels. Watching a balanced set of measures that also considers the *uptime* outputs empowers you to make informed decisions that optimize performance in all areas to achieve the desired business output.

Hoshin Kanri was introduced earlier as a mechanism for strategy deployment. In addition to defining projects and activities and assigning responsibilities, it also produces an array of key performance indicators that are used to mark both progress (of your improvements) and the results you generate.

Performance indicators are an important link that ties the results you get from the processes you manage to the strategic goals you are working toward, both within maintenance and asset management and at the corporate levels.

ENDNOTES

1. Quoted in "Tom Peters Revisited: What Gets Measured Gets Done," *Office Solutions*, April 28, 1986. See also Thomas J. Peters and Robert H. Waterman Jr., *In Search of Excellence* (New York: Harper & Row, 1982), and Tom Peters and Nancy Austin, *A Passion for Excellence* (New York: Warner Books, 1985).
2. Fortunately, many management accountants see maintenance costs as an investment but correctly recognize that maintainers who are often focused exclusively on technical details do not generally manage that investment very well.
3. There are commonly used measures of availability: mechanical availability and production availability. Mechanical availability accounts for downtime due to maintenance action (repairs, etc.), whereas production availability accounts for all of the downtime, including time to shut down, cool down, isolate, recommission and ramp up to full production. Mechanical availability is usually greater than production availability, but its use can lead to arguments with production people who are more interested in how much utility they get from their assets.
4. Some prefer to consider only unplanned downtime and ignore downtime that is planned. The underlying assumption is that planned downtime is needed. However, planned downtime is only needed if it can be shown as necessary or if there is no need for the additional production (e.g., you need only two out of three possible shifts). Also, the duration of the planned downtime can usually be improved through planning, work management practices and benchmarking. When speaking of downtime, be sure to specify what you are including in your definition.
5. In a strictly mathematical sense, reliability is a probability that the asset will perform its mission over a fixed interval of time under given operating conditions. We commonly use MTBF (or its inverse—the failure rate) as a more intuitive measure of reliability.
6. Cycle time is the time required to produce a product or service. Ideal cycle time can be determined through benchmarking or by using historical measures of the best production performance in the organization. Cycle times can also be replaced by production rates or rate of delivery of a service.
7. Often, this is simply the total product produced minus the quantity of rejected output.
8. OEE is widely used in applications of total productive maintenance (TPM). World-class levels of OEE are on the order of 85%, but beware of making comparisons, particularly between different manufacturing processes and product lines.
9. Many of the performance benchmarks shown are taken from "Best-in-Class Maintenance Benchmarks" by James B. Humphries, published in *Iron and Steel Engineer*, October 1998. The numbers used here are a compilation of top-quartile figures for companies that were all considered top quartile in their industries. The numbers are not industry specific unless stated.
10. *Proactive* refers to preventive, predictive and failure-finding work. See Chapter 8 for further explanation.
11. One estimate puts the figure at 60%.

7

Management and Support Systems for Maintenance

> Before you become too entranced with gorgeous gadgets and mesmerizing video displays, let me remind you that information is not knowledge, knowledge is not wisdom, and wisdom is not foresight. Each grows out of the other, and we need them all.
>
> **Arthur C. Clarke**

Clarke's caution to use computerized systems only as an enabler of improved decisions on business processes strikes at the heart of the role that software plays in maintenance management. Information and communication technology systems are valuable tools that handle time-consuming tasks so we can use the time for other activities that add greater value for our companies.

There are many automated systems that are useful in maintenance—perhaps even too many for some of us. The dizzying array of available choices makes it difficult to determine which will provide the most benefit to our businesses. The first part of this chapter describes various support systems that have the greatest potential to produce a substantial return on investment (ROI) quickly. These tools and systems can help make managing the maintenance function much easier and more efficient, freeing up valuable time and revealing developing failures that can be handled before they result in complete loss of function. The last part of the chapter is about computerized maintenance management systems (CMMSs)[1] in their various guises. These are packaged software tools designed specifically to support the maintenance business process. Some of these systems are quite simple, others are very complex and prices vary accordingly. If they are implemented and used as intended, they help you manage more efficiently and deliver results. Whether simple or complex, these management systems are enablers. They are neither complete solutions to management problems nor are they a substitute for people or processes. Their greatest value is that they provide complementary support.

SYSTEMS ARE NOT REPLACEMENTS FOR STRATEGY

Successful software utilization is extremely reliant on the work environment and other plant issues that go far past the purpose of the system. In fact, software is not meant to be a replacement for strategy, but rather a part of a broader management framework in which informed decisions can be made. Senior management routinely requires that a ROI be created before they fund the software project. However, whether through the selection of inadequate software, poor implementation or poorly articulated goals, software projects rarely deliver the anticipated return (Figure 7.1).

In a recent CMMS survey, 50% of those surveyed did not consider the ROI, while 28% reported that their CMMS implementation failed to generate the anticipated ROI. Only 22% characterized their CMMS implementation as successful. Some encouragement can be taken by the fact that so many companies did not use the ROI method in their CMMS selection and implementation. It indicates that they recognize the system as only an enabler of the work processes and not a revenue generator. On its own, software cannot deliver ROI—it must work in support

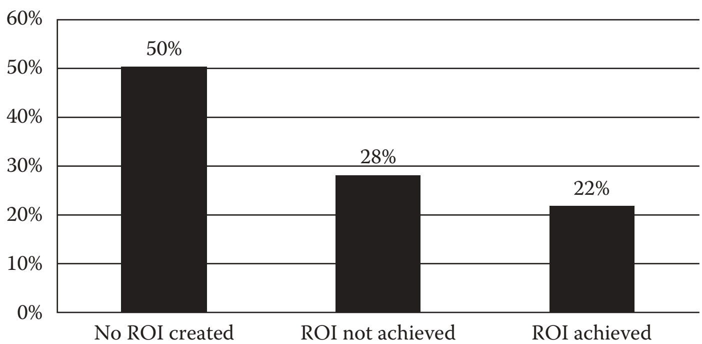


FIGURE 7.1
Return on investment. (From Thomas, Steve and Terrence O'Hanlon, "CMMS Best Practices Study," *Asset Management White Paper Series*, 2011.)

of a decision framework and processes. The whole "management system" (which includes use of the software) is what delivers the ROI.

WHAT MANAGEMENT SYSTEMS SHOULD DO

Document Management

An electronic document management system uses a computer system and software to organize, edit and distribute documents to facilitate workflow. For asset-intensive companies that may have thousands of asset-related documents, document management enables a ROI in the document management process by reducing the time it takes to find, manage and update these documents.

There are a variety of things that document management software can support, including the ability to convert paper and electronic documents to PDF format for easy distribution and collaboration. They normally offer document version control and integrate with popular word processing and email programs, feature security and access control to protect sensitive documents from unauthorized viewing (Figure 7.2).

CMMSs typically do not provide the level of sophistication and control needed to manage documents effectively, although with time this will likely change. For the present, stand-alone document management

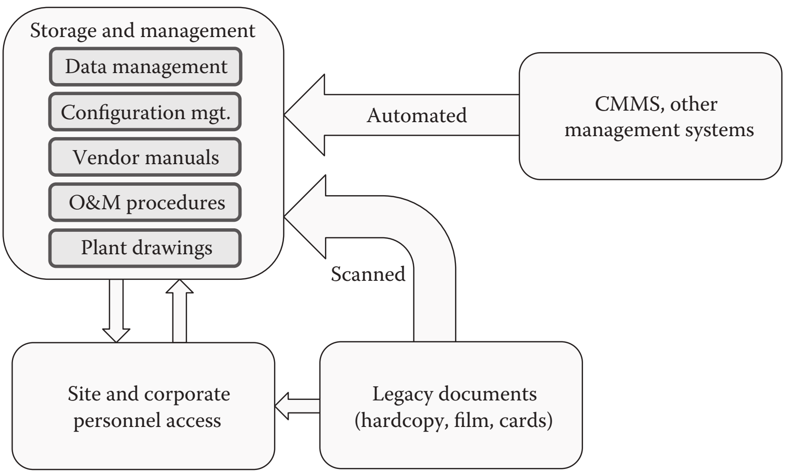


FIGURE 7.2
Document management system.

systems are necessary; however, it is important that the software integrates and communicates with your company's CMMS. Doing so assures that relevant drawings, contracts, maintenance schedules, testing reports and other documents are linked to the assets in the CMMS for easy retrieval.

Workflow Management

Regardless of the industry, a significant portion of the workday is spent coordinating and exchanging information between departments and locations through computer searches, email and Excel, as well as meetings and telephone usage. As this is a part of everybody's workday, the costs involved are hidden with no value being added while money and energy are being wasted in large quantities as a result.

A workflow management system takes over most of the information sharing and coordination, making sure the right task gets to the right person at the right time. Simply put, a workflow management system is software that helps to define, administer and coordinate different business processes. This allows personnel to focus on their core jobs, eliminating the need to track down or locating missing or improperly routed documents and authorizations.

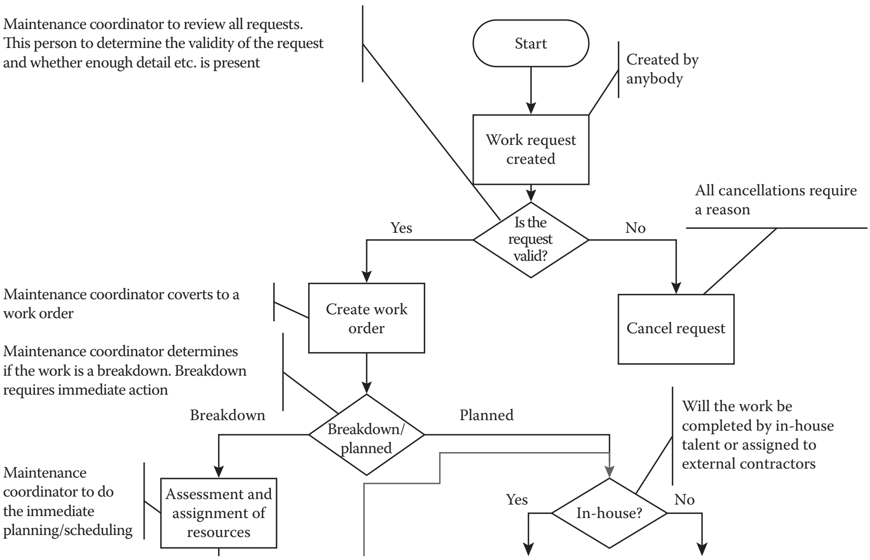


FIGURE 7.3
Sample work request approval workflow.

As shown in Figure 7.3, a typical workflow will route work orders to the appropriate approver depending on the work status, type and responsible department. Rules can be also set for special cases such as requesting the next level of authorization if the job cost exceeds a predefined level or for approvals of emergency work.

Records Management

An electronic records management system is a record-keeping software that retains the contextual aspect of records and their interrelationships. It serves as a storehouse for the safeguarding of, and access to, meaningful business records throughout their lifecycle. These records can be both electronic and hardcopy.

ISO 15489 defines records management as the field of management responsible for the efficient and systematic control of the creation, receipt, maintenance, use and disposition of records, including the processes for capturing and maintaining evidence of and information about business activities and transactions in the form of records.

The key word in this definition is "evidence." A record is evidence that a particular event occurred within the company. Operating licenses, employment forms and insurance policies are all evidence that a business event has taken place. Strict adherence to records management policies assure that, for example, regulatory compliance can be proven with an audit-trail of completed inspections back to a particular point in time.

The major requirements for record management software are the ability to create and manage unique record identifiers, prevent unauthorized changes through the use of encryption or digital signatures and create an audit trail of changes made over the lifetime of the document.

Reporting

Companies generate reports daily on a multitude of events such as shift activities, production losses, material costs and equipment failure. While each individual report has specific event information, as a whole they contain significant amounts of information in common. Through a reporting system, a company can create a document template into which data from different sources are merged for on-demand automatic output generation. Significant time savings are realized by having information pertinent to a

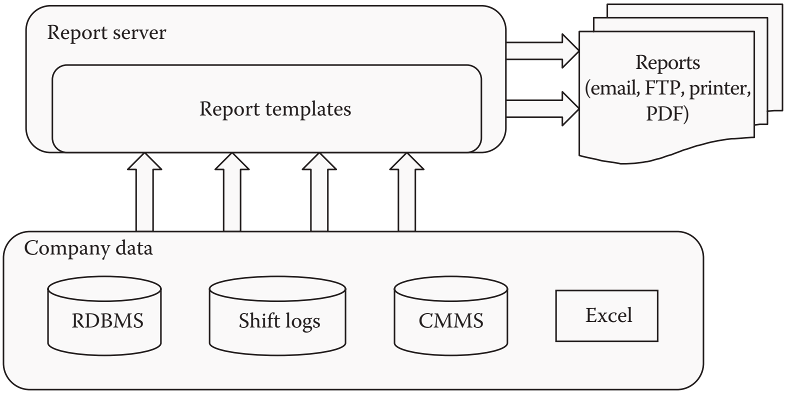


FIGURE 7.4
Reporting system.

job function in a single, automatically generated report instead of trying to manually cross-correlate data across multiple documents (Figure 7.4).

A good reporting system should support the following basic functions:

- *Connectivity*. The system should be capable of connecting to a wide variety of data sources and should also support connectivity to multiple sources simultaneously.
- *Report building*. The report design interface should be well organized, flexible and easy to learn how to use.
- *Templates*. How the report looks is important for readability. A system that supports multiple report formats (i.e., Word, charts, graphs, etc.) is preferable.
- *Output Format*. Support output to your company's standards and be able to choose from a variety of formats such as DOCX, RTF and HTML or printed.
- *Integration*. Integrating reports into existing applications should be straightforward and simple to set up.

DIFFERENT TYPES OF MANAGEMENT SYSTEMS

CMMS versus EAM versus ERP

The number and complexity of equipment systems managed by a typical maintenance engineer is awesome. When you consider the number of assets in a typical plant and the resources used to maintain it (i.e., parts and supplies, the various specialist skills and the effort required to predict, prevent and repair problems), it is incredible that anyone can keep it all straight. But to make the most efficient use of all these resources, that is precisely what you must do. You must know, for example, what is in use and what is not; what and who is available for work; which spares, tools, test equipment and consumable items are available (or not); what skill sets are available; what work has an established work plan; the schedule for PM and other required work; and many other things. You must also be able to coordinate and integrate this knowledge. This all dictates the use of some sort of information management system.

The sheer volume of maintenance information can be staggering. An international airport facility in the Far East, for example, with 7000 equipment systems and 20,000 stock-keeping units (SKUs) in maintenance stores, generates 100,000 work orders each year. At an electrical appliance manufacturing plant with 2000 pieces of equipment and 30,000 store SKUs, 150,000 work orders (110,000 of them "urgent") are filed annually. A Canadian public transit fleet generates 250,000 work orders or service requests for 950 vehicles. It controls 25,000 store SKUs and has 415 tradespeople and a direct maintenance cost of over \$100,000,000 per year. A large integrated mining and metals operation in Asia has over 800 maintenance employees, another 800 contractors at any given time, 9000 pieces of equipment, 5000 planned component change-outs annually and a budget of over \$80,000,000 per year for maintenance, and does nearly 50% of its work on an urgent basis. The number of data transactions for these businesses easily exceeds 1 million per month. It would be impossible to handle this volume manually, and this is the primary reason that CMMSs have been almost universally adopted.

In addition to managing prodigious amounts of data, these systems also help us to categorize the data and do analysis of the data. The statistical techniques used by CMMSs facilitate decisions about reordering stock, which orders go to which vendor, who is available at what times for work to be done, what equipment is available for work, which work order to do first, which equipment is falling below its reliability targets, which equipment is still under warranty, which standard job plan to use and when to write a work order for condition-triggered corrective maintenance work (i.e., condition-based maintenance).

Most businesses today have some sort of CMMSs, and the trend, especially in medium- to large-size enterprises, is to use the maintenance modules that come with the corporate enterprise resource planning (ERP) or enterprise asset management (EAM) system. Some companies have developed their own systems in-house, but most have chosen one of the hundreds of commercially available packages. Unless you have a passion for computer programming and your knowledge of maintenance management can rival that of the leaders in the CMMS industry, developing your own system is not something that is likely to pay for itself. Interfacing home-grown software with any vendor-supported software (e.g., purchasing or inventory management) will lead to an unending stream of modifications to your software just to keep up with vendor-supplied upgrades and revision changes. Some companies have opted for home-grown collections of spreadsheets and databases to serve their maintenance needs, but they rarely, if ever, interface with each other. Those collections of systems do not make information retrieval and data mining easy, and the challenge of keeping it all straight can result in errors and omissions.

Integrated computer systems and information technology (IT) are very much a part of our lives today. Much of today's workforce grew up in the age of IT. The Internet is virtually everywhere and computers are common in homes and even via wireless devices that can be used anywhere today. Navigation through most software packages is highly intuitive, making it easy for casual users to find their way around.

IT grows rapidly. In 1965, Gordon Moore observed the exponential growth in the number of transistors per integrated circuit. He predicted that this trend would continue, and his prediction of capacity doubling every 18 months became known as "Moore's law." It is an observation that is still in force today. Intel, the world's largest maker of computer chips, predicts that the trend will continue at least to the end of this decade. The growth and evolution in IT are phenomenal. It has led to dramatic changes in the capabilities and availability of software tools to support maintenance.

If your CMMS is more than 3 years old, it might benefit your company to take a look at what is currently available. The market for CMMSs has changed dramatically over the past 10 years, and the number of vendors supplying these specialized systems is still in the hundreds. The capabilities of these systems can range from little more than work-order tracking for a small job shop to multisite enterprise management of the entire maintenance and inventory process spread across continents. The more capable maintenance systems are now referred to as EAM systems. The growing popularity of these important business systems was not missed by the makers of ERP software. Originally the ERP systems looked after materials requirements mostly for production purposes. Later ERP systems included a much greater array of functionality, including maintenance. Some ERP companies bought out the smaller EAM companies and integrated the two products. Financial management systems were often the backbone of these ERP and EAM systems: some were transformed into wholly integrated suites of software and some became a patchwork of different systems "integrated" together to work in a more or less seamless fashion. Today, ERP vendors often target the chief financial officer (CFO) of their customers' companies in making their sales. Their products quite logically serve financial data collection and reporting needs first. The addition of any sort of maintenance capability is usually done to make the package more broadly applicable and to enhance its appeal in the marketplace. Some of these systems evolved to meet the needs of specific industries like mining, utilities, military or pulp and paper. Their built-in processes continue to serve those industries well and have been adapted to meet the needs of other industries. Over time, some financial systems companies gobbled up ERP and EAM companies, integrating their products.

Over the past 10 to 15 years, many software companies were spun off, acquired or merged. There was a great deal of fear associated with the reliability of IT systems as we approached the year 2000. That fear foreshadowed what was to come. The IT markets crashed, the "dot com" bubble burst and what remained was the "dot com bomb." Now, more than a decade later, the dust has more or less settled. Many of the players from the early 2000s have not survived. Many new players have appeared. The IT markets remain no place for the faint of heart, and the evolution continues with only a few dominant players left in the ERP market and the number of serious EAM and CMMS players much depleted. This state of affairs, while it has somewhat narrowed the number of choices, has not made system selection much easier. Moreover, system implementation is just as challenging as ever.

It has been well documented that up to 70% of ERP systems implementations fail to achieve their stated goals, and reports of the use of only 20% to 30% system functionality are quite common. In all fairness, today's systems are designed for clients in many varied industries, so there is a lot of functionality that is specific to each industry built-in and not intended for use by all. In larger companies today, a common refrain is that maintenance demands are not being met by the systems that are installed. That complaint has not changed much in the past two decades. Today we find that many of those complaining are in companies where they have one of the larger, fully integrated ERP systems. Complaints that the systems are "user hostile," too complicated or programmed with unfamiliar terminology are common. With few exceptions, those systems began "life" as either financial or materials requirements planning systems and grew to include maintenance almost as an afterthought. The maintenance modules are often designed around that financial or other functionality, system architecture and data structure rather than around the need to manage the maintenance process.

Smaller companies are more likely to be using an array of specialized systems rather than the larger (and more expensive) integrated packages. They are the companies that make up the bulk of the still vibrant CMMS market. In these smaller companies, there is often a high degree of satisfaction with the CMMSs—they use most of the system capabilities and are generally pleased with the results. These systems are often called "best of breed" for a reason. The two most important CMMS features commonly found in companies that have had success with these systems are ease of adapting to maintenance processes and user-friendly navigation. With these two features, the systems get used.

The larger and more "functionally rich" systems tend to compromise in the area of user friendliness. They are usually more challenging to implement and to learn. For both reasons, they are often underutilized and are referred to as being "user hostile." Companies that have invested in these systems often alienate the maintenance employees who these systems are intended to help. Even younger maintainers, children of the computer era, find these systems cumbersome and frustrating. The companies that manufacture and sell these systems are aware of this (even if they deny it) and are working hard to correct the deficiencies. In some cases, the damage to their reputation has already been done; in others, technology meant to make work easier has made it more chaotic. The author and his colleagues have visited several facilities that have purchased and are using a CMMS, unaware that their global ERP systems have the same capability. Fortunately, there are many specialty software companies that develop tools for integrating user-friendly applications with corporate ERP systems and for extending their functionality in ways that the ERP cannot support on its own. Looking into these products requires some time and effort, but the payoff is well worth it when your users come on side and begin to use your systems as intended.

What appears to be happening in the major ERP and EAM systems is a trend toward exercising ever tighter control over transactions and, by extension, over the actions of those who make the transactions. This trend was reflected in a quote used in an advertisement for American Express that appeared in the magazine *Chief Executive* in June 2005: "I control the path of every dollar at my company. I control spending differently for each employee. I control all the Cards, and I can do it online. Control is a power thing." There is an inherent problem with this kind of thinking. People do not like to be controlled and they do not like feeling that others have "power" over them. Attempting to control people and their behavior actually stifles creativity and initiative. This control syndrome is a legacy of the industrial age that has persistently refused to disappear. If anything it is enhanced in any area where finance and accounting are involved. Those disciplines today are bound by strict rules and regulations brought about in the wake of very high profile scandals. Their response to those rules has had far-reaching and often stifling effects in other areas of the business—maintenance among them. Chapter 2 discusses "self-organizing teams" and the benefits they can bring to a business. If the management systems available to these teams do not work compatibly with people, potential benefits are minimal and difficult to achieve.

The smaller CMMSs have limited functionality so they do not attempt to control everything. They usually offer a great deal of user-friendly flexibility. That gives more control to the users and because of that they are more empowering—it is small wonder they are very popular. Smaller organizations do things less formally, usually more simply and with a greater degree of human interaction than is typical in larger organizations. They can do this because smaller is also more human and therefore more natural. Moving away from this toward bigger, more integrated and more electronic is going against the grain.

Companies that have bought into the thinking of bigger, better and more integrated with the underlying motive of gaining tighter control over things risk discovering that this may be detrimental in the long run. Instead of using guiding principles, these companies are imposing a system of rules, and the rules are being broken. Control can become a game, and people will find myriad ways to circumvent controlling rules that do not work, are unduly restrictive or get in the way of getting the job done. Computer system rules are often very tight and unbending. If they do not serve an immediate purpose, however, people find ways around them. Those companies that appear to have well thought out business processes supported by an array of IT systems often compound the problem with workarounds.[2] When the workers who put the workarounds in place leave, the processes grind to a halt. Maintainers just want to do their job and to do it well. They do not want to spend a lot of time navigating their way through a complex, user-hostile computer environment. When they are looking for parts or materials, the last thing they want to do is wade through endless screens of information and fill-in-the-blanks.

So what do these systems really do for us? The complete list of functionality of these systems is too extensive to include here, and this is especially true of the many “nice to have” features that do not always serve a needed practical purpose. It is important, however, to provide a list of basic functions a good system should provide and what it should do:

- Keep track of physical assets using the asset register, parts, materials master files, vendors and manufacturers and their contact information.
- Automate parts of the work and materials management processes to save time, improve the productivity of planners and schedulers, help coordinate maintenance activities and integrate parts ordering with supply chain management systems. This often eliminates a great deal of paper documentation.
- Collect and manage large volumes of transaction data, such as work orders, purchase orders, repairs, parts usage, equipment condition-monitoring results and reliability statistics.
- Carry out calculations such as currency conversion; determine total pricing on materials orders, labor, parts and contract cost allocations to various accounts; convert failure history record data into reliability statistics; and aid in defining work schedules.
- Manage the movement of data among corporate information systems like finance, accounting, purchasing, human resources, time tracking and asset tracking.
- Manage large volumes of supporting information, such as drawings, technical manuals, standard job plans, parts specifications, machinery specifications and tradespersons’ skills. This capability is becoming more and more important.
- Generate reports on work done, work outstanding, backlogs, parts usage, repair costs, labor utilization, equipment condition and reliability statistics.
- Extract data for special purposes, including reliability analysis and improvement efforts.

There are many more capabilities, but most of them will fall within these few broad categories. All of these capabilities are intended to help companies save time and effort overall. In large, integrated systems, the degree of interconnectivity among business functions, business units and processes is high. Often that means that seemingly simple transactions appear more complex at the point of data entry. Less capable systems do not exhibit that front-end complexity because they do not support it as well at the back end. They appear to be user-friendly and are often helpful to those working at the point of entry, including maintainers and stores people.

Large, complex systems are based around financial integrity, whereas the CMMS is focused on equipment and work management. Unless the financial systems and CMMSs are integrated, the cost data collected in the CMMSs will usually vary from that contained in the financial systems and that can lead to confusion. However, the CMMS uses terminology that is familiar to maintainers, whereas the financially based systems tend to use unfamiliar financial terminology. Although CMMSs are weak in back-end number crunching capability, the trade-off is that they are actually used by front-end staff.

CMMS Overview

At the heart of maintenance execution is the management of work and materials. Chapters 3 through 5 addressed various ways to enhance maintenance and materials management. Figure 7.5 shows an overview of what a CMMS could cover in maintenance with a link to materials, and Figure 7.6 shows materials processes linked to maintenance. Maintenance software manages a series of transactions all tied to work orders. Those transactions are linked to maintenance, repair and operations (MRO) materials transactions through those same work orders. There are numerous detailed links between the various subprocesses that are not shown in these two figures, for example, the links between planning a job and ordering stores material for issue against its work order. Maintenance and materials management processes must be designed with these links in mind before a computer system is configured. This process design and definition is one of the first and most important steps in implementing these support systems. Once configured, the computer program lays out the entire cycle, beginning with the requirements and ending with an analysis or purchasing and inventory control. The complete maintenance plan is addressed, from identifying what work is to be done to analyzing the completed work.

Maintenance and materials processes converge in the plant and equipment configuration, in the bill of materials and in the common requirement to provide reports. In its simplest form, the CMMS

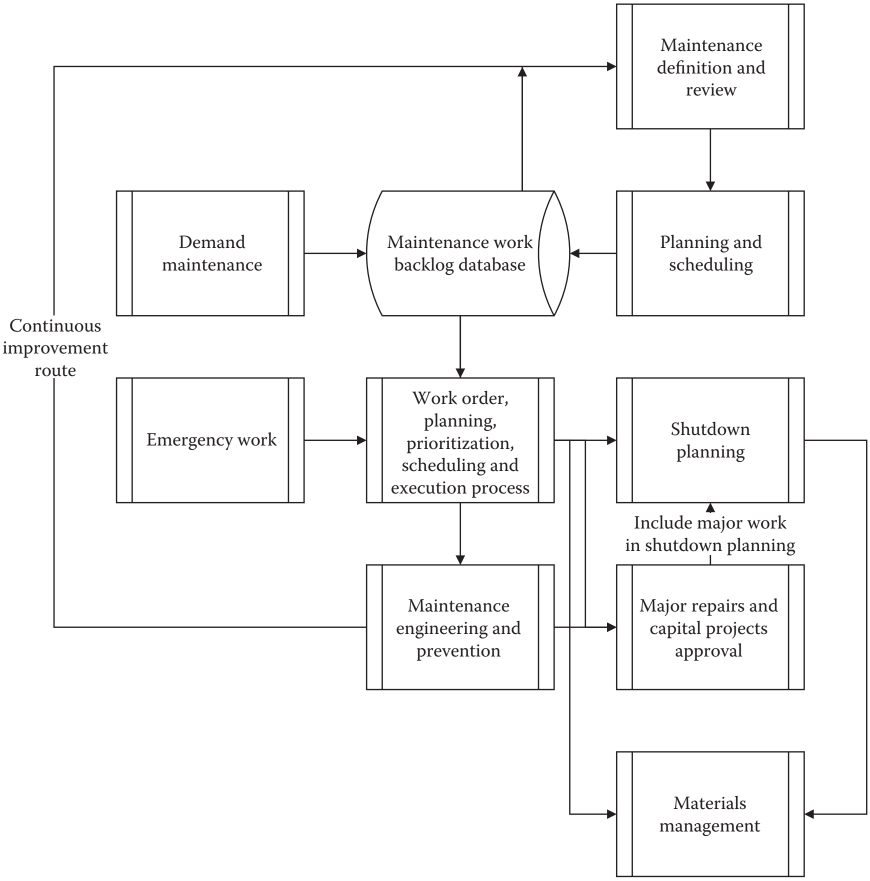


FIGURE 7.5
Maintenance linked to materials process.

automates the various subprocesses and the flows of information within and among them.

The CMMS of today may run on a computer network that uses mainframe computers or networks of desktop machines interconnected on an intranet or via the Internet, using either hard wiring or wireless network connections. Many of these systems can now be accessed from anywhere at any time over any secure Internet connection via handheld devices. The busy maintenance manager can now check up on things at work even while away from the office.

The CMMS is usually divided into modules of related functions, which operate the various data management and analysis activities. Following is a brief description of eight of the more common modules and what they

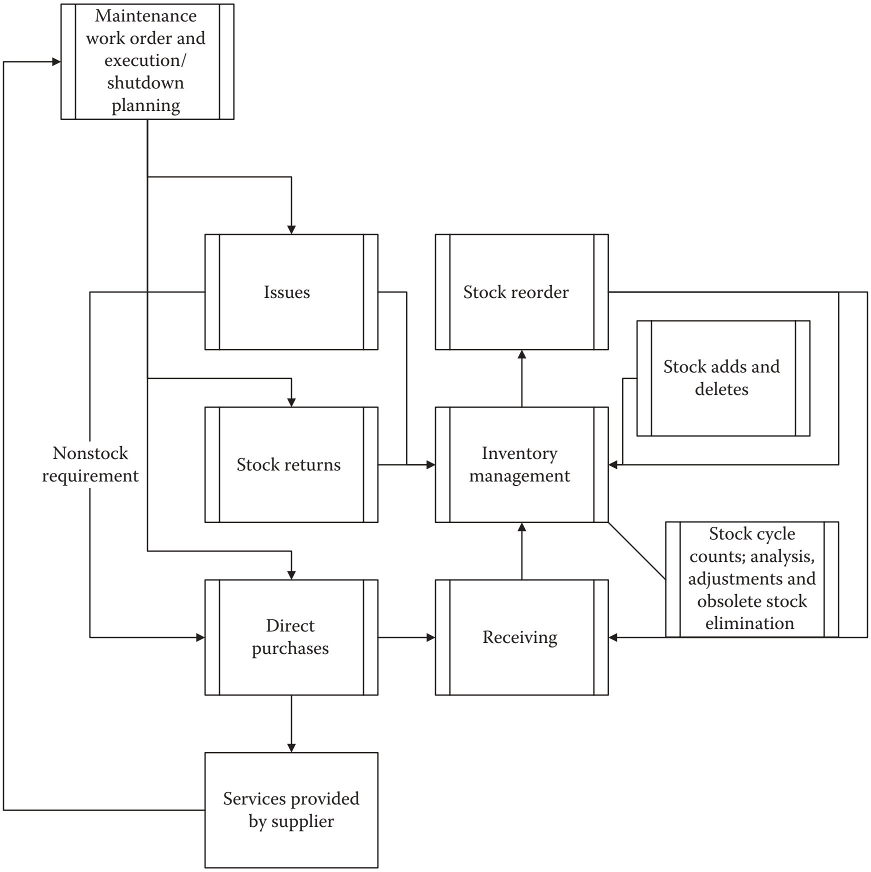


FIGURE 7.6
Materials linked to maintenance process.

do (see Figure 7.7). These modules are used to manage various maintenance and materials processes (like those shown in Figures 7.5 and 7.6), but the modules do not necessarily match the process headings because they usually have more than one process function.

- *Equipment identification*. This is usually one of the first modules to be set up and used. All the equipment covered by the CMMS is logged in with "nameplate" data. Then, the assemblies, components and parts that make up the equipment are identified and linked according to hierarchy or relationship.
- *Preventive maintenance (PM)*. This is a critical module that helps establish the schedule for all proactive and regularly scheduled work.

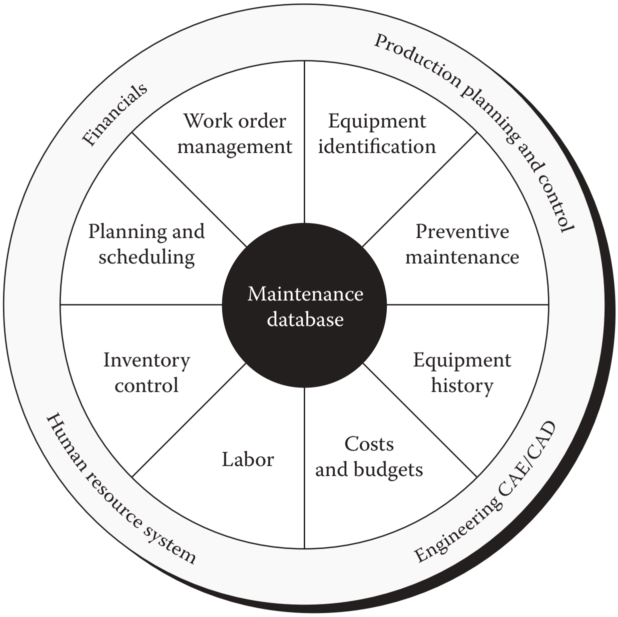


FIGURE 7.7
Key CMMS modules.

It describes required tasks and materials, allocates costs and helps maintain schedules, often automatically generating work orders for execution.

- *Equipment history.* Key functions of this module are to keep histories of overhauls, repairs, costs, labor, downtime and utilization and to track failure causes and special events in the equipment life cycle.
- *Costs and budgets.* Most packages are able to accumulate projected and actual costs in multiple cost centers for labor, materials, services and allocated overheads.
- *Labor.* This module keeps an inventory of individuals, their skills, vacation schedules, training history, availability and utilization to enable accurate work order and project scheduling as well as backlog control.
- *Inventory control.* Available with most packages, this manages the stores inventory. Many businesses use their accounting or production control software to do this job, often on a separate computer. Today's integrated software packages usually manage inventory for maintenance as well as production and office supplies together. The

function of this software is to track inventory on hand as well as use, costs and allocation of inventory items used. It usually integrates with the company purchasing software, although some systems contain a purchasing module as well.

- *Planning and scheduling.* This develops task times, resources required to do the work and schedules for all types of maintenance work, whether preventive or corrective.
- *Work order management.* This manages the process of opening a new order, estimating its cost, tracking its status and ranking it according to priority.

Depending on how sophisticated your package is, many more functions are possible, especially if it is part of a suite of other business system applications. Today, with the growth of asset management as a discipline (see Chapters 11 and 12), integration with engineering systems, specialized document management systems, and asset investment planning tools is growing.

Management via the Web

Companies that want to avoid the IT support costs of running their CMMSs on a corporate network now have the option of using vendor-hosted solutions over the Internet. Software as a Service (SaaS) is a subscription-based service model where, for a small monthly fee, the subscriber can access his or her secured hosted data using a desktop computer, tablet, smartphone or laptop. All the subscriber needs is a web browser and an Internet connection.

SaaS is considered a component of cloud computing and is not a new concept. Introduced back in the 1960s, it was referred to as "time-sharing" and later as "hosted." It was not until the great recession of 2009 when IT departments were having their budgets slashed and old concerns about data security began to subside that cloud computing became an attractive alternative, helping to streamline costs while maintaining a satisfactory level of service.

Reduced total cost of ownership is the primary driver to adapting SaaS. There are no software licenses or annual maintenance fees, which can be substantial for the larger on-premises applications. The SaaS provider is totally responsible for infrastructure, software, hardware, data backup and data security.

SaaS is relatively fast to implement because the vendor has already installed and tested the software, and because SaaS is scalable, as the company grows, additional users can be added with little time and effort.

Despite its many benefits, there are some potential concerns that may hold companies back from adapting SaaS. These include the following:

- *Data security* is a top concern for many companies. Trusting sensitive data to a third party and storing them on the web require addressing issues of access management and control. Of course, one must ask, "Are most maintenance data really all that sensitive?"
- *Integration.* Connecting a company's on-premises applications to a cloud application can be very complicated because of dissimilar data storage methods and the need to send data over the Internet. Fortunately, there are integration service companies that will assist with the integration of on-premises and SaaS applications.
- *Regulatory compliance.* Regulatory data protection requirements have to be met and SaaS providers have different methods to address it. Since those providers are specialists in what they do, their capabilities in this realm may even be superior to those of their customers.
- *Internet connection* speed and connectivity issues can slow down the business processes especially when compared to corporate network speeds. This is still a big concern especially in more remote or less-developed locations.

SaaS delivers a high level of flexibility while lowering the total cost of ownership for companies while addressing many concerns very well. It may be a good solution to explore.

SPECIALIZED SUPPORT SYSTEMS

Condition Monitoring

Condition-based monitoring makes up the lion's share of successful proactive maintenance programs. In equipment, most failure modes give some warning that they have begun and that they are progressing toward a fully failed state. Equipment, systems or process parameters are monitored periodically to detect telltale signs that failure is imminent while watching for normal, warning, alarm and critical readings. The particular warning sign will vary from asset to asset, depending on the failure mode. For example, deterioration of lubricant properties will warn of pending bearing and sliding contact failures and increased temperatures reveal that insulation is breaking down. Watching those lube properties and temperature trends, maintenance can see emerging problems and take timely and appropriate action. Many conditions can be monitored with human senses—touch, smell, sight and sound, but these are not the most consistent of monitoring devices. What you consider abnormal may sound quite normal to someone else. To get around this weakness, maintenance relies on a vast array of condition-monitoring tools.

There are various parameters to watch for in the physical (particle, dynamic and visual), chemical, electrical and thermal realms. Appendix 4 of John Moubray's book, *Reliability-Centered Maintenance II*, contains a comprehensive listing of the various techniques that can be monitored. Most of these have corresponding monitoring devices, such as

- Vibration analyzers monitoring displacement, velocity and/or acceleration to produce overall (broadband) readings, whole vibration spectra, etc.
- Spike energy and shock pulse monitors for very high frequency vibrations
- Ultrasonic and acoustic monitors to detect high-frequency sound waves in air or metals
- Ferrography to detect metal wear particles
- Pore-blockage monitors to detect wear particles
- Light extinction and light scattering particle counters
- Ferromagnetic sensors (chip detectors) for large particles in oil
- Spectroscopes to detect wear metals
- X-rays to observe cracks and other physical defects
- Gas chromatographs to detect gases released from deterioration of insulating oils
- Electron microscopes to detect microfractures or cracks
- Exhaust emission analyzers for engine performance and fuel economy
- Chemical titration to look for deterioration of lubricants and fluids
- Dye penetrants to detect surface cracks
- Magnetic particle crack detectors for surface and subsurface cracks
- Borescopes for visual inspection inside equipment

- Strain gauges to monitor creep and strain under load
- Viscosity monitors to determine lubricant properties
- Infrared scanners to detect temperature gradients
- Meggers to monitor resistance in electrical circuits and insulation
- And many, many more

Many of these devices come with software for recording and analyzing the signals. They help the user interpret what is being observed so that diagnosis of problems is more accurate. The data they collect can be used in fault diagnosis and in decision making about what maintenance intervention is appropriate and when. Data for future use can be stored either within the software provided (e.g., vibration data stored in software provided for their analysis) or separately. Sometimes, but not often, they are stored in the CMMS, more often in a data warehouse or historian system. Regardless of where they are stored, the data should be readily available to planners and reliability engineers for later use. Understanding the ways that the data can and will be used is very important and helps determine what data to store as well as how and where to store them. In many instances, data are collected and stored without regard to their future use or usefulness. If you do not know what you want to do with them, then why collect them? Adding technology for the sake of technology adds little value and can create a technology management nightmare for your engineers and IT professionals. For data to be a valuable corporate asset, they must be used.

Condition-monitoring devices and the systems that work with them have become big business because of their huge potential to prevent or reduce unexpected downtime and its costs. Understand what is available and how it will benefit your company before you jump into acquiring more and more technology. Make sure your investment in technology fits your strategic goals as well as your immediate technical requirements.

Portable Computers and Handheld Devices

The hardware and software tools that work with the various condition-monitoring devices are often portable so that they can be used in the field for immediate diagnosis of problems. Portable computers as well as dedicated field devices are now commonplace in most large companies. These tools can be used in place of paper work orders and to record condition-monitoring data. Some of them are wireless, for instance, cell phones and personal digital assistants that help you keep up with CMMS changes. Others contain memory chips for uploading and downloading data at the beginning and end of a shift. All of these eliminate paperwork and minimize errors because data are only entered once. Bar code scanners for work order and parts data and data-logging devices that take condition readings also improve accuracy.

Decision Support Tools

In addition to the software used with condition-monitoring devices, there is an array of software that manages data storage, analyzes the data and performs reliability analyses that facilitate decisions about equipment or component replacement and inspections. Reliability analysis makes extensive use of statistical modeling techniques, many of which are impractical to perform without a computer. For example, maintenance planners can use software tools like Reliasoft's Weibull++, Dr. Nick Hastings' RELCODE, Dr. Jardine's OREST and others to conduct Weibull[3] analysis quite easily on a computer. Dr. Jardine's PERDEC and AGE/CON, Omdec's EXAKT, Fulton Findings SuperSMITH and others offer other useful reliability and economic models.

One excellent decision support tool, EXAKT, takes failure history data, condition-monitoring data, cost data and various economic criteria into account before giving a "go" or "no go" response about continued operation of equipment that is being monitored. By correlating past functional and potential failures with condition-monitoring data, it can determine which signals give the best indications of pending failure and observe when those signals are indicating problems. This tool has helped companies to extend the mean time between equipment removals by quantifying, managing and reducing uncertainty so that the best[4] decisions may be made over the long run. It improves on the human judgment and helps maintainers predict more accurately the remaining useful life of the asset before it fails.

Equipment and component replacement decisions require an analysis of historical failure data and economic data. These analyses determine the age at which life-cycle costs are minimized by considering variable usage rates, depreciation and resale values and how they decline with age, inflation and discount rates, as well as asset replacement costs. Excellent software tools exist to facilitate this investigative process as well as forecasting of future financing needs for capital investment budgets.

Various mathematical models support spare parts analysis to determine initial spare inventory levels and parts distribution. These models take either item- or system-based approaches, the latter being more complicated but far more valuable for planners attempting to squeeze high availability of spares to support critical maintenance work from limited budgets.

Other expert systems help operators and maintainers make decisions that would normally require the input of experts or consultants. These systems try to replicate a human expert and include intelligent reasoning engines. A good example is Solvatio, an automated fault diagnostic tool used to detect and diagnose problems in running equipment. Customized for each application, this tool guides the user during the search for the problem and its cause, takes corrective measures and then updates the knowledge database. This updating function is the way the system "learns" from its expert human operators. It is an indication of the future direction of related software industry.

Other leading software packages were designed to be integrated with a proprietary CMMS using preprogrammed warning, alarm and shutdown levels to trigger messages and work orders when condition-monitoring readings exceed predetermined levels. This is an "expert system" in the simplest sense. Maintenance planners receiving these notices know almost as quickly as the process operators when something is going wrong and can respond quickly to help keep equipment running at the warning and alarm stages—before you get to a shutdown situation.

Integrating condition-based monitoring data with fault diagnostic and prognostic tools are areas of current research and significant development effort. These systems are not yet widespread, but that is changing. You can expect to see them used as commonly as the CMMS is today. As is often the case, the most successful companies will adapt and deploy these new technologies as soon as possible to gain competitive advantage.

IMPLEMENTATION CONSIDERATIONS

CMMS Implementation

Like any sophisticated business computer system, the CMMS cannot be simply installed and turned on. Plug-and-play systems are rare and their capabilities are limited. CMMS suppliers are constantly working to develop industry-specific templates, a measure that reduces implementation time and costs, but a great deal of dedicated effort is still required to bring the systems online successfully. The larger and more complex the system is, the longer you can expect it to take to implement successfully.

It is this area of implementation that leads to many of the failures noted earlier. Rarely are failures of these systems related to inappropriate matching of computer software requirements to supporting hardware infrastructure. The software vendors and your own IT professionals work hard to ensure that does not happen. More often than not, the failures occur in the implementation process.

A key to success in implementing a CMMS is to consider maintenance, inventory and supply chain processes together. Even if inventory management and supply chain have been worked on already, they will need to integrate as seamlessly as possible with maintenance planning and scheduling processes to ensure the efficient management of maintenance resources. Considering only one or two of these critical processes is almost certain to result in messy results and unhappy users.

Implementation refers to the process of configuring the bare-bones system that you buy from a vendor to meet your specific requirements. It is a setup and tailoring process and the outcome is a custom product that, if properly configured, is right for your business. However, you are probably not an expert in setting up these systems, after all, if you are in a capital-intensive industry, producing something other than software. A good way to start an extensive exercise regimen is to get help from a personal trainer. Software is similar. Get expert help from an implementation consultant, someone who does this for a living. This individual can guide you through the configuration process and help you make the configuration choices that are best suited to your specific needs.

The implementation process has remained relatively constant despite the dramatic changes in IT and in the systems themselves. It always begins with the desire to have a system to support your business processes. Because most companies already have a system in place, the real issue is looking at the benefits to be derived from changing what you have to some newer version or to an entirely different system. If you are considering a system that is geared only to maintenance and materials, Table 7.1 provides some practical guidelines.

Once you know your objectives, you can begin to find a system that will help you meet them. Be aware that no system can meet all of your

TABLE 7.1

Sample CMMS Objectives

Overall Goal	Objective	Business Requirement	System Requirement
Increase capacity	Improve availability, reliability and maintainability	Reduce failures Reduce stoppages Increase speed	Support analysis of equipment history and reliability Manage equipment data Keep skill profiles Keep bills of material Support creation and scheduling of PM routines
		Reduce variance Reduce rework	Monitor machine variance from desired performance Monitor work order status and identify rework
		Performance monitoring	Track cost and performance data on equipment Track cost and performance data on work management process
Reduce costs	Reduce overall maintenance costs	Reduce labor	Enable work and control Enable planning of labor and materials
		Reduce inventory holding	Analyze inventory usage Analyze inventory investment
		Reduce emergency work	Support PM scheduling Support reliability data analysis
		Reduce paperwork	Automate work orders Automate purchase orders
		Performance monitoring	Track costs by area, job, type of expense, labor

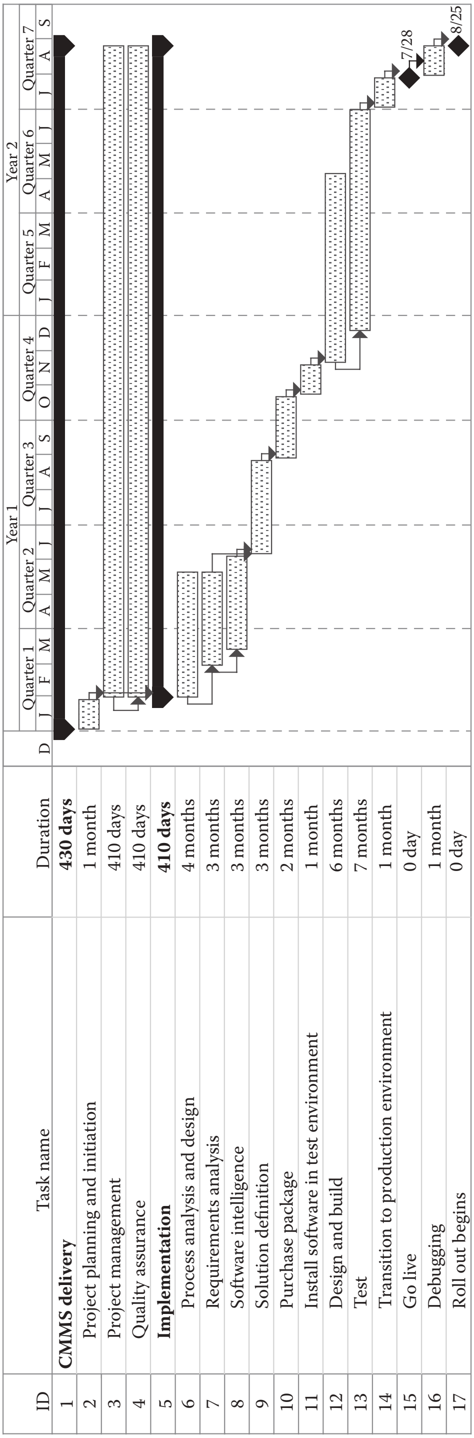
objectives on its own. It must be supported by sound business processes and be operated by motivated people using those processes. If you are implementing a CMMS for the first time, it is especially important to understand that you are not just buying “a tool”—this particular tool can support and streamline your business processes and serve as an excellent catalyst for implementing a wide range of changes in the way you do maintenance management. You are well advised to think beyond the tool itself and fully appreciate its power to enable many other functions and operations. Consider redesigning your business processes as the most important part of the system implementation project; otherwise, you may find that you are only making your old and possibly ineffective processes faster. It is also beneficial to consider including the support or "maintenance" packages offered by the suppliers of your software to ensure it is updated and remains current. Be cautious however, if you are doing any form of customization (which is NOT recommended), then the updates could destabilize those customized features.

Replacement of an existing system is often driven by obsolescence. Occasionally, a system is replaced because a vendor has gone out of business or no longer supports the older version of its product. Software companies do not support their old products forever. The rapid pace of technology growth in that industry prohibits this; to remain competitive in the business, these companies choose to stay abreast of technology changes. The tide never stops, and if you do not want to be simply swept along, you must keep focused on your objective and needs—maintenance and materials. If not, you may become part of a much larger project, a corporate move to an enterprise-wide ERP system. If this occurs, your objectives will become part of a larger picture, and some of the features you want may be compromised in the name of corporate data integrity and the integration of all business functions.

Regardless of the scale and scope of the changes and the nature of the software you acquire, the implementation process is basically the same. It will follow a methodology like that shown in Figure 7.8. The timeframe associated with implementation may vary, but the figure shows a typical project for a single site. If you have multiple sites to implement, then a roll-out task begins following initial "go live" and debugging. Duration will depend on the approach you take (big bang versus phased) and the complexity and extent of changes at the additional sites.

Following this kind of methodology ensures that the system will be implemented and will match your business requirements. Success hinges on the underlying business processes and how well you manage the transition to the new system. The benefits will not derive from the system itself; they will come from the business process changes you implement and follow. The major steps in the methodology are given as follows.

Process analysis and design. Process design is included here as a first step in any major system implementation project as it is absolutely critical. Your processes should be reviewed, analyzed in detail and redesigned to meet your business needs. This involves mapping all the processes, whether automated or manual. In detail, define what you do in each



ID	Task name	Duration
1	**CMMS delivery**	**430 days**
2	Project planning and initiation	1 month
3	Project management	410 days
4	Quality assurance	410 days
5	**Implementation**	**410 days**
6	Process analysis and design	4 months
7	Requirements analysis	3 months
8	Software intelligence	3 months
9	Solution definition	3 months
10	Purchase package	2 months
11	Install software in test environment	1 month
12	Design and build	6 months
13	Test	7 months
14	Transition to production environment	1 month
15	Go live	0 day
16	Debugging	1 month
17	Roll out begins	0 day

FIGURE 7.8
CMMS delivery methodology.

business process, what information flows are involved and how you want them handled. For example, part of the maintenance work identification process may come from condition-based monitoring. At this point you do not need to worry about how it gets there, just identify that it is needed. It is often argued that process design should be done later, once the system has been selected, to avoid reworking process maps to fit system functionality. Not so. The system should support your processes or some other system should be selected. Of course, it is unlikely that you will find an exact match, so you will search for the best fit. Always remember, however, that your choice should be predicated on what is best suited to your processes—do not attempt to fit your processes into what a system can do. It is also advantageous to learn what system capabilities exist and whether these capabilities can facilitate your process design work. Figure 7.8 shows a lot of overlap between process analysis and design, requirements analysis and software intelligence. Depending on your choice, these three steps become somewhat iterative.

Requirements analysis. This step ensures that your requirements are identified and documented. Ask yourself if this information is to be input directly into the CMMS up front or whether you will accept manual monitoring and analysis. In this step, you are identifying the major capabilities that the system "must have" to meet your business requirements at a high level. There is no point in getting too detailed here. Do not be so specific that you tie the vendor's hands. On the other hand, it is important to make informed decisions. Benchmarking, along with other research into what is available, will help you appreciate what is possible but do not turn this search into a big project—by the time it is done, the technology available will have changed again. The next step is to scout your system, both software (application) and hardware (technology), from among the many products and vendors on the market. If your hardware environment is fixed, then your software choices will be more limited, but not as severely as you might expect.

Solution definition. This phase expands on the process mapping started earlier and takes you into a more detailed definition of what the system will do and how. It moves you from the required modules identified earlier to the specific functions that the software package supports. In the earlier days of CMMSs, these functional specifications resembled laundry lists and were very long and detailed. They often listed very specific technical requirements for each module but omitted information about the module's functions. Today, most available systems have virtually all the same features—they just execute them in different ways. If you give a vendor a long list that describes system features that you want, that list will almost certainly be returned to you with all the boxes ticked "yes"—we have that feature. Why waste your time on that very predictable outcome? Specifications that you send to vendors can be brief. Simply let the vendor know what you want the system to do. You can evaluate vendor submissions on how well it does what you want it to do later when you compare it to your newly redesigned processes.

Select vendor solution. At this point, interfaces with other company systems are defined. Many maintenance CMMS and EAM packages may have already been integrated or at least interfaced with the various major financial systems, but it is best to ask whether this has been done with those systems (and versions) that you have. Find out from those other users whether the systems and integrations work well. Again, there is little value in being overly detailed at this time.

You are now ready to contact suppliers and ask them to submit solutions. Do your own research first and eliminate those systems that do not meet your basic requirements. This reduces the number of vendors bidding for the contract and also reduces your workload in evaluating vendor submissions, which are usually bulky and very detailed and require a thorough review. Providing your newly designed processes to the vendors will enable them to show you just how their systems can meet your requirements.

Vendor pricing can be confusing, so be cautious in your comparisons and make certain you are looking at all the costs. The cost of the licensed "seats" is just the beginning; when you add it all up, the total bill can be two to five times the value of the licenses. Do not forget to factor in costs associated with implementation, user training, future maintenance and upgrades (especially if you expect to have customized integration interfaces), user help desks and 24-h technical support.

Keep in mind that the CMMS sales market, as in all software markets, is highly competitive. Most vendors are reputable and reliable, but some vendors have been known to do just about anything to get your business. Not all vendors do this, but there are a few vendor "stunts" you should watch out for:

- Not "flowing" all of the terms and conditions from your contract down to subcontractors. In one case, an implementation subcontractor used credentials that violated another vendor's confidentiality in a sales situation while in partnership with a different prime contractor.

- Proposing to use staff who are (at the time of proposal) neither part of the supplier's company nor even under contract.
- Subcontracting the consultant who helped you in the requirements definition and specifications phase as the project manager for implementation services with an aim to gaining an inside track.
- Buying their way into the requirements definition and specification process as low-cost (or even free) advisors.
- Presenting a single unified team in the proposal but later using team members from various companies that do not all agree on strategy.

In some cases, the vendors even sabotage themselves. One software vendor, for example, had a team working on requirements definition for a client. The vendor was not excluded from the bidding and was invited to bid on supplying the software. The request for proposal (RFP) had been reworked before it was sent out to bidders. Normally, the previous work would have given the vendor a tremendous advantage over its competitors, but this vendor failed to bid on several required sections of the modified RFP. When asked why, the vendor responded, "Because they were not in scope when we worked on the project." The vendor simply assumed that the customer had accepted the earlier work without question and added or deleted nothing. That was a fatal assumption and another supplier was awarded the contract.

In another case, a client had over a dozen operating sites worldwide, most of them using a particular vendor's software. As part of a global transformation project, the entire company was switching to a single, globally integrated software platform. The vendor that the client had worked with previously was one of the few contenders capable of delivering a desired solution and was asked to submit a proposal. The vendor knew that they had very limited field of competition; they put little effort into the proposal and it was appalling. It failed to respond to major RFP issues and did a rather poor job responding to other concerns. In that case, that vendor had just been taken over by another software company (something that happens frequently in the software industry), and the client, who was hoping to save money by integrating the new software with software already deployed, gave the vendor a second chance. The second proposal was no better than the first and, once again, another supplier's proposal was accepted. The vendor had incorrectly assumed that the client, who was already using the company's software, would make a choice based on prior association. The company failed to appreciate that although its software was installed in most of the client company's global sites, the versions installed at these sites were not conducive to integration, a major objective for the client.

A final note on vendor solutions is to separate the contract for external support from any contract for implementation support services. Some companies prohibit the consultants who help them select their systems from even bidding on the implementation services. This helps to keep the playing field more even in a competitive landscape.

Design and build. Once you have selected and purchased your system, you can begin the implementation process by customizing the package to fit your operation. There is no point customizing a new system to suit old processes that fail to take advantage of the new system's full capability. If not already done, the first step is to review, analyze and redesign your processes. Even if you did a thorough job on your processes earlier in the acquisition process, you may still need to review them for compatibility with the chosen system's capabilities. The process review should consider using successful new practices and changing or eliminating inefficient or ineffective practices. Integrate your maintenance, inventory and supply chain management processes. Failure to do this can create a great deal of angst if new systems do not deliver on their promised results. This phase of the project provides a wonderful opportunity to get your business processes right, efficient and fully integrated with each other. This process redesign and customization can take anywhere from 3 months to 2 years, depending on system complexity and how much it is integrated with other functions like HR and finance.

Beware of implementation consultant capabilities in guiding you through this process-oriented phase of the project. They should know their software and its capabilities well, but they will not necessarily know your processes. They may have a tendency to steer your decisions to fit the way the system was originally designed to work rather than customize the settings to fit your processes. Watch too for the less experienced consultants who only know the software or only one way to implement it. Again, they can steer things in directions you do not intend by simply doing what they know best.

Do not be surprised by version upgrade during the course of your implementation. New versions of many of these packages appear in 24-month cycles or even more frequently. You will need operation procedures for data conversion, installation and daily use. Do not neglect or scrimp on training. This is probably the single most common cause for implementation failure. When you have all your requirements tailored into an acceptable solution, you can turn the system on for general use, but it is best not to "go live" without testing whether it works.

Test. Make sure that the users (the maintenance and possibly production people), not the systems department or supplier, test the CMMS in the workplace. You want the system to operate under conditions as near to real life as possible. During the testing phase, you will find many of the little bugs and mistakes that filtered into the complex tailoring process. You may also find bugs in the software itself. It is preferable to find these bugs now, in a controlled test environment, than to find them when you have hundreds or thousands of users trying to do their jobs on a system that is just not quite "right." Your operators and maintainers are best able to judge whether the system is covering the ground in maintenance management, user and technical procedures, backup and recovery, security, volume and performance. Let them "play" with it and follow the new processes and procedures with it. Let them try to "break it" with work-around processes and shortcuts. They will find most of the bugs for you, usually quickly, and you can correct them before turning the system loose on the entire company.

Transition. This final phase is important to get your new system up and running without any major kinks. It involves converting data, fully installing the new CMMS and manual procedures and most importantly, handing over responsibility to user management. When your system is ready to "go live," your first task will be to transfer into it "dynamic" information that users will need. This includes any open work orders from the old system, information on open purchase orders and material requisitions, inventory stock levels and other similar information. All information is transferred into the new system at the last moment before you switch it on (often in the middle of the night) so that people do not lose the work they have already done.

If you are doing this across multiple sites, you will probably want to do some tailoring to accommodate minor differences in the way those sites work, test again and go through the "go live" transition at each site. Rarely will two sites work in exactly the same way. Your first site implementation will be the template that can facilitate the process at other sites, but do not assume that each site will be the same. These sites are staffed by people, and this means variables.

Whichever package solutions you eventually purchase, it is a good idea to buy the maintenance contract as well. First, it ensures that your software will remain current with the periodic updates issued. Second, if you become an active participant in the software company's user conferences, you can influence the direction these updates take. If your industry is strongly represented in the customer installed base, updates will likely be geared to your business. The cost of the maintenance option is usually about 10% to 15% of the software cost annually. The key to success in any project, including CMMS implementation, is your people. They must accept and use the new system, so it is best to involve them in the process from the start. Involve them in developing the business case for a new system. Involve them in defining system requirements and selection. Involve them in implementation. The system will be successful if it truly helps them to do their jobs better, makes their jobs a bit easier and helps the company excel. Your people may accept and use an enterprise-wide integrated system that is not user-friendly if it enables them to achieve their personal goals. If it makes their job harder, they will not be supportive; if they use the system at all, they will very likely not use it well.

The "people factor" is an important consideration for evaluating whether a CMMS is a worthwhile investment. But because these systems take a long time to specify, select and implement, other factors must also be considered when weighing the cost/benefit ratio. These are discussed next.

JUSTIFYING YOUR CMMS

Total costs for a CMMS can easily run from tens of thousands into tens of millions of dollars for enterprise systems. If you are buying maintenance as part of a corporate ERP, for example, the cost may be hundreds of millions for the entire ERP. Software costs are typically less than half of the total installed and implemented cost at the lower end of the range and less than 20% of the total cost at the higher end. If you consider the entire cost—customizing, interfacing with other systems, training, implementation effort, communications and the incremental hardware capacity (such as add-on printers, scanners, radio frequency and portable devices)—the costs add up quickly. This does not include the cost of your own staff and the related costs of changes in processes and practices that will be required to make the system work. In the long run, the CMMS can save you money, and it enables data collection in support of efforts to improve asset availability. Nevertheless, a convincing case for improved maintenance productivity and increased asset availability is needed in order to justify this expense.

Maintenance productivity can be defined as output divided by input. Output is measured as equipment availability, operating speed, precision, and reliability. Input is money spent on labor, materials, services and overhead. In and of itself, CMMS will do little to improve your productivity. CMMS, EAM and ERP vendors do not like to admit this because it makes their job of selling systems considerably tougher. Their sales pitches will often refer to huge potential cost savings, productivity gains and ROI. These systems will help you "lock in" process improvements or trigger process improvement initiatives so that you become more productive. If a system does not do either of these, there is no need for it.

Failure rate and duration of downtime, as well as other performance standards, depend greatly on a maintenance program that is properly developed, scheduled and executed. That, in turn, relies on equipment failure histories, records of repairs and overhauls completed, lists of the correct materials and resources used. Much of the data originates in the hands of your tradespersons and technicians. Even with the best systems available, collecting and analyzing the available data is a challenge. Minimizing downtime for inspection, repair and overhaul requires scheduling and coordination of labor and parts. It is not data management that makes this happen; it is people. These people need training; often, they need to change long-established behavior patterns associated with the old processes and ways of working. Both training and behavior modification come at a price.

Despite the cost, effective data management clearly has an impact on maintenance output. Many companies have found that using information management effectively can produce significant results:

- Equipment effectiveness (the product of availability, speed and precision) can jump from 50% to 85%.
- Reliability (mean time between failures) can rise 20%.
- Workforce productivity can increase 20% to 30%.
- Usage of materials can be reduced 20% to 50%.

More efficient use of labor, materials and outside contractors often means savings of 5% to 15% of total maintenance costs. It is always difficult, however, to attribute the savings to any one activity or change. The CMMS is only a tool. It acts as an information framework around which to manage maintenance. Did the savings actually come from inputting data, manipulating information and generating reports? Of course not! Did they arise from developing and implementing a solid PM program that is supported by a module that is now there to be used? Possibly, but this is a moot point. What really matters is that you will not get the savings if all of the work is not done. In justifying the move to a new CMMS, you really should consider all those costs—the software, hardware, implementation effort and time, etc.

Surveys by various software vendors, maintenance periodicals and consultants working in the field show that real benefits are achieved in both increased productivity or production and direct maintenance cost savings, but they come from how you use the system not from the system itself. One intangible benefit is often improved communication between and among operations, materials management and among your tradespeople. Some companies have found it difficult to achieve these benefits without outside help. The example below illustrates what can occur.

A wood products plant was getting nothing from its brand new, state-of-the-art CMMS, which was purchased from one of the most reputable vendors at the time. The company was spending a great deal of effort on implementing the system with no outside help. A top maintenance supervisor was leading the implementation, a job he had never done before. The system was not working right and bills for dial-up technical support were high. There was a root cause for all of these problems—no one at the plant had reviewed the underlying business processes and the new system was merely automating the old ones. The implementation lead (the supervisor) was consciously setting the tool up to support the way it worked so it could be more efficient. He did not even consider that maybe it could work in a different way. The added complexity of the system actually increased the time it was taking to issue work orders and order materials. Retained to improve the situation, the author and his team first had the company shut the system down and start doing everything manually. The underlying premise to this was to discover whether the problems were being caused by the way the work was being done. If it was not being done correctly manually, it would never be done correctly with a computer. This, in fact, proved to be the case. Once flaws in the work process were revealed, the business processes were quickly streamlined and became efficient. An experienced implementation consultant cleaned up the errors that had been made in the earlier tailoring efforts and matched the system tailoring to the new processes. Several weeks were spent on training users who then tested the system. Two months after the system was turned off and the plant went to paper-based process, the reconfigured system went live and this time, it worked. Users were happy; work order and material orders were faster; and records were finally being kept—automatically and efficiently. The informal interpersonal networks that were built up during the period of manual operation created positive working relationships; when glitches turned up, there was always a way to fix them quickly. The company in question got the help it needed, but it paid a price for the long delay in getting things to work smoothly while its people muddled around in unfamiliar territory.

A Case Study in CMMS Implementation: Molson Canada

An interesting case study for CMMS application is Molson's Brewery in Canada. This case study appeared in the original edition of *Uptime* published in 1995 and is updated in this edition to show the development and use of a system based on what is now considered "old" technology. It is an excellent example of how the implementation process works and is still relevant today. It demonstrates that a CMMS can be a long-term investment regardless of technological advances in IT. It also shows the importance of key people in championing and sustaining these investments. Regardless of the technologies being used, the situation described here can be found in many companies today.

The brewing industry in Canada consists of many medium-sized and small plants in each province. Provincial laws stipulate that beer be made in the province where it is sold. Molson has plants in every region, coast to coast, across Canada; many of those plants are fairly small servicing only one (sometimes small and sparsely populated) province in each case.

In the early 1980s, each of Molson's plants had its own local maintenance approach. The plants had time-based PM programs, corrective maintenance for breakdowns and overhauls during scheduled shutdowns. Systems were ad hoc, both manual and automated. In the mid-1980s, the engineering group recognized the potential cost savings and capacity improvement of making three changes in the way in which maintenance was managed. First, fix the process; second, automate it; and third, get leverage by doing it the same way in all Molson plants. Molson developed a systematic approach to work order management, PM development and maintenance store management. The brewery then purchased IBM S36 minicomputers and the ShawWare (MARCAM) maintenance and materials management package. After a blitz of implementation, improvements were achieved in the planning and control of maintenance. With the usual promotions and engineering staff turnover, implementation slowed down before the full integration of the process and systems was completed.

Furthermore, Molson underwent a merger with Carling O'Keefe, the third largest brewery in Canada. The restructuring was comprehensive, with complete integration of operations.

In the early 1990s, it was difficult to get vendor support of the S36s and their application programs, but there was a need in upgrading the software. IBM AS400s replaced the less capable S36s, and the manufacturing, financial and CMMSs were upgraded as well. A network was established linking the largest of the eight regional plants. The CMMS configuration in these plants included 5 AS400 minis, 120 PC/terminals and 30 laser printers, networked across all functions and all locations.

The capital cost for the project totaled over $3.5 million. This included software, hardware, networking, outside help and in-house IT staff. In addition, three user representatives were assigned full time—a champion from maintenance engineering, a storage inventory specialist and a systems application specialist. With this investment, Molson's senior management was looking for quantifiable returns. After the first 2 years (1993–1994) of implementation, improvements in plant performance and cost reductions were excellent, approaching the $3.5 million capital cost. Equipment effectiveness was up, and overtime was down. Maintenance productivity was up at the three largest plants, and stores inventory savings were substantial. Other savings were being realized in purchasing efficiency, reduced overhauls and staff effectiveness.

At the time, the project champion was confident that these savings would grow as the remaining plants took full advantage of the system capabilities. Maintenance costs represented about 16% of operating costs across Molson plants. The overarching vision was to reduce this to 12% over 3 years—the number achieved by their best plant. That was achieved. The project manager believed that the main reasons for this success were supportive management, accountability for results and a true vendor partnership with the software company.

Some 13 years later, the system known internally as MARS was still in operation. Since initial implementation, several of the brewery's plants have been shut down to consolidate production capacity and gain scale efficiency. The system was being used at all five of the remaining plants in Canada. However, because of differences in the degree of implementation at the various locations, only Montreal and Toronto (the largest plants) are really using it for maintenance management. In late 1995, the system administrator function was eliminated. Then, in early 1996, the engineer who had been most responsible for introducing the software at Molson left to pursue other career opportunities. Without a real champion, the software was not as rigorously implemented in the other plants.

The system's original vendor underwent several management and ownership changes over the years and continues to evolve. The company had a form of "Reliability Centered" processing, a graphic user interface (GUI) front-end and other enhancements. In mid-1998, the engineer overseeing MARS decided that Molson should no longer upgrade the application to keep it current with the vendor's ongoing offerings. The company would, however, continue to improve the MARS system in-house. Since that time, numerous minor improvements suggested by users have been implemented. Several of the more significant upgrades were to

- Interface the system with the corporate e-Procurement application
- Implement handheld RF devices in Montreal for stores issues and physical inventory functions
- Develop many ancillary reports and data extracts to assist users' specific requirements
- Implement a capability for importing vendor pricing updates
- Interface with the payroll application to import Montreal maintenance labor costs

One veteran user reported that the company was using four fully implemented MARS modules to their fullest: MRO procurement, inventory control, accounts payable and maintenance management. For reporting and scheduling functions not provided by the software, Molson was using more current stand-alone products.

Although MARS was an old CMMS technology, the Molson plants were using the work order management component at 100% for equipment care. The planning function was being used for work order generation from PMs, customer requests, condition-monitoring[5] alarm acknowledgement and generation of condition-based maintenance work orders, routine repairs and modifications. They were tracking labor, stock and nonstock parts and materials, as well as contracted services by entity in their asset register through a cost-centered link between general ledger accounts and equipment numbers. Scheduling was performed using a feed from the MARS-generated backlog of work orders exported to a separate spreadsheet or project planning software tools to assist in tracking execution. The automated PM capability was being utilized for inspections and minor repairs as well as for tracking inspection history. Approximately 50% of the PMs had a linked material list to stores and equipment nameplate data. Tradespersons' names and work execution dates were being manually entered onto their PM work order records to track both "as found" and "as left" conditions—keys to later reliability analysis.

In addition to implementing the MARS system, Molson set out to improve maintenance work management practices. The company succeeded in moving away from firefighting (i.e., reactive work) to performing more proactive work. The old method of waiting for something to break and then throwing resources at it almost completely disappeared at Molson. The use of more accurate terminology helped to change behavior. The tradespeople, for example, were called "line support" and were delegated to proactive work from a line support resource pool. This paid large dividends in terms of increasing *uptime* for the lines. The company has also introduced a progressive overhaul approach.

Stores inventory was managed using a combination of Max and Min settings, contract vendor supplied items for high turnover consumables and low-cost and high-volume vendor managed items. Stores inventory management in MARS was described by its users as running "like a Swiss watch."

Labor costs were tracked in MARS, although not as accurately as in the separate payroll software system. In the Toronto plant, the link between MARS and payroll was not as complete as that in Montreal.

Accounts payable was centralized across Canada and became a corporate accounting function. The A/P module got an e-commerce link to assist in hands-free invoice payment. As long as there is a work order in the system linked to a purchase order, which is a system-generated electronic purchase requisition, parts and materials receiving records are balanced and A/P ran very smoothly.

Despite its success, MARS eventually became difficult to support as both hardware and software technology continued their relentless advance. It was replaced with a newer technology.

HARDWARE AND SOFTWARE TOOLS: AN OVERVIEW

There are many IT and electronic communication tools that support the maintenance and materials functions. This is a technological arena that is constantly changing and evolving as computer capabilities grow. There is a wealth of information available on this topic on the Internet. Search for maintenance and reliability sites, and you will find more than you could possibly digest and far more than we can include here.

Along with desktop and portable computers, there are now PDAs and smartphones that can track work orders and their status in the field and data-logging devices that collect condition-monitoring readings. Radio-frequency wireless devices are used in storerooms to label parts, read bar codes and transmit stock transaction data, whereas wireless Bluetooth technology transmits continuous streams of condition-monitoring data to centralized collection points like an electronic clipboard. There are tablet PCs for field diagnostic work and various mobile computing and communicating devices for mobile workforce applications. Similar powerful tools are being developed all the time, hardware put together in a variety of configurations to help people with a variety of tasks.

The Importance of Data

All of these software tools rely heavily on accurate input of the right[6] data. Needless to say, if the data going into your systems is inaccurate or incomplete, then the result will confirm the familiar "garbage in–garbage out" adage.

The state of many companies' maintenance data, even those using excellent CMMSs, is often not all that good. One of the biggest obstacles to the effective use of most CMMSs is the lack of accurate data, particularly data about failure history. Many hours of effort can go into "cleansing" the data that are available, and even then there is some uncertainty about its accuracy. This situation is so prevalent that you might want to give serious consideration to converting only basic equipment and parts information to a new electronic database—leave the historical records in the old system and save yourself millions in data conversion costs. Moreover, while condition-monitoring data are readily available, especially with automated collection, the sheer volume of the data can pose storage problems. Data that come from work orders (especially paper ones) are notoriously inaccurate and incomplete.

One company is already tackling this data problem head on. Omdec has created a software tool that is provided with its EXAKT program mentioned above. It used to gather data from CMMS-generated reports to generate an "events table" for use in the software algorithms. The company has done an excellent job of considering numerous and varied data problems currently encountered but only specific to the EXAKT application.

A great deal of work is currently being done by mathematicians and computer programmers in the field of machine learning, such as that done by Solvatio. The approaches they are using include neural networks and support vector machine methods that simulate the human thought and learning processes. Neural networks are computing systems with simple processing elements, a high degree of interconnection among them (just as in the human brain) and simple scalar messages (yes/no) plus adaptive interaction among the elements. These systems learn by adapting as signals propagate through the network based on anticipated results and observed results. Support vector machine methods are mathematical supervised learning methods. A detailed discussion of these is beyond the scope of this book; they are mentioned here to illustrate that this is a very active field of technological advancement in maintenance management.

Advanced decision support tools of this nature require a shift in thinking and in what your employees do with them. For example, a number of CMMSs use reliability centered maintenance (RCM)-like data models based on failure modes and not just work orders. Technicians using the software must be familiar with the structure and language of RCM in order to translate field observations from work orders and CMMS reports into the tool for the analysis. This again underscores the fact that while computer systems make many jobs easier, it is qualified and motivated people that are needed to operate them properly. The key to data problems and solutions is and always has been your people.

WHERE ARE WE HEADED WITH SYSTEMS?

There is a real need in the market that is only now being addressed by the software community. The trade-off between user-friendliness (and hence user acceptance) and the need for a high degree of visibility and control of costs often leads to compromises.

Large integrated systems (ERP systems) offer very high degrees of control and provide for single data entry for multiple uses at just about any scale, but only if they are implemented fully and well. They have evolved to provide a vast scope of functionality serving data processing needs across entire companies. These enterprise systems are truly remarkable in both scope and scale, but they are also very expensive and hard for many to use, even with training. Despite the high cost and the unresolved issues related to using these systems, software companies that sell them and financial people who like the high degree of control they offer view them as the "Holy Grail" of computing.

Small single function or single process systems (for example, dedicated CMMS) do not provide the scale or scope of ERP systems, and integrating them with other single process systems can be quite expensive. Maintaining those integration points can be a challenge—every time either system changes, the custom integration software must be updated too. Just ask anyone who has integrated a major CMMS with a major financial or procurement package. These systems, however, are usually easy to use and are often preferred by shop-floor and operations people, the end users. They are less popular with corporate financial people who prefer greater cross-enterprise cost visibility. The problem is not the CMMS itself; it is often the integration package that adds considerable complexity. Ask yourself if that is really needed. Are we taking integration too far—sacrificing usefulness for an unattainable goal of extreme accuracy. We are counting pennies in multibillion dollar enterprises. Do we need to do that?

For the past decade, the financial concerns have won out in the effort to comply with ever-tighter regulations and reporting requirements for publicly traded companies. Smaller, specialized CMMSs rarely fit well with the ERPs that the financial world prefers, but they still have a place in smaller enterprises. There are fewer and fewer of these smaller systems in the market, and at the same time, it is increasingly clear that the large integrated systems are not serving user needs very well. As a result, some functions of the large systems are not being used at all; single modules are ignored while users work around them by using another system or a combination of systems, even if these are not officially mandated by the company's IT people. Compounding this situation is the growing array of purpose-built and highly specialized decision support tools, monitoring tools and engineering systems discussed earlier in the chapter. They rarely integrate with either the large systems or the smaller ones, yet they depend in part on some of the data that these systems contained. This has led to the development of various "middle-ware" packages, which gather data useful for these tools.

For the moment, neither the large nor the small software companies seem to be inclined to offer a simpler solution to the problems encountered by their customers as they are more or less locked into their perceptions and ideas of what is best for their chosen market. For most vendors of large systems, moving away from those positions is untenable because it threatens their "unique" and expensive solutions and exposes them to greater competition. Companies that produce smaller systems simply do not have the market clout to do anything but go along with this. With only two major choices available, customers are compelled to pick the least of two evils. Going the large, integrated route invariably means adding a number of specialized stand-alone or bolt-on packages; going with a patchwork of smaller functional systems also means additional, stand-alone packages. This guarantees a lot of work for IT people worldwide but does not serve the needs of the user very well. Fortunately, there is a solution that has the potential to work for both users and software companies alike, but it has yet to have significant impact.

A standard for data exchange that covers all business processes and functional areas could define the data elements needed to feed these various systems. MIMOSA[7] is a standard that enables the free exchange of machinery and operations information. Based on Internet protocols, MIMOSA moves the software packages away from older client–server technologies to fully web-architected systems.

Many (but not all) of the CMMS, EAM and ERP solutions provide a familiar Internet browser interface, and some are based on Internet technology even using cloud computing for data storage. However, many still rely on user company-based client–server technology and unique or non-standardized databases. Fully web-architected systems use a common web services standard for full interoperability. Unless they follow an Internet-based standard, the systems will not work on the Internet.

If they can comply with the demands of this Internet-based standard, information software companies will eventually be able to exchange information between and among their systems much more easily. Data warehouses already work on this concept to a certain extent. Because there is no Internet-based standard for data warehouses, they have all created their own. Integration among various client–server systems still requires that each be interfaced to the data warehouse and often requires data conversion from one to the other. There have already been mergers of different data warehouse standards, but, to date, there appears to be no industry-wide collaboration.

With access to fully web-architected systems, a user company will be able to pick whatever software solution it prefers and easily interface with other web-architected systems. Through simple interface, for example, data collected by maintenance will be easily accessed by purchasing, accounting, human resources and others, without expensive and complex data conversions. Similarly, the maintenance system will be able to optimize its various data tables by adding important data extracted from those other systems. The maintenance system will use employee trade skills information from the HR system. Parts usage for any given maintenance work order will be available via the data warehouse and used by the inventory management system. Data required for reliability analysis will be extracted from condition-monitoring systems, work orders, operational control and monitoring systems and accounting.

The large integrated system vendors (ERPs) probably have the most to lose from this Internet-based interface standard because it all but eliminates their strongest suit—their respective unique versions of client–server technology. The web-architected model opens each of their modules up to competition from smaller system suppliers that might have more user-friendly products. The smaller system vendors are likely to benefit from increased connectivity to other systems, but the nature of the competition among them for specific customers will probably change. Data warehouse suppliers will probably see the need for their products disappear. In the end, the user will have the most to gain.

UPTIME SUMMARY

Computerized systems are important and now seemingly indispensable tools for business. Just remember the last power failure you experienced and you will understand that there is very little that is not computerized these days. Technology and its business applications continue to grow and proliferate. The world of maintenance is no exception. Most maintenance work is not computerized, but it is complex and managing it requires sophisticated tools. Using those tools effectively will improve the efficiency with which you deliver maintenance services. Use them poorly and you only add cost.

There are two broad categories of technology that maintainers work with: support systems and management information systems. The first category includes the various specialized support systems for data gathering, processing, analysis and decision-making support. These tools are meant to help today's knowledge workers, your maintenance technicians and engineers, do their jobs efficiently and effectively. They are used to monitor equipment condition, analyze equipment performance trends, analyze failure history data, perform complex reliability calculations, provide support to equipment replacement decisions and forecast probabilities. They are often designed as stand-alone systems to be used by trained specialists, and they seldom integrate seamlessly with management information systems. These tools, in the right hands, can produce remarkable results and quickly earn a return on your investment.

The second category includes the various management information systems: CMMSs, EAM systems and ERP systems. These systems automate business processes and information flows associated with a variety of business transactions. In maintenance, these systems use the work order as their primary transaction document. They can produce management reports, schedules and plans from which it is possible to see trends in performance measures and then make management decisions. Their main function is to support management processes. They are expensive to acquire, install, implement and operate. They can take months or even years to get going. However, when coupled with business process redesign, the implementation of effective maintenance, inventory and supply chain processes, they can add a great deal of value.

All of these systems are undergoing constant development and expansion of capability. The single-purpose systems and simpler forms of management systems tend to be easier to use. The broader the capability and the greater the functionality of a system, the more difficult it is to use. Suppliers of these systems are working hard to change that. One development is the emergence of standards for data interchange using Internet architectures that would permit multiple systems, each having different purposes, to share data. This opens up the possibility for specialized decision support systems to gather needed data from management systems and vice versa.

The world of maintenance support and management systems is complex and crowded with competing products. To ensure you get the most value from whatever system you choose, ensure that you have a solid foundation—well defined and well documented business processes. Explore what you really need to achieve, define how systems can help and keep the choices as simple as you can. It will all change again tomorrow.

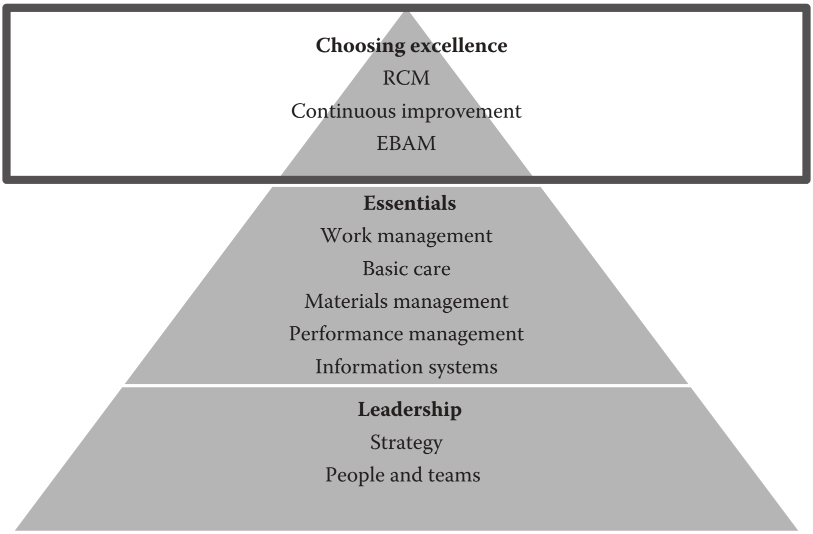
ENDNOTES

1. The term computerized maintenance management systems (CMMS) as used in this book generally refers to a broad range of products from those that are truly specialized for maintenance to those that are much broader in scope including maintenance. The latter are also known as enterprise resource planning (ERP) or enterprise asset management (EAM) systems.

2. A "workaround" is an alternative and usually simpler way of achieving a result. It is used to bypass an approved or formal approach because it is too cumbersome or simply does not work.
3. Weibull analysis: a commonly used statistical technique to analyze failure data for characteristics such as its mean time between failures, whether or not the failures are random, premature or age related, and to observe the consistency of the data.
4. "Best" in this case refers to an optimized decision considering cost, probabilities, and organizational objectives for the asset in its operating context.
5. Condition monitoring signals are gathered by a separate system and relayed to the MARS software.
6. The right data include a description of the as-found state of the asset at the time of a repair or preventive renewal.
7. MIMOSA stands for Machinery Information Management Open Systems Alliance. It is a nonprofit trade association that develops and encourages adoption of open information standards for operations and maintenance.

Section III

Choosing Excellence



This section is for companies that want to shift from good to great and become leaders in their industries. High performance in the essentials as described in Section II of the book will certainly pay off, but merely doing maintenance well is not enough if you are doing the wrong maintenance.

In this section of the book, we focus on doing the right things and on making continual improvements.

Arguably it makes sense to begin by defining the *right maintenance* so that you can focus on doing that well. In a green-field environment with entirely new systems, that is achievable and preferred. In fact, that is what is done using RCM (Chapter 8) with new aircraft before they are ever produced for commercial operations. In that situation, you would use this section of the book in parallel with Section II. However, if you find yourself in the more typical position of managing an existing operation with an existing maintenance program, you have already lost that opportunity. You may also have entrenched practices that may or may not measure up to the successful standards as described in Section II (Essentials). In that case, you need to tackle both the practices (Section II) and the definition of what work you perform as described in this section usually focusing on the practices first.

Begin by defining criticality (described in Chapter 3) and delineate between highly critical, less critical and noncritical assets. RCM is appropriate for your critical assets and simplified RCM methods for those that are less critical. Both are described in Chapter 8. Where you have an existing proactive maintenance (PM) program, you might want to begin with PM optimization as described in Chapter 9. Also in Chapter 9 you will find ways to improve on your existing maintenance program using root cause failure analysis and a variety of decision optimization tools all aimed at improving reliability on very specific case-by-case situations where reliability or even your RCM and PM optimization efforts may have fallen short. Continuous improvement using these methods is one hallmark of truly excellent performers.

Information technology enables us to gather, store and utilize large volumes of data. Those data and information from our employees can provide us with very useful evidence to support optimization efforts and decision making. Evidence-based asset management is rapidly becoming the *gold standard* in good reliability decision making. It is discussed in length in Chapter 10.

8

Asset Reliability 1: Being Proactive

There is little point in doing maintenance the right way if you are doing the wrong maintenance.

John Moubray

Maintenance is about sustaining productive/useful capacity in both proactive and reactive work. Repairs are required from time to time. If most of them are reactions to failures that were not anticipated, then your proactive efforts may be missing the mark. John Moubray's quote is to remind us that it is important to do the right proactive maintenance so that we minimize the reactive portion of our workload. Doing the right maintenance work the right way is not all that difficult, but there is no one "right way" to move from a reactive to a largely proactive environment.

John Moubray recommended starting by defining the "right work" using reliability-centered maintenance (RCM). Many others recommend starting with "the basics." That means dealing with the "essentials" as described in the *Uptime* Model of Excellence. Moubray's point was that you could spend a lot of time planning and scheduling the "wrong" proactive work—i.e., work that has little, no or even a negative effect at reducing future failures or their consequences. In fact, you need mastery of both the essentials and a method for defining the right work if you are to be truly successful.

In the *Uptime* framework you can start virtually anywhere—with RCM as Moubray would suggest or more typically, with planning and scheduling as many others suggest. Although it is not essential to think about overall maintenance strategy first, this is strongly recommended because it provides the overall direction that you will follow. The best place to begin is where you are weakest and suffering the most loss. You may choose to start with work management because this helps eliminate some of the chaos. You may also decide to focus on performance measures, which help inject some discipline into the process, or even begin by installing a new computerized management system. All of these are steps that go in the same general direction, so you cannot go wrong with any of them, but you will ultimately find that it is easier to stay on track if you follow some sort of strategic approach. As discussed in Chapter 1, that strategic approach should be tailored to suit your circumstances, including consideration of your current performance, strengths and weaknesses. In this part of the book, you will learn about approaches or methods that work at the site or business-unit level and embrace doing the right things in maintenance the right way. It is primarily about effectiveness rather than efficiency.

John Moubray's[1] excellent point about making sure you are doing the right maintenance lies at the heart of the process. If you are on the wrong path, you will not get where you are trying to go, at least not directly. For this reason, you must make choices that are consistent with your stated goals and lead to high reliability of your physical assets. One path is proactive, another is reactive and both are supported by a variety of techniques that can make implementation more precise.

Maintainers often use condition monitoring and overhaul tactics in proactive programs. Some opt for a traditional approach to developing maintenance programs, basing choices on historical precedence ("we've always done it this way"), on experience (hard-learned lessons) and on technical manuals from vendors. Others choose rigorous methods like RCM to determine the most appropriate failure management strategies. Where a maintenance program is already in place, preventive maintenance (PM) optimization is sometimes used to align existing programs with RCM concepts. Using the traditional approach of following manufacturers' recommendations and adjusting based on experience will not produce optimum results. Despite its name, neither will PM optimization. Even RCM is not perfect; it is, however, the most thorough method you can use.

Wherever companies put maintenance tactics in place using traditional approaches without RCM, they fall short, often far short, of choosing excellence. In some cases, these companies are not familiar with RCM and other optimization methods, but more often than not, they are trying to avoid investing in these RCM methods because they are not totally sold on their potential value. In those cases, they generally opt for a low-cost, shortsighted approach that gets them short-term results. It has always been easy to spot failure modes that were not addressed because failures have happened or tactics that addressed failure modes the wrong way because, despite doing some sort of PM, the failure happened anyway. Very often, this is also easy to see: The symptom is that far more maintenance work is done than really necessary. These well-intentioned but shortsighted efforts at quickly creating PM programs often fail to improve reliability performance substantially, they rarely reduce costs and they often damage the credibility of the maintenance department because they fail to deliver on promised business improvements. The quick and dirty approach, the silver bullet, simply does not work. Basic care (Chapter 4) is a great start, but it is not enough on its own. The most effective maintenance programs are developed using RCM at the design stage to determine which tactics are the most appropriate in each circumstance. RCM works extremely well, regardless of whether you are in the design stage or long after the asset has entered service. It is the most thorough method available to determine maintenance program requirements, and it is highly recommended, especially if the consequences of failure include safety, environmental and severe business loss risks. It is so successful that it is the primary method used in critical nuclear power, aircraft and military applications around the world.

Reliability management is all about maximizing uptime and minimizing the frequency of downtime incidents. The primary benefit of reliability management is that it increases asset reliability by increasing mean time between failures (MTBF). This, in turn, leads to increased asset (mechanical) availability, greater production potential (asset utilization) and revenue generation. Increased reliability reduces costs because it reduces the need for expensive repairs and downtime with costly production losses. Chapter 6 discussed overall performance measures, including reliability-related measures that are a key output of maintenance efforts. A few technical measures and their definitions[2] are a useful way to introduce RCM:

- Availability[3] (A) is the proportion of time that an asset is available for use.

  $$A = (\text{scheduled uptime} - \text{all downtime}) \div \text{scheduled time}$$

  Or, more simply, $A = \text{uptime} \div \text{total time}$.

  To improve A, we want to increase uptime and decrease downtime. In some definitions, total time excludes downtime for planned preventive or repair maintenance activities. Be aware that in that case, there is an underlying assumption that some planned maintenance is actually necessary—that is not always the case. Planned maintenance downtime, like downtime for any other cause, serves to limit availability. Sometimes it is needed, and sometimes it is not.[4]

- MTBF is the statistical mean of the failure distribution curve associated with any specific plant, vehicle, equipment or component failure history. Most failures tend to be random in nature, so MTBF is often approximated by dividing the "life" of the asset, or the combined life of a fleet of identical assets, by the number of failures experienced in that lifetime. Life, in this case, is the length of time the asset survived from the time it was put into service until the time it failed. A common error that is made in calculating MTBF is to include all downtime events as failures. Many are not actually failures and should not be factored into this statistic.
- Mean downtime (MDT) is the average length of time taken to restore an asset to service. MDT is calculated by dividing the total downtime (shutdown time + time taken preparing the equipment for work + repair time + warm up + start-up time, etc.) by the total number of reliability-driven downtime incidents for any reason, including repairs and preventive actions. Downtime for purely process- or production-related purposes is usually not included, although it can have a substantial impact on availability.
- Mean time to repair (MTTR) is the average length of time taken to repair an asset when it has failed. MTTR is calculated by dividing the total repair time for a number of failures by the number of failures. MTTR is a measure of maintainability for the asset—the greater the value of MTTR, the less maintainable it is. To increase availability (A), you want to minimize the time to repair.
- Reliability[5] (R) is the probability that any asset will survive for a specified duration of time (or mission). As a probability, it has no dimension. If the failures present randomly (and most do), then reliability is a function of the asset's MTBF. Consequently, MTBF is often used to express reliability. The greater the value of MTBF, the more reliable the asset.

RELIABILITY-CENTERED MAINTENANCE

RCM defines a common language that all personnel in your company can use to communicate effectively through all your business affairs.

Specifically, it is a method to determine the most appropriate maintenance policy for any given physical asset in its present operating context. RCM is not a way of doing maintenance, and it is not the same thing as condition-based maintenance (CBM), although those are two common misinterpretations. It is an analysis, decision-making and tracking method that should be used to capture and document trades' knowledge for future generations of tradespeople's benefit. After all, who paid the tradespeople for the knowledge they gained on the job over their work life? RCM can be used, on its own or in combination with other methods, to help change the work culture of the organization from one that is reactive to one that is proactive. For example, it is sometimes used within the context of total productive maintenance (TPM; discussed in Chapter 2) to define failure management policies for dealing with specific failure modes that arise in an asset's specific operating situation or context. It is an entirely proactive approach that anticipates which failures are likely to occur, what will happen when they do occur and what can be done to minimize or eliminate their consequences. RCM is about eliminating or reducing consequences, not just about improving asset reliability. Sometimes (in fact, often), RCM reveals running assets to failure as the best alternative. RCM output is correlated to specific operating environments and circumstances, so it is "right" for any given context or situation. It can be used in an existing asset environment, or it can be used at the design stage for a new asset. For the greatest benefit, it should be used early in the asset life cycle (preferably at the design stage), where its findings can influence the design itself, save considerable capital cost outlay and optimize operating and maintenance costs for the entire operational life of the asset. Decisions made in design influence maintenance spending and operational success many years later. In the 1980s, the author used an early version of RCM called reliability-centered support (RCS) extensively in a naval ship design project for integrated logistics support (ILS). Here, it resulted in substantial improvements in fleet availability to the extent that fewer vessels were needed to replace a larger fleet. That alone saved nearly \$2 billion in capital costs. In the mining industry, it has helped mines devise a plan to park excess vehicles and reduce both operating and maintenance costs. RCM is not, however, only for fleet environments—in a mine ore processing plant, RCM revealed operating problems that helped that company avoid over \$100 million in capital spending; and in an electric utility it reduced maintenance costs by over 20% while improving reliability.

Some Background on RCM

Up until the mid-1950s, industrial maintenance work was primarily reactive in nature, and "breakdown" (or "break–fix") maintenance was the norm. This was deemed to be the first generation in the world of industrial maintenance—the reactive stage. However, after this time, there began the second generation in the world of industrial maintenance—the preventive stage. Now, an understanding that most equipment could benefit from scheduled overhauls or scheduled replacement was dominant. Thus, time-based PM was born and led to the adoption of equipment failure prevention programs. Work planning and work control methods also became popular maintenance management approaches during this time.

RCM was launched in the US commercial airline industry during the early 1960s. It developed in response to rapidly increasing maintenance costs, poor availability of assets and concerns about the effectiveness of traditional time-based PM. The problems were obvious; so was the need—more reliable maintenance programs.

Studies of existing engineering techniques and PM practices were conducted. The results revealed two surprising facts about the traditional, time-based, PM approach:

1. Scheduled overhaul has little positive effect on the overall reliability of a complex item and can even worsen its reliability.
2. There are many items for which fixed-interval maintenance is ineffective, because those assets do not fail as a result of age or usage.

This research also revealed the six patterns of conditional probability of failure.[6] These are shown in Figure 8.1, where time is the base, adjusted for such usage factors as cycles, elapsed hours, hours used and distance covered. The vertical axis represents conditional probability of failure.

1. Bathtub
    - Increased probability of failure at the beginning and end of its life.
    - 3%–6% of all failure modes. The most common range is 3%–4%.
    - It is a combination of "worst new" and "worst old."
    - An example is a simple electromechanical system having only a couple of dominant failure modes. Home electronics—your VCR, DVD or CD player—are good examples. If the electronics survive the initial "burn-in" period, which is often the period

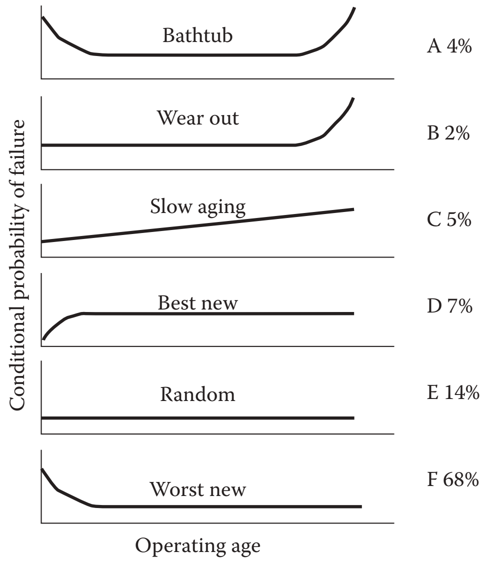


FIGURE 8.1
RCM's 6 failure patterns' conditional probability of failure.

when the warranty applies, it will very likely last a long time, until some of the mechanical components in the tape or disk drive eventually wear out.

- Two tactics, at least, are necessary to deal with early and end-of-life problems—in the example, we have a warranty for the early problem (transfers the risk to the manufacturer or vendor) and replacement at the end of useful life for the latter (because it is probably too expensive to fix it).

2. Wear out
   - Age-related failures.
   - 1%–17% of all failure modes.[7] The most common range is 1%–2%.
   - Examples include pump impellers in slurry service, crusher jaws, tracks, liners in chutes or hoppers and gear teeth.
   - To deal with this, we rely on fixed-interval or scheduled maintenance to replace or restore the failed components.
3. Slow aging
   - Steadily increasing conditional probability of failure with age, typically as the materials deteriorate with age.
   - 0%–5% of all failure modes. The most common range is 4%–5%.

- Associated with corrosion, erosion and fatigue. Material creep, or stretching (often, this is imperceptible without measuring devices), is one sign of this.
- Often, this occurs when the equipment is in contact with the product or stressed on a cyclic basis.
- Pipes, refractories, tires, many building and mobile equipment structural elements, hydroelectric poles, aircraft landing gear and wing struts and clutches are all examples.
- Use rebuild or component replacement tactics.

4. Best new
    - Not age related, except at the beginning of life.
    - 0%–11% of all failure modes. The most common range is 7%–11%.
    - As with all random mechanisms, condition-based maintenance is the best tactic (provided that the failure mechanisms give some warning that they are occurring).
    - Age-based routine maintenance is generally ineffective because we cannot predict random events.
    - Hydraulics and pneumatics are examples.
5. Random
    - This pattern, which is common in more complex devices and systems, shows no relationship between conditional probability of failure and operating age.
    - 14%–60% of all failure modes. The most common range is 14%–15%.
    - The failure causes are all random.
    - This pattern is also exhibited in systems that have the worst-new pattern, where those systems have been run in for a period of time before being put into service.
    - Many rolling-element bearings and electronic systems commonly exhibit this pattern.
6. Worst new (infant mortality)
    - Most common failure mechanism for complex equipment and systems by far.
    - 29%–68% of all failure modes. The most common range is 66%–68%.
    - Conditional probability of failure declines initially with age. It starts high because of design flaws, manufacturing defects, construction errors, material defects or human errors. As these are eliminated, performance improves, and conditional probability of failure drops.
    - Electronics, avionics, highly complex/integrated equipment and entire plants are all examples.

- Once the infant mortality problem is solved, routine maintenance plays a minor role since failures are the result of random events that we typically cannot control, but condition monitoring is highly effective at detecting when these failures have begun.

The original study was the result of work in the 1970s and confined to failures in aircraft. Since then, we have introduced far more complex control systems, computerization and extensive automation and mechanization in virtually all of our equipment and systems. This is driven by advancing technology and by rising labor rates. Since much of this new technology exhibits random failure characteristics, if anything, we are adding more randomness to the behavior of our equipment and systems, so it makes sense to adjust our maintenance practices to suit.

This study gives us some important tips about how equipment can be maintained:

- Failure is not usually related directly to age or use, so timing preventive actions based on age or use is unlikely to work in many cases.
- Failure is not easily predicted, so restorative or replacement maintenance based on time or use will not normally help to improve the failure odds.
- Major overhauls can be a bad idea because you can end up at a higher failure probability in the most dominant patterns (i.e., worst new and random). Random events are much more common than age-related ones.
- Age-related component replacements may be too costly for the same reason.

Many randomly initiated failures do provide some warning that the failure has been initiated and is progressing (e.g., bearing vibration increase, temperature increase, etc.).

Knowing which failure pattern you are dealing with is a big help in determining what maintenance or other failure management approach is technically most feasible. The results of these initial studies have extended far beyond the airline industry that prompted them. They were used to develop the basis of RCM, a logical approach to creating a PM program that can be applied to any industry.

RCM was first applied on a large scale to develop the maintenance program of the Boeing 747. Later, it was used for the L-1011 and DC-10. The results have been impressive. These aircraft achieved significant reductions in scheduled or time-based maintenance, with no decrease in reliability. For example, only 66,000 labor hours of structural inspections were required before the first heavy inspection at 20,000 flying hours on the Boeing 747, as compared to 4,000,000 labor hours over the same period on the smaller DC-8.

RCM (or MSG-3, as it is known in the aerospace industry) is now used to develop the maintenance programs for all major types of aircraft. Other applications include the navy, utilities, nuclear power, the offshore oil industry and manufacturing processes. RCM is particularly suitable in large, complex equipment, systems or plants, where equipment failure poses significant economic, safety or environmental risks. Thus, in the mid-1980s began the third generation in the world of industrial maintenance—the proactive stage. Now, there are many variations (industrial and military) on the original RCM concept developed in the airline industry by Stan Nowlan and Howard Heap (1978). In 1999, Society of Automotive Engineers (SAE) published a standard, JA-1011, "Evaluation Criteria for Reliability-Centered Maintenance Processes." According to the standard RCM is suitable "for use by any organization that has or makes use of physical assets or systems that it wishes to manage responsibly." In 2002, SAE published another standard, JA-1012, "A Guide to the Reliability-Centered Maintenance Standard," that amplified and clarified key criteria listed in JA-1011 and summarized issues to be addressed before successful application of RCM. Since Nolan and Heap's original work in 1978, various so-called RCM methods have emerged; some of these, unfortunately, do not fully comply with the SAE standards and should not be confused with true RCM. Many of these methodologies are based on purely engineering hardware and component approaches. Prior to Nolan and Heap, this approach to failure modes and effects analysis (FMEA) already existed for engineering analyses. They were based on these hardware-focused techniques, but even when supported with databases of failure modes, this approach can mean a great deal more work to arrive at essentially the same results as RCM's "functional" approach. Streamlined versions that attempt to shortcut RCM also exist. Although these methods have been somewhat successful, they invariably leave something out and complete only part of a full job.

The purpose of this chapter is to introduce RCM and explain how it is ushering us into the fourth generation in the world of industrial maintenance—the holistic stage, which is embraced fully in the International Organization for Standardization's (ISO's) standards 55000, 55001 and

55002, published early in 2014 and discussed in Chapter 11. RCM is a wise choice for industry because it sustainably serves what is known today as the "triple bottom line" for success:

- People—social responsibility
- Planet—environmental stewardship
- Profit—economic prosperity

Here, we will address RCM's functional approach, which develops failure management policies based on maintaining functions of assets as opposed to maintaining the assets (i.e., hardware) themselves. In this way, we can better meet the growing organizational and social expectations that industry has on modern-day physical assets—both plant and mobile equipment. Typical business objectives that must be met are as follows:

- Higher equipment availability and reliability
- Greater organizational cost-effectiveness
- Better company safety performance
- Better company environment performance
- Higher product quality
- Longer physical-asset life

At the same time, we must rise above certain challenges to accomplishing all of these that are before us—barriers such as growing equipment mechanization and automation, tightening global competition, increasing adoption of just-in-time (JIT) manufacturing and shrinking inventory and capital equipment budgets.

RCM applies our understanding of equipment failure to all industrial assets. Coupled with the new international asset management standards (i.e., ISO 55000/1/2 on asset management systems); very affordable CBM/predictive maintenance (PdM) techniques (vibration analysis, ultrasound, infrared [IR] thermography, oil analysis, etc.); and effective work management approaches (Chapter 3), it poises us for breakthrough improvements in our industrial workplaces.

RCM Process

This part of the chapter describes some of how to do RCM, but it is not intended to be an extensive textbook or guide that can be followed to perform RCM analysis work. Extensive training is required that covers more depth and detail than is appropriate in the scope of this book.

The first step is to decide which assets you will examine using RCM. At the design stage, you might choose to analyze all systems. For example, in an existing operation,[8] you might pick the assets that are causing the greatest financial "pain." However, in a business or industry, there are many ways to measure pain. So, by pain, we mean those physical assets that are most unreliable or those that are known to create safety or environmental problems when they fail. (See Figure 8.2 for some common measures of pain.)

Prioritize your assets and deal with the highest-priority items first. A high-priority asset is one that, if it should fail, exhibits a high risk (high consequence, high failure probability) to the organization (Figure 8.3). You may eventually want to analyze other assets with lower priority, a practice that some companies follow. Ultimately, the goal of any reliability improvement project is to reduce the exposure that the business has (to the risk that the asset should fail) to a tolerably low level. Performing an RCM analysis on a sequenced schedule of "bad actors" will reduce the exposure to business risk.

Measures of "pain"	Now	Desired
Reliability	3 wks	6 mths
Availability	88%	95%
Scrap	4%	50 ppm
Throughput	800 T/Wk	1000 T/Wk
Environmental incidents	4/yr	1 in 4 yrs
Manhours per LTI	150,000	1,000,000
MTCE costs	$520 k/yr	$300 k/yr

FIGURE 8.2
Common measures of "pain."

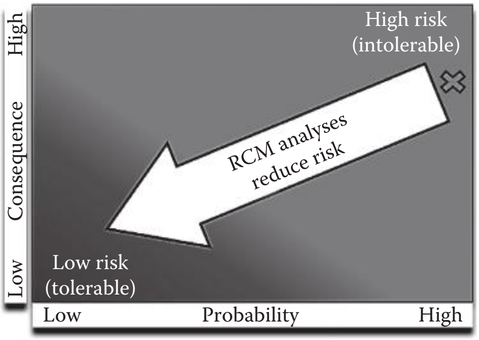


FIGURE 8.3
Risk matrix. RCM helps reduce both consequences and probability of failures.

Once you have decided what to analyze, you are ready to begin the seven-step RCM process (SAE 1999).

1. What are the functions and associated desired standards of performance of the asset in its present operating context? (What do we *want* the asset to do—not what it *can* do?)
2. What are its functional failures? (What are the ways it can fail—its failed states?)
3. What failure modes cause each asset's functional failure? (Why does the asset get in those functionally failed states?)
4. What are the resultant effects of those failure modes on their own? (Exactly what is the sequence of events that happen when each failure mode occurs?)
5. How do those failure modes matter? (Do we have any hidden,[9] safety, environmental, operational or other consequences that we want to minimize or eliminate?)
6. What proactive tasks can we perform to minimize or eliminate the failure consequences, and is it worth our while to do them? (Are there any condition-based or fixed-interval maintenance tasks that we can perform, and do they reduce our financial and other risk exposures to levels we can live with?)
7. If we cannot do anything proactively, then what else can we do? (Can we accept the failure consequences? Can we perform a function test? Can we physically redesign the asset? Can we do a procedure change or more training that will eliminate the failure? Can we do something else that will at least make the consequences of failure more tolerable?)

When systems are being designed, they often include some level of built-in redundancy. Redundancy is needed only in very critical circumstances, but it has often crept into overall design processes as a common practice. If RCM is applied at the design stage of the asset life cycle, it can identify where equipment redundancy can be eliminated and reduce the associated costs and exposure to safety and environmental risk. In one analysis carried out by the author, an entire engine and drivetrain system was found to be superfluous on a large shipboard propulsion system. It had been added as a result of traditional and very conservative design practices following guidelines established over 100 years before!

RCM favors CBM or PdM tactics over traditional time-based methods; run to failure is acceptable, where warranted. CBM works well for most failure modes because most failures are random yet give some advanced warning of condition deterioration, and these methods are often nonintrusive—usually, you can perform the checks while the asset is still operating. Time- or usage-based methods (fixed-interval maintenance—overhaul or replacement) may also be appropriate but only if a condition-based task is not feasible and worth doing and where the failures are not random in nature. (As equipment and systems become more complex through mechanization and automation, they also tend to exhibit more random failure characteristics. As such, you can expect more of your maintenance program to comprise condition-based tasks rather than fixed-interval replacements or restoration/overhaul work.) Of course, every proposed maintenance task is checked to see if it reduces risk to tolerable levels if it has safety or environmental consequences. It is checked to ensure it is the least costly approach in other operational or even nonoperational instances. In some cases, running the asset to failure is the most beneficial solution, a result that often surprises many old-school maintainers.

In RCM terms, this is known as "no scheduled maintenance." However, "no scheduled maintenance" does *not* mean "no planned maintenance." In other words, just because the RCM analysis team has decided that it is not worth performing a proactive maintenance task on the asset does not mean that nothing will be done to efficiently and effectively recover (i.e., get producing again!) when the asset does fail. On the contrary, it is expected that the needed spare parts will be on hand and easily available, hand tools are accessible and functional when required and skilled tradespeople are just a phone call away. In short, we are planning or getting "postured for success" when the asset does eventually fail. Any failure or proactive work that is identified using RCM becomes an immediate candidate for maintenance planning (Chapter 3).

A summary of the main steps required to run a successful RCM program is presented below. The steps follow the familiar plan–do–check–act sequence. Each is discussed in the following sections:

1. Select plant areas that matter.
2. Prepare for the RCM project.
3. Apply the RCM process.
4. Implement selected tactics.
5. Optimize tactics and program.

Steps 1, 2 and 3 constitute the planning activity. If you stop there, as many companies do, you will not achieve the results RCM is intended to deliver. Step 4 ensures that the RCM results are put into your computerized asset management system (CMMS) and actually used. Step 5 is all about checking and acting to improve on the results. These continuous improvements often reveal incredible treasures—in the hidden plant where capacity is lost due to unused or suboptimally used (i.e., underutilized) assets.

Step 1: Select Plant Areas That Matter

Businesses typically have thousands of pieces of machinery and equipment. These can range from pumps and valves to process systems and plants, pipelines, power lines, substations, rolling mills, presses, fleets of load-haul-dump (LHD) trucks, buses, automated trains, conveyors, ships, other vehicles or buildings. They may be fixed or mobile. Each asset will benefit from RCM in varying degrees. Before beginning the RCM process,[10] it is often useful to identify and prioritize the physical resources owned or operated by the enterprise. This initial stage involves the following:

- Create a physical-asset hierarchy—establishing a structured, comprehensive list of all physical assets owned or used by the organization that require some form of maintenance or engineering attention. This list is referred to as the plant register, plant inventory or equipment family tree. It is usually contained in the company's CMMS.
- Assessing the impact of the physical resources on the key business performance areas. These include impacts on plant availability, process capability, quality, cost, customer service, safety or environmental

risk. There are various methods that can be used to perform this assessment, and the precise method is not critical. Of more importance is selecting a method, documenting it and its results and then proceeding with the review. Usually, the highest- and lowest-priority (or most and least critical) systems will be obvious, and in some cases, a detailed assessment is not even required. Managers can usually tell you what causes them the most pain—in other words, which assets keep them awake at night! Again, see Figure 8.1. It is not always worth the effort to figure out the exact order of importance as long as you eventually deal with the critical areas. Be cautious about what you decide not to analyze; seemingly insignificant items can have surprisingly significant business impacts that are uncovered during the analysis. At the start, it may be enough to recognize the bad actors or the high-cost assets or those that create process bottlenecks to select your first candidates for analysis. Once you have established your top-priority analysis candidates, quantify and summarize the benefits you intend to gain from a few pilot RCM analyses.[11]

- Establishing the boundaries between equipment systems. Boundaries include everything necessary for a physical resource to do its job. This helps define the scope of the review and organizes it into manageable pieces. In doing this, you may find that the boundaries you set do not match the listings in your asset register. This is quite normal—the very practical functional approach taken in RCM does not always match up with the hierarchical physical breakdown of your plant and equipment. That match is unimportant for the analysis.

Step 2: Prepare for the RCM Project

RCM introductory training, a 3-day course, is needed for all project participants, preferably for all of your maintenance people and most of your operators.[12] See Figure 8.3. They will eventually be called upon to execute the results of the analysis work, and it helps a great deal if they understand the changes they will see to their old practices. The training of RCM facilitators is much more extensive than that for analysts and end users because the RCM facilitators will become your in-house RCM process experts.

From Figure 8.4, we see that RCM requires a modest investment of time for the RCM introduction training and for the RCM analysis work itself. It often provides paybacks of several times the initial costs within the first year, an excellent investment for most companies! This is because RCM

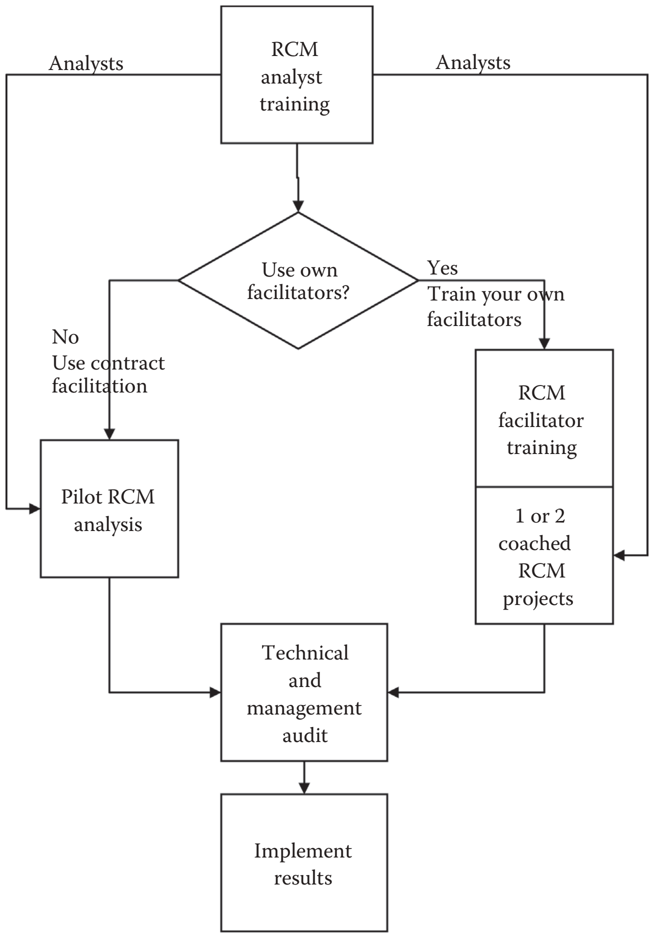


FIGURE 8.4
RCM introduction training flowchart.

analyses are performed in groups, which are led by a qualified RCM facilitator. However, the RCM group makes the final decisions (subject to an informed senior management audit). The advantages of working in RCM groups are many:

- The RCM analysis is based on more valid information.
- Additional people learn more about the assets, the work processes, the required tools, etc.
- The RCM analyses are done by more people, so that more work is done in less time.

- There is widespread ownership (i.e., buy-in) of the RCM analysis results.
- There is enhanced teamwork and bonding that occur between senior and junior workers.
- Real empowerment (the ability to make choices) is experienced by all.
- It harvests, spreads, reinforces and captures "tribal" knowledge both in the analysis records and in the next-generation trades.
- It gives people common concepts and a common language to support the new "proactive" asset maintenance and reliability improvement culture.

For a "greenfield" asset in its design stages, you will need to assign engineers and technicians, preferably those with maintenance and operations experience, to the team. The use of purely design-oriented engineers and technologists can be a mistake as they do not have the necessary operational and maintenance exposure that is needed.

In an existing or "brownfield" operation, RCM requires that you utilize some of your best maintainers and operators. The time of those who know the equipment best is scheduled for their RCM work, and replacement personnel may be identified to backfill for their time away from their usual jobs. The times for training and the RCM analysis are planned into their schedules.

A word of caution: Do not use teams of untrained RCM analysts or untrained RCM facilitators if you want quick, efficient and effective analyses. RCM facilitator training is like the apprenticeship of a tradesperson. Just taking a course does not make the person competent. Competency development requires formal training (e.g., a 10-day course) followed by a period of mentoring while the newly trained facilitator gains experience under the guidance of an experienced mentor. This mentoring usually occurs over the facilitator's first two full analysis projects. See Figure 8.4. RCM facilitation is not something that can be done by someone trained only in generic facilitation techniques. While those are very useful, the technical aspect of RCM requires an additional layer of competence such as found in a subject matter expert (SME). Following competency development, RCM facilitators are your in-house SMEs in RCM.

Selecting the right candidate to be your RCM facilitator is critical. The following are the leadership attributes you need to look for in an individual to be a great RCM facilitator:

- Always sets and meets (or exceeds) project targets.
- Helps others in the company exceed their plans too.
- Picks up asset/system knowledge very fast.
- Detail-oriented and runs a very tight ship.
- People trust him/her and are very loyal to him/her.
- Drives operators and trades to make decisions.
- Often performs impromptu, unbiased performance audits.
- Impatient but fair—demands quality and excellence.
- Usually receives excellent annual performance reviews, produces excellent work and may have received letters of commendation.

Project management is required, and, as discussed in Chapter 3 on work management, planning pays off—failing to plan is planning to fail!

An RCM analysis done in a brownfield (i.e., existing) operation is usually carried out by small teams of operators and maintainers working with a fully trained and qualified RCM facilitator to perform the analysis. Note that the RCM facilitator's skill has the most impact on the following:

- The RCM analysis quality
- The RCM analysis pace
- The participants' attitude throughout
- The overall impact and success of the reliability improvement initiative

Ideally, the team members and RCM facilitator are your own employees, but you may choose to use a qualified external RCM facilitator. Appreciate that your people are the experts—not some outside consultant. No one knows your people, your assets and your operations better than you. Also appreciate that the way you work is a result of a lot of history on top of some good, solid technical practices. Your PM program, CMMS, work culture, etc. began a long time ago and were based on the state of the art at the time, but they have evolved since, mainly through your people's experience. Your leaders have probably been around a long time and have formed a deep pool of experience to draw upon. They know what works and what is not working. They may or may not have kept up with research and findings in the field of maintenance and reliability (most have not). You, your people, your peers and your leaders probably have ideas of what to change to make things better. RCM facilitation realizes value for your organization by extracting, formalizing and capturing those ideas for your organization.

Committing to RCM

Initially, you might be unsure about your commitment to a full-blown RCM project that deals with many assets—you may want to prove to yourself that it will work at your site. External facilitators are useful if you are conducting a proof of concept to try out the RCM approach at your site for the first time. In other words, you want to avoid spending money on training your people in RCM facilitation unless there is a strong business case to do so.

A pilot project is an excellent way to do this, and you can use an external RCM facilitator for the pilot project to minimize your up-front investment in training. Except in the case of a greenfield application, it is ill-advised to use external RCM analysis teams because you want your own people to take ownership of the RCM analysis results.

If you take the pilot-project approach, carry out the analysis and implement the results. Compare your projected savings and reliability improvements with those you anticipated and see if the results justify a more extensive application of RCM. The author's experience with RCM reveals that results nearly always exceed expectations and disappointment is rare.

Some believe that it is not their "core business" to do RCM analyses, and therefore, their business model supports always using external RCM facilitators to perform their RCMs with their SMEs. However, if you choose to become self-sufficient by training your own people, they become internal RCM facilitators, and the knowledge stays in-house rather than walking out the door with the external RCM facilitator.

Either way, the RCM facilitator responsibility is to lead the group through the RCM analysis. It is the SMEs who make all the decisions in the analysis about the PM program to be used when maintaining and operating the assets. You are empowering your people, and they will take greater ownership of the final results—you will achieve sustained buy-in on how to maintain and operate your physical assets.

For a greenfield operation (i.e., a new asset in the design stage), the outputs of RCM are easily assimilated by the new crews that will be maintaining and operating it. Indeed, if they are experienced in new start-ups, they will appreciate having a maintenance program at the outset of plant operations.

RCM Operating Context

Not all equipment is operated in the same manner, in the same environment. Therefore, understanding the application of the equipment in its operating context is crucial to maintain the instantaneous capability of equipment between its initial capabilities (what it *can* do) and the desired level of performance (what we *want* it to do). It also provides assistance in making decisions about whether maintenance tasks are worth doing. An operating context must be developed for all assets of the system on which the RCM analysis will be conducted.

The operating context is a brief description of where and how the assets are being used. It provides a clear understanding and agreement of the assets' operating environment and the functions it possesses. It is performed at (sub)system level and shared with each SME on the RCM analysis team. The operating context provides a background for future changes to the proactive maintenance program.

The RCM facilitator is ultimately responsible for the creation and update of the RCM operating context. During RCM analyses, there is always a great deal of learning about your own assets and systems and how they work. The operating context, although created at the outset, remains a work in progress until the final management audit and summary meeting. At that time, the RCM analysis results are formally presented by the RCM analysis team to the senior management team for their review and approval to implement.

Step 3: Apply the RCM Process

Led by a qualified RCM facilitator, your trained RCM analysis team performs the RCM analysis by referring to the operating context for the (sub)system being analyzed and then asking and answering the seven questions listed earlier.

1. *Determine the functions of your (sub)system*. The purpose of any asset's failure management policy is to do the safe-minimum work to ensure that the equipment *can* always do what its users *want* it to do, on schedule, without serious consequences. That is the asset's function. Every physical asset has a function—usually several. These can be categorized as primary, secondary and protective:
   - Primary function: This is why the equipment exists at all. It is usually evident from its name, as well as from the interfaces that are supported between physical assets.
   - Secondary function: In addition to its primary purpose, a physical asset usually has a number of secondary functions. These are sometimes less obvious, but the consequences of failure may be

no less severe. These secondary functions often provide for one or more of these:
- Environmental integrity
- Safety and structural integrity
- Control/containment/comfort
- Appearance
- Protection
- Economy and efficiency
- Superfluous functions (sometimes you find something that is not needed at all)

Examples of secondary functions include containing system fluids, maintaining a pressure boundary, relaying local or control-room indications, supplying structural support or providing isolation. Sometimes, there are superfluous functions—things the asset can do that you do not really need or even want. In one tissue mill, for example, the permanent removal of a guard that was installed to protect equipment from a dripping air-conditioning system (that had long ago been removed) resulted in a substantial decrease in repair time for machine roll changes.

- Protective function: As processes and equipment increase in complexity, so do the ways in which they can fail and the consequences of those failures. To mitigate potentially dire results, protective devices are often used. Typical protective functions include warning operators of abnormal conditions, automatically shutting down a piece of equipment when it fails, eliminating or relieving abnormal conditions after failure, taking over from a function when it fails and preventing dangerous situations from developing in any way. To fully understand *can* and *want*, the following discussion relates to Figure 8.5. In addition to defining the asset functions, this process highlights the desired level of performance. These can include capacity, reliability, availability, product quality, safety and environmental standards. Although this may sound relatively straightforward, technical and maintenance performance are typically judged differently. This performance can be defined as follows:
  - *Built-in or inherent* (what the asset *can* do or was designed to do)
  - *Required or desired* (what we *want* the asset to do)
  - *Actual* (what the asset is doing right now)

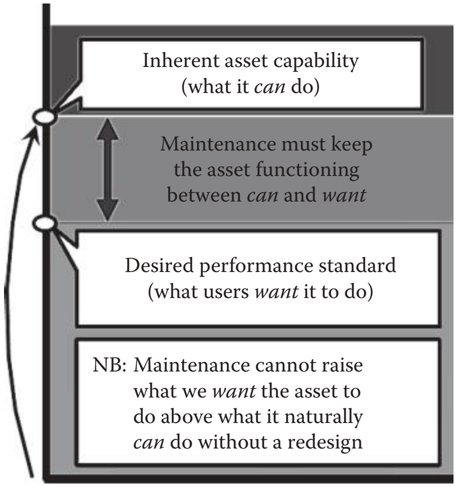


FIGURE 8.5
Can versus *want* asset performance levels.

In many instances, the equipment *can* deliver what is required of it with proper maintenance. Situations can arise where *what* is required exceeds what the physical resource is capable of. In these cases, no amount of maintenance will bring the asset performance to the desired level.

If there is only a small gap between the performance needed and the built-in capability, or the performance currently being achieved, the equipment or its operation must be modified. Options include replacing it with a more capable asset (increase *can*) or reducing operating expectations (decrease *want*).

Again, the purpose of the RCM review is to define the maintenance requirements for a physical asset that are necessary to meet the business objectives in its operating environment. It is important to remember that identical assets in different operating environments or modes may have different failure modes and different functional expectations. The level of performance reflects what is required or what we *want* from an asset.

2. *Determine plausible functional failures.* Once you have defined what you want the asset to do, you can define the failed states or ways that it can fail to achieve those functions. Partial and total shortcomings are considered.

Often, we tend to think of an item failing when it stops working—a "go" or "no-go" situation. Examples of this are a car that does not start or a compressor that does not start up to provide high-pressure air. Although this situation is typical for some equipment (notably electronics and electrical equipment), what constitutes a failure in other equipment is not as clear. Your car may start and run, but its acceleration is poor, and it uses too much gas. The compressor may run, but it does not provide enough air pressure or volume. Both of these are examples of *partial* functional failures.

The performance standards defined when we outline the functions of the asset provide clear guidance. If performance drops below a desired standard (what we *want*), it is considered a functional failure, even if the equipment is still performing at some reduced level. Any functional failure is the inability of a physical asset to deliver its expected level of performance.

The expected level of performance defines not only what is considered a failure but also the degree of specific maintenance needed to avoid that failure. As illustrated in Figure 8.6, this frequently creates intradepartmental conflicts. It is essential, then, that all concerned (the technical, operations and maintenance departments) play a part in drafting the performance levels. One-hundred-percent agreement is ideally what the RCM facilitator aims for, but it is not always possible.

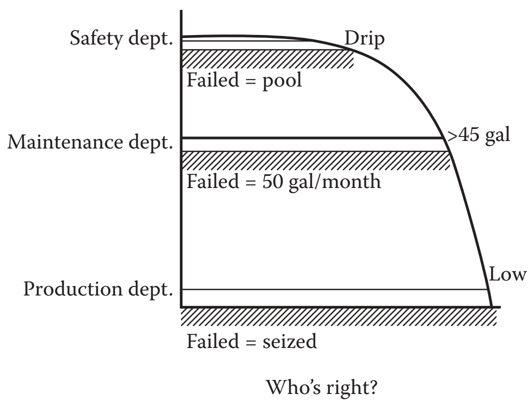


FIGURE 8.6
Performance standards and function failure.

What is essential is that all the analysts on the RCM team (i.e., the asset SMEs) *accept* the decision being made by the team.

3. *Determine likely failure modes and their failure effects.* The next task is to list the likely failure modes and describe their failure effects. A failure mode describes in simple terms what caused an asset's functional failure. For example, if a pump's functional failure is "unable to contain the pumped liquid," the failure modes are likely to be "mechanical seal worn," "casing ruptured," "casing gasket deteriorated," "vent valve corroded," or "drain plug missing after intervention" and so on.

   Failure modes are spelled out because the process of anticipating, preventing, detecting and correcting failures is applied to each failure mode independently of the others. So, when writing failure effects, assume that all other assets in the system being analyzed, other than this, work perfectly. While many potential failure modes can be listed, only those that are fairly likely to occur need be considered.

   Possible causes of the particular failure should also be identified because they have a direct bearing on the maintenance tactics used. This is done by the RCM facilitator asking the RCM analysts "why?" a sufficient number of times until sufficient detail exists to enable identification of a suitable failure management tactic. Some failure modes may have many different causes, and the nature of those causes makes a difference in how maintenance will address it. For example, a seized bearing might be caused by a lack of lubrication, normal wear, corrosion, fatigue, dirt, incorrect operation or faulty assembly. These will result in different failure management tactics.

   When stating the failure effects, describe as precisely and as completely as possible what actually happens when each failure mode occurs.

   In an RCM analysis, functions, functional failures, failure modes and failure effects are captured on a form known as an information work sheet. See Figure 8.7 for an example.

4. *Select technically feasible and worthwhile maintenance tactics.* The results of failures can range from trivial to catastrophic. The severity of failure impact influences the way a company views the failure and the steps deemed necessary to mitigate its consequences. Depending on the gravity of the situation, the action taken may be PdM or PM or adding backup systems. In some cases, labor-intensive activity may not be worth the effort and expense. To manage any failure successfully, a proactive maintenance task must have the following characteristics:

Function	Functional failure	Failure mode	Failure effect
1 To provide sea water between 250 m^3/h and 615 m^3/h for cold water operations and 1000 m^3/h for tropical operations at 3 bar for central cooling of all propulsion and auxiliary machinery.	1A Unable to provide sea water flow at all.	1A1 Power failure	No pumping capability results in inability to provide required cooling flows. Pressure indicators (both local and remote) would show loss of system pressure. Crew has ability to supplement cooling water from bilge/ballast pumping system unless it is too impacted by power failure. If flow not established quickly, machinery requiring water cooling would overheat unless shut down (includes main engines, may impact electrical generation capacity as well?). Ship unable to carry on with mission until cooling flow re-established. If this occurs due to power failure, restoration is quick, resulting in a delay to operations. If pumps are failed delay will be lengthy as repairs are carried out. Failure causes analyzed separately under electrical power system.
		1A2 Suction and/discharge valves on pumps and/or isolating heat exchangers or sea bays all left in shut position during start up after maintenance work.	When coming out of extended maintenance period and re-commissioning isolation valves are left shut. As above, no water would be available for primary cooling. If pumps started in this condition they would cavitate and likely be damaged. Machinery requiring cooling is unlikely to be operating in this scenario so no additional impact on operational capability. Crew would open isolation valves to allow system operation—resulting in a minor delay to scheduled activities.

FIGURE 8.7
Information work sheet captures functions, functional failures, failure modes and failure effects.

(*Continued*)

1	To provide sea water between 250 m^3/h and 615 m^3/h for cold water operations and 1000 m^3/h for tropical operations at 3 bar for central cooling of all propulsion and auxiliary machinery.	1B	Unable to provide 1000 m^3/h for tropical operations	1B1	1 or more of 4 SW circulating pumps unavailable or failed.	This is only a problem for full power operations in tropical waters. Loss of any pump would be indicated by loss of discharge pressure. Propulsion capacity would be reduced proportional to the number of pumps out of service with 25% reduction per pump. Supplementary cooling flow may be provided from the bilge/ballast pump. Crew would isolate pump(s) for repairs. Full cooling flow unavailable and propulsion capacity reduced. Repair time will vary depending on nature of pump failure—expect approximately 8 hours per pump in worst case (assuming tools, lifting apparatus and spares are all readily available to the crew).
				1B2	One or more pump isolation valves in closed position following intervention.	This is only likely following maintenance on a single pump during operational deployment. Full cooling flow unavailable and propulsion capacity reduced as in 1B1. Low discharge pressure will be indicated. Crew will open valves and restore system to normal operation.
				1B3	Variable speed drive on one pump (of 4) failed.	Loss of VSD capability could result in a pump operating at less than full capacity or not at all. Loss of control should be apparent in MCR (depending on VSD instrumentation).
				1B4	Pump suction side duplex strainer blocked.	A blocked strainer will restrict pump flow, eventually closing it off resulting in pump cavitation. Suction pressure drop will be indicated on CPI gauges. Propulsion capacity impact is the same as 1B1. Crew would trouble-shoot, notice which pump is cavitating, identify blocked strainer, switch to other side of duplex strainer and clean the blocked side.
				1B5	Breach of pump suction side piping due to corrosion or erosion.	Loss of pump suction and, depending on location of breach a possible discharge of SW from the sea bay into machinery space. Effects similar to 1B4 and crew could try to change duplex strainer. Changing duplex strainer will not correct problem. Pump requires shutdown and isolation for piping repair.

FIGURE 8.7 (CONTINUED)
Information work sheet captures functions, functional failures, failure modes and failure effects.

- *Technically feasible*. The task deals with the technical characteristics of the failure. Fixed-interval maintenance works for most age- or usage-related failures, whereas CBM works best for random failures.
- *Risk-effective*. In the case of failures having safety or environmental consequences, proactive maintenance reduces the risk to an agreed-upon tolerable level.
- *Cost-effective*. In the case of failures having other business impacts, proactive maintenance reduces or eliminates the cost consequences.

Technically feasible tactics for condition-based and time/usage-based maintenance must satisfy the following criteria:

Condition based

- It is possible to detect a physical resource's degraded condition or performance.
- The failure is predictably consistent as it inexorably progresses from first indication to complete breakdown.
- The asset health monitoring interval is practical and must be less than the time/usage to go from first indication (P in Figure 8.8) to complete breakdown (F in Figure 8.8).
- The interval between incipient failure and functional failure must be long enough to allow consequence-avoidance actions to be taken.

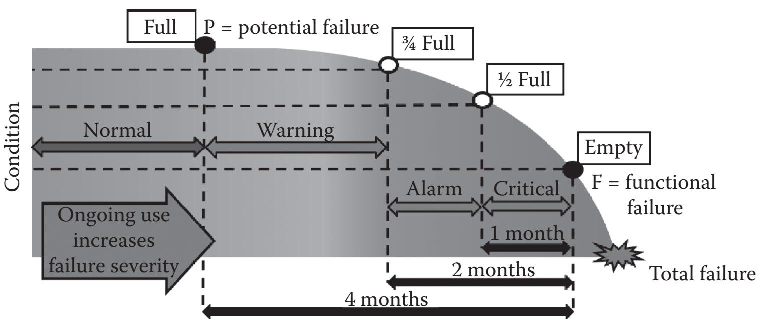


FIGURE 8.8
Deterioration of functional capability.

Time/usage based

- There is a particular point at which the physical asset shows a rapid increase in failure rate. It has a definite useful life.
- Most assets survive to that age/usage point. For failures with significant safety or environmental consequences, ensure there are no failures before this point.
- The PM task restores the asset to "like-new" condition. (Practically, this might mean only partial restoration if the asset is overhauled. Complete restoration is only possible if the item is discarded and replaced.)

Generally, to be worth doing, proactive maintenance will reduce the likelihood and/or consequences of failure to acceptable levels, be readily implemented and stay within budget. Within these limits, a maintenance tactic is considered worth doing if the following are true:

- For hidden failures, the PM task reduces the chance of a multiple failure to an acceptable level.
- For failures with safety and environmental effects, the risks are kept to a comfortable minimum.
- For failures with production setbacks, the cost of prevention tactics is less than the cost of production losses plus all repair and damage costs that otherwise would result over time.

If proactive maintenance measures are neither technically feasible nor worth doing, then, depending on the risk of failure, one of the following default actions is selected:

- For hidden failures, a periodic detective tactic is performed, called "failure finding," which is intended to reduce the likelihood of multiple failures. An example is testing the readiness/capability of standby equipment.
- For failures with unacceptable safety or environmental risks, system redesign may be required. This entails physically altering the equipment, changing the standard operating procedures (SOPs), changing the maintenance, instructions and/or (re)training operations and/or maintenance personnel.
- For failures with only production or maintenance consequences, no scheduled maintenance and corrective maintenance is apropos.

An RCM decision tree diagram can be used to integrate the consequences of failure with technically feasible and worth-doing maintenance tactics. A simplified version of this diagram is illustrated in Figure 8.9.

The RCM facilitator will place emphasis on what tactics are required in order to achieve the failure management strategies the RCM team defines.

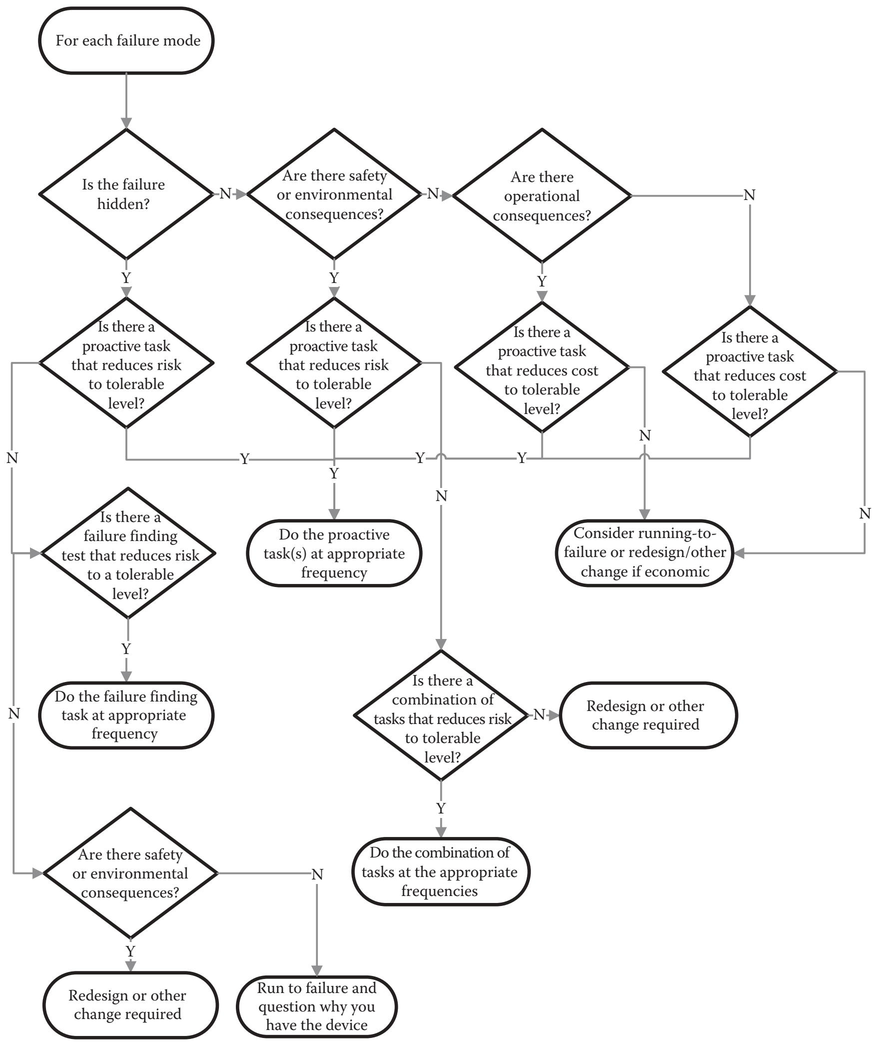


FIGURE 8.9
Simplified RCM decision logic diagram.

His/her goal is to create well-articulated PM tasks describing what must be done, how often and by whom.

The maintenance tactics used to deal with functional failures during an RCM analysis should be considered for selection in the following order:

1. *Condition-based monitoring (CBM) tasks*. These are inspections, or other checks, of equipment condition done at regular monitoring intervals to look for signs of performance deterioration. These monitoring tasks are usually unobtrusive and have the least impact on production. CBM tasks help minimize corrective actions because they promote getting the most possible economic life out of the equipment. Once the maintenance task has been chosen by the RCM SMEs, the monitoring frequency is determined. For condition-based tactics, the monitoring frequency is linked to the technical characteristics of the failure and the specific monitoring technique. Depending on these factors, the time can vary from weeks to months or even years. Deterioration from the point in time at which a potential failure (P) can be detected to the functionally failed state (F) is known as the P-F interval, as shown in Figure 8.8. As a general rule, the monitoring task is performed no less frequently than one-half the time it takes for the failure to progress (i.e., asset performance to degrade) from its first signs of deterioration, point P, to the functionally failed state, point F, or $(P - F)/2$.[13] Note that performing a more "granular" asset condition monitoring task, such as at frequencies of $(P - F)/3$, $(P - F)/4$, etc., will increase your chances of detecting incipient failure. However, it will also increase maintenance costs and expose personnel doing the task to safety and environmental risks, and may even cause secondary (collateral) damage to nearby equipment if an accident should occur.
2. *Time-based repair/restoration tactics*. These tasks are for failures that result from aging or usage of the asset. The restoration is performed at a fixed interval regardless of the condition the equipment appears to be in at the time. The invasive nature of this type of work makes it less preferable than CBM for a number of reasons:
   - It usually affects production or operations: This because you need to take the equipment "down" to perform the scheduled PM task.

- Overall failure rates can increase: This is because infant mortality[14] is introduced into an otherwise stable operating system, extending shutdowns/outages unnecessarily.
- The age limit can mean premature removals/repair: This is because the average life of the asset may not be known, especially if it is new.
- Additional shop work, replacement parts and tools required increases the overall cost of maintenance.

Fixed-interval task frequencies are applied according to the expected useful life of the physical asset. That is determined by the age at which wear-out, fatigue, erosion, corrosion, abrasion, etc. have progressed beyond a tolerable point. At that point, the probability of failure increases to unacceptably high levels.

3. *Time-based discard tactics*. These are generally the least cost-effective PM measures. They tend to be used where repair or restoration is impossible or ineffective, such as for components like filter elements, O-rings, seals/gaskets, some components in electrical equipment, etc. Frequency is determined as it is for time-based repair/restoration tasks.
4. *Combinations*. In some cases, a combination of tactics may be necessary to reduce safety and environmental risks to an acceptably low level. In general, this involves a CBM method along with some form of time-based maintenance. An example would be the in-place inspection of an aircraft engine by borescope every 50 flying hours, combined with time-based inspection and overhaul in a shop every 200 hours. Each task serves to reduce failure risk to a degree; when combined, they reduce overall risk to tolerably low levels. Ostensibly, doing more than one risk-mitigating task increases the impact (cost, safety/environmental risks, etc.) to the underlying organization. Hence, caution should be exercised to ensure that task combination approaches are only used where absolutely necessary.
5. *Failure-finding tactics*. This applies only to hidden failures (failures that are not evident to operators during normal operation). Hidden failures often occur in backup or safety systems where the protective device is normally dormant. There is no way to detect a hidden failure, but testing for it before a failure makes it manifest. How often the failure-finding tactic is needed depends on the required availability of the backup or protective device and the level of risk of multiple failures that can be tolerated.[15]
6. *No scheduled maintenance/run-to-failure tactics*. This applies when no other proactive approach is technically feasible or worth doing

and the consequences of failure can be tolerated. Run to failure is not a viable choice for safety or environmental consequences because it can lead to physical, social and legal consequences that no business wants to risk. If safety or environmental issues are a concern and you cannot take any proactive steps to predict or prevent failures (or cannot detect a hidden failure), then some other course of action must be taken. For failures having operational or nonoperational consequences (cost of doing business), run to failure may prove to be a cost-effective option.

7. *Redesign tactics*. Depending on the failure mode, you may opt to physically redesign the system to eliminate the failure mode or its consequences. An alternative is to provide training to operators or maintainers, update/create SOPs or maintenance instructions, install warning signs or some other appropriate "one-time-only" corrective measure.

After deciding on the appropriate tactical choice, the RCM team then determines the task frequency and decides who should execute the task. Those choices mark the end of the formal RCM analysis process. By this point, you will have completed and documented your analysis, and you have a number of failure management choices (preventive tasks, predictive tasks, failure-finding tasks, redesign recommendations, training changes or run to failure). It takes a fair amount of work to get to this point, but if you implement the results of your analyses, the payback is usually substantial.

Step 4: Implement Selected Tasks

The next step after developing and reviewing the equipment strategies with the cross-functional RCM team is to implement their recommendations, bring forth the necessary equipment repairs and corrections uncovered and continue collecting historical data for ongoing optimization efforts. Within the next year, these historical data will often support most of the RCM team's decisions, but new perceptions can emerge. RCM recommendations are not static, one-time-only decisions; they should be allowed to evolve.

In an existing operation, the failure management choices you have made replace the old PM program that you have probably been using for some time. For a new asset, this step will help maintainers and operators to get the program off to an excellent start. When inputting tasks for your maintenance management system, do so in conjunction with input about planning efforts and any other requirements for task execution. Tasks are triggered at the frequencies specified in the RCM analysis. In the case of CBM, the required actions to take if specified conditions are exceeded are precisely noted (for example, what to do when a vibration level goes above a specified limit). Some new tasks are the same as old PM tasks; others are minor variations on the old tasks, and some are entirely new. Regardless of which you are dealing with, it is the task as defined through the RCM process by the RCM team that must be implemented. The most common actions that must be taken to implement an RCM program include the following:

- Tweak existing maintenance schedules so they match recommended RCM choices.
- Develop or revise maintenance task instructions.
- Specify spare parts, especially critical spares, and adjust inventory levels to support them.
- Acquire needed diagnostic or test equipment and tools, including PdM technologies.
- Revise or write new operation and maintenance procedures. Sometimes, this entails developing checklists and other aids, perhaps from the Original Equipment Manufacturer (OEM).
- Specify the repair, discard or restoration procedures for the fixed-interval tasks.
- Develop (or start using) tracking systems for CBM readings and for initiating corrective work orders when condition limits are exceeded.
- Conduct any needed training in the new or revised procedures.

Senior Management Audit

Before making all the above noted changes, however, it is important for senior management to audit the outcomes and formally approve changes. This entails a brief review of the RCM analysis findings by a senior management team familiar with the objectives of the company's reliability improvement initiative. This meeting is usually held 1 or 2 weeks after the RCM analysis is completed. The senior management team includes the general/plant manager, maintenance manager, production manager, technical/engineering manager, HR manager, etc. Questions arising from this review are directed back to the RCM facilitator and the RCM analysis team for discussion. On completion of the management audit review, senior management should completely understand the scope of the RCM recommendations and all of their questions, and concerns should be fully addressed.

Objectives of Senior Management Approval

1. To prepare and present a high-quality summary of the chosen (sub) system's RCM analysis findings to senior company management. It must show what company reliability improvement initiative objectives have been achieved. It must also show what must be done to further deliver value to the organization going forward.
2. To obtain approval to implement the results of this RCM analysis into the CMMS database and related PM program. This approval provides formal recognition by senior management that resources (time, labor, money, etc.) must be applied for successful RCM analysis implementation.
3. To identify a person responsible for the RCM analysis implementation. This person will be accountable for the success of the rollout, tracking the status of the implementation, quantifying benefits wherever possible and reporting back to senior management in an ongoing and timely fashion.

Step 5: Optimize Tactics and Program

RCM is not perfect. Although it excels as a tool for identifying individual and even multiple failure modes, one of its weaknesses is that it cannot systematically identify combinations of failure modes that can cause serious consequences if those combinations are not hidden. Only fault tree analysis and root cause failure analysis methods will do this. Despite this and other minor weakness (sometimes used as criticisms of the method by those who do not want to use it), RCM has numerous advantages and benefits if it is implemented properly.

RCM analyses are always dependent on the quality of the effort invested. Once the RCM review is complete and the maintenance work identified, periodic adjustments to improve the program should be made. The RCM process is responsive to changes in plant design, operating conditions, maintenance history and discovered conditions (i.e., conditions that were not anticipated during the analysis). In particular, the frequency of the tactics is adjusted to reflect the operating and maintenance history of the physical resource. The objectives of this ongoing activity are to reduce equipment failure, improve PM effectiveness and the use of resources, identify the need to expand the review and react to changing industry or economic conditions. To achieve these goals, three complementary activities are integrated into a living program:

1. The periodic reassessment and revision of the RCM review results. The frequency of reassessment depends, to some degree, on equipment age but is usually conducted every 1 to 2 years. This ensures that undocumented design changes, changes to the operating context and new failure information are taken into account.
2. A continuous process of monitoring, feedback and adaptation based on RCM outputs. This process analyzes and assesses the data produced by production and maintenance activities for failure rates, causes and trends. Many of the parameters to be measured are identified during the initial RCM analysis. The process of continuously improving on RCM includes observation of the variances between actual and target performance standards. Corrective actions can then be taken. These may include changing the task type, scope or frequency; revising procedures; providing additional training; or changing the physical design. Continually reviewing and improving the initial maintenance program is akin to a quality management process that continuously improves product quality.
3. Monitoring of the functions of the assets that were analyzed and their performance standards. This is monitoring RCM inputs—the functions of the assets. Failure to perform to the stated functional standards will be identified as results are monitored, but the need for additional analysis due to a change in operating context or environment will be revealed by monitoring the functions that were defined. Are they still the desired functions? Do you still want reliability or availability, or both? Are the performance standards still applicable, or have they changed? By watching these, you can continuously adapt RCM analysis results to ensure that your systems continue to perform as needed by the business. Reliability modeling and simulation modeling[16] can help answer these questions and keep the RCM program alive.

RCM is a living program. A 1-day RCM review meeting is recommended about 12 months after the original RCM analysis is complete. The RCM facilitator reassembles as many of the original RCM analysis team members as possible, to review and modify the RCM analysis based on new findings uncovered over the past year. The PM program would be updated to reflect those changes, and remain so, until a future RCM review meeting when information suggests updating the PM program again. The annual 1-day meetings become an optimization ritual for the original RCM analysis team members.

Benefits of RCM: Creating Value for Customers

As desirable as it may be to have a comprehensive, logically based maintenance program, it is of little use unless it helps maintenance, and the company as a whole, create value for its customers and shareholders. Recall that value is delivered by increasing service and quality while reducing cost, time and risk.

$$\text{Value} = \frac{\text{Quality} \times \text{service}}{\text{Cost} \times \text{time} \times \text{risk}}$$

RCM delivers value in these five areas.

- Quality: The maintenance program that results is tailored precisely to the failure modes you are likely to experience, and it does so proactively, before you suffer the consequences. Maintenance tasks are defined precisely, leaving little room for error when they are converted to work orders for execution. All decisions are made using a consistent and logical approach and are fully documented. Any failures that are allowed to occur are only for failure modes that you can truly live with—there is no need to *react* to failures because you can now *respond* in an orderly fashion every time. Hidden failures that are often missed are caught because the maintenance program is more comprehensive than programs developed by traditional or other methods. Customer perceptions of maintenance improve. You are doing a better job because fewer failures mean more uptime and delivering what the customer wants.
- Service: Maintenance resources can be used much more efficiently doing only what needs to be done—the safe minimum. Higher asset availability delivers more uptime to operations, and higher reliability means fewer disruptions to production or customer service.

Customer requirements are met. RCM focuses on defining, up front, what functions the customer requires of the assets and then sets out to achieve them. The team-based approach to performing RCM results in greater cooperation between and among maintenance, production and operations and enhances future communications and teamwork. Both maintenance and operations tend to take more ownership of their roles in asset reliability.

- Cost: Doing only the maintenance required to deal with failure modes affecting functions desired by the customers means less downtime, higher product yield and a lower overall unit cost of maintenance. Unnecessary maintenance or overmaintenance of assets is eliminated. Repair costs are reduced since many failures will be caught before they reach catastrophic (completely failed) levels and before they result in secondary damage. The emphasis on condition monitoring reduces the need for invasive preventive tasks that are often more expensive to execute, require more spares/materials and additional downtime. Improved asset care results in longer asset life and/or increased resale value at end of the useful life of the asset.
- Time: Fewer failures are allowed to occur, so downtime and repair times are reduced. Elimination of many inappropriate overhauls reduces planned downtime and increases availability. Frequencies of maintenance and other tasks are more precisely determined, so tasks are not performed too frequently or infrequently.
- Risk: Safety and environmental integrity are a priority and dealt with quantitatively. Unacceptable failure consequences are dealt with. Hidden failures are dealt with, so the likelihood of multiple failures is reduced. Invasive work is minimized wherever possible, reducing the risk that maintenance activities will induce failures.

SIMPLIFIED RCM METHODS

In addition to its reputation as the best method for developing proactive approaches, RCM is also thought to be both challenging and expensive to implement. Admittedly, it does require effort and time, and of course, there is a price to be paid—there is no free lunch. However, RCM's negative reputation was earned as a result of failures to implement it correctly, not because the RCM method itself is flawed. Various competing "brands" of RCM have arisen to capitalize on its perceived weaknesses. These simplified methods invariably leave something out of the seven-step process or attempt to automate something that is still well beyond the capability of computers to do—think like a human. *Beware when using these "streamlined" or "simplified" methods, because you are taking risks that could negatively impact safety, the environment or your operations*. However, where you are confident that those risks are negligible or nonexistent, simplified methods may be helpful.

One such method eliminates some of the first steps in RCM (defining the operating context, functions and functional failures) and leaps directly to listing failure modes. This is a shortcut to the RCM method that produces quick results that are certainly better than doing nothing but far short of those produced using the proper RCM process. It is useful for noncritical[17] equipment and where there is an urgent need to put a program in place but insufficient time to perform an RCM analysis.

IMPLEMENTING RCM SUCCESSFULLY

To achieve success and manage change in an existing operation, there are a few key success factors to observe:

- Have clear and quantifiable business improvement goals and success metrics, and monitor your progress toward them as the analyses are completed.
- Strong leadership and project management skills; create a reliability project management office (RPMO).
- Involve your unions or employee associations in the process.
- Effective RCM teams and efficient business work processes.
- Integrated CMMS/enterprise asset management (EAM) system/enterprise resource planning (ERP) system database programs to manage the RCM results.
- Provide widespread training in RCM. The process will initiate a significant shift in corporate culture and training, which is an excellent way to get it off to a good start. Go well beyond those who will participate directly in the process.

- The business culture to sustain the results and ensure program compliance. Prepare yourself to manage substantial shifts in the way your maintainers and operators work to accommodate the results of your analyses. There may, for example, be concerns about job loss if workloads seem to be dropping.
- Integrate the RCM effort with other PM improvement programs.
- A solid management of change and continuous-improvement environment.

RCM complements other improvement initiatives, such as JIT, total quality management (TQM) and TPM. The basic building block of the RCM strategy is the cross-functional RCM review team of company employees, trained on the 3-day RCM introductory course.

Today's challenging maintenance environment demands a thorough and comprehensive approach to determining what work to do. RCM is the best method to do just that. In fact, if RCM is properly applied to a fully developed, traditional time-based PM program, it can reduce the amount of routine (i.e., cyclic) PM workloads by 40%–70%. RCM's benefits can be seen in improved safety and environmental performance, better service and throughput, improved quality of performance and reduced business risk. Although it clearly involves the help of several functions in the organization, it is very much a proactive asset-reliability methodology. The next chapter deals with other, complementary methods.

UPTIME SUMMARY

Doing the right maintenance is just as important as doing it the right way and in a timely manner. If you are going to achieve the reliability that is designed into the physical assets you are using, you must do the right maintenance. Beyond that, you must operate the equipment without abusing it, overloading it or otherwise operating it out of its intended range. Of course, the equipment must be capable of doing what you want it to do, its operating instructions must be correct and its operators must adhere to them. Success with your assets means achieving the reliability that your assets are capable of attaining. Those companies are truly choosing excellence.

Being proactive with your assets is all about managing the consequences of failures so they have the least negative impact on your business. Being proactive reduces risks. The advantage to doing this is that major business impact due to equipment breakdown can be avoided. High-performing companies manage proactively by foreseeing and avoiding problems. You can forecast what is likely to happen (failures) and decide in advance about what to do about those failures using a well-established and highly successful method—RCM.

RCM was developed in the aircraft industry and has achieved significant reliability improvements in aircraft. It is roughly 120 times safer to fly today than it was before RCM was developed. Despite its roots, it can be used in any industry and on any type of physical asset. When developing a maintenance program from scratch for a new project, it is unbeatable. RCM is a logical seven-step process. It can be applied to any asset in the early design stages, in the detailed design stages (preferably both), or later, after the asset has entered service.

RCM leverages the results of extensive studies of how things fail, combined with an understanding of the consequences of those failures, to prompt logical decision making for individual asset failure management policies. It produces maintenance tasks (preventive, predictive and detective); operator tasks (e.g., very specific inspection rounds); decisions to run to failure (where consequences are tolerable); and decisions to make modifications to procedures, processes, design and other factors that may be leading to failures.

One of the great strengths of RCM is that it does not require failures to have occurred in order to generate data for analysis. It is proactive. A trained RCM team, led by a highly qualified RCM facilitator, anticipates the most likely failure modes and deals with them and their consequences before the fact. Above all, RCM offers high reliability at optimum cost, balancing costs with risks in order to meet what your organization deems tolerable. Safety, environmental performance, quality, productivity of your assets and maintenance costs all improve. This is always done specifically for your assets in your operating environment. Any tendency to overmaintain or undermaintain, often a result of using other methods or following manufacturers' recommendations, is avoided.

Since it was developed in the 1970s and applied in aircraft, RCM has been used extensively in nuclear power, military systems, various fleet management environments, mining, oil and gas, chemicals, pulp and paper, gas, water, wastewater and electric utilities, telecoms, pharmaceuticals, facilities management and even hospitals. Today, you can find RCM in use in all sorts of capital-intensive industries where sustainable reliability is important. It is the cornerstone of many reliability improvement programs, especially those in successful companies.

RCM's success is based in its sound technical underpinnings and their application but depends heavily on careful application of the process and follow-up by implementing the results in your maintenance program and then keeping those results "fresh" as you learn in a continuous-improvement cycle. Many failures of well-run RCM programs have occurred because the outputs of the analysis are not put into practice in the operational environment or they were allowed to go stale over time as the operating context, use of the assets and other factors changed. Successful organizations keep their RCM programs alive using reliability analysis (based on good data collection and experience in operating the assets) long after the initial analyses were carried out.

ENDNOTES

1. John Moubray was a recognized leader in the field of reliability management. He authored *Reliability-Centered Maintenance II*, which was first published in 1991 by Butterworth-Heinemann, Oxford, UK.
2. There are many textbooks on reliability that present precise mathematical definitions. The reader is encouraged to review these. One particularly good reference is *Maintenance, Replacement, and Reliability* by A.K.S. Jardine, originally published in 1979 and revised in 2005 by Pitman.
3. See the definition and discussion in Chapter 6.
4. RCM is a very useful methodology that helps us determine where PM is and is not appropriate as a failure management policy.
5. See definition and discussion in Chapter 6.
6. Conditional probability of failure is the probability that a system or item will fail given the "condition" that it has survived up to a particular point in time. If the curve is flat, it means that there is no relationship between this probability and time or age.
7. There are several studies of these patterns with varying results. The most common range shown is from the studies where equipment is not "run in" extensively after repair. This equates to the most common industrial situation where equipment is repaired and then returned to service with very little or no run-in/testing period.
8. An alternative, albeit less thorough, approach for existing operations, known as PM optimization, is discussed in the next chapter.
9. A "hidden" consequence only becomes evident to the operating crew *after* a protective device *and* a protected function has failed. This is the definition of a "multiple failure."

10. The most successful companies also opt for formal 1-day or 3-day introductory training in RCM before taking any action so that they fully understand what it is they are getting into from the outset.
11. On assets deemed noncritical, some choose to perform a streamlined method of RCM rather than do nothing.
12. Although this seems excessive to many readers, it is the most effective way to gain buy-in from the workforce so that the results of the analysis are implemented effectively and with minimal resistance.
13. It is important to note that the P-F interval is not the same as the life of an asset. The P-F interval applies mostly to assets exhibiting random failure characteristics—not age or usage related.
14. Infant mortality is the term given to RCM's sixth failure pattern—curve F.
15. Detailed coverage about how to calculate failure-finding task frequency can be found in Chapter 8 of John Moubray's text, *RCM II* (Oxford, UK: Butterworth-Heinemann, 1991).
16. See the next chapter, on reliability and simulation modeling techniques.
17. "Noncritical" means that there are no safety or environmental consequences likely to arise from equipment failures and that their operational consequences can be tolerated. This presupposes knowledge of the consequences and, hence, the failure modes that lead to them, yet that knowledge is not always there. Defining equipment as noncritical without thorough analysis is inherently risky. The analysis to define criticality can be as time consuming as the parts of the RCM analysis being avoided, so the author questions the value of this approach on its own. Where this method is applied, RCM should follow when there is sufficient time to perform it.

9

Asset Reliability 2: Quick Start and Continuous Improvement

> Every day you may make progress. Every step may be fruitful. Yet there will stretch out before you an ever-lengthening, ever-ascending, ever-improving path. You know you will never get to the end of the journey. But this, so far from discouraging, only adds to the joy and glory of the climb.
>
> **Sir Winston Churchill**

The previous chapter explored reliability-centered maintenance (RCM), an entirely proactive, asset-centric approach to excellence. RCM is proactive because it anticipates what is likely to go wrong in the future. With this knowledge, you can avoid any undesirable consequences and prepare for the anticipated event appropriately. While RCM enables quantum leaps in performance, it can be preceded or enhanced by other reliability-focused continuous-improvement methods. In continuous improvement, failures (our mistakes) become learning experiences. Because important things have been learned, similar failures can be avoided in the future. In this sense, these methods can be considered to be reactive to what has already happened. They provide incremental improvements and can be used independently or in conjunction with RCM or within the context of total productive maintenance (TPM) as described in Chapter 2. They can also be built into our reliability management process.

In the Deming cycle of quality (plan, do, check, act), RCM can be considered the primary "planning" activity; its implementation is "doing." Monitoring of results/performance is "checking," and the steps taken to correct any deficiencies are our way of "acting" on those results. The methods described in this chapter are tools for acting on results and making continuous incremental improvements.

The methods in this chapter can also be used on their own, or in combination, to address reliability improvements in the absence of RCM or as complements to an RCM-based program. They are not limited to use only after RCM is done, although that will produce the greatest benefit if used that way. One example of this is that root cause failure analysis (RCFA), which deals with only one (significant) failure at a time, can be used to put out the metaphorical fires and help you get your operations "under control," freeing resources for you so that RCM can be applied in a less stressful and less panicked environment.

Truly excellent companies use the continuous-improvement methods described in this chapter to complement and improve upon what they can achieve. These methods generally require good information from data to be most effective. Asset information management is dealt with in Chapter 12. Companies that choose to rely solely on the methods in this chapter will experience improvements, sometimes substantial ones, but they will more than likely take a long time to do so. As Churchill noted, the path is ever lengthening, ever ascending and ever improving.

PREVENTIVE MAINTENANCE OPTIMIZATION

As a proactive approach, RCM was designed to be used at the design stage of any asset's life cycle but has also proven itself once the asset has been put into service. In fact, today, RCM is more often used after an asset has been put into service to develop or, more correctly, to redevelop a failure management program. If a plant, portfolio or fleet of assets is put into operation or service without adequate attention to its maintenance program (as is often the case), then maintainers and operators will quickly develop a combination of maintenance and operator tasks that aim to manage or eliminate the consequences of failures. Manufacturers' recommendations, the past experience of maintenance and operations people, problems already experienced and dealt with, outputs from process safety analyses and the results of RCFA are all used to develop those tasks. Many of these tasks are performed informally and on an ad hoc basis, often without any documentation, especially if performed by operators. Others are formally documented and managed by planners in the maintenance management system. Even without the benefit of a formal RCFA, people often add preventive or inspection tasks in response to failures that occur. These organically grown programs typically expand as failures continue to occur and new experience is gained. These programs may or may not address failure modes effectively, but seldom are they questioned.

Eventually, for a variety of reasons well explained by Turner (2001), these programs tend to deteriorate. The vicious cycle usually begins at the design and commissioning stages. Maintenance engineers are seldom involved in these stages. If they are, they generally deal with project work that consumes their maintenance budget because the projects are invariably over budgetary limits. At this point, the new asset or plant has yet to receive all its spare parts and is going through its start-up phase, normally characterized by teething problems (failure pattern F, as described in Chapter 8). Documentation for maintenance is lacking, and maintenance analysis, if any, is incomplete. At commissioning time, the design team leaves, and the maintenance engineer is left to second-guess the design intent while supporting operators who are testing the systems, often push them beyond their limits. Design and maintainability problems surface, but there is no project money to correct them. Maintenance policy is developed in an ad hoc fashion, often using traditional approaches that result in overmaintaining and generating additional problems in the process. The new maintenance program is put in place, again with little or no documentation. This lack of adequate documentation is discussed and dealt with in depth in Chapter 12 on asset information management. As the plant ramps up to full-capacity maintenance, the number of tasks and the frequency of tasks multiply as new problems surface. "More is better" becomes a maintenance standard. The maintenance workload soon exceeds available labor, and repair takes precedence over prevention or prediction. Fewer failures are prevented, and the workload grows. Rapid and temporary repairs are performed, and reliability suffers.

This cycle is all too common. The situation deteriorates to the point where minimal maintenance resources (staff) can barely keep up with the breakdowns that prevent operation. Availability ends up well below benchmark levels, and maintenance costs are usually high. The situation is unacceptable to the business; eventually, something will be done. The primary focus of that something will usually entail cutting costs and increasing reliability, often in that order. If the situation has not deteriorated to a critical state, the company may even try to improve on its maintenance program by using RCM, either across the board or (more commonly) by selectively focusing only on key assets. Another alternative is preventive maintenance optimization (PMO).

Whereas RCM begins with a zero-based functional approach, PMO does not. It begins with an existing maintenance program, evaluates its effectiveness, looks for critical omissions and then rebundles the results into a more effective program. Because PMO begins with an existing maintenance program, it is unsuited for use at the design stage of a project. Popular methods of PMO include OMCS's PMO2000[1] and Fractal Solutions' PM Optimization.[2] The two are similar. Typical steps in the process include the following:

1. Prioritize the assets to be analyzed based on their importance to the business. Priority is given to those assets that can cause safety, environmental or severe business consequences when they fail.
2. Compile a listing of the existing maintenance tasks being performed by maintenance and operations personnel. Gather the information for this list from existing PM records, your maintenance management system, operating procedures, checklists and interviews with operators and maintainers.
3. Determine the failure modes that the maintenance tasks address.
4. Determine additional failure modes that might not have already been addressed.
5. Determine what functionality would be lost as each failure mode occurs. Some methods consider this step optional because the consequences are usually apparent.
6. Describe the effects of each failure (briefly and concisely).
7. Describe the consequences of failure (safety, environment, business loss, etc.).
8. Describe what can be done to predict or prevent the failure.
9. Describe what can be done if you cannot predict or prevent the failure.
10. Review the results and approve implementation.
11. Implement the results in the field.
12. Continuously review the program for improvements. Like RCM (which also promotes a "living program" after the initial analyses are completed), this step is often done poorly or missed entirely.

Once the failure modes have been identified, the remainder of the PMO approach is essentially the same as RCM (except for the sequencing of steps). The PMO methods take advantage of the fact that an existing maintenance task may address several failure modes at a time and that examining the failure-mode lists generated makes it easy to spot duplicate tasks. RCM's strength, at the design stage, is that you do not have to experience the failures in order to do something proactive to avert their consequences.

Neither method is entirely perfect. Even the authors of PMO methods acknowledge that RCM is more thorough. They deal well with hidden combinations of failures, but neither method deals well with multiple failures in combinations if such failures are evident to operators. These evident combination failures are dealt with more effectively using fault tree methods or, after the fact, using RCFA methods.

There is a great deal of competition among practitioners of RCM and PMO, and these practitioners support their respective positions with excellent arguments for why their particular method is the best. Be aware that both methods work well and that both have strengths and weaknesses. Explore them both thoroughly and carefully consider your operating and regulatory environments before choosing one or the other. Alternatively, you can choose to use both in a complementary fashion.

Many successful companies use RCM only for "critical" assets. Those are assets having significant business, environmental or safety impacts when they fail. There are a variety of ways to determine criticality, but regardless of method chosen, only those assets with criticality ratings above some cutoff point are subjected to RCM. Simply doing nothing about the other less critical assets will leave failure modes that can be economically prevented or predicted without any form of mitigating action. PMO, in cases where an existing program is in place for those assets, can be used to "optimize" that program for those noncritical assets. It is also quite possible that there are noncritical assets that are already performing well and subject to an existing PM program. In those cases, it may make sense to simply "do nothing"—i.e., leave the existing program alone and ignore it when applying PMO to those assets that are underperforming.

Root Cause Failure Analysis

RCFA (sometimes known as root cause analysis [RCA]) is used after the fact to deal with failures that have already happened. It is inherently reactive and aims to identify the various causal factors that led to the failure to determine which, if any, of those factors can be dealt with differently to avoid having the problem arise again. A root cause is the most basic reason for the problem occurring that, if eliminated, will eliminate the problem. It is always an event or conditions in the chain of events that led to the particular problem you are trying to solve. In most cases, you will find that there is more than just one significant cause to be dealt with. Often, failures result from combinations of causes, at the very least some preexisting condition in combination with some event that triggers another event or leads to another condition. RCFA is one of several problem-solving[3] approaches widely used in the maintenance world.

A common challenge to companies embarking on RCFA is the determination of what problem to tackle first. Pareto analysis and log scatterplots are excellent methods for prioritization.

One of the simplest yet most powerful tools to determine where to focus your efforts is the Pareto diagram. Vilfredo Pareto, an Italian economist (1842–1923), observed that 80% of the land in Italy was owned by 20% of the population. He thus came up with the legendary 80–20 rule that seems to apply in most fields of human endeavor. It is a rule of thumb, and the percentages are not always exactly 80% and 20%, but they will be close. For maintenance, the rule means that 80% (or so) of the problems are associated with 20% (or so) of the equipment. TPM teams can focus their efforts on the problematic 20%. Pareto diagrams are used to identify problems in planning and scheduling of work and to analyze overall equipment effectiveness (OEE).

The Pareto diagram is a bar chart. The length of each of the bars corresponds to the number of occurrences of each failure type. It is used to help prioritize work and helps separate the vital few from the trivial many. In Figures 9.1 through 9.3 the downtime of an oriented strand board (OSB) plant manufacturing line is analyzed using monthly failure records. In Figure 9.1 you can see each step of the process in sequence; the number of failures; the downtime that each step incurred; and the repair, downtime and total costs.

The data can be sorted several ways to determine the equipment that requires attention first. Figure 9.2 shows that problems can be sorted by number of failures, by downtime, by repair costs and by downtime costs.

The process equipment that requires the most attention is on the left-hand side of each plot. But notice that each sort provides a different initial focus. Debarking has the most failures, pressing the highest repair cost, stranding contributes the most downtime and the forming line has the highest downtime (production-loss) costs. Which is the most important?

OSB manufacturing Pareto analysis

Step #	Process steps	# of failures	Total downtime	Cost of repair	Cost of downtime	Total downtime cost
1	Log sorting	13	5	$5000	–	$5000
2	Jack ladder	12	7	$7000	–	$7000
3	Debarking	24	20	$20,000	–	$20,000
4	Stranding	18	35	$35,000	–	$35,000
5	Wet bins	2	1	$1000	$5,000	$6000
6	Drying	3	4	$8000	$4,000	$12,000
7	Blending	5	7	$28,000	$7,000	$35,000
8	Forming Line	7	9	$36,000	$45,000	$81,000
9	Pressing	3	8	$ 56,000	$40,000	$96,000
10	Finishing Line	8	19	$19,000	$19,000	$38,000
11	Shipping	5	2	$2000	–	$2000
		100	117	$217,000	$120,000	$337,000

FIGURE 9.1
OSB plant downtime data.

A maintainer will carry out repairs and will probably focus on numbers of failures or repair costs because these costs are paid from the maintenance budget. A production manager who is worried about getting product delivered will be more worried about downtime and downtime costs because they keep him/her from meeting production targets. These are competing priorities, and focusing on one hurts the other. Pareto analysis can also be cascaded, taking the top 20% by one criterion, resorting by a secondary criterion, a third and so on, until you get to the top priority for action.

There is also the total business impact to consider. If you add the costs of repair to the opportunity costs associated with downtime, you get the total cost to the business overall (Figure 9.3).

Figure 9.3 shows that the pressing process has the highest combined cost of repair and downtime, followed by the forming line and then finishing. By plotting the graph over different time periods (weekly, monthly and annually), it is possible to discern which problems are chronic and which are acute.

Logarithmic scatterplots can also be used to plot mean time to repair versus frequency of failures and show lines of equal downtime. These are excellent tools that reduce the effort required to compile the decision-making criteria from several Pareto charts into a single diagram, as shown in Figure 9.4. Lines of constant downtime are easily plotted showing, like a Pareto diagram, which failures make the largest contributions to downtime. The plot can also be divided into quadrants showing acute and

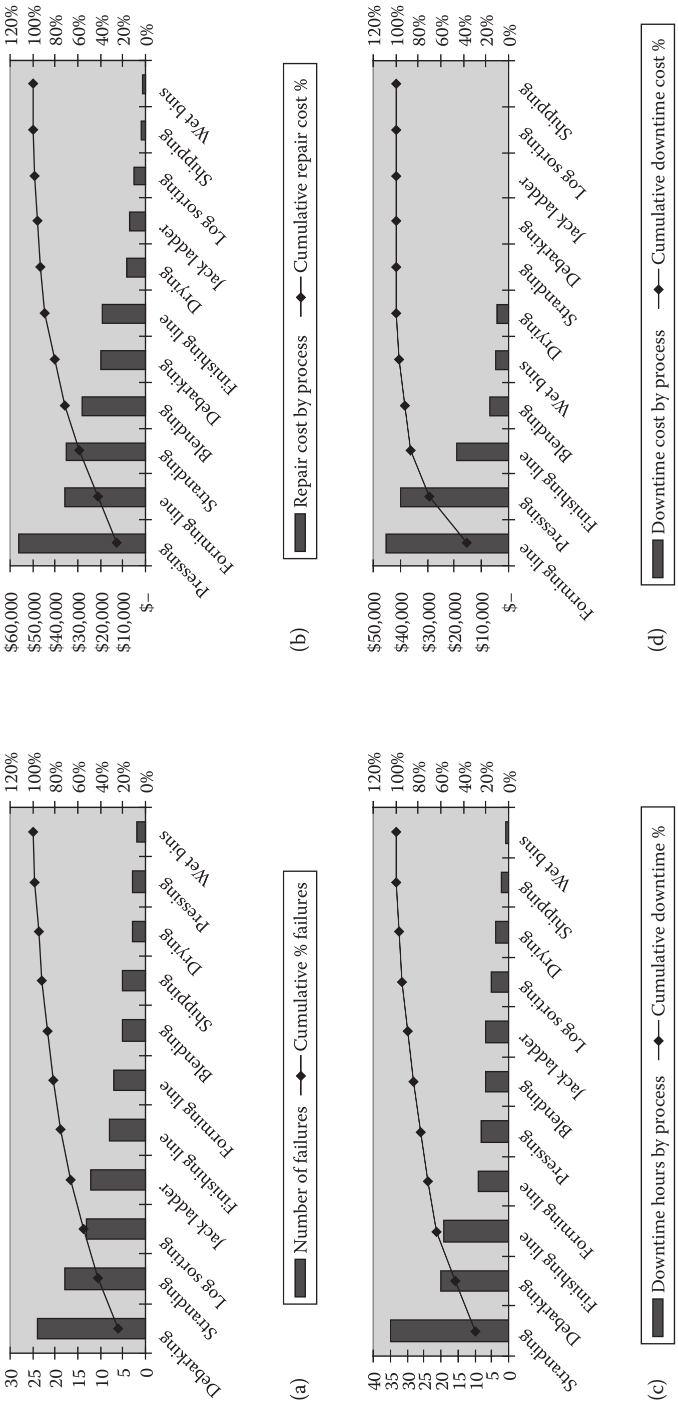


FIGURE 9.2
Various possible Pareto sorts: (a) by number of failures, (b) by repair cost, (c) by downtime, and (d) by downtime cost.

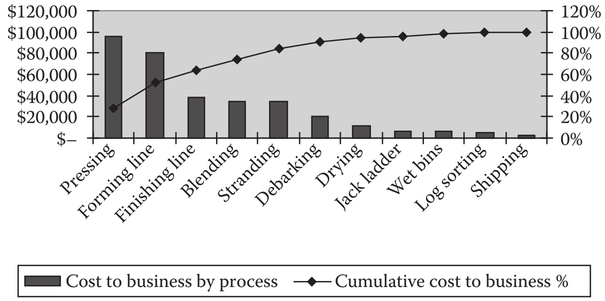


FIGURE 9.3
Pareto sort by overall cost to business.

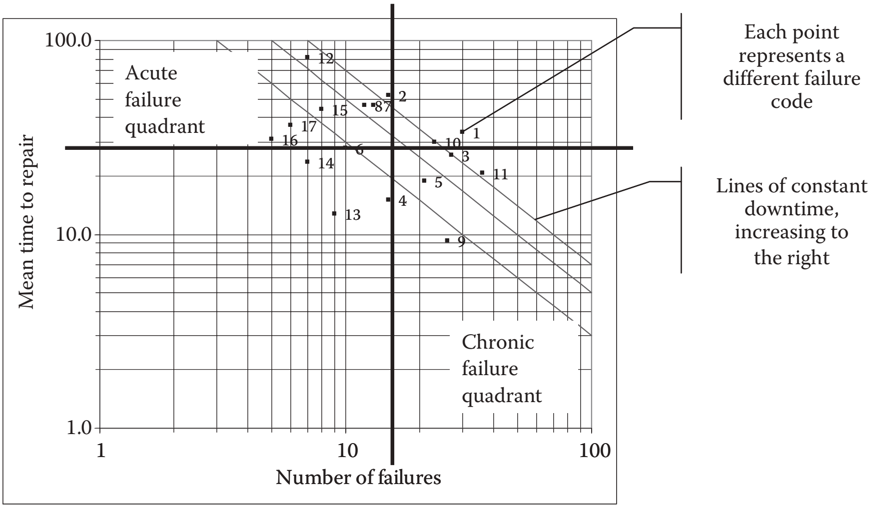


FIGURE 9.4
Log scatterplot of mean repair times versus number of failures. (Adapted from Knights, P.F., *J. Qual. Maint. Eng.* 7(4), pp. 252–263, 2001. Emerald Group Publishing Ltd., Bingley, UK.)

chronic failures. Acute failures are infrequent but significant contributors to overall downtime, while chronic failures are those that occur frequently. The upper-right quadrant includes top-priority failures that have both high downtime and high frequency of occurrence. Efforts to improve the business overall will be focused on those areas that are most significant over the longer term.

Once you have the problem you wish to tackle identified, you have a variety of RCFA variants from which to choose. One popular and very-easy-to-use method is known as the Five Whys. Simple and effective, this is similar to the learning process of inquisitive children and is widely used in the analysis phase of the Six Sigma "design, measure, analyze, improve, control" (DMAIC) approach for existing systems. It is also a popular feature of the Toyota Production System of Lean manufacturing and has been used extensively on its own. The Five Whys technique does not require the use of analytical tools like data segmentation, hypothesis testing, regression or other statistical tools. Simply asking "why?" an average of five times penetrates the layers of symptoms that often obscure the root cause of a problem. It is like peeling an onion, but there are usually fewer layers. Five questions is only a rule of thumb. Occasionally, you will get to the root of a problem with fewer questions; sometimes, more are needed. The trick is to stop when you have found some condition or event that you can manage and, hence, manage the entire chain of events.

RCFA using the Five Whys is easy to do without a lot of additional tools and supporting data, but you do need knowledgeable participants in your analysis team. It works very well in situations when statistical analysis does not help—for example, when problems involve human factors or human error. The method is very simple:

1. Gather a problem-solving team comprising those who know the issue best and are most likely to have a positive contribution to its solution.
2. Write down the problem and be specific. By writing it down, you increase your focus on the problem. You can clearly see what it is and what it is not. This helps to keep the team on track.
3. Ask the group why the problem has arisen. Brainstorm for an answer. You might get several possible answers. Cluster your answers to eliminate duplicates (some answers may simply be stated in different ways).
4. Explore all answers. Eliminate those least likely to take you to a practical solution. If an answer does not provide you with something that suggests a solution, ask the question again, focusing on that particular answer.

An example problem illustrating this Q&A process comes from an oil-loading facility. The cargo loading pump that moves crude oil from the onshore storage tanks to the bulk cargo tankers failed while in service.

Q: Why did the cargo loading pump fail in service?
A: Because it ran dry.

Q: Why did the pump run dry?
A: Because after pumping from the storage tank to the ship for several hours, the tank was empty, and the pump was left running.

Q: Why was the pump left running on an empty tank?
A: The pump was left running on an empty tank because the operator had other work to do, and there is no low-level shutoff switch to shut it down automatically.

At this point, you have a root cause—a problem that can be solved relatively easily—and you got there with only three questions. You can stop here and simply add a low-level shutoff switch and circuitry to eliminate this cause of the problem. Or, you could delve further:

Q: Why was there no low-level shutoff switch?
A: Because our design standards don't call for it. The contractor that built the loading facility didn't include it.

You can now move to correct a deficiency in your design standards and avoid any other future occurrences of the same problem. Of course, you will also want to check other pumping facilities to see if they already have the same problem.

The Five Whys method is simple and versatile and can be used in tandem with a number of analytical tools. It does, however, have a few limitations:

1. It relies on brainstorming for potential answers. Some groups (and this often applies to small groups) lack the creativity to do this effectively and can miss some useful answers. A large group, on the other hand, may produce too many answers. Exploring them all (with more whys) can lead to analysis paralysis.
2. It is not always repeatable. Different groups analyzing the same problem can easily come up with different solutions. This is not necessarily a bad thing; there is often more than one perfectly feasible solution to any given problem. It can, however, be counterproductive if too much time and energy must be expended on sifting through too many answers. The quest for perfection is a common reason for these and other methods we use to bog down and fail to produce results in a timely manner.

3. It may not identify a root cause. There is no way to be sure you have actually hit the root cause that provides the best opportunities to solve the problem. The ability of the group to identify root causes is dependent on the extent and depth of talent available within the group. Brainstorming is essentially a creative process, and it relies on creative minds. The example above illustrates that there were two root causes, depending on how far the group was willing to go in its questioning.

The Five Whys can also be used in conjunction with other forms of cause-and-effect analysis, such as the fishbone diagram or fault trees. Figure 9.5 shows a fishbone diagram for a pump failure incident similar to the one described above.

The diagram considers that there are three categories of causes that could have contributed to the failure: people, the asset design and the process itself. In each case, you ask why it could have contributed to failure. Keep asking why until you get a useful answer that suggests a practical solution. In this case, two possible corrective actions emerge: putting more emphasis on operator training and changing design standards for this type of system.

A fishbone diagram helps identify various possible causes of any effect. For any potential cause, the Five Whys can be used to drill down to root cause. The fishbone diagram is adaptable and can be modified to include

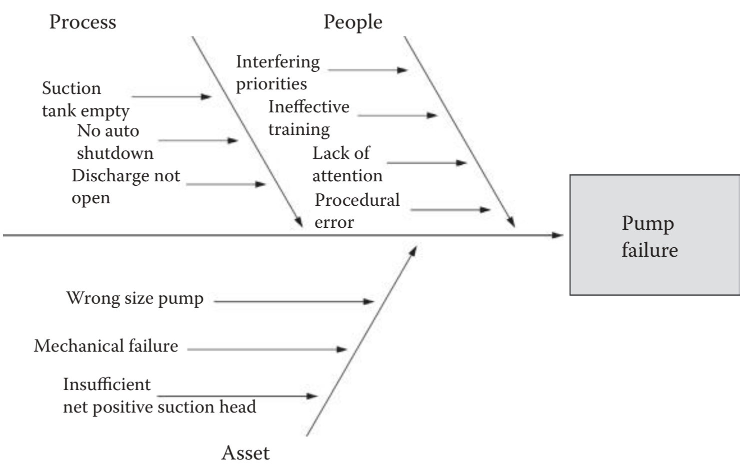


FIGURE 9.5
Fishbone diagram.

additional categories of failure-causing events or conditions. In manufacturing, for example, these might include machine, material, method, measurement, environmental and people factors. For most maintenance problems, the "machine" or "asset" category and the "people" category are the most important. The machine or asset is often examined alone, but it is also useful to consider people, processes, methods, materials, environment, application and applied operating load.

Caution is needed when using fishbone diagrams. Because they categorize the potential causes of a failure event, it is possible to miss an entire category. If you find a possible cause that does not fit within one of the categories you have chosen, then you may need to add a category. Alternatively, you may struggle to find causes in one of your chosen categories. In that case, you may be overthinking the problem.

Fault trees are more complex than fishbone diagrams and are usually used in the design of systems that require high reliability (such as nuclear plants or avionics), where it is critical to quantify the probabilities associated with various combinations of events that can potentially lead to undesirable consequences. The effort and time required to carry out a thorough fault tree analysis can be significant. Its big strength is that unlike other methods, it inherently considers various combinations of conditions and events, including very unlikely combinations that could lead to a failure.

There are several commercially available methods that achieve RCFA goals. Root Cause Analysis (Latino and Latino 2002)[4] is another popular and successful method that has been formalized by Robert and Kenneth Latino and marketed under that name. In Europe, TapRooT is another widely used commercial variant.[5] Apollo Root Cause Analysis methodology (Gano 2008), the Kepner Tregoe[6] Problem Solving and Decision Making method and others are all successful methods.

Some companies choose to improve reliability solely through the application of root cause methods. In doing this, they focus their efforts only on high-value (or highly critical) failures with pinpoint accuracy. The downside to this approach is that it only deals with those failures that have already happened. They have always suffered the consequences of those highly critical failures at least once before they do anything outside of their existing PM program to prevent or predict them. It is also safe to say that their existing PM program is somehow missing the mark. Of course, that can happen in cases where the PM program is defined using the far more thorough RCM method—failure modes can be missed. However, the probability of missing critical failures with RCM is far lower than if a PM program is deployed as they often are and described earlier in this chapter.

As with RCM and PMO, successful companies also use these root cause methods in a complementary fashion. RCM is great for defining your failure management tactics for critical assets; PMO is great for your non-critical assets. RCFA closes the gaps that may have been missed using both RCM and PMO—dealing with failures and failure modes that were missed in the initial analyses. RCFA is also an excellent tool used as part of the RCM and PMO living programs to ensure continuous improvement.

Decision Optimization

Decision optimization refers to the use of any one of several optimization tools. These tools are used to make decisions about asset replacements, repair versus replacement, fleet replacements, inspection intervals and repairs. As seen in Chapter 5, similar mathematical modeling methods apply to materials management. You can even apply optimization methods to organizational decision making to determine staff sizes.

Asset optimization tools enhance reliability and reduce costs. They add value to the output of RCM and may lead to modifications in RCM or PMO output decisions. They may also be used in conjunction with RCFA or on their own. They are particularly helpful in the area of capital planning to identify the timing of investments that will minimize the life-cycle costs associated with ownership of an asset.

Unlike the Five Whys method, decision optimization tools require data. The various mathematical methods that are familiar to reliability engineers are included in this category of technical tools. They typically deal with specific technical problems that require solutions based on statistics and economics. Like the root cause methods, these tools are often used after the data have been collected. Of course, you do not need to wait for a statistically significant number of failures to occur before using them; you can rely on data collected by others and available in databases if they are reasonably likely to be representative of your circumstances. That is what many reliability engineers do when designing new systems that require high reliability. Because they cannot afford to wait for failures on what are very often highly critical systems before making decisions, they rely (at least initially) on databases of relevant failure statistics.

There are many mathematical approaches to solving typical maintenance and equipment replacement problems. Many of these have come from the field of operations research. Some of the problems[7] that can be solved include the following:

- Optimizing the age at which equipment replacements are made using various usage and operating-cost profiles to determine the most cost-effective age for replacement
- Optimizing the decision for the time to swap duty and standby equipment combinations to achieve maximum backup availability and reduce the risk of multiple failures
- Optimizing the decision about when to replace capital equipment to maximize discounted cash flow benefits or to minimize total costs
- Optimizing the intervals between preventive replacements to achieve target availability
- Optimizing the time for group replacements of a large number of identical assets instead of replacement as they fail, in order to minimize overall cost (e.g., replacing lamps in a large factory or warehouse)
- Optimizing inspection frequencies to maximize profits, minimize downtime and maximize availability of emergency equipment
- Optimizing decision making related to overhaul and repair versus replacement policies and cost limits

Jardine[8] has provided excellent coverage of these and many other maintenance management decisions. The problems described in his book are based on statistical approaches, and the book also provides numerous illustrative examples. Extensive coverage of these methods is beyond the scope of *Uptime*, but be aware that these methods exist and merit at least a review.

Many maintenance problems can be solved using data analysis tools—software programs that can manipulate the data and produce the answers. There are many of these software tools available; most are stand-alone programs that can be interfaced or integrated with corporate databases. Several collect condition-monitoring signals that are input from field sensors and use those data in real time with history data and economic inputs to produce recommendations about whether to run equipment or to shut it down for work. All of these tools depend on accurate data to produce the best results.

Suffice it to say that these methods produce statistically and economically sound decisions—provided that the data used as input are accurate. That raises a significant point. The data collected in many management systems today are often faulty and incomplete.

Many companies that have embraced these methods and engineers trained in their use have run into significant data roadblocks, and missing data records about failures have led to misleading analysis—a failure rate may appear lower than it really is. Conversely, maintenance records that do not distinguish between repairs to failed equipment and repairs "just in case" can lead to the mistaken belief that failure rates are worse than they really are. Both problems—missing data and incorrect categorization of repairs—are widespread. One coal mining operation in Canada had extensive maintenance records. Rather than relying on these records, the company resorted to data sampling and deployed its engineers to collect the data for analysis. The engineers compiled accurate data, and this led to good results and significant improvements, but the data-gathering process took far longer than expected. In another example, a mobile equipment maintenance service provider hired a mechanical engineering student to visit the maintenance departments of four mines to determine the actual life of some critical large components. The available data were so sketchy that the results of the study were estimated to be accurate within ±50% at best! Dr. Jardine's work has led to a far greater awareness of the mathematical tools and their applications in the maintenance and asset management realms. Arguably, he has made the maintenance engineering world aware of a new gold standard in decision making—evidence-based asset management—which is discussed in depth in Chapter 10.

Information technology (IT) has come a long way since the first edition of *Uptime* was published in 1995. Unfortunately, the ability to use it has not kept pace. IT professionals often say, with some justification, that you can get a great deal of information from their systems. In truth, you can often get a great amount of data; less often, you can get true information (i.e., data in a meaningful context). That data and information are often in the form that the system designers thought you would use. Unfortunately, very few system designers know much about equipment reliability, and this sometimes defeats the objective. For example, one simple piece of information that is often missing from corporate maintenance databases is whether or not the item that was repaired on any given work order was actually found in the failed state. Once that information is lost (or there is a failure to enter it), it is nearly impossible to fill in those gaps. That one piece of missing information renders many corporate maintenance databases almost useless from a reliability analysis perspective. It is not the fault of the IT people but a result of poor definition of information requirements (not an IT job), integration (often budget constrained or simply left out) and communication (everyone shares responsibility for this one). The maintenance and reliability professionals have not told the IT people what they want. And often, even if they are asked, they themselves do not really know what they want. Fortunately, as the maintenance profession becomes truly professional, this situation is likely to improve. Chapter 10 deals with this problem of missing, incomplete and inaccurate data in its discussion of "knowledge elicitation," thus enabling optimization even in the absence of conventionally collected data in IT systems. Chapter 12 presents a framework for Asset Information Management and its governance so that useful information is more readily available.

RELIABILITY AND SIMULATION MODELING

When determining the most important area of a plant to improve and deciding how to allocate scarce reliability engineering resources, some companies use elaborate ranking schemes. These schemes are often based on criteria that are important to the company because they impact safety, environment and production output. Another technique is to build a computerized reliability model or a process simulation model of the plant systems. Reliability modeling involves complex mathematical models[9] that use computer software tools to model system reliability and availability. In simulation modeling, computers imitate, or simulate, the operations of various kinds of real-world systems, facilities and processes using largely statistical models. Both of these modeling techniques are excellent tools for revealing just where the plant production processes are most bottlenecked or constrained. For example, if a certain machine tool's capacity or reliability is limiting production, it can be targeted for reliability improvements, capacity increases or even replacement with a higher-capacity machine. Sometimes, these constraints are obvious to those in the plant, but that is not always the case.

A simulation model was used in a facility that processed spent nuclear fuel bundles for long-term storage. The newly installed systems seemed to be incapable of performing even close to the desired production levels. The modeling revealed that the overall process could not reach desired throughput because of flaws in the combined reliability of all machines in the process. It also revealed that certain machines were not performing up to their expectations because of constraints on inputs from other machines.

Overall, the processing-line configuration was not well balanced. Various physical configuration and operating procedural changes were modeled and showed that performance could be substantially improved without substantial new investment. The changes were made, and performance was improved (albeit not quite to the originally desired levels).

Simulation models can be used to simulate the anticipated benefits of various other improvement initiatives, such as RCM. If you target an improvement in one critical area, you can often see the impact (positive or negative) on other areas. This can be a big help in the planning improvement efforts, which can achieve multiple desired results and avoid or ameliorate undesirable results in other areas.

Increasing Awareness

Many professional development courses that focus on the methods and techniques discussed here are available to today's maintainers. Most of these courses are geared to promote a full appreciation of the value of support systems and data accuracy. Moreover, the mindset of responsible and mature maintainers is shifting from "fix it when it breaks" to "be proactive in avoiding the problems in the first place." There are many things that you can do to enable this attitudinal shift within your company. Hopefully, one of those options will be sharing *Uptime* and its principles with your people. Explore the work of researchers in maintenance and reliability and investigate the numerous technological advancements being made in the field of condition monitoring. You will find that the more you learn, the more you need to know, and this, as it should, will lead to additional productive research because learning, like continuous improvement, is a never-ending journey.

UPTIME SUMMARY

RCM is not the only reliability improvement method you can use to choose excellence. While it is the best you will find, it may be overkill for some less critical equipment and systems. Using the right blend of reliability methods is more cost-effective and delivers just as good a result. RCM takes time to implement. For a greenfield application, you have the time, but if you are already in operation and have an "out-of-control" situation, you need to reign in rampant failures quickly. You need to act quicker than you can doing RCM analyses alone—at least in the early stages of getting things back under control.

Equipment failures disrupt business. Once they have happened, you will want to avoid having them happen again. Some failures are a big deal; these acute situations get a lot of attention, and fortunately, most of those do not happen often. Other more chronic failures may be less significant; however, there are many of them, and they happen often. Taming an out-of-control situation can be done using a combination of RCFA and rapid PM deployment (see Appendix C). RCFA can also be used as an enhancement to a program developed using RCM.

RCFA is entirely reactive to failures that have already occurred. RCFA is a method of performing a sort of postmortem to determine what caused any particular failure. The intent is to eliminate the root cause—an identifiable cause that you can manage in some practical way. RCFA targets known failures, usually the ones that have caused you the most "pain" in some way. It is done after the fact, so you have already incurred the consequences of those failures at least once. It is highly effective, and in an out-of-control situation, it can deliver fantastic benefits quickly; however, keep in mind that developing your entire reliability program using RCFA would be foolish. RCM can deal with those failures before they happen, so do not use RCFA as a way of avoiding the effort required to do RCM well.

RCFA is also a very good way to enhance your RCM results. As good as RCM is, you can still make mistakes and omissions, which eventually show up as failures that you were supposed to be preventing, predicting or detecting early. RCFA is a good way to analyze those failures and then apply the findings as enhancements both to the RCM analysis and in your ongoing failure management programs.

RCM is a method that takes quite a bit of effort working in teams. It is thorough and delivers excellent results, but some organizations cannot afford the time required for those teams to do their jobs. In those cases, RCM is usually limited only to the most critical systems. For less critical systems, PMO is used. It has two applications—one in cases where an existing PM program is in place that needs to be optimized (hence its name), and the other, where no PM program exists.

PMO uses an abridged RCM logic to analyze, eliminate or modify maintenance activities of existing programs. It attempts to identify failure modes that may have been missed by the original maintenance program (or new failure modes where there is no program). Although its approach is not as thorough as RCM, it has achieved some very good results and merits consideration for use with noncritical assets.

Decision optimization techniques and tools help maintainers (usually maintenance or reliability engineers) to make fact-based decisions or improve on decisions already made. RCM can be used before an asset is put into service or without good data about past failures. In those cases, RCM decisions about task frequencies and failure modes are invariably subject to some degree of uncertainty. Once a program is put into place, some unanticipated failures will surface, or the frequency of failures may not match original estimates. Optimization techniques are used to analyze the in-service data to validate or modify the original decisions. It is a form of second-guessing that becomes more precise as failure data accumulated in service become available. These techniques can be very accurate provided that the data they rely upon are accurate. If the data are flawed, then there are knowledge elicitation techniques that can be deployed.

Reliability enhancement requires good data. If your early RCM, RCFA and PMO efforts lack good data inputs, then improvements using these methods later will require improvements to data collection and management.

Reliability and simulation modeling are computer-based techniques that engineers use to model, mathematically, the behavior of installed systems. They can reveal the location of process bottlenecks and predict whether (and where) another bottleneck is likely to surface once the first is handled. These models can also show the effect of various reliability improvements at different points in the systems and help focus engineering efforts more effectively. In cases where other reliability improvement efforts are failing to deliver expected or desired performance, it makes sense to look at process/system design, but keep in mind that the results are likely to point in the direction of design changes that could be costly.

ENDNOTES

1. PMO2000 PM optimization, by OMCS International, http://www.reliabilityassurance.com.
2. PM Optimization, by Fractal Solutions, http://www.fractalsolutions.com/Papers/PMO_LivingProgram.pdf.
3. See also *Maintenance Excellence: Optimizing Equipment Life-Cycle Decisions* by John D. Campbell and Andrew K. S. Jardine (New York: Marcel Dekker, 2001).
4. RCA and software to support it are products of Reliability Centre, Inc., Hopewell, Virginia, http://www.reliability.com.

5. TapRooT is a product of System Improvements, Inc., of Knoxville, Tennessee, http://www.taproot.com.
6. Kepner Tregoe is a consulting and training services company. The business is based on *The Rational Manager: A Systematic Approach to Problem Solving and Decision Making*, a book coauthored by Charles Kepner and Benjamin Tregoe (New York: McGraw Hill, 1965), http://www.kepner-tregoe.com.
7. For a comprehensive listing, refer to *Maintenance, Replacement and Reliability* by A.K.S. Jardine (New York: Pitman Publishing, 1973).
8. Another excellent source of this information is *Maintenance Excellence, Optimizing Equipment Life-Cycle Decisions* by John D. Campbell and Andrew K.S. Jardine (New York: Marcel Dekker, 2001).
9. The mathematical tools use probability theory, stochastic processes, stochastic models and Markov processes.

10

Evidence-Based Asset Management

> Look at the evidence and be willing to question your own truths, be willing to scrutinize things that you hold dearly because that way, that transparency, that self-awareness, will protect you from ever becoming somebody whose beliefs somehow make them have myopic vision of what could be.
>
> **Jason Silva**

EVIDENCE-BASED ASSET MANAGEMENT

In medicine, the gold standard today is evidence-based medicine (EBM), as opposed to relying on the opinion of a medical expert, currently considered the least valid form of evidence. All experts are now expected to reference their pronouncements to scientific studies. Evidence-based asset management (EBAM) has the same goal. In maintenance and asset management, we no longer want to base our decisions on hunches, rules of thumb, intuition or years of experience alone. In EBAM, the focus is on fact-based analysis rather than intuition-driven statements. EBAM consists of input, process and output. Inputs of EBAM are statistical data and/or accurate and unbiased expert opinion (also known as tacit knowledge). The process includes state-of-the-art mathematical and statistical techniques that analyze, clean and process data to produce accurate and valid outputs.

Applying principles of EBAM to asset management decisions has been demonstrated to generate huge savings for companies. Examples of such decisions include finding the optimum retirement ages of expensive assets;

calculating the optimum inspection frequencies for protective devices; establishing the most economical preventive replacement intervals for a component; buying expensive insurance spare parts in the right quantity; determining the best repair-versus-replacement decision policy; and making optimum condition-based maintenance decisions.

Areas where EBAM is proven include the following:

1. Optimizing life-cycle costing (LCC) decisions
2. Optimizing maintenance tactics such as preventive replacement strategies
3. Optimizing inspection policies such as predictive maintenance and failure-finding intervals (FFIs)
4. Optimizing resource requirements such as establishing maintenance crew sizes, estimating budgets, determining optimum spare-part requirements, etc.

In this chapter, we explain these and present a number of examples as carried out by members of the Centre for Maintenance Optimization and Reliability Engineering (C-MORE) at the University of Toronto. In some of these cases, historical data were available, but for others, a lack of data was compensated for by employing knowledge elicitation techniques.

OPTIMIZING LIFE-CYCLE COSTING DECISIONS (ZUASHKIANI AND JARDINE 2010)

LCC is gaining popularity, as its role in making long-term optimal decisions is becoming increasingly clear to organizations. The choice of "buying the cheapest" is losing its attraction, as managers become aware that the cheapest acquisition costs rarely result in the lowest life-cycle cost in the long run. An important question for any asset is "when does it have to be replaced with either a new or a technologically more advanced version?"

Option Evaluation

Companies use life-cycle cost analysis to determine the best option (new equipment, new building, etc.). Whatever is "the best" depends on your company's objective(s). It could mean minimizing the total life-cycle costs of an asset or maximizing the asset's total life-cycle benefits. The life-cycle costs of an asset are the sum of the present values (PVs) of all the expenditures it incurs and the risks to which it is exposed throughout its life cycle ("cradle to grave"). If the objective is cost minimization, the best option will be minimum discounted life-cycle costs. The following is an example.

A contractor requires specialized equipment for a period of 3 years. Given the costs and salvage values in Table 10.1, which is the best alternative? Assume that the costs provided in Table 10.1 are the only costs that differ from one asset to another. Note: Costs are in dollars × 100.

In the absence of other information, we might add up all the life-cycle costs of each asset to determine which equipment yields the minimum total costs. This approach results in the following:

Total life-cycle costs of owning and operating equipment A:

$$10{,}000 + 200 + 200 + 200 + 200 - 6000 = \$4800$$

Total life-cycle costs of owning and operating equipment B:

$$6000 + 200 + 400 + 600 + 800 - 3000 = \$5000$$

Total life-cycle costs of owning and operating equipment C:

$$12{,}000 + 200 + 100 + 160 + 200 - 7000 = \$5660$$

Based on the above calculations, the best option is to purchase equipment A. This solution is based on the simplified assumption that the value of money does not change over time. Although this might be acceptable for decisions whose cash flow is dispersed over a short period (a few months),

TABLE 10.1

Life-Cycle Costs of Three Pieces of Equipment

Equipment	Purchase Price	Installation Cost	Operating Cost 1	Operating Cost 2	Operating Cost 3	Salvage Value
A	10,000	200	200	200	200	6000
B	6000	200	400	600	800	3000
C	12,000	200	100	160	200	7000

it is too simplistic when the options you are considering have monetary implications spread over a long period (years or decades).

Time Value of Money

Assume we have deposited \$200 in a bank. Our expectation is that after 1 year, our deposit grows or, in other words, produces interest. The expected interest depends on many factors, such as the current economy, risk, inflation rate, etc. If the bank's annual interest rate for our deposit is 10%, we can expect our deposit to be worth 200 + 200 × 0.10 = \$220 in 1 year. If we leave the money in the bank for 1 more year, we can expect to have 220 + 220 × 0.10 = \$242. The associated cash flow is shown in Figure 10.1.

The above calculations can be summarized as follows: $\$200 \times (1 + 0.10)^2 = \$242$.

Now assume we will have a payment of \$242 to make 2 years from now. What is its value today (PV)? If we put \$200 in a bank, after 2 years, it will grow to \$242, so the value of a payment of \$242 2 years from now is \$200 in today's dollars. This is called the PV of the \$242 payment 2 years from now assuming that the annual discount rate is 10%. To find the PV of payment, we use the reverse calculation:

$$\text{NPV} = \frac{\$242}{(1+0.10)^2} = \$200$$

where NPV is the net PV.

Calculating the Optimum Buy Option

Now using the concept of time value of money, let us look at our three options. To solve LCC problems, it is useful to draw a cash flow diagram

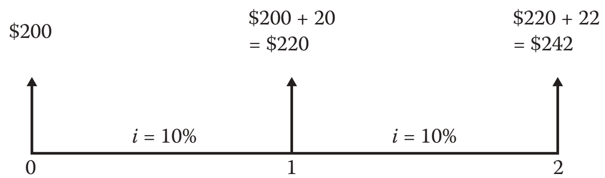


FIGURE 10.1
Time value of money.

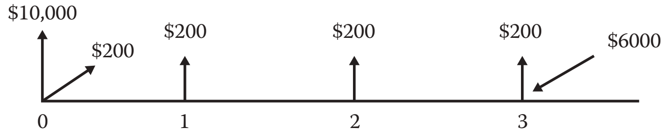


FIGURE 10.2
Cash flow diagram.

for all alternatives, as this provides a better understanding of what is happening during the life cycle of the options under evaluation. The cash flow diagram for equipment A looks like the illustration in Figure 10.2.

In a cash flow diagram, the horizontal axis represents time, and the arrows represent monetary transactions that happen at each point in time. The direction of the arrows indicates whether a monetary transaction is a payment (outflow) or revenue (inflow). Assuming an interest rate of i = 11%, the net PV of the above cash flow diagram would be as follows:

$$\text{PV (selecting equipment A)} = \$10{,}000 + \$200 + \frac{\$200}{1.11} + \frac{\$200}{1.11^2} + \frac{\$200}{1.11^3} - \frac{\$6000}{1.11^3} = \$6302$$

Continuing with the same calculation, we have the following:

$$\text{PV(selecting equipment B)} = \$5439$$

Similarly, the PV of purchasing and operating equipment C is $7448. Equipment B becomes the more attractive option.

In determining the best option, cost items that do not vary in cost from one option to another do not affect the decision, as those costs will be cancelled out from the PVs of all options under evaluation. The focus should be on measuring costs that vary from one option to another, but do not forget that all costs need to be considered for budgeting purposes. The sort of costs you should consider include, in decreasing order of visibility, the following:

- Purchasing price
- Installation
- Training
- Operation

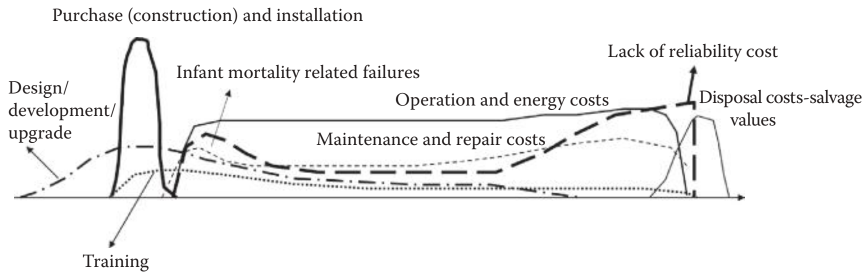


FIGURE 10.3
Life cycle costs of an asset.

- Maintenance
- Disposal
- Cost of lack of reliability
- Future development

Figure 10.3 shows the behavior of such costs for most industrial assets. Design and development start before construction or purchase and sometimes continue throughout the life of the asset with ongoing improvement and modification projects. Maintenance costs are expected to be higher when equipment is new, due to infant mortality–related faults exacerbated by the lack of experience of operators and maintainers as they learn through experience. Operation costs are expected to follow a similar pattern, but this depends on the type of the equipment. Lack-of-reliability costs represent operational, safety and environmental consequences of breakdowns, usually very difficult to measure or forecast at the time of asset acquisition.

When evaluating options, we must appreciate the importance of decisions made early in the life cycle of the asset. Those early decisions will have a profound effect on future life-cycle costs. The cost of making those decisions (generally during design) is a small portion of total life-cycle cost, but they create a significant cost commitment (Figure 10.4).

Case Study: Replacing Aging Screeners with New Ones in a Mining Company

A mining company decided to replace their aging industrial screeners. They identified three optional suppliers. A consultant was asked to oversee the final options and conduct LCC analyses to determine the best one. The consultant realized the initial and subsequent research to find the

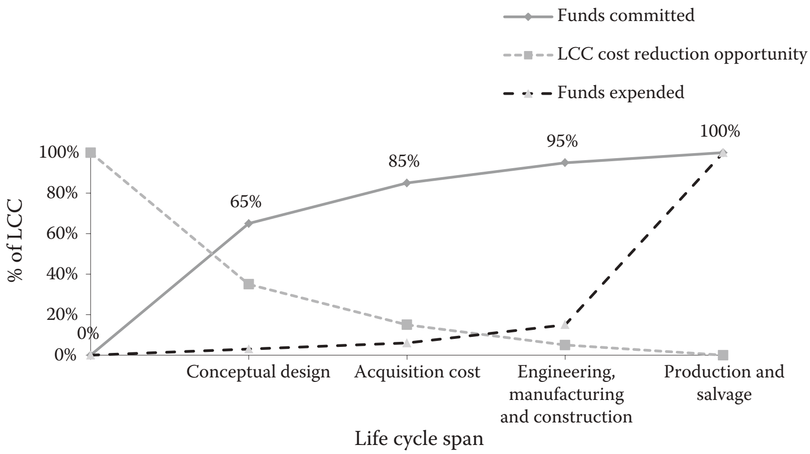


FIGURE 10.4
Cost commitment versus expenditure.

replacement options was done by junior engineers simply because they were more available and researching does not cost much. Given the sizable investment and at the request of the consultants, the research was done again, this time involving senior representatives of operations, maintenance and engineering. The main reasons operations wanted to change the old screeners turned out to be the following:

- Excessive use of lubricating oil
- Excessive damage to input strainer
- Frequent spring failures

In redoing the research, they found that none of the three replacement options could effectively address the above issues. They would miss out on several million dollars in savings annually. They had also failed to consider that a technologically improved piece of equipment, a semi-autogenous grinding (SAG) mill, which simultaneously crushes and screens rocks, is more energy efficient and reliable.

Case Study: Selecting the Best Gas Meter Replacement/ Repair Option for a Gas Distribution Company

A major gas distribution company had a dilemma when deciding what repair/replace policy to use for its large fleet of gas meters. The dilemma became more complicated when a new gas meter came on the market; it had more initial acquisition costs, but it was expected to have lower life-cycle costs and a longer life expectancy. After some discussion, they defined the following three possible policies:

- *Policy 1*: Always replace a failed meter with a new meter of the old technology.
- *Policy 2*: Always repair a failed old-technology meter once.
- *Policy 3*: Always replace a failed meter with a new meter of the new technology.

Data analyses revealed that a new meter using the old technology has a mean time to failure of 18 years, but after repair, it has 12 years. In contrast, a technologically advanced gas meter is expected to last between 20 and 24 years. Relevant life-cycle costs were estimated using historical data and data obtained from other gas distribution companies using the new technology. There were approximately 23,000 meters in service. The net PVs of the three policies were determined to be as follows:

- *Policy 1*: $36.7 million (replace failed meter with new meter of old technology)
- *Policy 2*: $34.0 million (repair failed meter of old technology once)
- *Policy 3*: $27.3 million (replace failed meter with new meter of new technology)

The company decided that whenever a gas meter failed, it would be replaced with a gas meter using the new technology. This meant a change to the current policy of the company, which had been to repair old meters once (policy 2), resulting in potential savings of almost $7 million.

ECONOMIC LIFE OF AN ASSET

Assets are commonly purchased to serve for a relatively long period, often several times longer than the asset's normal life, forcing eventual replacement. When assets are new, their operation and maintenance (O&M) costs are usually low, and assets are more reliable. Over time, as assets age, O&M costs tend to increase. However, due to technological improvements, assets with better performance and lower O&M costs may enter the market. The rate at which technologically improved assets enter a market depends on the type of the industry and pace of technological improvements and innovation. In these situations, it is valid to ask, "When is the best time to replace the current asset?" Or in other terms, "What is the economic life of the current asset?"

As an asset ages, its annual capital cost (also known as ownership cost) decreases. In its simplest form (not considering time value of money), the ownership cost can be thought of as the purchase price of an asset minus its resale value at the time of replacement, divided by the replacement age. Organizations tend to use an asset for as long as possible, thus reducing ownership cost per unit of time. Yet annual operational and maintenance costs, cost of lost production due to equipment breakdowns, consumed energy, etc. tend to increase as assets age. The total cost of keeping and operating an asset is the summation of these costs (one usually increasing and the other decreasing). A graph of that total cost will have a minimum point, the age at which the total cost function is minimized, called the economic life of the asset. See Figure 10.5. Some costs do not change as an asset ages and are, therefore, called fixed costs. As shown in the figure, fixed costs do not affect the economic life of an asset and can be ignored in the calculations (but do not ignore them for budget purposes).

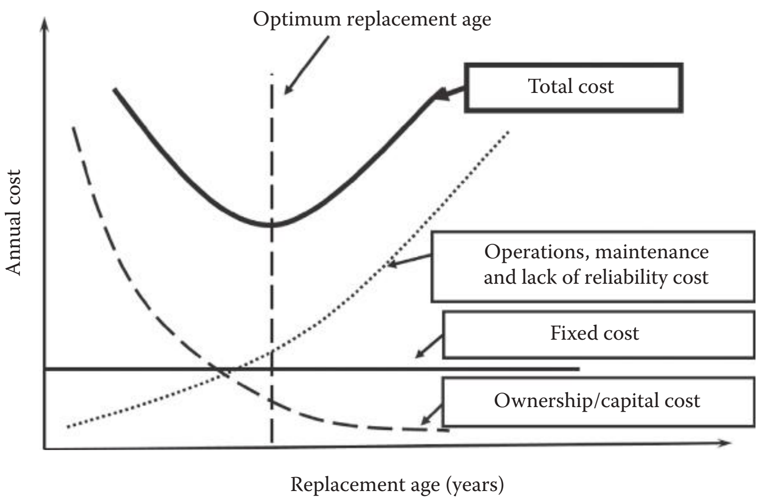


FIGURE 10.5
Economic life trade-off graph.

Economic Life of a Steadily Used Asset

Equipment deteriorates as it is used. Deterioration manifests in higher operation, maintenance and downtime costs. As these O&M costs rise, there might be a time when replacing the aging equipment is economically justified. If the equipment is replaced at its economic age, the total discounted life-cycle cost of the equipment is minimized. Let us assume that an old piece of equipment is to be replaced with a similar piece of new equipment, and the trend of O&M costs of the new asset is similar to that of the old asset. This assumption may be relaxed if the replacing asset has different life-cycle costs; the difference in life-cycle costs can be due to technological improvements or better maintenance and operation practice—a more complex problem (Jardine and Tsang 2013). For simplicity, we assume that there is no time value of money.

Developing the Model

1. A is the acquisition cost (purchasing price) of the capital equipment plus any installation-related expenses.
2. C_i is O&M costs, loss of production due to equipment breakdowns, etc. in the ith period after equipment installation. Here, C_i is assumed to be paid at the end of the period, $i = 1, 2 \ldots, n$. For simplicity, C_i is called O&M costs, but we know that this goes beyond O&M costs to include other life-cycle cost items mentioned above.
3. S_i is the resale value of the equipment at the end of the ith period of operation, $i = 1, 2 \ldots, n$.
4. D is disposal cost, including any removal costs such as dismantling, cleaning, transportation, loss of production during the dismantling process, etc.
5. n is the age of the equipment when replaced.
6. EAC(n) is called the equivalent annual cost associated with replacements occurring at intervals of n periods.

A cash flow diagram of life-cycle costs of an asset replaced at age n is shown in Figure 10.6.

The asset is purchased and installed at time 0 (present time). During the first year of operation, it incurs costs represented by C_1. We assume that the total cost incurred in 1 year is paid at the end of the year (note that this assumption does not always hold true and can change). Depending

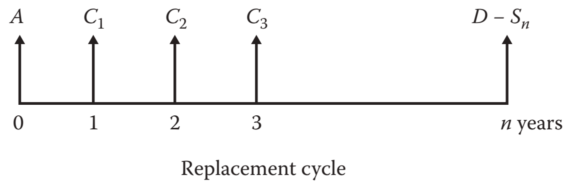


FIGURE 10.6
Cash flow of an asset life cycle.

on circumstances, the timing of C_i can change from the end of the year to the beginning of the year or the middle of the year, or be spread evenly throughout the year.

The equivalent annual costs (EAC) of the life-cycle costs of the asset can be parametrically represented as the following:

$$\text{EAC}(n) = (A + C_1 + C_2 + \ldots + C_n + D - S_n)/n \tag{10.1}$$

Using the above formula, annual costs associated with replacing an asset after n years can be calculated. Changing n gives us the EAC for the different replacement policies. The value of n that minimizes EAC is called the economic life of the asset.

Numerical Example

1. Let A = \$90,000.
2. The estimated O&M costs per year for the next 5 years appear in Table 10.2.
3. The estimated resale values over the next 5 years appear in Table 10.3.
4. The disposal cost D = \$6000.

TABLE 10.2
Trend in O&M Costs

Year	1	2	3	4	5
Estimated O&M cost ($)	9000	18,000	36,000	54,000	72,000

TABLE 10.3
Trend in Resale Values

Year	**1**	**2**	**3**	**4**	**5**
Resale value ($)	60,000	42,000	24,000	19,000	15,000

TABLE 10.4
Total Equivalent Annual Cost

Replacement Time(*n*)	**1**	**2**	**3**	**4**	**5**
EAC(*n*)	$45,000	$40,500	$45,000	$48,500	$54,000

FIGURE 10.7
Total costs calculated for different replacement ages.

Using Equation 10.1, we have the following:

$$\text{EAC}(1) = (\$90{,}000 + \$9000 + \$6000 - \$60{,}000)/1 = \$45{,}000$$

The above calculation is repeated for other values of *n*, and the results are summarized in Table 10.4.

A graphical representation is provided in Figure 10.7.

As shown, the most economical decision is to replace the equipment when it reaches 2 years of age.

Case Study: Purchasing the Best Combustion Engine

An energy company in South America wanted to buy four new combustion engines. The company wanted to know which of the two available engines had lower life-cycle costs. It was also interested in learning the expected economic lives of the two engines. The first alternative (engine A) had an initial purchasing and installation cost of $19 million. Both alternatives had anticipated annual O&M costs up to 15 years of age. After conducting life-cycle analysis, the company discovered that the economic life of engine A was 15 years. Actually, the planning horizon was 15 years, and at 15 years, the cost was still declining. Therefore, in the next 15 years, there was no expectation that the engine would need replacement. The graph in Figure 10.8 shows the trend in EAC associated with replacement ages ranging from 1 to 15 years.

Based on available evidence (O&M cost data were obtained from the original equipment manufacturers and from some generic databases accessible to oil and gas companies), the economic life was determined to be 15 years or more. In practice, after several years of operation, enough experience is developed among maintainers of equipment that their knowledge can be used to estimate future O&M costs of the assets they are working with. Engine A was very specialized equipment, making it almost impossible to find a customer for a second-hand engine; therefore, its salvage value was estimated as 0. The associated EAC with replacing engine A after 15 years was determined to be $5.36 million.

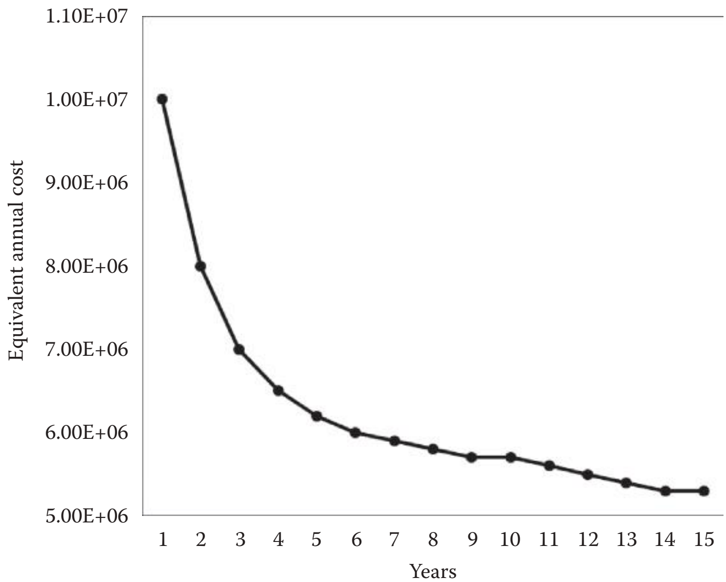


FIGURE 10.8
EAC trend for combustion engine A.

The alternative equipment (engine B) had a purchasing and installation cost of \$14.5 million. As in the case of engine A, estimated O&M costs were only available for its first 15 years of operation. Again, like engine A, since it was specialized equipment, its salvage value was estimated as 0. The resulting optimum EAC was \$3.17 million and occurred at age 15 years (see Figure 10.9).

Therefore, engine B was a better choice; it would save the company \$2.19 million per annum per engine. Since the company wanted four engines, the total *annual* savings would be \$8.76 million. The total savings over the life of the engine would be 15 × \$8.76 = \$131.4 million.

When dealing with capital equipment replacement problems, there are often significant uncertainties associated with future costs, interest rates and possibly the demands that will be placed on the equipment. However, the availability of specially designed software enables valuable sensitivity analyses. These "what-if" analyses allow the engineer to examine the effect of various estimates of trade-in values, interest rates, etc. on replacement cycles. Since a high degree of confidence can be associated with final recommendations to senior management on an asset's economic life, the

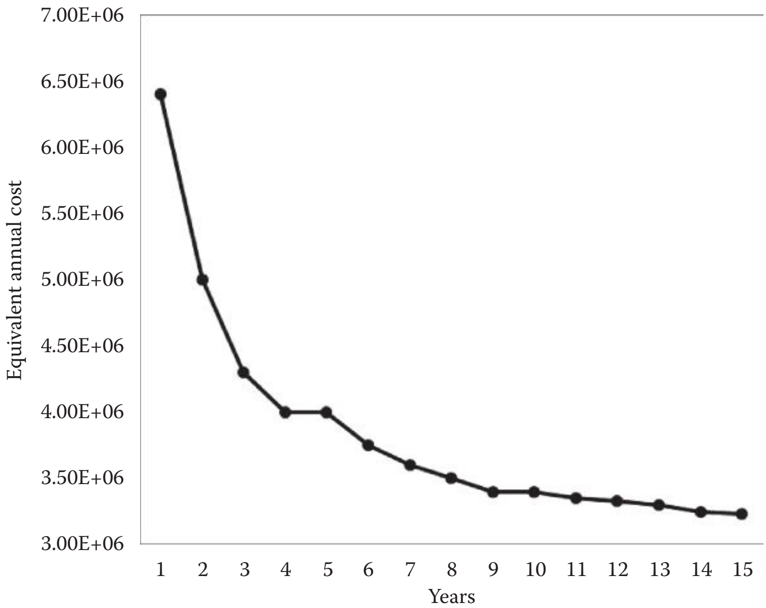


FIGURE 10.9
EAC trend for combustion engine B.

chances of obtaining approval for major capital expenditures generally increase significantly.

Case Study: Economic Life of a Bus Fleet Used in Urban Mass Transit

ABC mass transit had a fleet of 2000 GMC (formally GMC Division of General Motors LLC) buses. To determine the economic life of the fleet, the life-cycle costs of the buses, including annual O&M costs, capital costs and resale values, were analyzed. The company's practice was to replace a bus if/when it reached the age of 20 years. But the optimum replacement age was determined to be 13 years. With the adoption of the new practice of replacement sooner, the associated savings was calculated to be $9.4 million per year.

Case Study: Optimizing Economic Life Decisions for XYZ Bus Fleets

XYZ public transit wanted to know the economic life of its fleet of 54 coaches providing 11 service routes. The economic replacement age of buses was found to be 13 years. The company's practice had been to replace a bus after 18 years of operation. The associated savings when the new practice was adopted was estimated at $216,000 per year.

Case Study: Economic Life of a Light Truck

A North American mining company had a fleet of around 700 light trucks, with a 2-year replacement policy. A group within the company questioned the viability of this policy and invited an external expert to study the policy. Using historical data, the expert obtained the total cost curve shown in Figure 10.10, suggesting that the best replacement policy was 5 years. The estimated annual potential savings for the entire fleet was found to be around $3,000,000.

Case Study: Optimum Replacement Age for Underground Steel Mains (Wilson 2013)

One of the largest gas distribution companies in North America had more than $12 billion worth of steel mains and was interested in knowing the best time to replace a coated steel main based on its condition (health). The company also wanted to know the best repair-versus-replacement policy and the most economical maintenance tactics. During the project,

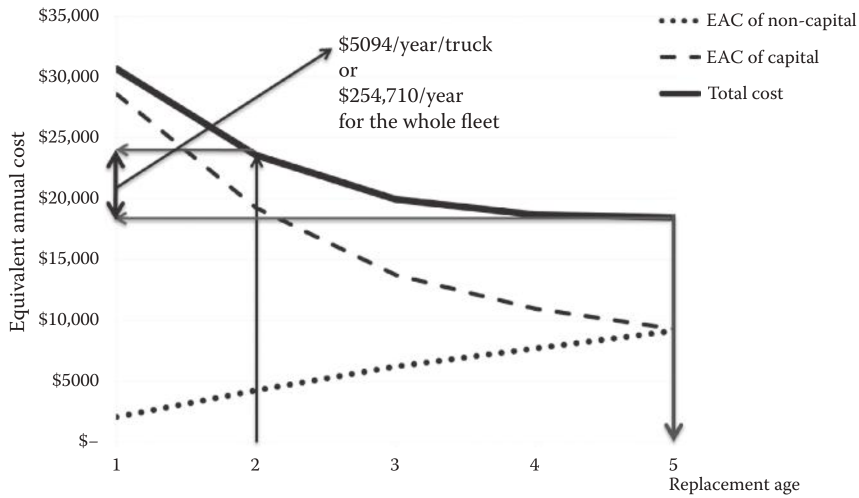


FIGURE 10.10
EAC trend for light truck replacement age.

they discovered many factors affecting the health condition of steel mains and, hence, their economic life, including the main's coating type, level of cathodic protection, type of soil, pressure class, age, etc.

Unlike equipment with rotary components, linear assets like coated steel mains are static, and major degradation is due to corrosion. The operating cost is negligible until part of a main starts to leak. In addition to the direct cost of repairing a leak, there are certain safety considerations. Gas released through a hole on a main can migrate to nearby buildings, causing an explosion, which may result in death or injury and destruction of the structure. As a main gets older, it corrodes; there is a higher likelihood of leakage, making safety and financial consequences a greater concern. Many other factors affect the health of a main as well, including the following:

- Coating type (Yellow Jacket, fusion-bond epoxy, etc.)
- Level of corrosion protection (cathodic protection, etc.)
- Soil type (clay, sand, loam, pea gravel, etc.)
- Level of stray current
- Number of service mains attached to the main

Considering all the factors involved (most of which are not included here), there is a relatively high heterogeneity in the health condition of steel mains, possibly because of other factors that are difficult to find/measure. As a result, the team considered the leak history of a main by looking at the number of leaks on a piece of the main over the previous 5 years.

Leak History of the Main

Certain factors affect the consequence of springing a leak:

- Pressure classification of a main
- Location of a main (proximity to populated areas)
- Pipe diameter (affecting both the outflow of the leak and cost of repair)
- Leak survey interval (the more frequent the survey, the greater the chance of the leak being detected and, hence, less chance of an explosion)

In addition, mains in the gas distribution company have different lengths: as short as a couple of meters and as long as 10 km. This length difference affects any conclusion regarding the likelihood of a leak on a section of main. If a main is 10 times longer than another main in a similar condition, it is approximately 10 times more likely (in expected number of leaks) to have a leak within the section.

Any combination of factors affecting the chance and consequence of a leak on a section of a steel main creates a different degradation pattern and O&M cost trend. Different O&M cost trends means that, mathematically, we are dealing with different assets. In the study mentioned here, there were thousands of different assets, each requiring a separate LCC analysis. Collecting and analyzing data for thousands of assets would be impractical: It could take hundreds of years, and even if done, since there is only one data history for each asset, the results would be statistically inaccurate.

To solve this problem, the team had to quantify the following:

1. The relationships between factors affecting the health condition of an asset with the chance of having a leak on that main
2. The relationships between factors affecting the consequence of a leak and the actual monetary consequence of a leak

As corrosion-related leaks are the main sources of O&M costs that vary with age, the team considered only those leaks. Other leaks, such as third party–induced leaks, are independent of the age of a main and do not affect its economic life.

The expected O&M cost of a main for any year is the product of the likelihood of having a leak in that year and the expected consequence of that leak:

$$\text{Expected O\&M costs} = \text{probability of having a leak} \times \text{expected consequence of a leak}$$

Probability of Encountering a Leak

The likelihood of a main having a leak depends on many factors. To formulate the probability of encountering a leak as a function of several factors, we can use a statistical model called a proportional hazards model (PHM), but a PHM requires many constants to be estimated. That requires an extensive data history, which was not available. The team chose to use tacit knowledge to compensate for this lack of sufficient accurate historical data.

Technique Using Expert Opinion

Fortunately, some techniques (Jardine and Tsang 2013; Zuashkiani 2008) can extract expert opinion and transform it to values of a statistical model's parameters. To this end, the team interviewed several persons considered very knowledgeable by their colleagues. In the initial interview stages, the team focused on the most significant factors in the likelihood of a leak on a section of main. In subsequent interviews, they estimated the values of the parameters of the PHM. The team combined the knowledge obtained with the historical data using a statistical methodology called Bayesian statistics.

Then they estimated the parameters of the model based on tacit knowledge, using a methodology based on case analysis and case comparisons (Jardine and Tsang 2013; Zuashkiani 2008). The questions were designed in such a way as to require little knowledge about probability and statistics from the experts. Sample interview questions are shown in Table 10.5.

In each question, the expert had to compare the probability of encountering a leak on two mains with different conditions. After asking about 50 questions to each of 12 experts, the methodology established the values of the PHM parameters. Then, using Bayesian statistics, the team combined knowledge collected from the experts with the historical data to produce more accurate and robust estimates.

TABLE 10.5

Sample Case Analysis Questions to Extract Expert Opinion

	Main A	**Main B**
Length	0.5 km	0.5 km
Number of leaks over the last 5 years	1 leak(s)	1 leak(s)
Level of stray current: A—high: P/S reading fluctuation > 199 mv B—medium: P/S reading fluctuation = 100–199 mv C—low: P/S reading fluctuation < 100 mv	B	A
Soil type (sand, clay, pea gravel, loam, wet clay, shale)	Sand	Clay
Type of coating (coal tar, Yellow Jacket, fusion-bond epoxy)	FBE	FBE
Corrosion history (percentage of the time the cathodic protection system has been up and working over the last 5 years)	90%	90%
Age	30 years	30 years
How much higher is the probability of encountering a leak during the next year in main B than in main A? Please provide an interval for your estimate that makes you confident that the answer lies within it.	Lower boundary =	Upper boundary =

Note: FBE: fusion bond epoxy; P/S: pipe to soil.

Expected Consequences of Each Leak

After calculating the probability of a leak on a section of main, the team needed to know the expected consequence of each leak. The factors contributing to the consequences include the following:

- Direct cost of repairing the leak
- Pressure class of the mains
- Location of the mains with respect to different types of buildings and structures (e.g., whether close to populated areas and commercial buildings; how easily a leak is detected by the public versus leak surveys)
- Leak survey frequencies
- Size of the main
- Gas migration path (e.g., soil, sewer system)
- Fines due to lawsuits when explosions result in injury, death or destruction of property
- Costs of rebuilding after damage
- Changes in public perception toward the company

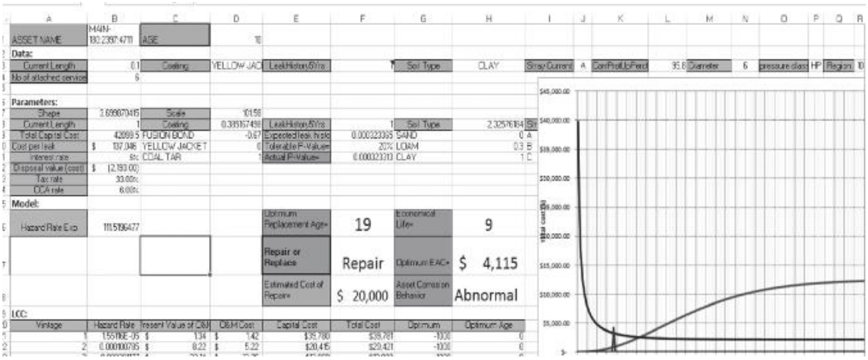


FIGURE 10.11
Snapshot of the program developed for the life-cycle cost analysis of steel mains.

Because of the safety issues, a robust and accurate technique was required to calculate the consequence of a leak based on all possible combinations of the above factors. Public companies running operations that may be hazardous to public safety conduct thorough risk analyses to ensure they do not expose the public to intolerable risk. Fortunately, the gas distribution company had already done this using the event tree analysis method. With this method, the team could build all possible scenarios stemming from the combination of different factors and calculate the consequence of each leak in each scenario.

Knowing the consequence of each leak and the probability of encountering a leak allowed the team to draw an O&M cost graph. A capital/ownership cost graph is more straightforward and is a function of the mains' installation cost + removal of the mains + time value of money + tax effects of depreciation of the mains (Jardine and Tsang 2013) + age of the main at the time of replacement. The total annual potential savings were estimated to be \$6–8 million. The PV of these savings would be \$90–120 million. Figure 10.11 provides a snapshot of the program developed for the life-cycle cost analysis of the steel mains.

Case Study: Optimum Replacement Time of an Old Turboexpander with a Technologically Advanced Substitute

A petrochemical plant was using a turboexpander installed in 1996 and then overhauled in 2000 and 2007. It was a dynamometer-type expander with three stages operating at 42,000 rpm. According to the manufacturer's recommendation, it was (at the time of the study) approximately halfway through its expected useful physical life. At that time, a technologically advanced turboexpander had come onto the market; it was more energy efficient, broke down less frequently and incurred fewer maintenance costs. The engineering and maintenance department had difficulty convincing management to switch to the new technology as the old one had almost half of its service life remaining. Using mathematical modeling similar to that described at the beginning of this chapter, the engineers were able to demonstrate that switching to the new turboexpander would create a net PV of more than $15 million. They got the required permission.

Concluding Remarks on LCC

This section of the chapter has described evidence-based LCC analysis. This type of analysis processes both hard and soft evidence using proven mathematical modeling to produce optimum LCC decisions. It is important to remember that LCC is about making the best decision in light of the available information. LCC is not aimed at making accurate and detailed evaluations, as this is both time-consuming and costly. Instead, the focus is on collecting enough information at the right level of detail to underpin a decision in a cost-effective manner within a rigorous process. Seeking higher-quality data is not the goal; rather, it is to show that a decision is largely insensitive to the vagaries of the available data. This type of approach to decision making is becoming increasingly acceptable to industry regulators and equity markets.

OPTIMIZING MAINTENANCE TACTICS

What Is a Maintenance Tactic?

A maintenance tactic is a maintenance plan or policy to maintain a satisfactory level of reliability or availability of a physical asset. It deals with the following:

1. When to do maintenance on a physical asset
2. What maintenance to do, e.g., partial replacement, complete overhaul or run to failure

Maintenance tactics include (but are not limited to) the following:

1. *Time-based maintenance (TBM)*: TBM sets a periodic interval to perform preventive maintenance (PM) regardless of the health status of a physical asset. With the rapid development of modern technology, products have become increasingly complex. At the same time, better quality and higher reliability are required, elevating the cost of PM.
2. *Condition-based maintenance (CBM)*: CBM recommends maintenance actions based on the information collected via condition monitoring. It attempts to avoid unnecessary maintenance tasks by taking maintenance actions only when there is evidence of a physical asset's abnormal behavior. A CBM program, if properly established and effectively implemented, can significantly reduce maintenance cost by reducing the number of unnecessary scheduled PM operations.

Time-Based Maintenance

To calculate the best interval for a TBM, we must analyze failure/survival data to ensure that the failure under consideration is actually an age-based one. In addition, the cost of running to fail must be considerably more than the cost of PM/preventive replacement of the component.

To analyze failure/survival data, we must select a failure distribution function. Of these, the Weibull distribution is the most commonly used in the field of reliability. Several software packages can conduct a Weibull analysis. They then combine the cost of failure and the cost of PM to establish the relationship between preventive replacement time and total cost per unit of time. Total cost includes the cost of PM and the risk of encountering a failure, all measured per unit of time. When PM is delayed, we expect reductions in PM costs per unit of time but also an increased risk of encountering a failure before the component reaches its next PM schedule. This relationship is illustrated in Figure 10.12.

TBM Case Studies

1. An underground nickel mine company in Canada wanted to know the failure behavior of individual components in its underground scoops and trucks to optimize PM intervals. It was estimated that applying optimal preventive replacement policies would yield an average cost savings of 15%, equivalent to an annual savings of $1,312,500.

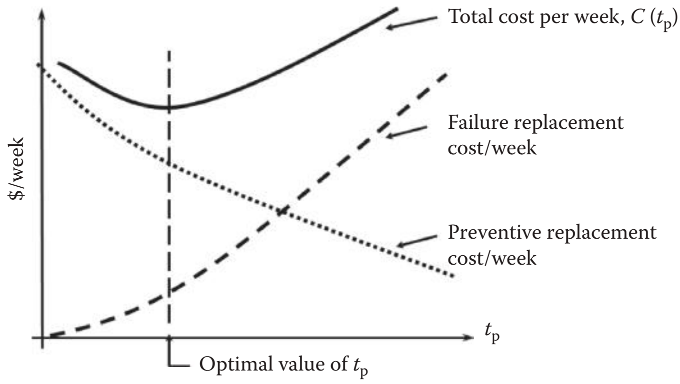


FIGURE 10.12
Optimal replacement time of a component.

2. A gas distribution company had about 2 million gas meters in operation. A new meter costs $64 and has an average life of 24 years. When a meter fails, it can be repaired once at a cost of $44. The repaired meter has a shorter average life of 14 years. The company wanted to know whether to repair or replace a new meter when it failed. When the study began, one-sixth of the new meters that had failed were repaired, and five-sixths were replaced. The study revealed that the repair policy was better (lower cost) than the replacement policy for meters. The annual savings by applying the repair policy was estimated at $150,000, equivalent to a total savings of $2,250,000.
3. A rail transportation company had a comprehensive maintenance program for its fleet of locomotives but was not sure if current maintenance tactics were optimum. The company wanted to see if principles of EBAM would ensure a more cost-efficient maintenance program. Table 10.6 shows their options and the resultant decisions with savings. Total annual estimated savings equals $1,310,000.
4. A mining company had a large fleet of haul trucks. Based on recommendations from the manufacturer, they had a policy of age-based preventive replacement for the trucks' diesel engines when they reached 18,000 hours of operation. They soon realized that most engines failed before reaching that operating age. Using an external consultant, they analyzed historical failure and preventive replacement data related to the engines. Considering the cost of a preventive replacement and running to failure, the optimum replacement age turned out to be somewhere between 7000 and

TABLE 10.6

Estimated Cost Savings as a Result of Optimizing Preventive Maintenance Times

Component	Power Assembly	Traction Motor	Turbocharger
Alternatives	Replace with new; wash and wear; overhaul	Major overhaul	Send to General Motors (GM) for rebuilding
Former policy	Wash and wear at 5 years	Overhaul at 5 years	Rebuild at 2 years
New policy	Overhaul at 4 years	Run to failure	Run to failure
Savings	$410,000/year	>$4,000,000/year	>$5,000,000/year

9000 hours, saving them more than $10,000,000 annually, as shown in Figure 10.13.

5. Another mining company was using run to failure as its strategy for replacement of the hoist cables in its fleet of eight shovels. The company was using different cable manufacturers and operating different types of shovels and had not seen enough evidence to convince themselves that the failures of their cables were age dependent. After analyzing historical data for the failures of the cables and taking into account the actual cost of running to fail versus preventive replacement, it was found that the optimum preventive replacement age is 500 operating hours. The company's estimated annual savings were approximately $1,000,000.

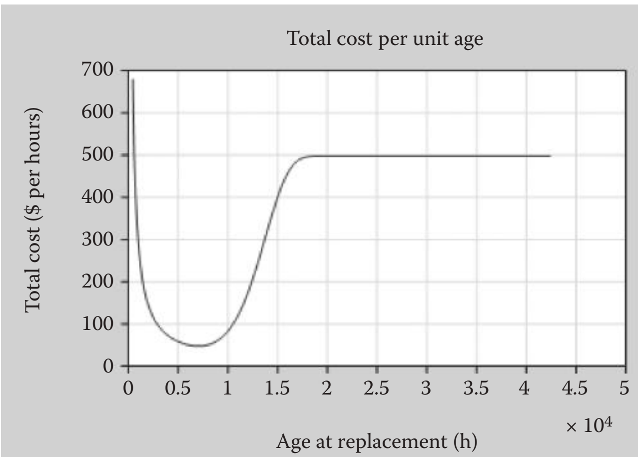


FIGURE 10.13
Optimal replacement time of a diesel engine.

Condition-Based Maintenance

The principle behind optimized CBM is very similar to TBM, but instead of considering only age, other factors may also affect the likelihood of failure. Mathematically speaking, CBM optimization is more complex. Yet TBM and CBM have similar trade-off relationships. As replacement action is delayed, there are some savings and some incremental risk of encountering failure. Optimized CBM minimizes the total cost function. A software package well suited for this purpose is called EXAKT. It was developed at the C-MORE at the University of Toronto and has been used in many applications, including the ones described in the case studies below.

CBM Case Studies

1. The ABC Mass Transit Railway Corporation had excessive traction motor ball-bearing failures in its trains. The current inspection interval was 3.5 years. When a CBM program was executed to monitor bearing grease color, it was discovered that the optimal CBM policy for the inspection interval was 1 year. The new policy reduced the expected number of failures per year from nine to an average of only one, with an associated total cost reduction of 55%. In the year following analysis, the actual number of failures was reduced to two, and in subsequent years, it was sometimes zero. This substantial economic benefit included quantification of the value of fewer passenger disruptions.
2. XYZ Pulp and Paper implemented a CBM program for its 12 paper stock pumps. When vibration measurements on pump bearings were collected using accelerometers, the EXAKT software found two that were significantly related to the probability of pump-bearing failure. By applying the optimal CBM policy, a savings of 33% was estimated. While the exact cost benefit of this improvement was not determined by the company, bearing replacement after failure was, on average, 3.2 times more expensive than a preventive replacement. The company installed EXAKT for everyday use and has developed a tool to link the relevant databases. They have also taken steps to make small modifications to the pumps to improve reliability. In the first 22 months, there were no pump failures, compared to 15 failures in the 5 years previous (for the 12 pumps).

3. ABC Coals has 50 wheel motors driving large electric haul trucks. They are monitored using oil analysis that considers 12 measurements. They found that two, iron and sediment, were significantly related to the wheel motor failure. The savings by applying an optimal CBM policy was estimated to be 22%. In this case, the cost of a failure replacement was, on average, three times more expensive than a preventive replacement.
4. ABC Soup Company is a food processing company. Vibration data were collected on shear pump bearings, with 21 vibration measurements provided by accelerometers. EXAKT found 3 of the 21 measurements to be significantly related to the probability of pump-bearing failure. The savings by applying the optimal CBM policy was estimated as 35%. In this case, the cost of a failure replacement was, on average, 9.5 times more expensive than a preventive replacement. Note: 9.5 is quite high and results from the high cost associated with production disruption due to bearing failure. The benefit of these methods increases with the value of lost production.
5. The gas distribution company described earlier was interested in optimizing its maintenance tactics for its steel gas mains. Specifically, it wanted to determine the following:
    a. Best coating (most economical)
    b. Whether to backfill mains with sand (known to prolong the life of steel mains as compared to clay)
    c. Best leak survey frequency conducted on steel mains

A cost/benefit analysis was performed for each to determine the optimum solutions, yielding optimized tactics and an annual estimated savings of $1,380,000.

CALCULATING SPARE-PART REQUIREMENTS

What Is Spare-Part Provisioning?

Spare-part provisioning (SPP) is used to optimize spare-part inventory control to facilitate corrective maintenance in cases where parts replacement is your only viable maintenance option. SPP differs from regular inventory control in the sense that SPP is not an aim in itself but a means to guarantee equipment uptime.

There are various ways to determine optimal stock size when parts are either nonrepairable or repairable. Optimization criteria include minimization of costs, maximization of availability and maximization of stock reliability (i.e., the probability that a spare-part request will not be rejected due to a lack of spare units in stock).

One of the most challenging issues for those responsible for managing assets of a company is spare-part management. How many spares to order each time? How much safety stock should there be? How many repairable spares should be purchased and stored? For example, a stores controller will want to know how many items to order each time the stock level of an item reaches zero. The more items he/she orders at any time, the more his/her ordering costs will decrease, since he/she has to place fewer orders, but his/her stock holding costs will increase.

As for repairable items, optimizing decisions is usually more complex and requires more advanced mathematics. The stores controller needs to know how many he/she should have in the inventory so he/she will not go out of stock with certain probability. If a component fails, a spare unit will replace it, and the failed component will be sent to the repair shop. Repairable components, unlike most fast-moving spares, are usually very expensive (that is why they are repaired versus replaced). They can be transformers, electric motors, pumps, generators, turbines, specialized circuit cards or other complex assemblies and components. How many spares must we have to achieve a certain level of reliability or to minimize the total cost of running out of spares and the cost of keeping the spares?

As mentioned, mathematical modeling required for these types of spare management decisions is complex. Consequently, software packages are required to address them. A leading software package is called SMS, developed at the C-MORE at the University of Toronto. The detailed mathematical model behind the software is given by Jardine and Tsang (2013). The software uses information such as mean time between failures of the component in the operation, mean time to repair the spare, number of components in the operation, etc., and determines the optimum number of required spares according to one of the following criteria:

- *Instantaneous reliability*: the probability that a spare is available at any given moment in time; also known as availability of stock, fill rate or point availability in the long run
- *Interval reliability*: the probability of not running out of stock at any moment over a specified period, e.g., 2 years

- *Cost minimization*: takes into account costs associated with purchasing and stocking spares and the cost of running out of a spare part
- *Availability*: percentage of nondowntime (uptime) of a system/unit where downtime is due to shortage of spare parts

SPP Case Studies

1. An open-pit mining company had 62 repairable electric motors in its conveyor systems and wanted to know the optimal number of spare motors to stock. Using SMS for different optimization criteria yielded the following:
   a. To achieve 95% instant reliability, four spare motors should be in stock.
   b. To achieve 95% interval reliability, seven spare motors should be in stock.
   c. To achieve 99% availability, two spare motors should be in stock.

   Note: In this case, cost was not the criterion of interest; it was system reliability.
2. A nonrepairable fume fan shaft with a long life span (25–40 years) was being used in a blast furnace in a steel mill. Replacement lead time was 22 weeks. If a fume fan shaft failed, operation had to shut down, at a loss of almost $6,000,000 per week. The company wanted to know how many spare shafts to stock. The shaft's cost was of secondary importance to the cost of this downtime. System reliability was the decision criterion. The optimal solution turned out to be stocking one spare fume fan shaft.
3. The barge pumping system of an oil and gas company consisted of six horizontal pumps on three barges pumping into three 36-inch lines. The pumps played a critical role in the success of the barge pumping system; the design allowed a 12-hour window to change out any component on an unplanned outage (breakdown). Having spare pumps readily available was crucial to avoid any production downtime. The SMS software package determined that the optimum number of spare parts required for the pumping system is three, with an annual cost of $38,216, including downtime costs, inventory costs and cost of capital tied in spares. This investment results in an annual savings of $686,000 when compared with traditional systems that suggest using $N - 1$ redundancy or simply

TABLE 10.7

Data Summary of Barge Pumps

Scenario	Number of pumps	6
	Planning horizon (days)	365
Reliability and maintenance	MTB removals (days)	456
	MTT repair (days)	14
Cost	Cost of spare pump	$110,000
	Cost of emergency pump	$330,000
	Downtime cost ($/day)	$125,000
	Holding cost ($/day)	$33.15

Note: MTB: mean time between; MTT: mean time to.

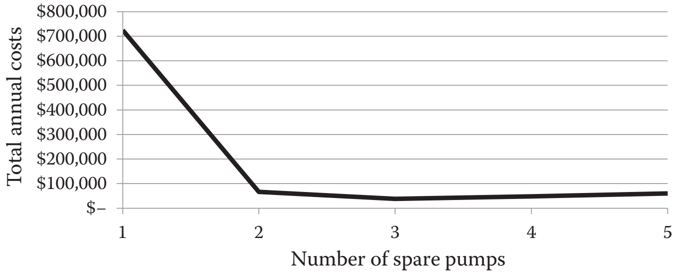


FIGURE 10.14
Total annual costs versus number of spares.

keeping one spare. Relevant data are summarized in Table 10.7, and the total cost curve as a function of the number of spare pumps is shown in Figure 10.14.

OPTIMIZING FAILURE-FINDING INTERVALS

Many types of equipment are considered "just-in-case" or "protective" equipment. They remain idle just in case an event happens (i.e., something goes wrong) and they are needed. Such assets include fire extinguishers, pressure safety valves (PSVs), switches, standby equipment, alarms, breakers, escape route signage, etc. We want them to work when we need them, and although they are sitting idle most of the time, they can fail and leave us unprotected. To reduce the chance of their unavailability, we usually do regular functional checks. These checks are called failure-finding tasks.

Many of these devices protect us against safety and environmental hazards; others prevent companies from suffering huge operational or cost consequences. If the consequence is safety and/or environmental, we want to ensure we have reduced the probability of such incidents to a tolerable level. If the consequence is purely operational, we want to make sure we have selected the optimum policy that results in the minimum total cost. To reduce the chance of both the primary asset and its backup or protective device failing at the same time, we have several options:

- Design/procure protective devices with longer life.
- Reduce the frequency of events requiring the intervention of protective devices (i.e., increase the reliability of the primary asset). The primary asset has a protected function, which is protected by a protective device (such as its backup).
- Perform more frequent functional tests, also called failure-finding tasks.
- Incorporate more redundancy (install more protective devices).

Each of these has a cost and results in different changes to the overall probability of the protected function and protective device being down together. To optimize the decision, we need to find the relationship between the chance of a catastrophic incident and the frequency of failure-finding tasks. An incident happens when a protective device is called upon (meaning that a protected function is lost) and the protective device is in a failed state. The following formula developed by Horton (Jardine and Tsang 2013) shows how the availability of a protective device can be calculated:

$$(1-A)=\frac{I}{2M}$$

where I is the FFI (inspection interval/functional test intervals), M is the mean time to failure of the protective device, and A is availability ($1-A$ would be unavailability) of the protective device. If a single PSV has a mean time to failure of 10 years and is inspected every year, the average unavailability of the valve would be

$$(1-A)=\frac{1}{2\times 10}=0.05 \text{ or } 5\%$$

This means there is a 5% chance that if the single protective device is needed, it will be in the failed state, causing a catastrophic incident. Assume that the chance of overpressurization occurring in a tank protected by the above PSV is 1% in any given year. This probability, P_{ted}, refers to the probability or frequency of failure of the protected function. Therefore, each year, there is a 1% chance of overpressurization, and when that happens, there is a 5% chance that the PSV is in a failed state. Thus, the chance of a catastrophic incident is 1% × 5% = 0.0005 or 0.05% or

$$P_{inc}=P_{ted}\times(1-A)=\frac{P_{ted}\times I}{2M}$$

For incidents with safety consequences, we must ensure that the probability of fatality is reduced to a tolerable level defined by available safety regulations/standards. If the consequences are financial, they need to be weighed against the cost of conducting failure-finding tasks so an optimum FFI can be calculated (Jardine and Tsang 2013; Moubray 1997).

FFI Case Studies

1. ABC is one of North America's largest mining and refining companies. The company wanted to evaluate its current inspection intervals and find an optimal inspection schedule with respect to availability for its fleet of PSVs. The steam and process pipes in the company's smelter are subject to variable pressure loads. Safety valves have been installed to protect the piping and downstream equipment from sudden pressure changes. The main function of a valve is to release pressure when it reaches a critical level. Failure to do so may damage downstream equipment or cause pipe failure, resulting in unplanned downtime and emergency replacement costs.

   Analysis determined that the time to first failure (first lifetime) of a safety valve and the time to later failure after the first failure (all other lifetimes after the first one) of a safety valve follow different distributions (i.e., the valves are not as reliable after they have been repaired). The optimal FFI giving 90% availability was found to be 1.1 year for the first lifetime but only 0.2 year for all other lifetimes after that first repair. Note: In this example, the chief criterion of interest was not cost but safety and environmental consequences.

The PSV is the most important safety device on a pressure vessel. Regular inspection and servicing are required to ensure that it will be operational when a pressure relief function is required. An oil and gas company sought the help of an external expert to determine the optimum frequency to inspect their PSVs.

To optimize inspection frequency, they needed to find the relationships between the PSV's design, the failure rate and the chance of a catastrophic incident. Information about the PSVs was obtained from various departments: the valve shop, reliability engineering, maintenance and quality assurance. The expert analyzed the data, and using the appropriate equation, he was able to calculate the optimum inspection interval for the nonprocess PSVs. The current practice of inspecting every 3 years was not the optimum inspection interval and did not provide appropriate safety protection for employees. The optimum inspection interval was 15 months, especially for PSVs in a corrosive environment.

2. ABC Company has seven blast-resistant trailers (BRTs). Gas detectors are used by the company as safety protection for persons working in areas where there is a possibility of gas leakage, fire, or explosion. If any lower-explosive-limit (LEL) gas or H_2S gas is leaking in an area, the gas detectors sound an alarm, alerting people to leave and take shelter in the BRTs. Different detector sensors are used to detect H_2S and LEL. Four sets of gas detectors are installed in each of the seven BRTs. Two sets are located close to the intake duct of a heating, ventilation and aid-conditioning (HVAC) unit, and two sets are located at the side entrances. Each set contains a sensor, transmitter and display unit. When low to high levels of gas are detected, they transmit warnings through blue strobe lights and a horn.

   The study was intended to accomplish the following:

   a. Improve the reliability of the gas detection system to ensure the safety of people
   b. Save money by selecting the correct number of detectors while designing a new gas detection system for new trailers
   c. Implement a proper maintenance plan to ensure the best performance of the system

Information on the gas detectors was obtained from site-wide utilities, reliability engineering and the detectors' manufacturer. The data were analyzed, and with the use of the appropriate equation, the optimum inspection interval was calculated. Their current policy of inspecting sensors every 3 months turned out to be acceptable if the number of the sensors were to stay at the current level of four per BRT. The company abandoned its plan to reduce the number of sensors (which were very expensive) to two per BRT.

UPTIME SUMMARY

Choosing excellence is a journey that will not end. No matter how well you are doing, you can always do better. Continuous improvement is perhaps the most evident hallmark of truly successful organizations. They do not settle for good when they can make things better. EBAM has emerged as our profession's gold standard for decision making. EBAM feeds continuous improvement and enables a degree of precision that is not possible using only expert opinion and gut-feel pronouncements. EBAM uses statistical and optimization mathematical modeling based on good (often scrubbed) data or inferences about data that can be gleaned from expert opinions through structured knowledge elicitation techniques. Today, EBAM is at the heart of good asset management and could be applied in almost every area in this field, not just decisions impacting maintenance. Properly applied, it can create substantial measurable savings and improvement in safety and reliability of any type of operation, both at the design stage and after they enter service.

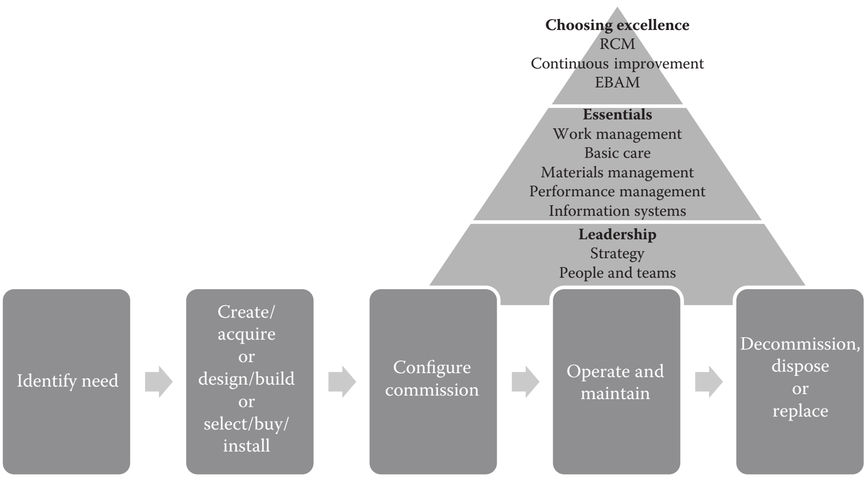
EBAM is considered by many to be the hotbed of new techniques in asset management. For example, in the United Kingdom's specification for asset management (PAS 55) the word *evidence* is used nine times. In ISO 55000, published only 12 years later, the word has been used 15 times. ISO 55000 states the following: "8.2.3—The organization should have the capability to make evidence-based decisions on proposed changes and the ability to consider scenarios systematically across the entire organization." EBAM provides that capability. A number of postgraduate programs in reliability focus most of their efforts in this field, and many of the master's- and PhD-level reliability engineers have explored new EBAM methods in earning their advanced degrees.

EBAM substantially enhances the tool kit available to maintenance and asset managers, although keep in mind that it can really only be used by well-educated and often specialized engineers. Companies that are truly on the excellence journey will find themselves deeper in the realms of good asset data and information management and use of that information with these advanced techniques.

Because of its application in solving both maintenance and asset management, EBAM is one of the disciplines that bridge the traditional maintenance with the emerging asset management disciplines.

Section IV

Asset Management



The first two editions of this book focused exclusively on maintenance management. Maintenance is but one part of what is usually the longest portion of the life cycle of any physical asset. The entire life cycle comprises the following: definition of need (we need a plant to do…), conceptual design and site selection, detailed design, building/acquiring, commission, operation and maintenance (O&M) and modification, decommission and disposal. Asset management deals with this entire life cycle. While it is broader in scope than *Uptime*'s primary focus, it is needed here as *Uptime* provides a highly successful framework for maintenance within the operational phase of any asset's life cycle.

At the time of writing of the second edition, a new specification for asset management had emerged in the United Kingdom—PAS 55-1 and PAS 55-2. PAS 55 was released in 2004 and revised in 2008. With PAS 55, the Institute of Asset Management (IAM) produced a competency framework and a self-assessment tool (available to its members). It was largely responsible for increasing awareness of asset management around the world. A new age in our profession was dawning.

In 2011, the IAM published its paper, "Asset Management—An Anatomy" (IAM 2014). Also in 2011, the Global Forum for Maintenance and Asset Management (GFMAM) published its paper, "The Asset Management Landscape" (GFMAM 2014). The International Standards Organization (ISO) produced a trio of international standards, ISO 55000, 55001 and 55002, which emerged in January 2014. In 2014, the IAM revised its "Anatomy" to reflect the second edition of the GFMAM "Landscape" (March 2014) and the requirements of the new international standards.

Note that ISO 5500X covers a somewhat lesser scope than the GFMAM "Landscape." "Landscape" covers some 39 subjects. ISO 55001 has 24 clauses and 71 "shall" statements (requirements). "Landscape" covers the available body of knowledge in asset management, while the standard details only those subjects required for an organization's asset management system to direct, control and refine asset management within the organization.

Like the United Kingdom's PAS 55, the ISO standards define what work must be done, not necessarily how to do it. ISO 55000 provides scope, principles and terminology to facilitate the creation of a business case for asset management system implementation. ISO 55001 spells out the requirements that an asset management system must fulfill to be compliant to the standard. Finally, ISO 55002 describes the application guidelines to be used in order to meet the ISO asset management system standard.

11

Asset Management

> Most practicing scientists focus on "bite-sized" problems that are timely and tractable. The occupational risk is then to lose sight of the big picture.
>
> **Martin Rees**
> *Baron Rees of Ludlow, Britain's Top Scientist*

As the quote states, a big risk is that we lose sight of the big picture. Planning, scheduling, materials management, teamwork, reliability-centered maintenance (RCM), root cause analysis (RCA) and so on are all tools. *Uptime* is a framework for one (albeit significant) phase in the entire life cycle of physical assets. Asset management (AM) looks at the big picture and creates the framework within which *Uptime*'s first chapter on strategy can easily fit.

Maintenance management is most successful when it exists in a collaborative environment with other departments and functional areas (i.e., cross-functional teams). It begins with direct support to a company's strategic direction. Teamwork, often maintenance and operations together, is the best way to unleash talent in your organization. The benefits of planning are lost if good materials management support is unavailable, and conversely, materials management cannot do its job without good planning and scheduling. Performance measures must reflect the inputs, outputs and processes of maintenance but also be sensitive to the needs and wants of internal and external customers of maintenance. Information technology (IT) is a tool that cannot exist only within maintenance. It has links to supply chain, human resources (HR), production and training. Its usefulness is determined by data quality, something that is discussed in this part of the book. Excellence in maintenance cannot be achieved without some level of accomplishment at having strategically directed and well-executed basics. Excellence means high reliability, and methods to achieve it are dependent on initial engineering and design followed by a good definition of the "right work" to be done. Once that has been done, performance measures monitor how successful those choices are, and adjustments are made using optimization techniques. Data—their consistency across the organization and their accuracy—become critical. The impacts of maintenance on all forms of corporate risks are well defined and must be managed.

Maintenance works as part of a broader perspective that deals with the entire life cycle of the physical assets—that is AM. *Uptime* only deals with the operational and maintenance phase of the asset's life cycle. Its tools contribute either directly to good maintenance management or, in some cases, to the broader AM perspective. For instance, RCM is one that contributes to both:

- Improved financial performance—RCM prevents failure modes that cause poor output, product quality, customer service and operating costs.
- Informed asset decisions—RCM uses a qualified RCM facilitator to engage subject matter experts (SMEs) in determining the right decisions on what work should/should not be done. Maintenance, operator tasks, training and other one-time changes result from the combined knowledge and efforts of the most knowledgeable people at your disposal considering your own operating environment and context.
- Managed risk—RCM values proactive tasks that mitigate safety/environment consequences before those that solely affect economic consequences.
- Improved services and outputs—RCM defines the "safe-minimum" work based on asset states for balanced scorecarding and key performance indicator (KPI) tracking use.
- Demonstrated social responsibility and demonstrated compliance—RCM formally documents operations and maintenance matters such that paper trails are provided for auditor/regulator reference.
- Enhanced reputation—RCM is a world-class, proven methodology in civil aviation. If it did not work, two or more commercial airliners would crash, somewhere in the world, every day. Likewise, it has proven itself in other highly critical applications, such as nuclear

power, ship propulsion and systems, power generation and military weapon systems.

- Improved organizational sustainability—RCM harvests retiring baby-boomer trades' know-how. This way, new trade cohorts can benefit and leverage past tribal knowledge, converting it into a usable form that will not be lost when someone retires. It is an excellent knowledge capture and decision forum.
- Improved efficiency and effectiveness—RCM values doing "the right work at the right time," nothing more but, certainly, nothing less. It has proven itself to reduce costs where maintenance was insufficient and where it was being overdone. It has proven itself to reduce safety and environmental risks as well as providing increased productive uptime—all of which achieve what AM sets out to do: deliver value.

WHAT IS ASSET MANAGEMENT?

ISO 55000 makes it clear that AM is an activity (something you do) to implement the AM system (something you define). The AM system is not just a computerized program as some might be inclined to believe. It may well employ computerized tools and probably needs to, but the AM system is not in itself a computerized tool or system, nor does it need to be.

AM is data and information intensive. It touches on nearly all aspects of any business, although many outside of our field probably do not recognize that so clearly. Under the heading of leadership, the standard points out that this is a multidisciplinary and multilevel endeavor involving the whole organization.

Why Bother?

There are plenty of examples of physical assets that have had a big impact on companies. For example,

- Finances: The impact of BP's Deepwater Horizon disaster in the Gulf of Mexico is expected to cost BP upward of $42 billion (not to mention the human, environmental and reputational costs).

- In Quebec, Canada, the recent Lac Megantic train derailment and fire resulted in deaths, destruction of a town and the bankruptcy of the Montreal, Maine and Atlantic Railway—its assets are now being auctioned.
- Production: The BP refinery explosion and fire in Texas City in 2005 had a 437,000-barrel-per-day impact in addition to its well-documented human and environmental impacts.
- Safety: The above examples all involve fatalities. Sadly, as engineers, our mistakes do often put humans at risk and often in large numbers. Even static civil assets can make big news, like the Montreal Champlain Bridge (now being reinforced after years of decay) and the I-35W highway bridge into Minneapolis that collapsed in 2007, killing 13 and injuring 145.
- Public image: BP's image is not one of being green despite all its marketing to the contrary. One of the companies it acquired (Amoco in 1998) had also suffered irreparable damage from its disastrous oil spill (1.6 million barrels) when the ship *Amoco Cadiz* grounded in Normandy, France (1978). Today's environmental awareness is driving hotel chains to upgrade their building portfolios to new Leadership in Environmental and Energy Design (LEED) standards lest they risk loss of business from a younger and more environmentally savvy clientele and even from governments who are insisting on LEED standards being met.
- Environment: Again, look to the above examples. Failure of even simple systems designed to keep wildlife away from waste ponds can result in loss of both wildlife and reputation. Canada's oil sands producers have been regularly accused of neglect, even though in some cases, weather has contributed to the losses.
- Quality: Mass production relies heavily on physical assets working correctly to produce within specified tolerances. Failures in those assets can impact on product quality and result in either high rates of rejects or out-of-spec product reaching the public. In 2008, Maple Leaf Foods, a Canadian food producer, sold tainted meat products that resulted in 22 deaths and 57 confirmed cases of listeriosis. Not only was quality impacted, but also costs, public safety and company reputation.
- Security: In cases where high-value products are being processed, failures in physical assets can result in product loss or exposure to risk of theft. In diamond mining operations, once diamonds are

separated from the kimberlitic ore, they are usually processed in closed systems. As the world's hardest substance, they wear transport piping systems easily; spillage must be cleaned up, all diamonds recovered and the systems repaired. All of those activities require human intervention in close proximity to an extremely high-value product. Likewise, any failure in any production line will expose the product to workers, contractors and possibly others who can take advantage of the opportunity for their own gain.

All of these examples, and there are many more, represent risks that must be managed. Good AM entails the identification, assessment, management and mitigation of these risks and their consequences. Risk management is one of the important corporate functions that are directly and intimately impacted by AM activities. It is also an excellent example of where the integration of AM with other corporate functions provides substantial potential benefit to companies that adopt these standards.

Indeed, AM, because of its interplay with other corporate functions, provides an excellent catalyst for the integration of those often-isolated functions. Good AM can lower a broad spectrum of risks, reduce costs and improve production and revenue-generating capacity.

STANDARDS, "ANATOMY" AND "LANDSCAPE"

The three ISO standards provide an overview with definitions (ISO 55000), a statement of the specific AM requirements that must be met (ISO 55001) and guidelines on how to meet those requirements (ISO 55002). The Institute of Asset Management's (IAM's) "Asset Management—An Anatomy" offers an appreciation of AM—what it is, what it can help to achieve, the scope of the discipline and a description of fundamental concepts and philosophy. The Global Forum for Maintenance and Asset Management's (GFMAM's) "Asset Management Landscape" provides a framework to enable AM knowledge and practices to be compared, contrasted and aligned around a common understanding of the overall discipline of AM. It has a core of AM fundamentals and 39 subjects, each with its own knowledge and practice areas (specialties).

ISO 55000 provides an overview of AM concepts, much like the GFMAM's "Landscape" fundamentals. The actual standards to be met are defined in ISO 55001. It is, of course, a voluntary standard—there is no regulatory impetus behind it (at least not yet), but its benefits are far-reaching and potentially quite substantial. It is context specific and sensitive, so it may not be for everyone, but for any company that has a significant investment in physical assets, it is, at the very least, worthy of investigation. Regulators are taking a keen interest in it, but many are loath to impose requirements that could potentially be used as "excuses" for raising rates. Insurers, on the other hand, do not worry about your costs for compliance; they are interested in managing risks. Considering the many man-made disasters for which insurers have been required to make large payouts, they are becoming drivers in the push behind standards.

At the time of writing, at least one organization (a utility) in Canada had been dropped by its insurers due to failure of the utility to satisfy the regulator that it had sufficient justification for funding to renew aging assets. The regulator was looking for evidence that the utility was managing its risks associated with those aging assets and was not satisfied. Compliance to ISO 55001 (or PAS 55-1) would have meant that the utility had the justification and needed risk management in place, and they would have been able to demonstrate it, but it was missing.

ISO 55000's overall requirement is straightforward. An organization (company, plant, mine, school board, etc.) has a portfolio of assets. It has a corporate strategy (or equivalent) that provides overall objectives for the entire organization. Those assets are intended (somehow) to deliver on part of those objectives. The AM system creates the link from corporate objectives, through a number of interacting elements to establish policy (i.e., rules), AM objectives and processes by which to achieve them. AM itself is the activity of executing that set of processes to realize value (as the organization defines it) from those assets.

ISO 55001 describes the specific requirements (i.e., what should be done to meet good AM practices) that must be met under seven major themes:

1. Organization context
2. Leadership
3. Planning
4. Support
5. Operation
6. Performance evaluation
7. Improvement

Organization context: An organization determines its external and internal drivers and constraints—anything relevant to its purpose and ability to achieve the outcomes of its AM system. The strategic AM plan (SAMP) includes AM objectives (linked to corporate strategic intent and objectives). An organization must determine and understand which stakeholders are relevant to the AM system, their requirements and expectations, the criteria for AM decision making, stakeholder requirements for financial and nonfinancial information and its reporting both internally and externally.

The scope of the AM system must be defined. What are the boundaries of its span (i.e., to what does it apply)? This considers the above drivers, constraints, requirements and any interactions required with other management systems.

There are requirements to document all of this and to continually improve the AM system, describing it all within a well-documented SAMP. Figure 11.1 shows the key elements within a SAMP.

Leadership: The standard describes three main requirements—leadership and commitment, policy and organizational roles and responsibilities and authorities.

Leadership and commitment requires that top management ensure the following:

- The AM policy, SAMP and objectives are established and compatible with organizational objectives
- AM system requirements are integrated into the organization's business processes
- Resources are available
- Communication of the importance of effective AM and of conforming to AM system requirements
- The AM system achieves intended outcomes
- Personnel contribute to the effectiveness of the AM system
- Cross-functional collaboration
- Continual improvement
- Support and other management roles demonstrate leadership
- Risk management is aligned with the organization's risk management approach

Much of this is arguably just good business management practice in a complex business having separate functional areas that must ultimately work toward common goals in each and all areas.

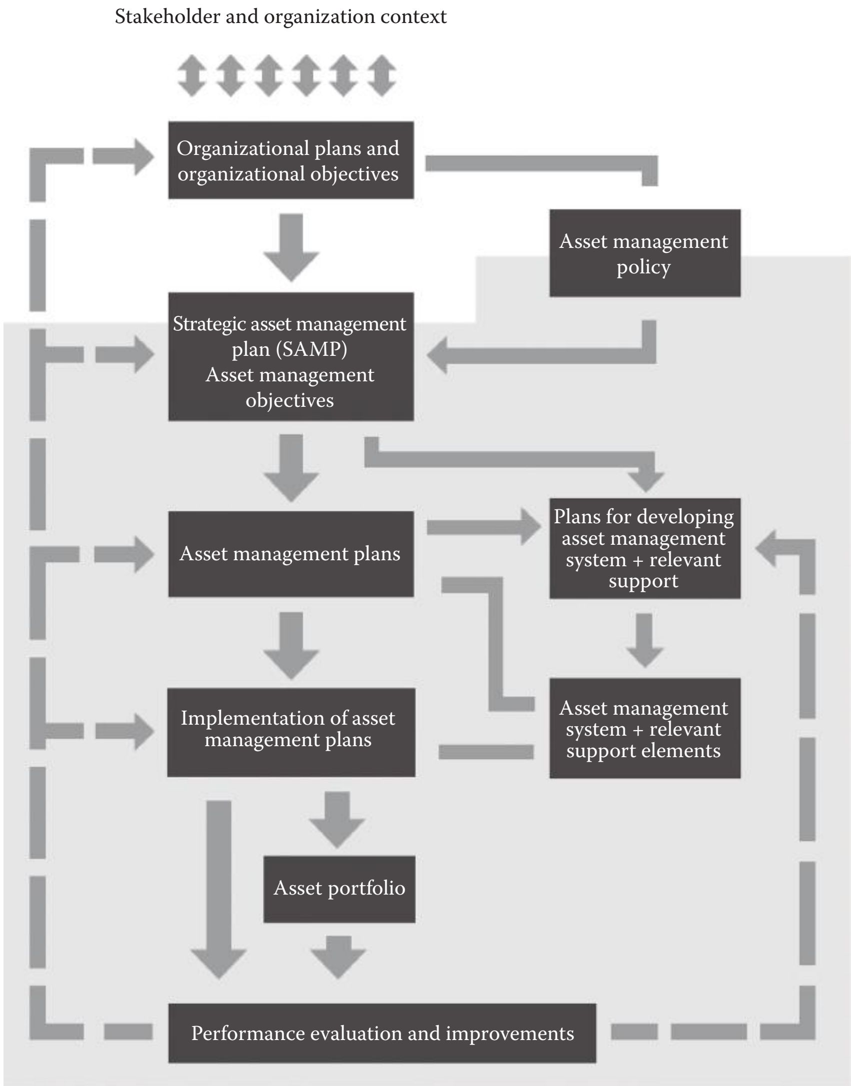


FIGURE 11.1
Key elements within a strategic asset management plan.

An AM policy must be established that is appropriate to the organization and provides a framework for setting objectives and satisfying them, as well as continuous improvement. It must be consistent with the organization's plan and policies; be appropriate to the organization's assets and operations; and be available, communicated, periodically reviewed and updated if needed.

Top management must also ensure that roles, responsibilities and authorities are assigned, communicated and effectively executed to achieve the following:

- Establish and update the SAMP
- Ensure that the AM system delivers
- Ensure that it complies to the ISO itself
- Ensure that the AM system is suitable, adequate and effective
- Establish and update AM plans (as needed)
- Ensure reporting on performance of the AM system to top management

AM is not something that can be abdicated to lower levels of management. Delegation does not absolve top management of responsibility or participation.

Planning: Planning is a key element of the AM system—it is where you come up with the details of how the organization will deal with risks, opportunities and its AM objectives. Plans describe what the organization will do to execute AM. The standard outlines a number of requirements that those plans should meet/consider.

As in any endeavor, there are both risks and opportunities. Those must be identified and addressed to ensure that the AM system can achieve its intended outcomes, to prevent or reduce undesired effects and to achieve continual improvement. Plans are needed to address both the risks and opportunities, considering how they may change with time and organizational context. Again, those activities must also integrate with AM system processes and, in turn, with other organizational processes.

Objectives are established for all relevant functions and levels considering the requirements of stakeholders and other financial, technical, legal, regulatory and organizational requirements. Those objectives should be aligned with organizational objectives; be consistent with the AM policy; be established and updated using AM decision-making criteria; be included within the SAMP; and be measurable, monitored, communicated, reviewed and updated as appropriate. All of this should be documented. Note that this is a recurring theme throughout the standard.

Objectives require plans for their achievement, and those plans should include the various activities, resources and other financing. Like the objectives, the plans must be aligned and consistent with the rest of the AM system. The plans should determine and document the following:

- Decision-making and prioritizing methods and criteria
- Processes and methods for managing assets throughout their life cycles
- What will be done
- Resources
- Time frames
- Evaluation criteria
- An overall time horizon for the plan
- Review periods
- Actions to address risks and opportunities (identification, assessment, significance and actions to deal with those risks and opportunities). Risk management for assets must be considered in the organization's overall risk management approach and contingency planning

This is arguably the area where you will see the greatest opportunity to integrate in a meaningful way with other established organizational processes and methods, especially risk management.

Support: AM does not exist in a vacuum. Cooperation and collaboration with other functional areas will be required for effective AM and execution of the AM system. Resources are needed to establish, implement, maintain and continually improve the AM system itself, and collaboration outside of the AM organization or functional area will be required.

Those doing the work must be competent. While that should go without saying, it is stated explicitly that persons must be educated, trained and experienced and where needed action is required to ensure they are. Effectiveness of the actions taken (e.g., training) should be evaluated, and documented information is retained to provide evidence of competence. Periodically, the competency needs should be evaluated and updated as needed.

The organization must establish its own information requirements to support assets, AM and the AM system in achieving the organizational objectives. The information should consider risks; roles; responsibilities; processes; procedures; activities; information exchange; and the impact of quality, availability and management of information on decision making. Information requirements are defined in detail, including specific information attributes; quality requirements; and how and when collection, analysis and evaluation will take place. This is all managed through defined processes, and it must all align with other organizational processes (financial and nonfinancial) as well as utilized terminology (to avoid confusion and miscommunication). Information must be consistent across its various uses—the concept of "enter once, use many times" comes to mind.

A page describes documentation requirements, but it boils down to having a formal document management system in place for all the information (processes, plans, procedures, methods, etc.) described in the standard. Documentation must be kept current, and only those current versions should be available for use where and as needed.

Operation: This section outlines the requirement to plan, implement and control the processes needed to meet and implement all the plans. Criteria for the processes are determined, control is applied, information is documented to ensure confidence and evidence is established to treat and monitor risks.

Change must be managed as discussed in Chapter 2. Change presents risks, both temporary and permanent, that must be managed. There is a requirement to manage these risks and mitigate any adverse effects.

The standard recognizes that outsourcing of activities is not uncommon. The risks associated with outsourcing must be identified and managed. Outsourced activities must still be managed; again, as with top management's responsibilities, activities can be delegated through outsourcing, but responsibility cannot be abdicated. A discussion of outsourcing is in Chapter 1.

Performance evaluation: Organizations must determine what needs to be monitored and measured; the methods to monitor, measure, analyze, evaluate and validate results; when it shall be done; and what results should be analyzed and evaluated. This is used to report on asset condition, performance, AM performance (including both financial and nonfinancial results) and the effectiveness of the AM system itself, including risk management. This information is used to feed improvement and investment decisions. Where asset performance or conditions are below expectations, you can choose to ignore them, correct them (maintenance or modifications), change them (modifications) or replace them. Performance management as it relates to maintenance is discussed in Chapter 6.

Evidence of the results of performance management activities and what they reveal is kept as documented information. Use of that information occurs in day-to-day maintenance and operational decisions, modification or upgrade decisions, disposal and capital replacement decisions. Successful companies have good asset investment planning processes in place to utilize that information in forecasting short-, medium- and longer-term investments. Utilities, for example, often have investment planning departments responsible for this activity as it ties in very tightly with their determination of the rates they will charge customers and, in some cases, have to justify to regulators. Asset investment planning can get quite complex as you consider many assets over long periods of time (investment horizons), the condition of those assets, the timing of needed improvements/upgrades/replacements and the different ages of the assets.

One electrical transmission utility commissioned an extensive study of its power transformers to determine future maintenance budgetary and replacement spending requirements. That study considered some 1,700 power transformers in 14 different asset "classes" that ranged in age from new to over 70 years. They were in service over a geographic area covering more than 1,000,000 square kilometers. Each year, there was a mix of ongoing preventive maintenance (PM), major midlife upgrades, minor and major repairs, decommissioning and replacement activities. In that study, they identified the major failures that had to be dealt with, forecast all their future maintenance requirements, demonstrated that it was economical to perform the midlife refurbishments that they were already doing (other utilities had a much earlier retirement age for these same assets in similar operating environments), identified the optimum replacement age (over 70 years) and were able to smooth out their forecasts of both O&M and capital replacement costs over the coming years. When the budgetary requirements were presented to regulators, they were encouraged to carry out similar studies of all major asset classes to help in justifying all of their forecast funding requirements more precisely.

In the utilities and facilities management industries, there are software tools and consulting support for more accurate asset investment planning.

Other similar examples are discussed in Chapter 9 where data are used to generate evidence in support of better AM decisions.

Internal audits are required at planned intervals to ensure AM system conformance with organization requirements and the requirements of the ISO 55001 standard and that the AM system is effectively implemented and maintained. An audit program is established, including frequency, methods, responsibilities, planning and reporting and consideration of the processes and results of previous audits. Each audit has a defined audit criteria and scope, auditors should be objective and impartial, results are reported to management and documentation is retained.

Top management has responsibility to review the AM system periodically to ensure its suitability, adequacy and effectiveness.

Audits and top-management reviews lead into the continual-improvement process, and like all else in the system, everything is documented. Audits are useful to identify what changes to make as discussed in Chapters 1 and

13 but caution is warranted due to their potential change management impacts as discussed in Chapter 2.

Improvement: Nonconformities occur if the AM system or its elements are not followed. An incident is when a failure of some sort results from an inadequacy or nonconformity within the system. Actions to control and correct are required along with dealing with consequences. An evaluation of the need to eliminate the cause is required to ensure that it does not happen again or elsewhere. Once decided upon, action is taken to correct the inadequacy or nonconformity, and those actions are reviewed for effectiveness. If necessary, the AM system should change. Again, documented information is required.

Preventive actions are required. The organization should establish processes to identify potential failures in asset performance and evaluate the need for preventive action. Methods to do this are discussed in Chapters 8 and 9.

And that is the extent of the requirements. For those of us familiar with good management practices, these requirements echo those practices nicely, albeit with an AM twist.

GFMAM's 39 Subjects

The GFMAM "Landscape" differs from ISO's themes. The themes cover actions needed to control, deploy and improve AM within an organization. They do not cover the entire scope of AM knowledge as GFMAM does.

The GFMAM core fundamentals are very similar to the ISO 55000 overall requirement and outline. It is the 39 subjects in six groupings, each describing a portion of the body of knowledge that is different. They are not action requirements as they are in ISO 55001.

1. Strategy and planning
   a. Asset management policy
   b. Asset management strategy and objectives
   c. Demand analysis
   d. Strategy planning
   e. Asset management planning
2. Asset management decision making
   a. Capital investment decision making
   b. Operations and maintenance decision making

   c. Life-cycle value realization
   d. Resourcing strategy
   e. Shutdowns and outage strategy
3. Life-cycle delivery
   a. Technical standards and legislation
   b. Asset creation and acquisition
   c. Systems engineering
   d. Configuration management
   e. Maintenance delivery
   f. Reliability engineering
   g. Asset operations
   h. Resource management
   i. Shutdown and outage management
   j. Fault and incident response
   k. Asset decommissioning and disposal
4. Asset information
   a. Asset information strategy
   b. Asset information standards
   c. Data and information management
5. Organization and people
   a. Procurement and supply chain management
   b. Asset management leadership
   c. Organizational structure
   d. Organizational culture
   e. Competence management
6. Risk and review
   a. Risk assessment and management
   b. Contingency planning and resilience analysis
   c. Sustainable development
   d. Management of change
   e. Asset performance and health monitoring
   f. Asset management system monitoring
   g. Management review, audit and assurance
   h. Asset costing and valuation
   i. Stakeholder engagement

"Landscape" defines each of these subjects, puts them in context, describes key considerations that fit within the subject and identifies the artifacts that may be produced and other key related subjects.

IMPLEMENTING AM

ISO 55001 does a good job of outlining what actions should be taken by any organization that wishes to manage its physical assets responsibly. While much of it is common sense, it is not always practiced, and this standard provides reminders of what might be missing. A common theme is that everything is documented, including the processes, procedures, etc. and the measurements and other reports that provide evidence of compliance. Clearly, there is a need to collaborate with other functional areas within the organization, most notably, finance, HR, information management (IT/systems), risk management and top management.

The last of the three standards is ISO 55002 guidelines for implementing ISO 55001's requirements.

ISO 55002 does a very nice job of melding the high-level requirements of ISO 55000 (including general explanations of "why") with the more specific requirements of "what" is needed from 55001 and adds considerable value in the form of "how" and helpful tips, ideas and pointers on what to consider.

ISO 55002 could almost be used as a training course because it gives sufficient detail on how to go about meeting the requirements of 55001 to inform someone who is somewhat new to AM. Note that it is not, however, a complete coverage of AM. For more comprehensive knowledge, refer to the 39 subjects of the GFMAM "Landscape."

In reading ISO 55002, it is possible to get a good understanding of why the standards exist, what they require and what sort of things are needed to implement then. Having said that, it is no "idiots' guide"—the reader must understand good management practices and would certainly benefit from having a technical background, given the subject matter.

In ISO 55002, the reader also gets clarification on what sort of documentation is/is not needed and where it may be found. Although there is talk of policy, SAMP, objectives, etc., there is clearly no requirement to build a bureaucratic empire. In pointing out where information may be found or included, ISO 55002 clears up (at least in this author's opinion) the confusion that led to the criticism of PAS 55-1 and 55-2 as being overly bureaucratic.

While the information must be available and documented, there is a great deal of latitude on just where the information resides. What is likely to be the biggest challenge to users of the standard is that while they may well be doing much of what the standards call for in terms of action in the field, they may not have it well documented. Tying it all together will require some effort, as it did for PAS 55, but there are a number of helpful tips that will help keep the level of effort reasonable.

Most of ISO 55002 expands on the requirements of ISO 55001, adding descriptive text, examples, tips and things to consider. It is not prescriptive—there will still be a need to interpret the requirements and put them into action in a way that makes sense to your organization, but the standard goes a long way toward making that easy. It is not quite a checklist, but you could use it as such with a bit of caution. If anything, it has more in it than many organizations will need because it is generic. If it were tailored for specific industries, it might be a shorter document.

One thing that is evident in the new ISOs is that there is nothing specific in them to any industry. This means they are completely generic, and to that end, they do not even speak to all the phases of an asset's life cycle. The international standards are written so that the end-user organizations can interpret them for their own environment and context. As such, the standards can be used in any industry having physical assets: railroad, utilities, manufacturing, resource extraction and processing, fleet management, facility management, government, etc.

Each user (e.g., a company) must define its own scope of coverage—to what does their own AM system apply, and how does it apply? They themselves will define what they will do to meet the requirements as outlined in ISO 55001. This is part of the early stages of strategic AM planning.

The areas where the most elaboration on the requirements of ISO 55001 can be found are the areas where experience (much of it with PAS 55) reveals that companies are likely to need the most help.

Many of the early users of PAS 55 in the United Kingdom discovered that there were two main areas where they were not complying with the requirements of the UK specifications. It took most of them roughly 2 years to become certified. The areas that were troublesome were

- Documentation
- Information management

In the United Kingdom, the early adopters were gas, electric and some water and wastewater utilities. Others voluntarily complied, but those utilities were compelled to do so. Indeed, it was those utilities that helped write the initial specifications.

DOCUMENTATION, RECORD KEEPING AND INFORMATION MANAGEMENT

What the early adopters discovered in audits was that they were doing many of the right things the right way, but they lacked documentation describing what they were doing. That lack of documentation led to inconsistencies in actions, thoroughness and then the record keeping that was done. Records were typically not all that good, probably because there was little purpose to keeping records except to keep them. There were records, but of what?

Solving the documentation problem was, in some cases, easy but, in others, quite challenging. Smaller organizations tend to be more consistent in approach, but larger ones need documented processes and procedures, or they will tend to vary widely. Even if differences from one area to another seem minor, it may be difficult to get the two groups to agree on which version should be used. Over time, they have become wed to their particular way of doing things and somewhat closed-minded. Martin Rees' observation on the big picture is worth remembering here.

Even where procedures and practices were very good, the lack of documentation meant that there was nothing to actually audit. Auditors look for your documented processes and then check your records for evidence that you are following them. In the case of AM (ISO 55001), the auditors must also determine if your practices are reflective of good AM practice. A degree of judgment is called for, unlike many ISO standards.

Documenting your processes, procedures and practices sounds like an easy task, but you can expect to be surprised by what you find when you start. There will often be a great deal of inconsistency and resistance to changing the way things are done. It can be a significant change management project. Almost certainly, you will find aspects of those processes and procedures that may have made sense in the past but perhaps not today. This is an opportunity to update them and bring them into alignment with today's realities. It is not unusual to find processes requiring manual signatures even though the IT capability exists to use electronic signatures. You will uncover inefficiencies in your processes as well as processes that simply do not work. Wherever you find work-around solutions (e.g., spreadsheets in use instead of the enterprise resource planning [ERP] systems), you will find problems that need to be resolved. This is an excellent opportunity to clean all that up.

Another opportunity you will find in this exercise is to ensure that the processes are integrated across your enterprise especially where it comes to managing risk. The ISOs emphasize risk management extensively. You probably have a risk management group or manager who is doing his/her best to manage a wide array of varied risks across the company. ISO 55001 is designed to work with the ISO risk management standards and guidelines. Implementing changes to align with ISO 55001 provides an excellent opportunity to create alignment with your risk management program and vice versa.

The other thing that proved troublesome to early adopters in the United Kingdom was the use of IT.

IT systems are meant to be tools that help us, and in many ways, they do. However, if there is no clear purpose or direction to what those tools should do, they will help institutionalize inconsistency and inaccuracy. That is part of what they found in the United Kingdom. The technology was there, and the capability was present; however, it had not been deployed in a coherent manner to ensure good record keeping, to ensure that records supported specific documented processes and to ensure there was consistency across an organization.

In implementing *Uptime* across many organizations around the world, our experience shows that the United Kingdom's situation is far from unique. Very few companies or other organizations use their IT as effectively as they could. Often, there is no consistency across organizations, and in many cases, multiple instances of the same system, running at different version levels, can coexist across multiple sites. Terminology (taxonomy in IT parlance) is often inconsistent, leading to many duplicated records, which can be a significant problem in some areas, such as spare-part management. Information that is generated in one area is often not shared widely, so it is duplicated, often with errors or omissions, in other areas.

In one large mining operation, we recently found that employee records kept for planning and scheduling purposes by maintenance were entirely different from the employee records in HR, where the shop assignments were almost all wrong. Both maintenance and HR were actually using the same "integrated" (and very expensive) enterprise management system. That is an example of poor information management that impacts both departments negatively.

IT is described in depth in Chapter 7 for maintenance management purposes. Bear in mind that AM is much broader in scope, covering the entire life cycle of an asset from cradle to grave, and that makes the challenges in managing information even more significant. Chapter 12, on asset information management, addresses these challenges.

CERTIFICATION

Certification is not necessary, but it is a good idea—the effort required to get certified will ensure that good AM is being practiced. Certification requires a third party to audit what you have said you will do and what documentation you have showing that you are doing it, and make an independent determination if what you are doing is sufficient. If so, your company (or site) can be certified. Certification is evidence of external recognition that you are doing the right things the right way. It does not mean you are getting the results you want, but it does say you are on the right track. Note that prior to carrying out an audit, it may be beneficial to have an assessment carried out to point out areas where an auditor may feel work is needed. An assessor is free to offer advice and help you implement it; an independent auditor is not.

Companies could get certified to the United Kingdom's PAS 55 specifications, but the certification was most meaningful only if you were a UK company. Indeed, the United Kingdom's Office of Gas and Electric Markets required gas and electric utilities to become certified. It was their way of assuring themselves that the gas and electric rates those utilities were going to charge were indeed justified insofar as costs associated with their physical assets were concerned.

Compliance to the ISO standards, at the time of writing, is not required anywhere, but it will come. Regulators and other bodies need ways to do their jobs more cost-effectively. Compliance to recognized standards is one way to do that. In the example given earlier, it is evident that insurers, smarting from some significant payouts, may well take the lead in requiring compliance.

To implement the standards, whether or not you are seeking certification, you will need to follow a path, not unlike that described in Chapter 1 (strategy) to get started. Understand the requirements of ISO 55001; identify what you have and do not have in place today. Get familiar with the content of the GFMAM "Landscape" and IAM "Anatomy" documents.

An assessment would do very nicely to help in that process. The IAM in the United Kingdom has made an assessment tool, based on Microsoft Excel, available to its members. It asks a series of questions about specifics under each of the seven topics in ISO 55001. Where you score low, work is needed. Identify that work and set up projects to put in place whatever is missing.

There is no need to have an accredited auditor help with that first assessment—you can do that yourself with the right information and understanding, or you can turn to third-party assessors for help. Note that auditors cannot help you with planning and improvements if they are eventually going to be your auditors—they must remain independent, or your certification will be invalid. An assessor, on the other hand, can help with improvements and guide the process for you but cannot audit and certify. Both are required to be certified in accordance with requirements specified in ISO 17021-5, "Competency Requirements for Auditing and Certification of Asset Management Systems." Testing and certification of assessors and auditors is new. One organization providing the service is the World Partners in Asset Management, a nonprofit joint venture of other nonprofit members, including the Asset Management Council (AMC, Australia); Plant Engineering and Maintenance Association of Canada (PEMAC), Associação Brasileira de Manutenção e Gestão de Ativos (ABRAMAN, Brazil), Society of Maintenance and Reliability Professionals (SMRP, USA) and L'Institut Français d'Asset Management Industriel et d'Infrastructures (L'IFRAMI, France).

PUTTING *UPTIME* IN AN ASSET MANAGEMENT CONTEXT

AM deals with the entire life cycle of physical assets—concept, design, building/acquiring, commission, deployment, operation/maintenance/modification, decommissioning, disposal and site remediation (if applicable). *Uptime* deals with the maintenance part of the life cycle and depends on information from the earlier phases. It produces information that is useful in the context of decisions about repair versus replacement or disposal. *Uptime* also deals with the phase of the life cycle that is probably the most costly. While engineering, design and construction of new assets are very expensive, the cost of maintaining them is often somewhere in the range of 2%–9% of the replacement asset value (i.e., capital cost) per year. Since most physical plants last many years, the cost of maintaining can easily equal or exceed the cost of building them. In fleet scenarios, the costs of maintenance are even higher in some cases, and life cycles are shorter. In all cases, however, the costs of downtime associated with the failure of these assets in service is often much greater than the cost of the maintenance required to repair those failures.

While choosing excellence through the application of methods such as RCM and evidence-based asset management (EBAM) will help you get the maximum value from your assets, they are only able to deliver the reliability built in at the engineering phase. In turn, that reliability as built into future systems can only be improved with feedback of valuable operating experience and data from the maintenance phase. *Uptime* helps provide that for your next generation of physical assets by gathering information reflecting your existing assets' performance and experience.

Another key limitation on getting maximum value from assets is how they are operated. If they are run too hard (but within capabilities), they will suffer shorter times between failures and shorter lives. If run beyond their capabilities, they will simply be unreliable. You can only change that by increasing designed in capability with new equipment or by reining in the rogue operators who are abusing the equipment. Good AM can capture evidence of this sort of activity so that it can be dealt with and corrected. *Uptime* on its own may provide the evidence, but like the maintenance managers it is meant to serve, it typically has little influence over operational practices unless your operators are truly partners in asset reliability.

UPTIME SUMMARY

Beyond *Uptime* (maintenance management) is the broader field of AM. It is mentioned throughout *Uptime*, but the term is not synonymous with maintenance management (as it is sometimes used in common practice). AM is a much broader field encompassing the management of physical assets throughout their entire life cycles, from early definition of their need to their eventual disposal. Maintenance management is but one aspect of good AM. *Uptime* provides a framework for excellence in maintenance that serves well in describing successful practices in maintenance management within the context of that broader framework.

Good AM entails a good deal of focus on risk management and integration with corporate risk management programs. Specific tools described in *Uptime* are especially valuable in helping to manage risks. For example, RCM provides an excellent definition of the right work for managing the consequences of failures of installed operational systems. It balances risks with costs and performance—exactly as required of a good AM system as defined in the new international standards, ISO 55000, 55001 and 55002. *Uptime* provides the framework for maintenance to deliver on its goals—more productive uptime as required to meet organizational strategic goals and delivering value to the company.

An AM system is a management system, not IT. While technology will undoubtedly be used by most companies as an enabler, it is not necessary. It is, however, very useful, if implemented well, in ensuring consistency of information sharing across an enterprise; ease of access to documented processes, procedures and practices; and consistency in record keeping.

The United Kingdom pioneered these standards with its specification PAS 55-1 (2002 and 2008) and required compliance in network utilities (gas, water, electric). In doing so, it raised awareness around the world. The International Standards Organization (ISO) then created its own international standards that are more generic and more widely applicable in any industry. They produced three new standards: ISO 55000 (overview and definitions), 55001 (requirements) and 55002 (guidelines). Compliance is voluntary at the time of writing. However, the authors can see that compliance to ISO 55001 (requirements) standards will become mandatory in some industries. Expect it eventually in regulated industries (e.g., utilities and transport); where there is oversight of industry activities in the interests of public safety (e.g., pharmaceutical, food); and where there is competitive advantage in showing that you can do AM better than your competitors (e.g., facilities management, O&M contractors and providers of outsourced maintenance services). Insurers who have been hard-hit with big claims (many arguably resultant from poor AM) are already stepping into the game and requiring demonstration of good risk management. They have yet to specify ISO 55001, but it does require a system that achieves exactly what the insurers want and aligns with globally recognized successful practices.

Excellent sources of information on AM are the IAM's "Asset Management—An Anatomy" and the GFMAM's "Asset Management Landscape," both newly revised in 2014 in response to the publication of ISO 5500X. Together, they cover a much broader scope than ISO 5500X and help in understanding the ISO requirements that are specific to an AM system.

AM is here to stay. It is the next generation in the evolution of our profession.

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Information Management and Governance

> The more extensive a man's knowledge of what has been done, the greater will be his power of knowing what to do.
>
> **Benjamin Disraeli, 1804–1891, British Prime Minister**

ISO 55000 clearly states, "Effective control and governance of assets by organizations is essential to realize value through managing risk and opportunity, in order to achieve the desired balance of cost, risk and performance" (ISO 55000 2014).

Chapters 8, 9 and 10 show tools and methods that rely on accurate and complete information in order to improve asset reliability. Chapter 5, on materials, speaks to the importance of information sharing—accurate information. Maintenance planning (Chapter 3) depends on accurate information. In all cases, the information needs to accurately reflect the asset(s) as installed and operating today (not years ago), it needs to be complete, and it must be the same information that anyone else in the organization can access and use. All too often, despite all of our information technology (IT) advances and integration of systems, we find ourselves swimming in data, much of it useless to us, and unsure of whether or not we can trust what we do manage to find. *Data mining* is a term used to describe the gathering of useful information from large volumes of otherwise meaningless data—often data lacking any useful context. The fact that data mining is needed at all reveals a major failing in our IT approach and tools.

In this connected age where technology advancements seem to always be at the forefront, it can be easy to lose sight of what business need underlies these innovations. Worse still, some managers and executives lose control of what really drives business decisions—information. In its simplest form, information leads to sufficient knowledge and ultimately drives decisions and then actions at all levels of any organization. Quite often, the word *information* is used interchangeably with *data*; however, there are some key, yet understated, distinctions that should not be overlooked. *Information* is the transformation of *data* into a usable form. Although data is information in and of itself, it is raw and outwardly inadequate to be of any specific use. For example, the number 3 is data, meaningless on its own. It becomes information when you can answer the question, "3 what?" "3" is the number of this edition of this book, *Uptime*. When data is organized with a context, it is transformed into a usable form as information and provides knowledge about a subject enabling decisions and actions.

In its raw form, crude oil has significant economic value, but its practical value is limited. Refining transforms crude into useful products such as gasoline, diesel, jet and fuel oil, coke, sulfur and asphalt. In the petroleum industry, there is a significant investment and effort placed on creating value by converting the raw material to useful end products. Data is like crude oil. We also invest effort into managing data; however, all too often, it is relegated as the presumed responsibility of an IT department. The data refining process is incomplete, and the products are of limited utility.

In the early days of IT, saving transaction-processing time was important, and data was essentially a localized by-product not considered of great value. Early material requirements planning (MRP) systems focused on demand and did not really consider timing. In the early 1980s, MRP II brought the two together in the planning process and became a fundamental concept in production management. In parallel development, both accounting and human resource management systems grew in popularity. The enterprise resource planning (ERP) systems of today are the result of incorporating these various systems into an integrated solution. Organizations were beginning to see greater value in their data beyond transactions, realizing that analyzing it could also support decision making. The need for better management and controls related to the organization's data was becoming evident. Throughout the 1990s, the ERP market boomed, and with that, the burden was placed on IT organizations to manage the delivery of technology throughout the enterprise and, in many cases, the applications used in running the business and the data that was produced. Although at a system or database level, access controls were implemented, the governance of data was a new concept. Through the early 2000s, the ERP boom subsided, but the volume of data was growing rapidly, even exponentially.

Today, the primary role of the IT organization is to ensure that the infrastructure and various systems are available, the individual users have the correct access to systems, and the data and information are controlled and protected. Although IT organizations in general do a very good job at managing systems and the associated data and information, they do not necessarily understand end-user needs. Their focus tends to remain highly technical.

The ISO 55000 series standards acknowledge that asset management is highly dependent on data. In 2012, the United Kingdom's Institute of Asset Management (IAM) outlined a conceptual model for asset management (IAM 2012). IAM considers all elements of asset management, including information systems. It goes on to state, "Asset intensive organisations rely on asset data, information and asset knowledge as key enablers in undertaking both strategic Asset Management activities and operational activities." Asset information is clearly important; it is an asset itself, and therefore, an asset information strategy should also exist. ISO 55001 refers to the need and embodies it in Sections 7.5 and 7.6 of its detailed requirements.

As part of an asset information strategy, companies should have an objective to enable a data and information management strategy. This imposes the need to take a close look at the company's asset data and information requirements, ensuring that there are processes in place to keep data and information unspoiled. The processes and controls underlying this strategy must result in data that is "like new" in quality; precise in its context; and effectively produced, maintained and consumed. To this end, organizations need to consider the people, processes and technologies that produce and add value to asset data and, ultimately, asset information across the physical asset life cycle.

The data and information that relates to any physical asset has a parallel life to that of the asset itself. The challenge is to ensure that data and information remain current and correct. In the modern plant, there can be thousands or even tens of thousands of discrete pieces of equipment, each with its own data and information "package." There are operating procedures, repair manuals, maintenance plans, spare parts, etc. Beginning with the initial build and through to operations and maintenance, a plant and its equipment will be in a constant state of change as supplier recommendations are enacted, process improvements are implemented, modifications are made and maintenance is performed. With each change to a physical asset, there is an equally important change that must be made to the data and information representation of that asset. Think of this as your "information plant," which must also be maintained.

The concept of an information plant is the aggregation of numerous systems, whether manual or automated, with links to provide a common view of data and information across multiple platforms. An example is the integration between an engineering computer-aided design (CAD) system used in the design of equipment, a computerized maintenance management system (CMMS)/enterprise asset management (EAM) system used in support of the work management processes, and an asset performance management system used to develop and manage reliability programs. Each of these systems has value to the organization while managing very different aspects of an asset's information throughout its life cycle. It is important that the data and information within each of these systems are consistent with the other systems—one version of the truth—throughout the entire life of an asset, which can span decades. This can be accomplished through the use of commercially available tools, through direct integration/interface and/or through integration of technology via middleware. Although many companies do have integrated systems, there are still many challenges with the data and information contained in the various systems as the processes used to manage and control the data and information are not up to the complex life-cycle challenge. Additionally, when considering the information plant, it becomes apparent that a number of different stakeholders are involved with different priorities and distinctive requirements as to how they need to see information about the same object. A well-defined asset information management and governance program adds significant benefit.

Asset information management and governance, sometimes referred to as *asset life-cycle information management* or simply asset information management (AIM), provides a framework that connects the various asset states and processes to the long-term operations and maintenance needs, performance and risk management and management-of-change (MOC) structures. This AIM framework ensures that processes and tools exist to allow changes specific to asset management to be fed back through the information and systems landscape, improving the probability that the physical plant and information plant match, consistently meeting the data and information needs of stakeholders. This is accomplished through well-defined processes to manage the data and information coupled with a series of controls (i.e., a governance layer) to ensure that the processes are being followed and the right stakeholders are involved.

When we think of governance in the context of a business, we often think of the overall accountability within an organization to maintain its viability and adherence to policy. This is accomplished by clear policies and practices and identifying the people responsible for directing and controlling these. Another common use of the term *governance* is in the IT domain. Similar to corporate governance, IT governance is a set of rules and practices dealing with the interactions between the business and IT, generally managing risk and ensuring that a business value can be derived. In both these cases, the governance model deals with controls and stakeholders.

The Data Management Association (DAMA International) is a not-for-profit, vendor-independent, global association of technical and business professionals dedicated to advancing the concepts and practices of information and data management. DAMA defines data management as "the development, execution and supervision of plans, policies, programs and practices that control, protect, deliver and enhance the value of data and information assets" (Data Management Institute 2007). DAMA has its roots in technology, and this definition relates to the IT organization mandate; however, they also clearly articulate that data management is a shared responsibility between the business data steward and IT.

Data governance is an advancing discipline that is becoming more important as the volume, variety and velocity of data continue to increase. As with both corporate and IT governance, data governance focuses on processes and controls to ensure the quality of data in terms of completeness, correctness and risk management in its handling within an organization. An organization's data governance model may be influenced by, and integrated into, an IT governance model and change methods with respect to the transitioning, service and availability of the information systems. Many businesses implemented basic data governance initiatives that initially focused on fixing information quality at a departmental level, such as marketing, procurement or financial reporting. In part, information quality issues resulted from disconnected systems that look at data differently based on the system requirements but also have data redundancies across the systems. Those redundancies are often assumed to be the same in other areas, but they may not be and often are not. For example, finance will track physical assets for depreciation and business valuation purposes, and maintenance tracks those same assets, often with different identifiers or "tags" for purposes of maintaining and supporting operations. In many cases, where a number of unintegrated systems exist, the processes used to manage the data are not unified with other systems. In some cases, the data quality has been reduced in current systems by a data conversion that brought forward data from a legacy system.

Businesses must have the ability to manage risk to an acceptable level by implementing various policies and controls. These policies and controls allow the business to sustain itself, continuing to add value through products or services. Proper asset data and information management supports the decision-making processes and management of risk in asset management.

Data and information management ensures that the data is controlled within the technology; data governance ensures that the right controls are involved in making sure that the *right* data is sustained within the technology and across platforms. The difference is that data governance is a set of rules and practices representing the MOC followed by the producers and consumers of data and information, not by the IT organization. This is an important distinction between data governance and IT governance. Although the goal is similar, ensuring that the correct controls are in place and being followed, IT governance is a set of rules and practices representing the MOC within the IT domain. Data governance, on the other hand, belongs to the users. The data governance model may be influenced by, and integrated into, the existing IT governance and change methods with respect to the transitioning, service and availability of the systems, but it is distinct. Although IT governance is critical, it is not covered here.

Data comes in various forms. At a high level, there are both structured and unstructured data that directly pertain to, or are associated with, physical assets. Structured data is part of a record or file, such as the attributes associated with a piece of equipment that are generally stored in a database. Asset design attributes such as flow, pressure, temperature, material of construction, etc. are often stored in structured data fields. Unstructured data, as the name implies, has no identifiable structure and could include items such as text, documents (paper or electronic), pictures, etc.

For decision making, there are three key data categories: master data, reference data and transactional data. Master data is basic business details about customers, employees, suppliers, equipment, materials, etc. Reference data are lists of acceptable values that can be utilized by either master data or transactional data. Transactional data is the result of events at points in time that refer to one or many objects, such as a work order (WO) or invoice. The transactional data created is critical for ongoing work management needs, inspections, etc. that is generally stored and tracked within the CMMS/EAM. Our main focus here is the underlying master and reference data.

In November 2011, PwC Germany (Messerschmidt and Stuben 2011) carried out a global study on master data management (MDM). They focused on 10 hypotheses in five categories: IT, governance and organization, the level of data management maturity, the causes of data quality problems and the business case for MDM. They concluded that "for the majority of companies, the use of IT applications has only partially solved data management issues, if at all." For a successful and sustainable MDM program, each company needs to have a governance structure and management commitment to the MDM initiative. Process optimization can also impact the success of MDM. The same study noted that (1) where a company's core processes have duplication of effort or gaps, redundant or inconsistent data will likely be the result, and (2) the MDM processes need to allow for data to be efficiently processed with an audit trail.

Many organizations are challenged in managing data and information. Organizations heavy in physical assets having incorrect or incomplete information can suffer costly and even catastrophic consequences. Here is what happened in one large-scale project at a chemical company to ensure long-term data and information quality. They had a basic requirement to create the master data set for a new EAM system implementation. The source data came out of two separate legacy systems and from new data associated with a $1 billion capital expansion. The legacy data was inconsistent between the two systems and had thousands of missing or obsolete records and data errors. The project team understood that all of this data needed to be closely analyzed, and a plan developed to cleanse and enhance it while steps were taken to ensure the long-term sustainability of the data. The team also reviewed and associated both electronic and paper content (i.e., manuals, procedures, etc.) with the master data records. The majority of the data from the ongoing construction project was in an unstructured format, primarily .pdf files. While that eliminated the need to convert paper documents into an electronic format, the unstructured format of each asset record had to be put into a structured format manually and validated. This organization understood the long-term value of a solid AIM program as a long-term solution within their operations and maintenance programs and were willing to put in the initial effort and cost. Implementing their AIM program has produced a valuable information asset with a definite long-term benefit in ensuring that the underlying data and information is correct and readily available.

That project operated to deliver against a mission statement declaring that the "solution is focused on providing a comprehensive toolset that allows for the systematic collection, consolidation and organization of engineering, construction, commissioning, operations and maintenance information (both master data and associated content). The objective is that the system will be the core enabler of an effective document and data management strategy through the asset life cycle and will also facilitate the creation and sustainment of an efficient operations and maintenance (O&M) program.

DEFINING THE AIM PROGRAM

Making constant improvements within maintenance requires information on how the maintenance organization and the assets being maintained are performing. As discussed in Chapter 6, a series of key performance indicators (KPIs) is fundamental to understanding what maintenance is doing and the results it delivers and to help direct improvements. For a maintenance organization to be more effective and efficient, these KPIs are central to decision making. In turn, it is therefore crucial that the data underlying these measurements be correct.

One downstream oil and gas producer understood the challenges they experienced with KPIs and knew that changes were needed, but they were not sure as to where the improvements should be made. The maintenance organization, consisting of 120 employees and 90 contractors, was stuck in a cycle of reactive work. Maintenance leadership was unable to shift the culture to focus on more planned and proactive work. One KPI stood out because it contrasted so drastically with the reality. Schedule compliance was near 100%! Looking deeper, they found that roughly 30% of the WOs remained open after 4 weeks, and 20% remained open after 3 months. Many urgent WOs were not being completed in a timely manner, and they were paying some hefty environmental fines. Although the primary KPI looked excellent (too good to be true), nothing else was working. They reviewed their processes and found a lack of effective controls.

Many duplicate work requests existed; work requests were submitted either against incorrect equipment or at too high a level in the asset hierarchy to identify where the work really needed to be done. Worse still, the majority of work requests were assigned an initial priority of "urgent." It did appear that scheduled work was getting done, but the wrong work and, often, duplicate work were being scheduled. Operators were identifying the need for maintenance, but the work requests were submitted by other crew members with limited information as to the true nature of the problem. The crew members entering the work requests, not usually the operators who first identified the problems, did not truly understand the priorities, so they defaulted to a high priority (urgent in this case). There was a false hope that planners and schedulers would react accordingly. Of course, this overburdened the planners in determining correct priorities and the schedulers who needed to leave large gaps to accommodate the truly urgent-priority work that would inevitably arise. There was some obvious process noncompliance in getting work entered into the system, but that was only part of the problem.

In analyzing the master data, it became evident that there was a great deal of missing data and incorrect and incomplete data. Descriptions used to identify equipment and the hierarchy were inconsistent and, at times, too cryptic to understand. The process compliance issues were resolved through better process controls. Underlying master data also needed to be cleaned up, or work identification would continue to be inaccurate. Once this was done, the operators identifying work would find the correct equipment in the hierarchy, see the criticality of the asset and be able to check for any current work requests. Planners would then be able to identify the priority based on the criticality and description of the problem and determine any permits or other special requirements, and the scheduler would be able to fill in the schedule gaps and clear out the backlog. By focusing on getting the underlying data correct (along with process compliance), this plant was able to get control of its reactive work and turn their energy to increasing proactive maintenance.

Although measurements typically are the result of a transaction, it is easy to see how they can be impacted by problems with the underlying data. In the above case, one of the key contributors to poor data quality was the age of the assets and the fact that changes over the years were rarely reflected in the data. Developing and implementing a program that manages and controls the quality of data is a key step in being able to increase overall efficiency and effectiveness in the maintenance organization.

The following is a general guide to the development and deployment of an AIM program in support of an asset management system. It is a general framework that can be adapted based on the specific objectives and needs of any organization. The general goals for an AIM program are to do the following:

1. Protect and enable the needs of data stakeholders
2. Enable better decision making in support of asset management strategies
3. Reduce or eliminate operational conflicts between producers, consumers and the custodians of asset data and information
4. Train management and staff to adopt common approaches to managing asset data and information
5. Build standard, repeatable and controlled AIM processes
6. Ensure transparency of the asset data and information management processes
7. Reduce costs while increasing effectiveness through coordination of AIM efforts

An effective AIM program drives data and information integrity critical to safe and profitable operations. To implement a successful AIM program, it is essential to provide a baseline or framework from which to develop and deploy standardized policies and practices while creating an organizational structure that ensures that it will be sustained. This is aligned with and supports ISO 55000 2.4.1: "An organization's top management, employees and stakeholders should implement planning, control activities (e.g., policies, processes or monitoring actions) and monitoring activities, to exploit opportunities and to reduce risks to an acceptable level" (ISO 55000 2014). With or without the International Organization for Standardization (ISO) standards, however, any maintainer can attest to the value of having accurate parts information, technical manuals, engineering drawings, piping and instrumentation diagrams (P&ID) and maintenance instructions. Those will simply not happen on their own.

With this in mind, developing an AIM program creates the primary reference for the policies, practices and methods associated with the creation, transformation and sustainment of asset data and information. Data stakeholders (i.e., equipment operators, maintenance staff, engineers, managers, etc.) want to be sure that the information they are deriving from the data is correct, and consequently, that their decisions are based on sound information. This supports the widely accepted data governance mission as outlined by the Data Governance Institute (2004–2012) adapted for asset information governance. At its highest level, the AIM program should have a three-part mission:

1. Proactively define and foster alignment to asset data and information management rules
2. Enforce those rules while providing ongoing protection and services to data stakeholders
3. React judiciously and resolve issues arising from noncompliance with these rules

Although each organization may have more specific requirements, an AIM program begins with the following goals:

- Provide general asset information and data management governance needed to improve the following:
    - The ability to maintain a safe working environment
    - Overall plant and equipment availability and reliability
    - The capture and centralization of knowledge and facilitation of workforce training
- Enable a single version of the truth for all asset and related master data and reference data
- Develop an integrated information plant to sustain the operations and maintenance data and information foundation of the physical plant
- Guide the integration of asset management information systems with other IT solutions
- Provide a suitable and embedded data and information governance structure
- Provide data and information management processes to organize, implement and control asset data
- Provide guidance and controls to oversee the integration of information systems
- Provide processes to develop the ability for collaboration, transfer and management of data between systems
- Enable the reuse of asset data and information by equipment classification

- Provide a series of policies that enforce standard business processes and procedures
- Enable processes that optimize and extend the life of assets through accurate maintenance information
- Enable business processes that effectively reduce costs by aligning maintenance schedules with broader activities such as procuring spare parts and external contractors

AIM Program Organization and Roles

AIM stakeholders from all locations will need to show a willingness to collaborate during the asset information requirements definition and design tasks. Although information needs across the organization differ, there is a need to standardize the underlying master data and the AIM processes. The business processes and practices that consume and use this data and information must be aligned and integrated with the framework. The development of an AIM governance office (AGO) or committee is a strategic factor and an essential step in ensuring long-term sustainment of the AIM program for both operations and maintenance domains, and it becomes a major link between top management and the asset management teams. The AGO is accountable for educating and supporting the belief that asset information handling is significant to the organization. Actions must result in asset data and information that consistently represent the true and accurate operating context and capacity of the asset to generate value. The AGO supports the AIM program and fosters a culture of asset information excellence. The entire organization is compelled to produce, transform and sustain asset data and information in a pristine state.

The actual structure of an AGO can vary from company to company and from industry to industry; however, the core focus areas are consistent:

1. Develop, and manage compliance to, policies, practices and standards
2. Provide management support and top-management communication
3. Define the security and accessibility parameters for asset data and information
4. Define data quality standards
5. Define data integration standards

The AGO is essentially a control group of asset management stakeholders. It does not need to be a large committee, but it should have adequate representation across the different stakeholder areas. The individual AGO members are defined during the initial development and implementation of the AIM program, and they meet either regularly or as needed. Like a corporate board, the AGO is not a full-time job. The time commitment is not great; however, the commitment to the compliance with the framework is critical for its success. Some key roles that should be incorporated into the AGO are the following:

- The AGO officer, or chair, provides oversight and control of the AIM program and adherence to policies and is responsible for communications with top management. This role is filled by a senior manager or process owner from the maintenance, engineering or operations domain.
- The AGO change review committee reviews and approves the initial AIM program and ongoing process or policy changes as may be required and deals with issues arising from noncompliance. It is made up of key data and information stakeholders from groups such as operations management, engineering, maintenance/reliability specialists and business process owners/specialists.
- The remaining AGO members are individuals who provide domain authority and expertise or site and business-unit representation. Individuals from operations, maintenance, reliability and/or engineering groups provide the needed focus on asset management, while representation from IT, records, document management and project-based workers (e.g., construction or commissioning) provide broader input.

While the AGO is focused on developing and managing the overall governance of the AIM program, the overall effectiveness of the program requires regular compliance of all individuals within three basic functions: data and information stewards, approvers and requestors.

The data and information stewards are essentially gatekeepers responsible for the data and information content and context. They ensure that business rules and standards are being applied correctly. They are responsible for what ultimately gets stored in a data field or information record. The individual stewards may be part of a business unit or IT organization; however, their primary mandate is to ensure that all data enters a system based on the rules defined in the AIM program. The following are some functional scenarios that are seen as the primary focus areas for the stewards:

- Master data build resulting from a capital project. Transferring capital project information to operations and maintenance in time for start-up. This involves data and information from an engineering, procurement and construction (EPC) contractor or vendor, engineering design teams, commissioning teams, etc. Without AIM, this is often very poorly done.
- The compilation of maintenance and inspection work plans with links to the appropriate equipment, spare parts and other related information such as procedures or safety requirements.
- Receiving and applying any change such as a recommended spare part or changed maintenance procedure for equipment that may arise from a vendor-issued change or an analysis such as reliability-centered maintenance (RCM).
- An engineering change that arises during the completion of a maintenance task or routine inspection that identifies any substandard or unacceptable condition of equipment. Make the change to the equipment in question; identify other potential candidates for the change and update equipment strategy.

The approvers are responsible for quality control and assurance of the data. As approvers, these individuals apply their authority and expertise to create, update or delete tasks related to the data and information as required to achieve the desired business outcome. The approvers will also support a continuous-improvement process and supply expertise to maintain and improve the processes within the AIM program. The following functional scenarios are seen as the primary focus areas for the approvers:

- Review all data submissions and apply authority and expertise in reviewing them.
- Support the data and information management effort by timely reviewing, approving or declining requests.
- Develop and maintain a continuous-improvement process for approving and declining requests.

The requestors are the consumers (end users) and/or producers of the data who have a request or need to create, change or delete data.

Consumers of data and information would include equipment operators, maintenance technicians, planners, storeroom staff, engineers, etc. They use varying aspects of asset information in creating transactional data like work requests, WOs, material requests and purchase orders. Producers of data might include external groups such as EPCs or vendors, providing raw asset or parts data or documents. Internal producers such as engineers, planners or procurement may be developing new maintenance strategies or tasks or adding new suppliers. The following functional scenarios are seen as the primary focus areas for the requestors:

- Submit a request for a new master data record. These requests will outline the details and the need for the addition of a new record, such as a new inspection route resulting from an RCM analysis.
- Submit a request for a change to a current master data record. A request could also be a modification to an already existing record, such as a specification change resulting from an engineering change approved through the MOC processes.
- Submit continuous-improvement initiatives. The end users of master data are responsible for submitting any new continuous-improvement ideas that would make the use and/or change of data better for the community of users.

Authorizations and Controls

Processes are used to control access to asset data. Security and the permissions assigned to individuals are related to their role in the AIM processes and will be tailored to support logical and safe MDM practices.

The AIM program is developed with these roles in mind and clearly identifies controls and control processes that must be followed to ensure that the AIM policy, practices and strategies are deployed with consistency and enforced with rigor. Changes to internal policy, practices and strategies will also need to be communicated to the AGO on a proactive and timely basis to ensure that any system changes are reflected in the established processes and policies. Examples of controls or processes that may fall under the AIM policy are as follows:

- Environmental, health, and safety
- Enterprise-level assets—engineering specification

- Enterprise-level supply chain, finance, materials management or procurement
- Enterprise system interoperability
- Regulatory and voluntary standards compliance
- Aspects of asset management that impact investors or the public interests

The AIM program will leverage business and IT MOC processes as the baseline decision support processes required to manage asset data and information.

Data and Information Requirements

The AIM program manages data for each asset as well as related objects such as spare parts, maintenance plans, etc. To ensure consistency in the management of asset and related data, we can look at the asset information life cycle through a five-step process—define, collect, transform, deploy and sustain.

- *Define*. We outline what asset data and information is required to operate and maintain the asset over its life cycle. Related data and information need to be considered as well as any system constraints.
- *Collect*. Data and information from many sources such as vendors, engineering systems, control systems, etc. must be verified, consolidated, mapped, integrated, enhanced and validated for use by the consumers of the data. This process requires collaboration with internal and external stakeholders. It is especially important early in the asset life cycle, where construction and engineering information must be captured for use later in the maintenance and operational life-cycle phases.
- *Transform*. Asset data should be structured to enable ease of access and usefulness to the users of the data. An asset classification system and asset hierarchy allows the organization to track assets and their associated locations and functions using physical, process and logical relationships, such as tag numbers, process locations and asset classes. Transformation entails the use of business rules to validate the quality and completeness of the data.
- *Deploy*. This step loads data into the target CMMS/EAM system ready for consumption by the end users. A part of deploying the data

is to ensure that consumers have access to it. There is no value in keeping the data locked away and inaccessible.

- *Sustain*. Once established and deployed, the data must be kept current with the physical plant, which will invariably change over time. Sustaining entails maintaining data in a pristine state and the inclusion of other systems that can be impacted by any change in the process for the life of an asset.

With different stakeholders involved throughout the life cycle of an asset, it is important to understand what is critical to these stakeholders and incorporate all of these needs in the definition phase. The requirements relate to the use of the data by different stakeholders within and throughout the organization. Once the requirements are defined and understood, the broader data definition at a system level is completed.

Using the oil and gas example above, it was evident that information related to specific equipment within the plant was insufficient. An operator or maintenance technician has to know where the equipment is and where to find information related to its operation and maintenance. The operators are concerned with process functionality, the maintainers, with physical attributes, performance, specifications and parts. Finance wants costs associated with that equipment tracked to the correct cost center. From these individual needs across the different groups, a broad requirement for the equipment data can be determined. The following is an example of some basic user needs related to equipment data and information:

- Operator/maintenance technician
  - Physical location and process location or function
  - Physical identifier such as a tag, or make, model and serial number
  - Safety, operating and/or maintenance procedures
- Planner/scheduler
  - System identifier and description
  - Asset criticality
  - Spare-part lists/bill of materials (BOM)
  - Warranty information
  - Other considerations such as permits or scaffolding
- Finance
  - Business unit
  - Cost center

In developing an AIM program, it is essential for each master data object to be analyzed at this low level to ensure that all stakeholders are included and that any data conflict can be identified and resolved. There are also industry standards that can impact on these requirements, for example, ISO 15926 (Industrial Automation Systems and Integration—Integration of Life-Cycle Data for Process Plants) or ISO 14224 (Petroleum, Petrochemical and Natural Gas Industries—Collection and Exchange of Reliability and Maintenance Data for Equipment). There may also be company-specific standards or specifications for things like detailed asset taxonomy and related attributes. All of these impact AIM program requirements and must be considered.

The following master data objects should be considered:

- Asset hierarchy—structural elements that provide context and organization to an asset registry
- Asset—physical assets associated with the asset hierarchy or other assets
- Asset classification—based on the taxonomy classifications of similar types of assets
- Spare parts—items or parts that are associated with assets
- BOM—assembly of spare parts associated with an asset
- Maintenance plans/jobs—a series of maintenance tasks triggered by an event
- Maintenance tasks—tasks and associated resources (parts, people, tools) associated with a maintenance plan or asset
- Maintenance or inspection point—a physical reference where a condition is monitored
- Content—drawings and/or associated documents, material safety data sheet (MSDS), etc.

Reference data are lists of acceptable values that can be used by master data and transactions within an EAM/CMMS. They are typically represented by drop-down or search lists. Examples of reference data would include items such as units of measure, maintenance groups, how found, damage and cause codes, cost centers, material types, asset types, statuses, etc. Reference data is used to ensure consistency across the organization and to ensure that data is grouped or transacted correctly. It reduces inconsistencies in data entry and provides for ease in analyzing data and information. For example, a maintenance lead or engineer wants to understand the history of a "bad-actor" equipment. Using predefined cause codes, they can determine if there is a pattern as to why there are a high number of work requests and if the causes are the result of internal or external factors related to the equipment. In some cases, this simple analysis can determine other problems either upstream or downstream in the process.

Data Rules

Evidence-based asset management (EBAM), as described in Chapter 10, relies heavily on good data. It enables better understanding of your physical assets and better decisions. EBAM is made much easier with a well-designed AIM program considering the entirety of the asset well beyond installation, commissioning and initial data load into a new CMMS/EAM system.

Transactions are activities taking place between any two things to create some change or impact in one or both entities. Transactions result in the generation of some form of transactional data. In asset management, transactions include work requests, WOs, inspections, parts issues, etc. There are rules for each of these types of transaction based on how you define the processes (e.g., spare-part issue and return). The EAM/CMMS has a number of these processes designed into the system. Data collected about transactions is what we use to generate and analyze various metrics and, in some cases, trigger other transactions. While most companies invest a lot when implementing a system to ensure that the transactional data is captured correctly, they often do not pay much attention to the underlying master data or associated reference data.

Success is determined by the processes and business rules related to the data, information requirements and standards. Data rules are conditions that must be met when creating or changing a record. A validation step, within the data management processes, that tests the data rules ensures that the changes are made within the defined boundaries for each field within a record. Examples of data rules include format for asset identifiers, naming conventions, abbreviations, unit of measure, number of decimal places, etc. In defining the data rules, consider that all assets will be in a managed state of change due to maintenance, modifications, process improvements and engineering or supplier recommendations. With each change to a physical asset, there is an equally important change that must be made to the information representation of that asset. Physical plant changes lead to corresponding changes in the information plant, and those changes need to be correct.

Technology is available to manage these corresponding changes, but it is the processes and compliance to these processes that is the core enabler between operations and maintenance processes, the AIM program and its role in supporting risk and MOC processes within engineering and finance groups. The design of your AIM processes ensures that changes are fed through the solutions landscape, ensuring a match between physical and information assets.

Be aware of, and design with, system constraints in mind. Although IT and data governance are separate, your system and application administrators will play a key role in defining, enabling and enforcing data governance with respect to master and transactional data passing through any system.

Data Flow, Data Management Processes and Controls

Next, we look at the overall asset data flow. This gives a high-level view of all the interactions between data and information objects, various systems that feed and utilize data and information and the processes that produce and consume the data and information. At this point, the individuals involved are not considered. The intent is to understand how master data and information are managed in relation to a business event that produces them (e.g., capital expansion, equipment replacement) and business processes (e.g., planning a WO, engineering change) that consume them. In working with data flow models, the key is to understand the high- and intermediate-level interactions, which allows an organization to ensure that processes surrounding the data can be developed with these interactions in mind.

In a recent capital project and associated data build, the source of new asset and spare-parts data was two different systems and manually generated spreadsheets. It was clear that a standard process and data structure was needed to load data to the new EAM system. It was also important that all the data was validated against the requirements and exceptions corrected so the data flow was also used to identify key approval points. With the spare-parts lists, BOMs would be derived, and the individual parts would need to be validated against parts already in the EAM system or be created. This organization had a library of standard task lists and maintenance jobs already available. They could be associated with the new asset, or a new task list or job could be created. Figure 12.1 outlines this asset data flow.

Understanding data flows and the interactions with events and processes enables the development of more detailed data management process flows with suitable control points. The control points may be a simple approval point with one approver or require a more rigorous workflow with more people involved, depending on the object, internal policies and system capabilities. It can be helpful to model the data management processes separately, identifying where approvals are required. From those processes, any detailed workflows can be defined independently as needed.

The data management processes themselves are developed at the maintenance-object level—equipment, spare parts, task list, etc.—and for the three basic data needs, specifically, to create, update or deactivate the data. From a system perspective *CRUD* is a well-known acronym for create, read, update and delete. Note that data is not really deleted; rather, it is deactivated or archived. Within the detailed data management flows, the interaction points with the other master data objects are included. The interactions with a business process flow are also identified, although the entry point for any data management process is typically a business process. Figure 12.2 shows the process to update an equipment record for only one object within the broad scope of an AIM program.

AIM throughout the Asset Life Cycle

Data management processes should be in place and utilized as early in the asset life cycle as possible. In many companies today, challenges with invalid or missing information can be tracked back to how the initial handover of information and data from the capital project was handled. In capital projects, the data challenges arise when ownership of asset data is transferred from engineering contractors (EPCs) to the owner/operator. This handover often occurs abruptly near the commissioning stage of the asset, and often using a dump-truck approach. With little time to build out the data prior to operation and maintenance, the data and information is often incomplete and, in some cases, incorrect. This can delay start-up or lead to initial reduced production capacity as a risk

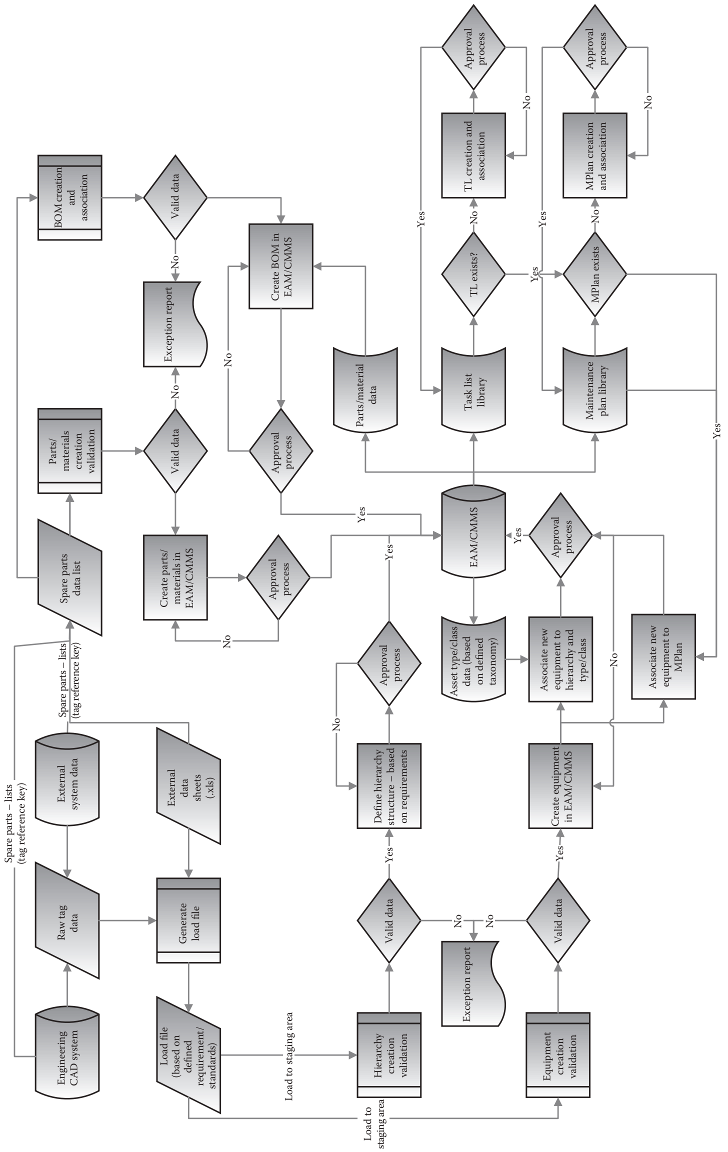

FIGURE 12.1
Asset data flow.

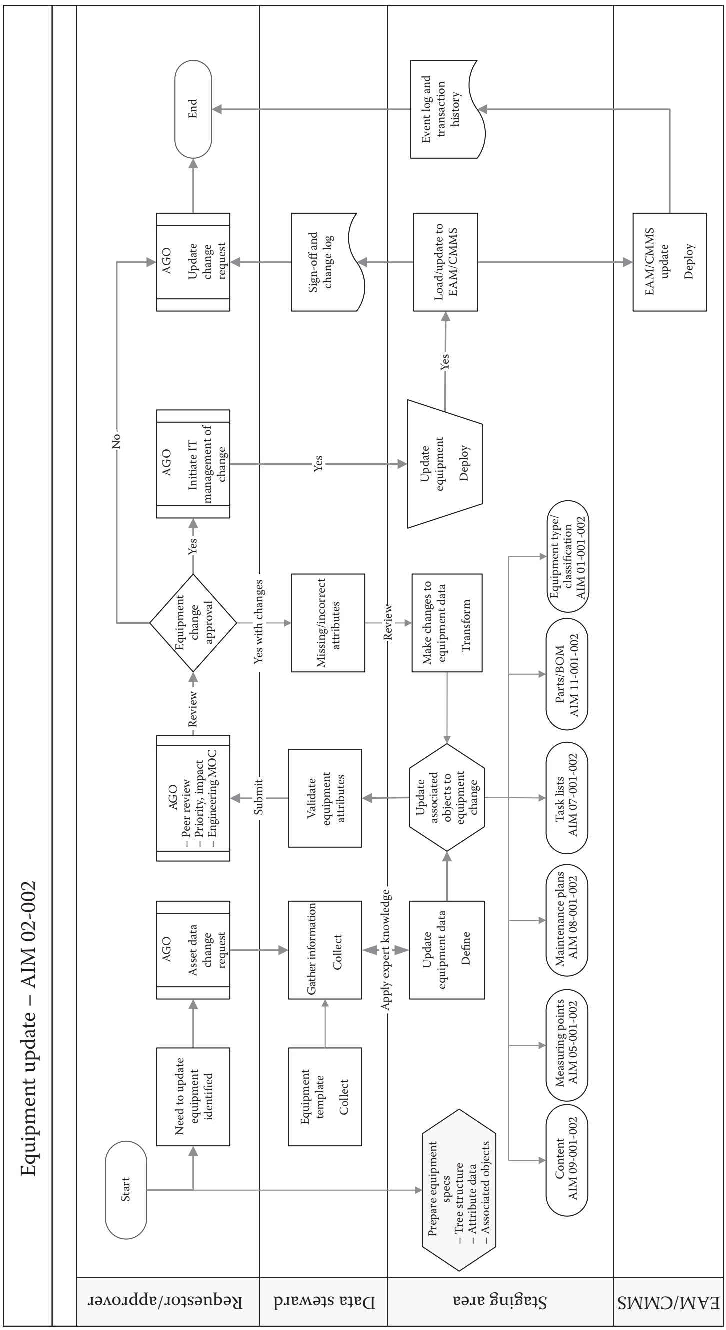

FIGURE 12.2
Process to update an equipment record for only one object within the broad scope of an AIM program.

reduction strategy. At the December 2007 EU Plant Engineering and Design Conference in The Hague, Netherlands, a review of the Sakhalin II project audit was presented (Mitchell 2007). It determined that not only were people unaware of what information management is; the average loss due to poor information handover can equal 1% or more of total capital project expenditures.

An AIM program, as part of a broader asset management system, can impact capital project handover, operational readiness, production capacity, maintenance strategy development and work management. Throughout the asset life cycle, asset data and information will be created, updated and deactivated by individuals, with many people and systems involved in the process. It may be viewed that it is easy to establish and implement an AIM program in relation to a "greenfield" operation, but what if this is an older established plant and we understand that we have data that are wrong and incomplete?

In a 10-year-old mining operation, a team performing equipment "walk-downs" to verify installation against drawings found up to 80% discrepancy in some systems. While this example is extreme, it is common to find information and physical plant mismatches in most organizations.

In the chemical plant case noted previously, operations had data in two legacy systems as well as a new expansion. The AIM program ensured that processes and controls were in place and that the stakeholders were aware of their roles in the processes. A complete plant data audit both for assets and the spares warehouses was carried out. For the plant walk-downs, the current asset registers (from the legacy CMMS) were utilized in the auditing tool. With over 55,000 individual assets in three plants at two locations, the walk-down was prioritized by equipment criticality as currently managed in the CMMS. For execution, it was split into various plant sections. The audit team was led by plant staff who understood the equipment. The team physically reviewed the asset against the CMMS record and corrected or added data as needed. The warehouse walk-downs followed a similar process. Changes captured by the audit tool were fed back to the legacy systems to be used as source data for the new replacement system.

Some of the issues that can arise due to bad data were clearly evident. In one case, the team established that a series of equipment in one area was never brought into service, yet numerous WOs were raised, completed and charged against them. It was established that the work itself was being completed against similar adjacent equipment, but no one realized the error. In the warehouse, hundreds of spare parts were missing from the system, wrong parts were being managed and inventory was being shown for items with zero parts actually in stock.

At this company, they understood that implementing an AIM program was not an easy effort and would not happen overnight. They also clearly understood the long-term benefits of the program. When first initiated, they knew there were issues related to their data, but not until completing the walk-downs did they understand the extent of these issues. The estimated savings in spare-part inventory and procurement costs alone paid for the initial expense of setting up the AIM program. Efficiencies were gained in planning, scheduling and the actual execution of maintenance work. When the new plant came online, although the workload naturally increased, the impact to the maintenance organization was minimal.

AIM Sustainment—Proactive, Reactive and Ongoing Processes

Many organizations do not take the time, when implementing a new system, incorporating improved processes into a current system, or adding a new layer of process or technology, to look at the current data and processes. You need to understand what value is being added and where. There is an old adage: "You can't manage what you don't measure." It is essential that you are able to measure the right things. Technology hype does not always equate to value. Value comes from what the technology can enable. The need for transactional data must consider how it adds value so that each data element becomes important to the information that is desired. Do not collect data just because you can, as is so often the case today!

While short-term benefits from discoveries of problems arising due to poorly managed data can be found, the real success of an AIM program is in the long term. In an effort to prepare for planned or unplanned data and information management tasks, a number of scenarios should be developed, reviewed and rehearsed to test assumptions and outcomes before implementing within an AIM program. The following are some examples of scenarios that can be tested:

Proactive processes include the following:

- Creating a staging asset hierarchy for commissioning of assets
- Creating data-load templates for equipment and material requirements

- Creating BOMs for all maintenance plans and strategies
- Performing as-built walk-downs to verify data before loading

Reactive processes include the following:

- Responding to errors or omissions as the result of a service request
- Building new material and BOM based on an unplanned equipment change
- Modification of asset or material types to address changes in specifications or dynamics
- Making changes to documents and forms used to capture transactional data

We cannot see into the future and know what technology will be available and how that will impact the use of data and information in 5 years, 10 years or even longer. A successful AIM program focuses on the people and processes involved, understanding that technology constantly advances. This perspective underlies the importance of an ongoing review of the AIM program itself—it must be reviewed so that it can adapt, accommodate and take advantage of future developments. Ongoing processes should include the following:

- Periodic AGO meetings to establish or update standards and procedures
- Improvement programs to foster innovation and optimization of data handling
- Periodic education refreshers and coaching sessions to sharpen skills
- Monitoring and fostering involvement and education in industry practice and standards organizations

The people, processes and systems that are in place now are just the starting point. This chapter provides a brief look at the evolution of data and its changing importance over time as well as the importance of information. Technology will continue to advance, and the sheer volume of data will continue to grow at even greater rates. An AIM program is built around the understanding that managing the right data properly is critical for the business to thrive in today's information intensive world. Acknowledging that it is a joint responsibility across the organization will ensure long-term excellence in operations and maintenance.

UPTIME SUMMARY

Asset management (including maintenance and EBAM), depends heavily on the availability of accurate and complete information about physical assets. Often, that information is generated, gathered and stored in separate corporate information "silos"—engineering, maintenance, human resources and finance. It is used by each of those groups, operations and even marketing in making decisions about needed improvements, training, budgets and forecasting of future production and capital funding requirements. If each group is working with a different version of the information, all of which is supposed to represent a single asset, then you have a potential problem. Decisions in each of these areas can impact the others. If those decisions are based on erroneous information, problems can arise. Getting your organization to a single trusted version of the information that all can share confidently is what AIM is all about.

AIM is a somewhat technical topic focused on ensuring that structured and unstructured information is managed effectively and that record keeping (transactional data) is collected consistently and accurately. There are two main data types of concern: master data and reference data. Respectively, those are the description of various data fields and what will go in them. Get those wrong, and your data generation, sharing and use are at risk. Note, too, that AIM is not an IT function—the data, and hence the information that can be derived from it, belong to the creators and users of the data: the operational, engineering, maintenance and other functional areas in your company. IT has a role to play as custodian and provider of the enabling technology, but it does not own AIM.

Many organizations struggle with AIM. In 2002, the United Kingdom's PAS 55-1 became a requirement for UK utilities to comply with, and they had to do it by 2004. One of the big stumbling blocks that utilities encountered, in addition to a lack of good and consistent documentation (a form of information), was their inability to share information consistently across their organizations. AIM was often ineffective and had to be cleaned up to get certified against the asset management specification. Today, ISO 55001 implies similar requirements. Already, some companies (utilities) are being compelled to comply, not by regulators (as expected) but by insurers. AIM is a part of what must be done to comply with the new ISO asset management standards. This infers the need for AIM programs and an appropriate governance system to ensure compliance.

Asset management and the new international standards are indeed raising the bar for asset managers worldwide. AIM is but one critical area linked tightly to good asset management practices and an organization's ability to sustain them in the long term.

Section V

The Journey

Uptime provides an overall framework for excellence in maintenance management based on successful practices observed in high-performing companies. The first three parts of the *Uptime* Pyramid of Excellence deal with specific activities, methods, tools and approaches that can be applied under the general headings of leadership, essentials and choosing excellence.

Reading through those in sequence, it should be evident that the various elements of the *Uptime* model work together. Putting those together so that they work well in your specific environment is a challenge faced by many.

Section IV of *Uptime* introduces asset management—a much broader subject area of which maintenance management is but one important part. Asset management is the next step in our professional evolution. It raises the bar substantially and holds us far more accountable for risks and their management than ever before. As regulators and insurers latch onto the new standards for asset management, the pressure on us to deliver value while managing risks at reasonable cost will only grow. We need to get it right in maintenance or your asset management program and your organization will fail to achieve its strategic objectives.

Excellence is a journey: as soon as you think you have arrived at a new and higher level of performance, you discover that there is more that can be done. The new standards in asset management embody continuous improvement as a major element of your AM system. Likewise, every element of *Uptime* has a continuous improvement component. The challenge to be excellent never goes away—each of us only carries the baton in a never-ending journey. The more you and your company learn about managing maintenance, the more you will discover and the more likely you will be to remain ahead of the pack among your competitors. If you do not embark on this journey, sooner or later, you will be left behind.

Choosing excellence entails a great deal of commitment, resolve and very likely a cultural change in your organization. If you have not been on a continuous improvement journey for a long time already, then complacency has probably set in and you may well be lagging in your industry. You will be challenged to implement the *Uptime* framework.

Maintenance is unlikely to be considered as one of the more interesting of management discussion topics. It is a specialty field that, if done well, remains very much in the background. If done poorly, it ends up being blamed for problems that arise and can even end up putting you in the headlines. Despite its “behind the scenes” nature, maintenance is an important part of any business. Your physical assets consume resources, time and money in their care and use while delivering services, products or both. They affect every aspect of a company’s performance. Your assets and, by extension, their maintenance impact uptime and revenues, downtime and losses, safety and environmental performance, energy efficiency, security, regulatory compliance, your permits to operate and your reputation. Getting it right can bring substantial benefits; getting it wrong can be disastrous.

13

Implementing Uptime

> If you are going to achieve excellence in big things, you develop the habit in little matters. Excellence is not an exception, it is a prevailing attitude.
>
> **Colin Powell**

Excellence is a journey. You will never achieve perfection, but you can always do better. If you do not improve, your competitors will, and this is a compelling reason to achieve more all the time. In maintenance, it is your people using your process to get the most out of your assets that make improvements happen. Within this framework, as Colin Powell observed, are a host of big things that are dependent on "habit in little matters." Excellence is an accumulation of those habits—all of them important in their own ways as parts of the greater whole.

Habits are things that you do over and over, both good and bad. As a rule, it takes some 21 repetitions for a new "action" to become a habit. Implementing *Uptime* will take time, probably more than it takes to repeat any one action 21 times—remember that you are establishing new habits across a broad audience, some of whom will resist. The stock answer for changing an entrenched maintenance culture is 3 to 5 years. The truth is that the culture really never stops changing. At some point, likely about 10 years into the future, you look back and realize that you now have a culture of continuous improvement that is being sustained, but in truth, you never really get "there" because there is no "there" to get to; the journey just keeps on going.

It is difficult to break a habit once it is formed, so in choosing excellence, it is more about instilling new "good" habits than eliminating older "bad" ones. If a new habit produces better results, it will eventually become "the" habit. Start doing the desirable action repeatedly and eventually it becomes a habit. As one customer liked to say, "We use gentle pressure, relentlessly applied." As you see the benefit of doing the new habit, you will eventually see the old habit die off.

Implementing *Uptime* is really about putting a whole cluster of new actions into place, repeating them often enough that they become a habit and letting go of the older, less successful habits. Those old habits, because they are less successful, will naturally die off without any significant effort to kill them. They simply fade into irrelevance in light of the newer more successful practices that, by that time, you have turned into habits.

WHY BOTHER?

Companies that are high performers[1] in maintenance are invariably high performers in virtually every other aspect of their business. There is an atmosphere of achievement and a positive attitude. They are relentless; they never quit expecting top performance. Like professional athletes, they make it look easy because they are so good at what they do, and they constantly strive to do better. For these companies, change is normal. It must be; you do not continually improve without change. They are good at managing change. They stay focused on the changes and complete them before moving on to the next thing. They finish what they start, realizing that every journey is made up of many small steps.

High performers embrace new technology, new methods, new ideas and inputs from their people, but they do not jump on the bandwagon of something new just because it is new. As innovators, they are willing to try something new, but they are also quick to admit mistakes and abandon what does not work. They are intelligent risk takers—they realize that they cannot improve without risk; and they realize that not all risks will pay off; they can admit to mistakes and move on. If they do not have the tolerance for risk that an innovator has, they are the early adopters who watch what the innovators do and pick up the best of the new ideas that are showing promise. They watch what is going on (you will see them at conferences and often as speakers); they invest in their future and in their own success. They learn what they can from the experience of others. They know that investments in maintenance improvement contribute to the triple bottom line (social, financial and environmental). Their people are active and fully engaged participants. They take part in the changes that affect what they do, how they do it and when. They are highly motivated and they genuinely enjoy what they are doing.

They share in the company's success through job satisfaction, compensation, greater job security and a safe, clean and pleasant working environment.

One obvious "tell-tale" indicator of a company like this is that its people are happy. They clearly enjoy their exciting, challenging yet rewarding environment. They still have their disagreements and challenges, but they have learned to resolve them quickly and move on. They are profitable and they are businesses that will be sustained over the long term. This provides satisfaction and it is why they bother.

In many other companies, those that do not perform as well nor sustain it, the business environment is generally driven by short-term thinking. They want results fast and seem to have abandoned any genuine interest in the long term. Executives at all companies are challenged to create long-term value while under pressure to perform today and produce quick shareholder returns. They all know that their tenure is short, but some focus on the short term almost exclusively. In doing so, they may miss the opportunities for long-term gains that will benefit the next CEO or next year's shareholders. The business cases for new projects tend to focus only on the next 3 or 5 years—no longer, even though the assets may last decades. They inadvertently (we hope) leave the longer-term, more difficult problems for the next leader to resolve. So long as the problems do not happen "on their watch," they are satisfied. A hallmark of these companies is that they tend to start improvement initiatives but never finish them. Unless the initiative generates short-term returns, they lose interest and it loses steam quickly. These companies are good at starting but not at follow-up and finishing—at least not for the long term. They get too busy reacting to today's challenges to finish what they start that may have an impact on tomorrow's results. Why is the short-term focus so attractive?

Reacting to problems and challenges that are very real and present is like starting up a new operation. It is challenging and exciting, but it does not last long. People get a certain rush of adrenaline and oxytocin (the feel-good hormone) when they have a "win" in the battle against some present danger or emergency situation. Like junkies, they get hooked on the reactive environment because it generates those good feelings. Eventually they want to stay there (even if only subconsciously), and they genuinely feel they are doing something right because they are solving all those emergencies that arise. The emergencies become a self-fulfilling prophesy. When these adrenaline junkies do finish something, their work has often been executed quickly, without a lot of planning or thought. Effectiveness and even completeness of the solutions are questionable. These companies evolve very slowly, often taking only short steps forward; they are rarely, if ever, leaders. Being nimble in business does not mean being reactive—it means responding quickly; response is not reaction.

Executive compensation is usually tied to short term gains. It is very difficult to tie it to results that may occur years into the future so, like politicians looking for votes, executives remain steadfast in their pursuit of short term gains. Boards of directors seem unable or unwilling to even see this, let alone act on it. As a consequence, many companies are systemically focused on the short term at the expense of their long term results and ability to sustain gains made today. There is no quick fix for this but the emergence of asset management provides us with a mechanism.

With the emergence of asset management as the next phase in our professional evolution, we are becoming much more aware of our responsibilities to society and stakeholders including those beyond our businesses. Regulations, while they may be onerous and in some cases go too far, are society's way of setting minimum standards. Mess up and you are in trouble. Good asset management compels us to look at all our business risks and manage them proactively—not just to stay out of trouble but to be a good corporate citizen. It encourages us to use "evidence" (the new gold standard[2]) as the basis for decision making. It encourages consistency and accuracy.

Maintenance, which has an impact on virtually all aspects of our business, is on the front lines. It is where poor asset management is often revealed. Bad design can show up as failures, long repair times, extensive modifications, high costs and avoidable risks. Lowest cost purchasing practices result in assets that will not be supported by the manufacturer, where parts are soon to become unavailable and parts are substandard.

There is less and less tolerance for errors that injure or kill people, harm the environment, cause loss of public services and utilities or put shareholders at significant and avoidable financial risk. When maintenance decisions are made correctly and *Uptime* is used as intended, the physical and financial consequences of failures can always be managed. So how do you get there? How do you implement *Uptime* successfully?

GETTING THERE—IMPLEMENTING *UPTIME*

Each chapter of *Uptime* contains some "how to" instructions but generally not quite enough to just use *Uptime* as a handbook. Chapter 1 (strategy) puts

Uptime in a strategic context and includes deployment of strategy as a new topic, one that was very much needed. Previous editions of *Uptime* avoided most of the "how to." This edition attempts to provide enough information to get you started,[3] although you will probably want help with parts of it.

For instance, if you want excellence in planning and scheduling, materials management, reliabilty centered maintenance (RCM), etc., you will need to dig deeper than these pages. Each is a fairly deep subject and books are available on each of them. You can find those other books, but not many actually read them and then put them into practice successfully on their own. You can find training or external consultant support, but what do you focus on first? Is there a sequence that works best? How do you go about planning your *Uptime* implementation? Chapter 1 speaks to strategy and its deployment, beginning with some form of an assessment and/or education. Indeed that is where you begin and there are different approaches to achieving that.

New to Chapter 1 is a great deal of content on strategy deployment. It speaks to business cases, the use of assessments, training, implementation planning, outsourcing as a strategic choice, etc. On their own though, each of these is just a tool. Except for Hoshin Kanri, most of the material in that chapter has been in *Uptime* since the first edition was published in 1995. Hoshin Kanri is added to provide the readers with a very useful tool for getting their ideas implemented—but there is still a need to get those ideas first.

The steps you will follow in your implementation will depend on where you are today and where you want to go. There is no cookie-cutter plan. In the late 1800s, Lewis Carroll said, "If you don't know where you are going, any road will get you there." Indeed you need to know where you are going. What is your strategic intent? Your goals?

You must also know where you are. What are you doing well, poorly or missing entirely? There are models of maintenance excellence that look different from *Uptime*, but beneath the surface they are very similar. What often differs is how they are intended to be used. *Uptime* is not a prescriptive step-by-step method—it is a model, a framework, not a series of steps. In theory you can start anywhere in the framework and get to your desired destination. The paths you can choose are entirely up to you, and to a large degree, it does not really matter what you do first. Of course, depending on where you are now, there are some logical starting points that become evident as you get into the planning process.

Implementing *Uptime* since 1995 and seeing what companies have done with *Uptime* and other models has taught us that very few clients begin at the same point. The approach we have followed to determine the starting points and the steps we need to take has changed as a result of our experience. Once you have a plan, it is then time to get into action. In doing that you will run into challenges.

One big challenge is "change resistance." As described in Chapter 2, you can expect resistance and there are ways to manage it. We are all good at change, but we all resist being changed. No improvement initiative can be successfully imposed on your workforce—they must choose it. So how do you get them to choose *Uptime*?

ASSESSMENTS VERSUS TRAINING

If you begin your *Uptime* initiative with a detailed third-party assessment, then you will very likely run into resistance. An assessment is a tried and proven starting point in many consulting approaches. It will deliver results, but it will also lead to a degree of change resistance that can be avoided. You will struggle to get buy-in to the improvement initiative. If the ideas for change come from your own people, there will be much less resistance to those ideas. Of course you probably need to know what is possible. If you already knew what "better" or "good" looked like, you would not need much outside help.

An alternative approach is to provide training right up front. By educating your employees on good maintenance management practices, you show them what is "good" and enable them to choose what they feel is needed. The training does not tell them they must do anything or that they must do it in any specific way. It is not prescriptive. It only plants seeds. The rest is up to the students.

Assessments are useful tools for finding just how well you are doing and identifying what you need to do to get to some standard. Using *Uptime* as a "standard" we can make some very good recommendations, but doing so runs the risk of alienating your people. Here is why.

No one likes to be told that what they are doing could be improved. Even if they know it already, they feel bad that they have been doing something wrong (even if it is only slightly wrong) and it has been pointed out. The messenger who tells them risks becoming a lightning rod for their feelings. The cycle of change (Chapter 2, Figure 2.1) begins with loss, doubt and discomfort. It is common to affix blame, point fingers and challenge the very premise that change is needed. An external assessor who has not been there very long and really does not know all the ins and outs of your operation is an easy target. The assessor becomes a symbol of all that perceived evil that is about to be imposed.

Your employees know what they are doing. They may know where they need help and they may not. Your current performance measures probably give some indication. Through training, they will discover areas where they could be doing better. Benchmarking for best practices (Chapter 6) is also intended to do that—enable learning of practices that are better than you are using today. You could start with benchmarking visits—but they do take time.

One mid-sized pulp and paper company did just that. They took a year to identify, visit and learn from others in a variety of industries. They targeted identifiable high performers and traveled to visit them. They carried out interviews, took tours, examined performance statistics and took away as much knowledge as they could. Then they compiled all the learning into a concise list of practices and then asked for help in implementing those practices. Needless to say, that list of practices looks a lot like the elements of *Uptime*. We had no hand in creating that list, but we were delighted to learn of this independent and unintentional validation of our model.

Consider too that an experienced consultant who is offering training has already visited many sites and seen many practices—both successful and not. That consultant has tried various methods and approaches, had successes and failures. Like you do with benchmarking visits, the consultant has learned a lot in gaining experience, and he/she comes with that knowledge right from the start.

Our experience told us that it makes little difference where you start in the *Uptime* model. Eventually you will discover all the steps you need to complete. German Field Marshall, Helmuth von Moltke (the elder), the creator of a new more modern way of directing armies in the field (in the 1800s) said, "No plan survives contact with the enemy." He knew that flexibility was required and only adherence to a general directive was required. Things happen in the field and you must adapt. What is important to success is that the general directive made sense and that field commanders had flexibility to adapt. Similarly, your maintenance improvement plans are likely to evolve over time as they are implemented and as experience is gained in your "field."

Since the publication of *Uptime's* second edition in 2006, we have applied a "training-led" approach where our clients have agreed. We recommend that they forgo any form of formal third-party assessment—save that money and hopefully avoid much of the change resistance that arises when a consultant tells you how badly you are doing. We assumed (and rightly) that their people know their operations better than we ever will. We also assumed that if they have a standard to compare themselves to, they are quite capable of telling us where they need to make changes.

We provided training, answered questions, encouraged the client to provide their ideas on what to do and then guided the process of putting those ideas into a workable plan. We plan the general sequence of events or milestones (e.g., RCM applied in all critical systems might be a milestone; achieving a target percentage of planned work might be another). The plan covers the entire range of improvements at a high level, but we only detail about a year of activities at a time. Any more than that and you will spend a lot of time later changing those longer range details. So why create them? The plan for improvement grows as it is implemented—each quarter we review progress, adjust the balance of the annual plan and decide what detail should be added to a new final quarter.

Allowing for this experience-driven growth ensures that the plan remains realistic and doable in light of whatever changes take place in your operations throughout any given year. Frustration with falling behind is minimized because of the flexibility to adapt. The overall goal remains clear; only the details will change as you make progress. This applies a form of continuous improvement—we plan, we do what we plan, observe (check) on how we are doing and then adjust (act) on what we find.

The experiment worked well in places where the employees wanted empowerment and a say in their own future. This gives them their say—indeed it relies on their choices. Where that desire for empowerment was lacking a more prescriptive approach was needed, and we had the knowledge to provide it.

A NEW APPROACH

Now, unless senior management insists, we avoid the formal assessment altogether and jump into an educational phase. We train our clients in *Uptime*. Arguably anyone could read the book—we would love it if they do, but in the real world, many will not. We provide training workshops—1 day for the leadership and management teams, 3 days for the working levels—to introduce and explain the concepts and methods in

Uptime. Throughout the course, we gather their ideas for improvements. There is never a shortage of ideas. At the end of the training, they perform a simple self-assessment to help them visualize where they are today. Then they are asked if there is benefit in making the changes they have suggested. Invariably the answer is "yes" and then we ask for specifics—where is the money, the risk reduction, the safety enhancement, the improved environmental performance going to become evident? They tell us.

At that point, we have achieved several remarkable milestones. You have

- A group of more informed employees and managers
- A long list of improvement ideas
- A clear vision of what improvements could do for your site
- A clear idea of just how far from that vision you are
- A good sense of where the value will be generated if you follow through on the ideas
- A feeling of accomplishment at producing all of that
- A strong sense that you can indeed make the changes and improvements

Instead of complaining about an assessment and the consultants who did it to them, there is a sense that success is within grasp—the motivation is real and comes from within.

That motivation is real and you can actually feel it in the energy of the group. You are now off to a good start. But beware, it can be short-lived. Action needs to follow and it needs to follow quickly. A few quick wins are needed to reinforce the "can do" attitude and galvanize it into something more lasting. What is needed now is a workable plan, one that is, again, developed with a lot of client input.

PLANNING

There are typically about 80 to 100 action ideas arising from a 3-day training session. Depending on the size of your staff, you will want to train a large portion of your maintenance and operational/production departments as well as your management team. You will have run several courses. Many of the action ideas will be the same—that is good; it means that your people are of like mind about what has to happen. Those ideas will be in no particular order, but they can usually be grouped logically. The *Uptime* elements make a good starting point, but you may find ideas in other areas that are equally as important. All ideas are good ones, and they all represent someone's concerns.

A facilitated planning session is needed to turn your collection of ideas into a plan. This will usually take a few days with a group of people who have had the *Uptime* training and demonstrated a real interest in being a part of the improvement efforts.

The ideas have come from within your own organization. The seeds may have been planted by an external trainer, but they landed on fertile ground to spawn improvement ideas. Your people already "own" the program, in its raw form. The plan is best drawn up with the participation of those same people, again, to ensure "ownership." It is not necessary, nor advisable, to have everyone involved, but you do need a planning team from within that same group of training participants. Those who want it will usually make your best implementation leadership team, but do not be afraid to recruit key influencers and recognized leaders to your cause. So long as they are not opposed to it, they can make valuable contributions to the effort.

The facilitator will first review the list of ideas from the training. Each will be listed on a separate card. It is not uncommon that after the initial training, some people do more research on their own and come up with more ideas that should be included in the mix. To accommodate this, the group will have another opportunity to come up with ideas—additional actions, barriers that may need to be overcome and enablers that can help. For example, a barrier might be, "middle management will never support this" (more on that later). An enabler might be, "we need a business case for finance to buy into paying for all this." Those ideas are also listed on cards. The cards are then grouped by common theme or subject. Groups might include reliability improvement, planning and scheduling, KPIs, training and so on.

The planning team then votes on which of the groups of actions are most important to deal with first. With a hundred or so ideas, you will not be able to do them all at once. The top 4 or 5 groups of tasks, as identified in the voting, are then assigned to small teams to review, weed out obvious duplicates and come up with consolidated plans of action for implementation. Those action plans will be fairly crude still, but they are full of good ideas. They are presented to the overall group. The remaining ideas are retained to be added to the plans later, along with any new tasks arising after the first quarter year of progress. Your overall priorities will already be set, and all that is needed as you progress and free up project resources is to add in the next highest priority action.

The "plans" at this stage will be somewhat rough. Even the best facilitation cannot get to a highly detailed level of planning with a group that is not familiar with project planning, but the skeleton of those plans will be there and the bones will be solid. You will recognize that some of the activities will impact on others and that those interactions must be managed. Meat will be added to those bones, by action team leaders, usually with the help of the facilitator in smaller one-on-one or small group planning meetings. If it is necessary (as it often is) to get cost and benefit estimates, this is something the facilitator or consultant can help with.

It is a good idea to have a designated leader for the initiative—someone who is respected and who has, or can be trusted with, the necessary authority to spend and take actions during implementation. Business case development, if it was not done before the initiative began, should involve this leader.

Approval of the business case by senior management must be quick. Senior management must avoid the temptation to tinker with the plans, trim costs or assert their own particular agenda. Either accept or reject the whole plan and business case and do it quickly. If rejected, give clear guidelines for what is needed to make it all acceptable on the second attempt at approval.

GOVERNANCE

Your initiative needs to be executed and cannot be allowed to derail when things go wrong. Effective leadership goes well beyond having a designated project leader. The whole initiative very likely started because of a specific business need—to reduce costs, improve reliability, improve productivity or possibly fit within another broader business excellence program. It is quite possible that corporate strategy dictates the need for improved asset management, and in turn, a maintenance improvement project was deemed necessary. Regardless of the origins of the initiative, it can be started, planned and led the same way. Hoshin Kanri, as described in Chapter 1, is a highly effective way of deploying high-level strategies across many corporate functional areas leading to the need for an *Uptime* project.

Governance is about leading initiatives and making sure they get done and that they deliver the outcomes desired. It is a set of mechanisms, processes and relationships working together. The *Uptime* initiative cannot be successful if it is an "orphan" within the company. It cannot achieve its potential if it is a "maintenance only" initiative. It needs the participation, help and support of materials management, operations, production, finance, human resources, training and possibly other groups. Because of the broad impact of maintenance and physical assets on business results (revenues, costs, safety, environment, quality, security, reputation/image), it is important that the initiative remain focused on delivering positive impacts in all those areas.

This degree of cross-functional impact requires a senior level sponsorship that has authority across all the functional areas that could be needed to support the initiative as well as those that will benefit from it. Sponsorship at the site level should be the site's general manager, and the governance team (steering or approval committee) should be made up of a cross section of managers who report to her/him. If the project is multisite, then the sponsorship should be at the C-suite level with a correspondingly senior level corporate steering committee.

The project itself requires a leader and a leadership team—typically the action team leaders responsible for the activities that are being undertaken. At a multisite corporate level, that team includes the project leads from all the sites as well as the corporate leader. Because activities will be initiated, executed and completed as you make progress through your plan, team composition may also change with it. If you are using external support to help with technical aspects, training or overall project management, then that consultant should be included.

Treat the implementation like any other project with regular reporting on progress, activities and results. Do not miss reporting on the results. Far too many projects avoid this, claiming that results are in the hands of the guys in the field and not the project team. In the case of *Uptime*, the guys in the field make up the project team. Do not let them off the hook.

Expect problems to arise. Problems need to be highlighted and dealt with decisively at whichever level is needed in order to ensure that problems in one area do not impede progress overall. The software world has well-established processes for reporting and resolving bugs. The military world has its "Failure Reporting and Corrective Action System." Something like those will work well here. Problems must be kept visible until solved.

A project charter is needed to summarize all of the governance provisions and methods. It will describe the leadership structure and the reporting responsibilities, and will define accountabilities and which level is responsible for what sort of decisions. It will outline how problems will be identified, investigated and resolved. It will provide a clear mandate for supporting groups' involvement and participation in steering committee or other project activities. It will name responsible individuals for the key roles such as sponsor, project leader, lead consultant, etc. It will outline the overall goal and specific objectives to be achieved and where those are expected to be realized. It will outline when action teams, project team, steering committee and other groups will meet to review reports and decide on courses of action. It will outline the process for reviewing project progress and quarterly reviews to close off completed actions, consider internal and external factors that are impeding or supporting progress and add new project activities from the original list of ideas that did not make it into the first groupings.

INITIATIVE OVERLOAD

Chances are that your company or site has more than one improvement initiative on the go at the same time. *Uptime* may be but one of many in an overall program of business excellence. Each of those projects will need resources, money and time to implement. They will compete for all three. Each will impose demands on staff across the organization, and each will have the potential to disrupt business as usual. They should—that is why you are doing them—business as usual is no longer acceptable. The competition for resources, time, money and attention and the disruption that you can cause in other areas can be very destructive if it is not managed well. If all those initiatives are to succeed, they cannot be robbing each other of resources and over taxing people so that they can no longer get their normal day jobs done.

In one large multisite manufacturer, we found ourselves running a corporate *Uptime* initiative in competition with a major supervisory and management training initiative, a support services staff reduction exercise and a major expansion at one of the sites. Employees were suffering from initiative overload—they simply had too much to do, they were fearful for their jobs (even if they were not in support areas) and they were all doing their best to look valuable. Consequently, they were performing well as individuals but poorly as a team. Job, department and project performance all suffered. The company had many good intentions and strong business drivers for each of its initiatives, but tackling them all at once in an uncoordinated way was killing the chances for those initiatives to have any real success. Ultimately, the staff reduction initiative was halted, the training initiative was spread over a much longer time frame and the *Uptime* initiative was reduced in scope to merely getting things under control. The expansion was largely in the hands of a contractor so it was left alone. Within *Uptime*, the reliability improvement parts were delayed to a future initiative and time frame. Those changes helped people cope, and results finally started to improve albeit more slowly than anyone had hoped. Doing too much too quickly just does not work—it is like shooting yourself in the foot.

Good corporate level governance across all of your initiatives should result in a coordination of efforts. Many projects have overlapping and complementary objectives, albeit with different approaches to getting results. It is important not to overload your workforce—after all, they do have a day job to do.

If you find yourself struggling with too much competition for resources and attention, you may be in this overloaded situation. If you have any doubt about it, just ask your employees. They will be quick to tell you that there is just too much expected of them. If that is the case, then it is time to slow down, take stock of the initiatives and their impacts and possibly make some tough choices. It may be necessary to delay, cancel or extend the time frame of some initiatives. It may be advantageous to blend initiatives that are closely related. For example, efforts to redesign various business processes can work well in conjunction with initiatives to improve performance in work management and materials management/supply chain. Human resource initiatives to better define job descriptions, rationalize positions and make sure that people are well trained for their jobs are a good fit with any maintenance improvement initiative. It is highly likely that the jobs will change and the human resources efforts are very complementary.

What is important to remember is that people can only handle so much. We all have fears and concerns about jobs as well as limitations that may be highlighted when something new comes along. We all have good ideas and generally want our business to succeed. But if you overload with too much work, too many projects, competing priorities and goals, we become frustrated and resistive. Avoiding this requires good oversight and governance of all, not just each initiative, with a continuous listening to what people are telling you. Change entails a lot of communication and much of that is listening.

ACTION TEAMS

Each action idea (or group of like action ideas) that is turned into an action item is treated like a miniproject. For example, an action item to "improve planning and scheduling" may entail the use of an external trainer, coaching, hiring of planners, reworking of business process interfaces between planning and materials, etc. That activity must be coordinated and managed effectively, and it can be done at a level very close to the action itself. A small team of planners or planner supervisors, production supervisors, materials management or stores supervisor could lead such an initiative. One of them is designated as the action team leader, and he/she sits on the overall project team that is led by the project leader. The action team is responsible and empowered to take the actions needed to get their specific tasks completed. They should be able to hire trainers, coaches, new planners, etc. as needed and approved when the original business case is approved. Every action item is worthy of this sort of attention and approach.

MIDDLE MANAGEMENT

Senior management is usually sold on *Uptime* when they see a compelling business case. Financial managers have often been among its strongest supporters because of the financial benefits it will produce. The shop floor is usually sold on the benefits of their jobs getting easier, the removal of frustrations they have been feeling for a long time, etc. They will probably be suspicious that jobs may be lost, but in these days of overly lean companies, that fear is largely unfounded. If anything, it is more common to identify the need to increase jobs. But middle management can be a whole different case.

Middle management will generally be very supportive of these initiatives while in the early training and planning phases. Many will remain supportive throughout the initiative unless they feel threatened by it. Generally the supporting managers (stores, supply chain, human resources, training, etc.) will be supportive in spirit, but they may need nudges when it is time for actions on their parts.

It is not unusual for the middle level managers who have responsibility for the areas where the most change will be needed (stores, maintenance, and sometimes production) to find themselves conflicted. As managers they are responsible for a steady output from their functional area—they achieve that through established processes and practices. In some cases, they may have been the authors of those practices, and there may be a degree of emotional ownership of them. The *Uptime* initiative will be challenging and changing those. Not only does this "rock the boat," it also makes the job of managing output difficult while the transition takes place. Good managers are the ones who keep things stable. They quite naturally resist the changes that will destabilize and, depending on how they are compensated, the changes that could impact their own bonus. Bonuses and the impact of changes on the status quo should be considered in designing your initiative.

Those managers, even if they agree with what is going on in principle, may resist change. Whether their resistance is passive or active, conscious or unconscious, they can get in the way, and this resistance must be managed. It needs to be recognized for what it is and dealt with.

To avoid resistance, it is important to pay particular attention to middle management in the early stages of the project to get them to buy in to the need for changes. They must participate in the training, idea generation and planning. They may feel bad that they have been managing things ineffectively or failing to deliver results. In truth, they were probably doing their best and with the best of intentions working within the constraints of their jobs, positions, authority and their own knowledge of what works and what does not. Bear in mind that someone with years of successful experience will be difficult to convince of a better way. During planning of your initiative, they may even try to steer the plan in the direction of producing exactly what you have today.

Because companies often have very structured departmental management arrangements, it is possible too that managers, effectively working in silos, do not understand or even realize the impact they are having on other functional areas. For the most part, dealing with middle management resistance is an exercise in education and broadening their perspectives. Once they see the bigger picture, they often become strong supporters, but there are exceptional cases to watch for.

Beware of the managers who may well have reached their career peaks. There is a management theory known as the "Peter Principle" (Peter and Hull 1969). Many supervisors and managers are promoted because of their superior performance in their old role, not because of their ability to perform in the new role. Eventually they get to a level where they stop getting promotions because they are now failing to function effectively at their present level. They have reached their "level of incompetence." Companies and in particular human resource departments are well aware of this theory. Many have put promotional processes in place to weed out those who will be ill suited for promotion, but there are still many examples out there. If you are dealing with a manager who has topped out in his/her career, you may be dealing with a very defensive and resistive manager. If so, these people can be a real challenge. In one case, an electrical utility, one such manager who was near retirement age was offered a generous early retirement package and he gracefully left. This left the door open to a manager who was better suited to the role—problem solved.

Ego can also play a role here, particularly with managers who lean heavily on the strength of their personalities or their technical track records. A maintenance manager who is technically competent and has contributed significantly to the success of the organization to date and has a strong ego may be highly resistive to new methods that are different from what he/she has used in the past. These managers often feel that their way has worked well and it should be used. They are often closed to new ideas and sometimes for very good reason. Managers like this can add a lot of value if they can contribute and be open minded. Otherwise they can be very problematic, and sometimes the best solution is to remove them from the picture. If the organization is demonstrating a need to move beyond their purely technical and often hard-nosed approaches, then it has also moved beyond the need for those managers. They will do far better and be far more satisfied working somewhere else.

One mining operation hired a replacement maintenance manager who had a solid reputation as a tough but competent manager. At the mine, work execution discipline was lacking, and his tough approach was very helpful in improving work performance. He also came with very fixed ideas of what worked well and what did not. His command and control style of management did not "sit well" with his much younger engineering staff. Supervisors had already learned to fear him and his obvious lack of interpersonal skills. Despite his success, he generated a great deal of resentment, and with that, respect for him plummeted. He did not agree with a corporate focus on reliability improvement and remained convinced that the existing PM program would work given the improvements he was getting in work execution. In a very practical sense his focus was solidly on the "Essentials" level of the *Uptime* model, but he rejected the whole model as if it were entirely irrelevant. Through good work discipline, the PM program did begin to deliver improvements but nowhere near the level needed. Plant and fleet performance improved but remained well below industry averages. Despite that obvious indicator and the proven success of reliability approaches elsewhere, he steadfastly refused to support the RCM part of the initiative. Until he left, his improvements plateaued, and when he departed a couple of years later, much of the discipline he had been enforcing disappeared. Without his strong personality, the processes and abilities of his supervisory staff were simply not up to the task. The gains were lost.

Highly competent technical people are sometimes not the best management material—their focus and their passion are usually on technical matters, not people. They may pay lip service to change, but they often do not understand or appreciate the challenges that change management poses and the very human issues they will need to deal with. For those managers who are open minded, education is often the solution, but they may also need coaching and strong support from someone who has the necessary people skills (so long as there is no appearance of undermining their authority). If the ego is in the way, then sometimes these managers are better off in different roles. However, in some cases, they know their own weaknesses and welcome the help—these managers can be very helpful and supportive. The manager in the previous example was technically competent but unwilling to learn more. He had his fixed ideas on how things should be and it was "his way or the highway." When he left, and his sheer force of personality was gone, things unraveled.

JUST DO IT

You have got a lot of good ideas, an informed and motivated workforce, a high level plan of action with the first year detailed, you have identified the enablers and barriers to change and have plans for dealing with them, governance and your charter are established, your teams are formed and you are ready to roll. Many companies are very good at getting this far—they love to plan and organize, but then they drop the ball on implementation. Sometimes their own bureaucracy gets in the way, but all too often they just lose focus. Governance is needed to keep that focus.

Do not waste time getting moving. Do not get distracted if things go wrong. Expect mistakes to be made, and expect that delays will occur in your scheduled work. External events will interfere, and even other projects will compete with you for resources. Stay the course. It is important that in your planning you have considered the opportunities for quick wins. A few early successes will help to encourage and sustain momentum. Not all of your activities will produce quick wins, so get those wins where you can and early. They will help sustain encouragement to continue when other activities are taking longer to produce results.

Momentum is important. Once you are making progress, do not stop. If you lose momentum, you may struggle to regain it. People will get the sense that the project has ended when in fact it has only stalled. It may be waiting for a decision or some funding, but most of your people will see only a lack of action and that tells them that this was not all that important after all.

If you run into snags, it is important to solve them and move on quickly. Good governance should allow for quick decisions, and the authority should be there to spend if needed. Delays while you seek approvals and build business cases for a snag that is really only a small part of a much bigger picture are unnecessary, and they send the wrong message. You want people to remain engaged—in it with their hearts and not just their minds. Do not kill the heart with delays and dithering while you struggle to get the perfect solution to whatever problem or snag arises. Just find a solution and act on it quickly. If you are only 80% right, you are way ahead of doing nothing and usually those 80% solutions take very little effort.

SUSTAINABILITY

Sustainability is an overused word but for a good reason. It is usually used in the context of environmental matters where indeed we have been poor stewards of our planet. After all, we must sustain our environment so that it can sustain us. But sustainability also refers to our businesses, the processes we put in place with our *Uptime* project and ultimately our jobs.

We want to sustain our ability to deliver goods and services in increasingly competitive markets. To do that we must work smarter, not harder, and we must produce more with less. In the Western world, we cannot afford to be inefficient—our labor costs are much higher than elsewhere, and our production capacity is often less than that in newer plants elsewhere. *Uptime* cannot solve all the problems a business is faced with these days. What it can do is support cost-effective production or service delivery through the provision of physical assets that perform their functions well. We can do that in cost-effective ways doing the right work at the right time, nothing more and nothing less. We can repair failures when they occur in orderly ways that are also cost effective because they were thought through in advance and planned. We can ensure that our workforce is deployed to get the maximum use of their skills doing what they do best. Planners plan, materials managers look after parts, tradesmen/artisans work with their tools on the equipment in which they are specialized, supervisors supervise and so on. *Uptime* is a method to ensure sustainability of the physical assets while they are in the operational phase of their life cycle. Good asset management ensures that our organizations get the most value from our assets in a way that manages risks and costs and balances them with performance, safety and environmental concerns. But how do we sustain good asset management and good maintenance management?

Implementing an asset management or an *Uptime* framework is the first step. Get the implementation done. But once it is done, do not just let it fall apart. It is not like a building or a highway that, once built, can be taken for granted for a long time. Good use of *Uptime's* framework and asset management means sustained use of process and practices, continually monitoring them and the results they deliver, assessing whether or not they are working as intended and making adjustments as needed.

Sustaining the changes means that your project has produced processes. Those processes, like work, materials and performance management, need to be managed. They must be reviewed periodically to ensure that they are delivering their intended results. Performance measures are a good way to do this (see Chapter 6). Watch performance of the assets, themselves—are they still performing? If not, then what decisions need to be made to restore performance? Watch your processes. Are you still having a high level of success with planning and scheduling? Are your condition-monitoring efforts paying off by finding failures before they manifest? Are you getting to those identified problems and managing the consequences effectively? Are you preventing failures that can be prevented, predicting those that can be predicted and detecting those hidden failures before they result in multiple failure events and serious consequences?

Look at your RCM program. Once you have implemented RCM, you will have made many decisions about maintenance tasks, operator tasks, running some assets to failure, changes to training, procedures and processes. You will have task frequencies and resources assigned to those tasks. If your work management is successful, you will be following those programmed tasks and you should be seeing benefits in terms of increased reliability, more availability of systems and fewer failures except where you have consciously chosen to run to failure. Emergency work should be minimal. Planned work is the norm. Is this all being sustained?

Over time you will probably add assets, change how some are operated and find failure modes that were missed in the initial analysis. Data collection will probably improve, and you can validate or disprove assumptions made. Are you adjusting your results with an ongoing program of reviewing the old RCM analyses? Are you applying RCM to the new assets that are being added? In short—have you created a sustained RCM culture, or have you let it end when the initial analyses were completed and results implemented into your CMMS? One electric utility that had tremendous success with RCM did not invest the effort to keep the program "live" and 12 years later found themselves starting over.

There is much to do in sustaining what you start. Your business is sustained and depends upon your physical assets. Is the program that sustains those assets also being sustained?

Uptime provides a comprehensive framework for managing maintenance in your day-to-day operations and sustaining your physical assets' performance. It is part of the broader subject of asset management, which has a clearly stated goal of sustaining the delivery of value from physical (and other) assets throughout their entire life cycle.

Sustainability is an aspect of asset management too. ISO 55001, the new standard for asset management, requires that performance be monitored and corrective action taken when you encounter deviations, noncompliance to your program and incidents that arise. It requires periodic audits to ensure that you have the process and practices in place, have them documented, have deployed them consistently, follow them and can prove it all with documented evidence (i.e., good records). It also puts the onus on senior management to ensure that the entire program is working as intended and is delivering value to the stakeholders. These are all mechanisms aimed at sustaining the asset management system and the value it is delivering.

UPTIME SUMMARY

Uptime and its model of excellence provide a framework for good maintenance management. The journey of excellence in maintenance management requires that you do the things described in *Uptime*. You need direction, plans and people (leadership). You need to be doing the essentials well before you will really have a chance to target high reliability using the reliability methods described as choosing excellence. This does not mean that you must be a high performer to advance to the more technical realm of reliability, but you will have greater success with RCM and PM optimization if you have a high degree of success in getting your proactive work done on schedule. Doing that implies that you have got good planning and the right materials are available when needed. It is unlikely that you will be managing successfully without some degree of measurement of KPIs backed by data gathered and stored in your CMMS. Tightening it all up with good documentation, consistency and accuracy of your asset information is needed for compliance to the new global standards in asset management. Getting there requires work.

Implementing *Uptime* is a project made necessary if you are not getting the output (uptime) from your physical assets that you expect and/or if you are not getting it cost effectively. Implementation requires vision and plans based on ideas that preferably arise from within your own organization once it has been introduced to successful practices. Hoshin Kanri is an excellent planning and deployment methodology for using those ideas and getting them into the field as practical projects with their own KPIs.

Your implementation will be at risk if carried out in isolation from other functional areas within your company. Operations, finance, materials management, human resources and others must be active participants and party to governance of the initiative. Indeed what you must do will touch on their areas and they will impact on you. Good governance will keep your initiative on track and avoid the problems that can arise if you have too many initiatives on the go at the same time, often with similar goals yet competing for the same resources. Your action items can all be treated as small projects within the broader *Uptime* context, each with its own action team and leadership. Put as much of the work in the hands of your own people as practical, but be sure to support them with training and other external help. They are good at doing what you hired them for—such as producing and maintaining. They are not used to implementing major improvement projects, and they will need help, training, coaching and possibly other support.

Change management will be important but do not treat it as a separate project—embed it in all that you do and all that you say. As a rule, the senior management and the shop floor levels will buy in to *Uptime* quickly. Middle management may feel threatened by it, and they must be helped through the transition. Finally, do not forget that you will need ongoing performance management, audit and senior management reviews to ensure that you keep the whole initiative sustained well into the future, long after the project to implement *Uptime* has ended. Your goal is to turn *Uptime*, the framework, into your way of doing things complete with a culture of relentless continuous improvement.

CONCLUSION

Those who invest in maintenance are investing in a long-term process with long-term payback. Companies that have chosen this path and stuck to it have seen significant results. They have not wavered from conviction that the payback is worth the investment in people, tools and strategies, and they have not succumbed to short-term pressures to cut staff or cut budgets when things get a bit tough. They understand that maintenance performance is a journey and that continued good performance relies on continuously improving the people, tools and strategies involved. They are investing for a good return.

Excellence is a choice that entails ongoing effort. The journey is long and never ends. Starting that journey is a daunting prospect. But once your initiative is started and momentum is gained, it is relatively easy to continue. Much of the effort must come from your employees and from those who provide support to them in your storerooms, purchasing, engineering, information technology and human resource departments. Your role as a manager or executive is to provide support for their efforts and to nurture them. This support entails more than just words. You must walk the talk and lead by example.

The workforce today is well educated and getting even more educated. Slow economic times have kept younger people in school longer. They emerge smart, having a lot of exposure to a wide array of subjects and knowledge. Many were raised to be independently minded and to challenge what they see as wrong or questionable. This is helpful; they will keep you on your toes and continuous improvement will be natural for them. But they will not take orders blindly—at least not for long.

The manager of the future can deal with this newer breed of more empowered thinking employees. Managers must embrace change and learn to guide people through the transformations that change brings. You and your people will make mistakes along the way, but mistakes are part of the learning curve. There is little value in looking over peoples' shoulders and micromanaging. Provide guidelines and standards and then let them do their jobs. Help them to get it right, but do not ride herd.

Whole books (in some cases, many books) and standards have been written on the topics covered in these pages. Our objectives for *Uptime* are to raise your awareness of the scope and depth of what is out there, give some idea of how to implement *Uptime*, get on that journey of excellence and give some insight into what is entailed in the realm of asset management that is dawning globally. Hopefully, we have achieved those objectives for you.

ENDNOTES

1. A "high performer" has a low cost per unit of output, an excellent safety record and an excellent environmental record, and focuses only on success—consistently and efficiently achieving what it sets out to achieve.
2. See Chapter 10.
3. Caution: this chapter (indeed no book) cannot answer those questions in a way that is immediately specific and applicable to your particular business, but we can give some idea of how to determine your path. We can point you in a general direction, but it is up to you to do the choosing—make the decisions and take the necessary actions to make it happen.

Appendix A: The *Uptime* Assessment

Assessments are used to gauge how well you are doing in comparison with some standard of what "success" looks like. There are several types of assessment:

- Self-assessment
- Peer assessment
- Third-party assessment

A self-assessment is inherently biased and subject to individuals' personal agendas influencing the outcome. It also suffers from a significant drawback—those doing the self-assessment may not have a good idea of what success looks like. Quite often, your personnel have not been exposed to a wide array of different ways of doing things at different sites or companies. Their ideas about what is "good" may be limited to what they have seen at your location, and their perspectives may be somewhat rosier than they might be otherwise. Peer assessments can suffer from the same malady, but if the "peers" are from different sites, there will be less bias. The third-party assessment is the least biased and most likely to bring a broader perspective to success and successful practices, but it, too, has a drawback. Despite the experience a third-party assessor has, his/her experience is not necessarily in your sites, your company or even your industry. Some view this as limiting—"how can he/she possibly know what will work here?" However, it is that input of experience from elsewhere that can lead to breakthrough insights and potential for significant performance gains. In Chapter 6, that is discussed in the context of benchmarking.

In all cases, the assessor attempts to get perspective on how well you are doing. The assessor observes what is being done in each of the key areas of maintenance management depicted in the Pyramid of Excellence. By gathering objective data, carrying out a thorough visual tour and "inspection" and asking questions of various individuals who work in these areas and their "customers," you get a very clear picture of what is happening and how it is being viewed internally and then compared with the external perspective.

It is possible to judge how well things are being done, but a great deal of caution is required in doing so. There is no single "right way." What may appear to be less-than-ideal practice may actually work extremely well in a particular situation; conversely, what seems to be ideal is not viable in another. It is always the results that matter; as long as they are legal, methods do not. Be cautious in your choice of assessor—a biased or highly opinionated person who believes there is only one right way to do things will not provide a balanced assessment.

It is best to avoid making judgments about what is good or bad practice. After collecting the review information and evidence of results, compare what you have been doing with what other high performers are doing. Good results indicate that something is being done well—how those who are getting those results achieve that is important to learn.

An example that illustrates why this distinction between observing practices and results concerns a newsprint paper mill using a homegrown computerized maintenance management system (CMMS) to manage work. As a rule, those homegrown systems are very limiting. They are developed by the site by those who really do not do information technology (IT) system development for a living. The company had high compliance with its work schedules, a low incidence of rework, a high ratio of planned to unplanned work, smooth shutdowns and relatively few emergencies. Despite the homegrown CMMS, which is often considered a "worst practice," things were going very well, and the company was achieving desired results. The homegrown system had been perfectly designed to match their business processes, it was fully utilized to support those processes and the company was making very good use of it and getting excellent performance from its maintenance group. Of course, the homegrown system did not work as well in all respects. For instance, it was not particularly suitable for financial reporting, because it did not track maintenance cost details. Overall costs were tracked separately in an accounting system. At budget time, to support their forecasts for the following year, the maintainers manually correlated their work reports with financial reports. A fully integrated CMMS, enterprise asset management (EAM) system or enterprise resource management (ERP) system may have been more useful than their homegrown stand-alone systems for that purpose.

The question here is which result was more important to the business: managing the maintenance process or managing maintenance financial reporting? The implications of this kind of trade-off are important. If a commercial, fully integrated system is not used by the maintenance tradespersons because it is "user hostile," then it is better to use a homegrown system. If the cost of management's budgeting processes outweighs the benefits of excellent work management, using a homegrown system is ill advised.

A diagnostic review can point out the cost–benefit ratio between practices and even suggest other options. Choices can then be made with a full awareness of the trade-offs, and these choices are the product of "conscious management."

Whenever a company makes choices consciously, it has a much greater chance of achieving its goals. Leaving these choices to others is a way of abdicating from the responsibility of managing your business. Moreover, relinquishing your control means giving that control to others even though the ultimate results will be your responsibility. Later, if something is not working, blaming those others for your choices is not going to solve your problems.

LEARNING AS A PRECURSOR TO ASSESSING

Consciousness in maintenance management is characterized by being aware of your options and making choices based on that awareness. Although you do not need an outsider for this, you do need to maintain objectivity, and this is sometimes difficult for anyone who has a stake in the outcome.

As noted already, it is important that the assessors know their subject matter. If there is insufficient budget for a third-party or peer assessment, then the only option left is self-assessment or the use of our *Uptime* Performance Assessment app (see below).

In any case, there is no substitute for knowing the subject matter and having a broader perspective on successful practices. Your employees could read this book and gain a great deal of that knowledge, but it is unrealistic to expect many to do so. Very few people read books,[1] and when they do, they tend to read fiction, romance, action, adventure or science fiction. Technical and business books are not at the top of most people's reading lists.

Training is highly recommended for those who are embarking on any sort of improvement program aimed at excellence in maintenance management. The authors and contributors to *Uptime* all work together in helping companies improve their performance. While anyone can read the book, not everyone has all the insights that went into its writing. The author and his colleagues offer training in *Uptime*, making it easy to introduce these concepts to large groups of employees in a short time without expecting them to read a technically oriented business book.

If that is not practical, then another alternative is to simply use the maintenance performance grid (Table 1.1) shown in Chapter 1. Have your employees read the descriptions in the columns under each heading and choose which best describes your current state. The grid is quite generic, and the descriptions may not always be good fits with your environment, but it is a reasonably good place to start.

Nevertheless, the best solution to this objectivity issue is a diagnostic review performed by an independent third party. The following outline shows key areas examined during a maintenance diagnostic review:

1. Overall business context
2. Leadership

    - Maintenance strategy and its fit to the business context
    - Organization, people management (e.g., training and development) and teamwork
3. Essential practices
    - Work management
    - Materials management (including its integration with planning and scheduling)
    - Basic care and 5S
    - Performance management and benchmarking
    - Management and support systems
4. Choosing excellence (reliability methods)
    - Reliability-centered maintenance (RCM)
    - Rapid preventive maintenance (PM) deployment, PM optimization, root cause failure analysis (RCFA)
    - Evidence-based asset management (EBAM)
5. Asset management
    - Management of asset-related risks
    - Consistency of practices
    - Integration of maintenance and engineering with other functional areas
    - Information management
6. Results

QUESTIONS TO CONSIDER IN YOUR ASSESSMENT

Overall Business Context

- Business plan and competitive dimensions; nature of the business cycle
- Products and customer profile
- Role of the plant/facility or fleet in meeting the overall business plan
- Special regulatory, environmental, safety or material handling considerations
- Plant layout, facilities, fleet sizes and makeup, age
- Process flow and technology; equipment criticality
- Capital expenditure history; plant upgrades
- Sales inventory and operations
- Planning (get a sense of the state of the business)

Leadership

Maintenance Strategy and Its Fit to the Business Context

- Documented, communicated and understood vision, mission or mandate, principles, objectives and improvement plans
- Degree of fit with business characteristics
- Organization level of maintenance management
- Overall maintenance budget over past several years
- Use of contractors, outsourcing, cosourcing, partnering
- The annual budgeting process and involvement

Organization, People Management and Teamwork

- Organization structure and labor levels
- Existence of maintenance planning, maintenance engineering
- Number of personnel, by trade and function
- Key accountabilities of each key position; overlaps and gaps
- Communication styles and effectiveness
- Training processes: technical, general, supervisory, problem solving, teamwork
- Compensation system, incentives, recognition, rewards
- Performance evaluation, employee development, career progression; selection of new employees
- Degree of autonomy, self-direction, teamwork
- Are RCM and other task-force teams truly empowered?
- Is a total productive maintenance (TPM) program in place?
- Are TPM principles being followed?
- Suggestion plans, continuous-improvement teams, continuous improvement manager (or similar)

Essential Maintenance Practices

Work Management

- Responsibilities for fault identification, general work identification
- Priority setting, collaboration; scoping the work
- Planning activities, sequencing, coordinating skills, estimating
- Scoping for parts, components, materials; cost allocation
- Availability of special tools, mobile equipment, rigging

- Reference drawings, safety reminders
- External contractor arrangements, special orders
- Use of standard procedures for repetitive work
- Backlog of special work, PM, shutdowns
- Coordination with production, stores; daily, weekly meetings
- Net capacity review for special skills
- Scheduling horizons for production planning, labor balancing
- Use of decision support tools, large-job scheduling techniques
- Use of work order types: PM, lubrication, corrective, urgent, standing
- Authorization levels and procedures, costing technique
- Use of work order records: costs, productivity, failure analysis, job plans, backlogs, scheduling
- Feedback provided on actual versus planned
- Quality control and management on maintenance activities and schedules

Materials Management

- Clear purchasing policies, procedures, accountabilities
- Vendor qualification; performance monitoring on cost, accuracy, quality, service, stability
- Vendor partnering, systems contracts, cooperative negotiations
- Approval process, levels for purchase requisitioning
- Coordination with maintenance on specifications, quality, service
- Level of urgent, emergency requisitions from maintenance
- Purchasing performance monitoring recost, customer satisfaction
- Expediting procedure
- Administrative processes for procurement, accounts payable
- Warranty management procedures, discrepancies
- Use of purchasing for obsolescence, engineering changes, new-item testing
- Stores layout, locations, access, space, racking, security
- Availability and use of mobile equipment and stores management tools
- Degree of automation, bar coding
- Use of substores, shop-floor stores, free-access items
- Receiving, issuing, stocking schedules, labor, procedures
- Direct-charge item storage
- Parts and materials quality assurance, accuracy

- Management of telephone orders, delivery, kitting/pick lists
- Consignment stock locations, vendor access
- Requisitioning procedures
- Catalogs, referencing, online information
- Inventory reconciliation and absolute value of deviation
- Use of statistical analysis by inventory category, stock history
- Measures of investment efficiency, turnover, value, number of stock-keeping units (SKUs)
- Obsolescence review, no usage analysis
- Stock control techniques, max–min, EOQ, EOP
- Control of repairable items/rotables
- Service-level/stock-out measures, back orders
- Stock counting policies, schedules (cycle counting)

Basic Care

- Compliance tracking for applicable regulations (safety, environment, etc.)
- General housekeeping and equipment condition
- Coverage of equipment, areas for planned maintenance
- Level of detail on preventive, predictive maintenance routines
- Work generated as a result of inspections
- Use of condition-based and nondestructive techniques
- Drawings for layout, equipment configuration, updating, control

Performance Management

- Cost reporting, availability of information, cost control
- Key performance indicators that are in use and how they are estimated or measured
- Data collection, data entry, integration
- Records management for personnel, equipment, costing
- Use of dashboard or scorecards
- Visibility of performance reporting
- Acceptance of performance management within workforce (both salaried and hourly)

Management and Support Systems

- Completeness of equipment records
- Identification of critical equipment, configuration management, asset lists
- Availability of nameplate and procurement information with bill of materials
- Assets clearly marked with a nameplate
- Records management for manuals, drawings
- Is there a CMMS either in place or planned?
- Degree of CMMS use and coverage
- Capability of modules, functions (do the capabilities match business processes?)
- Integration with other systems
- Degree of user-friendliness (is it used by shop-floor personnel?)
- Use of analytical and decision support software tools
- Use of automation in stores, shops, etc.
- Are workaround solutions in place?

Choosing Excellence (Reliability)

RCM

- Has RCM been used, or is it being used?
- Is RCM being applied for all critical assets?
- Are past RCM program results reviewed for relevance over time?
- Are reliability results used to upgrade or change RCM decisions?
- Is the PM program clearly linked to RCM outputs?

PM Optimization and Rapid PM Deployment

- Is PM optimization being used on noncritical assets as a complement to RCM?
- Has PM optimization been used to review old PM programs?
- Has rapid PM deployment been used to help get an "out-of-control" reactive environment back under control?

RCFA

- Has one of the methods for RCFA been used to close any gaps left by RCM/PM optimization efforts?
- Is RCFA the only reliability improvement method in use?
- Are "root causes" validated by monitoring the results of corrective actions taken?

Optimization and EBAM

- Availability of histories of faults, failures, causes, repairs, actions, costs, times
- Access to records, use of records for prediction, problem solving, capital replacement, life-cycle management
- Use of equipment histories and mathematical models for fault/failure analysis
- Decision support methods and tools in use
- Are data available, accurate, complete and can they be trusted?
- Are interview techniques (knowledge elicitation) used to close any data gaps?
- Are advanced modeling and mathematical methods used to help make reliability and asset life-cycle decisions?
- Is there accurate documentation of downtime, causes, corrective action, inspection schedules?

Asset Management

- Is there a proactive program (such as RCM) used to identify asset-related risks?
- Are those risks managed in the context of your risk management program or otherwise?
- Is monitoring of your maintenance program in place to ensure that actions (e.g., regular maintenance tasks) are being carried out as intended?
- Are your maintenance and asset management practices consistent across departments, sites and even regions (if applicable)?
- Are your maintenance and engineering processes integrated to ensure sharing and exchange of information?
- Does maintenance have influence in the design process for new assets?

Asset Information Management

- Is documentation (e.g., drawings, manuals, diagrams, parts lists, etc.) consistent across all departments?
- Is everyone using the same single version of the truth when it comes to technical documentation and data?
- Are master and reference data managed effectively and used as intended?
- Is transactional data collected and its accuracy verified?
- Is there an information governance program in place?
- Is the data owned by stakeholders or IT?

Results

- Safety record, loss prevention, analysis and correction, discipline, participation
- Overview of plant, facility, fleet condition, housekeeping
- Overall working conditions, degree of satisfaction, labor relations
- Morale, absenteeism, turnover, grievance level
- Level of unplanned, urgent, emergency, standing work orders
- Level of planned, preventive, predictive scheduled maintenance
- Degree of compliance with planned work schedules
- Accuracy of costs, estimates and budget control
- Equipment performance for frequency and duration of failure, speed, precision, availability, utilization, reliability
- Process performance, such as work orders by status, PM compliance, time on planned work, backlog, new tactics applied
- Employee performance, specialty training, application of skills, teamwork, progression
- Response time to urgent calls, flexibility, coverage
- Housekeeping after repairs
- Level of confidence in maintenance by production

ASSESSMENT TOOLS

There are various assessment questionnaires you can find, download and access online. Those questionnaires are usually based on a model, such as *Uptime*'s Pyramid of Excellence, and they provide a very good starting point. Rather than provide a questionnaire specific to *Uptime*, we have provided access to our *Uptime* Performance Assessment app (see below).

Bear in mind that administering questionnaires can become an onerous task. To get a balanced picture of your current state, you need balanced input. That means you need to collect a number of opinions, each scored, and then look for averages, outliers and trends. For instance, it is not uncommon for management to have a rosier perspective than the shop-floor employees. Some people will also struggle to answer the questions if they are outside their particular work area (e.g., materials management people often struggle to answer questions specific to maintenance). Often, those individuals, in the interests of participating fully, will provide answers even if they are unsure. Those answers, while well intended, may be misleading. You will also find some people to be particularly optimistic or pessimistic. Their answers tend to show up as outliers—well outside the range of most answers.

Spreadsheets are handy tools for collecting responses and determining statistical trends in the responses, but they cannot interpret the data for you. That requires experience.

To make the job easier, there is an *Uptime* Performance Assessment app[2] available for download. It works in both Google's Android and Apple's iOS environments using handheld smartphones. The app asks for some basic information (i.e., industry, company and site identification) so that the data can be managed in a broad database. It then asks questions in each of the areas of the *Uptime* Model of Excellence. Users score their answers by moving sliders left or right on a scale. The app tabulates the responses into averages for each of the *Uptime* elements and compares those with the overall database, the site and company and even industry results as contained in the database. It can be downloaded for free (by individuals) at www.consciousasset.com. Those who wish to use it for a site or broader group will need to ask for site and company identifiers to ensure that their users input data consistently and that they can be related to the inputs from other site and company users.

Figure A.1 shows the two types of output screens. The app will also, upon request, send a summary of the results to the user.

For those who subscribe to the site and company-level services, more detailed reports are available.

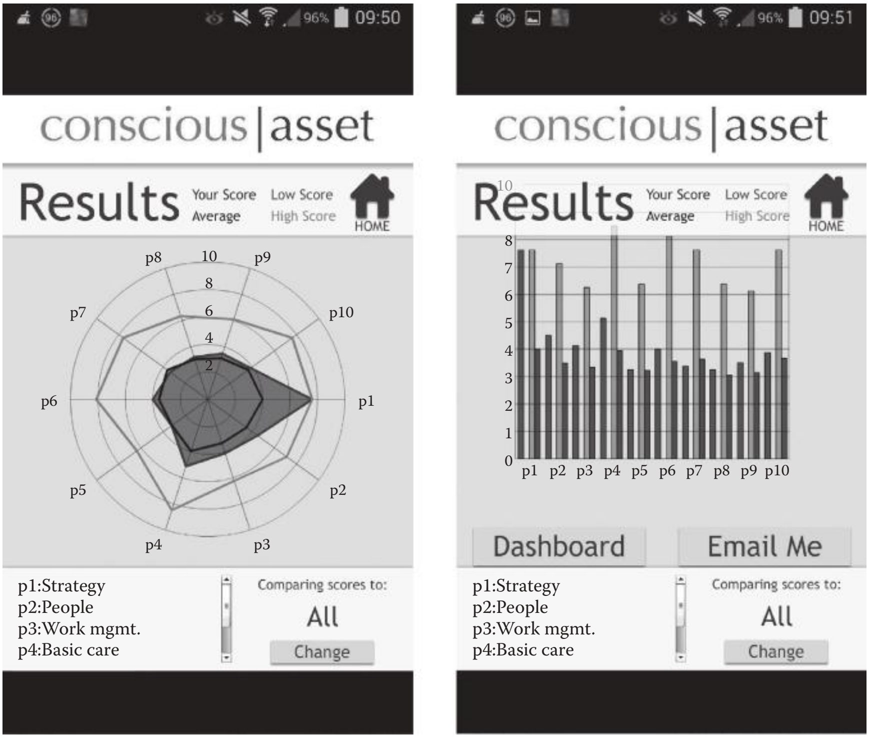

FIGURE A.1
Two types of output screens.

The results obtained from the app itself are indicators that you can use in determining where you have strengths and weaknesses. They are intended not to replace the expertise of a third-party assessor but, rather, to supplement or provide general guidance to the users.

In time, that app will be but one of a range of online tools intended to help companies start their improvement programs.

ENDNOTES

1. Pew and Gallup performed a study showing the decline in readership of books in America. The percentage of people who did not read a book in the past year grew from 8% in 1978 to 23% in 2014. In 2014, 23% read no books, 31% read 1 to 5 books, 17% read 6 to 10 and 28% read 11 or more. Education and income correlate to these statistics; the more educated and the higher the income, the more likely to read.
2. The *Uptime* Performance Assessment App is available free for download at http://www.consciousasset.com/mobile-app.

Appendix B: Glossary of Maintenance Terminology

Acceptable condition: That condition agreed on for a particular use, not less than that demanded by statutory requirements; meeting a functional standard for equipment operation.

Activity board: An information-sharing display prepared by a team or group to facilitate communication between operators and maintainers in a TPM environment.

Acute loss: Infrequent or one-time performance shortfall, the gap between actual and optimal performance; usually associated with a major defect.

Adjustments: Minor tune-up actions requiring only hand-tools and no parts, and usually lasting less than a half hour.

AM: Asset management.

Apprentice: A tradesperson in training.

Area maintenance: A type of maintenance organization in which the first-line maintenance foreperson is responsible for all maintenance trades within a certain area.

Asset(s): The physical resources of a business, such as a plant, facilities, fleets or their parts and components.

Asset information management (AIM): The governance and management of all technical and other information related to physical assets.

Asset list: A register of items usually with information on manufacturer, vendor, specifications, classification, costs, warranty and tax status.

Asset management: The systematic planning and control of a physical resource throughout its economic life.

Asset number: A unique alphanumerical identification of an asset on a list, often in a database, which is used in its management.

Autonomous maintenance: Routine maintenance, PM and PdM carried out by operators, with or without help from maintenance tradespersons who are often a part of the same team as the operators.

Availability: The period of scheduled time for which an asset is capable of performing its specified function, expressed as a percentage.

Available: The state of being ready for use; includes operating time and downtime for reasons other than maintenance.

Backlog: Work that is waiting to be done; it is estimated and awaiting planning, prioritization, scheduling and execution.

Bar code: Symbols for encoding data using lines of varying thickness, designating alphanumeric characters.

Benchmark: A measurable standard for high performance based on a survey or study of comparable businesses or business processes having similar key performance drivers.

Benchmarking study: A formal study aimed at determining benchmarks and practices used to attain those high levels of performance.

Best practice: See *Successful practice*.

Bill of materials (BOM): List of components, from complete assemblies to individual components and parts for an asset, usually structured in hierarchical layers from gross assemblies to minor items.

Breakdown: Failure of an asset to perform to a functional standard.

Breakdown maintenance: A policy where no maintenance is done unless and until an item no longer meets its functional standard, often when the asset is no longer able to operate at all.

Call-back: A job that is redone because the original repair did not correct the failure.

Call-out: The practice of calling maintenance workers in to work at times outside of their normal workday.

Capital spares: Spares, usually large, expensive, difficult to obtain, or having long lead times, that are acquired as part of the capital purchase of the asset for which they are intended to be used or later, after the risk of not having them is realized; accounting often treats these spares as capital items with their value depreciated over time.

Catalogue: Description of a part or other stock or nonstock item that is used in the maintenance of equipment.

CBM: See *Condition-based maintenance* and *Condition-based monitoring*.

Change-out: Removing a component or part and replace it with a new or rebuilt one.

Charge-back: Maintenance costs charged to the user department that requested the work.

Chronic loss: Frequently occurring performance shortfalls, the gap between actual and optimal performance.

Cleaning: Removing all sources of dirt, debris and contamination for the purpose of inspection and to avoid chronic losses.

CMMS: Computerized maintenance management system.

Code: Symbolic designation, used for identification.

Component: A constituent part of an asset, usually modular and replaceable, that is sometimes serialized depending on the criticality of its application and interchangeability.

Component number: Designation, usually structured by system, group or serial number.

Computer, mainframe: A digital processor with the highest capacity, speed and capability, normally used at the corporate level of a company.

Computer, micro: A digital processor having moderate capability relative to a minicomputer or mainframe computer, usually desktop, operated by an individual user.

Computer, mini: A digital processor having significant capacity but less than a mainframe, often used at the corporate or site level.

Computer, workstation: Equipment, usually a keyboard and display, used to access a mainframe or minicomputer; sometimes used to describe an office work area for one person; sometimes used to describe a desktop microcomputer for individual use.

Conditional probability of failure: The probability that a failure will occur in a specified period given the condition that the item has survived to the beginning of that period.

Condition-based maintenance: Repair or restoration of an asset based on its condition at the time; also known as on-condition maintenance.

Condition-based monitoring: The monitoring of equipment performance or other condition parameters to determine the condition or "health" of the equipment or system. Condition-based monitoring is used as part of a predictive maintenance program to determine the need for condition-based maintenance.

Contract maintenance: Maintenance work performed by contractors.

Contractor: An individual or company providing specific services to another under contract for those services, tasks or specific results.

Coordination: Daily adjustment of maintenance activities to achieve the best short-term use of resources or to accommodate changes in needs for service.

Corrective maintenance: Maintenance done to bring an asset back to its standard functional performance.

Costs, life-cycle: The total cost of an item throughout its life, including design, manufacture, operation, maintenance and disposal.

Critical spares: Spare parts that have high value or long lead times or are of particularly high value to the important and unspared equipment on which they are used. They are carried to avoid excessive downtime in the event of a breakdown.

Criticality: A measure of the importance of an asset relative to other assets.

Defect: A condition that causes deviation from design or expected performance, leading to failure; a fault.

Deferred maintenance: Maintenance that can be or has been postponed from a schedule.

Detective maintenance: Testing an asset to make sure it is still functional; used primarily to check dormant devices that can fail in such a way as to be undetectable until it is needed to function.

Deterioration rate: The rate at which an item approaches a departure from its functional standard.

DM: See *Detective maintenance*.

Down: Out of service, usually due to breakdown, unsatisfactory condition or production scheduling.

Downtime: The period of time during which an item is not in a condition to perform its intended function, whether scheduled or not. The distinction between "scheduled" and "unscheduled" downtime is stated where it is relevant to the discussion.

EAM: Enterprise asset management system.

EBAM: Evidence-based asset management.

Emergency: A condition requiring immediate corrective action for safety, environmental or economic risk, caused by equipment breakdown.

Engineering work order (EWO): A control document from engineering authorizing changes or modifications to a previous design or configuration.

Equipment configuration: List of assets usually arranged to simulate the process, functional or sequential flow.

Equipment repair history: A chronological list of defaults, repairs and costs on key assets so that chronic problems can be identified and corrected and economic decisions made.

Equipment use: A measure of the accumulated hours, cycles, distance, throughput, etc. that an asset has performed in its function.

ERP: Enterprise resource planning system.

Evident failure: A failure mode that, on its own, becomes apparent to the users of the asset under normal operating circumstances.

Examination: A comprehensive inspection with measurement and physical testing to determine the condition of an item.

Expert system: Decision support software with some ability to make or evaluate decisions based on rules or experience parameters incorporated in the database.

Failure: Termination of the ability of an item to perform its required function to a desired standard.

Failure analysis: A study of failures; to analyze the root causes, develop improvements and eliminate or reduce the occurrence of failures.

Failure coding: Indexing the causes of equipment failure on which corrective action can be based, for example, lack of lubrication, operator abuse, material fatigue, etc.

Failure effect: A statement of what chain of events follows occurrence of a failure.

Failure-finding task: A scheduled task used to detect whether or not an asset is in a failed state, generally used on assets that are normally dormant (e.g., safety devices, backups).

Failure mode: The event that leads to failure.

Fault: See *Defect*.

Fault tree analysis: A review of failures, faults, defects and shortcomings based on a hierarchy or relationship and beginning with a statement of an undesirable event, such as "failed"; used to find the root cause or multiple causes of the event; used primarily where reliability is of utmost importance (e.g., airlines, nuclear power, pharmaceuticals).

Five S (5S): Derived from the Japanese words *seiri* (organization), *seiton* (tidiness), *seiso* (purity), *seiketsu* (cleanliness), *shitsuke* (discipline); focused on the workplace and successful habits that contribute to equipment condition.

FMECA: Failure mode, effect and criticality analysis; a logical, progressive method used to understand the root causes of failures and their subsequent effect on production, safety, cost, quality, etc. Used as part of RCM.

Forced outage: Downtime caused by a failure.

Forecasting: The projection of the most probable: as in forecasting failures and maintenance activities.

Functional maintenance structure: A type of maintenance organization where the first-line maintenance foreperson is responsible for conducting a specific kind of maintenance, for example, pump maintenance; heating, ventilation and air-conditioning (HVAC) maintenance; etc.

Hard-time maintenance: Periodic preventive maintenance based rigidly on calendar time.

Infant mortality: Failures that occur prematurely; often, these occur because of design, material, workmanship, installation or quality problems in any work that was done prior to starting the asset up for service.

Inspection: A review to determine maintenance needs, condition and priority on equipment.

Inventory: Stock items that are actually on hand in a storeroom or elsewhere ready for use.

Inventory control: Managing the acquisition, receipt, storing and issuance of materials and spare parts; managing the investment efficiency of the stores inventory.

Inventory turnover: Ratio of the value of materials and parts issued annually to the value of materials and parts on hand, expressed as percentage.

Issues: Stock consumed through stores.

Labor availability: Percentage of time that the maintenance crew is free to perform productive work during a scheduled working period.

Labor utilization: Percentage of time that the maintenance crew is engaged in productive work during a scheduled working period.

Lean manufacturing: A manufacturing system that focuses on minimizing the resources required to produce the product or service (i.e., eliminating waste).

Level of service (stores): Usually measured as the ratio of stock-outs to total stores issues.

Life cycle: The sequence of stages in the existence of an asset: conceptualization, plan, evaluate, design, build/procure, operate and maintain, modify, dispose.

Life-cycle cost (LCC): The total of all costs of the asset throughout its entire life cycle, including all work done on or to the asset, depreciation, and other costs of ownership; normally, LCC takes account of the time value of money.

Logistics engineering: A systems engineering concept developed for military weapons systems; it advocates maintenance considerations in all phases of an equipment program to achieve specified reliability, maintainability and availability requirements.

Maintainability: The rapidity and ease with which maintenance operations can be performed to help prevent malfunctions or correct them if they occur, usually measured as mean time to repair (MTTR).

Maintenance: Any activity carried out to retain an item in, or restore it to, an acceptable condition for use or to meet its functional standard.

Maintenance audit/review: A formal review of maintenance management practices and results carried out by an independent third party for the purposes of evaluating performance, identifying areas of strength, weaknesses and opportunities for improvement.

Maintenance engineering: A staff function intended to ensure that maintenance techniques are effective, equipment is designed for optimum maintainability, persistent and chronic problems are analyzed and corrective actions or modifications are made.

Maintenance history: A record of maintenance activities and results.

Maintenance policy: A principle guiding decisions for maintenance of an asset (e.g., this asset will be run to failure and then repaired vs. this asset will be monitored for vibrations to avoid having it fail unexpectedly).

Maintenance prevention: Design of assets to avoid the need for maintenance.

Maintenance route: An established route through a facility along which a maintainer carries out proactive maintenance, detective maintenance and minor repairs on a routine basis.

Maintenance schedule: A comprehensive list of planned maintenance and its sequence of occurrence based on priority in a designated period of time.

Maintenance shutdown: A period of time during which a plant, department, process or asset is removed from service specifically for maintenance.

Maintenance strategy: A high-level statement of vision, mission and objectives with a description of a general plan for achieving them; also used to describe the specific approach to be used for maintaining a specific asset.

Maintenance window: The time frame in which maintenance work can be performed without incurring any unplanned production losses.

Major defect: A single defect that can cause equipment breakdown and operational losses.

Material safety data sheet (MSDS): Information sheets that come with chemical products giving the formal name of the chemical/compound, a description of its toxicity, handling instructions, warnings about its use and first-aid treatment for exposure.

Menu: A selection of functional options in a software display.

Meter reading: A numerical reading of the accumulated usage of an asset using an hour meter, odometer or other device.

Minor defect: A single defect that cannot cause losses on its own but may contribute to losses in combination with other minor defects.

MRO: Maintenance, repair and overhaul; used in describing the material resource requirements to support maintenance activities.

MTBF (mean time between failures): See *Reliability.*

MTTR (mean time to repair): See *Maintainability.*

Natural deterioration: The inherent deterioration that occurs in an asset as a natural result of its usage or age.

NDT: Nondestructive testing of equipment to detect abnormalities in physical, chemical or electrical characteristics, using such technologies as ultrasonics (thickness), liquid dye penetrants (cracks), x-ray (weld discontinuities) and meggers (voltage generators to measure resistance). Some forms of NDT carry a risk of damaging an item or increasing the probability of failure for the item being tested (e.g., meggers and dye penetrants that require equipment disassembly), and some are completely nonintrusive (e.g., x-rays).

Nonroutine maintenance: Maintenance (usually repairs) performed at irregular intervals, with each job unique, and based on inspection, failure or condition.

OEE: See *Overall Equipment Effectiveness.*

Online: The state of being available and accessible while the CMMS is operating.

Opportunity maintenance: Maintenance work that is performed in an unanticipated maintenance window or to take advantage of a planned maintenance window to get more work accomplished than scheduled.

Outage: A term used in some industries, for example, electrical power distribution, to denote when an item or system is not in use.

Outsourcing: Contracting of all or a major part of the maintenance work required by an organization.

Overall equipment effectiveness (OEE): OEE is a measure combining availability, production rate (i.e., utilization of the available time) and quality rate of an asset.

Overhaul: A comprehensive examination and restoration of an asset to an acceptable condition.

Pareto: Analysis to determine the minority of equipment that is causing the majority of the problems.

PdM: See *Predictive maintenance*.

Pending work: Work that has been issued for execution but is not yet completed; maintenance work in process.

Performance indicators: Measures that indicate the degree to which a specific function is being performed.

Performance management: The act of using performance measurement as a means of identifying shortfalls and correcting them with an aim to improve overall performance results.

Performance measurement: The act of measuring performance using performance indicators.

Periodic maintenance: Cyclic maintenance actions carried out at regular intervals, based on repair history data, use or elapsed time.

Pick list: A selection of required stores items for a work order or task normally used by stores to prepackage the needed materials for use.

Plan: The comprehensive description of maintenance work to be done, including task list, parts and materials required, tools required, safety precautions to be observed, permits and other documentation requirements, an estimate of the duration of the work, effort and costs.

Planned component replacement (PCR): See *Scheduled discard*.

Planned maintenance: Maintenance carried out according to a documented plan of tasks, skills and resources.

Planner: An individual who plans work (see *Plan*); often, planners also schedule work.

PM: See *Preventive maintenance*.

PM frequency: The frequency for performing PM work, also used for inspections, PdM and DM frequencies.

PMO: See *Preventive maintenance optimization*.

Potential failure: A detectable operating or equipment condition that can be used to indicate that a failure is about to occur or in the process of occurring.

Predictive maintenance (PdM): Use of measured physical parameters against known acceptable limits for detecting, analyzing and identifying equipment problems before a failure occurs; examples include vibration analysis, sonic testing, dye testing, infrared testing, thermal testing, coolant analysis, tribology and equipment history analysis; used to identify the need for CBM.

Preventive maintenance (PM): Maintenance carried out at predetermined intervals, or to other prescribed criteria, and intended to reduce the likelihood of a functional failure.

Preventive maintenance optimization (PMO): A process of analyzing an existing PM program with the intent of optimizing its performance, sometimes used as an alternative or a complement to RCM.

Priority: The relative importance of a single job in relationship to other jobs, operational needs, safety, etc., and the time within which the job should be done; used for scheduling work orders.

Proactive: A style of initiative that is anticipatory and planned for; includes PM and PdM.

Process safety management (PSM): Regulatory requirements designed to increase safety and environmental performance in manufacturing processes.

RCFA: See *Root cause failure analysis.*

RCM: See *Reliability-centered maintenance.*

Reactive maintenance: Maintenance repair work done as an immediate response to failure events normally without planning, always unscheduled.

Rebuild: Restore an item to an acceptable condition in accordance with the original design specifications.

Refurbishment: Extensive work intended to restore a plant or facility to acceptable operating condition.

Reliability: The ability of an item to perform a required function under stated conditions for a stated period of time; usually expressed as the mean time between failures.

Reliability analysis: The process of identifying maintenance of significant items and classifying them with respect to malfunction on safety, environmental, operational and economic consequences. Possible failure mode of an item is identified, and an appropriate maintenance policy is assigned to counter it. Subsets are failure mode, effect and criticality analysis

(FMECA); fault tree analysis (FTA); risk analysis; and hazard and operability study (HAZOP) analysis.

Reliability-centered maintenance (RCM): A method used to determine the appropriate failure management policies for any asset in its present operating context.

Repair: To restore an item to an acceptable condition by the renewal, replacement or mending of worn or damaged parts.

Restoration: Actions taken to restore an asset to its desired functional state.

Return on investment (ROI): Financial performance of an investment.

Return on net assets (RONA): Profits generated expressed as a percentage of the net value of physical assets that produced that profit.

Rework: Work that has to be done over.

Root cause failure analysis (RCFA): Analysis used to determine the underlying cause or causes of a failure so that steps can be taken to manage those causes and avoid future occurrences of the failure; sometimes called root cause analysis (RCA).

Rotable: Components that are rebuilt after their useful life and rotated through maintenance stores back to use; a repairable item.

Routine maintenance: See *Scheduled maintenance*.

Run to failure: A failure management policy that allows the asset to be run to the failed state without any effort to predict or prevent it before it occurs.

Running maintenance: Maintenance that can be done while the asset is in service.

Schedule: A time-phased list of work to be done.

Schedule compliance: The number of scheduled jobs actually accomplished during the period covered by an approved schedule; also the number of scheduled labor hours actually worked against a planned number of scheduled labor hours, expressed as percentage.

Scheduled discard: Replacement of an item at a fixed, predetermined interval, regardless of its current condition; a type of PM, a planned component replacement (PCR).

Scheduled maintenance: Any maintenance that is prioritized to be done at a predetermined time; scheduled work may be planned or unplanned.

Scheduled outage: Downtime that was intended for maintenance, servicing, operational or other purposes.

Scheduled restoration: Repair or restoration of an asset at a predetermined interval, regardless of its current condition; a type of PM.

Scheduler: An individual who schedules work; see *Planner*.

Scheduling cycle: The length of time for which scheduling is normally done for work backlog, often weekly or biweekly.

Scoping: Outlining the extent and detail of work to be done and the resources needed.

Seasonal maintenance: Maintenance work carried out at a specific time of year, e.g., repair of potholed roads in northern climates, repairs to school buildings during vacation periods.

Service level: An expression of the percentage of spares that are issued on demand; also a specification of the desired service standards to be met by a contractor.

Servicing: The replenishment of consumables needed to keep an item in operating condition (e.g., lube oil, ink, wearing surfaces, cleaning of working surfaces).

Setup and adjustment: A process of changing from one manufacturing configuration to another to accommodate a change in product being produced on the same asset.

Shelf life: That period of time during which materials in storage remain in an acceptable condition.

Shutdown: That period of time when equipment is out of service; also refers to major maintenance work where primary producing assets are down while the maintenance is being performed.

Shutdown maintenance: Maintenance done while the asset is out of service, as in the annual plant shutdown.

Six losses: In TPM, these are the major losses that occur due to inadequate equipment operation or condition—i.e., breakdown, setup and adjustment; minor stoppages; speed reductions; quality defects and rework; yield reductions.

Specifications: Physical, chemical or performance characteristics of equipment, parts or work required to meet minimum acceptable standards.

Sporadic loss: See *Acute loss*.

Standard job: A preplanned maintenance job with all details required for work execution delineated and stored (usually in the CMMS, EAM or ERP) for repeated use.

Standby: Assets that are used as backups to others that are installed or available but not in use.

Standing work order (SWO): A work order that remains open, usually for the annual budget cycle, to accommodate information on small jobs or for specific tasks.

Stock: A term used to describe parts that are normally kept on hand in a storeroom.

Strategy: (1) The overall approach for managing the life cycle of a specific physical asset (e.g., its maintenance strategy); (2) an overall direction and flexible high-level plan for business.

Successful practice: A practice that leads to superior performance or results in a specific process; sometimes called "best practice," but this implies that it is the only way to execute the practice.

Superintendent: A second-line manager who is responsible for a maintenance group or department.

Supervisor: A first-line manager who is responsible for a group of tradespersons.

Survey: A formal inspection of a plant, facility, civil infrastructure or vehicle to look for condition and defects.

Tactics: The choices made to implement a strategy and manage the people, processes and physical asset infrastructure that make up your business.

Task: A single item on a task list that informs an inspector or maintainer on what to do, an instruction.

Task list: Directions to an inspector or maintainer telling him/her what to do and in what sequence, e.g., check oil level, clean, adjust, lubricate, replace, etc.

Terotechnology: An integration of management, financial, engineering, operating maintenance and other practices applied to physical assets in pursuit of an economical life cycle.

Total productive maintenance (TPM): Company-wide equipment management program emphasizing operator involvement in equipment maintenance and continuous improvement in equipment effectiveness.

Trade: A specific skill or set of related skills in a particular area (e.g., millwright, electrician, machinist, boilermaker, carpenter, rigger, etc.).

Tradesperson: Skilled worker who normally has completed an apprenticeship program; in some jurisdictions, certain tradespersons must be tested and licensed in their respective trades.

Unplanned maintenance: Maintenance done without planning; could be related to a breakdown, running repair or corrective work;

unplanned maintenance may be scheduled during the normal schedule cycle.

Up: Used in reference to an asset that is available and being used.

Uptime: The period of time during which an item is in a condition to perform its intended function, whether it is in use or not.

Utilization factor: Usage of an asset expressed as a percentage of schedule time.

Variance analysis: Interpretation of the causes for a difference between actual values and some norm, budget or estimate.

Visual control: The use of easy-to-read indicators to show equipment status and performance (e.g., red, yellow or green gauge markings; normal reading zone indicators; color-coded oil cans and filler caps).

Warranty: Coverage for repair costs incurred in the event of a defect caused by a supplier of equipment, materials, services.

Work in process (WIP): Partially completed production "product" at some interim stage in the production process; product that is still being worked on prior to being considered ready to deliver.

Work order (WO): A unique control document that comprehensively describes the job to be done; may include formal requisition for maintenance, authorization and charge codes, as well as a record of what work was actually done, time and materials used.

Work request (WR): A simple request for maintenance service or work requiring no planning or scheduling but usually a statement of the problem; usually precedes the issuance of a work order.

Workload: The number of labor hours needed to carry out a maintenance program, including all scheduled and unscheduled work and maintenance support of project work.

Appendix C: Rapid Preventive Maintenance (PM) Deployment Suggestions

The ideas presented in this appendix are offered as suggestions for situations where there is little or no proactive maintenance, and it is necessary to get a highly reactive work environment quickly under control and started on the path toward being more proactive. It is not intended as a replacement for the use of rigorous analysis methods like RCM, RCFA and PMO as discussed in Chapters 8 and 9. These ideas are also not intended to replace the sound judgment of your own engineers, experienced operators and maintainers. Note too that predictive and detective maintenance actions may reveal problems before they have manifested as complete loss of equipment function. To take full advantage of these, it is imperative that upon discovery of any incipient failure conditions, action should be taken to correct those situations in a timely manner.

PREDICTIVE MAINTENANCE

1. If it rotates at high speeds (i.e., greater than 1,800 rpm), use an overall velocity reading on vibrations. Anything reading over 0.35 inches per second (ips) is unacceptable; have it repaired.
2. For low-speed rotational equipment (i.e., crushers) go with displacement readings. Anything >1/2 bearing clearance is bad, repair as soon as possible.
3. For very high speed machinery (e.g., turbines, turbo-expanders, compressors, etc.) use accelerometers to provide readings of acceleration (vibration). Refer to the documentation provided by your vibration analysis equipment supplier for appropriate warning, alarm and shutdown reading levels.
4. For all vibration readings—take them weekly. They can generate "routes" to follow (taking readings at every accessible bearing

housing and right over the bearings; take one radial and one axial reading each). The routes can be listed on charts for use on clipboards or mobile recording devices and used as checklists.

5. Trend all readings graphically (you can use spreadsheets for this) and monitor any equipment that is trending upward daily. Avoid the tendency to act too quickly on trends or your maintainers may think they are doing work for no reason. Equipment with issue trends caught early may appear fine to the naked eye when dismantled in the shop, even though there may be microscopic scale defects.
    a. Take an initial reading at installation of anything that is repaired to see the baseline. If possible (and this is difficult to do, so do not dwell on it), take readings when equipment is under constant load and at the same load for all readings (i.e., make sure it is running at or near the same conditions each time), or readings will be highly variable. Do not take a single high reading as an indicator for removal—watch for trends to avoid any premature action based on false or erroneous high readings.
6. For equipment with open oil sumps (i.e., not those sealed with screwed plugs), take oil samples; analyze for particulates, water and contaminants; and act on recommendations from analysis. Sample monthly; act on results within 1 week unless analysis points to greater urgency. Create routes as above. Note: If oil change frequency from a manufacturer is only a month or two (or less), then omit from this sampling/analysis and rely solely on oil changes.
7. Convenient and reliable oil analysis techniques are ferrographic (visual inspection of particles under a microscope) and particle counts. Do not rely on spectrographic methods. Spectrographic methods work with very small contaminant particles—generally particles smaller than needed to cause real damage. Readings will rise while the damage is still minor. As damage worsens and particles get larger, the readings will fall. This gives a false sense of things getting better, just when it gets bad enough to worry about. Spectrographic methods cannot detect larger particles. Do not get too excited about what metals are in the oil samples—that information is useful only for diagnostics and generally is only worth doing if the machine is critical and unspared (i.e., no backup).
8. Carry out infrared (IR) inspections using IR cameras on all electrical switchgear quarterly. Look for hot spots. Ideally, this is done with cabinets open (*caution*: follow arc flash procedures) but can still give

results even with cabinets closed in situations where the problems are already significant.

9. IR may also be useful for any other areas where problems show up as heat—blocked pipes carrying normally hot fluids (downstream looks cooler); rotating equipment couplings (no need to remove guards to check this); bypassing steam traps; loose or misaligned belts; excessively loaded motors; motors with dirty cooling fins; gearboxes overheating; uneven exhaust temperatures on engines; blocked or partially blocked heat exchangers; damaged insulation on tanks, pipes, exchangers, roofing and outside walls; etc.
10. Visual inspections can be carried out as operator rounds twice in each shift—at the start (immediately before or after shift change) and halfway through the shift. Operators need to be taught what to look for (see below under "cleaning"). Any anomalies need to be logged and reported as work requests for action. Operators need to know that any condition they feel is "uncomfortable" to them is a potential problem that must be dealt with. It is better to be overly cautious and find a problem than to miss it and potentially suffer downtime or worse. Watch for leaks, spills, signs of excessive wear, increased vibration, increased noise level, unusual smells (burning, smoke), changes in lighting levels and tools or parts left lying about.
11. Carry out visual inspections by the maintenance foreman once per shift. As above, this can also be used to investigate any reports from operators of potential problems and to see that operators are indeed doing their cleaning.

PREVENTIVE MAINTENANCE

1. For mobile equipment—follow manufacturers' recommendations for oil/filter/component changes and overhauls. This may be overkill (in some cases), but doing it will rarely hurt. If you have experience that varies from the recommendations (e.g., longer frequencies), then go with the site experience.
2. For any plant equipment with closed-loop oil systems, change oil and filters at manufacturers' recommended frequency.
3. Conveyors—lubricate rollers and idlers; watch belts for signs of damage and tracking error and slippage (predictive).

4. Cleaning—see Chapter 4 on the subject of 5S. Clean equipment and work areas. Watch for signs of leakage while they are small. Keep contaminants out of equipment. Do not allow minor problems to become major by ignoring these early signs of trouble. Cleaning eliminates some safety hazards and helps foster a sense of pride in the work area.
   a. This applies to mobile equipment as well as shops and plants. Anyone doing cleaning must know how to do it without harming equipment (i.e., no water hoses aimed at bearing housings etc.), and they must know what to watch for. Cleaners should be trained (this does not take long) to look for obvious signs of equipment distress—leaks that soil cleaned areas soon after cleaning is done, higher vibrations or sounds than normal, cracks in grout or foundations of equipment or in floors near equipment, loose guards, etc.
5. Heat exchanger cleaning—experience generally reveals where heat exchangers have been problematic in the past. In those cases, schedule cleaning at a frequency less than that of the problems arising.
6. Roads (mines)—keep graded and clear of large rocks or other debris that can harm truck tires. Keep them watered to reduce dust in the air.
7. Shops—clean them up! Avoid sources of contamination such as dusty lay-down areas outside the shops. Make sure lay-down areas and driveways into shop areas are paved to avoid raising dust.

DETECTIVE MAINTENANCE

1. For all backup/standby equipment—testing once per month to prove that it is capable of starting.
   a. If the equipment is subject to wear-out-type failures (e.g., air compressor valves, reciprocating pumps), do not equalize running hours with the normally running equipment. Use monthly testing to prove operation and the autostart (fake the low-pressure condition etc.), run for a short time and then switch back to normally operating equipment. If equipment wears out with age or usage, then equalizing running hours is a recipe for multiple failures occurring at roughly the same time.
   b. If the equipment is subject to random types of failures (e.g., mechanical seals and bearings on centrifugal pumps), then the test is accomplished by starting the standby equipment and putting it into operation until the next test interval (i.e., swap the

equipment back and forth). Equal running hours are not a problem in this situation. Use duty and standby equipment equally.

2. Safety devices are tested to prove operation. This is a full "end-to-end" test if possible, not a simple push of a test button to watch lights go on—that only tests the bulbs. This applies to things like high/low level/pressure/temperature alarms and stops, process parameter–driven stops or alarms, fire alarms, etc. Frequency—monthly for most devices unless testing is impractical (i.e., testing increasing risk of failure or cannot be done without disrupting normal operations).
   a. For things like safety valves and fire alarm systems that may be covered by some sort of legislation/regulation, do them at the legislated frequency, usually regulations require these to be changed and tested offline.
3. Signage—check that all warning signs are where they should be, clearly visible (unobstructed) and in good condition (e.g., lit and clean) so that they can be read. Remember that these signs are for people who are *not* normally in the area, as well as constant reminders for operators and maintainers who already know the risks. If you have emergency escape route signs, make sure they are pointing the right way! While doing this, inspect escape routes to ensure they are unobstructed by debris, tools, scaffolding, parts, etc.
4. Safety equipment (fire extinguishers, first-aid kits, etc.)—these are probably inspected/tested in accordance with regulations; make sure this is happening.

OPERATIONAL BASIC CARE (MOBILE)

1. Carry out circle checks of equipment before using it. A "circle check" is a thorough check of various equipment conditions and parameters (e.g., oil levels, tire pressures, coolant levels, condition of windshield wipers, condition of tire treads, etc.). It is usually carried out by walking around the equipment in a predetermined sequence and recording the findings on some sort of checklist or log book with any defects being reported for action. The operators need a good checklist, and supervisors must make sure they do this thoroughly.
2. Drive equipment within its operating parameters—zero tolerance for equipment abuse. If someone breaks the rules—discipline him/her.

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