



Industrial **ROBOTICS**

How To Implement The Right System
For Your Plant

Andrew Glaser

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FOREWORD

Bill Canis
Vice President

The Manufacturing Institute, an Affiliate of The National
Association of Manufacturers (NAM)
www.nam.org/institute

It's often said that today's manufacturing = technology. That shouldn't be a surprise because the largest share of technology is invented by manufacturers for use in manufacturing. Over 70 percent of all U.S. business research and development is conducted by manufacturers and the resulting application of technology is the reason for the huge leaps in industrial productivity over the past twenty years.

Industrial Robotics is an excellent addition to our understanding of how investments in technology boost a company's competitiveness if the proper analysis is done beforehand. Andrew Glaser has a strong understanding of robotics and he brings a spotlight to this part of today's manufacturing in a way that is valuable for business owners, plant managers, and anyone who has an interest in a stronger U.S. manufacturing sector.

In this book you'll learn about the warning signs that, when flashing, often point to the need to evaluate an investment in robotics: lack of skilled workers, quality problems, and rising costs. Mr. Glaser knows from his firsthand business experience that managers may still shy away from robotics because of certain risk factors that they may incorrectly weigh. Unfortunately for those companies, the result is that no new technology investment is made when it might make a significant difference in the company's performance. To that

end, the Risk Gauge in this book is a tremendous asset to any manufacturing executive.

Mr. Glaser identifies twin competitiveness issues that are — or should be — on the minds of every manufacturer, whether their business is large or small:

- Mastering lean manufacturing, and
- Identifying and attracting skilled workers

Adopting lean manufacturing on the factory floor has a wide range of benefits, from eliminating waste to improving processes. The discipline of instituting continuous improvement helps manufacturers meet customers' rising expectations of more value-added services, more innovation, and lower costs. Many executives who have seen the benefits of lean in manufacturing are pushing the same concepts into their front offices, product development groups, and their own value chains.

Robotic technology can be a part of lean. Andrew Glaser points out that robots are intelligent and agile manufacturing tools that are very adaptable as conditions and needs change. Yet robotics go beyond just lean. Whereas lean establishes a methodology for production, he says that agile manufacturing — achieved through robotics — “enables the firm to become the lowest-cost producer, period, against any labor rate in the world.” That’s a perspective that any manufacturer will want to investigate further in this highly-competitive global marketplace.

The other twin issue is attracting a skilled workforce. Fully half of all manufacturing employees are Baby Boomers who will retire in the next decade. Where will those seven million new replacement employees come from? Already we know from surveys by the National Association of Manufacturers (NAM) and The Manufacturing Institute, that 80 percent of manufacturers are facing a moderate to severe shortage of skilled workers now. This acute shortage will only accelerate in the years ahead.

Robotics is part of the solution for this shortage — using the machines to replace hard-to-find employees — and it also demands

a more skilled workforce. Personnel factors to weigh in adding robotics include an open-eyed evaluation of whether all these factors are in place: shop floor technicians who can support robotics, employees who will embrace the new system, a team that has had some robotics experience specifically or generally, and a workforce ready to get the training to enable the investment to succeed.

The message in this book is very timely because manufacturers are facing these choices now. I recently visited a tool manufacturing facility in Omaha, Nebraska that has such good business that it is expanding its relatively new facility. But because it can't identify skilled workers to do business as usual, it has purchased a sophisticated robotics machine. Employees load the tools into it during the day, and during the night the robot produces a wide variety of high-quality products to customer specifications. It's "lights out" manufacturing with no one in the plant at night while the robot is doing its work.

We need to make sure our schools and community colleges are turning out the kind of skilled workers manufacturers need right now, and even more in the decades ahead. There are many steps executives can take to secure that kind of workforce and one of the missions of The Manufacturing Institute is to help develop those strategic solutions. Even with success in developing that workforce, this insightful book makes it clear that robotics are a key ingredient in our manufacturing future as well.

FORWARD

John Burg

President, Ellison Technologies Automation

Recipient of 2002 Engelberger Award (Robotics Applications)

www.ellisontechnologies.com

1. Companies that manufacture products in the United States are being challenged to be competitive with products that are manufactured by companies located anywhere in the world.
2. Transportation and communication networks are allowing distance from the source of a product to the user of the product to be a non-factor in sourcing decisions.
3. Consumers are not interested in where the products they use are manufactured.

If you have interest in this book it is probably a safe assumption that you are some how involved in manufacturing and in many cases probably work in a facility in North America.

Under that premise do you ask yourself, how you are going to save your factory in the competitive environment that is characterized by the three statements above?

The information Andy presents in this text is very focused on the Why and the How of robotic automation. The book provides details about the things that need to be considered to implement robotic automation in a manufacturing facility. If you follow the process that Andy describes to evaluate a possible robot installation in many cases you may find a lot of reasons to not implement a robot into your current processes.

I would hope most of you had to read this last sentence at least twice, asking, what did he say? Did he say we will decide not to implement robotic automation in our current process in most cases? Yes, that is exactly what I said. In most cases there are a lot of reasons that robotic automation will not work in your current process.

The important words are “current process” and even more critical in most cases, current culture. Is your culture ready to start the transition from employees who perform work to employees who manage and maintain systems that perform work? Can you imagine any operation, part or product line in your facility that can be manufactured without thinking about that process?

In his book “The Game Changer” by A.G. Lafley, the chairman of P&G states that “A culture is what people do day in and day out without being told.” That is why robotic automation in many facilities is difficult to implement because we do not develop detailed processes that are done without thinking about them.

Many of you are wondering why Andy asked me to write this foreword when I’ve just told you that most of your companies are not ready for robotic automation. The reason Andy asked me is because every day Andy and I meet people who want to “Save your factory” and if you don’t start down this path you will not be able to do that, if the factory is operating in North America. Remember the premises listed above:

1. Companies that manufacture products in the United States are being challenged to be competitive with products that are manufactured by competitors located anywhere in the world.
2. Transportation and communication networks are allowing distance from the source of a product to the user of the product to be a non-factor in sourcing decisions.
3. Consumers are not interested in where the products they use are manufactured.

So what are you going to do? I suggest that you do read this book, it contains a lot of valuable information. There are also thousands of robots being installed every year that are very successful instal-

lations; yours can be as well.

I also want to encourage you to prepare for the culture shift of moving from doers of work to managers of work. Focus a substantial portion of your energy on the preparation of your co-workers to understand how technically advanced equipment will change their lives for the better. Include them in the process of implementation, and train them to exploit the advantages. It's time consuming, it can be tedious, and there will always be those who will say it will never work. Follow the steps outlined in Andy's book, embrace the principles of lean manufacturing, educate all those affected, and you'll "Save your factory". What could you do that is more important than that?

P R E F A C E

I have been involved as a team member with hundreds of robotic systems over the course of my experience selling, and at times, implementing robotic systems. I have learned that, regardless of the application type or the industry segment, the same rules apply in achieving the system expectations that were planned for during the planning stage and benchmarked well after the system has been released to production. I am simply an engineer who takes enormous pride in seeing a concept evolve into a working system that achieved the results we all expected. I want to share my experience as well as the experiences of other industry professionals, to challenge you in making the right decisions about your project. The underlying message in this text is increasing productivity and lowering costs. There are so many different and unique success stories in how robotic automation impacts productivity that it's what continually drives the sales growth and buzz.

The idea for this book simply came as a result of wanting to share the “devil’s” in the details,” insider information when it comes to what integrators do on a daily basis like qualifying, validating, and engineering systems. Topics like design for small batch runs, high mix or large batch runs, and low mix, are topics that are not often covered in articles or seminars but they will be in this text. Additionally, managing items like buffers, redundancy, error recovery, diminishing returns versus flexibility, judging a project as a good or bad project, and designing for zero change-over are just a few examples of real issues that engineers want to gain insight about. This book covers these topics and more because this book is written by an author who everyday is charged with the task of providing robotic solutions that will work. Did I make mistakes along the way? Absolutely, and I still do, which is why this text will also share those experiences so that you can benefit from them, also.

Preface

The line-up of end users and industry experts that participated in the creation and influence for this text is second to none. They are available as always to host plant visits, but they are truly the innovation leaders when it comes to applying robotics. My most successful customers over the years were those that started with a simple first system and then several years later applied robotics to every project they quoted. Many of the users now have anywhere from 10 to hundreds of robots, all capable of providing improved productivity 8760 hours per year, the total available hours, to benchmark productivity. This text will describe in the words of each president or manager, their motivation, results, pains, and lessons learned in applying robotics to their manufacturing strategy. The experts that are noted in the acknowledgment section are also important resources for anyone reading this text. These people are the folks you and your colleagues travel to see at the local AWS, SME, AFS, or AMT chapter meeting, or whose articles will prompt you to pick up that industrial magazine and read an article about another robotics story. As a technician, engineer, manager, or president, you want to learn something new or gain some insight into the risk/reward of applying robotic automation. This text will not let you down in terms of providing that level of expertise and reference.

In 2004, a non-commercial, non-partisan movement began in the USA called the Save Your Factory initiative. The task of the initiative is to create awareness about the internal and external challenges that especially affect the largest sector of the US manufacturing base in small and medium-sized companies. The Save Your Factory (SYF) website, and message were designed to educate small and medium-sized manufacturers about the advantages of keeping manufacturing in the US. Investing in manufacturing technology and innovation can achieve a sustainable competitive manufacturing advantage. SYF also offered alternatives in dealing with the lack of US skilled labor, and driving productivity into every aspect of manufacturing. There are organizations such as the Robotics Industries Association (RIA), the National Association of Manufacturers (NAM) and National Council for Advanced Manufacturing (NAFCAM) that provide educational insight into how critical the manu-

Preface

factoring base is to the US economy, as well as providing tools for manufacturers to learn about managing internal and external challenges. Through the exercise of writing this text I have come to understand even more the importance of the education of best practices in manufacturing through various organizations associated with manufacturing. It is worthwhile to become familiar with these organizations. I support what the NAM organization is doing for the US manufacturing base and that is why I asked Bill Canis the Vice President of the Manufacturing Institute, an affiliate of NAM to write a foreword for this text.

The other gentleman contributing to the text is John Burg, the recipient of the Engelberger Robotics Award in 2002 for Robotics Applications. John is a pioneer in the integration of industrial robotics, starting prior to 1983. There is no one better in the business than John Burg and if you get a chance to meet John you will agree.

I have dedicated the first chapter to the theme of emphasizing that robotics among many other innovations can enable US manufacturers to provide competitive, reliable, and high-quality products here in the US. The reality is that, as an employee involved in manufacturing, representing the generation before baby boomers, our responsibility is to carry the message that we must be engaged in driving innovation and productivity.

Imagine we're in your conference room and we're meeting for the first time to develop a concept on the white board about how we're going to automate the machining, washing, and gauging process for five styles of ductile-iron castings for which you recently heard your organization won a contract. In hindsight, integrating automation as part of your value proposition helped not only to convince your customer that your organization could achieve the delivery schedule of machined castings, but also reduced the cost per piece. You think you have a budget, and process in place but then everything about this project changes on a daily basis including product design. The extent of your organization's innovation over the course of the last seven years was to buy a standard welding robotic system to weld sub-assembly components in the fabrication department, you applied some lean initiatives in the paint

Preface

process, and you have two gantry loaders along with some older lathes. Not a whole lot to point to in helping you organize the plan for the new machining cell. With so much to manage in this project, and other responsibilities, as well as little experience to leverage from, you need help with a plan for automation. The automation after all is the engine that keeps the system running. Hence my motivation for writing this text which is to share with the reader a practical guide in organizing the project, as well as setting the right expectations.

The underlying message of this text is why manufacturers automate – they can't find enough skilled employees. This text isn't about eliminating an employee, which is nothing but a myth, but rather being more productive with the employees and capital equipment you already have. You, the reader have been given a task to increase productivity, increase quality, and lower the costs in your manufacturing processes. I want you to be armed with practical insight and a plan. Thank you for reading the book.

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1

Why Automate the Small and Medium-Sized Manufacturers (SMMs)?

The National Association of Manufacturers (NAM), a lobbying organization (<http://www.nam.org>) working on behalf of the US manufacturing community, has published the following data about small and medium sized manufacturers:

- Small manufacturers are companies with less than 500 employees
- Medium-sized manufacturers are companies with 500 up to 2000 employees
- There are hundreds of thousands of small and medium-size manufacturers in the US
- SMM's make up about half the manufacturing work force in the US
- About 95 percent of all manufacturers are small and medium-size manufacturers
- The rate of productivity growth within the SMM sector is much higher than in the rest of the US economy
- Wages for workers in the SMM sector average 20-25% higher versus non-manufacturing jobs
- Seventy (70%) of the business R&D that drives innovation and new products comes from the SMM sector

Thanks to the SMM, the manufacturing sector is the backbone of what America represents in terms of a leader in R&D, innovation, new products, technology, and people. Manufacturing certainly includes the large automotive companies and others, but for the purpose of this text many of the examples are specific to the SMM.

Chapter 1

Manufacturing has a negative stigma at times because of union battles, layoffs, and the fatalistic media portrayal about offshore manufacturing pummeling the US manufacturing sector. The media thought the transition from 1999 to 2000 was going to stop all computers. We know how that turned out. The US has lost jobs to offshoring but the impact is minimal, and thanks to the resilience of SMM managers, owners, engineers, and operators in finding ways to increase productivity, the Bureau of Labor Statistics (BLS, <http://www.bls.gov>) indicates that productivity is higher than ever. Experts state that productivity, not off-shoring, has the greatest effect on job losses, or rather the lack of job growth, in manufacturing. In fact, China and other countries have lost significantly more jobs than the US because of productivity.

The age of industrial robotics, modeling software and simulation, combined with computer-driven manufacturing software, have provided productivity tools for the manufacturing engineer that never existed before. Productivity performance programs such as Six Sigma, Lean, and Kan-Ban, are yielding immediate results when implemented. The days of the shop floor operator performing redundant tasks such as loading a machine, lifting a box, operating a press, or welding a sub-assembly are diminishing because of innovation. One aspect of innovation as reviewed in this text, focuses on utilizing industrial robotics for the purpose of achieving unmanned “lights-out” production. Manufacturing is a great place to be if you’re interested in applying robotic technology for real world applications.

The importance of small and medium sized companies is also critical to the US government, as can be imagined, for the tax base alone. The US government agency Manufacturing Extension Partnership (MEP, <http://www.mep.nist.gov>), is a wonderful organization that has been working for years to support SMM all over the nation. MEP is a nationwide network of resources, transforming manufacturers to compete globally, supporting greater supply chain integration, and providing access to technology for improved productivity. MEP implemented a study about barriers to productivity improvement for small manufacturers. The study was completed in

Why Automate Small and Medium-sized Manufacturers?

February 2004, and its conclusions were as follows:

- The regulatory environment creates a competitive disadvantage for the small manufacturer
- Small manufacturers are often unfamiliar with changing technology and business practices
- Small manufacturers are generally isolated, and have few opportunities for interaction with other companies in similar situations
- It is difficult for owners and managers of small companies to find high quality, unbiased, advice and assistance
- Operating capital and investment funds for modernization are difficult to obtain for small and medium-sized companies
- Other challenges facing the small and medium-sized manufacturing sector are lack of skilled labor and low-cost labor, global competition, and lack of productivity improvement plans.

Not all is gloom and doom, however. According to the Bureau of Labor Statistics, US manufacturing has shown the highest rate of productivity performance over the 1990's and 2000 period, as compared with previous periods. Among factors that contributed to the increased productivity growth rate over the last decade has been the adoption of lean manufacturing strategies, as well as other programs (i.e. Six Sigma, Kanban, and 5S). Figure 1-1 shows a list of various lean principles.

Productivity Can Save the Factory

A trend that continues to contribute to manufacturing productivity gains is the growth in implementation of robotic systems. The Robotic Industries Association

(RIA, <http://www.robotics.org>) tracks the installed base of North American robot sales, and reports that in 1994-1996, sales of robots averaged 8,000 units per year. In 2004-2006, sales of robotic units exceeded 12,000 units per year with 18,000 sold in 2005.

Manufacturing advances will continue to go to the companies

Chapter 1

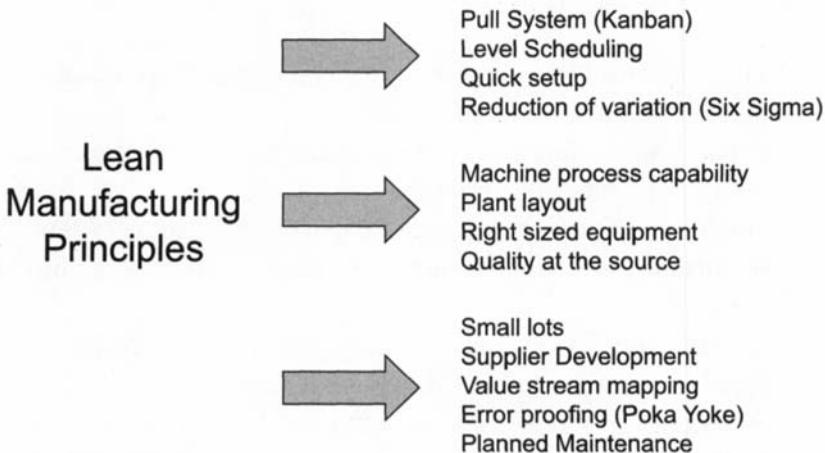


Figure 1-1 Lean Manufacturing Principles

that embrace automation and productivity performance initiatives. There are numerous case studies that demonstrate how US companies beat Chinese firms, and the US is in the best position to win the war against offshore low-wage producers. The primary issue facing US manufacturers, that unfortunately is more difficult to control, is the lack of skilled labor. Companies like Caterpillar Inc., and John Deere will experience a significant amount of retirements among shop floor personnel. The retirement of the baby boomer generation, undeniably will create a supply and demand gap for manufacturing jobs. Today the challenge is finding “skilled” operators (meaning trained, and reliable workers), and almost every industry struggles with this task. FANUC Robotics, along with a community of robotic integrators and users, started an initiative appropriately named Save Your Factory. The initiative creates awareness about how small and medium-size manufacturers can utilize technology, robotics, productivity, and quality programs, to overcome challenges facing US manufacturers. Within the Save Your Factory (<http://www.saveyourfactory.com>) presentation there are examples of the farming and steel industries using technology to increase productivity while reducing the labor force. Figure 1-2 illustrates the impact of technology on the farming and steel industries.

Why Automate Small and Medium-sized Manufacturers?

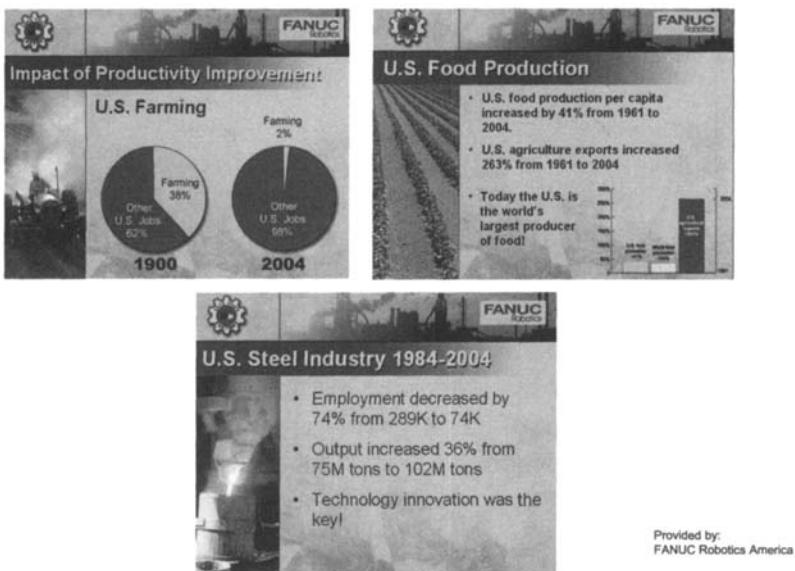


Figure 1-2- Save Your Factory Excerpt on Technology Impact to Farming and Steel

Some experts believe that productivity and efficiency gains are the reason for manufacturing job losses, and not off-shoring. Additionally, there are predictions that the manufacturing shop floor will be different in the near future than it is today and has been in years past. The trend will shift the manual tasks on the shop floor to non human operators in the forms of automation including industrial robotics. This trend has and will continue to grow through all industrial nations because of the economies gained by innovation. The manufacturing shop floor stereotype will be a memory. The shop floor operator will be a technically skilled worker who will manage a series of automated cells, perform various levels of inspection, and maintain the flow of material through the area.

All firms would love to grow their business without having to proportionally grow their workforce. Firms that have grown their business while decreasing the labor cost in making the end product have enjoyed significantly higher profitability than those firms that have not. As a point of interest, using robotics does not result in lay-

Chapter 1

offs. Simply put, the role of the shop floor operator will change, and firms that are savvy at automation will exhibit greater throughput with the same amount of resources. For example, a US firm manufacturing machine tools in the US wants to become a \$2 billion dollar-organization while still maintaining about a 1200-employee headcount. Today the firm's revenue is about \$1 billion with 1200 employees. This firm is implementing two robotic systems per month, and when their goal is reached it is easy to imagine how much labor content will be reduced in the overall cost of producing a machine? No firm in the world will be able to touch them in terms of cost to produce a similar style machine.

Like the examples of farming and the steel industry, robotic innovation and other technologies will enable manufacturers to grow their businesses while reducing the robot-to-employee ratio. For example, the ratio of robot-to-employee for a typical US company is 1 to 240. Some of the premier manufacturers in the US, that serve as real examples for this text, have been able to achieve 1 to 6 ratios. It is no surprise that these companies are extremely profitable. The Save Your Factory website sponsored by FANUC Robotics America goes into detail about the hidden costs of doing business off-shore. In addition, there are examples of how US firms have achieved lower costs to produce the same product here in the US, versus low-wage countries, by automating.

There are countless examples of manufacturers keeping work in the US because the labor factor was eliminated altogether when the process was automated. Chasing low-cost labor is an exercise in futility, so why not take the labor component out of the equation? The reality is that the hidden costs of doing business overseas or somewhere other than your own backyard can be a problem. By leveling the playing field with robotics, the SMM and certainly the large manufacturing firms, can stay globally competitive.

Industrial Robots Reduce Labor Costs and Increase Productivity

The value of a firm equals total assets minus total liabilities. The first and most important goal of every firm is to make profit, unless

Why Automate Small and Medium-sized Manufacturers?

the firm is a not-for-profit organization. The efforts injected into successful robotic systems are micro examples of how manufacturers working alone or together can drive production costs lower than a competitive organization or supply chain that is not engaged in driving to a lower-cost philosophy. Manufacturing, like sales and marketing, is a strategic tool, and one that will provide a sustainable competitive advantage when implemented correctly.

The focus of this text is primarily the implementation of industrial robotics for the non-farm manufacturing sector that consists of manufactured durable and non-durable goods. Durable goods include primary metals, fabricated metal products, industrial machinery and equipment, transportation equipment, and glass and stone products. Durable goods are defined as products that do not quickly wear out and have a life of at least three years. Non-durable goods have a life span of less than three years and include cosmetics, food, textiles, clothing, and paper products.

The robot work-cell won't necessarily affect the cost of raw material such as steel coils or castings that are purchased. Nor does the robot affect the cost of the packaging, insurance, or shipping freight. Robots exploit two primary targets, reducing labor costs, and increasing productivity. A secondary group of benefits from implementing robotics includes reductions in process changeover and lead time, maintained capacity, costs of operator safety, and consistent quality. The first group of categories result in what the world measures as a gage of manufacturing success and that is productivity. The US Department of Labor's Bureau of Labor Statistics (BLS, <http://www.bls.gov>) defines productivity as a measure of economic efficiency that shows how effectively economic inputs are converted into outputs. Simply put, productivity is the ratio of output to hours worked. The BLS measures productivity using a North American Industry Classification System (NAICS), six-digit code to classify industries. Productivity, described in output per hour, is the benchmark for how the media reports productivity statistics. Figure 1-3 illustrates the relationship between productivity and labor costs from 1970 – 2004.

Chapter 1

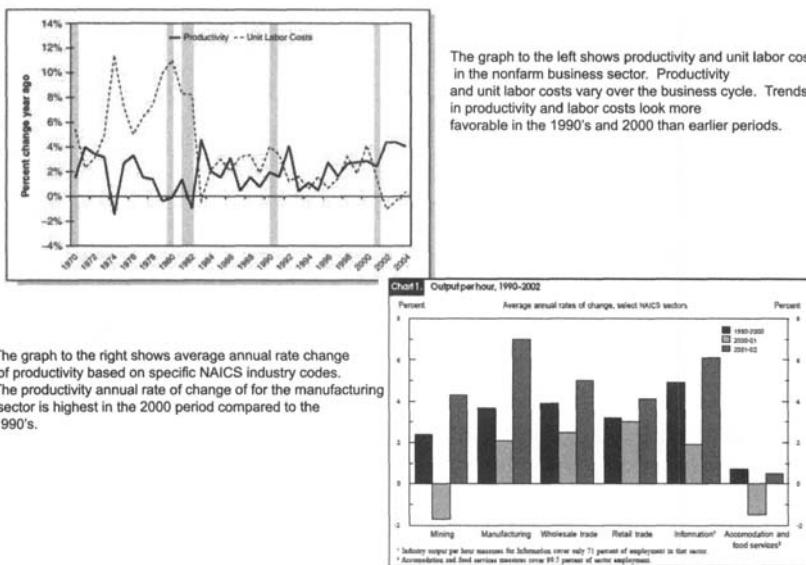


Figure 1-3. Trends in Manufacturing Productivity Changes

A manufacturer's goal to drive costs lower can be achieved by producing the same amount of output with less input. For example, before deciding to purchase another lathe for additional machining capacity, it is wise to make sure that productivity is optimized with the current lathe(s) because the operation is probably not as efficient as it could be if lathes are left to manual operation. Direct labor is a major contributor to the input side of costs and one that is easily exploited by robotics. Robotic automation dramatically increases productivity in performing a specific task because of the rise in the efficiency of asset usage (i.e. the machine tool) resulting from the availability of the robot to perform the task 24/7 without breaks, lunch, vacation, and other causes for downtime that always happen. Robotics will provide a double-dip effect on productivity by reducing labor and increasing throughput with the existing assets.

According to the BLS, the non-farm business sector labor cost in the US represents more than 60 percent of the value of output produced. Assuming that this statistic is accurate, the remaining 40 percent of the cost to the firm lies in material cost, and manufactur-

Why Automate Small and Medium-sized Manufacturers?

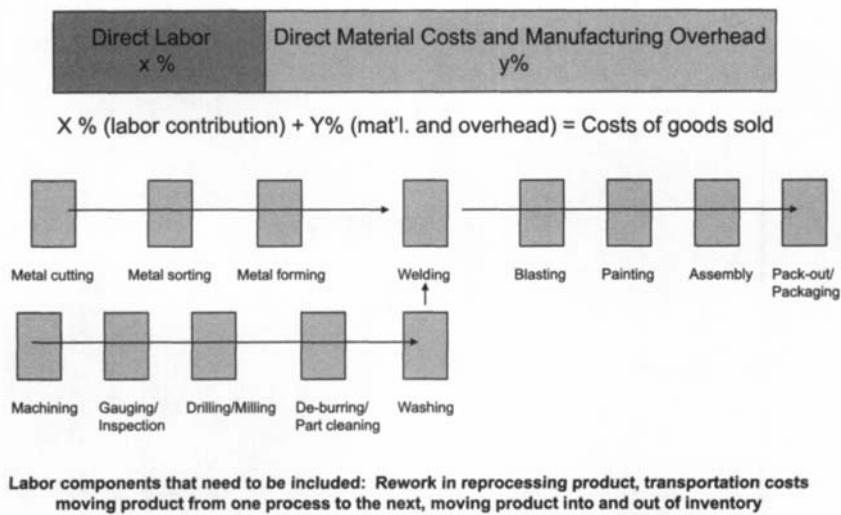


Figure 1-4 Describing where manual labor is attached to the firm's ability to produce an output

ing overhead. All three components; direct labor, direct material, and manufacturing overhead, contribute to costs of goods sold and cost of inventory. Figure 1-4 describes a typical manufacturing “value” chain consisting of various process steps, each with its own direct cost labor and material components. The direct labor component will vary for each step in the chain. The BLS statistic merely states that the aggregate direct labor measured as a function of productivity is greater than 60 percent. In the author’s opinion, based on talking to firms, the percentage of direct labor is toward 30 percent on average, with firms that have implemented lean principles, and with robotic automation it is lower than 15 percent and often less than 10 percent. For some applications that are rather process intensive with manual labor, such as grinding castings in a foundry, or arc welding, according to manufacturers their labor costs approach the 60 percent and higher figure as a percentage of costs of goods sold.

Figure 1-5 shows a more detailed cost breakout for the welding process step from the chain of manufacturing events shown in

Chapter 1

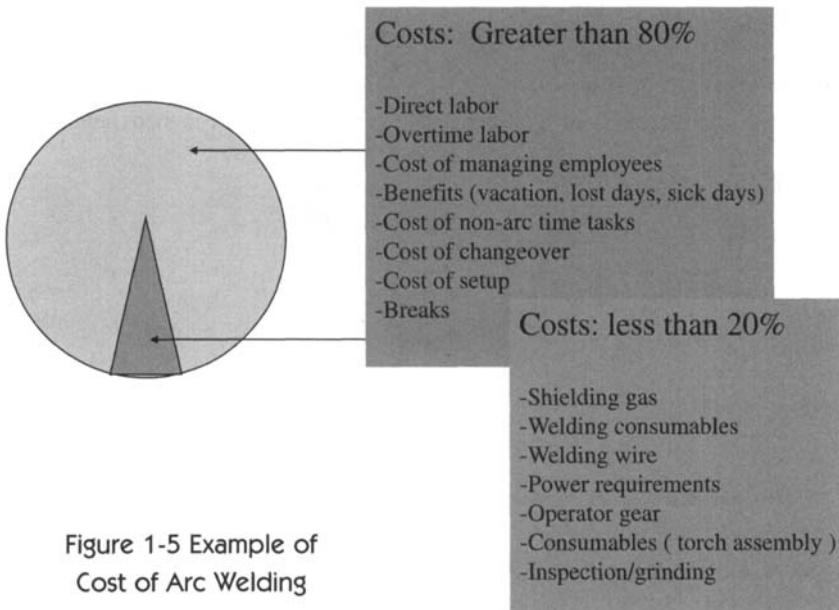


Figure 1-5 Example of Cost of Arc Welding

Figure 1-4. The welding cost example has been validated through studies, which indicate that the welding process typically involves greater than 80 percent labor-related cost versus 20 percent material cost to produce a finished product in the welding area. Most labor-intensive projects that include manipulating a tool such as a welding torch, grinding wheel, or cutting knife, by taking the tool to the work-piece or the work-piece to the tool, have a higher direct-labor component than picking and placing work-pieces from one location to another. Arc welding would certainly rate higher than most processes in terms of the labor cost percentage as a function of the manufacturing process.

Manufacturing processes that exhibit higher labor content such as welding, paint, or material removal, should be prioritized as areas to exploit with robotics and to be made lean, when an entire manufacturing facility is being audited. Not only can significant productivity gains be achieved, but these three applications rely on a higher level of labor skills to achieve consistent quality. Other applications, including machine tending, assembly, and palletizing, are cer-

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tainly as important to automate as welding, painting, or material removal. Again, increased productivity is a core benefit to the user, but the ergonomic benefits for these types of redundant, task-focused applications are just as important.

Partnering with your customer and supplier to reduce costs

According to the BLS, output per hour is the statistic most cited in the media about the state of manufacturing. Assuming robotic systems do not exploit cost reductions for the direct material cost portion, or manufacturing overhead, everything would be great if the cost stopped there and producing the commodity was then complete. In terms of global competition, it could be assumed that the material costs are somewhat consistent for a manufacturer anywhere on the globe. Maybe not in some places, but let's assume this is more or less true. What is interesting to pursue is the concept of Network-Centric Manufacturing in terms of the example of the community of suppliers and OEMs partnering to drive costs lower, and increase performance for the marketplace. The manufacturing value stream example in Figure 1-4 also makes the point that, assuming material costs to be relatively even in a global sense, then the competitive war begins as soon as the manufacturing process starts, meaning that someone or something adds value along the manufacturing value stream that is producing the commodity. Each operation in the manufacturing process creates cost. Each process step of the manufacturing value stream for the individual manufacturer allows the lowest labor cost producers, wherever they are, to take advantage of every competitor that is not engaged in driving the value stream to its lowest common cost denominator. As an example, take the production of a tic tac toe game with machined aluminum X and O pieces, and an aluminum fabricated base for the tic tac toe board.

If two producers, in China and the US, both have the same raw material cost for the aluminum bar stock for the game pieces, and aluminum plate for the game board, then the competitive advantage in terms of the low-cost producer will go to the company that drives

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to the lower cost at each step of the manufacturing chain to machine game pieces, as well as cut, form, clean, and assemble the game board and final assembly. The US simply cannot compete from a wage standpoint with countries like China. Even with the freight of shipping the tic tac toe game back the United States, the cost to build the game will be far higher in the US, due to the wage gap. The manufacturing engineer's task is to level the playing field by driving the manufacturing costs at each step as low as possible, using industrial robotics, lean principles, and other productivity tools to take cost out of the process. The Network Centric concept takes the value stream to a big-picture level, where suppliers of aluminum work with the OEM of the game to jointly develop ways of enhancing the product in terms of functionality, options, delivery, or some other competitive advantage for the end-user.

Thinking in the big picture, the engineer needs to apply the principle of driving cost lower at each step, for each manufacturer in the supply chain feeding the OEM materials that are provided to the end-user. The community of tier 1, 2, and 3 suppliers in the supply chain, all add value and costs. A strategy that outwardly focuses on reducing costs at each supplier and OEM, creates a large compounding effect on the overall value to the end-user. Imagine the competitive advantage that the supply chain companies can achieve through collaboration, as each organization in the chain understands its individual role, to provide value through productivity, delivery, or other attribute. Organizations such as the National Council for Advanced Manufacturing (NAFCAM, <http://www.nacfam.org/>), and MEP are actively sharing these concepts with industry, and manufacturers need to know about these organizations to be able to make broader decisions concerning business practices.

Chasing lowest-cost labor is an endless exercise because there is always a region in the world that will have lower-cost labor. Exploiting the fact that greater than 30 percent of manufacturing costs are associated with direct labor, and for some applications the labor costs can exceed 60 percent, allows the manufacturing engineer to have considerable control over cost reduction and continuous improvement. Industrial robotics is one tool that allows the firm

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to achieve the elusive cost-competitive advantage by leveling the playing field for cost per work-piece as compared with producers using low-cost labor. Manufacturing will go to the organizations that embrace automation and are engaged in lowering costs and improving quality.

Justifying Robotic Automation

There are many drivers that are considered to be important when justifying a robotic project. All end-users establish their own unique criteria for judging whether a robotic project is good or bad. In terms of justification, the most popular explanation for automating an existing or new process is because of the lack of skilled labor. Interestingly, the lack of skilled labor has been the most popular explanation for at least fifteen years, and the response is the same regardless of the geographic region. For example, Mexico has a skilled-labor shortage. The lack of skilled labor is a topic of extreme importance and influence on US national policies affecting manufacturers. Even China has a lack of skilled labor, emphasizing the term skilled as meaning someone who has been trained. Training of operators for running industrial robotic work-cells, or running any type of machinery in a production environment, is absolutely critical.

Another driver that is certainly on the minds of owners as well as managers is the economic justification. In evaluating a robotic project the estimation of payback needs to be considered almost immediately. There are many ways to examine this payback. Using the complex or the simple return on investment (ROI) calculator will bring similar conclusions. The 80/20 rule applies to the economical evaluation of a project, meaning that 20 percent of the criteria being judged contribute to 80 percent of the value. There are certainly reasons in some instances to continue to examine the remaining areas for savings. However, for a quick barometer or gage of payback, the exercise is not necessary. The total cost involved with a manufacturing task or process is called the total ownership cost (TOC). The characteristics that contribute to the 80 percent of the TOC or the important “tangible” economic drivers for justification of a robotic project are as follows:

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Direct labor, expressed in terms of labor hours for each shift of production including overtime, is typically accumulated on an annual basis. A single production shift consists of 2050 available annual hours, assuming two weeks of vacation. There are 8760 total available hours annually, when twenty four hours per day, 365 days per year is considered.

Asset utilization expressed in terms of machine percentage efficiency. The asset utilization affects productivity and available capacity. The lower the efficiency of an asset, assuming the asset is available to be used, the lower the productivity.

Process on-time, described, for example, as “arc-on-time” for welding, is important for process-intensive tasks such as welding, de-burring, grinding, or where an operator is adding value to the work-piece. This category is another measure of productivity.

The three categories listed should be considered in the payback evaluation. Other considerations to be included in the ROI analysis at some point, are the effects of the robotic work-cell on the immediate up- and down-stream operations. This principle is important because automating one step in the value stream, when the other steps have problems, makes little sense. Problems with the manufacturing flow should be fixed before automating. This aspect illustrates another reason why robotics is complementary to the principles of lean manufacturing. Robotic systems sometimes fail to meet expectations because operations prior to, or after the robot work-cell were not properly configured for automation in the manufacturing sequence. Some examples of how robotics can drive the cost of a work-piece lower, in addition to the aforementioned three categories, are as follows:

Robotics are inherently ideal poka-yoke devices (a go – no go gage) because they can prevent defects moving through a process where the costs to repair the defect can compound

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when they occur in downstream processes. This concept can be called quality at the source.

Transferring raw material into the work-cell, and discharging finished material. Efficient material flow is a vital requirement for a robotic system, and efficient material flow is a prime essential for lean manufacturing. A robot work-cell that is starved, either because it is not fed efficiently, or finished parts can't be removed at once, isn't making money.

Building an adaptable process that eliminates scrap, and provides a statistically consistent procedure. Every manufacturing operations book explains that quality saves money.

Providing a flexible, programmable, and re-deployable operator that is available to perform a task for 8760 hours per year.

Long cycle times drive down the cost of automation per unit of measure, such as automation cost/spindle in machining, or in automation cost/production line in palletizing. Examples are as follows:

- Robot servicing multiple machine tools decreasing cost of automation/spindle
- Robot servicing multiple case conveyor lines and palletizing multiple unit loads, reducing overall costs

The longer the process cycle time, the greater the ROI of the automation.

Peripheral cost reductions can be achieved in terms of the following examples:

Welding	Reducing shielding gas, welding wire and other consumables by means of an overall reduction in over-welding or cutting, etc..
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Material removal	Reduction in costs of grinding media because of an overall reduction in media wear
Machine tending	Consistent and predictable tool life, that permits improved process control Consistent loading, reducing scrap and improving quality
Generic	Reductions in costs of protective safety gear, uniforms, and tools necessary to support a manual process

In cost-justification models, cost of consumables will inherently increase for a robotic solution versus a manual operation, for the prime reason that productivity will increase, requiring additional raw material inputs, and consumables usage. Power requirements, and costs of other utilities will also increase as a function of the increased throughput.

An important question for a manufacturer to ask during the justification exercise is “what does it cost to not automate?” For example, injuries, operators not showing up for work, qualifying, testing, and training of employees in the event of turnovers, and unpredictable capacity levels, all cost money. The success of the Toyota Production System (TPS), which is the model for manufacturing, is certainly challenged to demonstrate a higher productivity for manual versus robotic operations. Integrated robotic cellular manufacturing is today’s ticket. An article titled, “Machining Today and Tomorrow,” printed by Modern Machine Shop (2007) is a great testimonial, describing the productivity improvements achieved by automated machining work-cells, at Roberts Tool Company, which is a tier 1 supplier to Boeing and other aerospace companies. The owner, Brad Hart is quoted as saying, “cells are the only way to make healthy profits”, and then goes on to further state, “adopting lean and cellular manufacturing is essential if we are to keep this

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kind of manufacturing in the United States.” At Roberts Tool Company, automation uses linear pallet pool systems, not industrial robotics, primarily because of the specialized products being machined, but either way, a form of automation was utilized in a cellular environment.

Not every work-piece or application should be automated, but the bottom line is to use the correct form of automation for the application and use manual labor where it makes sense. A big advantage of automated processes is that they eliminate the human variability that is introduced every time a person touches a process.

Other questions that owners and managers should be asking is how best to operate a given process. If there is no motivation to automate, then the following additional questions need to be answered:

- How reliable are your operators, shift over shift, everyday?
- What kind of efficiency are you getting out of the process?
Efficiency can be determined by dividing the throughput into the total available time for a given interval.
- Are you running production during breaks, lunch, and shift changes?
- Do your operators sometimes walk away to talk to someone, or do they simply appear to work slower one day versus another?
- Does your throughput vary from one shift to another in a multi-shift setting?
- Does your operator make mistakes, with the result that rework or downtime is incurred?
- Have you been in a position where production could not be run because an operator wasn’t available?
- Do you find defects in your product downstream that should have been caught earlier?
- Have you shipped non-compliant product to a customer because a process such as rust inhibitor wasn’t applied?
- Have you had to schedule emergency overtime or simply over time to try to meet a shipment for a customer?

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Answering these questions should provoke thought about the flaws in the way you're running your process regardless of how well you designed it. You will probably realize you're not achieving the efficiency you thought you were. Responses to the questions above will show clearly whether manual operators introduce variables to the process.

The ROI Power of Industrial Robotics

Never automate a bad process is rule number one, because not every project is a good robot project. That being said, this section of Chapter one is meant to be thought provoking. In other words, if the lights are on and parts are being produced on a single shift basis, then why not compare the total cost of ownership to a robotic solution and see what happens.

Think about the cost savings resulting from running even a single-shift, lights-out operation, versus paying an operator \$10 or more an hour to perform a redundant task. The ability to keep a robot system busy for approximately 1400 hours annually is the milestone for getting into the 25% annual return and three year pay-back. Obviously more working hours contribute to better ROI and vice versa. Looking even beyond the conventional one-, two-, or three-year ROI requirements used by many for yes/no decisions, examine the simple cost per hour to run a robot system. For example, most firms are hard pressed to find labor for much lower than \$10 an hour in the US, including uniforms, training, benefits, and other costs. A \$150,000 investment in automation will cost approximately \$17/hr to run on a single-shift basis using a three year lease calculation and basing usage on 8 hours per day and 22 days per month. On a two-shift basis the \$150,000 investment will cost \$9/hr to run. The conventional ROI may not provide enough information to make a decision, so the decision making may be changed to comparison of robot vs. operator in terms of the cost per hour, and ultimately the profit per hour.

Running a plant unmanned for two shifts per day will signifi-

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cantly increase the profit per hour based on productivity gains and labor savings. Imagine going from \$25/hr profit to \$125/hr profit making the same part. That part is now being made more efficiently and with less labor cost. Figure 1-6 illustrates an example of the power of labor savings and increased productivity.

Assuming that manufacturing engineers participate in 401K

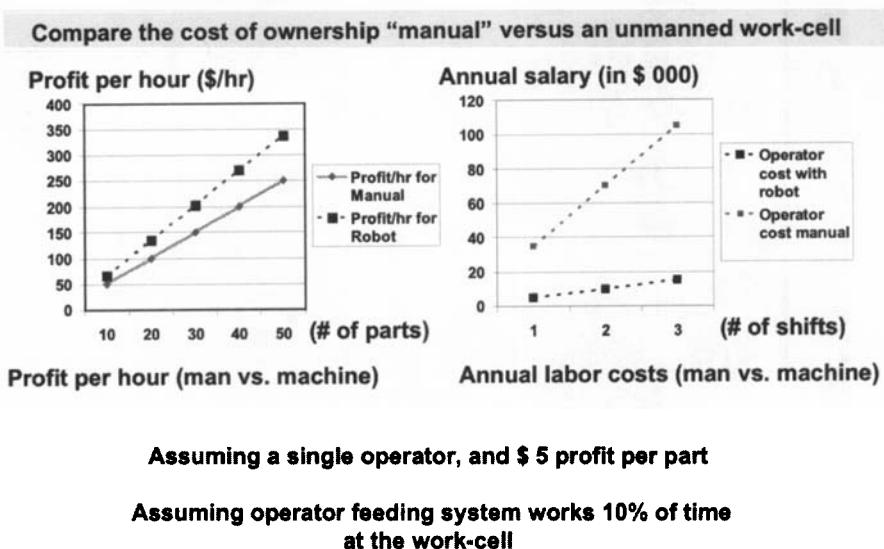


Figure 1-6 The Power of Reducing Labor and Increasing Productivity

funds, and are concerned about saving for the future, then rate of return becomes important to them. Whenever money is invested in anything, the return on investment is important to the decision about whether there is value in making the investment. A financial planner will advise that, over time, the best investment vehicle in which to place personal money is the stock market, or a fund that includes the stock market index of companies. Figure 1-7 represents the periodic table of investment returns for virtually every type of mutual fund from the period of 1986 to 2005.

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ANNUALIZED RETURNS																				
1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	
69.44%	24.63%	29.47%	35.92%	8.96%	51.19%	29.14%	32.56%	7.78%	38.36%	23.12%	35.18%	38.79%	43.09%	22.83%	14.02%	11.50%	48.54%	22.25%	14.02%	
Foreign Stock	Foreign Stock	Small-Cap Value	Large-Cap Growth	U.S. Fixed Income	Small-Cap Value	Foreign Stock	Small-Cap Value	Large-Cap Growth	Large-Cap Value	Large-Cap Blend	Large-Cap Value	Large-Cap Growth	Small-Cap Value	Small-Cap Value	U.S. Fixed Income	Small-Cap Value	Small-Cap Value	Large-Cap Value		
19.98%	5.31%	28.27%	34.68%	8.72%	41.70%	12.58%	23.77%	4.56%	37.53%	22.95%	34.83%	35.02%	33.83%	13.24%	8.44%	10.25%	46.03%	20.25%	7.05%	
Large-Cap Value	Large-Cap Growth	Foreign Stock	Multi-Cap Growth	Government Bond	Small-Cap Value	Large-Cap Value	Small-Cap Value	Multi-Cap Growth	Large-Cap Blend	Multi-Cap Blend	Multi-Cap Value	Multi-Cap Growth	Multi-Cap Growth	U.S. Government Bond	U.S. Fixed Income	Small-Cap Value	Large-Cap Stock	Large-Cap Value		
19.80%	5.25%	23.63%	31.63%	-0.26%	41.64%	8.57%	18.65%	2.62%	37.18%	21.88%	33.35%	28.60%	33.16%	11.63%	7.23%	-11.43%	38.59%	16.34%	6.85%	
Diversified Portfolio	Large-Cap Blend	Multi-Cap Value	Large-Cap Blend	Large-Cap Growth	Multi-Cap Growth	Diversified Portfolio	Multi-Cap Value	Large-Cap Growth	Large-Cap Growth	Large-Cap Blend	Large-Cap Blend	Large-Cap Blend	Large-Cap Blend	U.S. Government Bond	U.S. Fixed Income	Small-Cap Value	Multi-Cap Value	Large-Cap Value		
18.78%	3.92%	23.16%	25.99%	-1.39%	41.27%	7.77%	18.07%	1.3%	37.03%	21.64%	31.78%	20.00%	26.96%	8.04%	-4.33%	-14.46%	31.14%	16.49%	5.72%	
Multi-Cap Value	Multi-Cap Growth	Large-Cap Value	Large-Cap Value	Multi-Cap Growth	Large-Cap Growth	Multi-Cap Value	Large-Cap Value	Multi-Cap Blend	Multi-Cap Value	Small-Cap Value	Foreign Stock	Multi-Cap Value	Multi-Cap Value	Multi-Cap Value	Multi-Cap Value	Diversified Portfolio	Large-Cap Value	Large-Cap Value		
18.66%	2.76%	20.37%	24.22%	-3.19%	30.40%	7.6%	14.35%	0.2%	33.50%	21.59%	30.49%	16.48%	21.03%	7.0%	-5.59%	-15.18%	30.97%	14.7%	5.26%	
Large-Cap Blend	U.S. Fixed Income	Small-Cap Value	Multi-Cap Value	Large-Cap Blend	Large-Cap Blend	Diversified Portfolio	Diversified Portfolio	Multi-Cap Value	Large-Cap Growth	Multi-Cap Value	Large-Cap Value	Large-Cap Blend	Large-Cap Value	Large-Cap Value	Large-Cap Value	Large-Cap Value	Small-Cap Value	Large-Cap Growth		
15.36%	2.69%	17.97%	22.35%	-6.66%	29.96%	7.40%	13.37%	-1.54%	31.04%	21.37%	28.74%	15.63%	16.75%	-2.78%	-6.28%	-15.52%	12.22%	5.17%	11.60%	
Large-Cap Growth	Diversified Portfolio	Diversified Portfolio	Diversified Portfolio	Diversified Portfolio	Diversified Portfolio	Small-Cap Value	Small-Cap Value	Small-Cap Value	Multi-Cap Growth	Large-Cap Value	Large-Cap Value	Large-Cap Value	Large-Cap Value	Large-Cap Value	Large-Cap Value	Diversified Portfolio	Large-Cap Value	Multi-Cap Growth		
15.31%	2.20%	16.59%	20.17%	-8.08%	25.41%	7.23%	10.66%	-1.95%	28.84%	15.63%	22.83%	13.50%	7.35%	-9.23%	-15.94%	29.75%	10.67%	4.91%	11.55%	
Foreign Bond	U.S. Government Bond	Large-Cap Blend	Small-Cap Growth	Multi-Cap Value	Multi-Cap Value	Government Bond	Government Bond	Government Bond	Large-Cap Value	Diversified Portfolio	Diversified Portfolio	Large-Cap Value	Large-Cap Value	Large-Cap Value	Large-Cap Value	Large-Cap Value	Large-Cap Value	Large-Cap Value	Large-Cap Value	
15.26%	0.50%	12.00%	14.53%	-8.85%	24.55%	5.22%	10.06%	-1.98%	25.75%	11.20%	20.59%	9.85%	6.65%	-14.17%	-11.88%	-22.09%	29.02%	6.93%	4.7%	
U.S. Fixed Income	Large-Cap Value	Multi-Cap Growth	U.S. Fixed Income	Multi-Cap Value	Large-Cap Value	Large-Cap Blend	Large-Cap Value	Small-Cap Value	Small-Cap Value	Small-Cap Value	Small-Cap Value	Small-Cap Value	Small-Cap Value	U.S. Fixed Income	Large-Cap Blend	Large-Cap Value	Multi-Cap Growth	Small-Cap Value	Multi-Cap Value	
14.25%	-0.13%	11.27%	14.23%	-17.4%	16.00%	4.99%	9.75%	-2.43%	18.47%	6.05%	9.65%	6.86%	-0.82%	-22.42%	-19.63%	-27.88%	28.67%	6.30%	4.55%	
Multi-Cap Growth	Large-Cap Value	Large-Cap Growth	U.S. Government Bond	Small-Cap Growth	U.S. Fixed Income	Large-Cap Growth	Small-Cap Value	U.S. Fixed Income	U.S. Fixed Income	U.S. Fixed Income	U.S. Fixed Income	U.S. Fixed Income	U.S. Fixed Income	Large-Cap Growth	Large-Cap Growth	Large-Cap Blend	Small-Cap Value	Large-Cap Growth		
7.41%	-7.1%	7.89%	12.43%	-21.77%	(5.32%	12.17%	3.69%	-2.92%	10.34%	9.55%	1.23%	1.49%	3.63%	1.49%	2.23%	-22.42%	-20.42%	28.03%	4.10%	2.66%
Small-Cap Value	Small-Cap Value	U.S. Fixed Income	Small-Cap Value	Small-Cap Government Bond	Foreign Stock	Multi-Cap Growth	Multi-Cap Value	U.S. Fixed Income	U.S. Government Bond	Small-Cap Value	Small-Cap Value	Small-Cap Value	Small-Cap Value	Small-Cap Value	Small-Cap Value	Small-Cap Value	Small-Cap Value	U.S. Fixed Income	Small-Cap Value	
3.58%	-10.48%	7.03%	10.54%	-23.45%	12.13%	2.87%	-3.38%	11.21%	2.77%	1.78%	-6.45%	-2.23%	-2.23%	-21.44%	-30.26%	3.48%	2.43%	8.22%	8.22%	
Small-Cap Growth	Small-Cap Growth	U.S. Government Bond	Foreign Stock	Multi-Cap Value	Large-Cap Growth	Foreign Stock	Large-Cap Value	U.S. Government Bond	Foreign Stock	Small-Cap Value	Small-Cap Value	Small-Cap Value	Small-Cap Value	Small-Cap Value	Small-Cap Value	Small-Cap Value	U.S. Government Bond	U.S. Fixed Income		

- Diversified Portfolio/Equal allocation to all asset classes
- Large-Cap Blend (S&P 500 Index)
- Large-Cap Growth Category (Russell 1000 Growth Index)
- Large-Cap Value Category (Russell 1000 Value Index)

- Multi-Cap Growth (Russell 3000 Growth Index)
- Multi-Cap Value (Russell 3000 Value Index)
- Small-Cap Growth Category (Russell 2000 Growth Index)
- Small-Cap Value Category (Russell 2000 Value Index)

- Foreign Stock Category (MSCI EAFE Index)
- U.S. Fixed Income Category (Lehman Brothers Aggregate Bond Index)
- U.S. Government Bond Category (Lehman Brothers Government Bond Index)

Figure 1-7 The Periodic Investment Returns from 1/86 - 12/05

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What is interesting about this table is that the average rate of return for the best performing funds over the time period is 13 percent. This 13-percent return is very good, and most people would be satisfied with an annual 13 percent return on their 401K's. Using the rule of 72 to calculate the number of years required to double an investment requires dividing 72 into the interest rate of 13, which shows that the investment would take 5.5 years to double in value.

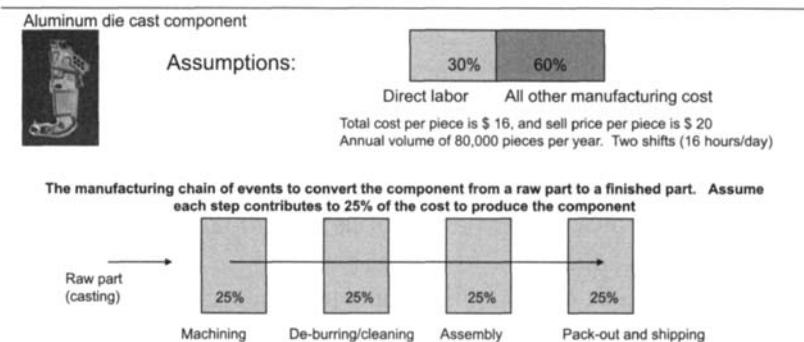
Using 13 percent as the benchmark of a great rate of return, industrial robotics exhibiting a 13 percent return would never be justified, because waiting 5.5 years to earn the payback of the investment in full would never fly at most manufacturing companies. Qualified and well-defined robotic projects typically achieve payback periods of 1-2 years or less, and worst cases 3 years. Using the rule of 72, robotic investments deliver rates of returns of 25 percent and certainly in the 1- to 2-year payback period, 36 percent and greater. Where can a manufacturer invest funds and earn that kind of return? Let's apply these thoughts to a manufacturing chain, and try to understand how industrial robotics can impact the overall cost of producing a product.

The example in Figure 1-8 illustrates the point of how removal of significant direct labor costs from a process results in large savings. This example illustrates a main reason why the direct labor component is one of the first categories to examine. Normally, the examination of robotic justification is on a micro level, often in terms of comparing the manual process to the robotic process for a specific task like welding or machine loading/unloading, grinding, or palletizing. The basic initial data inputs required to examine the economic feasibility for any application type across any industry are as follows:

- Number of hours per shift, shifts per day, or hours per year, worked in the process
- Number of operators per shift
- Throughput of manual operation in terms of work-pieces per hour
- Cycle time per piece for manual operation

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- Amount of time used for breaks, vacations, and other scheduled downtime for manual operators in units of minutes
- Capital investment of automation including ancillary costs such as installation, training, rigging of equipment, freight, utilities, other
- Operator wage with full burdened benefits for insurance, uniforms, protective gear, vacation, disability, and other costs
- Estimated profit per work-piece



Example: Savings from automating the machining process and combining the de-burring/cleaning with machining

- 50% of the manufacturing stream consists of costs from machining and deburring/cleaning. This means \$ 8 of cost contributed from machining and deburring/cleaning
- Of that \$ 8 of contributed cost, 30% is attributed to labor costs, or \$ 2.4 per piece. So automating could affect \$ 2.4 of savings every piece
- Assume 250 days per year and 16 hours per day. This equals 4000 hours per year to produce 80,000 pieces

Figure 1-8 Industrial Robot Cost Savings Example

The inputs will compare robotic costs with manual process costs in terms of productivity. Automation is exploiting the ability to produce more output with the same assets because of the efficiency gains that can be achieved, as well as producing more output with less labor. A critical component of the efficiency side of the comparison is that robotics exhibit 98 percent uptime, meaning they are

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always available to perform a task. Industrial robots are very reliable, and published mean time between failure (MTBF) data exceeds 70,000 hours. The efficiency of the robotic process is still a function of setup, changeover, delivering raw material, and discharge of finished material. The robot cannot control these parameters of the process. A good efficiency to use for most robotic applications factoring in the uncontrolled parameters is 90 percent.

The example in figure 1-8 shows that \$2.40 per piece can be saved due to reductions in the direct labor component that happened to contribute 30 percent of the machining and deburring/cleaning process costs. The deburring/cleaning, as well as the machining, contributed 50 percent of the overall manufacturing cost. If the goal is to make 80,000 pieces per year, then the labor savings is approximately \$192,000 annually. The other area for significant savings is the hours saved to produce the 80,000 pieces. The example is using 4000 hours to produce 80,000 pieces per year. If the productivity gain between the manual labor and the robotic labor is approximately 30 percent, the 80,000 pieces can be produced in 2800 hours

Application	Manual Efficiency (%)	Robotic Efficiency (%)
Arc welding (including cutting)	30-35	90 +
Material removal (de-burring, polishing, grinding, buffing)	25-30	90 +
Machine tending (conventional lathe, HMC, VMC)	55-60	90
Press tending	40-50	90
Pick/place	70-75	90
Palletizing	70-75	90
De-palletizing	65-70	90

Figure 1-9 Typical Efficiency Ratings by Application for Manual vs. Robotic
(not including time for changeover setup equipment)

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with the same equipment, versus 4000 hours. Each hour would be worth \$320 because $80,000 \times \$16/\text{piece cost}$, divided by 4000 equals \$320 per hour, to produce about twenty parts. So the 1200-hour capacity gain enables the customer to save another \$384,000 annually. That extra capacity could be used to produce a different part or more of the same part, if more than 80,000 pieces can be sold. This is only an example, but it shows the power of labor and productivity savings when a process is automated.

Figure 1-9 describes efficiency that is typically derived from robotic applications, compared with the manual efficiency counterpart.

Efficiency erosion due to changeover, setup, and downtime, whether machine- or material flow- related, has other parameters that must be considered when justifying a robotic system. The rule is that, if the robot is inhibited in its ability to achieve a significant increase in process efficiency, the project may not be a candidate for robotics. The efficiency gain that has become notorious for industrial robotics is a reason why engineers should not be concerned with the exact cycle time for a task to be completed from start to finish. If you measured the cycle time from start to finish for a task manually and with a robot, the time for the operator to complete the task will usually be less. The efficiency gains made over an hour, shift, day, and annually, is what will drive the increased productivity, because an operator cannot continually repeat the same cycle over and over in the allotted time frame. The important benchmark is finished pieces at the end of a time period, not the length of the individual cycle. Looking at the influence of efficiency, Figure 1-7 illustrates how a robotic solution makes sense in the automation of a single machine work-cell, in a single-shift application.

The example in Figure 1-10 is designed to allow the user to input information about how production is run for the targeted process as well as enter efficiency ratings, cost of investment, and profit per part. Each application type will have additions and subtractions regarding the inputs, but for the most part, Figure 1-10 shows an ROI calculator that can be used for all types of applications.

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Variables When Considering Automation	Typical Company	Your Company
Number of Shifts Currently Running	1 Shifts	1 Shifts
Numbers of Hours in a Shift	8 Hrs.	8 Hrs.
Morning Break Allowed	10 Min.	10 Min.
Lunch Break Allowed	30 Min.	30 Min.
Afternoon Break Allowed	10 Min.	10 Min.
Average Part Cycle Time	0.83 Min.	0.83 Min.
Average Operator Part Unload / Load Time	0.16 Min.	0.16 Min.
Average Robot Part Unload / Load Time	0.22 Min.	0.22 Min.
Average Operator Wage Per Hour with Benefits	\$12.00 Per Hour	\$12.00 Per Hour
Average Part Weight Being Considered	4 Lbs.	4 Lbs.
Estimated Profit Of Your Part	\$3.00	\$3.00
Vacation Time Allowed For One Operator	2 Weeks	2 Weeks
Spindle Efficiency Rating Of Cell Manual Load (60% is avg.)	60%	60% %
Anticipated Spindle Efficiency Rating Automation (90% is avg.)	90%	90% %

31. Total Robot System Price: \$ 150,000.00

The numbers calculated for this justification DO NOT take into consideration Overtime wages paid to operators, time for shift changeover, potential weekend production, workman compensation claims, insurance benefits paid to operators, on time delivery percentages, normal work stoppages (restroom breaks, telephone, ect..)			
Annual Production With Operator	69,203 PPY	Parts Produced In One Shift With An Operator	266
(Total Working Min - Oper. Breaks) / (Part Cycle Time With Oper. Load) * Manual Efficiency * 5 Days * 52 Weeks * Year			
Annual Production With Automation	106,971 PPY	Parts Produced In One Shift With Robot	411
(Total Working Min - Zero Breaks) / (Part Cycle Time With Robot Load) * Robot Efficiency * 5 Days * 52 Weeks * Year			
Increase Parts Produced With Automation	37,769 PPY	Parts Lost Currently Over Breaks In One Year	4,457
(Annual Production with Automation - Annual Production with Operator)		Parts currently lost over lunches In One Year	6,686
Profit variation Automated vs Manual	\$ 113,307 per year	Parts Lost Currently Over Lunches And Breaks In One Year	11,143
(Decreased Parts Produced With Automation * Estimated Profit Per Part)			
Your Companies Yearly Wage For Operators	\$ 24,960 per year		
(Hourly Wage) * (Number of Shifts) * (Hours per Shift) * 5 Days * 52 Weeks			
Total of Operator Wage and Efficiency Benefit	\$ 138,267 per year		
(Profit variation Automated vs Manual * Your Companies Yearly Wage for Operators)			
RETURN ON INVESTMENT	1.085 # of Years		
(Total Product System Price/Total of Operator Wage and Efficiency Benefit)			
If Automation Is Not Purchased Your Operator Will Lift This Amount Of Weight In A Year.	277 Tons		

Figure 1-10 ROI Calculator Example for Machine Tending

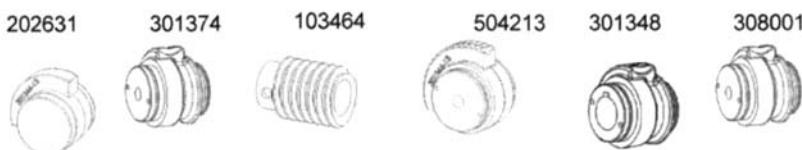
The justification side of Figure 1-10, shows the productivity comparisons, and how they relate to increased gross profit. Additionally, for this example, the justification describes the tonnage that the operator has to handle manually on an annual basis. OSHA regulations limit the amount of weight that can be handled by an operator. The threshold is typically around 35 lb. before an operator is required to use a lifting device. Ergonomics is a big deal

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to many firms because of the cost of employee injuries, so that asking someone to lift tons of materials a day is not acceptable in many workplaces. Lifting devices help, but they reduce the throughput. Generally, the heavier the component, the larger the safety risk, so that ergonomic benefits further justify robotics.

The following example helps illustrate the usage of the ROI calculator. Figure 1-11 described five parts starting as forgings that are machined in two operations (turning and drilling). The annual part volume is as follows:

202631	12,000 pieces/year
301374	13,000 pieces/year
103464	13,000 pieces/year
504213	13,000 pieces/year
301348	8,000 pieces/year
308001	12,000 pieces/year



➤ Mixed family of part types

Part #	Dia "	Height "	Weight (lbs.)
202631	2.5	2.5	5
301374	2.5	2.66	5
103464	1.6	2.1	3
504213	1.6	2.2	3
301348	1.3	2.3	3
308001	1.4	3.4	5

Operations:

- Turning in lathe
- Drilling in Vertical Machining Center

Figure 1-11 Example of Sample Part For a Machining Cell

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Other pertinent information about these applications is that there are 2050 hours available annually for a single shift, and the operator costs \$12 an hour, including wages and total cost burden. The machines exist, and they are going to be redeployed for the six new part styles. The total number of machine hours required to achieve the annual demand is 1245 hours at 100 percent efficiency. Evaluating the real efficiency, the operator spends 60 percent of time in loading and unloading parts. Including cutting tool changes and work-holding setups for the five parts that the robot solution is estimated to run at 90 percent efficiency. Single-shift production is planned.

The conclusions derived from this example show significant advantages to the user from automating the six work-pieces. The comparison of manual vs. robotic are as follows:

Criteria	Manual (60% eff.)	Robot (90% eff.)
Capacity requirements (hours)	2075	1383
Extra capacity in one year	(-25)	667
Overtime required	Yes	No
Cost of automation	N/A	\$ 150,000
Cost per hour for employee	\$ 12/hr	\$ 17/hr
Cost of ownership (employee-specific items)	\$ 2500/yr	N/A
Cost of operator after 1.085 years	\$ 12/hr	\$ 0/hr
Cost of increased process consumables		15% increase
Tax Benefits		TBD

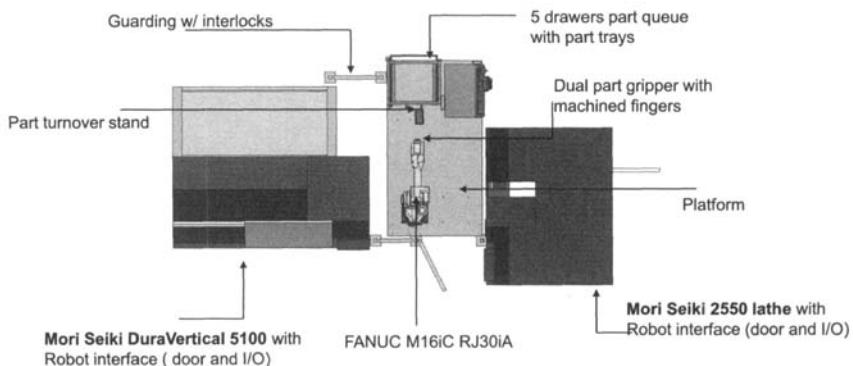
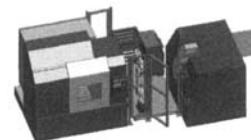
The comparison indicates that the robot cell will produce the parts in 692 hours less than is needed for the manual operation.

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Those 692 additional available hours on the machines are extremely valuable. The data also indicate that overtime would be required for manual production to keep up with demand, and more overtime further will be needed every time the operator fails to achieve the 60% efficiency. When the investment is factored into a cost per hour calculation, this type of automated system ends up costing less than paying an operator to run a work-cell on a per hour basis. The example for the parts detailed in Figure 1-10 yields a 1.085 year payback for a single-shift application. If the application included additional production shifts, the payback period would be even shorter because more labor would be saved by use of the robot.

Based on elimination of labor and the additional throughput, the ROI calculator indicates the robotic cell is paid for at the end of the 1.085-year payback. The robot operator will be usable for at least 15 years, and will always be re-deployable. The main limitations of the robot are its reach, and the payload capacity while carrying the gripper and parts. An important advantage is the ability for the robot cell to run “lights-out” at the end of a shift, when an operator can fill the raw material queue and let the robot cell run until the queue is

Figure 1-12 Concept Robotic Work-cell for Machine Tending



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empty. The lights-out concept works very well for machine-tending operations because typically, a queue of parts is staged for the robotic cell.

Additional Benefits of Implementing Industrial Robotics

One drawback of labor savings and increased throughput is the requirement to run the robotic work-cell with an operator standing at the cell full-time. Standard welding cells are useful, but they typically require an operator to stand at the cell fulltime, to feed and empty the system of parts. Most systems in general, but specifically welding, will utilize at least two stations for loading and unloading, and the operator is often performing a setup such as tack welding, or loading/unloading parts into and out of fixtures while the robot is welding. This concept allows the load/unload time or the setup time to be included in the robot welding cycle.

It is an advantage if the welding cycle is long enough to allow the operator to walk away from the system. However, it must be kept in mind that there will always be some component of labor in feeding and removing product from a robotic work-cell, although innovations in robotic bin picking now allows robots to randomly pick piece parts from a bin for pick and place, or machine tending. There also may be value in paying the operator to load and unload parts for the welding cell. The robotic process is intended to provide higher levels of consistent quality and consumable usage than a manual process. Additionally, there are savings to be achieved in the arc-on time versus manual welding of the work-piece. The issue comes down to having someone always nearby, to feed the cell.

Applications that are cycle-time intensive, whether in welding, machining, or material removal, are excellent candidates for automation because of the “on-process” efficiency gains previously mentioned. The increased throughput is also sometime misrepresented. In the earlier example, the user may not care about the additional capacity of the robot cell because the user can’t find additional demand for machining work. Even though the robot yields a higher throughput than the manual operation, if there is no demand

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for the additional throughput, then the ROI aspect of additional productivity needs to be considered. The benefit of robotics is that they only need to run on demand, and don't require to be run all the time to achieve some ideal operational result, as if there were concerns in shutting the robot on and off at a regular frequency. The robot system allows for users to have flexible capacity without having to manage temporary workers for peaks and valleys of production. Managing and training temporary employees is a huge task and there is a cost. This worry can be eliminated by introducing the new machine operator in the form of the industrial robot. The goal in the author's opinion for any robotic system is to strive for "lights out" meaning unmanned production.

Arc-welding ROI calculators will exploit information about arc-on time and not machine efficiency. Arc-on time is defined as how much time the welding arc is on, depositing filler metal, measured over 10-minute durations and expressed as percent efficiency. Thirty percent for a manual operation versus greater than 90 percent efficiency, validates the rule of thumb that one robot can match the productivity of three operators. Material removal operations are regarded as being similar to welding in terms of how the ROI analyzes the on-process time of manual vs. robotic efficiency.

Other areas of exploiting cost savings that contribute to the total ownership cost (TOC) are:

- Scrap rates
- Cost of overtime
- Cost of personal items to enable operator to perform task
- Tax rate
- Hurdle rate
- Cost of increased utilities, consumables related to process
- Depreciation method of capital investment
- Arranging material flow into cells, reducing WIP and increasing throughput

One of the last advantages that are difficult for ROI calculators to validate, as been previously mentioned, is that the robot is a re-

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deployable asset over the course of its useful life. A robot should be viewed as a 15-year plus employee that always shows up to work, never gets sick, never complains, and is ready to go 8760 hours per year. Should the original, intended project disappear, the robot can be re-deployed for whatever comes next. The constraint is the robot reach and payload. Robots often are converted in terms of the process, such as material handling to welding, or vice versa. Assuming the original payback of the robot was under 3 years, that leaves at least 12 years to deploy an asset with the only remaining costs for electrical usage and maintenance.

As a point of interest, there are tax incentives for capital equipment, one of which is specifically called Section 179 ([http://en.wikipedia.org/wiki/179_\(Internal_Revenue_Code_Section\)](http://en.wikipedia.org/wiki/179_(Internal_Revenue_Code_Section))).

Applying Present Values to Evaluate the Robot Investment

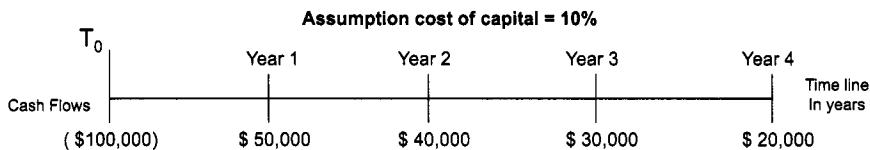
Another exercise would be to select characteristics that might guide the choice among the many projects that manufacturing engineers might have on their plates. Finance managers will want to examine the total cost of ownership inputs when the project is evaluated for final approval. A cash flow stream is used to calculate the payback period using net present value. The hurdle rate, or cost of capital, is typically included as the rate to be used in the net present value calculations. The hurdle rate allows the cash flows in each year to be factored along with the rate of return required for the firm, based on the cost of borrowing money. Figure 1-13 shows an example of the present and net present value financial tools that are commonly used.

When the Net Present Value exceeds zero, the project is considered to be good. The stronger the NPV value, the stronger the program is thought to be.

The purpose of Figure 1-13 is to show how common financial tools can become a barometer in determining whether a robotic project is a good investment and when the payback will occur. The first step is to examine the savings from labor, productivity gains, and all the other criteria previously reviewed. At the end of this first

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- Find the present value of each period's cash flows, either by using a financial calculator or by referring to a present value table. In the example below, the discounted value of \$ 50,000 at a 10% cost of capital is \$ 45,400. The other values are also found using a present value table
- Discount the cash flows at each time period by the cost of capital.
- Total the cash flows, and include the initial investment (\$ 100,000) in the equation. The calculated cash flow number is the net present value (NPV).



$$NPV = -100,000 + 45,400 + 33,000 + 22,500 + 13,800 = 14,700$$

Figure 1-13 Net Present Value (NPV) as a Robotic Justification Tool

step there is a savings in terms of dollars. The example in Figure 1-13 indicates that there was a savings of \$50,000 the first year. Below is an example of where the savings came from for that first year:

Labor Savings (single shift)	\$ 23,000
2000 more parts produced at \$ 10/part profit	\$ 20,000
Overtime reduction	\$ 4,000
Reduction in scrapped parts	<u>\$ 3,000</u>
Total	\$ 50,000

This step needs to be repeated for each of several years, the number of years being discretionary. Usually four (4) or more make sense. It is necessary to select at least the number of years beyond the payback period that occurs when the initial investment equals the sum of the savings each year. In the example above, the payback

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period will be around 2.5 years, so it is necessary to extend the cash flow stream from the savings beyond three years. The initial total investment, including the robot system, installation, training, and shipping costs also must be included. The analysis will start with a negative (\$100,000) because at time zero, the user purchased the system with total costs of \$100,000.

Year one savings was determined to be \$50,000, and year two was \$40,000, and so on for the example in Figure 1-13. A net present-value (NPV) table found on calculators or in financial books is used to cross-reference the number of years, whether it be year one, two, three, four, etc., and the discount factor, which is a percentage. The present-value table is important because it allows an equally-valid comparison of the value of the investment made now, and the realized savings in the future, that are paid at different times. The value of a dollar today is always worth more than the value of a dollar in the future because the dollar can be invested today and a year from now it will be worth more than a dollar. The discount rate used from the present-value chart is whatever interest rate the firm thinks could be earned if the money was invested elsewhere. For example, the 13 percent earned in a mutual fund, which would then become the discount rate used in the present-value tables.

The discount rate is multiplied by the savings for each year to arrive at a new value for each year called the discounted cash flow. This process of multiplying the discount rate by the savings at the end of year one, two, etc. enables all the dollars through the time line to be represented in a present-value sense. This step is repeated for as many years as the cash flows to be analyzed. The sum of the total investment made today, plus the discounted cash flows from each year, will provide the NPV value.

Resources that Manufacturers Need to Become Familiar With

Despite the volume of robot sales, one of the commonly-held beliefs of the robot industries is that 90 percent of the manufacturers in the US have yet to purchase their first industrial robotic system. That is sort of a staggering statistic, given the potential return

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on investment data, as well as all the other benefits that organizations can achieve by automating. Traveling in southern Indiana a few weeks ago, the author visited two potential clients, to review possible robotic projects. Both clients had no automation installed but thought it was time to do something. During a meeting with the manufacturing engineer and the plant manager the conversation was classic, relative to about every client that has yet to automate. The stereotypical discussion goes as follows:

- We have to automate but don't know exactly where
- We have a lot of changeover, so a robot won't work for us
- What does the robot cost
- We really haven't started looking at our product mix, and we will have to hunt for part prints, but we will find them
- We can't find reliable operators so we have to do something

In general, many engineers and managers get locked up in taking the first steps to identify good or bad automation projects. There is a huge dichotomy in manufacturing between those that embrace and use technology and those that have stuck to doing things the way they always have. The most successful firms have integrated robotics into their manufacturing strategy across the entire manufacturing value stream from fabrication to paint. Typically, several years after the first robot is installed, the factory has several, and often many, robotic work-cells. Moving past the first step or road block in implementing automation involves education and a plan.

Education is available in many forms and from many organizations. Several agencies offer educational support through consulting and websites, with free published articles about manufacturing. Organizations such as the Robotic Industries Association, and the National Association of Manufacturers (NAM) are committed to the welfare of their industry constituents. NAM is an organization that focuses on the manufacturer and policy issues related to taxes, OSHA, EPA, trade, tort, regulations, energy, pensions, health care, and the workforce. Industry- focused organizations such as the American Welding Society (AWS, <http://www.aws.org>), the

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Fabricators & Manufacturers Association, International (FMA, <http://www.fmanet.org>), and others, provide industry contacts, case studies, and local consulting.

NACFAM is a policy research organization that focuses more on the manufacturing issues of technology and innovation, workforce preparedness, and supply chain value creation. One of the more recent initiatives of NACFAM is the concept of Network-Centric Manufacturing. The concept involves the OEM developing intense collaboration with its supplier network to focus on driving down costs, improving delivery, releasing products faster to market, and raising quality, among other benefits. The concept is powerful when every supplier is focusing on what they do best to provide as much value as possible to the OEM that supplies the end-product to the marketplace.

The definition of value chain in terms of the Network-Centric concept will change the relationship of suppliers and OEM from a coordinated transactional arrangement to an intense collaboration involving product design, and joint product development. An example of Network-Centric Manufacturing in practice is the Supplier Excellence Alliance (SEA), which is a membership organization of prime contractors, tier-one suppliers, and other supplier companies in the aerospace, defense, and space industries. SEA was formed in 2004 to promote the adoption of lean manufacturing, and other techniques that bolster supply-chain efficiency and competitiveness.

The FANUC Robotics America Save Your Factory website provides information about the hidden and real costs of off-shoring manufacturing, as well as encouraging manufacturers about embracing automation and lean strategies. The Society of Manufacturing Engineers (SME, <http://www.sme.org>), and the RIA organizations, are resources from whom to obtain the latest information on the use of technology, emerging technologies, and case studies, as well as networking with other manufacturers. These organizations also offer various training capabilities. It is essential to have the employees within the manufacturing firm participate in some way with these various trade organizations, especially from

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the educational standpoint.

Owners and managers of small and medium-sized manufacturers have a lot of tools available for assistance in driving productivity and performance, as discussed in just some of the examples discussed in this section. The text in subsequent chapters will provide guidance to implementing the robotic plan, relying on the best practices used today.

2

Implementing Robotic Automation – Getting Started

Getting started in evaluating whether robotics is the right thing for a firm begins with motivation, typically through the means of identifying pain in the manufacturing process. Pain comes in many forms such as waste, scrap, ergonomics, high cost per piece as compared to competitors, and finding reliable operators. Based on many years of selling automation, the following process seems to work well:

Step 1: The firm has identified pain somewhere in the process

The firm has motivation and management support to pursue robotics as solving a problem

Return on investment, hurdle rate, and/or payback period requirements for the project are identified

The firm has a reliable process

Step 2: Defining the process

- If this is the first robot project, identify a low-risk process and product that will be an immediate win upon installation
- Identify product(s) to be automated
- Identify project design criteria (the constants). In other words, what are the expectations and requirements for the project parameters

Step 3: Develop concept (This exercise serves as a litmus test for the merits of the project)

- Establish a rough order of magnitude of costing for all equipment and services

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- Define a preliminary automation solution
- Determine responsibilities within the firm as well as outside integrators, contractors, etc.
- Identify the unknowns
- Identify where the system will be located
- Identify resources to operate the system

Step 4: Decide whether the project makes sense economically and technically

Figure 2-1 shows a typical flow chart for implementing robot projects. This chapter deals with the audit/discovery aspect of such a project.

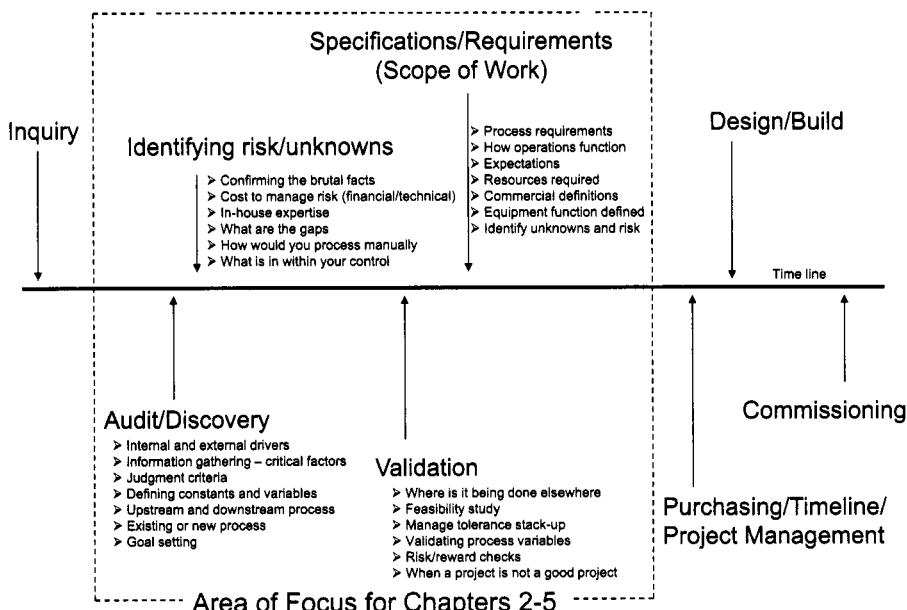


Figure 2-1 Best Practices- Life Cycle for Implementing Robotic Projects

Implementing Robotic Automation—Getting Started

Robotic Implementation is Always a Team Effort

There is no question that a team is necessary to implement a robot project, because many disciplines are required to add value in the stages of planning and implementing such a program. To be most effective, the plan must be developed by a team, as with many programs, for example, an ISO quality management program. The personal profiles of a team that would be ideally suited for developing a robotics plan are as follows:

Job Role	Contribution to the plan for industrial robotics
Project Manager	Primary point of contact and communication with suppliers and “Champion” internal customers such as operations people. Manages schedule, develops scope of work. Personnel are typically manufacturing engineers, program managers, project managers, quality managers, and sometimes technicians.
Production	Manage the system on a daily basis, track system uptime, manage process consumables such as pallets, slip sheets, welding wire, and grinding media.
	Manage daily system problems. Personnel are typically operators who were involved in the process prior to the installation of the robot, or technicians.
Maintenance	Installation of the system, and maintenance over the life of the system. Personnel are typically maintenance technicians
Engineering/Design	Design work-holding, fixturing, and product design to enable the process to be “robot and operator friendly.” This role is typically associated with process development. Personnel are typically from the engineering group (i.e. Industrial Engineering)
Facilities	Manage logistics for utilities, installation, and floor requirements. Facilities may also be responsible for building components such as electrical panels or fabricated components.

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Finance	Validate the ROI and put together the justification package. Typically other personnel also assume this role.
Programming	This role consists of programming for system controls and robots. Personnel are typically engineering, operator, technician, and maintenance people.
Safety	This role manages the safety compliance of the equipment brought into the facility. There maybe a safety director, or safety may be managed by others.

Teams will vary based on the scope of work and organization size. The roles and responsibilities are the same across any organization implementing robotics. Other roles and responsibilities of the team include supplier selection for any outside-sourced components, process development, especially if the process is new, and criteria for justification including quality, reduced direct labor costs, productivity increases, safety, etc.

Other members of the team are often outside suppliers or consultants. Especially for first-time robot users, system integrators are often contracted to provide a “turn-key” automation solution to accomplish a task(s) within a manufacturing process. System integrators are organizations that have the capability of managing the qualifying, justification, quoting, project management, installation, and commissioning of a robotic system. The firm will also rely on the system integrator to train their employees in the use of the system, as well as adapting additional products into the system. The system integrator organization is set up to include all the disciplines mentioned above. The relationship between the manufacturer and the system integrator will vary for every project, and the relationship is based on defining which organization is responsible for various attributes of the project. Trade-off's always need to be considered when dealing with a system integrator in terms of how much risk the manufacturer is willing to manage, the internal versus external costs of designing and building system components, delivery needs, internal capabilities for services that would otherwise be pro-

Implementing Robotic Automation—Getting Started

vided by the integrator, and availability of resources within the firm. There is no wrong or right decision.

Consultants sometimes provide equipment such as hardware, but often are contracted to provide design or project specifications that will facilitate a request for quote from a system integrator, or to write the execution plan if the system is to be managed internally within the firm.

Ingredients of the Robotic System

Figures 2-2 through 2-6 illustrate a typical robotic system for machine load/unload, arc welding, palletizing, material removal, and press tending. Although the applications are different, the ingredients that are contained in the system are similar. There is always the consideration of transferring raw material into, and finished product out of, the system. For each application, the means is different, however the ingredient is still required or the system is incomplete. The point is that, regardless of the application, the planning and auditing of a process is the same because different

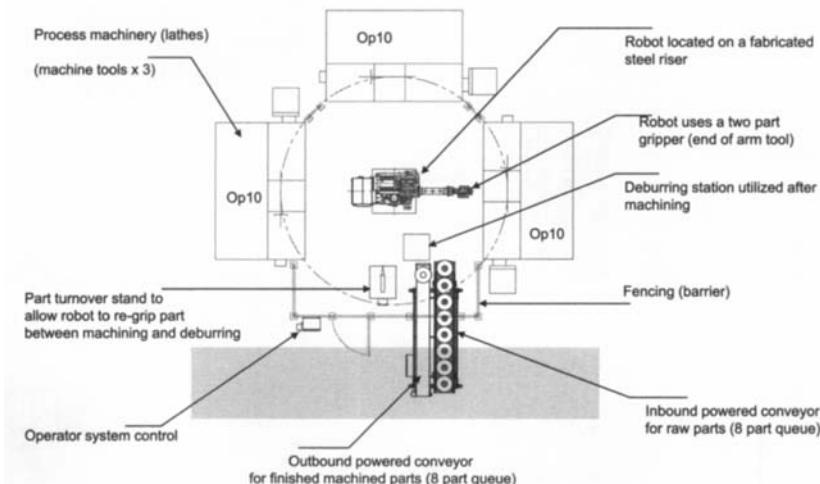


Figure 2-2 Anatomy of a Robotic Machine Tending System

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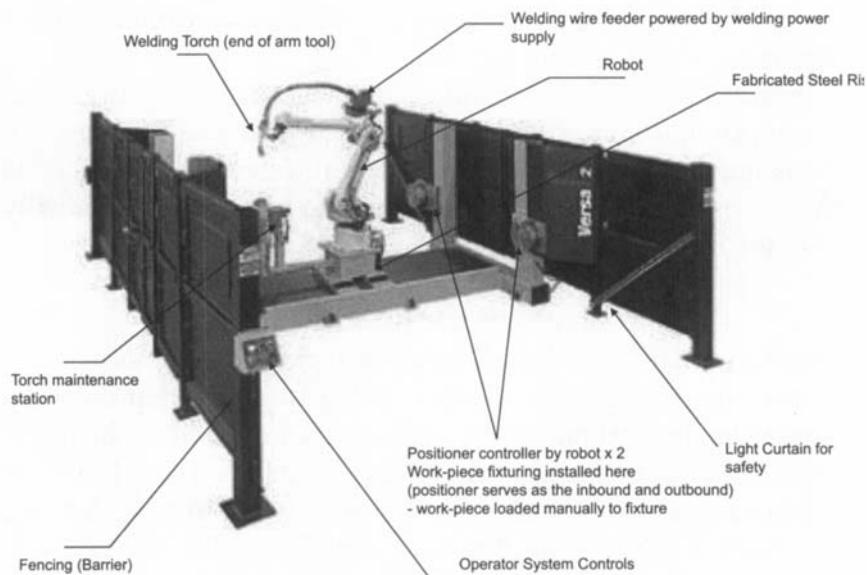


Figure 2-2 Anatomy of a Robotic Welding System

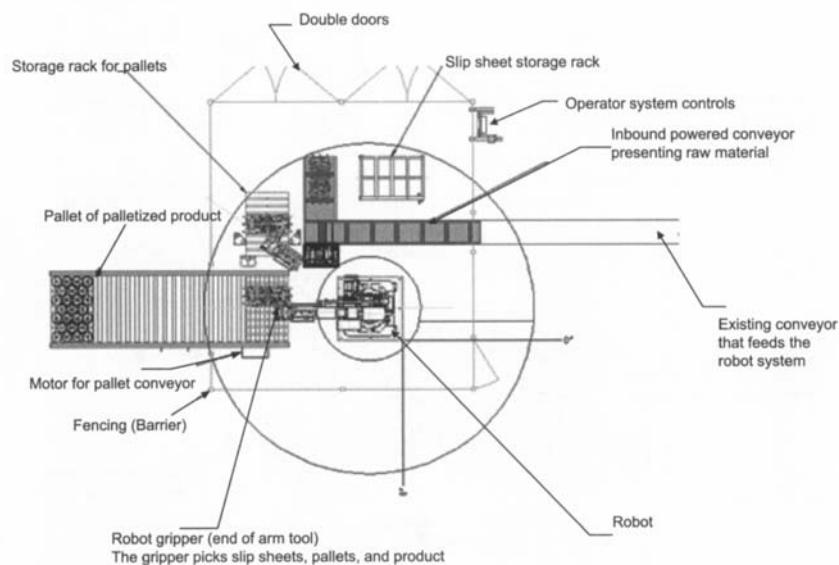


Figure 2-3 Anatomy of a Robotic Palletizing System

Implementing Robotic Automation—Getting Started

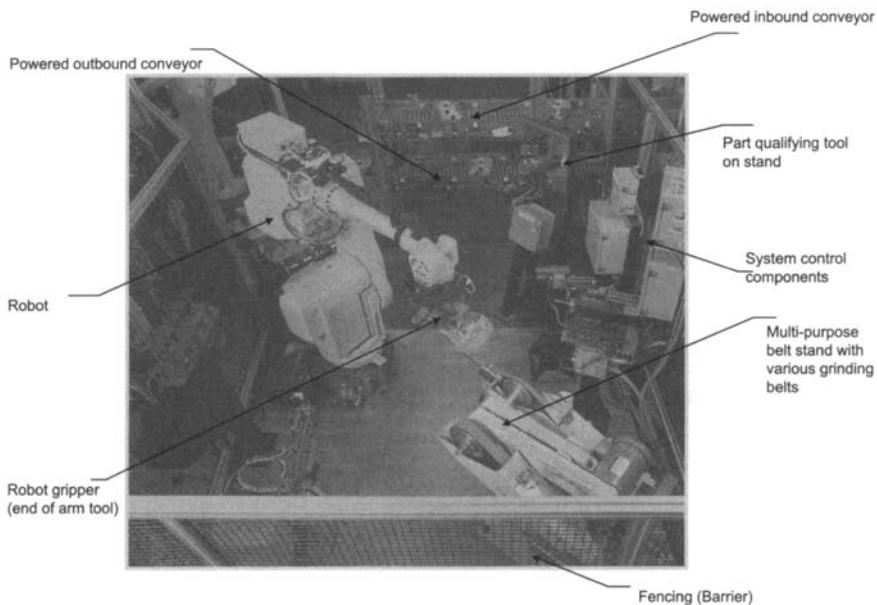


Figure 2-4 Anatomy of a Robotic Material Removal System

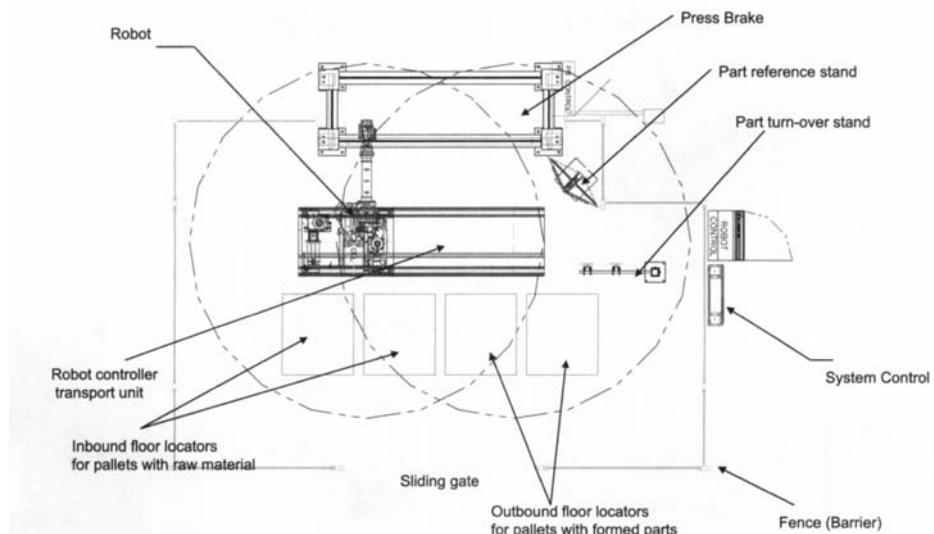


Figure 2-5 Anatomy of a Robotic Press Tending System

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robotic systems require the same ingredients, which are illustrated in Figures 2-2 through 2-6.

Regardless of the application or industry, the integrated components of a robotic cell, as well as the planning process, are virtually identical, although each application has unique process-specific characteristics. For instance, applications such as robotic press tending differ from robotic arc welding. Essentially then, the planning process for one robotic system can serve as a model for future robot systems, regardless of the application. It is worthwhile to understand the typical ingredients for planning and purchasing a robotic system. The recipe for automation follows the similar rules regardless of the application and the integrator source, whether internal or external. Various system elements and their contributions to the system are shown in the list below. Not every system will contain all of these components, so some items may not be applicable. Nonetheless, careful consideration is needed to develop a robotic system shopping list of the items that are illustrated in figures 2-7 through 2-15, and the items fall into the following categories:

	Ingredient (Category Component)
Robot	

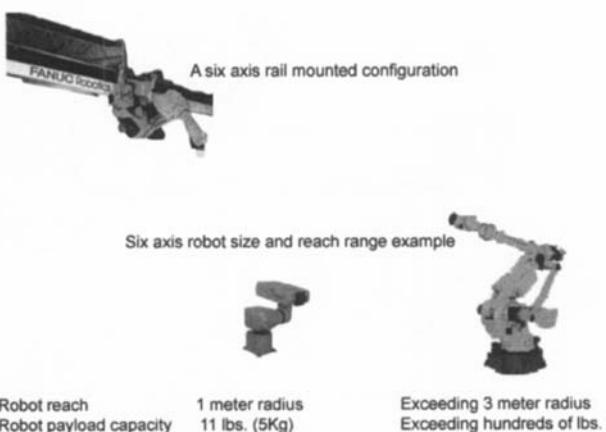


Figure 2-7 Contrasting Robot Size, Reach and Configuration

Implementing Robotic Automation—Getting Started

Role/Responsibility

The robot is the manipulator that performs the sequence of operations within the process. Throughput requirements establish the number of robots needed. The process establishes the robot criteria in terms of reach requirements, number of robot axes, weight-carrying capacity, and robot configuration to support such specialized applications as vision, auxiliary axis, interface to machinery or process devices, and other needs.

Inbound



Welding headstock/tailstock positioner



Pallets on Floor containing materials



Tray/Drawer system



Various Conveyor styles

Figure 2-8 Inbound and Outbound Material Transfer Devices

Role/Responsibility

Inbound describes the hardware that enables raw material to be transferred into the system. Examples include conveyors, turntables, shuttles, AGVs, and fixed stations in the form of a table, or floor location.

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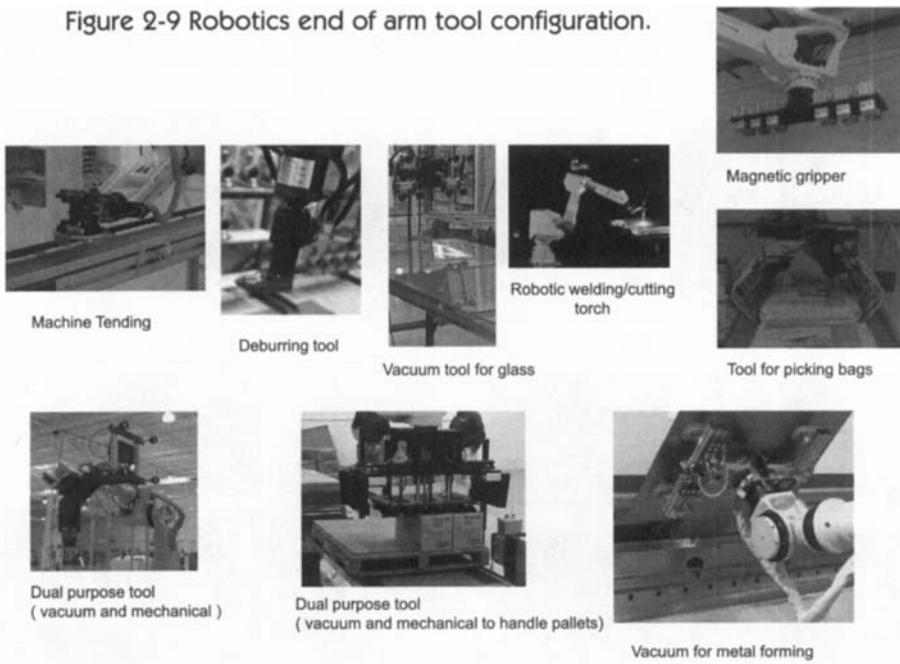
Outbound

Role/Responsibility

The hardware that enables the finished material to be transferred from inside to outside the system. The hardware is similar to that for the inbound

End of Arm Tool

Figure 2-9 Robotics end of arm tool configuration.



Role/Responsibility

The gripper or “end of arm tool” is the functional tool used by the robot to perform the process task. Tools are part- and process-specific. Some processes such as welding or cutting, can often use a common tool. Tools used for material handling or material removal often are varied from process to process.

Implementing Robotic Automation—Getting Started

Tool Changers



EOAT Changer Plates with Storage Rack

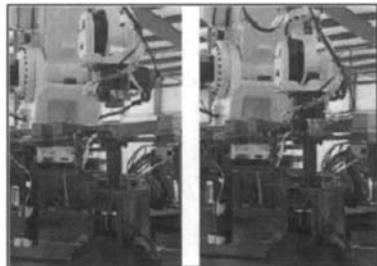


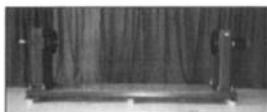
Figure 2-10 Robotic Tool
Changers



Role/Responsibility

Tool-changers are quick-disconnect (male/female) devices that allow the robot to change tools automatically. Changing tools allows for different processes to be performed by the robot as part of the robot program.

Auxiliary Axis System



Headstock/tailstock positioner

Figure 2-11 Auxiliary Robot Axis



Robot transport unit



Robotic Servo Boom



2 axis tilt & rotate positioner

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Role/Responsibility

Auxiliary Axes are additional axis of motion controlled by the robot control system. The aux axes are programmed through the robot control system. Aux axis can control the motion of the part or the robot to the part through the process. Many additional axes can be added to the robot control for the purpose of providing a greater level of flexibility in the robot's process.

Controls

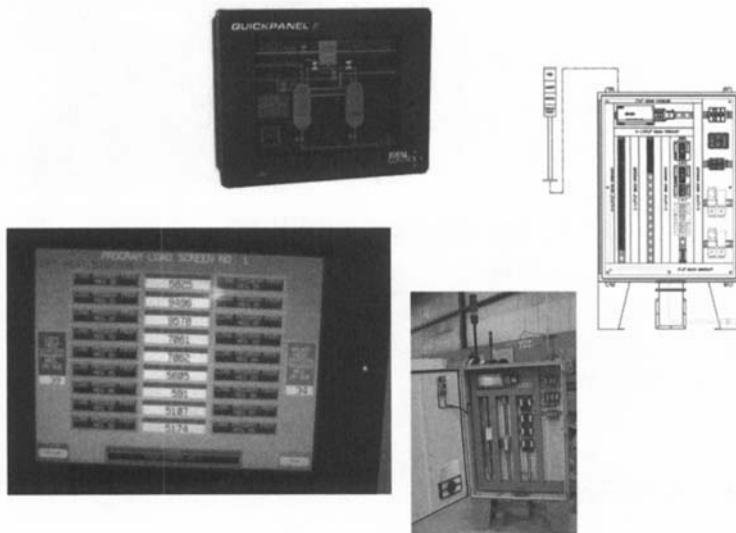


Figure 2-12 Robotic System Controls

Role/Responsibility

The control system serves as the interface for the human operator to manage and monitor operation of the system. For example, some users require what is called "Overall Equipment Effectiveness". This function requires a system control to gather system data and report the data related to downtime, faults, uptime, top 5 reasons for faults, and other production data that allows the user to track the efficiency of the system.

The control system is also used for information transfer and com-

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munications between all the devices in the system, as well as controlling the robot. The control system can be PLC or PC based, or can be within the robot control. Often the interface to the control system is referred to as the Human/Machine Interface (HMI) or Graphical User Interface (GUI). Selecting parts to be run in production, collecting and archiving system data, monitoring system parameters, and transferring/receiving data within a larger-scale network are additional functional requirements of some system control schemes

Larger scale control systems utilize Supervisory Control and Data Acquisition (SCADA) systems. These systems are responsible for information management at the system and remote from the system. These systems also can interact with Oracle, and SAP databases for downloading production schedules for the robotic system as one example.

Fabricated components



Fabricated platform containing the automation for machine tending



Fabricated turntable for robotic glass handling



Robot risers



Welding positioner

Figure 2-13 Fabricated Peripheral Components

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Role/Responsibility

Components that are necessary to the robot system, usually in a supporting role for the process itself. Examples are robot risers, positioners, turnover stands to enable the robot to re-grip a work-piece with a specific orientation for machine loading, stands, racks, reference tables, storage equipment, and other items.

Process equipment



Press Brake



Welding Equipment



Machine Tool



Lasers

Figure 2-14 Process Equipment

Role/Responsibility

Process equipment is a very broad group. Within the process there is machinery that does something to a part, or provides the robot with the capability to perform a process such as the welding equipment for welding. Other examples include tending to a machine tool cycle, forming on a press brake, or operating a laser for cutting or welding

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Safety Guarding

Role/Responsibility

Consists of wire mesh fencing, light curtains, safety mats, limit switches on the robot arm to define robot motion, sensors and switches on conveyors and access gates. Typically any device that limits the ability of the robot and the human operator to share the same space at a given time. Safety can also include custom flooring to prevent slipping in a hazardous environment, or a smoke exhaust system to remove welding particulates.

Miscellaneous items

Role/Responsibility

An even broader classification. Examples include inspection devices, gages, washers, diptanks, pallet dispensers, welding torch reamers, stretch wrappers, pin stampers, part markers, bar code readers, or any piece of equipment that is integrated within the sequence of operations for the system.

Devices to locate the work-piece

Role/Responsibility

Robots are blind. Requirements to locate the work-piece from a casting, tacked welded assembly, steel blank, or bag of seed corn, is concerned with managing the tolerance for locating through the sequence of process operations. Examples include welding fixtures, powered conveyors with V-block locators to hold a shaft, or pushing devices at the end of a powered roller conveyor that moves the bag of seed corn to a specific location at every cycle.

Protection Tools



Figure 2-15 Robot Protection Tools

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Role/Responsibility

Typically designed to protect the robot from a harsh environment. These items include robot suits for a wash-down environment where oxidizers or other liquids are used to sterilize and clean the robot. Additionally, NEMA 4 enclosures, severe dust and liquid hazards for equipment, and cooling or heating robot suits are required.

Installation requirements

Role/Responsibility

The services required to install the electrical and mechanical components of the robotic system from utilities to floor requirements.

Internal or external integration services

Role/Responsibility

The man hours required to design, build, integrate, de-bug, and manage projects, and validate, document, and install the components of the system.

Training

Role/Responsibility

Training is imperative. An educated user is absolutely one of the most important items on this list of ingredients. Training in managing system faults, and general error recovery is critical in maximizing system uptime.

Programming

Role/Responsibility

Every system requires programming of the robot through the use of a teaching pendant, connected to the robot control or off-line within a PC. enviroment.

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Robot motion is an aspect of programming in addition to the system controls, to ensure that the sequence of operations is executed seamlessly.

Vision and Sensors

Role/Responsibility

Vision has simplified robot cells and at the same time increased flexibility, especially for small batch runs. Sensors and vision can detect presence or lack of presence of physical features, and can determine part location and orientation. Vision and sensors are also used to validate in-process quality, in optical character reading, and in part identification

The shopping list is a tool to begin organizing a scope of work for the system. The robot itself is just one component of the list. Defining the robot is normally the simplest task of the project. The system risk and primary cost are driven by all the peripheral ingredients, especially the criteria for the transfer of raw material in and out of the system. The saying “you can do anything with automation” is a true statement, it just takes money. Developing a scope of work that defines the ingredients in a robotic system, as well as the functional specification, makes all the difference in reducing the system risk and cost. The costs of robot systems are a function of the part requirements, process, level of flexibility, and the services responsibility. The system hardware is generally the major part of the system cost, as compared with the servicing hours associated with the engineering, management, and integration of the system. It is easy to see why automation requires a team effort, and why there is a large market for system integrators that manage the details. The devil is in the details and the more details can be defined early in the plan, the lower will be the integration costs, and the more successful the system.

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Judging a Good Project from a Bad Project

For every application type, sources are available to serve as tools for defining the needs and wants of the project. At the start, the most important first step is to identify the need. In other words, the source of pain in the manufacturing value stream needs to be identified. The conclusion may be obvious, but there is an important exercise that first needs to be performed.

Before robotics can successfully be implemented for a particular process, the engineer needs to understand the manufacturing sequence of events. This exercise is important because the sequence must be defined before the process can be integrated with robotic automation.

Furthermore, the relationship between one sequence and another within the value stream, from the receipt of raw material until the product is packaged on a pallet ready to ship, also needs to be defined. Automating an inefficient step, or the wrong step in the value stream, can backfire quickly, and the gains the user assumed would be received will not be realized. In other words, never automate a bad or undefined process.

A common approach to planning automation is to examine how the process needs to operate in a manual operator state, because most engineers already understand how to manage the manufacturing process with direct labor. Whether the manufacturing process or value stream is already in place, or is being redefined because the process is new, the exercise of defining the process with manual labor allows the engineer to determine many factors. These factors include throughput requirements, labor requirements at each step, cycle time of each step, and the overall sequence of events. At every step it is necessary to examine how waste can be removed and reliability added in.

Defining the process using direct labor establishes a reference to which automation results can be compared later. The following criteria are applicable for most processes, both those in place, and, if the process is going to be new, those to be included in a new order. Some important questions regarding a hit list of process information are as follows:

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- What is the throughput required in units per day or shift to meet demand for each of the individual parts to be produced?
- How many hours need to be planned on a daily basis to meet this demand?
- What are the sequential steps in manufacturing the component? Process sheets outlining the operating steps are very useful here
- How much labor is needed at each step to achieve the overall throughput?
- What changeover requirements are necessary for the operator to switch from production of one product to another, and how much time is associated with the changeovers?
- What decisions need to be made at each step in order for the operator to produce a compliant or quality part?
- What kind of inspection is required in the process and what is the frequency of inspection?
- What are the characteristics of a “good” part at each step?
- Are there any safety, ergonomic, or environmental concerns to the operator?
- Are there redundant operations in the process where the operator task is the same, over and over, for every cycle?
- What is the scrap rate, and where do quality problems lurk. Understand the root cause of any quality problem. Is the product within tolerance?
- Are there any current floor space, utilities, or ceiling space constraints for where the process is located today, or where it will be located later?
- What is the means of material flows from operation to operation?
- Are part prints and models available?

Other benchmarks that need to be identified, especially for existing processes, are related to achieving the intended throughput rate. End-users often say “I am getting 45 parts per hour”. The problem is that the available time on an hourly basis indicates that the

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throughput should really be at 65 parts per hour. Overtime rates and the number of shifts also should be taken into account because robotics will impact efficiency, resulting in a higher throughput using the same quantity of assets. The reverse could also be important, meaning that even though the robot system is capable of producing 65 parts per hour, the customer demand is for 45 parts per hour and there is no benefit to building up inventory.

The heart of the matter is: “is this a good or bad robot project”? While going through the exercises above, the engineer will learn a great deal about the process, whether it is new or existing. It is best to answer the questions directly to users. However, it’s usually obvious if the robot project is not a good project. There is a quick mortality rate for bad projects because right away there will be indicators, often with the shop floor operator struggling, and there is no sense in automating a bad manual process. Examples are lack of chip control in a machining operation that causes chips to build up at the work-holding locations and prevents the robot from loading the work-piece.

Another example is weldments with a gap condition that exceeds the welding wire diameter several times over, or welds that simply cannot be accessed. The other immediate feedback is when the economics and/or justification shoot down the project. Also, there is sometimes a better way to skin the cat than to use a robot. Not every process should be automated, and for some projects the economics make no sense versus alternative forms of automation, or the cost is too high to manage all the sins of the process. Some examples of applications that can be bad candidates to automate are as follows:

- The process, by design, prevents parts from meeting print tolerances
- Operator intervention is very high relative to decision making and dexterity. Examples are special inspection requirements that a conventional gage or sensor cannot measure, or when the inspection is more visual than empirical, or there is a need to adapt to varying welding part conditions, that require the operator to compensate to make an acceptable part at each cycle

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- Changeover requirements are too drastic, so that a significant amount of the daily hours available are used up in changing or adjusting hardware. There certainly are jobs like this, but not generally. The problem is that the robot efficiency can never be exploited because the process does not allow enough run-time.
- Another form of “dedicated” automation is a better fit because of too much variation from part to part in each cycle, or the same redundant process is used in a high-volume setting. Examples are a linear pallet pool (LPP) system for a flexible machining system that is machining a batch of one production flow. At each cycle, a new part with unique geometry is introduced into the system. Again, there are exceptions where robots will replace the LPP as the primary device servicing the machine tools. Another example is a high-volume lathe-welding process where end caps are welded to each end of a pressure vessel. Typically a dedicated form of automation will be used to accomplish the “common” task with a fixed welding torch and the work-piece turning 360 degrees under the fixed torch.
- Floor space or other external constraints make automation impossible. Often in food-focused industries, for example in bakeries, the infrastructure of process equipment and space was never planned for automation. Older facilities are especially land-locked in their ability to support the space for a robotic system.
- Automating a process with significant downtime caused by poor running equipment, or a poor process.
- Automating a process where the operators or production culture are not sold on automation. Attitudes are among the most critical characteristics governing whether a project is going to be good for automation.

Many more examples of good and bad projects are discussed in this text.

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The next section describes the importance of gathering details when the project parameters and solutions pass the litmus test in terms of economics and technical feasibility.

Gathering the Right Details

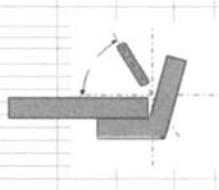
The detail that is gathered to justify or to initiate a robotic project really is the same across all industries and applications. There are process-specific and applications-specific criteria, but the methodology is the same.

The first thing that should be gathered and the item that drives the entire process, solution, and cost, is the parts/products that are being manufactured, and specifically the process steps considered for automation. This first thing may take the form of prints, albeit 2D, but availability of 3D solid models makes a big difference in the type of analysis that can be developed. The old GIGO saying that garbage in is garbage out is absolutely true when it comes to gathering the detail. As a minimum, a start should always be made with the prints.

The applicable checklist for any application is the list detailed in the previous section. The following pages describe a more detailed list for various application types:

Criteria for Arc Welding

Example of a Weld Procedure Table	
Weld Number 1	Weld Number #1
Joint	
Process	
Part Orientation	
Torch Angle (travel)	
Torch Angle (joint)	
Torch Position	
Electrode	
Gas shielding & flow(CFM)	
Power source	
Travel Speed (inches/min)	
Length of weldment (in)	



Example of a Weld Procedure Table

- Weld procedures (gas type, filler metal, weld travel speed, bead size, joint type, number of weld passes per joint type)

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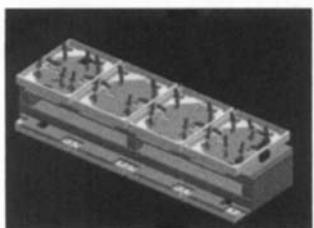
- Preheat, post-heat, or inter-pass temperature requirements
- Work-piece positioning to enable each weld to be welded in the flat or horizontal position
- Quantity of welds for each assembly or sub-assembly, and length of weldments
- Product weights
- Product base material
- Pre-tacked parts or loose parts. Can loose pieces be locked and tabbed to simplify fixturing
- Welding sequence for distortion management
- Tolerance of the weld joint (dimensionally, and as a gap condition of the weldment)
- Managing fume collection
- Definition of a “good“ weldment (i.e. penetration, size, appearance)
- Definition of inspection criteria if applicable
- Floor layout constraints
- How the system interacts with the operator for part changeover and part setup prior to robotic welding (i.e. tacking, heat treating, prepping work-piece)
- Monitoring of process parameters and deciding which criteria is important to monitor. What kind of feedback is being measured, and what actions are to be taken when a parameter falls out of specification? For example, the variations may be in a flow switch controlling water flow to a water-cooled torch or a flow meter controlling shielding gas flow to the weld area.
- How to balance operator load/unload time of finished and pre-welded assemblies while welding continues
- Safety precautions to protect the operator without interrupting the robot weld cycle during the load/unload cycle

The critical component for the robotic welding cell is the fixture holding the work-piece. There are two primary fixture styles; holding fixtures that hold a tacked assembly in place, or a tacking fix-

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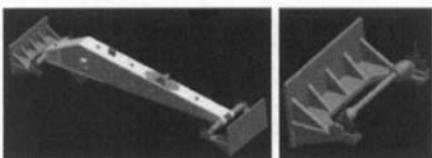
ture where the pieces are loosely held and the robot tacks and welds. Fixture design affects robot access, torch access, changeover from one part style to another, weld cycle time, part tolerances, and cost. Access to the weld areas of the work-piece, and part dimensional tolerances, are critical to reliable welding. These requirements are the reason why manual fixtures often do not work for robotic applications. Fixturing is the key to a successful welding program.

Figure 2-16 Weld Fixturing Examples



Multiple work-pieces on two sides of a fixture allow a balanced throughput between operator load/unload time and welding time. In this fixture the operator loads both sides of the fixture.

This positioner will be integrated to a rotating robotic headstock/tailstock positioner. Parts are not tacked when located in the fixture



This fixture is an example of a holding fixture that secures the part with open access for the robot to weld. This fixture will be installed within a robotic headstock/tailstock positioner

The fixture designer must be aware of how the process is defined and where the robot and weld torch need to be positioned to achieve an acceptable weld. Whether the fixture is automatic or manual is another consideration that needs to be addressed. How the operator interacts with the fixture needs also to be understood. In other words, how automated is the clamping function of the fixture. Designing for quick changeover of fixtures also is necessary if multiple parts styles are to be welded in the system. Fixtures must be designed to resist weld spatter. Fixtures may also have to be designed to confirm part presence, to validate that the part is secured correctly, and that it is located within the tolerances needed for welding.

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Criteria for Tending Machines

- Part weights
- How the machine tool work-holding is holding the work-piece for each operation
- Type of work-holding for each process
- Dimensional tolerances of component and tolerance for loading machine fixture(s) at each step
- Required orientation of the work-piece when the machine is loaded for each operation
- Base material for each component to be machined
- List of sensitive part surfaces that must not be touched by robot grippers
- Can parts be allowed to touch in the queue at the inbound or outbound sides of the conveyor
- How large a part queue is needed at the inbound side
- Cutting times for each process step
- How are chips managed in the fixtures and discharged from the machine tool
- Machine tool type and quantity at each process step
- Do the machines have shuttles or pallet changers
- Machine tool quantity by type for each cutting operation
- Machine tool control brand and model
- Where do programs reside for the machine tool
- Signals for hand-shaking between robot control systems and machine tools
- Gauging requirements or other inspection tasks
- Washing or deburring requirements
- System controls for feedback and monitoring of process parameters, and how operator interacts with the system for changeover
- Air blow-off
- Floor layout
- Requirements for access to machines without interrupting robot cycle

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- How parts are presented to system (drawer system, conveyor, dunnage, shuttles, bin, pallets, etc..)
- How parts are transferred out of the system. If they are palletized, what is the design of the pallets, and what is the palletizing pattern.
- Managing parts that fail in the machining process – where do they go
- Keeping the floor clean of coolant spillage
- Buffer requirements in the event of uneven machining cycle times between processes
- Time study of machining process
- Can chip breakage be incorporated in the tooling
- Does the work-piece require a pusher or other mechanism for reliable loading
- Is a washing operation required after machining
- What is the tool life, and the frequency of tool adjustment or changing
- Will an air blow step suffice to separate the part from chips or is a washing operation necessary
- How do offsets get updated in the machine tool

An example of a machining time study is shown on next page:

The key to machine tending, and where the bulk of the cost lies, is associated with the transfer of product into and out of the work-cell. Machine tending is ideal for running lights-out, depending on the design criteria of the inbound and outbound systems. A good approach is to design the raw material inbound queue to enable the system to run a reasonable amount of product without an operator presenting new material and removing finished material. Typical queues are planned around 30 – 60 minutes. For long cutting cycles, or parts that can be picked directly from a bulk container as an example, production can run for significantly longer unmanned periods. See Figure 2-18 for an illustration of bulk part presentation.

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Figure 2-17 An example of machining time study



Multiple layers of parts located within a buckhorn container. The robot is responsible to find and locate parts as well as pick the black divider board the parts are resting on

Robotically picking product out of wire mesh container



Palletized product waits for the robot to remove wooden divider boards on top of product and then remove Individual pieces based on system demand



Figure 2-18 Example of How Bulk Raw Material can be Presented to a Robot System

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Criteria for Press Tending

- Part weight
- Thickness of blanks
- Base material
- Painted surfaces
- Oily, sticky, surfaces of raw material
- Press type (tonnage, bed length, control system, gage system)
- How product is transferred into and out of the work-cell
- Are formed parts palletized, and what types of pattern or nest are used
- System control requirements for production monitoring, part selection, and part changeover
- Defining brake tooling for the die and punch
- How each part type is processed through the bend sequence, indicating the bend
- Bending tolerance and inspection requirements if applicable
- Changeover requirements for brake tooling
- How will tooling be set up in the brake (i.e. progressive tooling)
- If the base material is stainless, is there a plastics covering on one side
- Floor layout
- How is tooling changeover managed

Unlike machine tending, where the emphasis of cost is in the material transfer into and out of the work-cell, the inbound queue for press tending is much simpler because the raw material is flat blanks that are stacked on top of each other. Press tending is ideal for a small-batch process where the system is designed to be automated for many part styles. The key and emphasis on cost are related to the grippers that are required to handle all the potential part geometries through the forming processes. Additionally, in brake forming, how will the tooling be configured for small batch runs. If changeover is minimal, then a high uptime can be assumed. It may also be possible to use the robot to change brake tooling to reduce changeover time.

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Palletizing/De-Palletizing Data

- Pallet types and sizes
- Slip sheet types and sizes
- Description of each product (size dimensions, weights). Are they boxes, buckets, containers, etc.
- Unit load description (number of layers of product, are layers of product flipped every layer, product per layer (pattern))
- If bags, what material (polythene, paper, etc.)?
- Wash-down considerations, or special environmental requirements for cleaning or hazardous specifications
- Floor layout
- If cases are used, what kind of cases. Do cases need special handling to avoid damage. Do labels need to be presented in a certain way when the case is placed onto the pallet
- How pallets are presented to the system
- How are slip sheets presented?
- Mixed-unit load requirements
- Are stretch wrappers or other wrapping methods required?
- How is raw material presented to system (i.e. conveyor)?
- What is the control system for production monitoring, and product changeover
- Is integration to a higher plant level control required
- Managing buffer in a system when a full pallet is transferred out of the cell
- How are full unit loads transferred out of the system
- If de-palletizing, what is the tolerance for product location as it rests on the loading unit
- What tolerances are required for the inbound raw material to build a uniform unit load
- Product inspection prior to reaching robot cell, and arrangements for dealing with non-compliant product. (i.e. checking bag weight as bags are conveyed to robot)
- Definition of a “good” unit load
- Flap management requirements (i.e. flap detection)

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- Use of lock'n'pop or other means to prevent cases shifting during transport

Palletizing and de-palletizing systems need to be configured primarily around transfer of raw materials in, and finished unit loads out, or vice versa. Palletizing can be cellular where the cell is fairly simple, as shown in figure 2-3. Robotic palletizing can also become very complex, especially in a high-volume palletizing facility with multiple product lines and/or product, converging on a centralized palletizing area. The complexity involves a high level of material transfer equipment such as conveyors and high level system controls to manage the additional products and maintain communication between devices.

Criteria for Material Removal

Material removal is a very broad term but for the purpose of this text it is considered to include deburring, grinding, de-flashing. Buffing, and polishing are related processes.

- Defining a good part or surface finish/condition for every region on the work-piece to be processed
- Does a constant force need to be applied to the surface to achieve surface finish requirements
- Defining the part tolerance where removal of surface material is required. For example if the work-piece is a casting then the tolerance of the surface to be removed will vary
- Identifying where material is to be removed from the work-piece
- Defining the range of product by size, weight, and base material
- The physical size range of burrs, gates, flashing, and parting line that is to be removed
- How product is to be transferred into and out of the work-cell
- Tolerance for how much material is required to be removed relative to the base material
- Defining the media that is currently used manually (type,

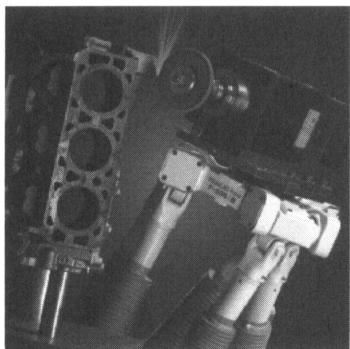
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style, and grit)

- Defining the tool life and frequency of changing tools
- Feed rate in removing material
- Base material type

Material removal is defined in two ways. Figure 2-19 illustrates an example. The media or also called tool (e.g. Snag Grinder) is taken to the work-piece or the work-piece is taken to the media or tool. In either procedure, compliance is also a major factor in providing a reliable robotic process. Compliance is defined as maintaining a constant force during the material removal process, taking into account such factors as the variable surface tolerances of the work-piece, gravity, the position of the tool, and media wear. Material transfer into and out of the work-cell is also a large component to the system concept, just as with the other application types.

Tool (media) to part



Part to tool (media)



Note: Smaller parts are often presented to the tool (media). Larger parts are usually fixtured and the robot takes the tool (media) to the part

Figure 2-19 Material Removal Examples, Tool to Part or Part to Tool

The need for robotic material removal is more important than any other process because of safety, quality, direct labor cost, scrap

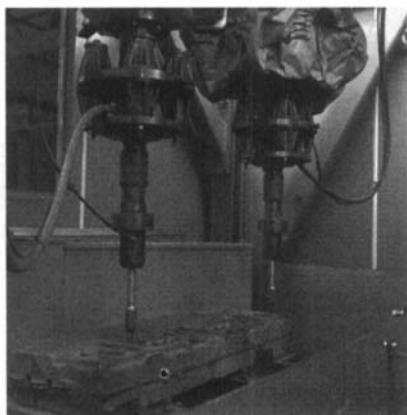
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reduction, and difficulty in finding and training operators. Material removal is a brutal job to perform manually. Usually new employees get material removal duty first because it is a brutal job. At the same time, material removal poses the greater risk compared with other robotic applications. Risks are associated with defining a “good part” and the trial and error that goes into developing a reliable process, given varying part tolerances. Most material removal projects require a validation phase whereas for other applications the validation phase is minimal or not required.

A good start in assessing how robotic material removal can be accomplished is to first examine the tools currently being used by the manual operator and process. Figure 2-20 illustrates a before and after example where the robots tools were designed to mimic what the operator used.



Before automation



After automation

Figure 2-20 Applying the Tools Used Manually for Robotic Automation

Constants and Variables of a Robot System

Constants are defined here as what is known about the process as well as what are the rules. The data that is gathered during the audit phase of the project is termed design criteria. Design criteria are the known parameters of the process. Examples are noted below. Understanding the rules about the process requirements is what

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drives objectives, goals, expectations, and benchmarks. The variables are associated with how the solution will be conceived, designed, and built. At some point in implementing a robotic system, the system has to be validated in terms of function and performance to ensure that the design of the system solution achieves the goals within the rules set early on in the project audit phase. Providing answers to the application question lists in the examples establishes very quickly how well the process is defined and what it is that you know and don't know. Most expectations fail to be achieved because the constants are not accurately defined up front. During the audit phase it seems that many engineers are rushed into a time frame to implement a system where details are overlooked, ignored, or simply guessed. An example of establishing constants and variables during the audit phase of a project is as follows:

Examples of Constants (Design Criteria):

- Defining the generic manufacturing process by sequence of operations
- Product information (including prints, solid models)
- Description of how product needs are to be transferred into the system
- Description of special requirements in locating parts for the robot process
- Description of what happens, and the requirements of each operation
- Description of manual intervention at each operation
- Process sheets for each operation

Examples of Variables (Automation Solution):

- Robot process achievement rate
- Robot access through all the robot motion in a program, avoiding obstacles and having sufficient reach
- Robot gripping in terms of feasibility between how the product needs to be gripped and what can be designed

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- Achieving material quality requirements (weld profile, surface finish as examples)
- Functionality of peripherals. For instance, will vision work in the shop floor environment, or will the fanning magnet actually separate the steel blanks so that the robot doesn't pick two blanks instead of one at the beginning of the process

Defining the project design criteria using the example project shopping lists is a good habit. One of the by-products of the defined design criteria is a set of variables that make up the automated solution. The variables (unknowns) are sorted and ranked by various levels of risk. Managing the unknowns is what separates the good and the better system integrators as well as the users. Unfortunately, in some instances, the unknowns are not even known until the system is built and in a position to be run. Having a plan to manage risk ultimately improves cost, delivery, and reliability of the robotic system.

3

Robotics and Risk

Risk of the unknown goes together with robotics more often than with any other piece of manufacturing capital equipment purchased by a firm. This chapter will discuss risk in two different ways. First, the perceived risk associated with change. The change in terms of moving from traditional manufacturing using direct labor and replacing the process with robotics involves risk. The second aspect of risk is related to the unknowns associated with an automation project, either in terms of inconsistent inputs (process raw materials), lack of a sound plan, or utilizing new technology.

The following five categories embody the winning formula based on experience in working with hundreds of robotics users nationwide. The best robotic users in the world are those that:

- 1) Design the manufacturing process up front for automation. For instance, designing slotted and tabbed parts for a steel assembly.
- 2) Select programs to pursue where automation offers a competitive advantage. Focusing on product mixes that minimize changeover of process machinery, or parts that require a quality specification.
- 3) Commit to developing the right team of people on site that accept accountability,
- 4) Invest in a culture of understanding technology as well as the application of robotics, especially after the system is installed, and
- 5) Establish a realistic budget for executing the program without having to take shortcuts.

First-time potential robotic users play out a familiar scene. First there are the usual suspects of pain that the user has been enduring

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for a period of time. For instance, the lack of skilled labor, quality problems, and/or the unbearably high cost per piece. Then, during the audit and discovery phase, many of the firms' manufacturing and management team conclude that robotics will provide positive results, but the thought of robotics in place of traditional manufacturing is perceived to be too risky. In the definition of this type of risk, the following short list applies:

- What will happen if we still need to run the process manually for whatever reason
- Our firm doesn't have sufficient volume to use robotics because we are a job shop
- The general fear that robotic technology is too complicated to use
- The fear on the shop floor where operators see a robot doing a job that was previously done by an operator and begin to wonder if their jobs are in jeopardy

All these are valid fears. Chapter 6 was specifically developed to respond to the second point concerning small-batch runs because that topic is one of the most often perceived obstacles to the use of robotics. So far as the other perceived risks go, there isn't much to argue about because they are subjective and based on emotion. Education certainly is the right approach to break down perceptions but typically, most firms wait as long as possible to teach employees how robotics can be adapted to their manufacturing environment, or they wait until the pain becomes severe enough. Operators losing jobs because the firm invests in robotics is a myth, because one of the biggest sources of a firm's pain is that they can't find skilled operators.

If a firm is more profitable as a result of its commitment to reducing costs there is all the more reason for it to be able to retain employees. The goal, of course, is to train employees to perform more complex operations, leaving the robot to perform the more redundant work. Additionally, the firm wants to increase productivity with its existing labor. Simply said, firms don't invest in automa-

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tion so that operators can be laid off. Firms certainly will increase output with less labor, but the skilled labor that was present before the robot was installed still remains the most valuable resource the firm has. Robots often enhance operator responsibilities by forcing the operator to do tasks that are more complex, somewhere else within the firm. Certainly there will be the need to monitor the robot system.

The capital investment for automation is significant, regardless of the amount spent. However there is always an investment, regardless of whether the process to produce something is automated or manual. Many managers forget that there is always a cost to manufacture a product, and they sometimes don't take the time to examine what savings could be achieved with robotics. As noted earlier, the cost of ownership for a manual process is a reality. Along with the perceived risks of robotics, there are certainly risks associated with manual intervention in producing a commodity as well. Some firms feel that the lesser of the two evils is to manufacture the old fashioned way by paying a human operator to pick up a welding torch or a grinding wheel, or stand in front of a machine all day. The challenge for most firms in pulling the trigger to make a capital investment in robotic automation is a function of the fundamental lack of understanding about how their process can be adapted to automation.

For instance, comparing the purchase of other forms of capital manufacturing equipment such as a CNC lathe, a CNC laser and punch, a press brake, an injection molding machine, a stretch wrapper, or a custom drilling machine, the equipment delivers a known technical capability per the manufacturer's specifications. Robotics themselves deliver known values as well, such as reach, number of axes of motion, and weight-carrying capacity. What is interesting is that the user doesn't hedge in the buying decision of a stand-alone piece of capital equipment, other than perhaps the brand and version. There are versions of robotic systems that are approaching the level of product acceptance and maturity as shown by the examples in this book. The challenge is to continue to educate potential robot users about driving costs out of the manufacturing value stream.

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When manual labor is used in an existing or new process there is a whole set of process parameters that can be assumed to exist in order to accomplish the production needs. For instance, why worry about the shopping list of process criteria discussed in Chapter 2 when the process is manual? The firm need only worry about getting the job done and not necessarily the means. That same thought process is also the Achilles heel of US manufacturing because it is contrary to lean, and to driving to lower costs. An example is that one of the obstacles commonly cited as to why a firm will not automate is because they run small production batches. The reality is that we live in a world today where manufacturing must support a batch of one, a production environment that in itself defines Lean manufacturing.

The fact that robotics epitomize the theme of lean manufacturing, due to their inherent traits of programmability, consistency, and adaptability, is something that has to be validated for each user, because it is not yet common knowledge. The connection with how robotic automation can be utilized to further emphasize small batch production also is not fully understood. The perceptions about automation are often myths and not reality. Unfortunately, the perceptions about what automation can do are also myths when it is considered that a firm could simply assume that, “robots will solve all my problems”.

Consider a new program where process equipment must be purchased. The firm quotes the program on a cost per piece basis. The cost per piece is derived from labor inputs, process equipment cost, raw material cost, and overheads. Robotics will level the playing field with low wage competition for the labor component, but will also drive the overall capital investment component, which can be daunting. Firms look at the robotic investment with two sets of glasses. One set provides the view of fear, failure, and the unknown. The other set provides a sense of comfort because that is the experience of the decision makers. The global market however is not forgiving and has only one set of values; quality products delivered on time at the best cost, and by the way, tomorrow's needs will change in terms of product style and quantity. One of the sayings

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that is appropriate here, from the CEO of FANUC Robotics' Rick Schneider, is "Innovate or Evaporate".

Firms spend considerable funds training their employees in adopting the principles of Six Sigma, ISO, Lean, 5S, and other improvement initiatives. It is interesting to note that, after engineers attend these various programs the implementation of automation is a natural next step. A firm committed to hiring a Lean engineer or Six Sigma black belt, as an example, should be challenging its manufacturing team about using automation. Engineers and managers will absolutely acknowledge they see the light concerning the value of robotics, and how they can be adapted to complement the manufacturing value stream. From the author's perspective, dealing with an educated user makes all the difference in whether a robotic program will be successful or not. Part of the qualifying process in working with a new potential robotics user is to evaluate the internal capabilities and education, first about their process and second, about their ability to define their goals and objectives surrounding the proposed robotic automation. In effect, a lack of education and lack of knowledge about the initial scope of the work is a major red flag.

Based on many interviews, people engaged in implementing robotic systems would certainly all agree that they have made mistakes that contributed to a robotics system having less than stellar performance, relative to the user's expectations. Not to be too controversial here, but the greatest contribution to poor system performance is usually the fault of the party that intends to use the robotic system. The hot list that follows defines the majority of reasons why robot systems "go wrong":

- What were thought to be the product tolerances proved to be inaccurate, so that problems were much worse than expected, and of a random nature
- Specifications were hidden or changed after the scope of work was defined
- The scope of work was not adequately defined at the beginning of the project

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- The shop floor personnel simply did not embrace the robotic system and the system was doomed before it arrived on the user's floor
- The robot was used as a band-aid to solve a bigger-picture process problem
- The robot system was mis-applied in the first place
- The system was rushed into production without adequate run-time
- The highest application, with the highest level of risk, was selected, versus a more straightforward application that had a better chance of success
- Lack of continuity in key team players from start to finish of the project
- Lack of a defined budget, causing serious pain later, when the system was delivered, because what the firm wanted and budgeted were not in line

Lying to ourselves about how bad a current process or process inputs can be is not a good thing with robotics. Additionally, speculating about the criteria for a new process that is not yet in production will also set up the engineer to fail. Obviously one cannot know everything about a process, nor is there enough time for study. Whether you're selling or buying robotic automation it is vital to make sure that the full spectrum of part conditions is put on the table for the team to understand. For example, in a robotic welding application, understanding the extremes of gap condition for a particular weldment will affect how the process is developed to cover the cross-section of process conditions.

Many of the seven risks listed at the beginning of this Chapter can be avoided by effective communication. There are however some basic principles to adhere to and one of those is to acknowledge the brutal facts and set the expectations accordingly. Given the aforementioned list of the seven deadliest robotic automation sins, there are still countless systems that have been in production for years, despite the technical challenges, because realistic expectations were set. The point of this section is that regardless of a good

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or bad robotics program, if a sound approach is followed to understand the process, followed by the definition of needs and challenges, then the risks become manageable.

Risk and Cost

Naturally there is a proportional relationship between risk and investment. Most of the first-time robotic users would feel the “fear” risk of the unknown, in installing a robotic system. That type of risk doesn’t correlate to additional cost. The risk that affects cost has to do with presenting an inconsistent input, and converting the input to what would be considered a “good” part. Risk is also a function of taking responsibility for something that you don’t control. In other words, a user may need to automate a new program and desire to find suppliers that will take responsibility for making a good product. However, the suppliers don’t necessarily control the condition of the raw material, so may not be able to perform as expected. Risk also comes in the form of “what you don’t know,” and usually appears when the system is already built. The system is being de-bugged for production and there is literally no way to find out about this type of risk until the system is being validated.

Using a conventional dictionary, risk in terms of automation can be defined as many things, but the short list would include the following:

- The probability that a particular threat will exploit a particular vulnerability of the system
- There may be external circumstances or events that must not be allowed to happen for the project to be successful. If such an event is likely to happen, then it would be a risk
- The chance of something happening that will have an impact upon objectives. The risk is measured in terms of consequences and likelihood

Risk is everywhere in manufacturing, especially when something new is being developed. One of the greatest strengths of US manufacturing is its ability to develop new products and have a “do what

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it takes” attitude. This section tackles the “realistic” aspects of risk when considering the implementation of a robotic system. Risk of unknowns is fine, and robotics would not have proliferated in world manufacturing to the extent it has without managing that risk, and having a sound implementation plan.

It is ironic that the robot itself is the most reliable piece of equipment in any manufacturer’s facility anywhere in the world. Of course when a “system” has a hiccup, you always hear, “that robot is a problem”. For definition purposes, the risk that is referred to in this section is completely targeted at the robotic system, as including all peripherals that are integrated together to perform a process or task. Robots today exceed 70,000 hours mean time between failures and there are hundreds of robots in the industrial workplace that have exceeded 15+ years without a failure or with minimum maintenance. In summary, risk is associated with the following attributes;

- the integrated solution that includes all peripheral components apart from the robot
- the introduction of raw materials with variable tolerances (inputs)
- the process used in converting inputs to outputs

With the appropriate amount of cost, just about any application can be automated. In the quoting or estimating process of a robotic system, the issue isn’t necessarily how the solution can be derived. The issue is the cost to manage the risk, and who takes responsibility for the cost of that risk. On behalf of system integrators, this point is summarized in two questions, “who is responsible for making a good part, and what is the definition of a good part”? Users often use the term “turnkey” which needs to be defined carefully. Turnkey and risk can be synonyms because turnkey means process and part responsibility. Turnkey also means suppliers do not get fully paid until the requirements are met. In the author’s experience, most users do not have the internal capability or resources to take on projects in a turnkey sense. A result of this trend has been the cre-

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ation of a large network of robotic system integrators who are more than willing to take on turnkey programs. At the same time, risk is then transferred from the user to the supplier, creating a situation that requires strong communication.

The Categories		Risk point values
User Defined Factors (OPTIONAL). What the user is taking responsibility for		
List unique criteria in this section - categories are unique to user and the project		
Example: Work-piece requires washing as well as satisfy a cleanliness specification - user provided washer		1 thru 5
Example: Parts are required to be picked from Dunnage/tray system - user providing trays		1 thru 5
Personnel Factors		
Shop floor technicians/operators have capability and attitude to support the robotic system		1 thru 5
The project allows for a manageable time frame from concept to install		1 thru 5
The installation site is close to where the automation team is based or is easily accessible		1 thru 5
In-House integration capability		1 thru 5
The shop floor personnel are accepting of automation		1 thru 5
The team has prior robotics experience working a similar project		1 thru 5
The team has prior robotics experience in robotics in general sense		1 thru 5
Technical Factors		
Is the end product currently being manufactured successfully with or without robotics		1 thru 5
Is this project a repeat project of something already in production		1 thru 5
The technology to achieve the desired system performance exists, or can be demonstrated		1 thru 5
System performance metrics are defined and known		1 thru 5
Raw and finished product exists as well as part prints and solid models		1 thru 5
Does the system have any special codes (i.e. UL), or regulations (i.e. Washdown)		1 thru 5
Is cycle time realistic to achieve		1 thru 5
Description of Rules:		
1. Rank each criteria 1-5 with 5 being extremely risky because its unknown		
2. Maximum score for technical category is 35. Maximum score for personnel category is 35		
3. Add as many user defined criteria as needed and then rank them 1-5		
4. If the technical or personnel category has an overall score of 23 or higher then take time to validate red flags		
5. Any criteria with a risk factor of 4 should be noted as a red flag		

Figure 3-1 Risk Gauge for Robotic Automation

There should be a risk gauge. Figure 3-1 shows an attempt to describe a measurement tool for risk developed by Tim Lang. The gauge can be completed fairly quickly, and was designed to be used as a barometer for measuring risk versus reward, in terms of the capital investment decision. Just because there is risk does not mean that the project is bad. It is simply important to identify the risks early on in the project to save time and money later, when typically there are no funds or time to troubleshoot problems. Additionally, the capital investment increases with risk. The gauge describes three primary categories, one of which may or may not be used by the user. The optional category has to do with project-specific items for which the user is taking responsibility. Examples are noted in

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the chart. If the user is expecting to take no responsibility for the robotic process, then that category would not be used. Another purpose of the gauge is to identify red flags that are not yet defined. The next Chapter discusses ways to eliminate or validate these red flags.

Supplemental information for Figure 3-1a is shown below. This list is intended to ask the user some generic questions regarding the project, and determine how the project ranks within a risk/reward map. The map and gauge are certainly not the gospel, but are indicators to challenge the team about whether appropriate costs and risks have been identified.

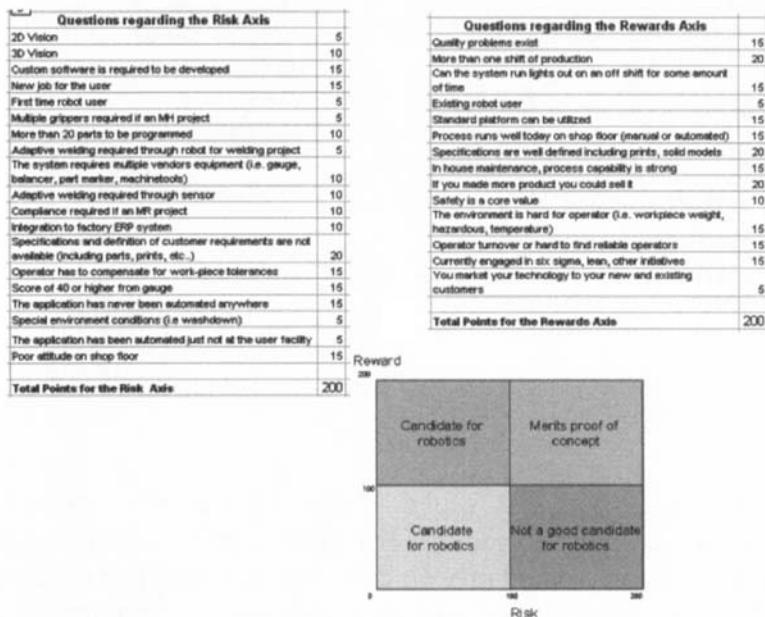


Figure 3-1a Additional Robot Product Evaluation

The gauge and risk/reward map are applicable to custom-engineered robotic systems. There is also a large market within the robotic industry for standard robotic platforms, regardless of the application type. Standard robot systems are inexpensive, are literally a commodity item, and are good value. At the low-risk end of the gauge there are many standard robotic platforms with many

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robotic applications that can be immediately drop-shipped, plugged in, and made ready to run.

Figure 3-2 illustrates some examples of standard robotics solutions consisting of hardware and software, including the integrated deliverables that typically accompany a common platform. The user needs only to install the utilities and the system is ready to be used. In its condition as a standard, the system is not applied, meaning it is not programmed or configured to do any task.

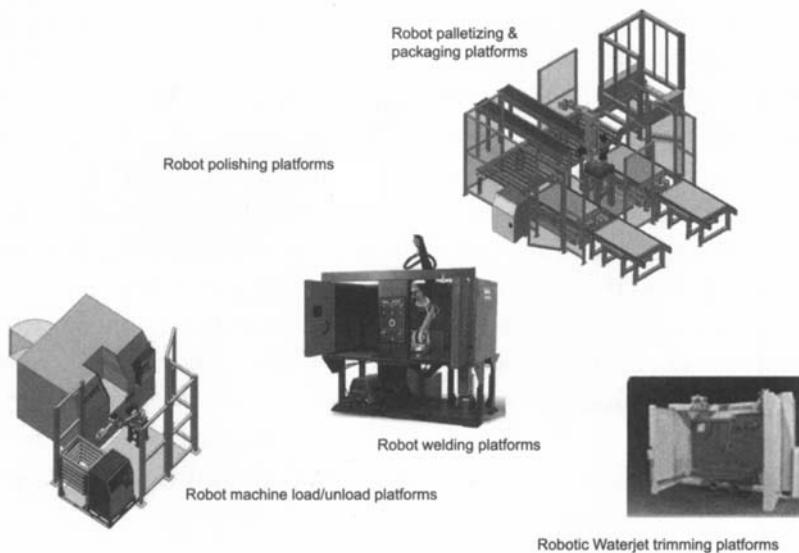


Figure 3-2 Examples of Standard Robotic Platforms/Systems

For instance, the welding industry has primarily fitted its applications into just a few standard configurations. For any of these configurations, the user or contractor is responsible for integrating a welding fixture, a means of exchanging any fixture for another in a reasonable time frame, programming robot motions and welding schedules, and test/de-bugging the process until the program is ready for production. The capital investment for the standard configuration is low, varying in relation to the complexity of the part and the process. The same goes for the cost of machine tending; the

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robot gripper fingers, the system to identify raw material location/orientation, and the robot motions, which are all requirements beyond the standard platform. Standard systems, including the hardware side and the value added, generally yield excellent return on investments for users, especially when the robot system can be kept busy for more hours of production.

The examples of standard robot platform applications shown in Figure 3-2 are widely accepted and the equipment is quoted and sold like the commodity capital equipment previously described. As in any other industry, the principles of product life cycle apply in the world of robotics, as illustrated by the product life cycle (PLC) curve in figure 3-3. Robotics for many applications have arrived at the maturity point on the curve, although many curves would be required to capture where robotics are, relative to the PLC curve. For instance the welding market for robotics is more mature than the market for robotic press tending, at least in the US. The interesting dynamic about robots is that they are programmable machines with a very long life in terms of manufacturing machinery. New technology enables robots to be continually upgraded or redeployed, for tasks that are completely different from the original purchased use. Thus, in effect, new technology, especially in robot software, extends the growth period of the PLC curve for conventional

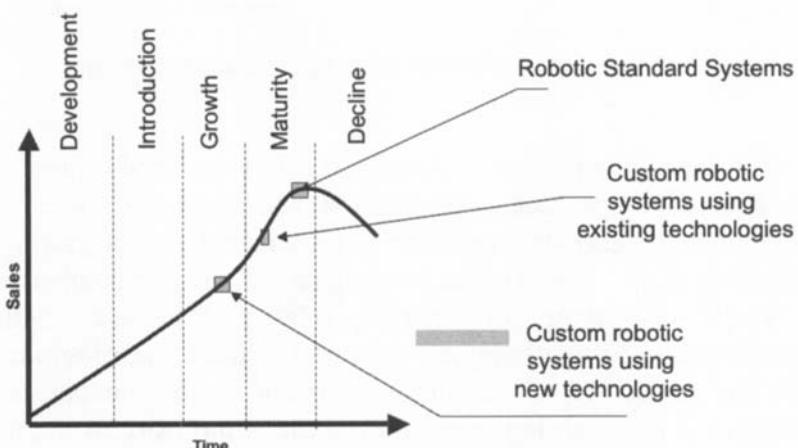


Figure 3-3 Typical Product Life Cycle Curve (PLC) Industrial Robotics

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robots.

Regardless of a standard low-risk system, the seven sins are still lurking. For instance, Figure 3-4 illustrates a fairly simple-looking part. The customer's expectation is that a standard welding system will locate and rotate the cylindrical part in a repeatable and accurate position, to achieve welds that comply with the customer's welding specification. The expectation is that the supplied equipment will make a component from the user's specified raw materials, that will pass inspection, cycle after cycle.

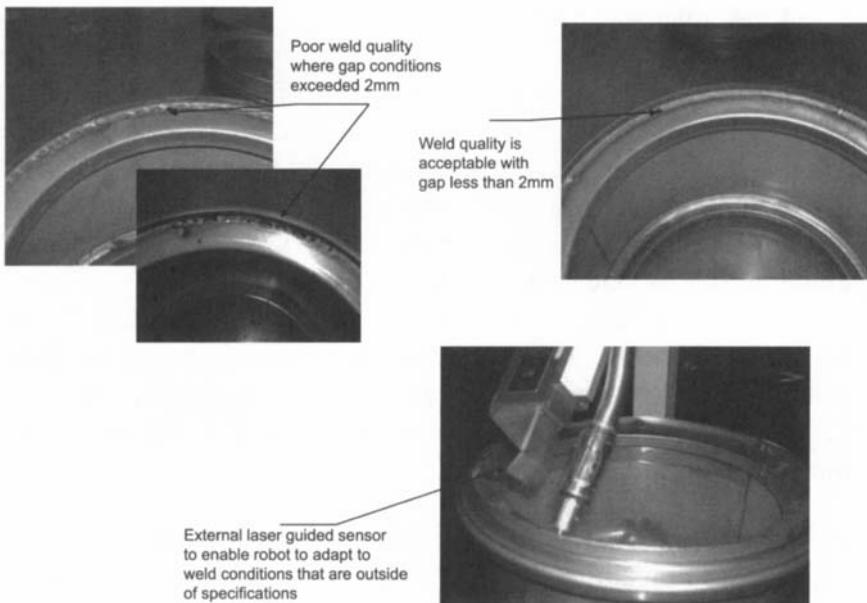


Figure 3-4 Visual Differences in Weld Quality and Product Quality when Joint Fit-Up is within Specification

At the initial glance the system requirements look simple enough because a standard platform can be applied and robotic welding is mature technology. Now here is the bad news with this turnkey application:

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- The raw material tolerances exceed the tolerance for successfully welding the weld joint, because the assembly tolerance exceeds half the width of the welding wire diameter, which is the rule for robotic welding
- The assembly is subject to thermal distortion when heat from the welding arc is introduced into the part. As a result, a consistent weld procedure is virtually impossible to achieve because of the dynamic changes in joint fit-up as a function of weld distortion
- The cycle time requirement for welding the work-piece is shorter than was initially specified

The risks associated with this project are fairly severe, relative to producing a reliable, inspection-compliant, robotically-welded work-piece, although there is a solution that will remedy the risk and enable the system to produce an acceptable and reliable product. The fact that the risks and problems occur in everyday implementation of a robotic system is fine. The point that this chapter is trying to make is that it is necessary to take the time to identify the risks and unknowns so that contingency plans can be weighed against the cost and project requirements. For the welding example in Figure 3-4, the optional methods to overcome the risks and known problems are as follows:

- Use a laser-based guidance system to track the weld joint position in real time in order to keep the welding torch properly positioned in the joint
- Use the guidance system to dynamically adjust welding settings, including welding travel speed, to maintain the appropriate procedure for a given weld joint gap condition
- Possibly weld the joint in two passes to ensure appropriate weld size and fill
- Program the robot to weave the weld deposit to bridge the fit-up gap
- Have the operator fill in the gaps manually, where the gap condition exceeds the wire diameter prior to robotic welding

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Depending on which option(s) work, the engineer needs to weigh the value of utilizing them to ensure that a reliable work-piece is produced at every cycle. The consequences are as follows:

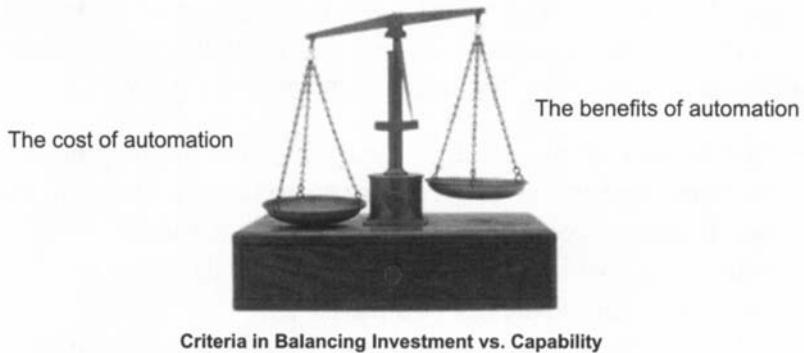
- Additional cost overall in programming and de-bugging the welding, sensor, and robot programs to accommodate all the possible weld conditions caused by random part fit-up
- Additional cost in welding wire (filler metal), if the weldment must be accomplished in two passes
- Additional weld time (reduced productivity), if the travel speed has to be reduced, or the weld deposit has to be weaved
- Additional operator intervention within the process if operator preparation of the work-piece is required, prior to robotic welding
- Additional complexity, training, and maintenance, due to the use of a laser guidance system

The saying, “it is what it is” seems appropriate here. The condition of the raw material (input) coming into the process does not allow the process to be successful, so adjustment and additional decision making are required to ensure a consistent output. Because of these requirements, the project cost will increase, but at least everyone will understand this, and a decision can be made to move forward, knowing the risks.

The risks and unknowns are determined by going through the shopping list outlined in Chapter 2. The purpose of the shopping list was two-fold. The first was to develop the project design criteria. The second purpose was to identify risks and unknowns that affect costs. Most often there is a solution to convert poor inputs to acceptable outputs. The heart of the matter is at what cost? One can do anything with automation, it's only necessary to spend money. Of course, if the return on investment, or the benefits of the investment, are not present, why do it. This is why every project is not a good candidate for robotic automation.

Figure 3-5 is a simple illustration that addresses the core of the

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Criteria in Balancing Investment vs. Capability

- Operator intervention within the process (some or none)
- Changeover from one product to another (automatic or manual)
- Compliance tools for converting varying inputs to consistent quality outputs (adaptive tools)
- Adapting to potential future projects (expandability, mobility)
- Level of flexibility to handle product mix (more or less flexibility)
- Shop floor resources to support system (level of training, and personnel capability)
- Inspection or process validation/feedback (robotic or manual management)
- What does the firm take responsibility for and pass onto others

Figure 3-5 Judging the Robotic Investment Versus Robotic Benefits

decision-making for whether a project should move forward or not. Unfortunately there is no universal formula to weigh a decision on a good or bad project. Cost, risk, and capability of the robot system, need to be compared on a case-by-case basis. As mentioned several times in this book, cost and risk are directly proportional to the agility of the robot system. The definition of agility is that it consists of a combination of flexibility, adaptability, and the level of decision making required of the system. There is a balance between the level of agility and the investment. It's easy to see diminishing returns on the automation investment when the equipment is required to take on more process responsibility with little incremental economic gain. Vice versa, the robot system has to be able to deliver a wide set of capabilities to make the investment worthwhile.

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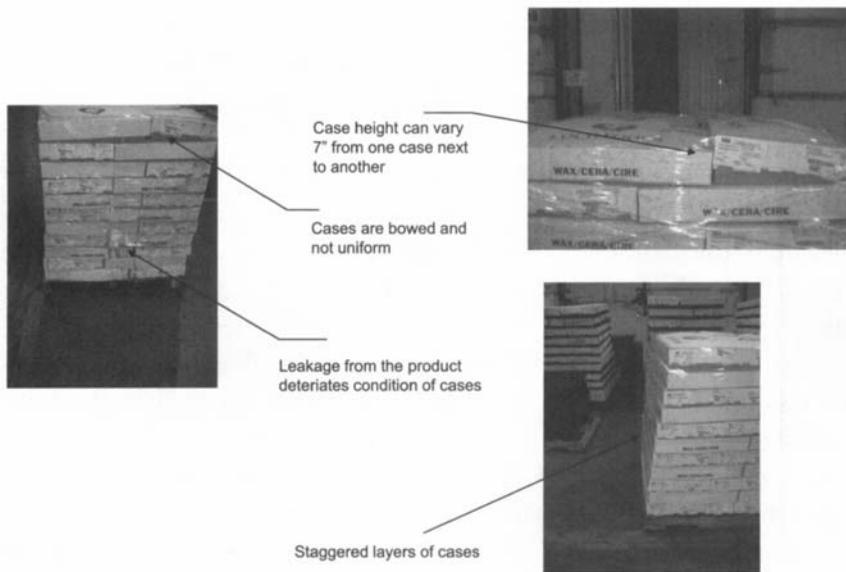


Figure 3-6 Example of Robotic Compliance Requirements in De-Palletizing Non Uniform Unit Loads

Figure 3-6 illustrates another example of a situation where additional cost is required to convert poor input to acceptable output. Examination of the stacking arrangement of the cases on the unit load shows that each case varies in position in the X, Y, and Z planes, and there is no relationship between one case and another. The project expectation is that cases will be picked up by the robot from the incoming unit load and restacked on a new pallet within a certain time frame per unit load. The risks are as follows:

- The cycle time requires that multiple cases be picked up in each cycle
- There is no rhyme or reason relative to the positions of each individual case
- Some cases are warped and some are not warped
- Figure 3-6 shows that each layer of cases is staggered
- The bottom and top halves of each case are held together

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with two plastics straps. Sometimes the straps are missing, or there is leakage from the items in the case, causing deterioration of the case condition when picked up.

This application requires the robotic system to have the ability to identify the position of each layer of product, to establish a frame of reference for that layer. Additionally, the robot gripper must be designed to allow movement in the Z direction to suit the varying topography of the cases in a layer. To make the specified cycle time, the entire layer is required to be picked up at each cycle causing further risk and challenge because the gripper itself has to comply with a layer of cases that are all at varying elevations.

At the left in Figure 3-7 is shown some iron castings, each of which has a riser that is located in a common position, left over from the casting process. The user's supplier of the castings tries to grind the risers down to a nominal offset from the outer diameter of the base material, but with a manual process the riser height still varies within a tolerance of ± 0.188 inch. The casting is to be loaded into a vertical lathe for machining. As seen at the right, the machine has a three jaw chuck to grip the casting OD. The risk that results from the poor input is as follows:

- If the robot locates the casting where the three jaws can grip on the outside surface where the riser is located, a misload could result if the riser is too large. A misload could damage both the part and the machine. Certainly there would be downtime

This application requires the ability to detect where the riser is located on the casting at every cycle to enable loading to be done safely. The consequence is additional cost in terms of the technology to enable the riser to be detected. The user can't rely on an operator to place the castings with the riser orientated in an exact position when the operator is loading the system with raw castings.

Figure 3-8 illustrates the need for many variations of material removal applications. The technology of adaptive control through

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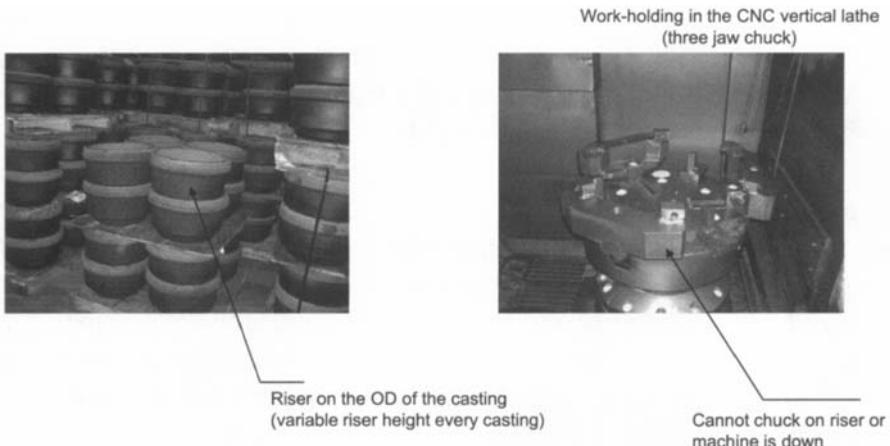


Figure 3-7 Machine Load/Unload Example

the robot or a peripheral device is widely accepted for material removal applications because of the frequent part-to-part dimensional variations, as well as variations in quantity/size of material to be de-flashed or trimmed. For instance, in the plastics blow-molding process, the parts shrink while cooling, which adds a whole other twist to successful de-flashing/trimming of the work-piece. Of all the robotic applications to pursue, material removal should be a priority from a standpoint of achieving consistent quality, reducing work-related injuries, increasing throughput, and labor savings. These jobs are among the most manually intensive, and, unfortunately for the firms concerned also have the highest quality requirements.

Material removal (finishing operations) tends to be one of the last processes in the value stream, prior to the customer receiving the product. There is a great deal of standardization in robotic material removal, from polishing and buffing, to de-flashing. The standardization in flexible devices and robot software technology that enables systems to remove material and to achieve uniform surface edges has resulted in lower investment costs for the user. That is the good news. The risk in these projects is to do the development work in choosing the right auxiliary device, the best media for removing

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material, and the trial-and-error process programming development to achieve the consistent surface finish that meets specifications. Additionally, the firm will require a talented technician to manage the system on the shop floor on a daily basis.

The balance is in programming all these components to make a good part, otherwise a scrap part will result. Imagine the challenge of deburring transmission components such as high-alloy gears that cost thousands of dollars to make. On the one hand the operator introduces a high probability of making a mistake and scrapping a gear, which further justifies the need for a robotic gear de-burring system. On the other hand, the cost to develop a robotic system may involve a return on investment longer than the ideal. The bottom line is, what does it cost the firm to scrap a part? The robot system serves as an insurance policy for preventing a potential future problem.

For material removal applications, unless a robotic process is developed and tested around a specific part type and process, there is no way to know whether the process will work. Thus, for material removal applications where, if the identical process is not presently being done elsewhere, an engineering study should be performed to bring up red flags and then plan around the cost of risk. It is one thing to see something similar in a material-handling application, but an entirely different thing to see a similar material removal application. Similar still means not identical. Chapter 4 will cover material removal applications as the subject matter for developing an engineering proof of concept, prior to making capital investments.

The several examples mentioned previously describe the classic struggle of using a robot that by its very definition, will do the same task the same way, over and over, except that this time we want the robot to adapt its cycle in terms of converting variable-input conditions into consistent, workpiece-compliant outputs. Robot technologies have now enabled the robot system to do exactly that task, which is a wonderful thing. The shopping list can be used to expose risks and unknowns. Unfortunately, process risks don't become visible until the system is built and in the de-bug mode. At this point, additional cost to manage a hidden risk is not a good thing. At a

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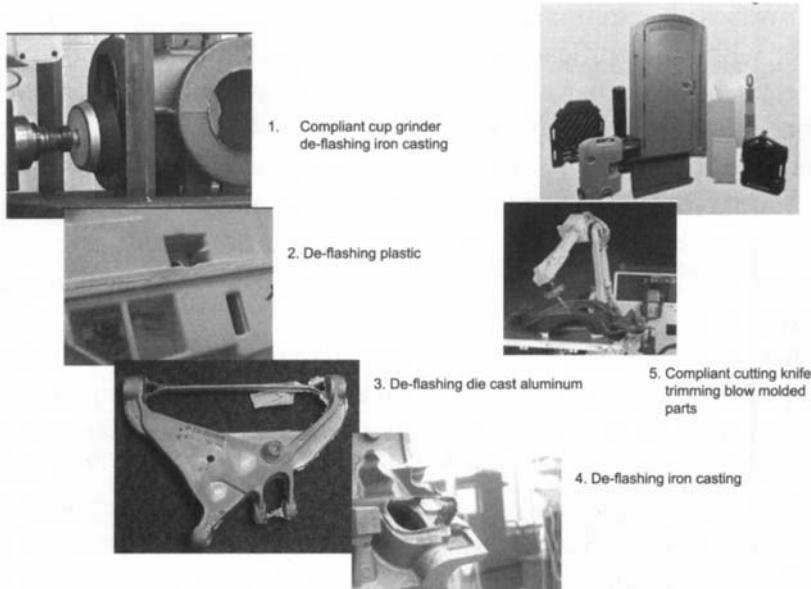


Figure 3-8 Examples of Material Removal Applications Requiring Adaptive Control through Robot or Compliance Device

minimum, if the engineer knew the risk early in the audit phase, the budget could be adjusted for the additional cost. Hidden risks equate to hidden costs, after the fact. This situation is where the party providing the turnkey solution, and the customer for the turnkey solution, battle over who is responsible for the costs to overcome the challenge. Integrating and building a robotic system is fairly simple. Making a good part over and over, within the overall throughput requirements, is where you earn your stripes.

Hidden Risk

No one likes surprises that cause additional work or costs in any endeavor, and especially not in robotic system implementation. Even though there are surprises, in a 15-year career the author has seen only three (3) systems that were built and never shipped, and that is over hundreds of robot systems. All three of the projects worked, and what the robots were doing was impressive. The prob-

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lem was with specification criteria that the robot system could not meet without significant additional funding, which was not available, so the projects were cancelled. There have been problems with other systems, but with the exception of these three, everyone worked through the issues and the systems continue to run today. Any organization that is focused on implementing custom-engineered systems will have problems. There are simply too many details, and until the system is built, the process cannot be debugged completely.

An interesting story about hidden risk has to do with a turnkey project for welding the handle of an automatic hand clamp, used by construction workers. The hand clamp was a very popular tool and was advertised on television because of its ease of use. The robot system was purchased to weld two sections of the clamp together along a butt seam. There was only one weld per clamp side, and the weld bead was about 3/16 inch wide, and 4 inches long. A standard system was to be used, and welding tests had been accomplished prior to the system being approved. The expectation of the user was for the system to produce a reliable and acceptable part.

The interesting thing is that, as the system was being installed the user learned that the parts had to pass destructive testing, where the base material had to fail before the weld, and the base material was known to be made of high-carbon steel. The logic for selecting the welding filler metal during the project implementation phase was to match the filler metal to the base material,. This decision to match the chemistry of the filler metal to that of the base material was not a good idea. Sample after sample failed the destructive test.

The user was in a position where, if the system could not make a testing-compliant part, then costs would escalate and the user could lose the contract with the customer. The battle lines were drawn. There were two opposing arguments. The provider of the turnkey solution was required to produce a “good” part, and should have known that a different filler metal would have to be selected to achieve the mechanical properties in the weld that would withstand the destructive testing. The other side of the argument is that, had the user defined the parameters adequately, or even had known that

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destructive testing was a requirement, the situation could have been avoided. The arguments are to an extent irrelevant because in the end, the process has to work, and without a solution, both sides lose. The conclusion was to select a new filler metal that would allow the weldment to achieve a much higher level of toughness, and as a result the base material would fail in a brittle condition before the weld failed.

Other examples of problems are listed below:

- Adding a chiller unit to a washing system after a machining process, because, during the washing cycle, the die cast aluminum part was heated excessively, causing thermal expansion problems for the next machining process,
- Finding that an attribute of a product (input) changes after the fact. An example is that, during the validation phase of a project it was confirmed that the loading and unloading of an iron casting into and out of a special machine fixture was consistent. The engineer then specified those surfaces as suitable for the robot to grip the part so that it could load the machine. However, the engineer was lucky on the day he was testing the process manually, because the castings were consistent on that day. The selected gripping surface was later found to have a very broad tolerance, and as a result an accurate loading process was no longer valid.
- Palletizing bags of seed, where the bags would be presented to the system with a broad distribution in terms of where seed settled in the bag. A bag flattener and weighing system were added to ensure that uniform bag content and shape were presented to the robot, prior to the palletizing sequence.
- Finding an interference or access problem between the robot gripper and a location that the robot needs to reach, after the system is built. For instance a welding fixture prevents the robot from reaching the position on the part for welding, or there is not enough room for a robot arm to reach inside a machine tool door to unload and load a part to be machined.

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- Exceeding the time you thought it would take to program, especially with process-intensive applications such as welding or material removal. Teaching the robot where it needs to move to in space is straightforward. Making a good part is different. For instance, achieving the correct weld attributes, or the specified surface finish of a chamfered, machined, edge after deburring, are examples of trial and error tasks.
- Obstruction of a machine tool chuck by metal chips or debris, causing problems with the robotic loading process.
- Finding out that humidity affects the properties of raw blocks of plastics polymer that a robot system is de-palletizing. The blocks stick together in conditions of high humidity as the robot moves blocks from a pallet to a conveyor that transfers the plastics to a mechanical shredder.

Risks of Your Own Managers and Personnel

A company that produces equipment for the agricultural industry finds that its biggest obstacle in achieving good productivity is proportional to how the shop floor operators decide they're going to work on a given day. This company uses welding robots, and the systems rely on the operator feeding the system. The operators in this situation affect productivity, with or without automation. Without automation, productivity would certainly be significantly lower, but the firm struggles to achieve the uptime it knows the robot systems are capable of producing.

Another company sells machining time and fits a classic job shop model of producing something different every day. This company struggles with the risk of their customers keeping their commitments to product volumes. In other words, their customers could pull contracts or adjust contracts for part volumes in an instant. As a result, it is difficult to manage people resources and capacity planning. Hiring and then laying off employees doesn't seem to work well for any long-term continuity. Additionally, the firm has to be very careful about long-term investments that limit its ability to react to customer needs. Each investment has to have inherent flexibility as part of its core requirements. The definition of automation

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includes words like re-deployable, consistent, flexible, and adaptable. Automation allows the firm to stay agile, which is the key for manufacturers regardless of fitting the job shop or OEM model. Product lines continually change, as do customer demands. Whether automation is the solution to this long-term problem is hard to answer, but robotics will continue to become more flexible and easier to use, allowing users to adapt to the ever-changing business climate.

Ryan Burg of The Department of Legal Studies and Business Ethics at the Wharton School of Business brings up an interesting point of view about manufacturing: “There is considerable debate in academic management over the question of why American manufacturers have done such a pitiful job at lean manufacturing implementation. My view, and I think I am not alone, is that lean manufacturing and the Toyota model are better grown than built. Lots of complex systems are better grown than built: operating systems are a good example. Windows XP is a pretty good operating system now, a mere ten years after it was designed to be released. Mac OSX is a good operating system, built with a UNIX backbone, parts of which are decades old. When you need complex order, it has to evolve. Lean systems (kan-ban, just-in-time, inventory-free) are not in themselves productivity inducing. What they actually do is make it possible for processes to be adjusted more actively (“constant improvement”) so that the system will be able to evolve. There are moments when clean slates are useful, but they can destroy as much value as they bring. The best laid plans can fail because missed details accumulate. The trick is, therefore, to design in a way that can be adjusted, or at least it seems at first glance. However, when you look more closely, I think you find that the REAL trick is to have people who actually care to make the adjustments and are empowered to do so, people who work in collaboration to achieve the constant improvement. This is the part that America, and the contentious politics of our labor have really struggled to work through because the best manufacturing practices in themselves do not make anything.”

The best automated system designed to be completely fool-proof

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still requires support. The point is that people will always make the difference in how effective manufacturing processes will become, with or without automation. The ability of talented caring employees, who have the attitude to make positive changes must not be underestimated. These people must be empowered to make decisions.

Managing What You Control

New users and even existing users to some extent, will want to know if their project is being automated somewhere else. Any first-time user should take a road trip to see automation in a production environment, and chat with all the various members of the team from maintenance to the owner. Education is the best practice when pursuing a first-time project.

What does a firm control when it decides to move forward in evaluating automation:

- The user understands the customer requirements in terms of the product specifications that need to be delivered
- Product volume and delivery requirements to the customer.
Albeit this category could be completely undefined, or demand is on a daily basis and the only rule is that change will happen
- Raw material cost to produce the product in the specified volumes and time frame
- The process or sequence of operations required to make the product
- How much capacity in process machinery and labor are needed to produce the product
- Amount of profit per part
- Process requirements to convert (raw material) inputs to (finished product) outputs

An educated user will understand these categories and by identifying risks within them should be able to communicate them

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throughout the team. In terms of automation the user controls:

- The decision to build the robot system internally or externally
- Specifications for the automation requirements, defined in a document labeled scope of work

How the system is designed isn't really the user's concern, other than that the system has to perform to the requirements in the scope of work. Imagine then, that there is no scope of work, or the scope of work is poorly defined to meet the project expectations. The scope of work is discussed in Chapter 5 and it is truly a make or break process in terms of controlling costs and risk. Requirements and personnel always change, but those changes do not mean that the scope of work is disregarded. Ultimately users control the level of definition for someone else internal or external to the firm, to deliver something. Getting back to the standards that users buy, in terms of the commodity capital equipment, including the robot itself, there is no issue here. The risk is all with the level of definition laid down for a custom system, between the user and the supplier.

Risk of Technology

Despite the maturity of the robotic market, the inherent flexibility of robots enables new technology to be continually developed, as well as new applications being created with existing technology. There are two concepts regarding technology and risk. First is the risk associated with a new robotic application that is unique and can't be compared to any other application, anywhere else. Second is that new technology may be validated in the development lab but not necessarily in the production environment. Either form of risk will yield a high score on the risk gauge, but that is not necessarily a bad thing. There would be a higher cost associated with the implementation due to lack of experience for either event. Cost is relative though, to the specific benefits that can be gained.

Any investment in a robotic system today will yield significantly greater value in terms of cost to functionality ratio, and reliability

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than ever before. Robotics themselves have been inherently improved in terms of reliability and ease of use. The reliability and ease of use have certainly decreased the risk of a robot investment. Earlier text mentioned proof of concept, which will be covered in Chapter 4. Some applications that should be further qualified with proof of concept to avoid hidden risks are as follows:

- Dynamic robotic sorting of laser-cut blanks. This technology is applicable to any CNC-based cutting table (waterjet, plasma, laser, or router). See Figure 3-9. This sorting process can be a huge manual bottleneck in the value stream.
- Robotic random bin picking, eliminating the need for an operator to sort raw material for the robotic system. See Figure 3-9.
- Robotic force sensing for assembly. See Figure 3-10.
- Adaptive robotic welding to accommodate varying weld joint volume. See Figure 3-11.
- Adaptively “flexible” robots coupled with trimming, routing, de-burring, grinding, and polishing tools, designed to remove excess material such as parting lines and flashing on steel, composites, and plastics components
- Palletizing mixed loads of products on a single pallet. See Figure 3-12

The trend here is that robotic control technology is continually being developed to enable the robot to make dynamic process decisions based on a set of varying inputs, while converting them into an acceptable output. The robot, in a sense, is an intelligent and agile manufacturing tool that can adapt to changing conditions. The risks are the complexity, setup time, and maintenance of these tools. Robot technology will continue to find ways to mimic human dexterity and decision making. The reward is cost savings to the user because the robot is essentially adding more and more value to the process. Finding that balance between capital investment and robotic agility will still be the right thing to do for the user.

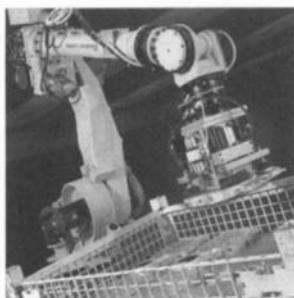
Without the important adaptive tools and software technology

Robotics and Risk

1. Dynamic Robot Part Sorting



Robotic de-nesting of cut blanks from a CNC cutting table (i.e. plasma, waterjet, laser, router). The robotic system is integrated to the CNC nesting system to receive positional data to pick cut blanks from a master sheet including the remnants. Each cycle, the master sheet could have a completely new nest in terms of the recipe of shape styles, location, and orientation. There would be too many possible combinations of recipes so every cycle requires dynamic robot paths created from nesting information about each shape attribute. Other challenges are handling parts that are tabbed to the master sheet.



2. Robotic Bin Picking

Robotic bin picking of randomly located work-pieces in a basket, bin, container, gaylorb enables the user to eliminate the manual staging of raw material to the robot system. Unmanned production is the direct benefit and for material handling systems the benefit is significant savings.

Challenges include picking the work-piece with literally any orientation, parts that are interlocked with each other, avoiding the container sides, robot path planning into and out the bin to pick randomly located product. Another challenge is planning for safe retreat out of the bin in the event of a fault condition

Figure 3-9 Examples of Applications where Proof of Concept is Useful to Avoid Hidden Risks

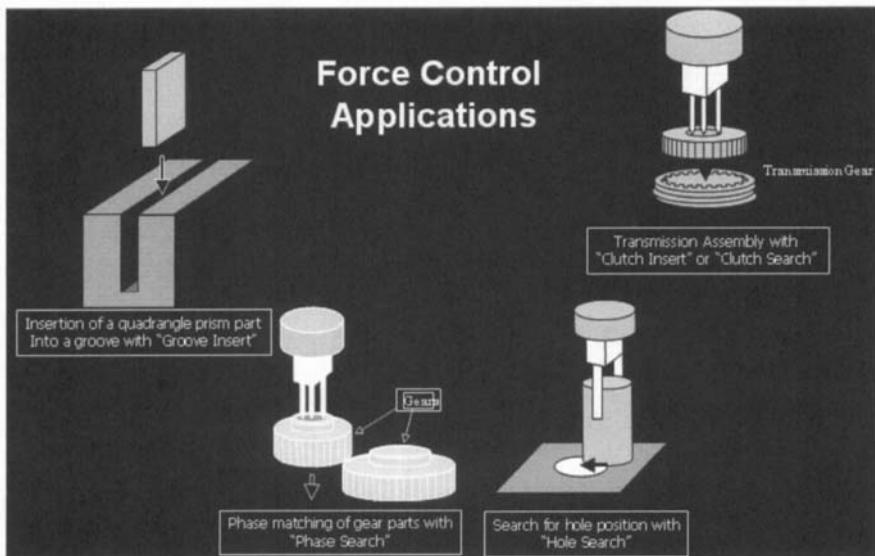


Figure 3-10 Examples of Applications Where Proof of Concept is Useful to Avoid Hidden Risks

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Adaptive Welding (through the robot and peripheral sensors)

- **Locating the weld joint**
- **Real time robot path correction**
- **Adaptive fill for varying weld cross section and gap condition**
- **Adaptive process parameters (weld travel speed, weave parameters, and weld procedures)**
- **Decision making about number of weld passes to adequately fill a weld joint**
- **Part verification prior to welding**

Ideal where work piece tolerances exceed the ability to use nominal weld procedures in order to produce a quality product;

- Casting to casting weldment
- Variation in forming, cutting process
- Stack up of tolerances from the pre weld assembly process
- Effects on the weld seam tolerance as a function of thermal distortion



Figure 3-11 Examples of Applications Where Proof of Concept is Useful to Avoid Hidden Risks

behind these tools, the market for robotics would be severely limited. The standard platforms are great but their growth is limited as well as their applications. Continually-changing technology is a good thing if you know the risks, and the proof of concept discussed in the next chapter plays a role in that technology-validation phase.

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Mixed Load Palletizing

- Multiple product types (skus) on a single unit load
- Handle multiple case sizes on a single unit load
- Build a unit load that is stable without control of when specific cases are presented to the robot
- Multiple customer orders on a single unit load
- Insuring the robot palletizing is not a bottle neck within the overall product flow

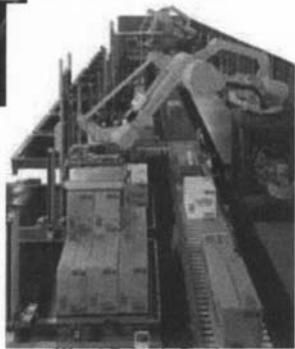


Figure 3-12 Examples of Applications Where Proof of Concept is Useful to Avoid Hidden Risks

4

Setting Expectations for Success

The saying “I am from Missouri, show me” describes the requirements often demanded by a firm that is contemplating the acquisition of a robotic system. The system was conceived to deliver a specific set of performance criteria, and the user wants simply to validate that the system has the ability to fulfill the requirements. This requirement is the essence of the definition of validation. For a mass-produced unit like a machine tool or a welding power supply, validation is straightforward. Machine prints enable manufacturers to continue to build machines to a known specification with known capabilities. All the inputs that go into building the machine, as well as the performance criteria of the machine, are constants. The objective for builders of standard robot systems is to meet the user’s requirements without having to validate anything relative to the system. The manufacturing world loves standards, and standard systems enable suppliers and customers to agree on the contract requirements without validation. The fulfilling requirements of the system are known to all.

Robotic standards have proliferated across the robotic arc welding segment more than any other application segment. Standards are widely accepted within the welding segment because there are only a few variables to manage in fulfilling the process requirements. Figure 4-1 illustrates four categories of basic standard welding cells, offered by Genesis Systems Group, that make up the primary offering of standard welding system configurations used in the marketplace. For the welding example in Figure 4-1, the user needs only to match the system relative to the work-piece weight and size, and decide whether rotation of the work-piece is required to maintain all the welding in the flat or horizontal position. Simple choices

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are made, and in minutes the system is selected. The user then needs to consider the work-piece fixturing requirements in terms of weight and size in addition to the work-piece itself.



Figure 4-1 The World of Standard “Platform” Robotic Arc Welding Systems

Figure 4-2 shows a stand alone cell that embodies the configuration changes that can be made within the standard system, and the variables that need to be managed. The definition of a standard robot system is an integrated set of modular components on a common platform. Each of the components or modules can be added and expanded to enhance functionality for handling larger-sized products, and robots can be added to increase throughput. Welding stations (tables and/or positioners) may also be added.

Once the standard system configuration is selected, the standard platform requires planning of installation, programming, and applying a welding fixture before an order is released to production on the shop floor. This robot welding platform configuration example

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is also usable for other application platforms in terms of an expandable set of integrated modular components on a common base. Limitations, regardless of application type, are work-piece size, process complexity, and flexibility. When the work-piece size exceeds the standard system capability, then a more custom-engineered system, still using modular components, will be necessary. When the process complexity or flexibility exceed the capability of the standard system, a more conventionally engineered system, specific to the application, is required.

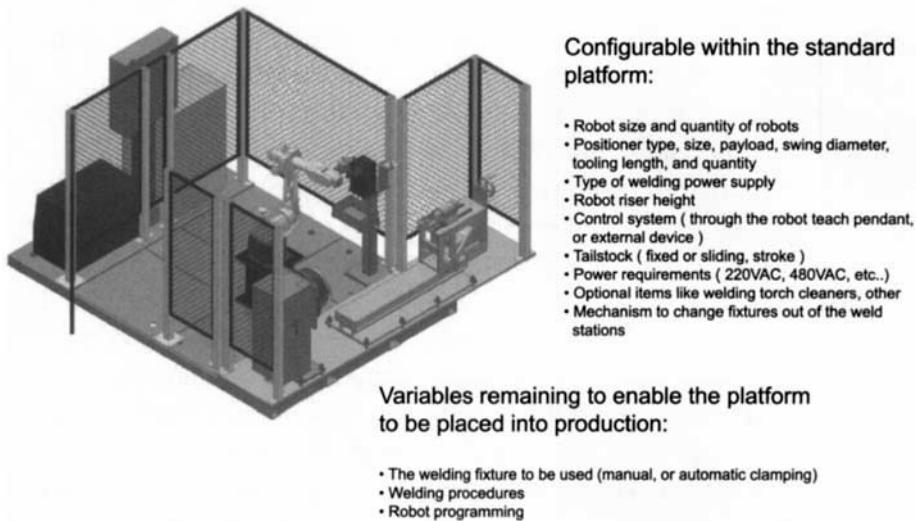


Figure 4-2 Variables and Configurations for a Standard Robotic Arc System

How does one prove that the robot system will work? It's not enough to bring utilities to a standard platform to validate that good product will be automatically produced. In the welding example shown in Figure 4-2, the work-piece requires a unique welding fixture. A unique welding program, welding sequence, and welding procedure, are also needed to make a good part. This is where the rubber meets the road on any robotic system, and the same can be said for any robot application. Ultimately the robot must be applied

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to make a “good” part. How is that statement to be validated? An example in the previous Chapter described how a standard welding platform struggled to make a good part because of the uncontrolled raw material tolerances in the pre-welded condition, and as conditions changed while welding.

What if the fixture could not position two components within the tolerance required to make a good part. What happens if the programming time exceeds the expected robot weld cycle time by 30 percent? What if a good weld simply cannot be made because of the pre-welded part design? These questions are relevant for any standard platform, and it is easy to imagine the questions that would arise for a custom-engineered robotic system that wasn’t built from a previously-generated set of mechanical and electrical prints.

Validation up front is everything. It takes time and money, but the time and money spent after the system is on the production floor, and not working because assumptions were made instead of validation, cost much more. Higher costs are especially likely for process-intensive applications such as material removal, and welding, where cosmetic expectations (surface finish, bead appearance, visual flaws) of the finished product always define a good or a bad part. The validation phase in robotic implementation is critical. In welding and material removal, the criteria for a good or bad part is also generally subjective, which makes validation up-front even more important. How do you know you can make a good or bad part without building a solution, and testing that solution within a production-like environment.

Simulation and offline programming tools are wonderful tools but they don’t make parts. To fulfill the system requirements, validation of the process prior to building a system, is of vital importance. Good ways to validate the design are to see the same part robotically processed within an existing system, or to develop a proof of concept incorporating tools necessary to demonstrate that the process will make a good part. The proof of concept section of this Chapter will cover several real examples of where proof of concept was the right step in implementation of the robot project.

The first thing the team should do when looking at matching a

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robot solution to a project need is to first check how a standard robot platform can satisfy the need. The team will very quickly learn whether the solution fits a standard system when they begin to ask all the questions about how each step within the sequence of operations will work, and will contribute to making a good part. Of course, the solution also has to achieve a specific budget and a specific throughput to be justified, or else it's back to the white board. The validation step takes all the information that was collected during the audit and discovery phases, and allows the team to examine the information within the world of constraints that the organization needs to be successful.

Tools for Validating the Robotic Process

Welding and material removal have been discussed from a validation aspect. For non-process-intensive applications such as robotic pick and place, and material handling applications, the team needs to be concerned with other issues. There is a core set of variables that come into play any time a team is trying to develop a robot solution. The development process starts with the parts and the sequence of operations needed to produce the solution that makes a good part. Figure 4-3 breaks out the validation criteria for each type of application but in general the solution for any application requires validation of the following list:

- How to achieve the required throughput
- How to manage process variables to produce a finished product that is defined by a set of constants. In other words, how to manage the stack-up of tolerances to make a good part every time
- How the system makes the right decisions at each step in the operation
- What risk is being introduced at each step of the operation, based on the team's choice about decision making

The world of constraints includes the budget, the condition of the raw material and other inputs into the system, the available space

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Arc Welding	Throughput (rate), bead appearance, weld quality (i.e. penetration, tensile/yield strength), part appearance related to weld spatter, sometimes dimensional tolerance requirements, weld defects (i.e. lack of fill, porosity, undercut, weld size, etc....), welding torch access, orientation, and reach to optimize weld conditions, obstacles in the way, robot reach, as-presented raw material tolerances
Material Removal	Throughput (rate), surface condition and defects (i.e. scalloping, marks, reflectivity, finish, etc..), dimensional tolerance to parent material, cleanliness, robot reach, access to work-piece surface area to be processed, obstacles in the way, orientation of tool or part to optimize process, robot reach, as-presented raw material tolerances
Palletizing/De-palletizing	Throughput (rate), unit load pallet pattern, robot payload carrying capacity, robot reach, obstacles in the way, securing product adequately in gripper throughout the pick and place cycle, pick and place tolerances of product, product mix by size
Machine load/unload	Throughput (rate), part loading tolerance (location and radially) into work-holding, robot reach, obstacles in the way, robot payload carrying capacity, gripping method to pick and place work-piece within process tolerances, gripping forces on work-piece, locating part at inbound relative to loading tolerance in machine, number of robot axis, product mix, type of machine and work-holding
Press tending	Throughput (rate), tolerance for locating the blank in the brake prior to forming, ability to grip surfaces of work-piece through the forming process, obstacles in the way, robot reach, payload carrying capacity, product mix, type of brake

Figure 4-3 Validation Process Requirements for Various Robotic Applications

(floor and ceiling), and the sequence of operations in terms of system flow and the flow within the value stream.

Now the team knows the task at hand. It's time to develop a solution that answers the questions above, and falls within the manufacturing constraints that were defined by the buying firm. One of the first exercises to be accomplished is to determine the process and flow that achieves the throughput requirements. Immediately following is the selection of the robot models and the quantity of robots to achieve the throughput. At every step of the sequence, pros and cons of floor space, level of risk, safety, and investment are planned. Many projects fail to move forward early in the audit and discovery phase because what the user wants to achieve fails to satisfy restraints on space, risk, safety, and/or investment. In answering whether a project is good or bad, one has only to look at how the solution matches up to risk, investment, safety, and space.

System concepts often have to be revised, and each revision

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includes trade-offs where compromising allows for a successful solution but with realistic conditions. Perhaps in the whole plan of robotic implementation, this exercise is the most important in the chain of events. The process and flow must be planned, then the system must be sized correctly for the required throughput. Resources have to be determined at each step, and the impact on safety, risks, space, and investment are finally examined. A lot of the tools, such as offline programming simulations, and modeling software, allow for quick responses in recreating and validation of new solution revisions. Essentially, this is the world of system integrators and users where, at the end of a quoting process, both parties arrive at a compromising solution. Unless a system fits the standard configuration, the time needed to derive a custom-engineered robotic system can take a few days to months. The amount of time is irrelevant without a cohesive team consensus, so plenty of time is justified in this phase.

Industrial robots are selected by their payload capacity, speed, and number of axes of motion (4, 5, or 6). Also, the environment, such as a wash-down cleansing environment, or hazardous corrosive environment, will influence selection of a specific robot model. The payload-carrying capacity of the robot defines the maximum weight the robot can carry, including the gripper, throughout its motion range. Additionally, the robot payload must be validated in terms of the moments of inertia, as a function of the center of gravity of the gripper and the work-piece on the various robot axes. Reach is validated by a reach study using a PC-based, offline, robot simulation software program. Additionally, the team will need to model the system in the virtual environment and begin to jog the robot to the various location positions, with the robot axis in the appropriate orientation, holding a tool and work-piece that are representative of the tool used in the actual process.

The tool, work-piece, machine, or peripheral device with which the robot is interacting, also need to be orientated correctly, as would be required in the production world. In other words, the simulation would incorporate a robot tool such as a vacuum gripper for press tending or palletizing, a cup-grinding tool for grinding, or a

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welding torch for welding. The simulation also incorporates solid-object models that represent every device and thing within the system, again to validate the process as close to production conditions as possible. Simulating the robot and tool motion throughout the sequence of operations allows the team to validate reach, speed, obstacles, and cycle time at each step in the sequence. The result is the correct selection of robots, and spacing for the various components relative to each other, including elevation heights.

The simulation exercise is a must on every job, including standard systems, because the success of each application hinges on making a good part. The simulation easily allows for quick changes needed to optimize the solution to fit the project constraints. Figure 4-4 shows examples of a simulation tool used in the validation phase of a project for welding. The illustration shows an inverted-mounted welding robot with a welding torch positioned at various weld locations, and with the work-piece orientated in varying positions in space. The simulation tool will save an immense amount of time by finding problems with part fixture design, robot positioning relative to the work-piece, and other deficiencies such as cycle time.

The simulation will not manage stacked-up tolerances or validate whether a good part was made. However, in many situations, the simulation is all that is needed to complete the validation process. The simulation tools also allow for robot motion and entire robot programs to be created off-line on a conventional personal computer, and later downloaded to the robot system to execute the created routines. With every simulation tool, programs created off-line will need to be touched up because calibration between the real and virtual world will have some unpredictable chance of error. The benefit of simulation is that it allows products to be programmed in a PC environment without interrupting the production system. Programming new products off-line allows a much faster to-market response for the user than if a new product was released directly to the work-cell and a new program was required to be written by the operator each time.

Two primary simulation packages are commonly used. One is the robot simulation software previously discussed, where robots are

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programmed off line and the software is used as a development and validation tool as well as a programming tool for new products. The other style of simulation software is based on production flow for the entire manufacturing value stream, where the robot content is one entity affecting flow. These tools are not covered in this text but are most useful for the discussions in Chapters 6 and 7, where the user is planning on implementing an entire manufacturing value stream from raw material to finished product.

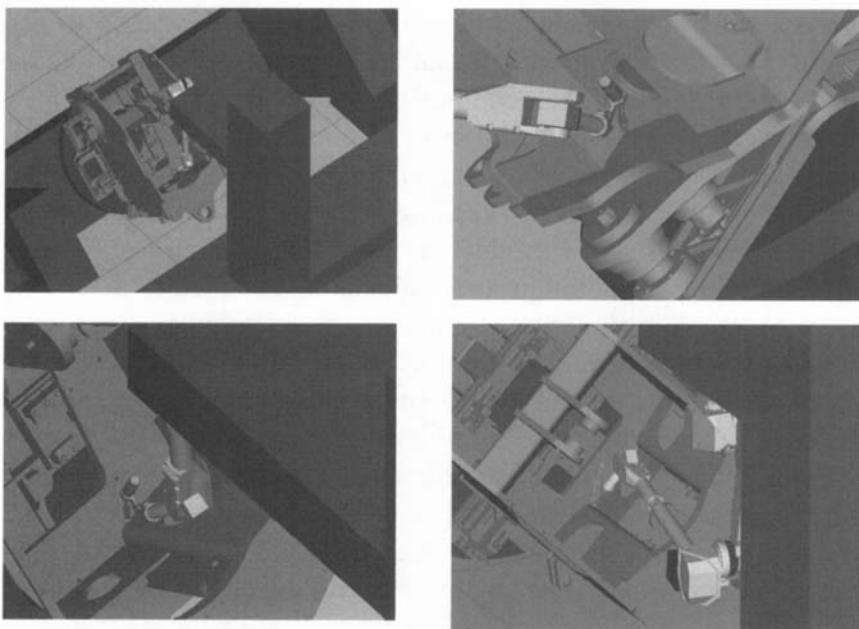


Figure 4-4 Example of PC Based Robot Simulation Software Performing a Reach Study for Robotic Arc Welding

The ability to achieve throughput is at the center of most projects. At the end of some defined amount of time, a specific quantity of acceptable finished parts needs to be completed. The throughput is almost always defined in units of parts per hour, and in palletizing, the terminology is in units of cases, pails, or bags per minute. It is

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important to incorporate an efficiency factor in calculating throughput. For instance, in a CNC machining process study, a factor for efficiency is applied to the calculated cumulative cutting time to determine the number of machines necessary to achieve the throughput, because the CNC machine will not be cutting parts 100 percent of the time.

For arc welding, a similar process cycle time study is applied using a weld calculator. Validating throughput is the foundation that the system content is built upon. For instance, the robot quantity, process flow, how many hours per day the system needs to run (which also drives supporting resources), quantity of process equipment, and the size of the equipment/system investment, are all a function of throughput. Throughput also affects the overall size of the system, as does its fitting within the allowable floor space constraints, and the logistics of feeding the system with raw material and removing finished product. Figure 4-5 illustrates a Genesis Systems robotic welding process calculator, designed to determine overall process cycle time to completely weld an assembly. Figure 4-5.1 illustrates an example commodity for which use of the calculator to determine the throughput for welding a work-piece will be discussed and the conclusions reviewed.

Developed by Genesis Systems Group, this welding calculator requires the user to enter data in the yellow boxes. This data includes the number of inches of weld for each weld size. An associated welding travel speed is given for each weld size. A welding time is automatically calculated as a function of the user-entered inches of weldment for a given welding size. A nominal welding travel speed from the table shown in Figure 4-5 is included in the calculation. The arc time is simply travel speed (in/min) / inch of weld (in). This table is a good example of how to calculate overall cycle time because it includes input from the user about non-arc (non-value) tasks, including positioning time, torch cleaning time, touch sensing time, and number of arc starts for the part, and incorporates the air moves of the robot in positioning the weld torch from one weld to the next. There is also a miscellaneous box that should include any load/unload time for placing a work-piece in and out of

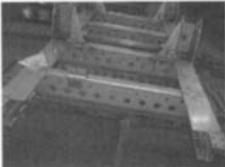
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Figure 4-5 Example of a Robotic Welding Cycle Time Calculator

Genesis Systems Cycle Time Calculator		Based on the following fillet weld average travel speeds:					
		$\frac{1}{8}'' = .37 \text{ IPM}$ $.035''@350IPM$ $3\text{mm} = .35 \text{ IPM}$ $\frac{3}{16}'' = .20 \text{ IPM}$ $.035''@400IPM$ $5\text{mm} = .15 \text{ IPM}$ $\frac{1}{4}'' = .18 \text{ IPM}$ $.045''@400IPM$ $6\text{mm} = .18 \text{ IPM}$ $\frac{3}{8}'' = .10 \text{ IPM}$ $.052''@400IPM$ $8\text{mm} = .10 \text{ IPM}$ $\frac{1}{2}'' = .03 \text{ IPM}$ $1\text{''}@450IPM$ $10\text{mm} = .03 \text{ IPM}$					
		Total number of arc starts per assembly:	0	arc starts	0	seconds	
$\frac{1}{8}''$ Weld length - total inches:			0	inches	0	seconds	
$\frac{3}{16}''$ Weld length - total inches:			0	inches	0	seconds	
$\frac{1}{4}''$ Weld length - total inches:			0	inches	0	seconds	
$\frac{3}{8}''$ Weld length - total inches:			0	inches	0	seconds	
$\frac{1}{2}''$ Weld length - total inches:			0	inches	0	seconds	
3mm Weld length - total		0 mm	0 inch equivalent	0 inches	0	seconds	
5mm Weld length - total		0 mm	0 inch equivalent	0 inches	0	seconds	
6mm Weld length - total		0 mm	0 inch equivalent	0 inches	0	seconds	
8mm Weld length - total		0 mm	0 inch equivalent	0 inches	0	seconds	
10mm Weld length - total		0 mm	0 inch equivalent	0 inches	0	seconds	
				0 sub-total			
				Misc. Time:	0		
				Estimated Torch Cleaning Time:	0	seconds	
				Based on a Torch Clean every 5 minutes of cycle time.			
Positioning of the part required? If Yes, add a "1" in this box:		0	If you feel extensive minor axis positioning is required, add a 2 or 3 in this box. (3 moves per		Estimated positioner move time:	0	seconds
				Based on three positioner moves at 1 second each.			
Will the system have a main sweep exchange axis? If Yes, add a 1 in this box:		0			Estimated exchange axis time:	0	seconds
				Based on 4 second main sweep move exchange - i.e: 4M, RC3, V3M, etc.			
Touch sensing required? If Yes, add a "1" in this box:		0	If you feel extensive touch sensing is required, add a 2 in this box. 1 = 33% of welds requiring TS, 2 = 66% of welds requiring Touch		Estimated Touch Sensing Time:	0	seconds
				Based on 33% of welds requiring touch sensing.			
				Total Cycle Time @100%:	0.0	seconds	or
				Cycle Time @ Efficiency Factor:	0.0	seconds	or
				0.0 minutes			0.0 minutes

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a fixture. The calculator has no factor for other weld joint configurations such as V- or J-groove styles.



- 79 1/4" welds 424 inches of weldment
- 27 3/16" welds 90 inches of weldment
- 18 3/8" welds 45 inches of weldment

- Summary: Positioner required to rotate frame to keep the welds in the flat and horizontal position. Assume about a 1/3 of all the welds will be touch sensed



- 559 total inches of weld, single pass
- 0.052" wire diameter mixed gas shielding
- 124 welds (arc starts)

Throughput summary using rough cycle time calculator

- Total arc time is 38.7 minutes
- Total non arc time (non value added) is 3.2 minutes
- With an 85% efficiency factor the total time to weld the frame with a single robot would be 49.3 minutes

Figure 4-5.1 Weld Calculator Example- Frame Assembly

Another important factor to consider is that no machine or process operates at 100 percent efficiency, and for our example in Figure 4-5.1, a nominal 85 percent efficiency was applied. There will always be some form of downtime related to changeover and setup, non-process time, maintenance, or a device that is not working, etc. If a manufacturing process cannot tolerate even the slightest level of downtime, then redundancy must be incorporated in the manufacturing value stream at all critical steps. The conclusion for the frame example is that a frame can be fully welded using a single robot within a standard system having two welding stations, so that while the robot is welding on one station, the operator is unloading a finished frame and loading/tacking a new, pre-welded frame at the other.

If the customer can accept a completed part every 49 minutes

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then everything is great. The supplier will configure the standard system for the right-sized robot, welding equipment, and positioner to weld the frame. The user will supply a holding fixture to hold the tacked assembly, and all that is left is to program the position of the frame at each welding station. Weld paths can be programmed offline and then touched up on the real system, and additional fixtures can be applied in the future, so long as the size and weight are compatible with the standard system specifications. On the other hand, if the user needs a frame every 10 minutes then a solution is necessary that is way beyond a standard system. Factors to exploit include the non-value added time, the efficiency of 85 percent, welding speeds, and the manufacturing flow. We'll come back to this example in Chapter 7 and review the user's choices to get to a 10-minute cycle time per part to achieve the required throughput.

In trying to minimize cost and maximize throughput, a lot of thought is devoted to validating whether the production rate can be made, using the smallest number of robots and other resources as possible. Examples of drivers that affect the throughput for various applications are as follows:

Application Criteria that affect throughput

Arc Welding Number of welds, and time to access each weld, given the level of obstructions that the robot has to maneuver around.

Welding procedure; number of weld passes, and weld travel speed needed to achieve the proper weld characteristics

Amount of non-arc time including robot motion in space, torch cleaning, and positioning the work-piece in the flat or horizontal position for welding.

Load/unload (LUL) time of raw and finished product. Multiple stations allow load/unload time to be within the welding cycle. Additional process time such as weaving, slowing travel speed to bridge gaps, and searching the weld profile and location

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because of inconsistent raw material tolerances. The rule of thumb is that tolerances need to be within plus or minus half the weld wire diameter, or robotic technology such as arc-seam tracking, touch sensing, and vision/laser guidance, may be necessary to make a good part

See Figure 4-5 for a sample weld calculator that determines the approximate robot weld time. Note that an operating efficiency is still required to be applied to the cycle time.

Machine LUL Machine door open to machine door close time, where the robot is unloading and loading finished and raw parts to the machine tool work-holding fixture. To minimize this time, robots are fitted with dual grippers to speed up the part swap with the work-holding fixture. This time is applicable to lathes but not to machining centers with pallet changers, which enable the robot load/unload time to be included within the machining cycle.

Qualifying time to enable incoming work-pieces with inconsistent tolerances (location, orientation) to a consistent location and orientation for loading the work-holding. Applying a fixture to incoming product is a way to eliminate the time needed to qualify the locations of the raw in-bound product. The most random form of in-bound raw material is a container where product is randomly located. Using 3-dimensional vision technology will enable the robot to locate, orient, and pick up the product within acceptable work-holding tolerances, although sacrifices in cycle time will be needed.

Product changeover. The robot and robot peripherals can be designed for automatic changeover. The machine work-holding fixture can use redundant tooling and quick-change tooling. The changeover time will affect throughput because the machine is not cutting parts during this event unless the following changeover features are used.

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The workpiece can be re-gripped between machining operations in order to change its orientation for the next machining operation. For manipulating shaft parts, and parts that the robot can grip on the body, the wrist axis of the robot is capable of turning the work-piece 180 degrees so that the work-piece can be held at either end during machining. This feature eliminates the requirement to place the part into a re-grip stand and then re-grip the part.

Ancillary robot motion between one sequence and the next increases overall cycle time.

Palletizing Palletizing can control the location at which the inbound product is picked up and the location where the outbound product is placed. Additionally, palletizing can control the number of tasks that the robot must perform in each cycle when palletizing or de-palletizing.

The slowest axis of industrial robots is the waist, so that minimizing the waist axis motion is important. Vertical movement of incoming product relative to unit load height also affects robot motion. Minimizing robot motion to pick/place product from one location to another is obviously important.

Palletizing patterns affect the efficiency of each robot pick and place cycle. Each product, on each layer, of a palletized unit load has a specific location and orientation. A simple pattern is columnar, and as the pattern changes from a simple columnar pattern, additional time is required to pick and place product. See Figure 4-6.

Picking slip sheets, pallets, and tier sheets reduce robot throughput because the robot is handling these items as well as the product in any given cycle. There are automatic dispensers of sheets and pallets that will increase throughput.

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To expedite handling rates in palletizing, robot grippers are designed to handle multiples of product at a time, up to entire layers of product.

Time is required to transfer full pallet loads out of the robot palletizing zone, and to transfer empty pallets into position. Conveyors can be designed to expedite this downtime or the robot has another pallet location to palletize to, during the pallet transfer at the first station.

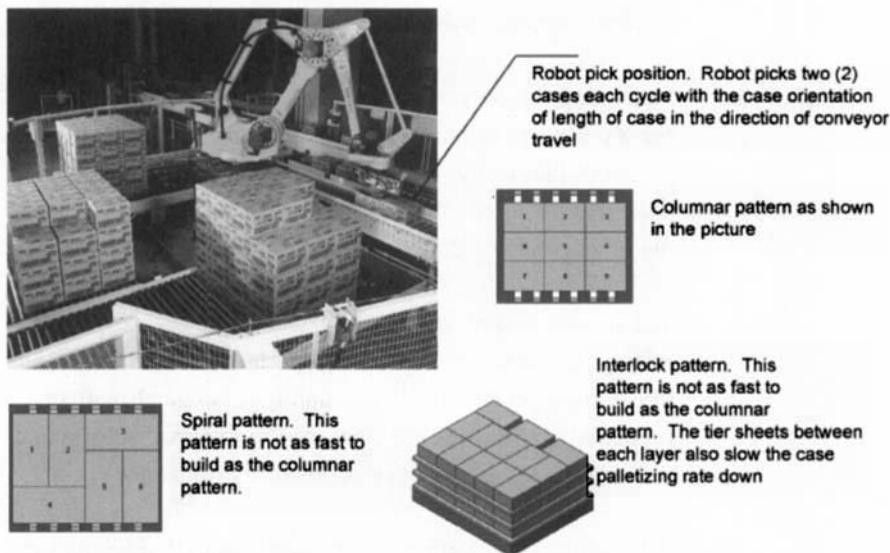


Figure 4-6 Example of Palletizing Pattern Effect on Throughput

De-palletizing product, meaning removing product from a pallet unit load and placing the product in another location, is affected by searching for the product location on the unit load. Searches might be for partial layers of product, or for inconsistent product location on the unit load. In the first example, the robot must search for the layer at the first pick-place cycle unless an operator signals the robot where to start picking up product. The second example requires the robot to take some additional time to find the product at every cycle. Figure 4-7

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represents a de-palletizing project where the robot uses a vacuum tool to pick up individual glass sheets and place them on a flat conveyor. If the glass on the conveyor is required to be placed within a tolerance smaller than the tolerance of the glass location on the pallet, then additional search time is necessary to match the tolerance difference at the pick and place locations.



Glass on rack. Stack up of tolerances:

- The indexing table
- The pallet location on the table
- Each piece of glass in the unit load on the pallet

There is a required location to place each piece of glass on conveyor



Figure 4-7 Example of Tolerance Effect on Throughput

Material Removal	The need to Qualify inbound raw material tolerances regardless of the process of taking the media to the work-piece or the work-piece to the media, decreases throughput. Depending on the tightness of the tolerance requirements for the material removal process, consideration for part presentation is critical. Even with the technology of active and passive force-compliance tooling that enables tools to maintain a constant force throughout the removal process, to cater for variable
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surface tolerances, the part still requires to be qualified. Loosely-located product may require Renishaw probes, laser-based sensors, or vision to qualify surface features prior to removal

The rate of removing material(feederate) is a feature that is critical to throughput. Feederate is a function of the media and base material type, but also affects the amount of material to be removed.

Predicting throughput for material removal is similar to a machining time study. Each tool that is used has a time associated with the tool change and the material removal process.

Press Tending Separating inbound blanks that are stuck together with oil, and rust, and detecting blanks that are stuck together, is time consuming. Magnetic blank separators, and double blank detectors on the robot tool, may reduce the time taken for these problems.

Qualifying the blank takes away from forming time, but is a necessary step unless inbound blanks are already presented in a qualified fashion.

Time taken to re-orient the part during the forming process. Tool changing on the press brake is critical, though the robot is capable of changing tools. Brakes allow for multiple tool setups, acting in a sense as a progressive die. Manual tool change will take away from throughput.

If the robot uses magnetic grippers to grip the work-piece, additional time will be required to release the work-piece, often using compressed air.

Many factors affect throughput for a given application. The underlying theme for all the application types is that there are tasks

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that increase throughput and tasks that reduce throughput. Lean manufacturing tells us to eliminate waste and non-value added tasks. The exercise of validating throughput should force the engineer to ensure that there are minimal waste and non-value added tasks. For instance, welding travel speeds should be maximized by increasing the deposition rate of deposited weld metal, for instance, by using a larger wire diameter, or adopting tandem MIG (dual) welding torches on one robot. Increased throughput can be gained by using the right tools and processes. Another example, which will be covered extensively in Chapter 6, is the use of robotic vision to replace conventional robot touch sensing, using the welding wire to define weld locations. The speed of this non-value added task can be increased significantly by using vision instead of the welding wire to locate the weld path. In welding, loading and unloading time should be kept within the process time whenever possible, because loading and unloading parts by means of the robot system is non-value added activity.

Robotic touch sensing controls where a weld seam is located, relative to where the seam should be. In other words, the touch sensing routine determines the offset between the “golden” part and the actual part. Tools like touch sensing are necessary with weld seam tolerances that exceed half the width of the welding wire diameter. The reality is that raw materials (inputs) presented to a robot welding system will rarely achieve the tolerances that are ideal for robotic welding. For any robotic system, regardless of the application, there will be a mismatch between the tolerances of the inputs and the tolerance expectations of the finished products (outputs). The challenge for the engineer is to manage tolerance mismatches while minimizing waste and non-value added tasks, all in the pursuit of throughput. As may be recalled from Chapter 1, throughput is very important in contributing to productivity, capacity gains, and lowering costs.

It takes time to manage variability, and at a minimum, money. There are many tools available to use in managing the stack-up of tolerances, but their use will incur additional cost and training. The thing to remember about validation is, that the final product con-

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straints are constant – throughput, and product quality. The trick is to validate what is needed in regard to tolerances, and then validate whether the tools you decide to use can achieve the project expectations. Four examples described in Figures 4-8.1 through 4-8.4, illustrate this point for several applications. All the project examples are still working well in production today. The point of these examples is to illustrate the considerations that are present for any application in terms of process tolerances. At the start of each of the projects, the team had to analyze what were the variables and what were the final expectations. The team then had to manage the solution that enabled the process to work with zero defects. Costs for managing the variables while achieving the specified throughput were just part of the overall robotic system investment.

Managing the stacking up of tolerances is one of the critical components that require validation because a machine (robot) with zero senses (sight, touch, smell, hear, taste) is being forced to work with

Example 1. Robotic tending of turret punch. 8' x 5' mild steel blanks are presented in a stack of (80) pieces on a pallet. The robot picks a single blank from a stack and loads the turret punch table



Origin location for placing blank

Inputs (tolerances)	Output (tolerances)
Blank location at the inbound stack is +/- 0.375"	Blank to be located on the table +/- 0.035"
Blank length and width as sheared is +/- 0.062" along the width and length	Blank thickness needs to be within +/- 0.025"
Blank flatness – user can't state exactly, but within +/- 0.060"	
Blank thickness can vary +/- 0.035"	
Blanks stick together due to oily surface	

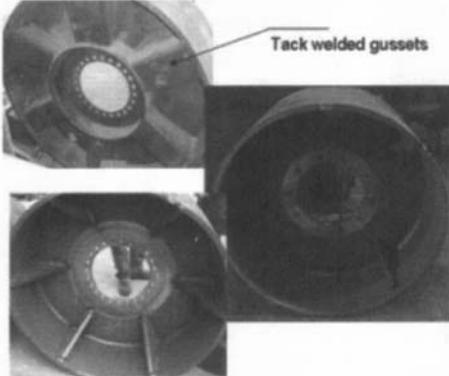
Solution to manage the tolerance variance between inputs and outputs:

- Double blank detection in robot gripper
- Requires an inspection station prior to loading the punch using laser guided sensors to capture blank location
- Inspection station also equipped with additional sensor to pass or fail the blank thickness specification

Figure 4-8.1 Stack up of Tolerances

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Example 2: Robotic welding of various wheel assemblies. Wheels are presented to the robot as tacked by the manual operator. Welding wire is 0.045" diameter ER70S-6 with mixed shielding gas



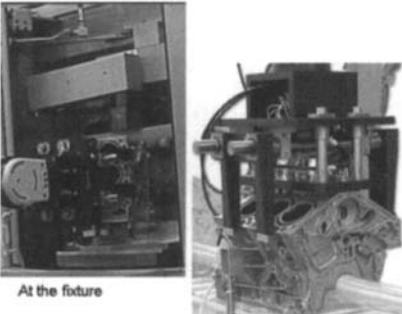
Inputs (tolerances)	Output (tolerances)
Radial orientation is needed for the wheel prior to welding so gusset position is located consistently	Weldment needs to be located +/- 0.022" Bead size to be $\frac{1}{4}$ " Throughout
Location of tacked gussets are +/- 0.125"	No visual weld defects
Random gap condition exists at gussets – worst case 0.125" gap	
Location of inner diameter weldment is +/- 0.125"	

Solution to manage the tolerance variance between inputs and outputs:

- Robot vision required or operator required to insure location of wheel radially within 0.125" when presented to the robot
- Robotic through arc seam tracking required for every weld to track weld joint offsets and keep robot welding torch in the weld joint. Seam tracking utilizes a sine weave procedure
- Welding travel speed and weave parameters (frequency and dwell) require overall slow down to insure gaps are filled while maintaining a $\frac{1}{4}$ " bead size

Figure 4-8.2 Stack up of Tolerances

Example 3: Robotic Machine Tending. Die cast aluminum engine blocks are presented to the robot for loading into a series of horizontal machining centers for machining and drilling on various engine block faces



Input (tolerances)	Output (tolerances)
The casting as produced in the die casting process exhibits dimensional tolerances that exceed the tolerances for locating the part in the machine fixture prior to machining	The casting has holes that can be used to locate the block within a tolerance that allows the robot to load the machine fixture
There is a stack up of tolerances for the gripper, robot, and the engine block. All of these variances cumulatively affect the tolerance for loading the block to the fixture	The fixture is designed with tapered pins that locate the block in the fixture
	The machine uses Renishaw probes to qualify the part location prior to machining

Solution for managing the tolerance variance of inputs and outputs

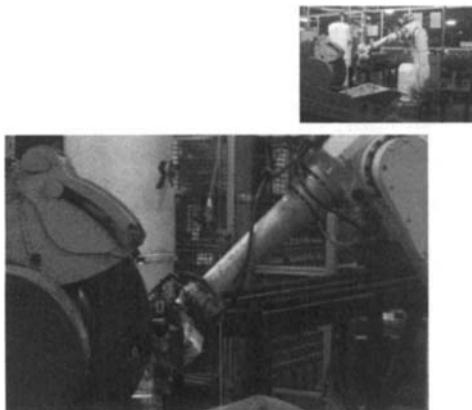
- Tapered pins allow easier loading when the robot locates the part holes onto the fixture pins
- Adding a Renishaw probe in the machine cycle relaxes the tolerance for the part location in the fixture
- Part presence sensors added to the machine to confirm the block is seated correctly in the fixture prior to machining
- Robot gripper is designed to center the block in the gripper based on how the gripper locates the block surfaces

Figure 4-8.3 Stack up of Tolerances

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Example 4. Robotic Grinding. Steel castings presented to the robot. The excess flashing is required to be removed around the casting surfaces as the robot takes the part to the media (wheel)

Inputs (tolerances)	Output (tolerances)
Wheel wear causes wheel diameter to become smaller but the wear is not predictable	Parting line on the casting to be within +/- .030" of the base material
Parts are castings and invariably change in size +/- .050"	Parting line flashing varies +/- 0.1875



Solution to manage the tolerance variance between inputs and outputs:

- Fixtured inbound conveyor utilized to present queued raw material within tolerance for accurate part location at the robot pick position
- Laser sensor attached to grinding wheel to offset robot path into wheel as the wheel wears in real time
- Grinding wheel attached to a compliant back stand that enables the robot to maintain a constant force when the casting is presented to the wheel surface regardless of dimensional part tolerance or amount of flashing on the casting surface

Figure 4-8.4 Stack up of Tolerances

something variable, in producing something constant. Human beings make this task look easy, which is why understanding the challenges of using machines is so difficult. In our imperfect world, humans make decisions in microseconds that overcome the slightest of variances to achieve consistent end results. Robot technology has been adapted continually to match the decision-making skills that humans take for granted. The irony is that, with all the sensory capability of human operators, it is impossible to achieve zero defects in a manually- operated process, whereas zero defects should be the benchmark with robotic automation.

Ultimately, a good or bad project should also be judged relative to the amount of investment and complexity in relation to the level of robotic decision-making and system design used to overcome poor process tolerances. On one hand, keeping the system simple is smart. On the other hand, using innovative tools that successfully

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manage tolerance mismatch, offers the user much more flexibility. If you have the right shop floor personnel, with the right attitude toward supporting the robot system, you should invest in as much technology as possible to gain the maximum from the robot system.

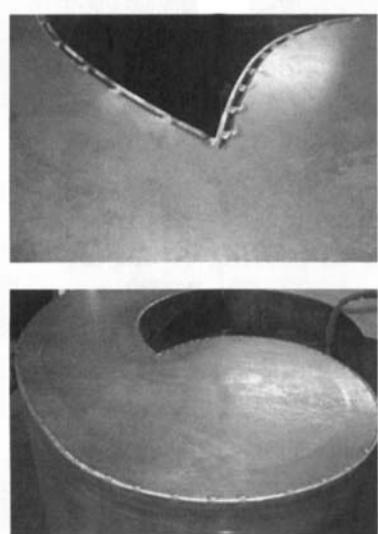
Proof of Concept Case Studies

Proof of concept, sometimes called an engineering study, or feasibility study, serves a valuable purpose in proving or disproving whether a solution will work without designing and building an entire system. Proof of concept is used when no other form of validation tool can determine whether the solution will work. Even if vision, for example, has been used successfully, hundreds of times, if it has not been tested in specific relation to your work-piece, then how can you be comfortable with investment in the projected robot system without testing the product? Proof of concept is commonly used in the following scenarios:

- Where the robot process controls the properties of the finished product, such as in welding or material removal
- Where the set of unknowns and risks cannot be validated through conventional offline PC-based simulation tools
- Applying new technology where there isn't enough experience to validate the success rate in relation to the specific application
- Determining whether a tool, even a robot option such as robot vision or other, will work for the specific application

For instance, a firm wants to determine whether its current line of architectural stainless steel assemblies, shown in Figure 4-9, can be welded by means of robotics. The challenge is to achieve consistent weld size, weld profile, and a throughput of seven assemblies per hour. The requirement is for a 3/16-inch corner weld around the perimeter of the assembly. Notice the variability of fit-up and gap condition, and remember that the rule of thumb for robotic welding is that the weld joint tolerance needs to be half the width of the welding wire diameter. If this rule cannot be met, then additional

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Risks:

- Tack size varies and seems generally too large
- Gap condition varies
- Overall weld joint tolerance as a function of the forming process, distortion during welding, and fit-up will exceed the $\frac{1}{2}$ the weld wire diameter fit-up rule
- The weld joint is in itself a tricky configuration

Expectations of the finished product:

- $3/16"$ weld size throughout the perimeter
- Minimal weld spatter
- No visual weld defects
- Minimum post weld grinding
- Minimum distortion

Figure 4-9 Example- Proof of Concept

tools in the form of robot options (touch sensing, through arc-seam tracking and even the possibility of vision or laser guidance for joint location and tracking) are generally required.

The robot is welding the perimeter of the assembly, which is a cover plate located on top of a container. Notice the size of the tacks and that, without testing, the cosmetic appearance of the robot weldment has to factor in the tack size. The proof of concept exercise will determine that the tack size needs to be reduced to achieve a good robotic weldment. The throughput is not as much of a concern because the weld calculator shows that throughput can be achieved based on the proposed welding travel speed. The judgment criteria for a go or no-go with this program is the resulting bead appearance and weld size, as well as the presence of weld spatter. These three characteristics significantly affect the next step in the value stream, which is grinding and polishing. The proof of concept will validate whether the robot process will achieve the production expectations, given the set of variable inputs in terms of the fit-up,

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tack size, and gap condition. The expectations of the weld size, weld appearance, and weld spatter, define the production constraints.

Usually the proof of concept will consist of the robot, a tool (gripper), and other tools that enable the process to be performed (i.e. the process equipment, vision system, robot software options, and process consumables). The proof of concept takes time and resources, and as a result, robotic system integrators or research institutions are set up to manage the effort better than the user. System integrators will generally credit all or a major portion of the proof of concept, in the event that a system is ultimately purchased. The value of the proof of concept is that a lot of information can be gathered about the potential success of the project for a minimal investment relative to the actual system cost. Validation is everything when you can get it early, versus finding out whether the process will work on the production floor or at a demonstration on an integrators floor. The important steps in developing a proof of concept are as follows:

- Identify unknowns and risk through the audit and discovery phase
- Determine how the criteria of unknowns can be validated (similar application, offline simulation, other research)
- Through process of elimination, whittle the unknowns and risks down to the short list of criteria that needs to be validated through the proof of concept
- Define the production requirements and expectations for the proof of concept
- Match the conditions of what has to be validated within the real world environment
- Determine the minimum amount of process tools that must be designed, built, and integrated, to validate the unknown or risk criteria needed to minimize cost and time

The following examples describe where it has been practical to pursue proof of concept:

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The first proof of concept example was developed to validate whether the robot system was capable of picking laser-cut steel blanks from the nest, as shown in figure 4-10. The specific risks were as follows:

- Each of the 16-gage steel blanks is tabbed to the main sheet by a single tab, and this tab has to be broken by the robot in order for the blank to be removed.
- The cycle time for each cycle consists of identifying the candidate to be picked up, breaking the tab, confirming the tab is broken, and palletizing the blank to a table close to the main sheet. Simulation will only validate the robot motion and not the time to break the tab from the main sheet
- There is a considerable difference amongst blank geometries that the robot and robot tool will need to handle. How can the gripper concept be optimized to handle all the geometries, with minimum impact on throughput and cost?
- Some blanks are mild steel and some stainless, so the material variance adds another twist to the robot gripper solution, requiring either magnets or vacuum to pick up parts

The proof of concept does not encompass any other aspect of the system because the remaining functionality has been demonstrated to work for this application. The remnants (skeleton) of the main sheet will also be required to be robotically removed but that is not an immediate risk for the project. The testing criteria is straightforward and specific to validating the three aforementioned risks. The validation included the following tasks:

1. Obtain prints of all the blank geometries and study them;

Overlay blank prints and categorize products by similar geometries and size

Examine each category for holes and slots in the blank “as-cut” for the purpose of determining where vacuum

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could be a limitation, because there would be a limited blank surface area to pick on with vacuum grippers. It is also necessary to identify the weight of the heaviest blank size

The results of task one will develop the gripper concept which, in this project, will be one vacuum gripper and three magnetic grippers for all the part styles. The vacuum gripper will be specially designed to position the array of vacuum cups to achieve a universal vacuum pattern for all the blanks that are compatible with vacuum picking. Cups will be arranged in quadrants on the gripper, and the gripper will be designed to allow independent control of the various quadrants, depending on the ID of the blank being picked. Three magnetic grippers were needed because of unique slot and hole patterns on the some of the blank part styles.

2. Build a mock vacuum gripper, not a production gripper for picking one of the higher volume blank styles, also a part having more complex geometry. Obtain the use of a six-axis robot with appropriate payload and reach for the application. The payload analysis will take into consideration the center of gravity for the largest gripper and blank when handled together.

Manually break tabs for a period of time and watch the operator perform this task for a period of time. Identify some of the most difficult blank styles to be removed by the operator, and select one of those parts for the validation.

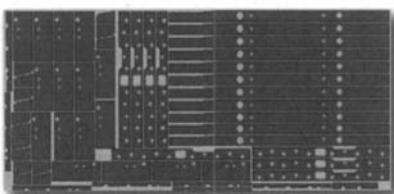
The value of step two is to validate the material-handling equipment (robot and end of arm tool) for one of the more complex blanks in terms of breaking the tab that joins the blank to the main sheet. Selecting one of the more complex shapes, and studying the manual sequence, will offer a lot of value in terms of the robot programming routine that will be developed.

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There are some assumptions that will be made and not validated. The assumptions are that the tab for the stainless or steel blanks will behave in a manner similar enough to not require a completely different test for each base material. The stainless steel blanks will be tested in this program because the more-complex shapes are made of stainless. Additionally, focusing on a complex blank shape is going to validate the removal for all the other shape styles, without having to set up additional tests or make additional grippers for other blank shapes.

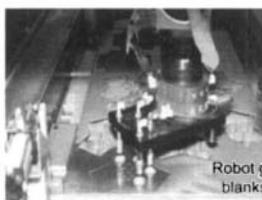
The proof of concept will thus include the robot, gripper, a table to hold “as-cut” blanks, and a table to allow the robot to place the blanks in specific patterns and orientations. The key to the robot programming will be to use the six-axis robot and tool to peel the blank at about a 45 degree angle to the main sheet but at varying speeds throughout the movement, while utilizing a motor-driven grinding wheel to break the tab as the robot is peeling away the

The robots task is to receive blank location and orientation from the translator software that converts nesting positional data to robot coordinates. The remnants (skeleton) will also be removed by the robot. Blanks will be sorted and palletized for the next operation in the value stream which is forming and welding



Sample of a TruNest™ I Nest

Parts are tabbed to prevent shifting during handling of the main sheet



Robot gripper example picking blanks from the main sheet



Robot gripper example picking skeleton remnants

Figure 4-10 Case Study Example- Robotic Sorting of Tabbed Nested Blanks

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blank. Additional work will be required in the proof of concept to confirm that the tab is broken, prior to the robot fully peeling the blank away from the main sheet.

Another example of situations where proof of concept can be invaluable is simply determining the “optimum” solution, because there are so many ways to automate a manufacturing process. For the situation under review there is no question that the robotic system will work. However, minimizing cost, keeping the solution as simple as possible, and providing the right amount of flexibility, all need to be investigated. The value of the proof of concept in this scenario allows for the best solution to come to surface, prior to making a major investment and a potential direction change, which will cost a lot more money and time.

The part attribute box for two steel castings that need to be machined in Figure 4-11, illustrates the project attributes. Outside of the part attribute box are shown the criteria that need to be optimized to match the user’s priorities through the proof of concept exercise. Some of the important decisions that will be considered, as the result of the proof of concept exercise, are as follows:

- Radial orientation of the steel castings is required prior to loading the lathe. It is necessary to decide on the best way to present the casting to the system to 1) qualify the part location for picking, 2) optimize raw part queue time to minimize operator time in feeding the system, and 3) find the radial orientation of the casting prior to robot loading of the CNC lathe. The ideas that will be floating around are as follows:
 - 3D vision bin for picking up parts from the container delivered by the casting supplier
 - Conveyor with 2D vision for establishing single-part orientation and location
 - Conveyor with fixtured nests (pockets) to capture and orient the part
- The castings have multiple diameters, and it is necessary to decide on the best way to have the system adapt easily from one diameter to another. All the choices above still apply,

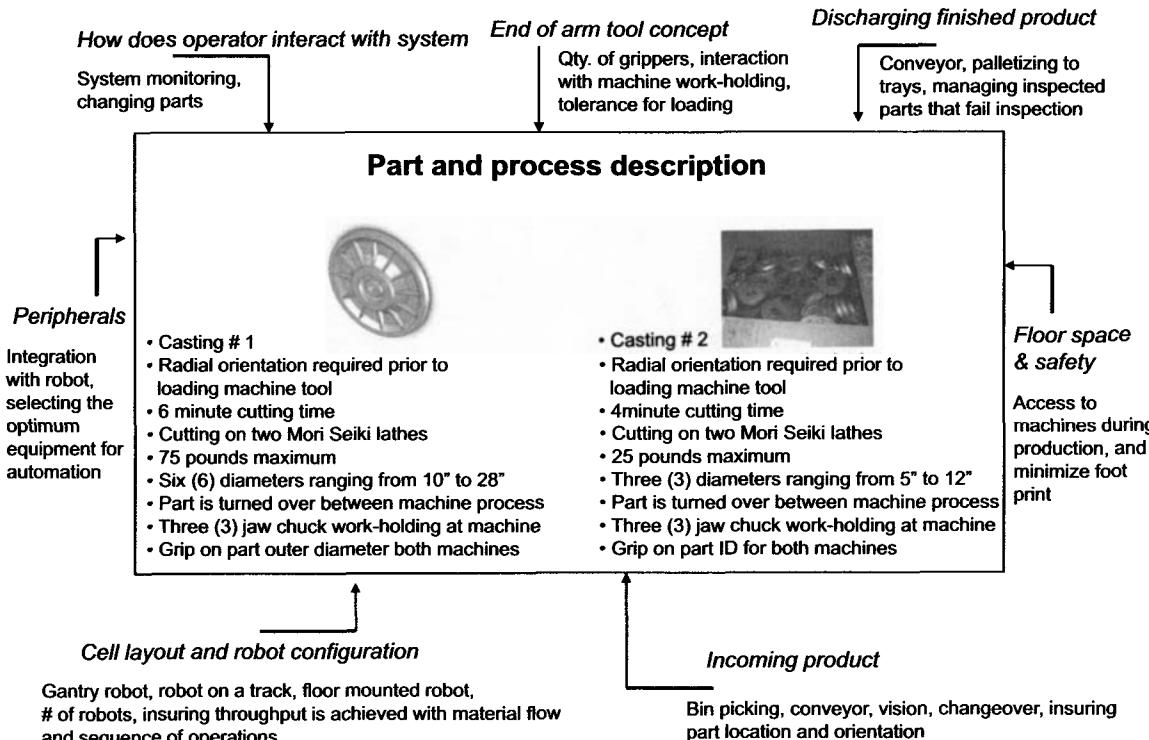


Figure 4-11 Proof of Concept Example- Robotic Machine Tending

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with the addition of how to design the gripping concept to adapt to the various casting diameters

- A second part design with several diameters is also going to be machined in the system at the same time as the first casting design. The choices are still all the same, except that they are compounded because two completely different part designs will be machined at the same time and they have completely different geometries, gripping surfaces, and machining processes. Two lathes will be used for machining one part design and two lathes will be used to machine the second part design.
- Inspection and part marking is required for every five parts, for each part size. The equipment to be used includes four lathes, plus inspection and marking equipment, as well as provision for parts to enter and exit the system.

The proof of concept for this example will answer the choices the user has in regard to how the system will manage the flexibility requirements in machining the two part styles concurrently. The proof of concept will define the team's compromises, expectations, and needs. Additionally, the proof of concept will determine the ideal system layout to: 1) achieve the part throughput for each casting style, 2) stay within floor space constraints, and 3) incur minimum investment. Ultimately the systems objective is to make a good part. The criteria outside the attribute box all affect the system's ability to make a good part. As the team works through the exercise in validating the optimum system criteria to automate machining of the two casting families, the scope of work is the end result.

The next chapter will review the final phase of robot implementation prior to designing and building the system, which is the scope of work. The better the team prepares a scope of work, through the practice of audit/discovery, identifying risks/unknowns, and proof of concept, the higher the probability that the robotic system will be successful. Without following through on these steps, the robot system will never meet or exceed expectations.

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The proof of concept is a powerful exercise, whether it's a simple simulation of a standard welding system, validating the optimum robot riser height so that the robot reach is slightly better for the programmer to optimize the weld torch angle for a few weldments, or full-blown application development. The life of the robot operator is greater than fifteen years, so additional time to validate the risks and unknowns, as well as chisel away to find the optimum solution is the best investment, beyond the monetary aspect, that the team can make.

5

Writing the Right Specifications

The difference between the firms that are successful and are not successful in implementing robotic automation on the factory floor lies in the clarity of the overall definition of what the company wants to do. That there will be compromise in most instances where the budget won't cover everything you want to do is accepted. Assuming that the budget looks realistic relative to the system content and capability, and the ROI is acceptable, the success factor is again a function of how well the specification is defined. Specification in terms of this chapter will be called the scope of work. The scope of work is the working document that establishes the rules around which the builder, whether internal or an outside system integrator, and the user, will base all future discussions.

All monies, time schedules, and metrics of the project are tied to the details outlined in the scope of work. Imagine the challenge in managing the expectations of the user, or what the supplier thinks needs to be delivered, if an ill-defined scope of work was the working document that both parties were working from. The scope of work does not need to be a 30-page contract like that used for a new house mortgage, but it has to have some very basic ingredients that define the user's needs and requirements, as well as rules for acceptance of the system, and ultimately paying the builder for the system content to which they thought they were designing and building. This chapter will provide three examples of scope of work from three different application types. Hopefully, this chapter will be useful as a guide for developing the scope of work for your project.

A well-defined scope of work is certainly important when the robot system is being built internally, and it is even more critical when the user purchases a system from an outside source. The value of any investment is very important to any firm, not only for the dollars going out to buy the system but also for the value of the sys-

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tem when delivered onto the shop floor. When it comes to money and scheduling, an ill-defined scope of work is a problem. The situation comes down to sorting out a series of assumptions and hearsay about what people thought they heard prior to making the investment in the system. The devil is in the details. If there is a detail important to the team, then it must be called out and documented in the scope of work. Arguing over two distinct points of view in terms of an attribute of the project after the projects starts, costs money and lost schedule time, and there are no winners.

Jobs and careers have been lost over such disagreements where a well-defined scope of work could have avoided a great deal of pain if it had been established from the beginning. The scope of work needs to be as black and white as possible, and if there is any gray then both parties understand why and agree to co-manage those assumptions. For system integrators and other builders of robotic systems, the scope of work is the contract from which all deliverables and services are defined in terms of what, how, when, and who. This chapter will describe two real case-study projects that the integrator and user developed, prior to entering into a contract.

All the effort and preparation from the audit/discovery in identifying risks and unknowns, and validations, are key ingredients to the scope of work formula. The old saying garbage in – garbage out applies here. One does not start from scratch with developing the scope of work, but rather goes through the process outlined back in Chapter 2, Figure 2-1. The scope of work is simple to develop if the previous three steps are followed. The process of developing the scope of work is literally filling in the blanks from the data that was collected in the audit/discovery phase. The risks and unknowns defined then allowed the user not only to identify possible cost pitfalls but also to develop a more refined solution that could potentially solve problems. Moving forward in determining questions to answer or unknowns and risks to validate, was important there because the right solution was derived for the optimum cost, and the rules for what the team could live with were agreed upon. Whatever is validated becomes part of the design criteria in the scope of work and the team will have to live with whatever is left over that isn't

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validated. The flow for a scope of work is as follows:

- Introduction that describes the general system requirements, how the system is intended to work, and the benefits of the system to the value stream
- Design criteria (everything that is a known requirement, as well as the definition of every aspect of the process)
 - Definition of the product itself that is being processed through the system
 - Prints and models
 - Part properties
 - Sequence of operations
 - Facilities layouts
 - Definitions of user-provided equipment
 - Electrical, mechanical, or other specifications for equipment in work-cell
 - Definition of manufacturing process
 - Tolerances
- Description of deliverables
 - Definition of the solution
 - Equipment description and how it will work for each piece of hardware
- Roles and responsibilities of each team member (whether internal or if project is built by outside vendor)
- Key requirements for the system
 - Throughput
 - Expectations of equipment performance
 - Definition of the state of the product incoming and outgoing at each step
- Key assumptions for the system
- Management procedures
 - Setting the rules about changing project parameters
 - How communication will be set up in terms of reporting
 - How reviews of progress relative to design and equipment runoff will be managed

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- Acceptance criteria
 - Definition of “what is a good part”
 - What validation is required for the system
- Training, spare parts, manpower to support system on shop floor, installation requirements
- Schedule of all tasks to design, build, validate, and install system

The length of the scope of work document will vary. Quality not quantity is most important.

Defining Elements of the Scope of Work

The purpose of this section is to provide some definition regarding the key elements of a scope of work. The aforementioned outline is simply a suggestion. The two examples in this chapter following this section are formatted differently, even though they both serve as a scope of work. The scope of work should be kept as simple as possible. What is interesting is that companies now feel that their specifications need to be massive volumes of details regarding hydraulics, pneumatics, electrical standards, formatting for drawings, and the list goes on.

Companies that send volumes of specifications will often be charged a premium for the simple reason that the group evaluating the program has to sift through all the documentation. The content and clarity of the scope of work drives the success of the program. However, there is no proportional relationship between the amount of documentation generated and the level of project success. In the end the system has to work on the shop floor, with shop floor personnel.

Of the important elements of the scope of work, the first section is the introduction, which should include the following elements:

- Titles of supplemental documentation that is included with the project. The documentation could range from ergonomic specifications to electrical standards, and metrics for acceptance criteria

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- A generic overview of the project and perhaps where it will be installed
- Specific goals and benefits obtained as a result of the project implementation

The next section is the heart of the scope of work. The design criteria will encompass all present and archived information that the user knows and requires concerning the robotic system. In the example later on, where a scope of work for robotic finishing of cast iron cylinder heads is examined, the criteria focuses on all the requirements for the project but does not go into speeds and feeds, tools, or how the process will work. That effort is part of the engineering phase of the project. The design criteria are meant to establish the rules for the project from which the engineering will be designed. These criteria are not meant to be an editorial, but rather should state the known facts about what is known and understood to be true from the user's perspective, and what the user requires of the system. The needs of the design criteria must not be confused with how certain aspects of the system need to work.

The description of deliverables is important, regardless of whether the firm is building its own system or purchasing a system from outside the firm, as in the example of a system integrator. If the firm is implementing the system internally, which many users do, then the deliverables details will enable the team to understand what is going to drive the costs of the project. Usually, it is good to start with hardware. Hardware in my opinion also includes software and the equipment that operates the software, but not the programming or set-up effort. Every robotic system will contain some form of the following deliverables:

- Robot
- Support for the robot (examples include pedestal, base plate, track, boom)
- Process tool (i.e. welding torch, gripper, chisel, drill head, grinding wheel)
- Hardware to provide work-piece location (examples include

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conveyor, fixture, pallet magazine, trays, vision, sensors, probes)

- Controls that enable communication to be maintained among all the process devices (examples include machinery, process equipment like welders, machine tools, press brakes, injection molding and die casting machines)
- Controls that enable interaction with the shop floor personnel. Human Machine Interfaces (HMI), PC, HMI software

It is worthwhile in the scope of work to agree on what the controls architecture will look like because there are so many ways to accomplish communications, but the range in price can be significant. Decide on the hardware protocol first. Examples could be Ethernet IP, digital discrete 24VDC I/O, Profibus, and Devicenet. Then decide about whether a PLC is required or whether the robot will be the cell controller. A flow chart should be drawn showing the system controls architecture, with a general schematic showing how information flows between all the devices, as well as designating the communications hardware.

If an HMI is being used, it is helpful to define what parameters should be included within it. Generic information on functions such as monitoring equipment effectiveness, starting the system, and selection of part style are included in the HMI function. A rough outline of what is required is helpful because the cost for an HMI can also be extremely high, and the following details should be included:

- Inbound data in terms of the method used to feed the robot system. This hardware may be the same as that used to locate the work-pieces, or additional equipment may be needed. For example, an inbound powered-roller conveyor feeding raw castings to be machined as the inbound, supplemented by a fixed camera over the robot pick location to serve as the enabling tool to find the location and orientation of the work-piece.
- Peripherals that enable the robot to perform the process (tool changers, part re-grip stands, and part-qualifying stands are

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examples)

- Peripherals that are important to the system but not necessarily the process. Examples include safety, robot hard-stops to limit robot motion, floor grating to capture coolant in a machine-tending work-cell.
- Outbound data in terms of how finished product is transferred out of the cell. The same mind-set here as in the inbound description, but with less emphasis at this point in terms of the work-piece location
- Safety systems that follow an internal code or codes that reference the particular region's safety code requirements
- Process equipment that the robot uses as part of the process. This equipment is mainly associated with material removal and welding, where welding equipment, or process machinery like a compliant (a compliant unit is defined as: a mechanism designed to maintain a constant force during a metal-removal process, taking account of such factors as variable surface tolerances) back-stand, are integrated with the robot to do something to the work-piece
- Process equipment in situations where the robot loads and unloads the equipment but the two entities do not work together to do something to the equipment. This item can be very long
- Other hardware with which the robot will interact within the system, which can be a very broad list. Some common items that come to mind are bowl feeders, bar code readers, RFID readers, gages, washers, leak testers, trim presses, etc.

The list above pretty much covers hardware. What remains is the effort needed to design, build, program, and de-bug the system. Decisions about which parts will be automated, and which parts will be validated as part of the acceptance of the system are important components to the scope of work, and that is why there is a separate section for acceptance criteria. The criteria for acceptance are also important because they provide the last chance to make sure the sys-

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tem works prior to handing it over to the shop floor. It is always best practice to test the system before releasing it to the shop floor because shop floor personnel and management get soured quickly when a brand new system is installed and does not run immediately.

Internal or external engineering resources will be required to implement a robotic system. As described back in Chapter two, robotic systems are not put together by a single person but by a team of people from varying disciplines. The scope of work helps define the level of contribution of each of these individuals. The underlying point to make here is that, regardless of standards or custom systems, all the aforementioned categories have to have some thought and definition if the system is to work as planned.

The next two sections are examples of two completely opposite systems. One is highly complex and the other simple. The risks, and associated costs are completely polar opposites. What they have in common is that the same exercise of audit/discovery, identifying risks and unknowns, and validation, enabled a scope of work to be created that enabled the user and the implementer, whether or not they were one and the same, to achieve positive results in terms of reliable systems that surpassed levels attained by any manual operation ever.

Scope of Work Example – Robotic Finishing Cylinder Head Line Case Study

The first example is extremely detailed and was developed around a robotic material-removal project. This example can be used as a guide for any application because the same rules always apply for the same scope of work. This chapter will include additional scope of work examples for additional application types.

The background for this first project example was provided by Foundry Solutions and Designs, an engineering consulting firm working in the foundry industry.

A major foundry was experiencing significant cost pressures globally in producing cast iron engine cylinder heads. for which the finishing process is highly labor intensive and accounts for over 40 percent of the cost to produce the casting. The company wanted to

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improve finishing operations on six (6) high-volume casting versions, which make up the bulk of present and future production.

The foundry was using largely traditional methods of chipping and grinding, with a mechanized grinding machine as well as hand tools and manual labor, to carry out all the internal and external finishing to the stage where the cylinder heads were ready for heat treatment.

Current plans are to make maximum use of automated machinery, robots, and manipulators, with the joint aims of raising the quality of finishing and removing the need for operators to engage closely in the often arduous and unpleasant work.

The plan is to install a largely automated cylinder head “finishing line” which will take castings from the molding line and deliver them fully finished and inspected to the existing heat treatment furnaces. The section describing the equipment in the solution is omitted here.

Foundry Solutions & Designs Scope of Work

Principle of Operation

The major objective is to finish a range of cylinder heads from shakeout to heat treatment, with minimum manual intervention. This aim will be achieved by the use of programmed CNC or robot devices, manually-operated manipulators, and special purpose machines, coupled with an automated transport system. Some of the mechanized finishing stations will use specific jigs and fixtures to hold the castings during processing. Attention needs to be given to developing a locating and holding fixture design that is common for all the specified products. If this aim is not economically feasible, then the exchange of locating and holding devices is to be accomplished automatically during cycle time. The entire system will be integrated using Level II controls.

Operation Stages

- All castings will follow the same general sequence as outlined on the following page:

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- Gates, risers, over-flows, and selected flash, will be removed by the manipulator
- Automatic surface grinding will be used for up to six faces
- Hole opening will be used to assist decoring
- Decoring will be done by high-frequency, low-amplitude pneumatic equipment
- Shot blasting will be done by existing equipment (modified to accept small heads)
- Fine finishing and removal of parting fins (not reachable with the large automatic grinders) will utilize robots
- Finished castings will be loaded onto pallets and stretch wrapped

Casting Variations

- With the current molding method (combination of core packages in green-sand molds) some slight variation in the castings and the size of the fins is possible.
- The proposed metal removal tooling should be of the “compliant” variety to allow for self-adjustment to accommodate slight irregularities in the castings.

Product Mix and Volume

The finishing line will be designed to process up to six (6) different designs of cylinder head. One style is unique and that is style number one. The second style head has five variations within the family.

The cylinder heads to be processed are:

Engine series	Quantity/mold	Processing Rate
Style # 1	2	240/hour
Style # 2a	1	100/hour
Style # 2b	1	100/hour
Style # 2c	1	100/hour
Style # 2d	1	100/hour
Style # 2e	1	100/hour

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Only one casting type will normally be processed through the system at any one time. The system will be designed to allow a switch to any one of the above six casting types at any time, with no significant loss of production during the transition stage from one type to the next.

Other cylinder head types may be brought into the system at a later date, provided that they conform to the overall dimensions and production rates of the above types. However, any additional locating and holding devices must be changed within normal cycle time.

Process Flow

- The entire system will operate as an automatic progressive processing line as shown in Figure 5-1. In other words, the line will consist of a series of independent work cells arranged in the sequence of operations required to finish the cylinder heads. The system will be a pull system based on customer orders, and the line will be configured for a batch of one process.
- Manual control will be allowed for local start-up, commissioning, and trouble-shooting.
- After loading by manipulator at a single loading station, all castings, except for the style-3 heads, will be transported

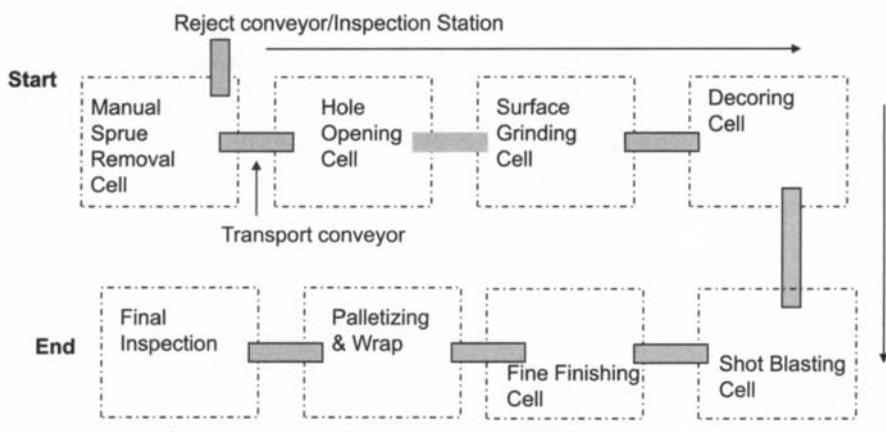


Figure 5-1 Process Flow Diagram

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automatically through the system at a rate of 100 cycles per hour, and will be loaded thus:

The style-3 series cylinder heads will be processed two at a time, at a rate of 120 cycles per hour, at each station, on each locating and holding device.

The other five types of cylinder heads will be processed individually.

- Every station may not be required for all cylinder head types, and the transport system will by-pass the unused stations with no loss of production capacity.
- Provision will be made at certain locations for castings to be removed for intermediate storage in the event of a system failure at any point. The control system logic will also provide the option of running the system out without loading new parts.
- Castings removed will be able to rejoin the system after restoration of normal operations.
- Casting types and orientation will be automatically identified at each sub-system to ensure that workstation settings are correct.
- Access to the shot-blast machines, for loading and unloading will be provided for other castings that are not processed through the automated stations.
- Downtime of the cleaning line must not be allowed to interfere with the uptime of the molding line feeding it.

Therefore, the manually-operated manipulators will be available to load unprocessed castings onto pallets that will act as a buffer zone at the shakeout apron conveyor

Scrap and waste material removal

Throughout the system, provision will be made for all waste materials generated within the system (sand and metal flash) to be removed and conveyed to the refuse system.

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Plant layout

A general arrangement drawing has been prepared and will be provided, showing the general layout of the proposed arrangement in the area available at the Mapleton facility.

The proposed layout will include some existing equipment (some of which may be relocated) and some new units. The installation sequence must be designed to cause minimum disruption to the flow of work through this existing section. A drawing has been prepared and will be provided, showing the underground network of conveyors for scrap and waste removal.

Processing Stages

Figures 5-2 and 5-3 following this scope of work description show pictures of the specific areas to be finished, and the casting finishing sequences, for both styles of cylinder heads.

Sprue Removal

Gates and risers will be broken off the castings by, two (2) manually-operated manipulators, located alongside the apron conveyor. These manipulators will also separate the gates and risers from the castings. The gates and risers will be left on the apron conveyor and will fall into a chute at the end of the conveyor, to be taken away by an under-floor system. Where required, special "helper" devices may be installed to assist the operator in breaking off risers or gates. Castings requiring these devices will be placed on the device with the manipulator, but clamped in the device itself during break-off.

Placement on Castings Transport Conveyor

The transport conveyor system will accept castings from either manipulator and convey them to a casting identification and orientation station. Any casting not conforming at the recognition stage will be diverted to a rejection conveyor where it will be identified manually and redirected into the system or removed for processing in another location.

Castings will be transported automatically using conveyors or robots, to the next processing cell.

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Hole Opening

Some of the cylinder heads will have core prints that are flashed over, which would impair removal of the core sand. To overcome this feature, hole-opening stations will be provided that will use powered tools to break the flash. These hole opening stations will be either CNC or robotic, and will be housed in noise and emission control cabinet(s) that permit necessary access. They will be provided with appropriate safety interlocks to prevent unauthorized access when in operation. Special devices will be utilized to check on tool wear. Two (2) such stations are required for redundancy. Each station will be capable of completely opening all the required holes on the castings. These stations will be loaded and unloaded automatically.

Automatic Surface Grinding

The automatic grinders will be designed to completely grind the top surface as presented, and the casting perimeter, including parting lines, core flashing, etc. Each cylinder head will be delivered by the transport system conveyor and placed into the locating and holding device of the grinder. Two (2) such stations are required for redundancy, and they will be housed in noise and emission control cabinet(s) that permit necessary access. The cabinets will be provided with appropriate safety interlocks to prevent unauthorized access when in operation. Special devices will be utilized to check on wheel wear. Each station will be loaded and unloaded automatically.

Decoring

All castings will be transported automatically to the decoring cell using the conveyor system.

Core sand remaining inside the ports and water jackets will be removed by a high-frequency, low-amplitude, vibration decoring process, in fully-enclosed, universal decoring stations.

Four (4) such stations are required. Each station will be loaded and unloaded automatically.

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Shot blasting

The existing BMD-DS shotblast machine will be modified to accommodate two 3500 heads per cycle, and will remain in its present location to shot blast all castings. After blasting, all castings will pass through a shot-emptying station to ensure minimum shot carry out.

Fine Finishing

Some parting-line flash may remain in recessed areas that the automatic grinders are not capable of removing. These areas will be processed using various small tools mounted on robots.

A series of robots with quick-change end-of-arm tools will be used to do fine metal removal on the casting surfaces. Each robotic cell will finish a complete casting, allowing the line to continue to operate (at lower capacity) if a cell is out of service. The robotic cells will be housed within a noise and emission control enclosure. Chutes will be used to direct the metallic residue to a removal conveyor. Special devices will be used to check the condition and wear of the tools.

Compliant tools will be used to compensate for slight deviations in the shapes of cored holes.

Palletizing and Stretch Wrap

After final finishing, the castings will be palletized automatically and transported to the (relocated) existing stretch wrap machine.

Internal Finishing and Inspection

Internal finishing and inspection will be accomplished manually.

Other aspects of the scope of work included the following additional sections:

- Appointment of a supplier representative who would be the focal point for all communications on behalf of the team that is implementing the system
- Safety and environmental specifications (ANSI, OSHA, and RIA robot safety codes)

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- FMEA (Failure Mode Effects and Analysis)
- Specification for operator manuals pertaining to individual pieces of equipment as well as the operation of the system and error recovery
- Specifications for drawing format, and how information will be transferred between the firm and the supplier of the system
- Preventive maintenance schedule and spare part requirements
- Response time for support
- Utility requirements (examples: power, compressed air, natural gas)
- Installation requirements (foundation, ceiling height, rigging of equipment, and wiring specifications between electrical devices and electrical panels)
- How the supplier will report schedule and project milestones
- Installation package in terms of how the mechanical and electrical contracting services are defined. Typically the system mechanical layout is drawn in Autocad with referenced dimensions to a known datum on the shop floor. Equipment is lagged to the foundation, and wiring between panels, electrical junction boxes, and other devices is permanently installed using conduit, or other permanent wiring method.
- How the supplier will validate the system prior to shipping the system to the firm. This is probably one of the most important items in the scope of work because the system is run-off at this point. This exercise is paramount in protecting the user and the supplier from unknown risks, prior to setting up a system on the shop floor. A system must never, ever, without exception be set up on the shop floor without being tested first somewhere else.

This milestone for testing prior to production run-off is to be viewed as report-card time, for it shows whether the supplier, albeit internal or external to the firm, will make a passing grade. In this particular example, the run-off requirements were as follows:

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- Finished castings had to be finished within a dimensional tolerance of $\pm 1/16$ inch of the base material
- Specified throughput had to be achieved
- Error recovery and safety systems checked out
- Equipment was all present per contract
- The line operated at 98 percent uptime with no failure for twelve hours
- Run-off on the shop floor. This validation exercise is typically similar to the previous run-off, and the pressure is pretty well off the team at this point because this milestone should simply be a repeat of the previous run-off
- Specifications for shipping requirements, training, and production support if applicable. Systems are sometimes set up at time of installation and commissioning to run some fraction of the overall part types being manufactured. Users will require additional support to program additional part versions as various part styles are scheduled into production. This is where off-line programming can once again add value by reducing the overall programming time for new products, and permitting the system to be used in production without tying it up during programming of new parts. However, there will always be some level of validation or touch-up when new product is introduced into a system.

The casting finishing sequences for the two style cylinder heads are shown in Figures 5-2.1 and 5-3.1.

What was interesting on this project was that new technologies and applications of robots were used to accomplish the finishing. This project also required an engineering study before the firm's team of personnel would agree to move forward with designing and building of the system, and new technology had to be validated. The challenges were:

- How the robot itself would handle the foundry environment of dust, and heat during all seasons of the year
- Could a robot be utilized to perform pre-machining processes

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Style Head # 1

Casting Finishing Sequence

- 1 Remove gating system & riser
- 2 Remove flash from side coreprints
- 3 Transfer to conveyor
- 4 Surface grind cover face
- 5 Remove joint-line flash
- 6 Remove joint-line flash
- 7 Remove joint-line flash
- 8 Remove joint-line flash
- 9 Open 3 holes on cover face
- 10 Decore
- 11 Shotblast
- 12 Remove injector hole flash and flash in hole in corner of recess on cover deck
- 13 Palletize & stretch wrap



Figure 5-2 Casting Finishing Process for Head Style

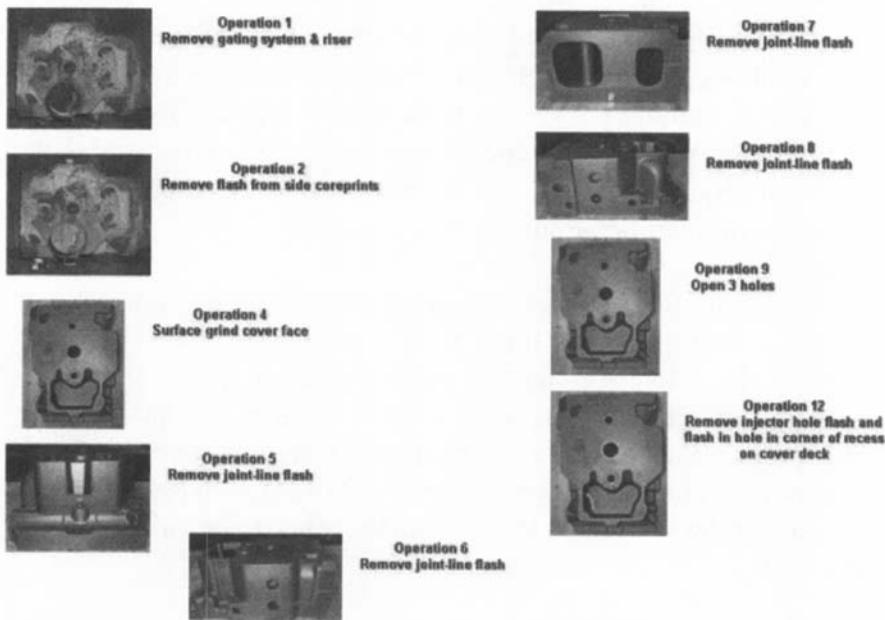


Figure 5-2.1 Casting Finishing Process for Head Style

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Head Style # 2

Casting Finishing Sequence

- 1 Remove gating system
- 2 Remove 4 risers
- 3 Remove in-gates on combustion face
- 4 Deflash intake ports (6)
- 5 Transfer to conveyor
- 6 Surface grind combustion face
- 7 Surface grind cover face
- 8 Remove fins on end
- 9 Remove fins on end
- 10 Remove flash from parting on exhaust side
- 11 Remove flash from side
- 12 Open 12 holes on cover face
- 13 Decore
- 14 Shotblast
- 15 Palletize & stretch wrap



Figure 5-3 Description of Casting Finishing

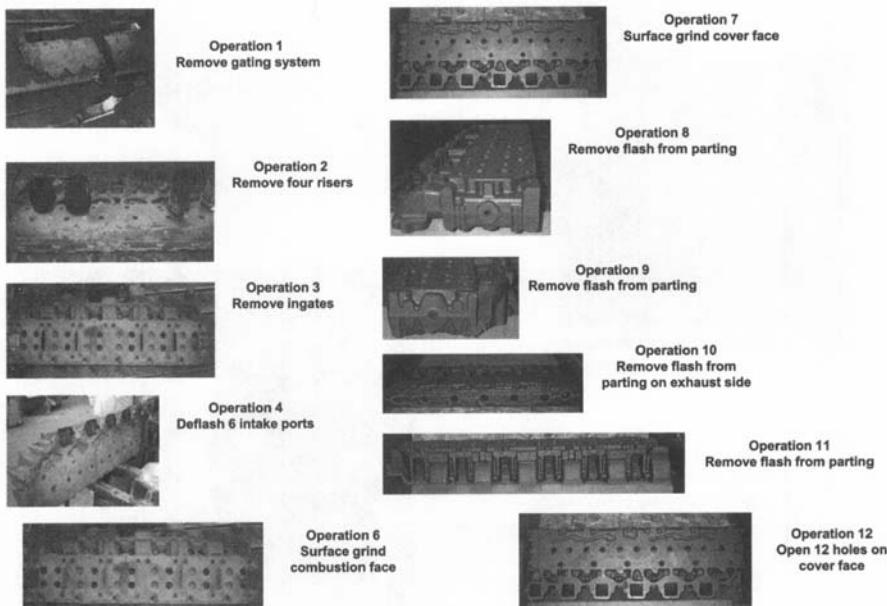


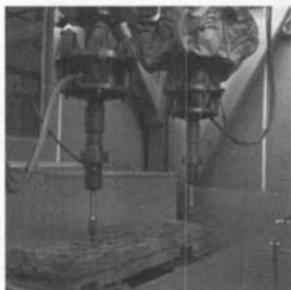
Figure 5-3.1 Casting Sequence

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on cast iron without damage to the robot itself, and premature wear due to the heavy forces applied to the castings to remove material

- Could the robot and compliance devices, with grinding tools as an example, handle the variations in the castings and achieve a process where the casting was finished within a tolerance of 1/16 inch of the base material
- Could a robot withstand the re-active forces if the robot needed to use chisel-type tools to remove gates and risers from the castings

These four criteria were all validated in an engineering study because they were unknowns, and risks to the success of the project. In hindsight, the engineering study was well worth the effort. The pictures of the completed system in figure 5-4 through 5-6 illustrate that point.



A pair of chiseling robots finishing Head Style # 2. The robots have protective suits over the robot cas



Robot (upside down) with high RPM and HP motor grinding surface of head style #1

Figure 5-4 Robotic Cylinder Head Finishing

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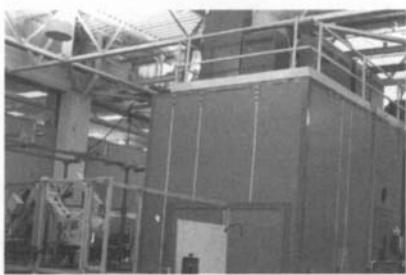
Robot positioning cutting tool to remove flashing from the casting surface



Material handling robot
palletizing finished cylinder head
style # 2 and ready for wrapping



Transport conveyor transferring castings from one operation to another. Notice the batch of one practice with head style 1 in single file behind style 2



Robotic finishing chamber

Figure 5-5 Robotic Cylinder Head Finishing

Chapter 5

Scope of Work Example – Robotic Press-Tending Case Study

In this example of a robot tending a press brake, the scope of work is significantly less in content than in the previous robotic finishing example. This case study is the second scope of work example because the application was simple, but the scope of work criteria follows very much the same theme as in the complex systems. This project involved automation of an existing press brake that was approximately eight years old. The return on investment was indicated by the following criteria:

- Single shift labor was eliminated and the operator was able to work on tasks that were more beneficial to the firm while the robot tended the press brake
- The robot continued to work through breaks and lunch periods
- The system was set up to be able to run for an unattended three hours every night after the first shift. With the extra work time, the robot was able to produce an extra 250 parts per shift
- The robot out-produced the operator in an 8-hour shift by a factor of two. The extra throughput accounted for a significant amount of extra finished parts at the end of the shift
- The robot was ultra-efficient when loading and unloading the press brake because a good amount of raw material could be queued up and the system left to run by itself. The firm could afford to be careless about set up time when it came to change-over of the brake to another job. The robot was always ready to remove finished blanks and load raw blanks. A typical set-up change took approximately 15 minutes

1.0 General Overview

The firm is a job shop and OEM. The existing press brake is utilized on a single-shift basis, and forming sequences are fairly simple, with the parts being formed in a progressive, two-stage die. A family of parts is formed in the brake, varying in size, gage thick-

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ness, and base material. The average batch size run is 250 parts.

1.1 Purpose

The purpose of this Statement of Work (SOW) is to document the products and services to be delivered and the rights and responsibilities of the various parties responsible for their delivery.

Upon acceptance, any changes or modifications to this SOW must follow the Change Control Process defined in Section 4.1 of this SOW. All approved changes will become attachments to the original approved SOW, which will then form the new baseline upon which future changes will be measured.

1.2 Description of Work

The following will describe the products and service requirements:

- Project Management
- Mechanical Engineering
 - End of Arm Tooling
 - Safety Fencing
 - Mechanical Floor Layout
 - Conveyor Specification
- Electrical Engineering
 - Electrical System
 - Electrical Panel
- Integration at User site
 - Programming
 - Test and De-bug
 - System Run-off
- (1) Six Axis robot with 1400 mm reach and 10 Kg payload
- (1) Lot Motion Control Software
- (1) Robot Base Plate
- (1) Vibratory bowl feeding system with enclosure, vibratory track, and part escapement
- (1) End of Arm Tooling (2) Gripper Bodies
- (1) Powered outbound conveyor
- (2) Safety System

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- (1) Press Brake Interface
- (1) System Electrical Panel
- System Documentation
- 6 x 6 Lay-in Nema 12 Wireway
- 5-foot Tall Safety Fencing

Details of the products and services to be offered as part of this project are provided in Section 3.0 of this SOW.

The development of this SOW was governed by the proposal design criteria established in Section 3. Should any of these criteria need to be modified, the team will need to re-evaluate the project scope for both performance and commercial impact.

2. DESIGN CRITERIA

2.1.1 Summary

The system is designed to robotically pick various styles of blanks and load/unload a two- stage die installed in an existing press brake, that will form blanks into finished products.

Manufacturing Process

Forming

- Two forming operations (Stages 1 and 2). Parts are transferred from the first stage die to the second stage die. Parts are finished at stage two. See Figure 5-7
- The process accomplished by the press brake when blanks are loaded by the robot is a two stage crimping process. At stage one of this forming process, the blank is partially crimped, and the second stage of the process forms the final crimp

Sequence of Operations

(the cycle starts with parts in the brake tooling)

- In one motion, the robot picks the finished blank from the second stage die and the half-finished blank from the first stage die
- The half-finished blank is presented to the second-stage die, and the finished blank is dropped onto a gravity chute that

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transfers it to a container for finished formed blanks

- Stacks of new blanks are arranged manually on an inbound powered conveyor
- The blank stack presence signals the robot that blanks are ready
- The robot approaches the inbound conveyor near the presented stack of blanks
- The robot searches for the top of the new blank stack to find the first blank
- The robot picks the first blank from the top of the stack. The search routine is required only for the first blank of a newly-introduced stack
- The robot presents the raw blank to the first-stage die
- The robot moves to a perch position away from the brake, and signals the brake to actuate
- The robot repeats the cycle

2.1.2 Customer Equipment

(1) Existing press brake

- There is a 24-VDC interface between the robot control and the press brake. The position of the press brake ram is a required modification for the robot interface
- The brake has a 6-foot bed, and is manually controlled by the operator through a foot pedal
- Prints are not available for the brake. Footprint and elevation dimensions are required
- Nominal blank size tolerance is within the loading tolerance of the tooling
- The brake will position above the tooling to allow access for the robot gripper when removing and placing parts in the tools
- Each die stage consists of a nest with pins that locate the blank in position for crimping

2.1.3 Customer Parts

Pre-formed blank

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- Ten part styles (aluminum, stainless, and mild steel plate), 16-gage, 14-gage, and 10-gage, different lengths and widths
- Each blank style has three formed edges as presented to the robot system. The forming occurs somewhere else in the facility
- Part weight is 1.5 lb. maximum
- Part drawings provided (range in length 4" – 6" and width 3" – 5")

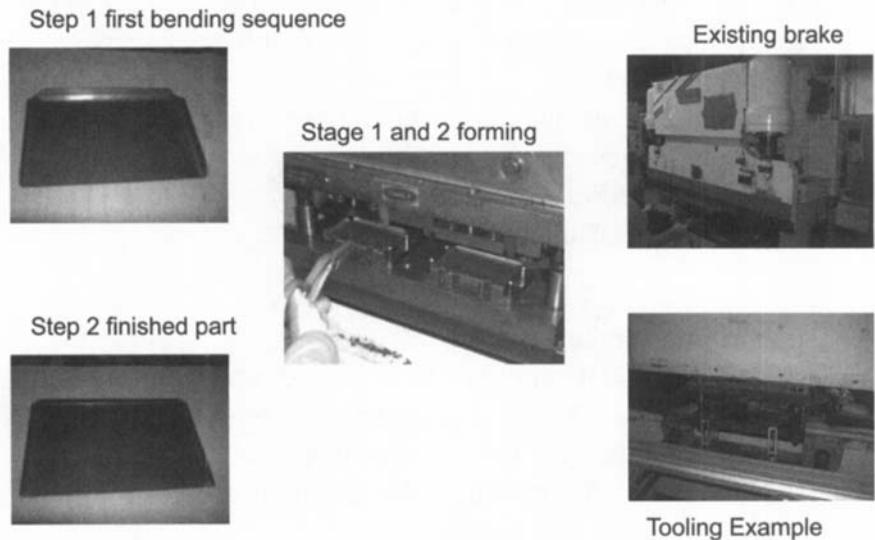


Figure 5-7 Sequence of Operations -Press Brake Forming

3. The System Description

Key Assumptions

The press brake will be modified by the user to communicate with the robot control system
The user will supply the rigging and placement of the robot equipment at its facility.

Roles and Responsibilities

User

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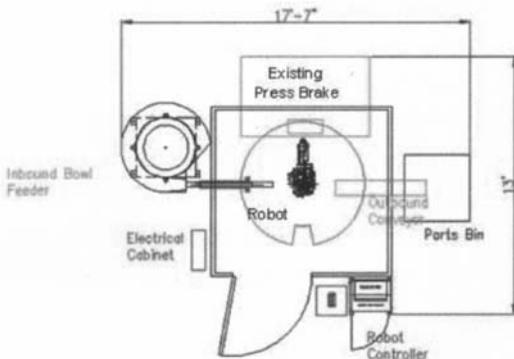


Figure 5-8 Example of Press Tending Robotic Work-Cell

Modify existing equipment – press brake

Provide blanks with consistent pre-formed edges for reliable feeding of blanks to the robot system

Builder

Provide deliverables outlined in deliverable section

Key Requirements

15-second process cycle time per piece

System Components

- (1) Robot – Six-axis robot with 1400-mm reach and 10-Kg payload – all specifications for robot listed here
(not shown)

Robot Mechanical Options

Robot Software Options:

- (1) Robot Base Plate
The riser/base plate is required to locate the robot at the ideal elevation for robot reach during the LUL process, as well as to secure the robot to the floor.

- (1) Inbound Feeding System
Raw blanks will be randomly nested in a vibratory bowl feeder and transferred via a vibratory track to an escapement for robot picking. Unattended production is required for up to 250 blanks, which will need to be

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the minimum bowl capacity

Raw blanks will be loaded into the bowl manually

Blanks will be positioned consistently for robot picking at the end of the vibratory track and escapement, with the orientation required for loading the blank into the stage-one die

Blanks will exit the bowl, travel down a vibratory track, and then be positioned against a hard stop location for robot picking

The bowl feeder will require a sound enclosure to reduce noise

The robot control system will control the bowl feeder

The bowl feeder will be configured by the operator during a tool changeover in order to feed the new part style

(1) End of Arm Tooling (2) Gripper Bodies

The robot will utilize a dual vacuum gripper, capable of picking two blank styles on the top-formed surface of the blank

The vacuum cups will be configured to pick any blank size

Part presence detection will be required

(1) Outbound conveyor

This conveyor will transfer finished formed blanks out of the system to a user- provided buckhorn conveyor

(1) Safety System

The safety system is responsible for preventing accidental exposure to the system. The system will utilize prefabricated steel frames with wire mesh panels, interlocked access doors, remote e-stops around the cell, operator awareness signs, and a system light tower.

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(1) Press Brake Interface

24-VDC discrete I/O interface will be required between the robot and the press brake system

The brake actuation will be controlled by the robot system through the existing foot pedal control of the brake system

The position of the brake ram will be monitored by adding sensors to the brake to detect the ram fully-open or -closed position

The signals between the brake and the robot system are as follows:

Robot controller inputs (from press)	Robot controller out-puts
Press service request	Robot ready
Ram in position	Press cycle start
Ram clear	Robot clear

(1) Electrical Panel

The Electrical Panel houses the electrical hardware for the safety relays and the I/O terminations connecting the mechanisms and the robot system

Robot Programming and Test

Robot programming consists of developing the software to handle the blanks during the forming process. The programming must teach positional points, integrate the I/O status of the independent elements, handle errors and operator requests, and provide teach-pendant operator interface information. The system will be programmed for the robot to service the single press brake. All ten part styles will be programmed. Other parts can be added and will be evaluated at the time of the firm proposal.

Demonstration at User Plant

The demonstration run-off at the user plant is designed to verify the capability of the automation system. The brake will be in its normal location on the user's shop

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floor, and the inbound/outbound system and robot will be set up to show the functionality of the automation system

Acceptance Criteria is running four part styles, in batches of 50 parts each

Parts will be inspected for crimping tolerances using a manual gage. The crimping tolerance is defined as ± 0.75 mm, which is the tolerance now used in running the forming process manually

The demonstration at the user facility is intended for verifying the capability of the automation system at the installation site. *All machines and robotic equipment will be set up and run at this point. Operation of all programming and loading will be verified.*

Installation & Commissioning

Type of Installation: Guidance Installation.

Agreed-upon criteria for installation guidance will be provided

Integration and Demonstration at Customer

System integration encompasses the effort related to commissioning of the automation system on the user's floor. These efforts include supervision of the component installation, final electrical and pneumatic connections, inter-machine connections, and on-site robot programming, which will result in a system that meets the agreed-upon acceptance criteria. Additional information required to prudently address this element will be developed as required.

Training

Type of training: Operator

Number of training days: 4

Shift: First

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Documentation

System documentation includes one (1) set of the following items:

- Standard Robot Manuals (CD)
- System Documentation (CD)
- Robot cell operating instructions
- Mechanical and electrical drawings for all system components
- Bill of material of all components supplied
- Recommended spare parts list with part numbers, name of manufacturer, and description
- Paper and electronic copies of all robot programs
- Safety assessment

Project Management

The Project Manager coordinates all details of the project to ensure that all needs and resources are balanced to meet the customer's schedule and delivery requirements.

Scheduling, design reviews, approvals, engineering change orders, etc. are all coordinated through the Project Manager.

The Project Manager ensures that all projects are well-organized and executed to the highest level of performance. The efforts of the Engineering Team, Manufacturing, and Integration are all coordinated through the Project Manager.

Numerous examples could be included in this text to show what the scope of work would look like. Every project is different, and the purpose of this chapter is simply to offer a flow chart for how information can be organized. The fact that the information is required is unarguable, but how information is formatted and presented is entirely up to the engineer. The two examples certainly

have different styles.

This chapter concludes discussion of the best practices for robot implementation. Focusing on the basics first was the theme of Chapters 2 through 4 because the up-front planning process is so important in leading up to the preparation of a scope of work. Subsequent chapters will focus on the meat of robotics automation, and how it is applied.

6

Lean Manufacturing With Robotics for Low Volume, Small Batch Runs

Chapters two through five were primarily concerned with the best practices in implementing robotic automation. It was important to start this book with the guidelines, rules, and considerations involved in making informed decisions about implementing robotics into the manufacturing value stream. The last two chapters of this text are about how robotic automation can be applied to maximize profit, which we should all agree at this point is the single most important goal of any firm.

The statistics hold true that one out of ten manufacturers plan and implement a robotic system for some task, whether it be welding, machine tending, palletizing, or whatever. A very popular obstacle that is often heard is, “we are a job shop and we don’t make enough volume of any particular part”, or “labor is inexpensive, and plentiful”. Last, and probably most common is, “we have too much changeover and robots are for high volume”. So there is a common theme here in the perception that setup and changeover is not compatible with robotics, and that for robotics to be beneficial to the firm requires “high” production volumes. The premise behind these obstacles to automating is one of the factors that motivated me to write this book, and specifically this chapter.

This chapter will set out to compare and contrast the presumed reality regarding small-batch runs and robots. Most of the discussion will be in terms of small batch to single piece, continuous flow, which requires the maximum flexibility. This passage could be titled “robotics for high changeover and small batch sizes” because it will validate the exact opposite premise to what is a commonly-perceived hurdle to automating in the first place. The material will describe how robotics can be more compatible with changeovers for

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small-batch and single-piece continuous flow than for plants in which the daily production parts never change.

Let's go back to some basics. Lean Manufacturing is a model for optimizing a manufacturing process. Lean manufacturing strives to enable a facility to be in a position to ship different quantities and different products on a daily basis with zero defects, and by the way, be globally competitive. In the author's opinion, the concepts of the job shop model and lean are not the same. Lean is a manufacturing practice that is implemented, regardless of whether a firm is a job shop or produces the same product everyday. Lean is all about eliminating the non-value—added tasks from the process. In a lean shop there are two types of products on the floor; raw material and finished parts ready to be shipped. There is no work in process, nothing happens without an order, and the manufacturing stream is agile in that it is designed to match the customer delivery requirements. The job shop model describes a situation where the firm will build anything for anyone, and never really knows what is coming next. The successful job shops that implement lean are those that practice the following precepts:

- They implement cellular, continuous-flow manufacturing, with single machines or multiple, linked machines
- They develop modular manufacturing work cells that allow for incremental capacity adjustment as a function of customer demand
- They implement the manufacturing work flow in terms of customer-driven demand (TAKT) time, to match customer delivery requirements
- They focus on programs that repeat in some sense of frequency versus a completely random forecast of production, which allows for predicted changeover/setups versus random changeover/setups
- They implement tools that reduce and minimize manufacturing changeover/setups from one batch to the next

Low Volume-Small Batch Runs

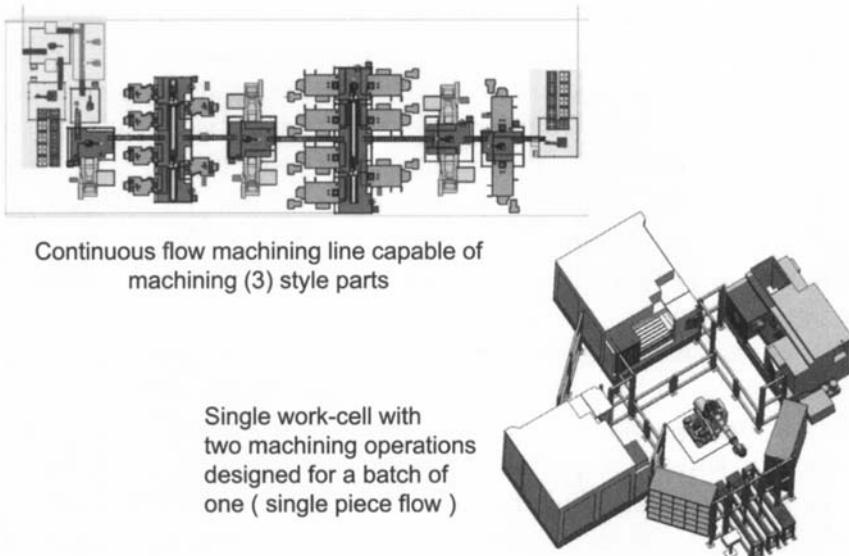


Figure 6-1 Example of Cellular Continuous Flow Machining Systems

In Figure 6-1, the single work-cell is designed around a lean job shop model where product shipped one day is different from what is shipped the next day. The work-holding fixture is a common fifty-taper tool, and the work-cell can be loaded with up to eighty (80) different part designs at any one time. The system will run unmanned for the entire time it takes to machine the (80) different pieces, which is more than twenty-four (24) hours. Every day the system can accommodate (80) new part designs, and because of the common work-holding arrangements for the parts to be machined, the system is capable of single-piece flow.

The other system example in Figure 6-1 is a series of machining work-cells that are arranged in machining operation sequence and connected by a transfer conveyor. The system is designed to handle three different style products, but again the work-holding is similar for each. No changeover or setup is needed for the robotic automation. Each work-cell is designed around a TAKT time that matches the customer demand, which is one part every 81 seconds. Multiple product styles can be in the system at the same time. The product

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starts in the raw state as a die casting, and at the end of the line the finished part is completely marked, inspected, packaged, and ready to ship. The line can be modified to handle additional future capacity with little interruption because each cell is independent and modular. In other words, equipment can be easily moved, relocated, or added, to reconfigure a work-cell over a weekend if needed. Processes where the product varies enough that changeover and setup are a factor will be reviewed later in this Chapter. All that being said, lean still applies.

Of course, no firm can react to its customer base with high labor cost per hour, inefficient manufacturing flow, high rework rate, poor asset utilization, poor planning with either too much or too little inventory, wrong equipment, and untrained operators. The desirable key ingredients listed below can't be achieved to the fullest potential without the interaction of trained human operators and robotics. Hiring low-cost labor may work for many firms, but there is still the cost of training, turnover, and the challenge of achieving zero defects. There is always someone in the world with lower labor costs. Labor cost should be a primary focus, as well as productivity gains to increase machine utilization or "on-process" time and reduce or eliminate the labor wage gap as in the welding example. The intangible benefits of enhanced quality, flexibility, agility, safety, consistency, right-sized equipment, cellular flow, and adapting to high changeover, can also contribute to reducing the cost per finished work-piece.

A few examples where industrial robotics overlap the lean manufacturing model are as follows:

Cellular manufacturing	Robot cells and manual operations coexist on the line
Quick changeover	Utilize the robot to manage as much of the changeover as possible through the programmability of robotics and complementary Quick-change tools

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Flexible Operations	The robot is a fully-programmable device, ideally suited for something new every cycle
Quality at the source	Robotics programmed to measure, inspect, and act, based on real-time feedback of product metrics
Pull Production	The robot will only perform a task based on an order. The robot will wait until raw material shows up at the work-cell inbound location
Production planning	The robot easily serves as the conductor in a work-cell, managing the production schedule
Automate redundant tasks	Robotics performing redundant tasks increase asset utilization or “on-process time” versus human operators

In summary, whether the firm automates with robots or not, lean manufacturing practices will reduce costs and increase productivity as the manufacturing process evolves. Thousands of small and medium-sized manufacturers provide testimonials about how profitable they have become applying the lean model to their manufacturing operations.

Man vs. Machine

What prevents a firm from running with 100 percent efficiency. As an example, pretend an engineer watched a process run for a single shift of production for the purpose of recording every second that was engaged in making the product and not making the product. Examples of criteria that contribute to downtime for a manual process might include:

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- Lunch and breaks
- Waiting for product to arrive
- Changeover/setup time in transitioning from making one part style to making the next
- Efficiency degradation due to inconsistent operator availability to perform the task every time (i.e. people do require bathroom breaks right ?)
- Varying effort to perform a task (some cycles will be slower than others for the simple fact that a human being will not consistently achieve the TAKT time every cycle throughout a shift)
- Maintenance of equipment
- Reworking product that was not made right the first time
- Varying cycle time as a result of inconsistent raw material (i.e. slowing down weld travel speed for an increased gap condition on a weld joint)
- Inspection

Now, compare man versus machine in relation to the aforementioned usual suspects of downtime. Back in Chapter 1, Chart 1-3 described the overall manual process efficiency for various applications. Sadly, for process-intensive applications such as material removal and arc welding, the process efficiency can be as low as 30 percent or lower. The highest rated efficiency was for manual machine tending at anywhere between 50 and 75 percent. There will be more discussion of machine tending later, because efficiency is certainly a function of the type of machine and the machining process. Although robotic automation is available to work 98 percent of the time, robot efficiency is degraded by the following criteria:

- Raw material unavailable – waiting for product to arrive
- Nowhere to place finished product
- Changeover/setup time is related to non-robotic equipment
- Equipment maintenance

Low Volume–Small Batch Runs

It is interesting to note the differences in the characteristics that degrade both manual and robotic process efficiency. Two of the four categories listed above for robotic efficiency can be eliminated by simply setting up an efficient material flow. A benefit of robotics is that they expose inefficient material flow, whereas manual processes do not, because shop floor operators will compensate for product variation without necessarily notifying anyone. In the big picture of production time, tolerance time management is typically a small percentage because the firm invests in tools that manage the incoming tolerance variation for the robot. Tolerance is defined again as producing a consistent, compliant-finished part, considering the variability that exists among the raw materials.

Discussion of equipment maintenance is not included here because it is external to the comparison of man versus machine, assuming that the same assets are used for either scenario. One critical category is changeover and setup time during the transition from one part style to another. The perception is that robotics and small-batch runs or low-volume production, do not mix. It is necessary to define the criteria that can be involved with changeover. Essentially, a new recipe or process configuration is involved. The recipe affects the following process attributes:

- Part work-holding, which can be weld fixturing, machine tool fixtures, chucks in a lathe, or a generic device that positions the product repeat ably and rigidly during the manufacturing process.
- Process equipment setup, which can be a routine or a set of routines and subroutines, that enable a piece of equipment to perform a task for a particular part type. For instance, part markers, press brakes, gages, shears, machine tools, and welding equipment, all have settings and programs for particular part styles
- How raw material is presented to the process. Material may come in bins, tubs, dunnage, manually built and staged, or stacked on a pallet. In general terms, how product is fed into the work-cell has a significant impact on changeover parameters.

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ters. So, when a batch run is completed of one product type, how does the process receive the new batch of raw material for the next run?

- How finished product is transferred out of the work-cell. For instance, parts may be stacked into a container in a specific arrangement or pattern different from the previous batch just run, or in palletizing there may be a different pallet pattern from one product to the next

Regardless of a manual or robotic operator, the changeover requirements for a process will be the similar because they are specific to the customer's needs for that product. Lean helps either the manual or machine process to evolve and adapt from one product run to another with as little wasted time as possible. The manual process certainly lends itself to easy adaptation because of the human senses. For instance, it is easy for an operator to pick product out of a bin to load a machine tool, and that simple effort covers the inbound changeover. In comparison, the effort involved to enable a robot to pick product from a bin like a human is challenging. Changeover is taken for granted for a manual operation, but for a blind machine, changeover can become a nightmare. Available tools that can be used to enable a robot to act exactly like a human operator when it comes to transitioning from one part style to another will be discussed later.

Regardless of changeover or small-batch runs, the first question in comparing man versus machine is whether enough production hours are available to keep the robot busy. For example, an 800-piece, annual production forecast probably is not enough production to justify a robot from a purely financial point of view. Other motives may be involved that will make sense for the firm to invest. The maximum amount of available production in a full year is 8760 hours. Rarely have robotic systems been utilized 8760 hours, but nonetheless, there are 8760 available hours to perform the "process". It is hard to say whether there is an absolute minimum number of production hours that are necessary to justify a robotic system, because there are many organizations that require robotics

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and have completely different sets of metrics that they use for robotic valuation other than productivity and labor savings.

Cost analysis has been used to examine the minimum production hours that will produce a three-year ROI for a robot system. Approximately 1400 annual hours seems to be an approximate crossover point for achieving the three-year ROI, or 25 percent annual return on investment. This 1400 hours is associated with a single shift of 8 to 10 hours per day. There are 2050 hours per year available on an 8-hour single-shift basis, and the loss of the 600 hours is attributed to changeover(s), and maintenance activity. What is staggering is that if the firm used a manual operator on an 8-hour, single-shift basis, the operator would only contribute approximately 800 to 1000 hours of production, which means a greater than 50 percent penalty for using an operator. Lunch, breaks, missed work, and general lollygagging, are realities of the manual shop floor operator. Out of an 8- to 10-hour day the process only runs for about 50 percent of the time available. Granted, on some days the throughput percentage was higher, but it was also lower on other days. In a multiple-shift operation, the throughput varies by the shift, with second and third shifts generally lagging behind the first shift.

An interesting analysis is how much do robots improve the effects of downtime, waste, and inefficiency, and what is that improvement worth to the firm? Another interesting question is what if robotics were so much more efficient than a manual operation that setup time and changeover became irrelevant? Furthermore, what if the cycle time to produce a single piece was not very important because, at the end of the day, more parts were always produced?

The bottom line is that the firm has a set of orders to make parts on a daily basis whether on a single-shift or on a multiple-shift basis. The orders need to be completed to fulfill customer demand as well as meet the quality expectations. Anything less than meeting this basic set of expectations costs the company profit. Firms sometimes become fixated on the wrong things. A classic example is the cycle time per piece. Cycle time is part of the equation, but

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arc-on time, machine spindle utilization, quality, etc. are often more important.

Changeover for Small Batches

Changeover and setup are relative to the extent that parts and processes vary. Obviously, the more variance, the more setup required. The more automated the system setup to save time and efficiency, the more the cost for the robot investment. Balances between flexibility and investment are always considerations for every robot system regardless of the application. Literally anything can be done with a robot and the old saying “it’s only money” holds true. There is also truth in the perception that robotics are not compatible with small batch runs, especially in the area where an alternative form of automation is a less-expensive choice or where the programming time and the work-piece fixturing aspect in terms of robot grippers, or other part fixtures, become too expensive for the volume of production. These constraints usually prevail when the part designs are significantly different in geometry. Additionally, automation expense is not practical for one-off parts that are set up for one run and never run again.

When looking at the variations of part shape it is sometimes just not worth automating that one extra part, which is why the 80/20 rule works so well when evaluating an entire product-mix for robotic automation. The Pareto 80/20 rule has always been a good rule of thumb, and staying away from extremes is another good idea. It never fails that 20 percent of product yields 80 percent of the profit, and/or volume. In other words, if a firm can earn a good ROI on automating 20 percent of the product, and keep the robot busy for the 1400-hour minimum, then this example could work well. Otherwise, evaluation of the product mix should be taken one product at a time and an attempt made to eliminate those products that absolutely require a brand new configuration. As more and more product is found to automate, and the company tries to automate everything, at some point it will always see diminishing returns on robotic automation. It is wise to continue manual processing of the unique or really low-running products.

Low Volume-Small Batch Runs

Changeovers are inevitable when small batches are run. Changeovers and setups relative to process equipment are necessary evils, regardless of whether a manual or robotic operator is used. Apart from the process equipment, changeover for the robot system can be completely manual or completely automated in most setups. For example, in press tending, the robot can be programmed to change the brake tooling as part of the procedure. However, in machine tending, the robot probably cannot change chucks on a lathe, although it can certainly change tombstone fixtures and pallets on a machining center. The point is that the available robotic tools have enabled changeover to be effected painlessly through the use of vision, and other tools. There is a cost for this flexibility, but the costs are significantly less than they used to be. For example, the days of purchasing tooling and hardware that was dedicated to a specific part number are long gone. Automatic changeover of the robot program in press tending or palletizing is certainly another way to exploit the advantages of machine versus man. In machine tending and welding, however, changeover of the process equipment, primarily the work-holding fixture that secures the work-piece, usually requires the human touch. The time associated with swapping out a weld fixture or changing chuck jaws on a machine, is a wash between man versus machine.

When the firm requires automated changeovers to eliminate the possibility of human error within the setup, numerous tools are available. For example, bar code readers, RFID tags, sensors, and robotic vision, can be used to read part identification so that the system can be reconfigured automatically. Often the term “recipe” is used as the definition of the system parameters that are required to be modified to support the configuration when a new part style is introduced into the system. The “recipe” can be reconfigured manually or completely automatically, and is driven by the product characteristics from one style to another as they enter the system as a batch of a single product or as a batch of “x” amount of product. For instance, these characteristics might include;

- Physical properties: weight, shape, base material, dimensional tolerance, and overall size

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- Finished properties: the final characteristics of the work-piece or finished product. In palletizing this code would mean unit load configuration of pattern, product per layer, and any slip or tier sheets as an example. Another example is surface finish in material removal, or bead size and weld penetration for welding.
- What is the application? Some applications are more forgiving than others, regardless of how different the product may be. Palletizing is a great example of the application of universal tools to a very broad range of product numbers

The greater the change from one batch of parts to another, relative to the two aforementioned part characteristics is what drives the extent of the recipe complexity and then ultimately the risk, the cost, and the downtime involved in the setup. Some applications by their nature require longer setup times than others. For instance, press tending starts with a flat metal blank that is formed into a three-dimensional shape. Regardless of its other characteristics, the blank starts flat so that it is easier for the robot to handle. On the other hand, in machine tending, one batch of parts may be cylindrical, with an accessible internal diameter to grip on for loading the machine tool. The next part is cube-shaped, with irregular surfaces and essentially as different as night and day in geometrical shape, compared with the previous part.

Case palletizing is another example where, if the robot system handles cases all day long the robot gripper can be designed to handle a myriad of case sizes and weights. There will then be zero changeover because the cases are of similar geometry and they can be picked from their top surface with an array of vacuum cups. On the other hand, if the palletizing application requires palletizing of cases with a top, followed by cases with a lid that could fall off, then a changeover is required if the system is required to handle both product types.

Products that are similar in terms of their characteristics or their dimensions, can often be accommodated by the system using what is called parametric processing/programming. The same core pro-

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gram and process can be applied to the entire product mix because the manner of handling and processing are compatible with the core program, which is easily modified or adjusted through the use of offsets. Offsets are defined as incremental adjustments in terms of distance or a numerical value, relative to a nominal position or parameter value. Each time a new product is presented to the system, adjustments are made by an operator or automatically, to input the new product data. A new process recipe is then generated that adjusts for the new product. When the piece is finished and the system is ready for the next product, the system waits for the next adjustment.

An example of a parametrically configured system is a robotic palletizing system where the various product types are similar in how they are handled and simply vary in size. Robot grippers, robot path programs, and inbound and outbound hardware, all exhibit zero changeover from one product to another. Offsets in terms of the product location as they are located on the unit load are easily

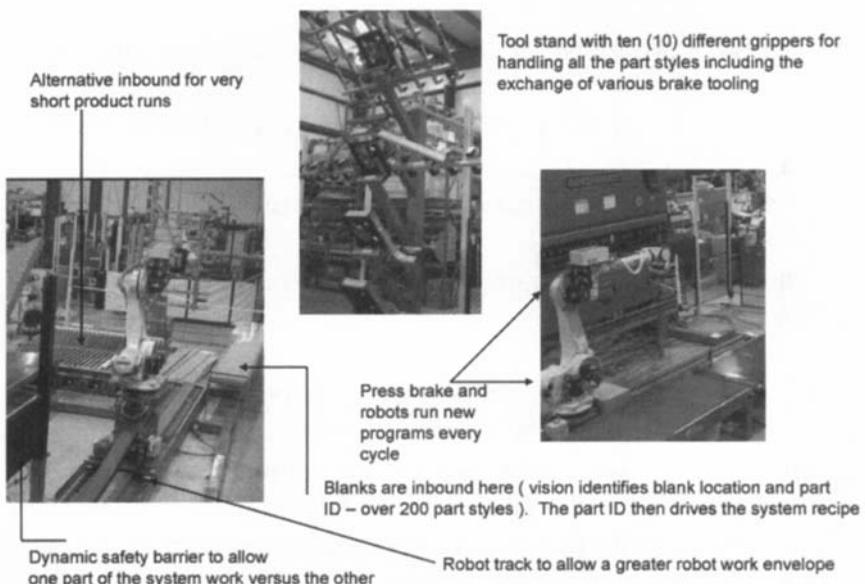


Figure 6-2 Example of a Highly Flexible Robotic System

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adjusted from one product run to another. Parametric programming obviously works best for a family of parts that can be handled the same way, transferred into and out of the system by the same method, and are subject to the same process. The products are scalable to each other, or at least have enough in common in terms of how they are produced that a common work-cell configuration can support the range of products. Parametric programming is certainly at the low end of the spectrum relative to the impact of changeover on a system, but families of parts are wonderful to automate and are less expensive on the scale of investment and risk to automate with robotics.

The recipe for Figure 6-2 is configured after the product enters one of two locations. For the continuous single-piece flow, or a batch of one part, a vision system controlled by the robot determines part location and identification from the unique punch pattern in each blank type. The system does require the blanks to be right side up as they are transferred into the work cell. Once the part identification is made, the recipe is generated. The recipe for the system in figure 6-2 includes:

- The robot programs for each robot to process the blank from raw to finished
- The end of arm tool (gripper) to be used for the incoming part
- The tooling for the press brake which is exchanged by the robot
- The press brake program containing the bending sequences for the product

If a blank cannot be read for whatever reason at the inbound station, the robot will place the blank on a location for an operator to examine later. If blanks come into the cell through the low volume conveyor, the robot will wait to receive the part identification from the operator that transferred the material into the system. Otherwise, on the continuous batch of one conveyor there is no operator intervention.

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Suggestions for the Design of a Robotic Work-Cell

Design robot systems are like manual systems with a cellular approach, where only a few or literally a single operation is completed in the cell. If multiple operations are required in a manufacturing stream, a series of cells can be arranged for an assembly-line approach with a conveyor or some other means of transferring the product from one cell to the next. The alternative would be to group a set of robots or operators into one location, but changeover in those situations becomes very difficult to manage due to the fact that the robots are dependent on each other like a group of operators, each with one leg tied to the next. Robots should be arranged within independent work-cells because error recovery and changeover is simpler than when they are combined. An exception to this rule is when multiple robots are linked together through robot technology that enables the robots to be programmed as a single set of coordinated axes.

Work-cells should be kept simple and focused on a specific task. With multiple work-cells in an assembly line, each work-cell needs to be designed to achieve the TAKT time that will enable the line to match the customer demand, which is the throughput at a rated efficiency. Figure 6-3 shows an assembly-line type of system for welding and fabrication of an agricultural component. Each cell is sized with the right equipment and designed to meet the TAKT time of 18 minutes. This 18-minute TAKT time was derived from the premise that the customer requires 2.6 parts per hour, or one component every 22.6 minutes. For this example the firm selected 80 percent efficiency for the overall process, due to the need for changeover of weld fixtures, touch sensing to find weld locations, and movement of the product from one cell to another. Each work-cell on the line was designed for an 18-minute TAKT time. Eight different style products were run on the line, with the average batch size of 20. The line also included manual stations where it did not make sense to automate some of the welding due to complexity in fixturing and torch access to the weldments.

Within each work-cell balancing the tasks that changeover associated with the tasks in a work-cell is not overly complicated. The

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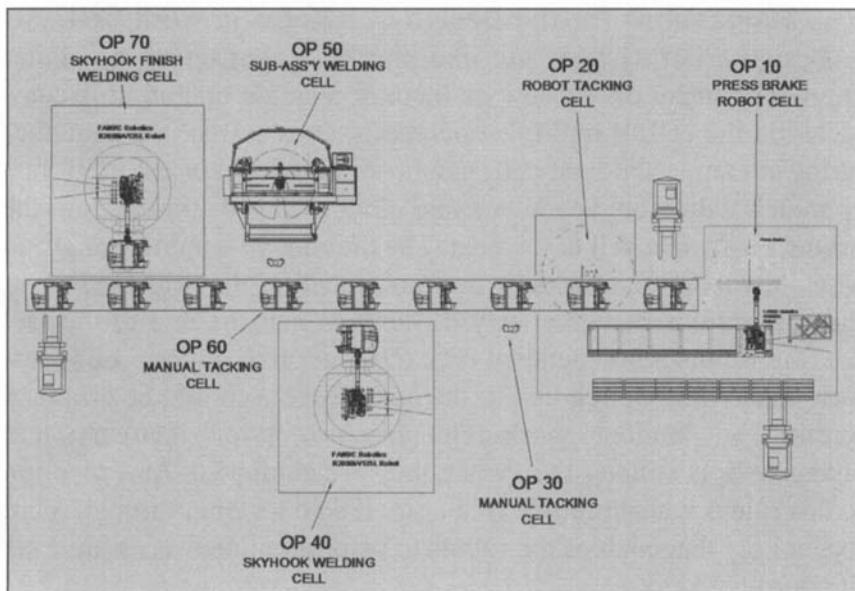


Figure 6-3 Assembly Line Robotic Welding and Fabrication System

keep-it-simple, cellular principle, allows expansion for incremental capacity increases, meaning placing more robots at a particular operation when needed and they can easily be inserted. Spreading the overall manufacturing stream over several work-cells that are performing only a few tasks, is a better choice than using only one or two cells to do everything. In the future, if the firm needed more capacity or changeover, addition of a few simple work-cells instead of a major hardware-intensive work-cell would be much easier to manage and less expensive. Other advantages include quicker delivery and a shorter time frame to make changes to simpler work-cells, lower investment, and less programming and configuring.

Manual labor should be used to perform the more-challenging tasks, where variable product mix makes it difficult to justify automation of certain operations of the process. Additionally, manual operators should be paid to use human dexterity to accomplish tasks versus paying for the robot to perform the same dexterous motions. These operators would also be the line operators monitoring the robot work-cells, and kitting raw materials. This strategy

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will yield higher productivity and efficiency with less labor content. Many firms will always have an operator present, even for a completely-unmanned system, and their model it to have the operator perform some of the tasks that can be expensive to automate, so that the robot can tackle the redundant work or perform inspection tasks.

Like robotics, lean manufacturing forces companies to use right-sized equipment in cellular modules that are designed around the customer demands. Robotics equipment is easily moved, removed, or added to the system, making the system extremely agile. Figure 6-4 shows a typical flexible robotic system designed as a cellular assembly line. The system was designed around the philosophy of a batch of one, but additional robot systems can be added or deleted from the line. The system in Figure 6-4 is designed to palletize three products per robot cell, with a unique part number being sorted ahead of the line using a bar code reader, and then transferring the product to a specific conveyor lane.

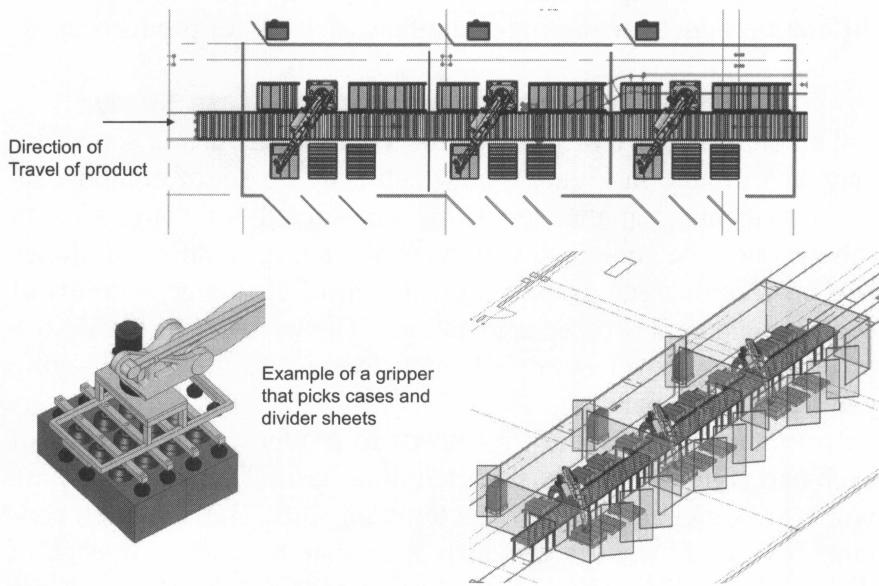


Figure 6-4 System Example Designed Around Incremental Capacity

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The gripper illustration shows how the product is picked up at each inbound conveyor lane and how divider sheets (tier sheets) also are handled along with the product.

The world is not perfect and in manufacturing the stack up of tolerances is something with which robotics constantly have to cope. Because of their inherent design for adaptability and compliance, and usefulness as tools to produce quality outputs from varying sets of inputs, robots have always been expected to be flexible, regardless of the application. This statement is true whether the robotic system is processing one part style or multiple styles. Nothing is ever really the same from one part to the next, so how can the need to automate batches of one, five, ten, or fifty parts change the rules of how robots work. Robots are programmable, adaptable machines - period. The next chapter will review large batch runs and infrequent changeovers. If the same product runs all the time, the irony is that the obstacle to automate with robotics is reinforced because a more dedicated and simple manipulator may be a better solution. Changeover is frequent requirement, and robotics complements the firm's ability to implement lean manufacturing in order to produce different products in varying quantities, each day of production.

Automating the machining process – Case Study

The compatibility of robotics for small batch runs is shown by another example in Figure 6-5, which shows a set of components for a machining application being considered for conversion to robotics or to be continued with manual tending. Tending machines is a process that can present a great deal of challenge in terms of changeovers versus other applications. The example in Figure 6-5 takes the changeover example to an extreme because of the varying geometry of the parts.

In this installation, the firm needs to produce small batches of each part style on a single-shift, ten-hour basis. There is one hour's worth of breaks and lunch in the ten-hour shift. The work-cell contains two machines, each of which is capable of machining each of the part styles. The process will be arranged for the ability to run any part at any time, based on varying requirements coordinated on

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a weekly basis. Going back to the criteria for changeover, if the process maintained the current manual output, the following tasks are involved with changeover:

- Fixtures at each machine tool need to be changed out, and the firm employs quick-change tooling. The maximum time to change over a fixture manually is about 15 minutes per machine
- The operator will retrieve empty bins and supply full bins of parts
- The operator will run the first part of each batch and inspect various dimensional features of the parts to check for dimensional compliance with customer specifications
- A new machining program is selected from the machine tool library

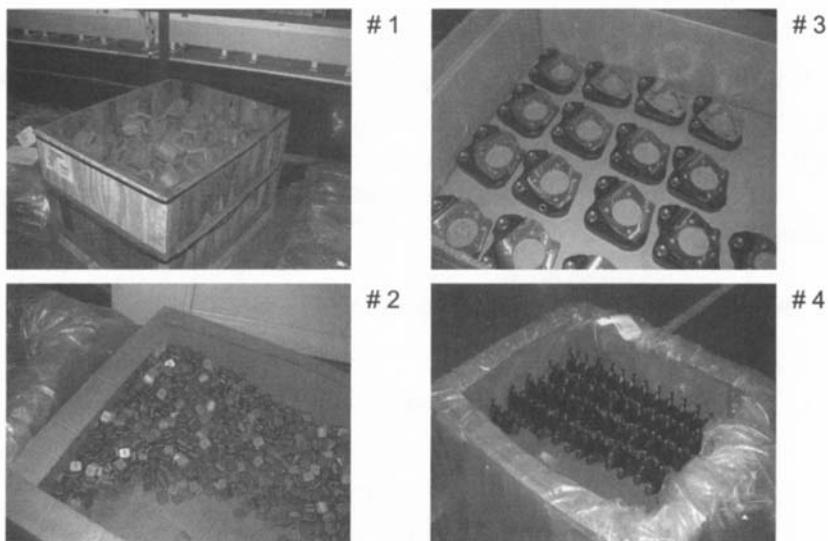


Figure 6-5 Varying Part Styles for Machine Tending Changeover

In summary the changeover time from one part style to another is approximately 25 minutes with the assistance of a fork truck oper-

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ator in bringing the bins of raw parts and an empty bin for finished parts. Table 6-6 describes the TAKT time for each part at a rated efficiency of 100 percent machining efficiency.

Table 6-6. TAKT time for four part styles in machine tending example

Part Item No.	TAKT Time per piece (sec.)	Annual volume	Total time(hr.)
Part style 1	145	12,200	491
Part style 2	180	13,000	650
Part style 3	45	13,000	162
Part style 4	160	11,000	489
	Total volume parts	49,200	Total hours 1,792

For this exercise it is assumed that there will be two changeovers per day per machine, also that the ten-hour single shift yields a maximum of 2500 hours available for annual production.

The summary of downtime related to breaks, lunch, and changeovers in the work-cell is as follows:

Task	Time (min.)	Total time (min.)
(4) changeover tasks	25 minutes/setup	100 minutes
(4) inspection tasks	5 minutes	20 minutes
(2) breaks	15 minutes	30 minutes
(1) lunch break	30 minutes	30 minutes
(6) cutting tool changes	10 minutes	60 minutes
	Total time	240 minutes

Throughout the year of running these four part styles in the manual work-cell, the operator misses workdays because of sickness,

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and a few scheduled conflicts. For the days missed, another operator is required to run production, but that requires additional training costs for the firm. Also, when a closer look is taken at the number of finished parts per hour, it is found that the operator averages, on a daily basis, only 65 percent efficiency. Why is this efficiency not higher? For machine tending it is a documented fact that manual efficiency will be somewhere between 45-70 percent. In other words, when the machine is ready to be serviced by the operator removing a finished part and loading the next raw part, the machine is idle, waiting on the operator. As a result, over the course of a day, only 65 percent of the available production time after breaks and setup's for tooling changeover and inspection is productive. What happened to the other 35 percent of the available production time after the setups and breaks? It is lost through the human inability to perform a task at the same required speed, over and over again at every cycle.

In summary then, the manual production process operates as follows:

Total time on a daily single shift	10 hours
Scheduled downtime	4 hours
Time in production	0.65 * (10-4 hours) = 3.90 hours

Out of a ten hour shift then, the firm realizes 4.55 hours of net productivity. The hours noted above, when the customer's annual demand was reviewed, required 1792 hours (179 days). It was assumed that with the 10-hour shift there were 2500 available annual production hours or 250 days. The 4.55 hours of productivity per day are calculated by $3.90/10 = 0.39$ days. The total days of production required to meet annual customer demand is thus 179 required production days divided by 0.39 production days = 458 days. This situation obviously presents a problem because there are only 250 production days in a year. The firm has the choice of running production on more machines with more operators on a single shift basis, or picking up an additional shift, again requiring additional operators. Most firms would adapt to the situation by throw-

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ing more operators and production hours at the problem. Although certainly not a way to lower costs, that will at least allow customer demand to be met.

If a robot loading system is applied to the above example, the considerations that are challenging for the robot system are as follows:

- How to grip each of the four varying geometries of parts, because a single gripper will not work
- How to present the parts accurately to the robot, given that the four part styles have different geometry
- How to manage part inspection
- How to manage where finished parts go, because the finished parts must not be allowed to touch each other
- How to changeover the machine tool programs without operator intervention
- How to arrange access to a machine for adjusting tool offsets when the cutting tools wear, as well as how to changeover cutting tools without stopping both machines running. The safety aspect of the operator and robot sharing the same space is a problem here
- How to arrange for the system to receive some level of operator intervention needed to facilitate changeovers, inspection, feeding the system, and removing finished parts

It is also a documented fact that robotics will provide 98 percent uptime, or in other words be available 90 percent of the time. The scheduled downtime, relative to the process of work-holding, changeover of cutting tools, and presenting new part styles, will be the same, comparing the manual and robotic process. Inefficiency linked to the operator in the form of machine asset utilization, inconsistency (wasted time), breaks, and lunch are criteria that can be exploited as a weakness by the robot. Robots do not take breaks, do not require training, insurance, or benefits, and never call in sick. In summary, for the robotic process, the robot is capable of producing:

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Total time on a daily single shift	10 hours
Scheduled downtime	3 hours
Total daily productive time	0.92 * (10-3 hours) = 6.44 hours

On a daily basis then, for the single shift operation, the robot will increase production by $6.44 \text{ hours} - 3.90 \text{ hours} = 2.54 \text{ hours}$ per day. Additionally, the system can be configured with an inbound system that will allow for a one-hour raw part queue. In developing an inbound system that allows for a one hour supply of raw parts, the firm can also run the system for one additional hour into the second shift unmanned, which amounts to daily unmanned production, less the cost of power and utilities for the system. Thus, the total robotic daily productivity contribution could be 7.44 hours. The 1792 production hours of required customer demand could be accomplished in 240 days, providing additional capacity of 10 days or 100 hours. The efficiency of the robot is estimated at 92 percent including the 8 percent for tool changes.

The interesting consideration here is that two machines can meet the production needs without requiring capital to acquire additional machines. The robot system provides almost twice as much productivity as a manual process but also reduces cost by decreasing labor, decreasing waste and inefficiency, and decreasing the cost of managing employee turnover and random days of missed work. Other considerations in terms of intangible benefits are the peace of mind that goes with having a consistent operator for at least 15 years, confidence in achieving improved customer satisfaction through consistent quality, and reliable daily output. The right decision for a firm that wins any new business is to challenge the manufacturing group in terms of achieving the maximum utilization of the firm's current assets through quick changeover methodology and robotics. Savings over the cost of new machines alone, versus getting the most out of current machine assets with robotic automation is ample justification.

What is also interesting is that use of a stop watch to time the manual operator and the robot would show that the manual operator will be faster in producing a finished part than the robot on a

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given cycle. Does it matter if, in this situation, the robot is slightly slower for a given cycle? The robot system still has the padded additional annual capacity of 180 hours.

The foregoing example sounds pretty good, though there are certainly other criteria to examine in terms of the justification of this program. The “fear” factor of the unknown should not be an influence, especially given the potential productivity gains. What if the average part run was less than 10 parts, and there were significantly more part styles, each with its own unique geometrical features? There should be a formula into which the user could enter data and derive a yes or no decision as to whether the firm should pull the trigger on robotic automation.

As discussed in previous Chapters there is a balance between how much flexibility is desirable in terms of managing changeover versus risk and cost. In the previous example, with only four part styles, and the fact that the firm would never achieve the asset utilization manually as it would with running robotically, the robotic program would probably make a lot of sense. Other costs and challenges to manage where the manufacturer runs small batch runs are as follows:

- A unique gripper possibly for each part style. The cost of storing the grippers, and of the grippers themselves becomes prohibitive
- Programming the system for all the part styles but also the parts that may be introduced, literally on a weekly basis, or even greater frequency
- Interactions between the robot gripper and the work-holding fixture for each part style, because each part may have unique features where the work-holding clamps the part during the machining process. The more parts and work-holding fixtures, the more complicated and difficult it becomes to manage the entire process
- Managing how parts are transferred into and out of the work cell

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A family of parts, meaning a series of parts like cylindrical pulleys or shafts, lends itself to being easily automated, regardless of the batch size being run. The characteristics to look for that lend the parts to be grouped together with a common automation strategy in managing the aforementioned challenges are things like:

- Common methods and surfaces for gripping (examples include the inner or outer diameter, or on the body itself if the part is cylindrical or shaft-shaped)
- Common designs for machine (CNC) work-holding fixtures, chucks and collets
- All the parts fit within a specific weight range and overall size. An example could be weights within 50 lb. fitting into a cubic space of 24 x 24 x 24 inches

Families of parts lend themselves to be automated if the parts styles start with the same casting part number but have different features as a finished machined casting, or if casting features vary from a basic form. The robot changeover concerns the physical aspects of handling the product as soon it arrives at the system. The robot is a blind device without a human hand, and the robot is mimicking a human task which is the basis of managing changeover. Changeover is a reality though, and managing changeover cost effectively is a manufacturing competitive advantage. Perhaps, in the future, there will be a programmable device that resembles a human hand that can be integrated to the end of a robot arm and act like a real human hand instead of a more-dedicated gripper design.

Automation that can be incorporated into the machining cycle itself by the inherent design of the machine tool already exists. For example, a lathe already has the ability to gage parts and send itself tool offsets, mark parts, and de-burr parts, as well as check for tool life or broken tools. Additionally, if the user is machining a shaft-type part the lathe can be retrofitted with a bar feeder that essentially feeds “bulk” lengths of round “rough” bar stock into the lathe automatically. It is difficult to automate this machining process because the bar feeder attached to the lathe is already feeding

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“parts” to the machine. Usually, finished parts will fall down a chute out of the machine.

Unless some post-machining task needs to be applied to the finished part, the robotics value is reduced by the worth of the bar feeder and parts catcher. Tasks that have to be accomplished after machining always add to the justification of a robot because of the possibility of exploiting slower and inconsistent human endeavors. For instance, inspection, deburring, washing, and marking are all post processes that can be easily automated with the initial investment of the robotic automation, the original purpose of which was to load and unload the machine. Many designs for robotics to service lathes include ways to allow the operator to access the front of the machine to change or adjust cutting tools and make minor changes to the machining program through the machine control system at the front of the lathe. Loading the lathe without having to open the door to get to the machine work-holding increases productivity because the door never has to open and close during the load/unload cycle.

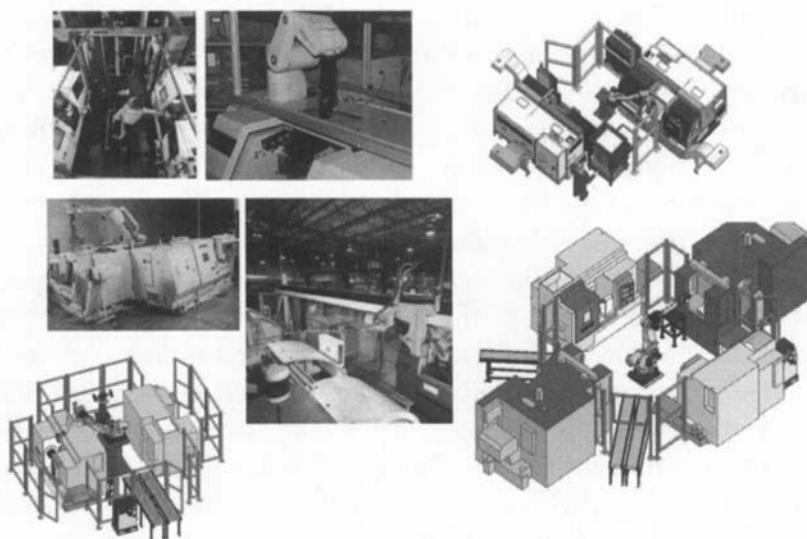


Figure 6-6 Various Examples of Robots Tending Machine Tool Models

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Machining centers typically have rotary tables (pallet changers) or linear shuttles that allow the operator to unload/load finished and raw parts outside the machine while the machine is cutting metal. In this situation, the unload/load time is embedded within the machining cycle, increasing productivity and lowering costs. Machining centers with the capability of operating with the unload/load cycle internal to the machining cycle are good candidates for robotic automation. Figure 6-6 shows examples of robots servicing various styles of machine tools.

Figure 6-7 shows another type of application for robotics and machine tending, which is its use as the master control for managing machining processes on multiple machines that previously have been serviced by more-dedicated forms of automation specifically designed to bring product to the machines and take away finished product, with a unmanned philosophy. Parts are held in tombstone fixtures and these fixtures are stored in a storage area where they wait to be retrieved in accordance with the robot's production schedule. As compared with more traditional dedicated automation such as this example and certainly many others (for instance, horizontal or vertical packaging equipment) robot systems benefit the firm in the following ways:

- Reduced floor space
- Six axes of robot motion that provide superior maneuverability due to the robot being more dexterous
- Future applications of the robot for other tasks
- Easy-to-adapt, custom tools for later use
- Significantly less moving parts, meaning higher mean time between failure (MTBF)

Automating the machining process whether on a single machine or on multiple machines, exploits the weaker human efficiency of simply performing the tasks. Human operators will rarely achieve zero defects and the side benefit for robotic automation is that zero defects can be achieved. It is an advantage to find one cell or more to automate and let an operator continue to service another cell

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where automation did not make sense because of the part mix, and the cost of the operator being spread across multiple systems and commodities. Profit per hour significantly increases with this strategy. With the addition of the robot operator replacing the conventional shop floor role in servicing the machines in one system, the shop floor operator becomes more versatile as well. Productivity per head and cost per piece often are enhanced.

When machine cutting times are long, for instance 15 minutes or more, exploitation of the robot efficiency versus manual efficiency loses some steam. Unless there are a lot of machines, as in a high-volume example to be covered in the next Chapter, it is difficult to take advantage of the robot's uptime because the machine requires attention much less frequently. A process like wire EDM is a clas-

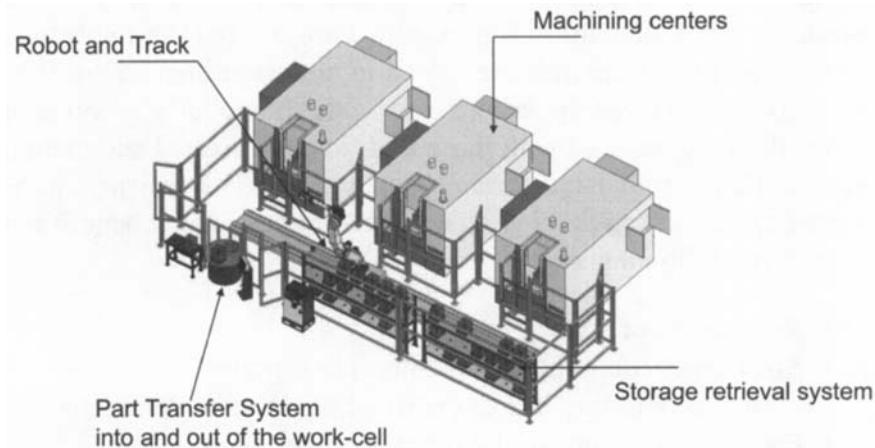


Figure 6-7 Using the Robot as the Master Control Servicing Machine Tools and Storage Retrieval System

sic example of a long cutting time. A single- or even dual-EDM machine process is not often automated with industrial robots because cutting time is usually in terms of hours. One advantage that can be exploited is re-configuring a system, with parts held in a storage retrieval system. With the long cutting times, a production schedule over a weekend can be set up. The robot has the ability to change the tooling (work-holding) on the machine, the part type

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being run, and all the programs, both at the robot and at the machine. There is some value in setting up a robotic machining system with this unmanned, long production duration, with or without changeovers.

If a work-cell is not automated with a robot, there are still many improvements available, including quick-change tooling, common fixturing attributes for handling, and storing programs on a database that can be remotely accessed. These examples of productivity tools that complement the machining to allow the work-cell to adapt should be used for the manual process but are also useful if the cell is automated.

How much capacity does a firm need to be able to justify the use of a robot operator for machine tending? The minimum conditions that need to exist include:

- Single shift of production if currently running manually (approximately 1400 annual hours)
- Product mix following the Pareto rule, meaning 20 percent of the product makes up a significant amount of the production hours
- The product is compatible for robot vision (i.e. has unique identifying features)
- The way product is handled is common across the part mix (i.e. slugs, shafts, cylinders)
- Existence of other areas to exploit that are motivations to automate (i.e. heavy parts, scrap problems due to mis-loading, and other tasks (i.e. deburring, marking, inspection, etc..))
- Miscellaneous criteria; safety, ergonomics, quality
- A sound machining process in terms of chip management and tool life

Automating the welding process for small batch runs

A manually-intensive process is a process in which the operator has to perform the task of converting the raw state of the work-piece to a completed work-piece, such as with arc welding and material removal. Comparing these two procedures with manual machining,

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the machine performs the task of converting the raw material stage to the finished component, and the robot system exploits the inability of the manual operator to utilize the machine consistently to its maximum potential. The two new examples allow the robot to exploit an even larger portion of the time taken to change a part from the raw to the finished state. Production efficiency in arc welding and material removal is lower than in any other process including palletizing, where documented efficiencies in the 25 – 40 percent range. In other words, in a ten-hour single shift with one hour for breaks and lunch, the operator can contribute $0.25 \text{ to } 0.040 * 9 \text{ hours} = 2.25 \text{ to } 0.36$ hours of productivity. The rule of thumb is that a single robot will contribute productivity of the equivalent of three welding operators. With this large differential between robotic and manual efficiency, the aspects of changeover and setup can become irrelevant.

Systems with large assemblies might use a pair of tandem robots welding on an assembly at the same time, or a very quick welding process with a high deposition rate called tandem metal inert gas (MIG) welding. Tandem mig welding deposits weld metal at very high rates by depositing filler from two welding arcs at the same time. One arc is the lead and the other is the follower. Welding travel speeds is what drives the welding TAKT time. The tandem mig process can attain weld speeds significantly faster than a robotic single-welding-wire process, and weld travel speeds up to 200 inches per minute can be achieved. The potential gains in productivity with these tools can be imagined.

Figure 6-8 illustrates an example of tandem mig welding. Unfortunately there is not an exact tool like tandem mig for material removal, but robotic material removal exploits other human weaknesses when it comes to this process. For instance, the gains in time and especially quality of surface finish in buffing, trimming, polishing, and grinding are great. Polishing times for impeller blades have been reduced from 20 hours to 4 hours time, utilizing a robotic solution, and the surface finish was consistent and in compliance with requirements. Additionally, the volume of polishing media is reduced, due to the even wear of the media that only a

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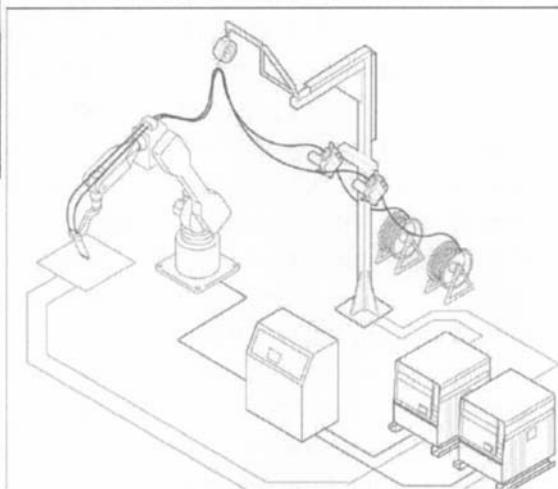
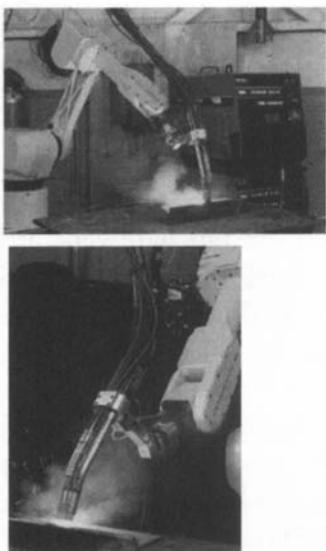


Figure 6-8 Tandem Gas Metal Arc Welding- Lincoln Electric Model

robot can achieve.

The demand for robotic welding systems is much higher than for machine tending for several reasons. First, the changeover/setup is simpler for arc welding because the robot always uses the same tool, regardless of the part geometry, whereas, in machine tending, the robot requires a specific tool for each unique part geometry. The second reason is the perception that exists about how arc welding robots are more compatible with changeovers than machine tending. For example, in arc welding, a welding fixture is always required for conventional welding whether the fixture is designed for robotic tacking and welding or is a holding fixture designed for welding manually-tacked assemblies.

The term “conventional welding” describes the classic procedure of an operator standing in front of a robotic work-cell, loading and unloading parts at either side A or side B while the robot is welding on the other side. An alternative way to develop a cellular approach for welding is to utilize a six-axis material-handling robot to pick, position, and present the work-piece to the welding robot(s).

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Coordinated robot systems using multiple robots are rising in popularity because of the flexibility, and certainly the ability to adapt to future product changes. Additionally, robots have few moving parts so the material-handling device in terms of the industrial robot versus another type of positioning device will be more reliable.

If a firm has fifty part numbers to weld robotically, then there are in principle 50 fixtures. There is a cost for the design, hardware, and maintenance of each of these fixtures. In machine tending, work-holding changes may be needed for producing different parts, especially for a machining center, but a lathe would typically use a common chucking system with perhaps change out of chuck jaws.

In machine tending, the robot does not require a gripper for every part style but generally a few gripper styles cover a range of parts. The point is that the equipment (device) used to secure a work-piece for robotic machine tending is less in content than the equipment to secure a set of parts for arc welding. In arc welding the perception is that it is acceptable in manual welding to have a welding fixture for a new part style and robotic arc welding simply follows the same precept. In machine tending, the perception of multiple part styles creates the concern that small batch runs are a challenge for the robot.

Product life cycles are also different between the two applications. Welding is a more mature robotics application and as a result there is a broader range of “standard” platforms, and acceptance among manufacturers. Because of the maturity of robotic welding systems there are many tools available to support changeover and to maximize utilization of the system.

In robotic arc welding, the weld fixture contributes to the most time-consuming task in changeover of a system. Figure 6-9 illustrates examples of how weld fixtures can be quickly disconnected and connected back into the system. Once the weld fixture is under control, the rest of the components are simple to changeover. For families of parts that exhibit similar geometry such as box-shaped assemblies for electrical panels, computer enclosures, and electrical breaker boxes, a universal fixture can be employed to secure a common geometrical shape that either expands or contracts in length,

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width, and height.

Figure 6-6 also shows an example of a universal fixture. Taking the fixturing changeover to the maximum flexibility would produce a programmable fixture that is configurable to whatever part comes next. Essentially the part surfaces that require to be secured in order to present the work-piece repeatability to the robot, are included within the recipe of every cycle. The fixture positions are programmable either through the robot or another device. The fixture locations also provide feedback to the system to validate that the fixture locations are in fact where they are supposed to be positioned.



Picture A



Picture B



Picture C

Figure 6-9 Examples of Managing Fixture Changeover for Robotic Arc Welding

Figure 6-9 shows three examples of ways to manage quick changeovers in robotic arc welding. Picture A is an example of a “picture frame” that is attached mechanically to the positioner as shown. The positioner is a headstock/tailstock, single-axis positioner, controlled by the robot. The picture frame serves as a mechanical structure that permits attachment and reattachment of

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another fixture shown in picture B. The attachment to the picture frame can be with bolts, or even quicker pneumatic couplings that allow more of a lock/unlock function as the fixture is located to the frame.

Quick-change fixturing is critical to maximizing robot utilization and certainly as discussed for other applications the machine itself, as with a press brake or machine tool. Picture C illustrates a series of fixtures that could be arranged as a progressive set of clamps that secure the work-piece in various orientations as welding proceeds sequentially from fixture 1 at the left, to fixture 2 in the middle, and to fixture 3 at the right. Each fixture has a base, and each base can be attached mechanically to a base plate that is welded or bolted to the table. As in the example of the picture frame, each fixture can be quickly located and locked in place; a new weld program is then selected and the job begins.

Another item to note in Figure 6-9 is that the fixtures are located on one side of a turntable. On the opposite side of the turntable (not shown) could be a completely different set of fixtures with an entirely different set of products. The robot is programmed to know which side of the turntable is in position to be welded for a given cycle, and the appropriate programs are then implemented. The turntable has a capability similar to that of the machine tool pallet changer in terms of increasing efficiency as the load/unload time of the fixture proceeds concurrently with the robot process.

Examples of other aspects of the welding system to be set up are as follows:

- Robot programs. Consist of the file containing the robot motion sequence and instructions to execute a new process
- The welding procedure may need changing if the base material, joint type, or material thickness changes. The procedure recipe would be part of the robot programming, and automatically managed by the robot programming structure
- Changes to the welding consumables (welding wire, welding torch, and accessories (feeder drive roll, liners, tips). These items would need to be exchanged, and the welding process

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also must be changed because of the aforementioned parameter changes

The idea of loading/unloading the weld fixturing while the robot is welding is to balance the time between the two so that the robot time and operator loading time are designed to meet the throughput requirements. If the daily production rate is high, and the welding time is long enough, then the operator can be called upon to tack assemblies together, prior to loading the parts in the holding fixture, or to do visual inspection of finished welded parts, and service multiple weld cells. It is essential to avoid severe mismatch in load/unload time where the robot can weld the parts faster than the operator can feed the system. In that situation it may be possible to find ways to lengthen the weld cycle again, to balance the operator's ability to load/unload and perhaps perform other tasks as just mentioned. Often a single operator will be on the shop floor taking care of feeding several robot systems, and that is a good thing in terms of ROI.

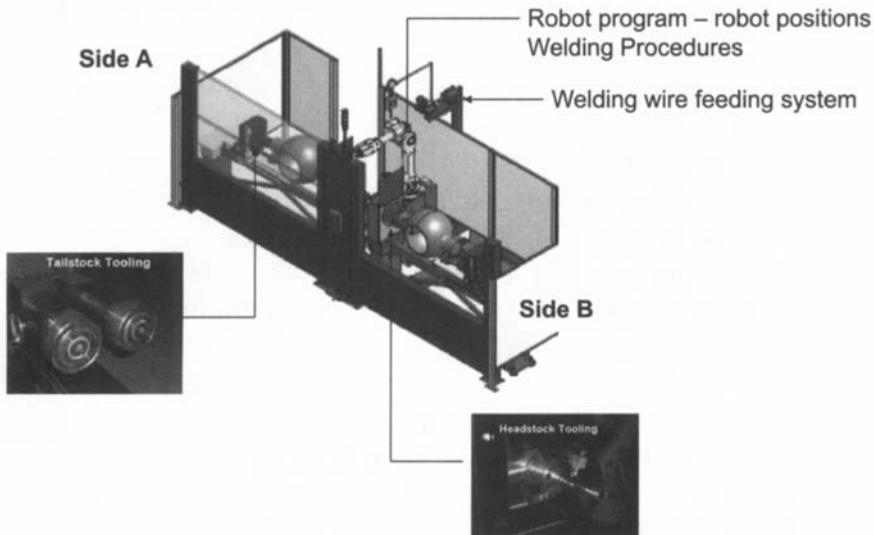


Figure 6-10 Considerations of the Components Requiring Changeover for Robotic Arc Welding

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Figure 6-10 illustrates a typical standard welding system and incorporates a shopping list of items to be considered for changeover when there is a product change. The system in Figure 6-10 was designed to weld various “shaft” type parts. The workholding in this situation is similar to that for a machine tool workholding fixture because the part family is all shaft based. There are two positioners to allow loading/unloading while the robot is welding, and the positioners again are single-axis headstock/tailstock, positioners, controlled by the robot.

Additional tasks that operators should complete while the robot is welding include preparing or completing hard-to-reach welds and/or small welds that may have benefited from fixturing but were not worth the expenditure because the welds were too small. An example might be a simple bracket that has only a couple of inches of weld run to the main body of the work-piece. By the time the operator has tacked the bracket in place, the bracket could have been welded to the main body without the cost of a fixture. The law of diminishing returns is often seen in welding, meaning at some point it's just worth keeping some welds manual because the company will never see any real economic benefit from robotizing every weld.

The shortcoming of a standard welding system is that an operator is always required to be present to feed the system. In other words, unless the welding system is fed by another form of automation, traditional standard welding systems will not support unmanned production. It is not a negative because again, the material handling and welding are occurring at the same time, and the weld productivity is 3 to 4 times greater than the manual process ever could be.

Custom (non-standard) welding systems (meaning that the part types do not fit a standard platform) are probably large assemblies. Robot-welding of large assemblies or parts with long manual welding cycle times, makes a lot of sense because the welding cycle times are exploited through the robot efficiency and arc-on time, and no operator is standing in front of the system to load and unload material. These systems are more expensive, and can be more com-

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plex than standard systems, but their return on investment can be substantially quicker because of the increased labor that would otherwise be needed to meet the customer's demands. Imagine loading a tacked assembly into a weld fixture that normally takes two operators four hours, or longer to weld. The robotic system completes the cycle in about a third of that time, with consistent quality. That facility provides a huge competitive advantage to the firm.

The changeover involved with long cycle-time work-pieces also becomes less of a factor because

welding is going on most of the time and there is no changing from part to part. What is interesting is the feedback: "We are not concerned about the setup or changeover time with my robotic welding system because we have so much increased throughput". Again, imagine the economies that can be gained with a single operator feeding two or more welding cells. Additionally, productivity gains make more time for torch maintenance (i.e. contact tip, torch reaming, and liner changes), which becomes minor in terms of the overall throughput.

Automating the material removal process for small batch runs

Moving over to the material-removal side of the process intensive applications, the equipment to perform these tasks always seems to require a higher investment than arc welding, and what is interesting is that operators in the cleaning area of the shop floor are generally paid less than a skilled welder. Material removal, in the author's opinion, is an application that should be automated simply because it 1) causes a high level of turnover on the shop floor, 2) ergonomics, and insurance concerns, and 3) has the worst operator efficiency. Additionally, in the home fixtures, and medical industries, material removal in the form of grinding, buffing, and polishing is what ultimately gives the product the quality surface finish that is the first thing the consumer sees.

The companies that manufacture medical components (knee and hip replacements), and home fixtures, automate the material removal process with robots. Their motivation is consistency, qual-

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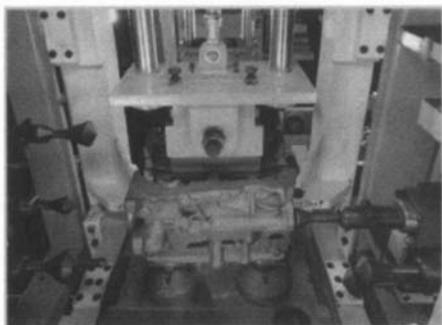
ity, safety, and throughput. The types of products seen in bathroom and kitchen fixtures are all over the board in size and configuration. Even knee and hip components vary among patients. The robotic material removal systems used to buff and polish these parts are designed to use parametric programming to enable quick changeovers from one batch to the next.

The challenge in material removal is not only that the parts vary in size and shape, but also the individual parts from one to the next in the same batch are different because of the inherent surface tolerances assumed as the part was produced. In plastics there is shrinkage, in foundries and die casting there are varying parting lines, flashing, casting size, and risers. The tools for overcoming tolerances in welding are “through the arc seam tracking”, touch sensing, vision, and laser guidance. The tools for coping with tolerances in material removal are active and passive force compliance, sensors and probes, and vision. The tools for the latter are very expensive to purchase. Additionally, higher levels of training, maintenance, and setup are required. Material removal is one of those applications with which the return on investment is either really good or a struggle. Material removal is most compatible with robotics in the following ways:

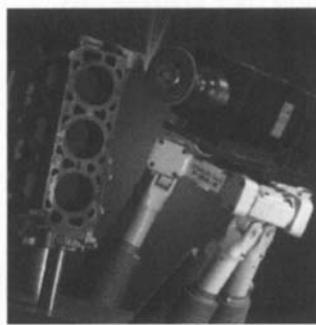
- As a post-process event to the main process. For example, the work-piece is extracted from an injection-molding machine, a blow-molding machine, or a machine tool, etc. The investment in the robotic system was covered in the material handling or the loading of the machine. The incremental investment for additional functionality in deburring, trimming, or whatever is minimal
- When there are large batch runs of the same or “like” family of part styles. This way, the process that is developed using the process tools is dialed in for all the parts after setting up one part. Then the programming becomes much easier to manage than it is when programs are developed for many varying part styles. Additionally, parametric programming can be implemented.

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- The work-piece is large and/or manually time consuming, allowing exploitation of the robot efficiency to become a significant financial benefit
- Where the discussion of quality and visual appearance previously mentioned are the consumers priority and they are willing to pay for the quality of finish, or the firm cannot afford the costs of scrap as a result of inconsistent quality



A dedicated approach to material removal



A flexible approach to material removal

Figure 6-11 Dedicated versus Flexible Material Removal Methods

There are alternatives to robotic material removal that do excellent jobs of removing specific features of a work-piece, and there are dedicated machines that remove a specific amount of material for specific part geometry. Dedicated devices are ideal for higher, more-consistent volumes, or like or similar parts. Both forms of dedicated and flexible automation have their places. If the removal process is the same every time for a family of work-pieces, the value of the changeover capability and flexibility of the robot offers less value to the application. Figure 6-11 shows examples of robotic and dedicated automation designed to perform material removal operations on engine blocks.

The same “recipe” methodology and parametric programming can be applied to material removal systems, just like any other application. The scope of work covered in Chapter 5 used the

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robotic cleaning of engine cylinder heads as an example for outlining a scope of work. For the engine- head cleaning system, the following tools were used to support changeover for the varying casting styles and management of tolerances:

- Vision to identify part type that automatically configures the system process recipe
- Probes to identify casting surface locations
- Robot grippers designed with variable strokes to handle varying part sizes
- Robot grippers that incorporate multiple functional mechanisms such as pneumatically-powered fingers to grip a casting, and vacuum cups to handle corrugated boards without making a programming or gripper change
- A system control that serves as the coordinator to ensure that the process recipe for the incoming casting is ready for each device. When the cycle is over, the coordinator purges the recipe and prepares to launch another
- Tool changers on the robot to pick up various cutting tools throughout the cleaning program. The robots exchange various milling tools and cup grinders automatically as they process each casting
- Vision to identify location and orientation of each casting as it is presented to the system, providing a reliable method for handling and loading process equipment

Figures 6-12a and 6-12b show some aspects of work-cell component arrangements that facilitate changeovers used for small batch runs. The same plan is used, regardless of the application, when designing for changeover. There is always a system recipe that controls how the process will be run. Each part style requires its own process recipe, and variations in the part characteristics as a raw part or as a complete part, will proportionally affect any changes to the recipe:

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Robot motion	Parametric versus specific robot path taught for individual part ID
Robot tools	Method for exchanging end of arm tools (automatic, manual)
Process	Procedure recipe executed as a series of subroutines for each part style
Material in	Vision and/or dedicated (fixed) method to secure work-piece
Material in	What kind of raw material queue for running unmanned if applicable
Material out	Fixed versus loosely-transferred product
Material out	Conveyed, palletized, packaged, dumped into a bin
Peripherals	Execute a specific task or program per part identification to perform a process
Control system	Managing how the part recipe is executed and the triggers for determining what recipe to run in each cycle
Safety	Ensuring that the system provides safety measures, given that the system may function differently from one part style to another

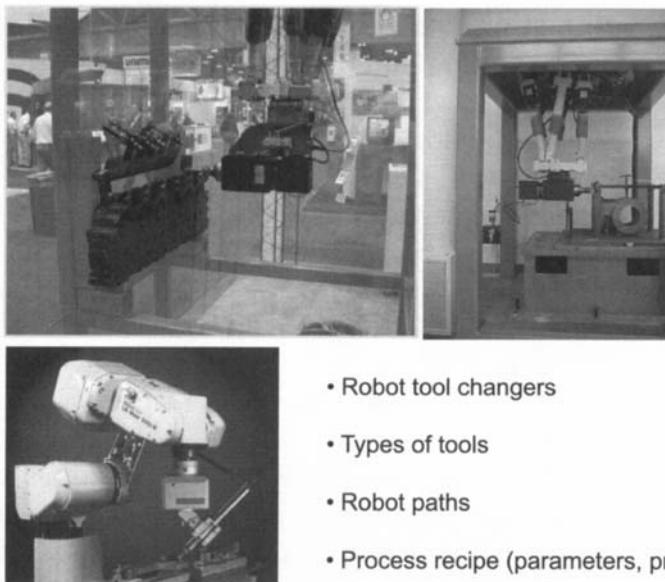


Figure 6-12a Considerations of Changeover for Robotic Material Removal

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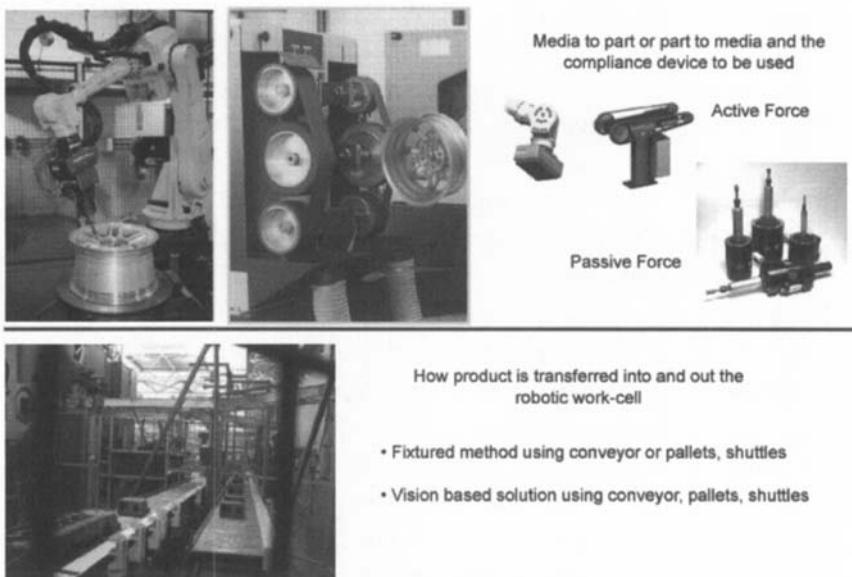


Figure 6-12b Considerations of Changeover for Robotic Material Removal

Automating small batch runs for press tending and palletizing

Before examining the tools that enable industrial robots to behave like human operator in handling small batches, and the associated system changeover, two other applications that have been only touched on will be reviewed. The first is robotic press tending. Press brakes and stamping presses are designed to form or change metal parts that start as flat blanks. From the robotic point of view, the flat blank is nice because it allows a vacuum or magnetic gripper to handle many style parts easily. Changes in the base material, for example, from steel to aluminum, will require a different gripper because a magnet gripper will not work on non-ferrous metal. In press tending the next biggest contributor to cost in having to change out a gripper is the pattern in the blank because, prior to bending, the blank is often processed in a turret punch machine that uses a laser to cut out the hole pattern. If the hole pattern is substan-

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tial, there simply may not be enough surfaces to grip with vacuum cups. Another driver that would affect gripper selection is the size difference in blanks. For instance picking up a 24 x 24-inch blank weighing 8 lb. is different from picking up a 40 x 60-inch blank weighing 134 lb..

Palletizing is similar to press tending in that the robot is being asked to grip a common surface side, usually flat, in order to pick and place the work-piece throughout the process. An engineer who is designing grippers will usually overlay the cases, in the palletizing example, or overlay the blanks in press tending, to see how much overlap and shared surface area exists among the product styles. Through a process of elimination, gripper selection becomes an exercise of matching products that can use the same grippers. Differences in base material, or between buckets , bags, and cases, immediately separate each product from the group into an individual entity. Glass handling is another separate item in this discussion.

Press tending can certainly become more complex than pick/place palletizing because the process causes the work-piece to be formed into a shape different from when it started. Additionally, the work-piece may need to be handled several times at different locations to ensure that the robot grips the part without interfering with the brake or press tooling. The brake tooling frankly is the biggest opponent to changeover for a manual or robotic process. Thus, changeovers associated with press tending are a function of the machine setup.

In an earlier machine tending exercise, the changeover was a wash between the robot and the manual operator, but the robot would exploit running production through lunch and breaks, and exhibit an efficiency that exceeded the manual process from between 40-50 to over 90 percent. Additionally, the press-tending system can be set up with a new stack of blanks at the end of a shift for the robot to work through, so that, at the end of every day, the firm could see 20 to 50 additional parts produced, essentially for free, with the exception of the utilities cost.

Press brakes can be configured with a long enough tool bed to allow for multiple punch and die setups to be installed in the press

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without the need for changeovers of one tool setup for another. The tool setup often is the limiting factor in press-tending efficiency, not the robot system. Additionally, manufacturing machines are similar, and it is in a firm's best interests to pursue a practice of quick-change tooling for any type of process equipment.

Small batches are ideally suited for applications such as palletizing and press tending. However, it's the production machine's changeover and not the robot that makes possible an even higher efficiency through quicker tool changes. There are readily available solutions for quick change tooling in press tending, and if the press bed is wide enough the bed will handle multiple setup's so that no changeover is needed. Figure 6-13 illustrates components involved in changeovers in a press tending cell.

Figure 6-14 illustrates various types of press tending work-cells, all designed to suit the way in which material is transferred into and

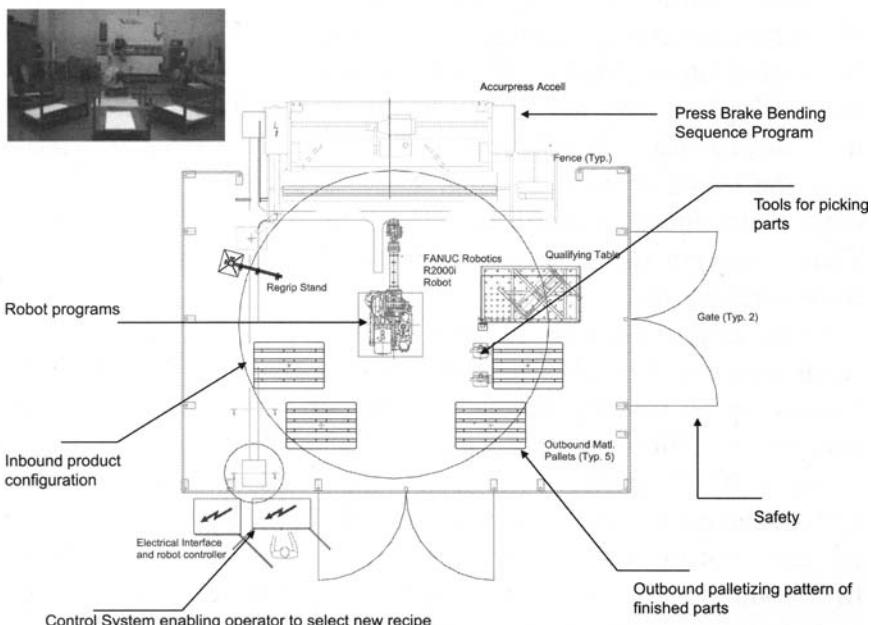


Figure 6-13 Example of Components Considered for Changeover Press Tending

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out of the work-cell. The differences are affected by how much unmanned production is desired, as well as how the system manages the running of different part designs. For example, there are multiple pallets on the floor for incoming and outgoing material. Each pallet represents a unique part style, enabling the robot to form blanks for a kit or a setup. A setup would include specific quantities of varying parts that make up the kit. The pictures in Figure 6-14 show systems with and without conveyance. The conveyance permits a much longer raw material queue, for longer unmanned production. The robot track enables the robot to become even more flexible, because its reach is considerably greater when the robot is not lagged to the floor.

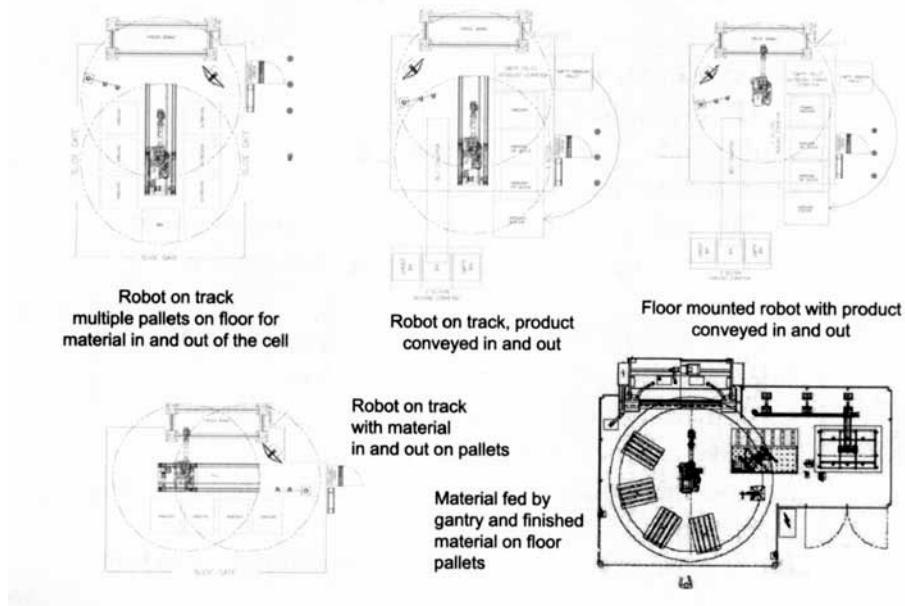


Figure 6-14 Multiple Examples of Robotics Press Brake Tending Cells

The following example compares conditions for changeover between a manual and a robotic press-tending application. The example includes the following conditions:

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- Seventy part styles

- Parts are made in kits. For this example, five (5) part styles are selected:

Part 1	60 pieces	using tooling A
Part 2	60 pieces	using tooling A
Part 3	90 pieces	using tooling B
Part 4	120 pieces	using tooling C
Part 5	60 pieces	using tooling D
Part 6	120 pieces	using tooling D

- Parts 1-3 are aluminum, and part 4 is steel
- Parts 5 and 6 are stainless steel with a plastics coating on one side of the blank
- 230T 10-foot bed press brake, 6-axis back gage
- Daily production is 16 hours per day – 2 shifts
- One operator per shift
- Production halts at break time and lunch – one hour per shift total time. So available manual production is 7 hours per day
- It takes all day, including tooling changes to make the kit
- There are four (4) changes of brake tooling per day
- Customer does not use quick change tooling on the press brake so a typical tooling setup is 40 minutes to retrieve the tooling, locate tooling in the press bed, and test a part
- Profit per piece or kit is unknown and not factored into this example
- A single operator services the brake and the heaviest blank is 35 lb.

What can be forecast, using this example:

- In a 16-hour day the amount of setup time is approximately 160 minutes, so that there are 1280 min. (total daily time) –

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160 min. (setups) – 120 min. (lunch/breaks) = 1000 minutes per day available for production

- 452 pieces are formed per day
- On a given day the throughput in 16 hours of production is 1000 minutes/452 pieces = 2.21 minutes average forming time per piece at an estimated 55-percent efficiency. The 55 percent is the estimated manual efficiency when the operator is picking blanks, forming, and then placing finished parts on a pallet. The operator goes to the bathroom, gets something to drink, talks to others, and generally will inevitably waste 45 percent of the available production time
- The robot will operate at 98 percent efficiency within the available production time because the robot is built and designed at 98 percent efficiency

What could this user do to increase productivity and lower costs:

- Quick change brake tooling would decrease setups from 40 minutes to 10 minutes. With four changeover's daily, this savings would gain daily extra production of 120 minutes
- Purchasing a press brake with a longer bed would enable multiple tooling setups to be accessed at any time without changeovers to tooling in the first place
- Compared with the 98 percent efficiency of the robot tending the press brake, the following results can be achieved:
 - 1000 production minutes yields 452 pieces manually at 55 percent
 - 1000 production minutes yields 804 pieces robotically at 98 percent
 - The additional production that can be gained by running through breaks on a 2-hour shift, and running the system with additional products on the off or third shift can be as much as an additional 100 plus pieces
- The cost savings to the firm is the labor of two shifts, and the ability to reduce one shift, while achieving the same throughput using the same press brake

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- Quick-change tooling, or a more flexible press brake, in addition to the robot tending, would provide even further capacity on a single-shift basis

What does it mean to the firm to remove an entire shift? The manual process efficiency could certainly be increased if it was felt that the operator would really produce at a higher level than 55 percent, day after day for a total of 250 days per year. That scenario would certainly offer a valid counterpoint to justifying robotic automation, but the reality is that the press brake asset can not be utilized on an equal basis by a robot process versus a manual process.

The return on investment in this situation is completely hypothetical. It does not matter here because the point was to show that even with an extreme amount of changeover, the robotic system along with some efficient tool-changing methods and/or right-sized equipment can double output with less labor content, improve quality, and provide a dependable operator every day.

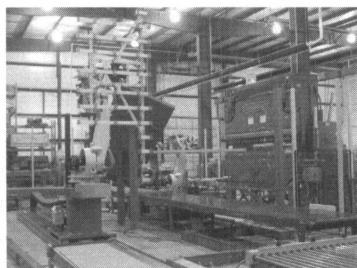
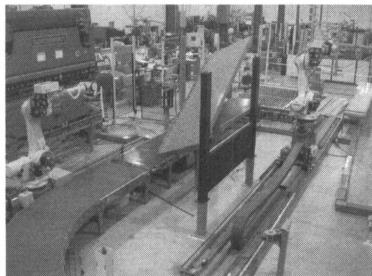
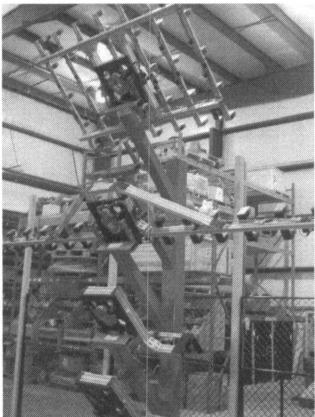


Figure 6-15 Robotic Press Tending System Designed for Single Piece Flow

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One of the most interesting projects relative to press tending is illustrated in Figure 6-15. This robotic system provided the following functionality:

- The robot is integrated directly with a punching machine so that blanks were cut from a master sheet, their hole pattern punched, and then conveyed to the robot forming system
- Over 200 part (sku) numbers were automated and caught in the system, using offline programming
- A bar code label for part identification was placed on each blank as it was transferred into the robot work-cell.
- The part identification established the system recipe including the robot programs, robot tools, and press brake tooling that the robot exchanged automatically, and the press brake forming program. Every cycle used a unique recipe, providing a batch-of-one manufacturing process, for single-part flow with zero operator intervention.
- There were ten (10) robot end-of-arm tools designed to handle various shapes of parts and hole patterns in stainless, phosphate coated, and plain steel blanks, and to handle the press brake tool sections (there were four sections of the die and punch that needed exchanging in the event that a tool change was required)
- The system worked on a three-shift basis, six days per week
- The robots were chosen to handle blanks weighing up to 150 lb. (previously two operators were required to handle the heavy blanks)

As mentioned, many material-handling applications can be designed to handle single-piece flow, and the part characteristics drive the level of flexibility around which the robot system must be designed.

Automating the palletizing process for small batch runs

Palletizing for small batch runs is also a fairly straightforward

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process. Figure 6-16 shows examples of end-of-arm tools designed to accommodate various vacuum and mechanical methods for picking up things for the purpose of palletizing. Palletizing robots use end-of-arm tools that handle pallets, cases, buckets, bags, divider sheets, etc. The robot control system tracks how every layer for each unit load is palletized, including the product patterns and when divider sheets are required between product layers.

Palletizing lends itself nicely to parametric programming. After the robot is taught one position for the first product placed on a pallet, that information can be used as the reference to offset every additional product placed throughout the unit load.

There are situations where multiple pallet types are required to be used, and the system needs to be designed to transfer varying pallet sizes into and out of the system. Where the robot is palletizing products having significant physical differences that affect how they can be picked and placed, the robot may be required to swap gripping tools, or pick up an adapter that is attached to the primary gripper but allows for picking something new.

Palletizing robots have no problem building a partial pallet where there isn't enough product to build a complete unit load at the end of a batch run. In the reverse, robots can also begin palletizing on a partial pallet that was left over from a previous production run. In this situation, sensors, vision, or a manual input may be needed to establish the starting point for the robot to begin its task.

By application, robots will exhibit varying numbers of cycles per minute which ultimately affect throughput. For case palletizing, the robot will typically exhibit 10-14 cycles per minute, depending on the application, and where the pick/place locations are located in the work-cell. The pick/place locations are related to where product is transferred into the system, and where the pallet is located. Additionally, the robots take longer for palletizing at the beginning and end of the unit load because of the distance for the robot to travel, relative to the elevation of where the product is entering the system. Some users will use a robot servo-controlled, scissor-lift to maintain a constant height location, to maximize robot speeds throughout the palletizing process. Bag palletizing can attain 20

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plus cycles per minute, given the fact that the location of bags coming into the system is generally very close to where they are palletized, and the tool acts much faster when gripping the product versus vacuum and picking cases. On the other hand, if the product can't be picked on the top surface so that the robot must use a fork tool to lift up the box from the bottom surface, the tool will take longer to operate than the vacuum system, and the robot's cycles per minute will be less.

Optimizing pick/place locations in the work-cell, that is, reducing the amount of motion the robot needs to accomplish for a cycle is very important. The slowest axis of the robot is the waist axis, and in palletizing every second counts considering that the robot may palletize thousands of cycles per day. The robot is capable of picking and placing something at every cycle t (products or a pallet, sheet, etc.). Using the robot to pick something other than the prod-

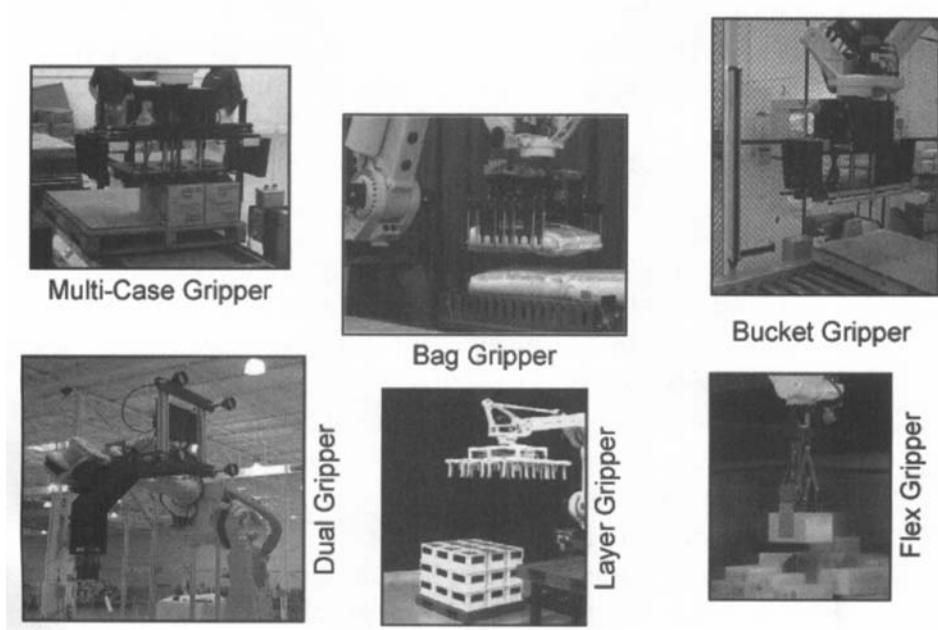


Figure 6-16 Examples of Functional Robot Palletizing End of Arm Tools

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uct obviously reduces the rate, but also provides greater flexibility. The question may be when to use an automated pallet dispenser and when to have the robot pick pallets from a storage stand or use an automated divider (tier) sheet dispenser.

Throughput rates in robotic palletizing are based on how much product the robot can effectively pick and place to build the appropriate pattern. The robot is capable of picking a single product, multiple products, and if needed an entire layer or layers of product. When examining many part numbers with varying physical sizes the tough process is to provide a universal robot tool that will handle all product without changeover of the tool. The quantity of product to be picked for a given cycle then is a function of the pattern.

A columnar pattern of 2 rows of 4 cases for example, is much simpler and quicker to palletize than a spiral pattern of 8 cases. The more varied the orientation of the products as they are presented to the system, as compared with how they need to be placed on the pallet, the more the palletizing rate is reduced, because additional robot motion is needed to compensate for the orientation differences. Patterns vary because users are required to optimize packing density and unit load height and weight for transportation to their customers.

The following list describes the characteristics that affect robot palletizing throughput:

- The tasks the robot has to perform (pick pallets, divider sheets, number of unit loads being built at one time)
- The time required to take away a full unit load (pallet) and bring an empty pallet
- Orientation of the product coming into the system compared with the orientation pattern required on the pallet
- The quantity of product being picked at a given time, which could be a single unit or an entire layer
- The location of the incoming product (elevation from floor and location to robot) relative to where the finished product is to be placed

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If the robot was de-palletizing, meaning removing product from a pallet, and then placing the product somewhere such as on a conveyor, throughput is also affected by the time for the robot to go and search where the product is located before picking it off the pallet.

Switching gears to non-conventional palletizing is a market that is increasingly popular in warehouses and distribution centers because the volume of product handling is extremely high, as well as the labor content. Non-conventional palletizing as it is called, deals with palletizing random product sizes that are fed to the robot in single-flow fashion so that one product after another can vary in physical size and weight.

There is another challenge in robotic random order palletizing, and that is building a stable load that will not tip over as the pallet is transported. Figure 6-17 illustrates an example of a randomly-palletized unit load. Random-order unit loads are used in the real world in the following ways:

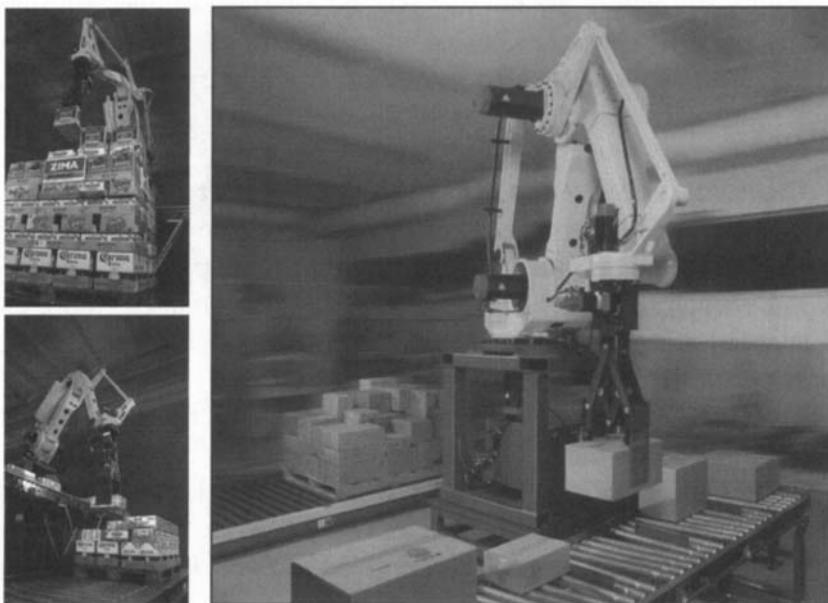


Figure 6-17 Random Order Palletizing Examples

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- Unit loads consist of a set of individual orders of products. The unit load then must be built to support the last order to be delivered at the bottom of the pallet and the first order to be delivered on the top. The unit load then is designed to handle small partial pallet orders
- In the warehouse or distribution center, the random order mixed unit loads are built to satisfy immediate order needs so that the product coming to the robot palletizing operation is completely varied, being based on customer demand

Random-order palletizing is a great example of utilizing the flexibility of robotic automation. The robot has to grip any box size without changeover, as well as make decisions ahead of time to where the box will be stacked in an ordered sense, to plan for a stable unit load. The robot can't simply pick and place boxes at random. The robot receives information regarding the product that is coming, and has to make decisions on how the product will be placed. The robot's decision making software will have to decide:

1) how and where the product will be arranged on the unit load, and 2) does the robot hold back the product for a later palletizing time slot that makes the load more stable, while trying to optimize packing efficiency and stability of the unit load.

Tools for small batch and high changeover production

The robot itself is a programmable, adaptable device that mimics human motion. The limitation of the robot is its payload capacity. Even its reach is unlimited, in the practical sense that the robot can be adapted with additional axes of motion if the standard six axes are not sufficient.

It was established earlier in the argument comparing manual versus robotic processing, that the changeover to the process excluding the robot is a wash between the two ways of doing something. However, there is always the flexibility versus complexity and diminishing returns argument for automation. In other words, beyond the investment for a “basic” functional robotic system, for X amount of added investment, what else is gained in terms of

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reducing cost and increasing productivity. The robot itself is a completely flexible device, which is why the same robot model is seen doing hundreds of different tasks across a myriad of applications and industries. The robot is simply equipped with and surrounded by the tools necessary to perform the tasks, and these aspects, combined with the level of flexibility in the peripheral tools, are what enable the robot to manage anything from a single part flow to batches of thousands. The peripheral tools are the key to success for managing whatever flexibility is required within the firm's manufacturing philosophy. With the advent of lean manufacturing, producers of robots and peripherals continually develop tools aimed at lowering the time and cost for changeover.

Robots are inherently blind devices that repeat movement to their taught positions within plus or minus thousandths of an inch, and that is a problem for the real world because normally nothing ever repeats. The risk, cost, maintenance, training, and implementation to enable this blind device to place a welding torch or a hot knife in the location it needs to occupy in space is the science. Loading the chuck in a machine tool with a part that has to be loaded radially within a few thousandths of an inch is certainly a nice challenge for someone who is blind. It can be thought of as having a human operator perform a series of tasks in terms of providing value to a work-piece while blind-folded and expecting a zero-defect product at the conclusion of the task. That is a problem.

In the words of “Amazing Grace,” “I once was blind and now I see.” Robotic vision among other sensory tools, has forever changed the world of the application of robotics, specifically in overcoming the aforementioned challenges. Vision is used across every type of robotic application. Examples are as follows:

- Validation of the presence or lack of presence of a feature (for instance, the hole was threaded or not)
- Orientation and location of a static or moving work-piece
- Character reading of a part identification as a 2D or 3D dot matrix
- Inspection of a feature characteristic (i.e. does the weld visual

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appearance comply with quality standards in terms of appearance, undercut, profile)

- 2D and 3D location of an object in space, whether it be located in a bin/container or stacked in a random orientation in space
- Finding the starting location to begin a process, given that the tolerance for locating the work-piece is not repeatable
- Part identification by comparing a unique part feature to a table of features among a series of parts

There are other tools that accomplish tasks similar to those that robotic vision can accomplish, such as probes, sensors, RFID tagging, bar coding, and mechanical means of capturing a work-piece in a repeatable location. Every application is different, and in many situations, vision is used in conjunction with other peripheral tools that give the robot “sight” and “intelligence”. Figure 6-18 illustrates many applications of robotic vision.

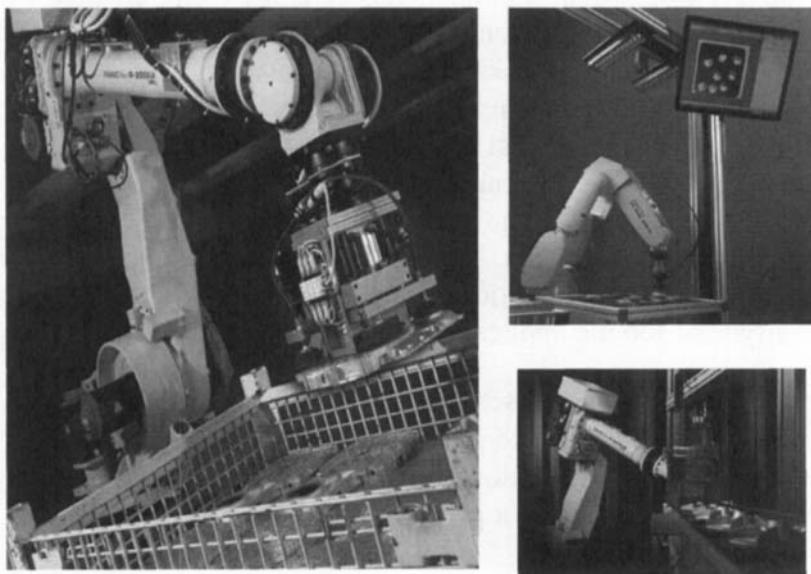


Figure 6-18 Example of Robotic 3D and 2D Vision

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The potential to implement robotics has dramatically increased as a result of vision because, not only can the robot itself become an intelligent device that was already flexible, but the level of investment to implement vision, versus more mechanical, rigid/fixed devices is significantly less. Changeover in a world of fixed mechanical equipment that is designed to enable the robot to overcome blindness is a challenge, and often not very practical for small-batch runs. Changeover now becomes a factor beyond the process “stuff” that the operator has to deal with anyway, like a tooling change on the press brake or other machine.

The cumbersome task of changing out hardware every time a new batch of product is to be introduced to the robot, so that the robot could pick the new part style versus the previous style is no longer needed. The investment in a robotic system is highly weighted in terms of how product enters the work-cell. Simplifying the part presentation with a universal versus dedicated means of presentation for a broad range of product styles is a major advantage for the user because there is no physical changeover. Furthermore, what if the product could be presented to the robot exactly as it is shipped from the supplier, without any operator intervention? An example is random order bin picking of product that is randomly located in a container newly arrived from the supplier. Figure 6-18 illustrates an example of random bin picking.

What if there was no welding fixture and positioner but instead a material-handling robot serving as the fixture and positioner, presenting the work-piece to a separate welding robot(s). Figure 6-19 shows an example illustration of this idea. The material-handling robot and the welding robots in the examples shown in Figure 6-19 are all controlled with one robot CPU, which enables movements on the six axes of each of the robots to be coordinated and controlled together. The flexibility of this system through the use of tool changers, and vision for the material-handling robot, would enable a work-cell to be configurable in positioning and securing the work-piece, which are the two of the areas that make the largest contribution of hardware in a robot system. Reducing the hardware not only makes the system more flexible, but also more reliable, with less moving

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parts and maintenance. Robots servicing robots to accomplish a manufacturing process is the ultimate, flexible work-cell.

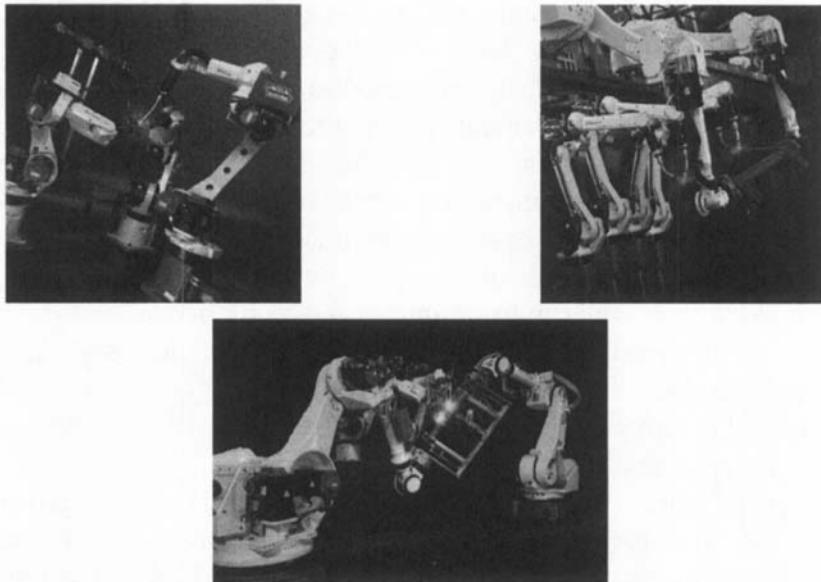


Figure 6-19 Robots Serving as the Positioner and the Fixture

In examining a robotic system in terms of what the robot can accomplish, the following criteria are used to outline the system component and tools to achieve single-piece work flow.

Component Category	Robotic Tools and Technology
Inbound raw material to system	Robotic Vision Automated part identification (i.e. bar coding, RFID) Sensors or probes, internal or external to the robot
End of arm tool	Programmable gripper Universal gripper Tool changers with multiple grippers Multi-functional gripper that accomplishes multiple tasks (i.e. cutting and welding, or picking pallets and cases)

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Programming	Parametric-based programming for a process that can be applied to one or more part styles/models Robot paths automatically generated from another source Programming is typically sub-routine based for each process step. Routines can be automatically turned off and on, depending on the recipe
Fixturing) (welding, material removal)	Programmable fixturing controlled by the robot or external control Using a robot to hold the work piece versus an external device
Positioner (work-piece manipulation)	Using a robot to position the work piece- Programmable positioners that adjust for tooling length, or swing diameter controlled either by the robot or by external controls
Robot hand-shaking with peripheral devices	Changing the process program or a parameter at a peripheral machine/device is standard and changes can be made on the fly by the robot system
Safety	The robot can be dynamically zoned In on a program change and peripheral safety devices such as light curtains and barriers can be dynamically controlled to limit access by an operator

There are other components within the robotic system that are classified as peripherals. A generic list of peripherals is as follows:

Bowl feeders	Stretch Wrappers	Stamping presses
Conveyor	Machine tools	Gages
Press brakes	Inspection equipment	Shuttles
Dial tables	Case erectors	Lasers
Feeding equipment	Pallet dispensers	Punch presses
Washers	Shears	Grinding backstands
Part fixtures (tack and hold)		Die casting machine

For the sake of argument these peripherals are out of control of

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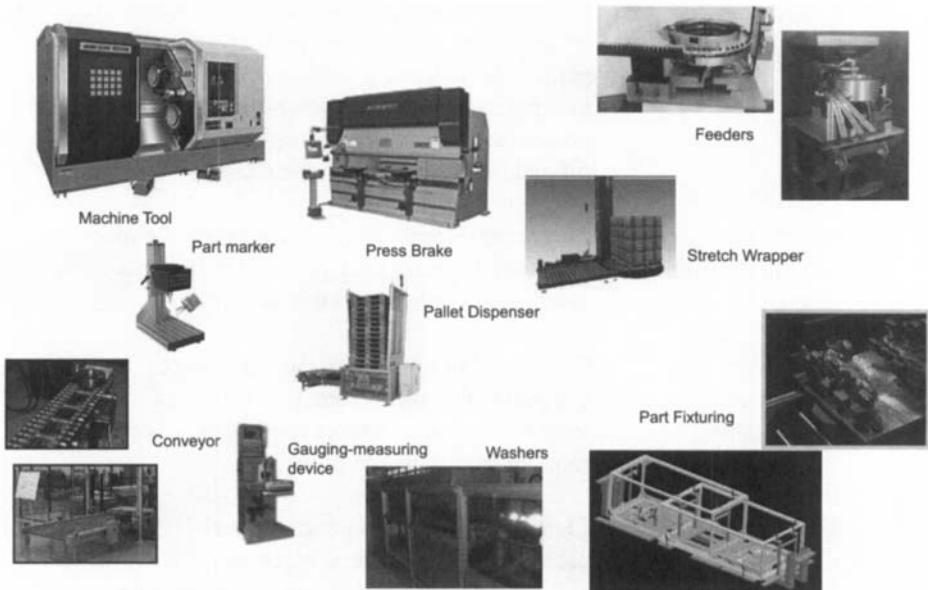


Figure 6-20 Examples of Peripherals in Robotic Welding Systems Requiring Changeover for Small Batch Runs

the robot, relative to managing changeovers of these devices. When it comes to the process equipment used in feeding, or performing the processes on the work-piece, these components of the robot system are limiting factors in achieving single-piece flow. For instance, an assembly operation for an engine cylinder head requires the assembly line to assemble up to 14 part models in a single-piece flow design. For instance, one of the processes is inserting guide tubes into the machined cylinder head casting. Guide tubes are bowl-fed to the robot for the assembly. In achieving single-piece flow, the work-cell that inserts the guide tubes requires a unique bowl feeder for every style of guide tube, of which there is a total of eight (8), requiring 8 different bowl feeders in the work-cell to cover any possible demand based on any cylinder head coming into the system.

Figure 6-20 illustrates some other examples of peripherals that may need to be configured in the system for small-batch runs.

As noted, process equipment has its own work-holding or tooling

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Example 1. Forty Taper Tool used as the work-holding for securing the work-piece within the machining process



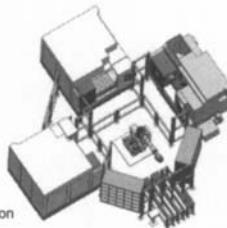
All the varying product



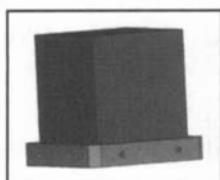
The common work-holding



How each part is secured in the work-holding at the machine tool



The simplicity in work-holding allows for easy bulk storage for hours of unmanned production with storage of parts that are never the same.



Tombstone fixtures that have unique work-holding to secure the work-piece but have a common pallet base to attach to. The pallet is loaded in the machine and that is what the robot grasps.

Note the system solution where hours of production are stored and ready to go in the racks all with individual part styles but the robot gripper needs only grab the pallet

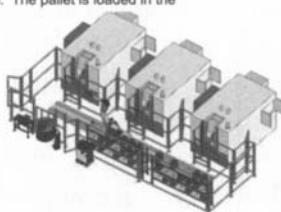


Figure 6-21 Examples of Flexible Work-Holding

configured for the part style being produced, and will require changeover at some point whether the equipment is serviced manually or robotically. Depending on the application, the robot is capable of performing an exchange of tooling or work-holding in the process equipment, as in exchanging the punch and die tooling for a press brake. The robot exchanging a 12-inch chuck in a lathe is another example that is probably not as practical, but with tombstone fixtures used to secure work-pieces in a machining center there is increased demand for using the robot capability to change the work-holding at the machines in addition to loading and unloading work-pieces. An example is shown in Figure 6-21, where the work-holding fixture is common for all part styles, enabling use of a single gripper style for the robot to handle any part. In both Figure 6-21 examples, the simplicity of the work-holding and the fact that it is common for the robot to handle, the systems can store hours of production containing a myriad of part styles.

Manufacturing changeovers to meet varying customer demand

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should be viewed as an opportunity more than producing exactly the same part every time. Changeover is often “a wash” between manual and robotic operators, so time is even more precious in terms of efficiency and maximizing utilization of the firm’s assets. Someone has to perform the changeover. The implementation of robotics eliminates the possibility that the changeover will be configured incorrectly. The future of the application of robotics is being driven toward single-piece flow with zero or minimal changeovers. There are countless examples, and this chapter showed a few of the robotic systems that have been designed for small-batch and low-volume production.

Keeping the robot busy across at least a shift’s worth of production is important in terms of achieving a reasonable return on investment. Not every program is the right program to automate, especially when the complexity of the parts doesn’t fall into the Pareto 80/20 rule; care needs to be taken to avoid automating these types of programs because the flexibility requirements are not justified. Finding programs that can be automated is a good exercise for a firm looking to implement its first robot system, to get rid of the dedicated hardware and the traditional model and move to programmable and agile equipment designed to adapt to real world tolerances and a robot system that can run unmanned small-batch production.

7

Lean Manufacturing with Robotics for High Volume, Large Batch Runs

The reality is that robots and job shops have a lot more in common than their differences, and incorporating lean manufacturing into the model enables the system to further evolve into something special. In contrast, no one argues the fact that if a firm runs high volumes of a single product style or at least a series of similar products, automating production with robotics should be carried out for all the obvious reasons.

High volume, low changeover, means production that is set up perhaps once per day, week or month to run a single part style. In welding or material removal, this mode could also equate to welding a very large assembly for earth-moving equipment or polishing an impeller blade where the "on-time" process is in terms of several hours. Another example is robotically laser cladding of low-alloy components for the energy industry, where literally hundreds of welding passes are applied to the component, one layer after another. Of course another example is the automotive or OEM business where the number of piece parts per hour is high and the same part style is processed at each cycle. These examples consist of thousands of parts per month and certainly annually.

High volume or high throughput per hour means something different depending on the industry. In assembly, and especially the food industry, rates are staggeringly fast. In packaging, and high speed assembly, the robot pick/place motion in each cycle can be measured at rates in terms of less than a second to a couple of seconds per cycle. In the last chapter was discussed the large palletizing robot that had travel speeds enabling the robot to accomplish 8-12 cycles per minute. As a result, the average cycle time for the palletizing robot is a 6-second cycle. With the constraint of 6 seconds,

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the robot throughput is increased by handling as much product as possible from multiple cases to layers of cases at a time, to achieve the highest throughput in each 6-six second cycle. For high speed applications, the robot gripper and the robot payload need to allow for picking and placing multiple products per cycle versus a single piece. Robots designed for high speed applications are capable of 60 cycles per minute as compared to the 8 to 12 cycles per minute of ordinary robots.

For high speed applications every little detail counts towards optimizing the rate. Examples of these details are as follows:

- Location of robot relative to incoming and outgoing materials
 - How the robot is mounted (inverted, on a wall, or upright)
 - Travel distance of the robot from the pick up location(s) to placing the product
- Robot axis speeds, and the ability to accelerate and decelerate quickly – robot motion is critical to ensure no wasted time
- Time for gripper to actually grasp and release product
- How many pieces can be picked up per cycle while staying within robot payload limits
- Part orientation requirements. In other words, is additional time required to change orientation of incoming parts relative to the next location they're to be placed
- Picking or processing product while moving or static
- Waiting on a peripheral device to confirm handshaking signals with the robot as with detecting presence of a part, or confirm that the clamp is open or closed
- If parts are moving while being picked up, a means for tracking and identifying part location as the piece travels is necessary (linear or circular tracking of moving conveyor for example)

Figure 7-1 illustrates examples of high speed robot applications that were designed for high speed continuous throughput. The examples show product moving at a high rate along a continuously-

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moving line where the line speed sets the TAKT time of the process. The picture with the red light shining on the conveyor shows robot vision that enables the robot to pick up product in a random orientation while the product is moving on the conveyor. Vision is another tool used to optimize the throughput of the work-cell. For any system, and especially for high throughput processes, the limitations of a single robot need to be understood, and then considerations for multiple robots, or multiple redundant cells, in order to achieve TAKT time of the line. High throughput requires redundancy, which means that if a system fault occurs, there is a backup system able to continue production, even if the rate is lower, until all the systems are back on line.

Robotic Machine Tending for High Production

High throughput for other applications, such as machine tending, might mean that a part is produced every few seconds. Extremely-

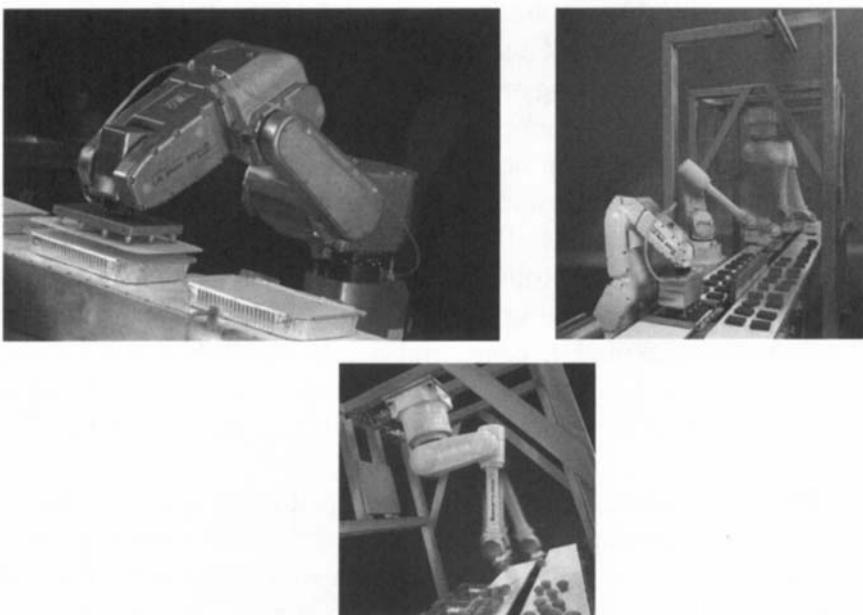


Figure 7-1 Examples of High Speed Robot Applications

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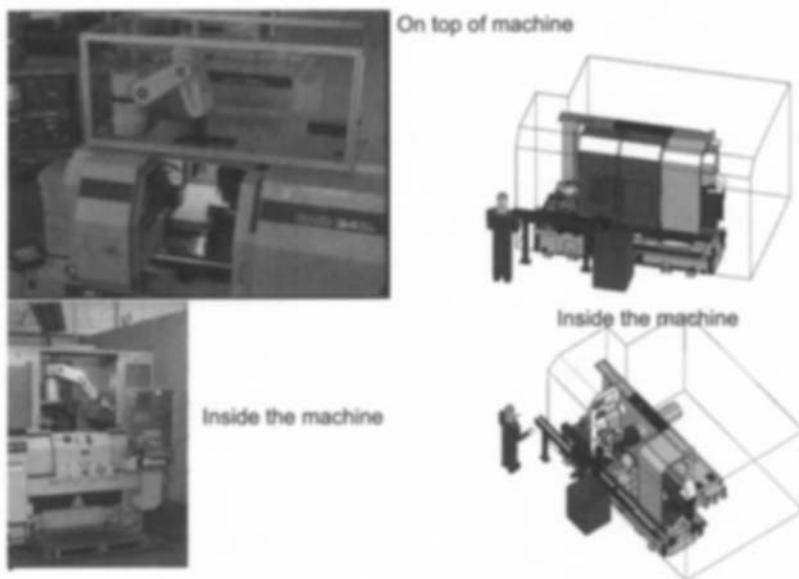
fast cutting times (a few seconds) are typically not accomplished on a traditional lathe or machining center but rather require custom machines with dial tables. Dial tables allow multiple operations to occur simultaneously instead of sequentially. Engineers who evaluate the sequential tasks of a machine tending application, find that robots typically take approximately 6-9 seconds to load/unload a CNC lathe, excluding the door open and close time. This cycle time includes the robot movement in performing a part swap with the machine work-holding fixture. The robot gripper is designed to hold a raw part in one gripper and remove the finished part held in the machine's fixture with the other gripper. The robot motion then enables the raw part to be inserted within the machine's work-holding mechanism.

Regardless of whether it is on a lathe or a machining center, the part swap is a classic way of robotically tending a machine tool. The load/unload time will be longer because of the clamping and unclamping time of the work-holding, the machine door open/close time, and waiting to confirm the door is fully open or closed. A solid minimum for using a robot to service two CNC lathes in order to insure the robot does not become a bottleneck to the process and the machines are not waiting on the robot is 30 seconds. The longer the machining cycle, the more machines the robot can service, or be used to perform post process tasks within the cutting time. On machining centers a flushing cycle is often required after machining, the pallet changer needs index time, and time is needed for part clamping/unclamping. Robots can perform a part swap in as little as 15 seconds on machining centers, but for larger machines the load/unload time may be considerably longer. Machines processing engine block and cylinder head castings can take up to a minute to swap out a finished part and load a raw one into the tombstone's fixture.

Taking the machine door out of the equation entirely is certainly a benefit. Sometimes, on machining centers, users choose to leave the door open, especially when there is a wall between the machining area with coolant, and the outside loading area. On lathes, the door can be bypassed by putting the robot in the machine, if there is

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room, or mounting the robot on the machine above the work-holding chuck as with a CNC lathe. The robot is mounted on the machine and is able to extend its arm through a shutter door located on the top of the machine to reach the chuck area while the front door remains closed. Figure 7-2 illustrates this example.



**Figure 7-2 Examples of Bypassing the Machine Tool
Doors for Robot Tending**

High throughput in terms of machine tending can be applied to a number of machines and operations, some of which are shown in Figure 7-3. For instance, the cycle time may be 90 seconds of cutting time per piece, but when the annual production volumes require a work-piece to be machined every 8 seconds then it's easy to start adding up the number of machines required to produce this volume of output from a system that has a 90-second cutting time. The high-volume system example in Figure 7-3 has the following characteristics:

- There are six operations labeled Op 10 through Op 60
- The machining operations are denoted as Op 30 and there are

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- (3) identical systems, each with the same quantity of machines and robots
- Each of the machining cells contains four (4) machines and one (1) robot on a track
- If one cell is down or faulty, the other two are capable of producing parts and the capacity of the line drops by one third
- The robot on a track is capable of keeping up with four machines without becoming a bottleneck. A fifth machine would be difficult to accommodate in the cell
- Twelve machines are required to achieve the required throughput, and the robot can keep up with four (4) machines, so there are three Op 30 machining work-cells

The advantage of this system is that one operator can tend all the machines. The operator's tasks include keeping the inbound queue supplied with raw material and managing removal of finished parts, as well as supporting various inspection duties. The cost of the

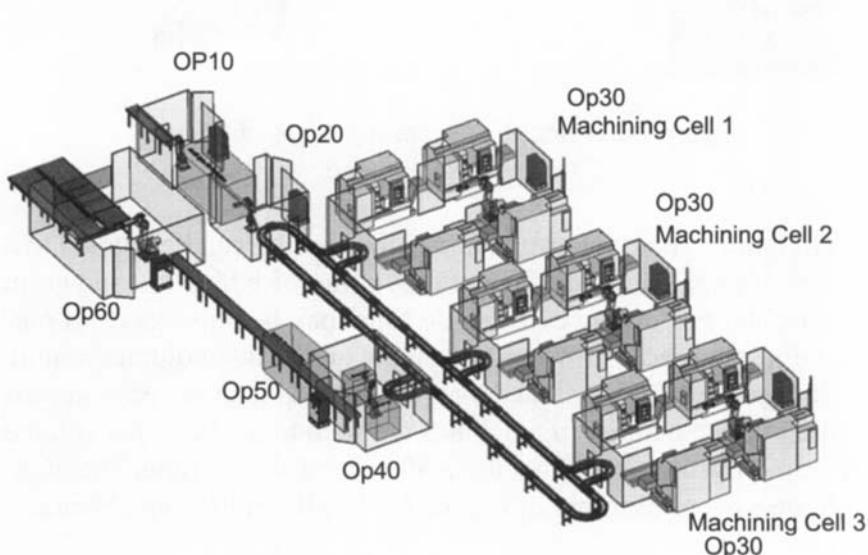


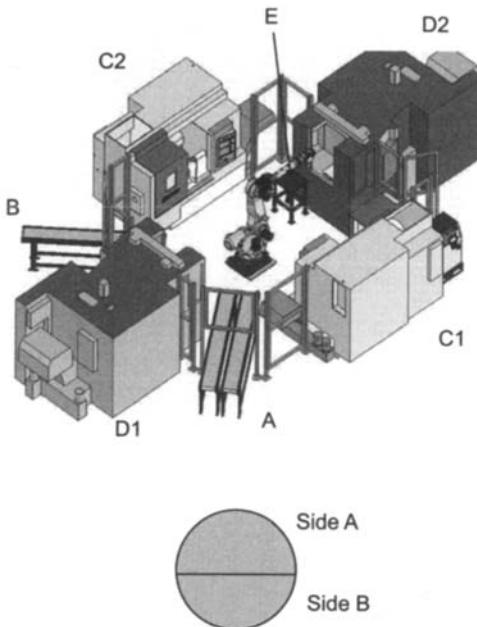
Figure 7-3 Example of a High Volume Robotic Machining System

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automation in a work-cell is spread across the quantity of machines in the work-cell. The more machines that can be serviced by a robot, in addition to performing post process tasks such as deburring, marking, and inspection, the more the ROI is improved. The line in the sand where automation makes a slam dunk argument to be utilized is when the automation cost per spindle hits the \$50,000 mark, or lower. The \$50,000 has a high probability, because a single robot is here being used to service multiple machines with compatible cutting times.

When planning installation of a high throughput work-cell involving machine tools and including post-processing tasks such as gauging or marking, it is best to first gather the information about the required overall throughput of the system with the factored efficiency. For example, consider a throughput expressed as thirty (30) parts per hour at 85 percent efficiency. Then examine the cutting times for each machining process. The slowest machining time in the process is the pace setter. In other words a work-cell could have four machines comprising two CNC lathes and two horizontal machining centers. The cutting time for the CNC lathes is 120 seconds for one piece and 180 seconds for the same piece at the machining centers. The work-cell can't produce any more than two parts every 180 seconds because that is the slowest cutting time or, in other words, the pace setter. Once the throughput of the cell is confirmed, the next question is, "when the robot leaves the pace setting machine, can it accomplish all the tasks necessary including post process tasks and move back to the machining center in 4 minutes". To answer this question it is necessary to track the tasks after the robot leaves the pace setting machine and add up the time for each task until the robot returns to the pace setting machine. If the cumulative time allows the robot to return to the initial step within the 180-second period, then the robot is not a bottleneck in the process. Figure 7-4 illustrates an example of the sequence of operations for a typical robotic machine-tending system.

The benchmark for the machine time is counted as door close to door open for a CNC lathe, or pallet index from side A to side B for a horizontal machining center. It is an important goal of robotic



Sequence of Operations	Time (sec.)
Time (robot just left machine D2 with a complete part)	0
Robot drops off completed part at B	5
Robot moves to A and picks raw part	5
Robot moves to C1	2
Robot unloads complete part and loads raw part	
C1 cycle begins	15
Robot drops part at E, re-orients part and picks it up again	
Robot moves to D1	10
D1 pallet indexes and side A is ready for service, side B is machining	3
Robot unloads completed part and loads raw part at side A	
Robot moves to B and drops off complete part	30
Robot moves to A and picks raw part	4
Robot moves to C2	5
Robot unloads complete part and loads raw part	2
C2 cycle begins	15
Robot drops part at E and re-orients part	
Robot moves to D2	10
Robot is ready to service D2	2
Total time (sec.)	108 sec.

Figure 7-4 Sequence of Operations for a Typical Robotic Machine Tending System

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machine tending to ensure that the machine tool does not have to wait on the robot when its cycle is completed.

Part deburring, marking, gauging, inspection, and washing are just some value-added tasks that can be accomplished within the machining cycle. The investment in the machine tending is justified by the throughput gains and labor savings of the machine tending itself, and performing the value-added components is just gravy for the firm. Most engineers also think about how to utilize the robot beyond just the task of servicing the machine tool. Quality becomes a tangible competitive advantage when the thousands of parts that need to be made right the first time are considered. The cost of human error is amplified when the production volume increases.

Running Lights Out

Lights out means running the robotic system for a period of time without the intervention of a human operator to ensure safe operation of the system. Thus, no in-process inspection, or other manual decision-making can be introduced into the sequence of operations. For example, there can be no part gauging within the machining cycle for checking part dimensions and adjusting program offsets throughout a shift. Another example would be automated weld inspection for the presence of welds and absence of visual defects. An example of lights out production is when the process just takes a long time, such as in welding a very large assembly that takes several hours to weld robotically. Another example is an intensive material removal process such as in polishing an impeller blade for a wind farm. Because of the sheer nature of the “on-process” time, the robot system can run for hours without human intervention. These types of programs are excellent candidates for automation because the amount of daily production time is so high that the firm can exploit the robot efficiency versus manual efficiency. Additionally, major benefits are realized in terms of reduction in labor and more-consistent quality. The setup to present the product to the system is generally easy as well, relative to the amount of processing time. In other words, setup time versus how long the robot runs is a very small amount of time in the big picture of pro-

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duction. Most of the available production time is taken up by the robot performing the work rather than setting up parts or the processing system.

When the process cycle time is in terms of minutes, lights out working becomes more challenging. The challenge to lights out production with shorter cycle time processes is feeding the system and taking away the finished products. One of the goals when examining potential projects for robotic automation is how long it is practical to set up the system for lights out production. The time may be in terms of minutes, hours, or shifts. Decisions have to be made on what is affordable and practical in maximizing the time during which the operator requires intervention with the system. On average, many firms require 30 to 60 minutes of part queue before an operator has to reload the system with raw material. For large batch sizes, the inbound and outbound mechanisms that control material flow into and out of the system are critical because they affect how long the system can run without manual intervention, as well as a significant amount of cost of the system.

Some characteristics that affect how the material transfer is designed for unmanned production, or even a small raw part queue are as follows:

Cycle time of the process. If the cycle time is in terms of seconds, then bulk feeding through bowl feeders or other types of feeding devices should be investigated. If cycle time is in terms of minutes then that changes things a bit and allows more flexibility such as the use of conveyors, or part pallets. On one hand you are dealing with hundreds of pieces and on the other with perhaps dozens.

Part shape, size, and weight. It is not practical to bowl feed some products, so other means such as a conveyor may be necessary to feed the system. The challenge is when the cycle time is in terms of seconds and the part can be practically bulk fed.

If the parts are heavy (exceeding 30 lb. and potentially into 100s of lb.) provisions are usually necessary to manage the size and weight involved. On the flip side, the process time is probably long,

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so fewer of the pieces need to be queued up

Part Orientation requirements. Orientation requirements affect how the work-piece needs to be secured and located for accurate handling by the robot. Complex geometrical parts are a challenge to queue up due to the high costs of fixturing the parts so that the robot can “find” them.

How the parts come from the supplier, and what process is being automated. For example, in palletizing, it is a given that product is almost always conveyed from the upstream packaging area, and the palletizing is often the last sequence of a continuous moving line, so that the queue is built into the overall flow of material. In de-palletizing, the inbound material will be an entire pallet of product, and the robot peels away individual products or layers of product.

For arc welding, more firms are looking at using robots to handle the work-pieces and present them to other robots, but for more conventional welding automation, operators load and unload fixtures. Without the operator loading and unloading fixtures, nothing happens. However, the disparity between robot and manual efficiency in welding is so significant that unmanned production does not need to be justified.

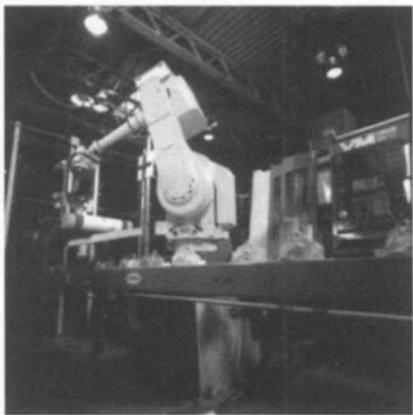
In machining, forming, and other machine-related processes, the chances are always increasing to set up work-cells for extended periods of unmanned (lights out) production. There are certainly the conventional means of conveyors, shuttles, and feeding systems, that require an operator for loading. The implementation of robotic vision has opened a whole new paradigm in staging raw material for extended hours of unmanned production for a broad set of applications

The use of vision for high volume production has decreased the investment cost and in fact simplified the implementation of robotic systems. Figure 7-5 shows examples of how vision has enabled bulk quantities of parts to be staged without the high cost of handling every individual piece. The ‘before’ picture shows a network of

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Asynchronous Conveyor with pallets
"Before" Picture



Belt conveyor with loosely located parts
"After" Picture

Figure 7-5 Paradigm in Part Presentation Implementing Robotic Vision

conveyors with pallets, presenting the casting work-piece to the robot to provide the robot with the ability to pick up the piece repeatedly. The network of conveyors and the control system to manage it, certainly will work well in a lights out environment. The cons in implementing this style of part presentation for this example are cost, floor space, and maintenance. Also, new parts would require a new set of pallets. The ‘after’ picture is the same machining process, but with the conveyor network replaced by a simplified belt conveyor presenting loosely-located castings to the robot.

Robot vision provides the ease of determining part orientation and location without “dedicated” hardware to accomplish the same task. Figure 7-6 implements vision in such a way that lights out manufacturing can be accomplished with little cost and setup. Bulk part presentation through the use of pallets, containers, bins, trays, and conveyor, all with loosely-located parts, allows a large amount of product to be queued up for hours of unmanned production. Using robot vision for work-piece location can provide for considerable unmanned production with accompanying cost savings.

The divider board between the layers of parts shown in Figure 7-6 is also picked up and set aside by the robot.

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Figure 7-6 Vision and Bulk Part Presentation

Ideally, when running large batches, a system can support an hour or longer of unmanned production. If orientation of the piece is required prior to processing, then vision should first be explored because of the ease of use and lower cost than that of dedicated hardware (i.e. “hardware” to capture the raw work-piece, such as transportation (i.e. the conveyor), and bowl feeders (with part escapements). Robots have the ability to handle dividers that separate layers of parts if they are palletized loosely on wooden pallets. Robots can pick from bins, but there is a sacrifice of time while the robot determines the part location and the safest motion into and out of the bin.

The best manufacturing situations consist of many minutes of cutting time. Vision can be used to de-palletize parts from a bin or pick up simple parts that are loosely located on a pallet as shown in Figure 7-6. The unmanned production is then extended into hours of machining time for little extra cost. The difficult situations consist of cycle times in terms of seconds, when part orientation is required. Running a cell unmanned for even 30 minutes can become complex and costly.

Chapter 7

Job Shop vs. OEM

High-volume/low-changeover production for other applications such as welding or material removal certainly needs to be configured to achieve the throughput that best corresponds to customer demand, but with the minimum of fuss in terms of changing fixtures, robot grippers, etc. Where the drive for quick changeover was the last chapter's focus, here the focus is on producing parts in massive quantities, and as a result, time required for part transfer into and out of the work-cell is critical. The emphasis shifts from managing the system recipe so as to set up the system configuration for the next part style, to managing system uptime. Running large batches across multiple shifts requires a different approach in terms of insuring contingencies for downtime. The high-volume system is arranged to execute one procedure (recipe), but the slightest bit of downtime cannot be tolerated. Rarely now will a firm run high-volume production manually, precisely because quality and uptime are not to be achieved across multiple shifts consistently, using manual labor. The process has to be automated.

Below is a comparison of the priorities of the two modes of manufacturing:

High-change/low-volume (Job Shop)	Low-change/high-volume (OEM)
Product identification	Maximize uptime of peripherals
Product qualifying	Design for redundancy
Minimize setup time of peripherals	Use of buffers
Make manual setup easy	Keep process constantly moving
Manage part recipes	Ability to incrementally add capacity quickly
Decision making	Maximize the raw material queue at the inbound
System recipe management	Discharge finished parts quickly as possible

Yes, there is overlap for low changeover or high changeover models in terms of the priorities, especially in maximizing the time the system can run unmanned without operator intervention feed-

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ing, and monitoring the system. However, in one situation the model is designed around the ability to make something new tomorrow, or even every cycle, versus designing for speed to produce one part style as quickly as possible. Another OEM criteria in common with the job shop model is that finished part inventory, and work in process, is a bad thing. These two items represent product that is not making profit for the firm. Both models require flexibility and adaptability in meeting the customer demands, whether it is changes in volume of parts or part styles. Neither model desires a lot of work in process, which drives both models to cellular manufacturing.

Manufacturing cells that are arranged within an organized flow that starts with raw materials from internal/external suppliers, and along the way each cell contributes a little value in producing the end product, is an outcome of lean manufacturing. Each work-cell is balanced relative to the piece per unit of time (i.e. pieces/hour) that matches customer demand. The key with a flexible cell using robotics is that the robot and system will not over-produce and is configured with the efficiency that insures high uptime and asset utilization. Additionally, if the work-cells are designed in a simple, modular configuration like a series of snap-together blocks, capacity can be increased or decreased by adding more blocks. The blocks can represent robot cells. The blocks can also represent components within a work-cell such as robots, and/or machines.

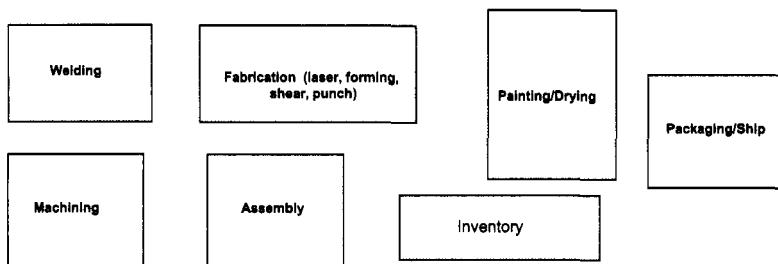
This concept is a key principle in the firm's ability to adapt to short-term fluctuations in customer demand and resulting production volume capacity needs. More equipment can be added when needed or equipment can be redeployed elsewhere, because the system is designed to be easily moved or altered when it contains a set of detachable building blocks. Some people would argue that robots are bad for situations where the capacity fluctuates a lot, because the firm paid for the robot equipment and there are times that the robot will not be working because there are no customer orders. However, it is necessary to look beyond the day that the robot is not working due to there being no demand or orders that the robot is configured to process, because the robot is an operator for 15 years plus.

Chapter 7

Robotic Cellular Manufacturing

One more word about lean manufacturing and how robots complement lean principles for high- and low-volume production, and that is to develop work flow for a constantly-changing environment. Work-flow should be configured so that it can be adapted easily to changes in capacity or product style. Series of work cells should be arranged with minimal and simple material transfer between the work-cells. Think of the work-cells as a series of operations along an assembly line. Allow for the line to accept robots, machines, or whatever peripherals are needed, quickly and effectively, and shun monolithic manufacturing processes or disjointed manufacturing flow.

Figure 7-5a and b contrast bad versus good work flows and illustrate the point of arranging the manufacturing stream into a series of work-cells that pull product from one to the next, starting at the time



- Manual weld booths
- Shears, press brakes manually tended
- Laser has material handling integrated within the laser process
- Plant has dedicated inventory
- Packaging and shipping area all manual
- Painting/drying is accomplished using power free conveyor. Painting is accomplished manually
- Machining, deburring, washing, and part marking all manual
- Manual assembly
- Work in process everywhere using containers to hold parts from one process to another in the machining area
- A lot of work in process stored at every department
- Considerable in-balance from one department to another in terms of capacity planning
- Inventory is costing firm money everyday parts stay in inventory
- Disconnects constantly between departments because of geographic location to each other and different managers not knowing what each other is doing
- Non compliant product is often not detected until assembly
- Constant traffic jams and floor space problems with transporting raw and wip material throughout the manufacturing flow

Figure 7-7a Example of Manufacturing Work Flow Full of Disconnects and Waste

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an order is received.

The manufacturing flow in Figure 7-5b allows for additional lines to be added to feed the main assembly and paint line or for additional cells within a particular commodity flow. There is no limit to how many factories are allowed within a factory or a commodity line that can feed the main assembly line. Cellular means a form of agility because cells can be added or subtracted and grown within the line to adapt to incremental capacity demands. Agile manufacturing is perhaps one more step beyond lean manufacturing because robotic “lights-out” processes are involved. Imagine the contrast between operators required to run the lean system utilizing multiple factory within a factory, or assembly line flow, versus designing for lights out production. A single operator could tend to an entire flow line in producing a commodity versus many operators required formerly. Additionally, the single operator can be performing on-the-fly inspection, resulting in higher quality at the

Multiple manufacturing lines producing a commodity or a set of commodities. Each flow line is a factory within a factory all feeding each other from raw to finish. Nothing happens without the order. The factory could also use the same flow whether the commodities that make up the end product are produced internal or external.

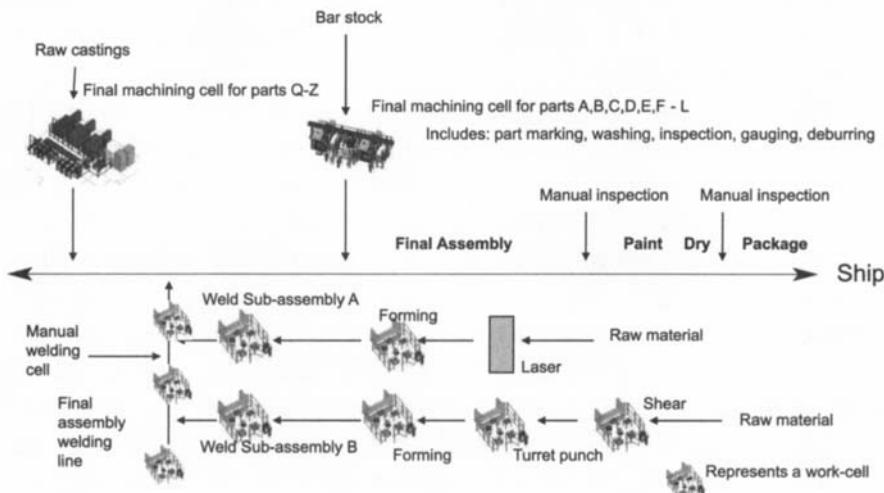


Figure 7-7b Example of Lean Manufacturing Work Flow with Robotics Cells

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source, which is another lean principle. The flexibility of this type of solution can include other forms of automation, or even manual processes for which robotics or automation are not justified, can be planted within the commodity flow line, working in tandem with the robotic cells.

All the work-cells, and the conveyor between the work-cells, are synchronized as a common fine-tuned machine producing to a balanced, customer-driven TAKT time. No inventory or work in process exists, other than the product in the machines themselves. Ability to find problems before they travel way upstream is another major advantage of automation.

Many firms are set up exactly as depicted in Figure 7-5b, and they are the global market leaders for their respective products. Their cost of labor is less than 7 percent of the cost to produce the product, and they are all extremely profitable. Firms that incur less than 10 percent cost of labor in producing their products don't really have to worry very much about low cost labor. Manufacturing with robotics is a step above lean. Lean establishes the methodology and rules for batch-of-one production, or batches of thousands. Agile manufacturing enables a firm to become the low-cost producer period, against any labor rate in the world, especially when factoring quality into the justification equation. Robots also allow a firm to achieve zero defects.

Discussion of some of the tools used in manufacturing that enable the line to be planned for things that go wrong, break down, etc., certainly cannot be an afterthought. The first example is the principle of redundancy. Redundancy ensures that some amount of production can continue whenever a machine or a work-cell is down, for whatever reason. In other words, the firm duplicates the process in the form of an identical process, as in a duplicate work-cell or duplicate machinery within a cell. Basically, redundancy is design for contingencies due to downtime, to make sure that some amount of capacity is operational, based on unpredicted downtime.

Buffers are a way to allow the processes in a manufacturing line, whether it's continuous or pulse style, continue to build product in the event that an adjacent process is down. Imagine a manufactur-

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ing flow line containing ten steps. Raw material is introduced at step one. The material moves from step two to ten and eventually after step ten the product is complete. If step eight goes down for a reason, the last thing you want is for steps one through seven to stop. So the line will continue to build some level of product (buffer) that allows time to get step eight back on line. Or perhaps product is off-loaded from the system at step seven and is completed manually if the downtime at step eight exceeds the buffer time. Essentially, buffers buy the manufacturing line some limited amount of time that allows the rest of the system to process product in a normal fashion until the rest of the line can catch back up.

The Application between high-volume/low-changeover and low-volume/high-changeover

The implementation of a robotic system regardless of the high or low changeover criteria is the same. The basic principles that apply are:

- Work-piece presentation
- Work-piece qualification
- Work-piece work in process
(take work-piece to process or process to work-piece)
- Discharge work-piece

By getting away from “fixed” components that are specifically designed around the characteristics of the work-piece, the user enables the work-cell to be inherently more flexible and accepting of future styles. The best advice is to design for flexibility wherever economically feasible.

The characteristics that enable the robot to be nicely compatible with high-changeover production are as follows:

- Programmability
- Few moving parts (reliability and low maintenance)
- Robot peripheral tools (i.e. vision, sensing, decision making)
- Six-axis dexterity
- Ability to mount the robot in various positions (invert, upright, wall, angle)

Chapter 7

- Broad range of robot styles by size, payload capacity, reach
- Ease of integration to many types of peripheral devices
- Ability to expand the robot reach envelope through overhead or floor transport devices
- Use of little floor space relative to reach as compared to other forms of automation
- Modular and movable
- Re-deployable

We have now reviewed all the reasons why robotics is the ideal operator for a job shop practicing lean manufacturing. The reasons why robotics would not be ideal for high-changeover are as follows:

- Not enough capacity to keep the robot busy, so there is little point in having one
- Too-small batch sizes and high changeover costs exceeding any practical ROI. In other words, the level of flexibility due to the enormous variances in product characteristics result in diminishing returns of the investment to robotize each piece
- An unproven process or a process that is not in control and as a result requires an exorbitant amount of human intervention

On the other hand, when there is a common, almost mundane, sense about the manufacturing stream, then the team has to examine all types of automation and not just robotics. There have been many projects for which robotics simply did not have the best mousetrap, because all that packaged flexibility in the six-axis robot, frankly was overkill. A “hard” or a more-dedicated form of automation makes more sense for a manufacturing process where everything is a constant. For example, welding round seams on a tank may not make sense for a robot system, and in fact, many firms believe that, and they implement a form of “hard automation,” designed to turn the tank and direct the welding torch to the seam, and start the machine. Another example is in the packaging industry, where a continuous line of corrugated containers travels along and packages of “whatever” are inserted into the containers at a high rate. Literally in

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about every application from palletizing, material removal, assembly, machine tending there is a “hard” or dedicated form of automation that is offered as an alternative to a six-axis robot. Again, for some situations these devices are the right approach. Usually the firm’s motivation is price related because dedicated or simpler automation tends to be less expensive. Hard automation devices tend to be less expensive because the firm is not paying for a six-axis manipulator such as the robot. Less axes of motion such as two or three axes may be sufficient for the application.

There are no wrong or right decisions about implementing either style of automation, and in many systems, both styles of automation are included. The implementation of robotics has certainly increased dramatically over the last few years at the expense of “hard” automation for all the aforementioned reasons. Additionally, instead of the robot industry experiencing inflation over the last twenty years, the opposite has happened, which obviously has been beneficial to the firm wanting to automate with robotics.

Chapters 6 and 7 were written to illustrate how robotic automation could be useful to the firm running high-volume or low-volume production, with or without high changeovers. A good plan that identifies risk and benefits as the right way to start implementing a robotic system is reviewed in Chapters 2 through 5. The planning process does not need to be complicated, but should be kept simple, at least for the first system. A project should be selected that will be a sure-fire winner, meaning that the confidence level is high in how the work-piece is produced from start to finish.

The success of the first robotic system will become a paradigm buster in terms of how the firm approaches manufacturing moving forward. In the closing sentence, this book is certainly biased toward the implementation of industrial robotics as a primary contributor to improving US manufacturing. Not every program is compatible, but if the plant lights are on for about 8 hours a day making “something,” then what does it cost to explore the possibilities of increasing productivity and lowering costs through the use of industrial robotic automation. Best of luck and thanks for innovating your business.

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