ENGINEERING MAINTENANCE

A Modern Approach

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B.S. Dhillon, Ph.D.

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Preface

Engineering maintenance is an important sector of the economy. Each year U.S. industry spends well over $300 billion on plant maintenance and operation, and in 1997 the U.S. Department of Defense's budget request alone included $79 billion for operation and maintenance. Furthermore, it is estimated that approximately 80% of the industry dollars is spent to correct chronic failures of machines, systems, and people. The elimination of many of these chronic failures through effective maintenance can reduce the cost between 40 and 60%.

This century will usher in a broader need for equipment management—a cradle-to-grave strategy to preserve equipment functions, avoid the consequences of failure, and ensure the productive capacity of equipment. This cannot be achieved by simply following the traditional approach to maintenance effectively—human error in maintenance, quality and safety in maintenance, software maintenance, reliability-centered maintenance, maintenance costing, reliability, and maintainability also must be considered.

Today, a large number of books are available on maintenance, but to the best of my knowledge, none covers all the areas listed above. Material on such topics is available either in technical articles or in specialized books, but not in a single volume. In order to perform the maintenance function effectively, knowledge of these topics is essential, but maintenance professionals find it difficult to obtain such information in a single maintenance text.

The main objective of this book is to cover all the above and other related current topics in a single volume in addition to the traditional topics of engineering maintenance. The book focuses on the structure of concepts rather than the minute details. The sources of most of the material are given in references, which will be useful to readers who desire to delve deeper into specific areas.

Chapter 1 presents various introductory aspects concerning engineering maintenance including engineering objectives, engineering maintenance in the 21st century, and maintenance-related facts and figures. Chapter 2 reviews the basic probability theory and other pertinent mathematical topics that will help the reader understand subsequent chapters of the book. Chapter 3 discusses various aspects related to maintenance management and control, including department functions and organizations, elements of effective management, management control indices, and project control methods.

Chapter 4 is devoted to preventive maintenance (PM) and covers topics such as preventive maintenance elements; steps for establishing a PM program; and PM measures, models, and advantages and disadvantages. Chapter 5 presents various aspects of corrective maintenance (CM) ranging from CM types and measures to CM mathematical models. Chapter 6 is devoted to the important subject of reliability centered maintenance (RCM) and covers topics such as RCM goals and principles, RCM process, RCM components, and RCM program effectiveness indicators.

Inventory control in maintenance is presented in Chapter 7. This chapter covers topics such as inventory types and purposes, inventory control models, safety stock, and estimation of spare part quantity. Chapter 8 and 9 are devoted to human error in maintenance and quality and safety in maintenance, respectively. Some of the topics covered in Chapter 8 are facts and figures on human error in maintenance, maintenance error in system life cycle, guidelines for reducing human error, and techniques for predicting the occurrence of human error. Chapter 9 includes topics such as the need for quality maintenance processes, maintenance work quality, quality control charts for use in maintenance, post maintenance testing, safety and maintenance tasks, guidelines for equipment designers to improve safety in maintenance, and maintenance personnel safety.

Chapter 10 presents various aspects concerning maintenance costing, including reasons for maintenance costing, factors influencing cost, labor and material cost estimation, cost estimation models, and cost data collection. Chapter 11 presents an important area of modern maintenance, i.e., software maintenance. Some of the topics relating to software maintenance are types of software maintenance, software maintenance problems, software maintenance tools and techniques, and software maintenance costing.

Chapters 12 and 13 are devoted to two areas closely related to maintenance, i.e., reliability and maintainability. Chapter 12 covers reliability measures, reliability networks, and reliability analysis methods. Chapter 13 includes maintainability management in system life cycle, maintainability design characteristics, maintainability measures and functions, and common errors related to maintainability design.

This book will be useful to senior level undergraduate and graduate students in mechanical and industrial engineering; maintenance and operations, engineers; college and university level teachers; students and instructors of short courses in engineering maintenance; and equipment designers, managers, manufacturers, and users.

The author is deeply indebted to many friends, colleagues, and students for their interest and encouragement throughout this project. I thank my children, Jasmine and Mark, for their patience and intermittent disturbances leading to desirable coffee and other breaks. And last, but not least, I thank my wife, Rosy, for typing various portions of this book, editorial input, proofreading, and tolerance.

B.S. Dhillon

Dedication

This book is affectionately dedicated to my wife, ***Rosy***

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Chapter 10: Maintenance Costing

Chapter 11: Software Maintenance

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1 Introduction

BACKGROUND

Since the Industrial Revolution, maintenance of engineering equipment in the field has been a challenge. Although impressive progress has been made in maintaining equipment in the field in an effective manner, maintenance of equipment is still a challenge due to factors such as size, cost, complexity, and competition. Needless to say, today's maintenance practices are market driven, in particular for the manufacturing and process industry, service suppliers, and so on.[1] An event may present an immediate environmental, performance, or safety implication. Thus, there is a definite need for effective asset management and maintenance practices that will positively influence critical success factors such as safety, product quality, speed of innovation, price, profitability, and reliable delivery.

Each year billions of dollars are spent on equipment maintenance around the world. Over the years, many new developments have taken place in this area. The terms "maintenance" and "maintenance engineering" may mean different things to different people. For example, the U.S. Department of Defense sees maintenance engineering as a discipline that assists in acquisition of resources needed for maintenance, and provides policies and plans for the use of resources in performing or accomplishing maintenance.[2] In contrast, maintenance activities are viewed as those that use resources in physically performing those actions and tasks attendant on the equipment maintenance function for test, servicing, repair, calibration, overhaul, modification, and so on.

Comprehensive lists of publications on maintenance and maintenance engineering are given in References 3 and 4.

MAINTENANCE AND MAINTENANCE ENGINEERING OBJECTIVES

Even though maintenance engineering and maintenance have the same end objective or goal (i.e., mission-ready equipment/item at minimum cost), the environments under which they operate differ significantly. More specifically, maintenance engineering is an analytical function as well as it is deliberate and methodical. In contrast, maintenance is a function that must be performed under normally adverse circumstances and stress, and its main objective is to rapidly restore the equipment to its operational readiness state using available resources. Nonetheless, the contributing objectives of maintenance engineering include: improve maintenance operations, reduce the amount and frequency of maintenance, reduce the effect of complexity, reduce the maintenance skills required, reduce the amount of supply support, establish optimum frequency

and extent of preventive maintenance to be carried out, improve and ensure maximum utilization of maintenance facilities, and improve the maintenance organization.[2]

This book directly or indirectly covers both maintenance and maintenance engineering and their objectives.

MAINTENANCE FACTS AND FIGURES

Some the important facts and figures directly or indirectly associated with engineering maintenance are as follows:

- Each year over $300 billion are spent on plant maintenance and operations by U.S. industry, and it is estimated that approximately 80% of this is spent to correct the chronic failure of machines, systems, and people.[5]
- In 1970, a British Ministry of Technology Working Party report estimated that maintenance cost the United Kingdom (UK) was approximately £3000 million annually.[6,7]
- Annually, the cost of maintaining a military jet aircraft is around $1.6 million; approximately 11% of the total operating cost for an aircraft is spent on maintenance activities.[8]
- The typical size of a plant maintenance group in a manufacturing organization varied from 5 to 10% of the total operating force: in 1969, 1 to 17 persons, and in 1981, 1 to 12 persons.[9]
- The U.S. Department of Defense is the steward of the world's largest dedicated infrastructure, with a physical plant valued at approximately $570 billion on approximately 42,000 square miles of land, i.e., roughly the size of the state of Virginia.[10]
- The operation and maintenance budget request of the U.S. Department of Defense for fiscal year 1997 was on the order of $79 billion.[11]
- Annually, the U.S. Department of Defense spends around $12 billion for depot maintenance of weapon systems and equipment: Navy (59%), Air Force (27%), Army (13%), and others (1%).[10]
- In 1968, it was estimated that better maintenance practices in the U.K. could have saved approximately £300 million annually of lost production due to equipment unavailability.[12]

ENGINEERING MAINTENANCE IN THE 21ST CENTURY

Due to various factors, it was established in the previous century that "maintenance" must be an integral part of the production strategy for the overall success of an organization. For the effectiveness of the maintenance activity, the 21st century must build on this.[13]

It is expected that equipment of this century will be more computerized and reliable, in addition to being vastly more complex. Further computerization of equipment will significantly increase the importance of software maintenance, approaching,

if not equal to, hardware maintenance. This century will also see more emphasis on maintenance with respect to such areas as the human factor, quality, safety, and cost effectiveness.

New thinking and new strategies will be required to realize potential benefits and turn them into profitability. All in all, profitable operations will be the ones that have employed modern thinking to evolve an equipment management strategy that takes effective advantage of new information, technology, and methods.

MAINTENANCE TERMS AND DEFINITIONS

This section presents some terms and definitions directly or indirectly used in engineering maintenance:[2,14–19]

- *Maintenance:* All actions appropriate for retaining an item/part/equipment in, or restoring it to, a given condition.
- *Maintenance engineering:* The activity of equipment/item maintenance that develops concepts, criteria, and technical requirements in conceptional and acquisition phases to be used and maintained in a current status during the operating phase to assure effective maintenance support of equipment.[14]
- *Preventive maintenance:* All actions carried out on a planned, periodic, and specific schedule to keep an item/equipment in stated working condition through the process of checking and reconditioning. These actions are precautionary steps undertaken to forestall or lower the probability of failures or an unacceptable level of degradation in later service, rather than correcting them after they occur.
- *Corrective maintenance:* The unscheduled maintenance or repair to return items/equipment to a defined state and carried out because maintenance persons or users perceived deficiencies or failures.
- *Predictive maintenance:* The use of modern measurement and signal-processing methods to accurately diagnose item/equipment condition during operation.
- *Maintenance concept:* A statement of the overall concept of the item/product specification or policy that controls the type of maintenance action to be employed for the item under consideration.
- *Maintenance plan:* A document that outlines the management and technical procedure to be employed to maintain an item; usually describes facilities, tools, schedules, and resources.
- *Reliability:* The probability that an item will perform its stated function satisfactorily for the desired period when used per the specified conditions.
- *Maintainability:* The probability that a failed item will be restored to adequately working condition.
- *Active repair time:* The component of downtime when repair persons are active to effect a repair.
- *Mean time to repair (MTTR):* A figure of merit depending on item maintainability equal to the mean item repair time. In the case of exponentially distributed times to repair, MTTR is the reciprocal of the repair rate.

- *Overhaul:* A comprehensive inspection and restoration of an item or a piece of equipment to an acceptable level at a durability time or usage limit.
- *Quality:* The degree to which an item, function, or process satisfies requirements of customer and user.
- *Maintenance person:* An individual who conducts preventive maintenance and responds to a user's service call to a repair facility, and performs corrective maintenance on an item. Also called custom engineer, service person, technician, field engineer, mechanic, repair person, etc.
- *Inspection:* The qualitative observation of an item's performance or condition.

MAINTENANCE PUBLICATIONS, ORGANIZATIONS, AND DATA INFORMATION SOURCES

This section presents selected publications, organizations, and data information sources directly or indirectly concerned with engineering maintenance.

Publications

Journals and Magazines

- *Journal of Quality in Maintenance Engineering,* MCB University Press, U.K.
- *Industrial Maintenance & Plant Operation,* Cahners Business Information, Inc., U.S.A.
- *Maintenance Technology,* Applied Technology Publications, Inc., U.S.A.
- *Maintenance Journal,* Engineer Information Transfer Pty. Ltd., Australia.
- *Reliability: The Magazine for Improved Plant Reliability,* Industrial Communications, Inc., U.S.A.
- *Maintenance and Asset Management Journal,* Conference Communications, Inc., U.K.

Books and Reports

- *Maintenance Engineering Handbook* edited by L.R. Higgins, McGraw-Hill Book Company, New York, 1988.
- *Engineering Maintenance Management* by B.W. Niebel, Marcel Dekker, Inc., New York, 1994.
- *Maintenance Fundamentals* by R.K. Mobley, Butterworth-Heinemann, Inc., Boston, 1999.
- *Maintenance Strategy* by A. Kelly, Butterworth-Heinemann, Inc., Oxford, U.K., 1997.
- *Reliability-Centered Maintenance* by J. Moubray, Industrial Press, Inc., New York, 1997.
- *Applied Reliability-Centered Maintenance* by J. August, Penn Well, Tulsa, Oklahoma, 1999.

- *Maintenance Planning and Control* by A. Kelly, Butterworth and Co. Ltd., London, 1984.
- *Quality, Warranty, and Preventive Maintenance* by I. Sahin and H. Polatoglu, Kluwer Academic Publishers, Boston, 1999.
- *Glossary of Reliability and Maintenance Terms* by T. McKenna and R. Oliverson, Gulf Publishing Company, Houston, Texas, 1997.
- *Maintenance Engineering Techniques, Report No. AMCP 706-132,* Department of the Army, Washington, D.C., 1975.
- *Guide to Reliability-Centered Maintenance, Report No. AMCP 705-2,* Department of the Army, Washington, D.C., 1985.
- *Queues, Inventories, and Maintenance* by P.M. Morse, John Wiley & Sons, New York, 1958.
- *Maintenance Engineering Handbook* by L.C. Morrow, McGraw-Hill Book Company, New York, 1966.
- *The Complete Handbook of Maintenance Management* by J.E. Heintzelman, Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1976.

Organizations

Professional

- Society for Maintenance and Reliability Professionals
  401 N. Michigan Ave., Chicago, Illinois, U.S.A.
- American Institute of Plant Engineers
  539 S. Lexington Pl., Anaheim, California, U.S.A.
- Society for Machinery Failure Prevention Technology
  4193 Sudley Road, Haymarket, Virginia, U.S.A.
- Maintenance Engineering Society of Australia (MESA)
  (A Technical Society of the Institution of Engineers, Australia)
  11 National Circuit, Barton, ACT, Australia
- Maintenance/Engineering Division, Canadian Institute of Mining, Metallurgy and Petroleum
  3400 de Maisonneuve Blvd West, Suite 1210, Montreal, Quebec, Canada
- The Institution of Plant Engineers
  77 Great Peter St., London, U.K.
- Japan Institute of Plant Maintenance
  Shuwa Shiba - Koen 3 - Chome Bldg.
  3-1-38, Shiba - Koen, Minato - Ku, Tokyo, Japan
- The Institute of Marine Engineers
  80 Coleman St., London, U.K.
- Society of Logistic Engineers
  8100 Professional Place, Suite 211, Hyattsville, Maryland, U.S.A.
- International Maintenance Institute
  P.O. Box 751896, Houston, Texas, U.S.A.
- Society of Automotive Engineers, Inc.
  400 Commonwealth Dr., Warrendale, Pennsylvania, U.S.A.

Consulting

- International Total Productive Maintenance (TPM) Institute, Inc.
  4018 Letort Lane, Allison Park, Pennsylvania, U.S.A.
- The Maintenance and Reliability Center
  506 East Stadium Hall, University of Tennessee, Knoxville,
  Tennessee, U.S.A.
- Maintenance and Housekeepers of Florida, Inc.
  750 S. Orange Blossom, Suite 106, Orlando, Florida, U.S.A.
- PM Maintenance Services
  RR5, Box 82-M, Georgetown, Delaware, U.S.A.
- Wolfson Maintenance
  Kilburn House Manchester Science Park, Pencroft Way,
  Manchester, U.K.
- Espinoza consulting
  P.O. Box 80935, Rochester, Michigan, U.S.A.
- Aladon Ltd.
  44 Regent Street, Lutterworth, Leicestershire, U.K.
- PM Safety Consultants Ltd.
  The Verdin Exchange, High Street, Winsford, Cheshire, U.K.
- Applied Reliability, Inc.
  11944 Justice Avenue, Suite E, Baton Rouge, Louisiana, U.S.A.
- BMT Reliability Consultants Ltd.
  12 Little Park Farm Road, Fareham, Hampshire, U.K.
- Bretech Engineering Ltd.
  70 Crown Street, P.O. Box 2331, Saint John, New Brunswick, Canada

Data Information Sources

- GIDEP Data
  Government Industry Data Exchange Program (GIDEP) Operations Center
  Fleet Missile Systems, Analysis, and Evaluation Department of the Navy,
  Corona, California, U.S.A.
- National Technical Information Service (NTIS)
  5285 Port Royal Road, Springfield, Virginia, U.S.A.
- Defense Technical Information Center
  DTIC - FDAC
  8725 John J. Kingman Road, Suite 0944, Fort Belvoir, Virginia, U.S.A.
- Data on equipment used in electric power generation
  Equipment Reliability Information System (ERIS)
  Canadian Electrical Association,
  Montreal, Quebec, Canada
- Data on trucks and vans
  Commanding General
  Attn: DRSTA - QRA, U.S. Army
  Automotive - Tank Command,
  Warren, Michigan, U.S.A.

- Reliability Analysis Center
  Rome Air Development Center,
  Griffith Air Force Base, Rome, New York, U.S.A.

PROBLEMS

1. Discuss the needs for maintenance.
2. Define the following terms:
   - Maintenance
   - Maintenance engineering
3. What are the objectives of maintenance engineering?
4. What is the approximate amount of money spent annually on plant maintenance and operations by U.S. industry?
5. Write an essay on engineering maintenance in the 21st century.
6. What is the difference between preventive and predictive maintenance?
7. What is the difference between maintenance and maintainability?
8. List at least five sources for obtaining maintenance-related information.

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