A Manager's Guide to

INDUSTRIAL ROBOTS

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INTRODUCTION

It is difficult to pick up a periodical or trade journal today that does not contain some reference to industrial robots. In almost every area of manufacturing, robots are being considered for one or more tasks. Industrial robots have appeared on television and have appeared in newspapers and business publications. A good deal of excitement and expectation surrounds the area of industrial robotics today.

The robot industry is one of the fastest growing industries. The capabilities of these machines, the number of units available, the number of manufacturers, and the number of installations are all growing at an astounding pace.

A new industry growing like this is a two-edged sword. While the growth and proliferation of robots provide a great deal of opportunity, they also cause some large scale problems. The manager, whether a manufacturing manager, engineering manager, production supervisor, or the like, is caught in the middle. Upper management sees the robot as a way of substituting magic, dependable machines for difficult to manage personnel. They are sending edicts through the organization to implement the use of industrial robots. Production employees may view the industrial robot as a threat. Since it is a new field of endeavor, it is likely that your engineering staff does not understand industrial robots. And among all of this chaos it is a manager who is responsible for implementing the plans and making things happen, and this manager may not even know what an industrial robot looks like.

Not understanding robots or their implementation is not something to be ashamed of. Robots are a new phenomenon to such a large segment of industry that it is not reasonable to expect managers, especially nontechnical managers, to have a working knowledge of their use.

Having been in that position once myself, I found that there are some very fine publications covering the engineering aspects of industrial robots. The engineering detail of their application and installation is addressed by a number of competent authors, and anyone with an engineering background that is willing to put forth the effort can become familiar with industrial robots.

If you are a manager, however, especially a nontechnical manager, the problem becomes almost insurmountable. The engineering detail is either unintelligible or uninspiring and provides virtually no guidance in handling the manager's problems dealing with robotics.

This book has been written to try to fill this need. Together with my colleagues, I have found some common management problems while installing automation for the first time in over 100 plants during the last few years. We have seen reactions to those installations that both did and did not work. We have seen both inspiring successes and dismal failures. We have found the common mistakes that cause failure and observed the general pattern that insures success. In this book I have attempted to formalize this information and present it to the manager who, for better or worse, must now live in the world of robotics.

An attempt has been made to provide a manual which is as nontechnical as possible. I have assumed no formal technical education or technical background on the part of the reader. Since robots employ technology throughout, however, it is impossible to present them without some reference to the science and engineering of their operation. I have tried to define the technical terms as I proceeded and have supplied a glossary of terms in the simplest possible language in the back of the book.

The industrial world is changing rapidly. Robots seem to be developing a real and permanent place in our factories. I hope this work becomes a survival manual for those managers caught between an ever increasing drive for improved productivity through robotics and a lack of understanding and skills in dealing with the world of robots. By avoiding the mistakes of others and learning from their successes, hopefully even nontechnical managers will regard robots as an opportunity and an asset.

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Chapter One
WHAT IS AN INDUSTRIAL ROBOT?

> **Robot** 1a: a machine that looks like a human being and performs various complex acts (as walking or talking) of a human being; also: a similar but fictional machine whose lack of capacity for human emotions is often emphasized; 2: an automatic apparatus or device that performs functions ordinarily ascribed to human beings or operates with what appears to be almost human intelligence; 3: a mechanism guided by automatic controls.

A friend of mine in the investment banking community spent the better part of a day discussing industrial robots with nontechnical investors. All through this discussion a series of scale models of various industrial robots sat on a desk. As the meeting was breaking up and the conversation turned from industrial robots, one of the visitors picked up one of the scale models, remarked that it was an interesting looking machine tool, and asked what it was.

To the uninitiated the word "robot" conjures up visions of mechanical creatures performing almost human feats. It at least conjures up a creature, like R2D2 from the recent movie *Star Wars*, which stands upright and squeaks in an unintelligible electronic voice. While these fantasy images of mechanical workers in industry have undoubtedly helped popularize the concept of industrial robots, they are unfortunately (or fortunately) not correct.

In an attempt to eliminate some of the confusion surrounding industrial robots, the Robot Institute of America (RIA) decided that a common, agreed upon definition of industrial robots was necessary. Repeated attempts to devise a simple, understandable definition failed before the following, somewhat gingerly worded, definition was adopted:

> A robot is a reprogrammable multifunctional manipulator designed to move material, parts, tools, or specialized devices, through variable programmed motions for the performance of a variety of tasks.

The frustrating part about trying to develop this definition is that by looking at a machine it is quite simple to determine whether or not the machine should be classified as an industrial robot. Attempts, however, to commit this intuitive knowledge to paper in the form of a simple definition were frustrating at best.

The definition finally agreed upon does not, unfortunately, prove very enlightening to the uninitiated. A nontechnical manager who has not been exposed to industrial robots will glean little understanding of their looks or capability or functions from a simple definition. In an attempt to properly understand the function of industrial robots in manufacturing businesses today, it's necessary to go back and try to capture that intuitive sense of which machines are really robots.

Robots in the Work Force

The very first fact which must be understood is that an industrial robot is simply a machine. It is not a highly intelligent, mechanical person but is instead a functional machine tool. Industrial robots are today, and will likely remain for sometime in the future, extremely limited in what they can do when compared to even the most unskilled person. Even though some industrial robots are powered by very complex and capable computers, they still perform a limited sequence of motions.

So again let me repeat: *an industrial robot is a machine tool.* However, comparing its performance to that of a person is a unique attribute of industrial robots and brings us to what I feel is the core of the intuitive definition of an industrial robot. Industrial robots are, by their very nature, direct replacements for human labor. Their job seems to be performing various tasks that normally would be performed by a person and performing them in essentially the same manner that a person would. These statements concerning the purpose of industrial robots conjure up deep, intense fear on the part of those who manufacture robots. They fear that any mention of robots, i.e., mechanical people, might result in a serious backlash by thousands or millions of workers who fear they will be replaced by these mechanical people. These fears might be well founded except for some realities that are not being considered.

The first fact that must be understood takes us back to our number one premise that an industrial robot is nothing more than a specialized machine tool. Because it is a machine, it requires someone to program it and set it up, someone to keep an eye on it while it is running, even if only indirectly, and someone to fix it when it breaks. Each of these jobs requires some level of skill and special training. However, because the robot is a limited machine, it will need to be placed in a highly regimented environment and perform a fairly simple, repetitive, unskilled task. Because the unthinking, untiring industrial robot can perform its tasks consistently and unchanged day after day, it will provide considerable savings over the unskilled labor it replaces. People do not function well in unthinking, repetitive, monotonous, and burdensome tasks. These are in general the only types of jobs industrial robots are capable of performing. It is not surprising then that industrial robots will do a superior job in many of these tasks. At the same time, however, installations of industrial robots open up a number of new, exciting, and challenging jobs where none existed before.

The blue collar workers within the manufacturing sector who will be affected by the introduction of industrial robots are an astute and intelligent group of people. They are quite capable of understanding both the changes and the opportunities that will result from the implementation of industrial robots. They can understand as well as management the true nature of industrial robots and can assess, in most cases quite accurately, the effect industrial robots will have on them individually. The attempt by some manufacturers to call industrial robots by another less threatening name to avoid a problem must be quite insulting to those at whom it is aimed.

If industrial robots effectively and economically can replace unskilled labor, what then is keeping them from putting all unskilled personnel out of work? The answer to this question is quite subtle. However, it can provide valuable insights into the kinds of companies and the kinds of applications in which robots will prevail.

Let's go back to the basic premise that an industrial robot is a machine. As a machine, even though it performs the same task as a person, it is handled quite differently by a business. The cost of a machine is capitalized and then depreciated over a number of years. That depreciation is a very real cost on the profit and loss statement. If the funds to purchase the machine were borrowed, a long-term liability was created which must be repaid. An employee, however, is handled differently. An employee's pay each payday is counted as an expense against the production; however, an employee's future salary is not considered a liability in any form. Should a business find that it no longer needs to produce as much product, it can lay off workers and quickly reduce its costs. With robots in place of those workers, costs continue.

Another way to look at this same concept would be to take an example of a small company which has a task that can be performed by either an unskilled person or an industrial robot. Assume production requirements increase so that 50 additional jobs are created. If those jobs are filled by employees and accounted for in the normal manner, there will be no effect on the company's long-term liabilities, and the soundness of the company's financial statement as determined by the various ratios used by the banking community will not be affected. If, however, 50 industrial robots were installed, a large, inflexible, long-term liability will have been created. The potential for additional profits through lower costs and more consistent output from the industrial robots may be negated by the major negative impact on the financial statements.

Why, then, even consider industrial robots? This question brings us to the basic core of the industrial robot market. Industrial robots should be considered for the same reason that other pieces of automated machinery are considered. When these machines fill a need within a company, are cost justifiable, and provide more return for the available capital than any other, they should be installed.

In the first part of this recommendation, the word "need" was used. The need to use industrial robots will likely increase, possibly at a very fast pace.

About 1960 the growth of the population in the United States peaked and then began to decline. The population as a whole obviously continues to increase, but that increase began to occur at a slower pace after 1960. By 1980 we were to experience some interesting changes in industry. During the 1970s the number of young people entering the work force each year was greater than the year before. With the end of the conflict in Southeast Asia, a large number of available workers returned to the work force, and for the first time women in large numbers also entered the work force. This meant that through the 1970s enough labor was available to increase the total goods and services produced within our country (the GNP) without having to resort to higher productivity methods. Enough labor was available to increase production by simply increasing the number of people producing. In fact, during the late 1970s lower productivity methods were used to the extent that companies substituted labor for capital equipment. The lagging productivity growth figures through the 1970s bear this out.

You can't really blame American industry for taking this route. It is by far the safest and most reasonable method for increasing profits. Increasing production by simply increasing functions within the plant that are already proven, debugged, and to some extent perfected, seems reasonable, especially when compared to developing new techniques and new technology and making major capital commitments to new forms of automation. A large portion of the automation installed throughout the '70s was being installed to take advantage of a potential for increasing profits. Automation was being installed and justified based on the savings available to the manufacturer when compared with other methods. It is interesting to note that in calculating savings and costs of new programs, seldom, if ever, does a company consider the cost of learning to function with the new equipment.

Between 1980 and the end of the century the number of people entering the work force each year will be less than the year before. This being the case, much of the thinking and many of the business techniques for expansion used throughout the '70s will no longer suffice in the '80s. Labor shortages could easily become commonplace. As shortages of special skills develop, manufacturers will be forced to provide training to their employees to develop these skills, moving the general level of competence within the plant to a higher level. The size of the unskilled labor force could easily shrink during this period, putting tremendous pressure on industry to automate. Part of this problem can be alleviated by a relaxation of immigration policies; however, great pressures will develop for the use of industrial robots.

Already today, monotonous, burdensome, repetitive jobs are becoming difficult to fill. Great pressures are being brought on manufacturing to remove people from hazardous spray booths, coating chambers, and so forth. Even unskilled laborers are becoming more selective in the type of jobs they are willing to do. The population trends already established cannot help but make this problem worse.

By reading the popular business periodicals and newspapers and examining comments from political leaders both on state and national levels, the beginning of a ground swell to increase productivity and reindustrialize the nation can be seen. This ground swell is a reaction to problems already being felt which will be a major driving force through the '80s. In light of the above, industrial robots will be a part of virtually every production facility in the country. They will not be replacing workers already on the job; instead, they will provide the future unskilled work force. A realization that this is occurring is commonplace today. This is further evidenced by the number of managers who feel it necessary to learn more about this new, emerging technology. This may be the reason you are reading this right now.

In establishing the concept of an industrial robot, we have already determined that an industrial robot is first and foremost a machine tool. What makes robots unique when compared to other machine tools is that (with apologies to those who fear this part of my definition) they are designed to perform tasks normally performed by a person. This, however, is not quite precise enough, since many pieces of fixed automation rapidly perform tasks that at one time might have been done by hand. As an example, an automatic machine that assembles a ball point pen certainly performs a task normally done by a person; however, few if any would consider such a machine an industrial robot. Therefore, it's necessary to add one additional concept to this definition. The tasks being performed need to be performed in essentially the same manner at essentially the same speed that a person would perform them.

An industrial robot is now being defined to be a piece of machinery that does a job in approximately the same manner as a person does. While it would be easy to point out industrial robots that can lift more, reach farther, or move faster than a person, this definition can provide, in a nontechnical and nonprecise manner, a good guideline as to what an industrial robot really is.

Engineering Principles

Now that you have a conceptual idea of what an industrial robot is and what it does, a common question of the uninitiated is, "What does it look like?"

Industrial robots come in a variety of sizes, shapes, configurations, and complexities. In order to understand this area it is necessary to segment robots into a number of different categories.

Before discussing these categories, it is necessary to understand the meaning of several engineering terms. The first term which must be understood is "axis." You will find that robots are many times specified by the number of degrees of freedom or axes contained. An axis is a degree of freedom or a basic motion allowed by the mechanism. As an example, the bedroom door in your home is considered by engineers as a one axis mechanism. The door is capable of pivoting around a line which goes through the center of the door hinges to which it is mounted. The door's swinging open or shut is the one degree of freedom available. It cannot, however, move up and down, tilt, or move in any other direction other than swinging back and forth around the hinge. Another one axis mechanism would be a child's electric train riding on a track. The only motion available to the train is either forward or backward along the track. Even though the track may curve or go straight at different points, the fact that the train is restricted to simply moving forward or backward and is guided (it cannot move side to side, up and down, etc.) makes it a single axis mechanism. From this you can see that an axis can be both linear like the electric train or rotary like the bedroom door, still restricted to a single degree of freedom. Each independent slide or rotary joint within a robot, then, is referred to as an axis. The electric train can serve as an example to explain the difference between a servo controlled and non-servo controlled axis.

If you had a spot on a long section of straight track at which you wanted to stop the toy train, there would be two different methods which could be used to accomplish this. The first and simplest method would be to find a very heavy obstacle like a concrete block, place it on the track in such a way that when the train is touching it, it is in the desired position. It is then necessary simply to run the train in the proper direction and wait for it to hit the block. Then it is properly located. This system, with a bit more finesse but not much more, is called a non-servo controlled system.

A second way to locate the train at the desired position would be to turn it on and as you watch it near the proper position, use the electric control to slow it down until it is properly located, then turn off the electric control. If you substitute a sensor that can tell how far the train is from the desired stopping point and allow the sensor to operate the electric control in place of the person, you have a servo controlled system. The major advantage of a servo controlled system is that it can stop at any point along the track without having to reposition the block.

Non-Servo Controlled Robots

As you might guess from this, robots are generally separated into either servo or non-servo controlled types. The non-servo controlled robots are generally fitted with mechanical stops and are driven into these end point stops, which define the desired positions. Stops between the end points can be cycled into place to provide intermediate positions other than the end points of the axes. It is, however, apparent that the major disadvantage of a non-servo type industrial robot is the limited number of points at which it can stop. This should not, however, be regarded as a condemnation of this type of machine. A tremendous number of tasks performed within industry can be efficiently and inexpensively handled by this type of simple robot.

Non-servo type robots are generally quite a bit less expensive than their corresponding servo type systems. Many are capable of using much simpler control systems than the electronic computer control found in most of the servo controlled machines. Simple air logic controls or electrical sequencing controls perform quite adequately with the non-servo type robot. These control systems can be obtained at a much lower cost than the servo type control systems.

Electrical sequencing controls come in many different configurations; however, all have one thing in common. They provide a program signal or signals *to* the robot and wait for a signal *from* the robot telling the control that some event has occurred. This event can be something as simple as an arm extension or a clamp closing. Once the signal indicating that the event has occurred is returned to the controller, the controller steps to the next preprogrammed combination of signals which is then sent *to* the robot. Again the controller waits for a signal indicating that the necessary event has occurred, at which time the controller steps to the next set of signals. In this way the programmer sequentially steps through a series of preprogrammed signals with each new step actuated by a signal from the robot indicating that the last step is complete.

Air logic control works very much like the electrical sequencing control except no electrical connections are necessary. All the steps and signals are controlled by the operation of a series of air valves. This type of air logic control has very definite advantages when operating in explosive atmospheres. Since no electrical signals are present, the chance of a spark igniting the environment is reduced.

While non-servo type robots are generally small and designed to handle small parts at high speed, non-servo machines are available which can handle parts weighing in excess of 100 pounds and moving over a fairly large area.

Non-servo type robots can provide surprisingly close accuracies at the end points of their travel. Since they generally operate against fixed, mechanical stops, the end accuracy of the robot is dependent on the mechanical give or stop that has developed in the system. This can be kept to a minimum. Small air operated non-servo robots can easily hold .001" overall accuracies, while .001" to .002" end point accuracies on some of the larger non-servo robots are possible.

Servo Controlled Robots

Servo controlled machines come in many sizes, shapes, and configurations. They are endowed with a variety of working envelopes and weight carrying capabilities. Much of the remainder of this book about industrial robots will direct itself toward these various servo controlled robots.

In general, servo controlled robots are much more capable than the non-servo type robots. They are also more expensive, although in recent times the most expensive non-servo robots and the least expensive servo robots are overlapping in price.

Servo controlled robots are generally controlled utilizing micro electronics and a computer controlled system. These controls provide the robots with a variety of different capabilities which are difficult or impossible to achieve using the non-servo type control. Computers have become a part of many products you use today. Some understanding of their operation is important and will become more important in the next few years. Computers started as large expensive systems, but with increased volume production they came down in price so that even the smallest business could afford them. They are now available for home use, and before long you will find them in most of your home appliances, television sets, automobiles, and the like. Within a few years computers will be a part of almost every aspect of daily life, and those who do not have a knowledge of their operation and basic functions may be considered functional illiterates.

Before you panic, let me assure you that even though computers may be very large and complex their basic operations and functions are extremely simple. The principles behind the operation of a computer are understandable by virtually anyone. You may take some solace in the fact that even those who work with a computer day in and day out, analyzing and programming, do not really understand all the intricacies of its operation.

A computer is essentially nothing but a very large collection of electronic switches. These switches can either be on or off, with one position representing the digit 1 and the other position representing the digit 0. The digits 1 and 0 are called "binary bits." A string of eight of these binary bits is normally called a "byte." These bytes then represent various numbers and letters. Within the computer there is a series of instructions such as "add," "subtract," "compare," and the like. These instructions perform various functions on the strings of binary bits. The computer program is just this sequence of these computer instructions.

In order to provide a useful function the computer must first accept data, compute the data, remember parts of the data that must be retained, and in some way communicate the answer to the operator. In order to perform these functions several additional devices are needed. First, an input device is necessary to feed in initial data. These devices are normally keyboards which look very much like a standard typewriter. As the information is typed in, it is displayed on a small television screen or "CRT." "CRT," by the way, stands for "cathode ray tube." In order to remember various parts of the program, several different types of memory devices are used today. The most common is a small chip called a "RAM" or "random access memory." These RAM chips can be given information which they will retain until they are told to erase it and replace the information with new information. So in essence, a RAM chip is nothing more than a simple scratch pad or blackboard within the computer on which the computer is capable of storing information as necessary. RAM chips, however, have one disadvantage. When power is removed or the computer unplugged, they go blank, or they erase themselves. This type of memory is called "volatile" memory. "Volatile" means that the memory will be lost whenever power is removed from the system. Should the data stored need to be maintained even if the power is turned off, then a type of "non-volatile" memory must be used. There are a number of different types of non-volatile memory in general use today. The first of these is a chip which looks very much like the RAM chip discussed before. This chip, however, is called a "ROM." "ROM" stands for "read only memory." These chips have the information or data permanently built into them, and this information can be read as many times as necessary; however, it cannot be erased and replaced with new data. The data within ROMs is permanent and is installed when the chips are first made.

A variation of the ROM is the "PROM." "PROM" stands for "programmable read only memory." These chips are designed so that data we wish to store can be read into the chips once, at which time it becomes permanent and can no longer be altered or erased. In many control systems the instructions used to operate the machine or operating system are stored in either ROM or PROM.

There are a number of magnetic type devices used to store computer data. The simplest of these is the magnetic tape. This tape, which is essentially the same kind used in audio tapes and 8-track tape players, is used extensively for backing up a system. "Backing up" means storing everything from the system on a reel of magnetic tape which is kept separate from the system. This is done in case