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An Examination of the Labor Time of a Robot Weld Cell

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Abstract

The purpose of this study was to determine the labor time differential, if any, of a robot weld cell as compared to manual welding methods. Also, the variability of labor time differential between part numbers was to be examined.

The results of the study was intended to assist future investment decision makers in maximizing the return on capital expenditures. It was proposed that the labor time differential determined by this study be applied to the future labor and overhead rates in determining the return on investment for a robotic weld cell purchase. The variability of labor time differential between part numbers is intended to provide a sensitivity index for the future investment decision makers.

AN EXAMINATION OF THE LABOR TIME OF A ROBOT WELD CELL

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Chapter 1
INTRODUCTION
Background of the Problem

Industrial robots were defined as automation devices that performed repetitive tasks such as welding, painting, assembly, and machine loading. Companies needed robots to increase productivity in order to compete in the world marketplace. The robots performed the work with less human labor input. However, U.S. industries lagged their Japanese counterparts in the purchase of robotic weld cells by a factor of seven. (Monnin, 1991). In order to maximize profits, every company had to invest its capital resources very wisely. A robot weld cell, costing more than $100,000, had to be carefully analyzed to predict the return on investment.

Abundis (1986) reported on previous efforts to study this problem: "Numerous attempts have been made in the past to accurately assess the cost benefits of having a robot on the shop floor" (p. 17). Previous research studied the performance of robots as compared to humans. A method was developed to estimate the productivity improvement provided by a weld robot cell. Examples of estimating methods are stopwatch studies of existing robotic installations, and predetermined time data analysis.

There were accounts of robot weld cells that provided productivity improvements (labor savings) of 500% or more. (Robot reduces, 1985). Other companies reported savings as low as 30%. (Robotic arc weld, 1986). With such a wide range of claimed savings, it was difficult for a company to assess the financial return of a proposed investment. A midwestern manufacturing firm has provided time study data on an existing robot weld cell which was analyzed for productivity improvement.

Statement of the Problem

This study investigated the labor time of a robot weld cell. The welding operations performed by a robot weld cell were examined to determine the labor time differential, if any, between robot and manual welding methods. Also examined were the variability of labor time differential between part numbers.

Statement of Purpose

The purpose of this study was to determine the labor time differential, if any, of a robot weld cell as compared to manual welding methods. Also, the variability of labor time differential between part numbers was to be examined.

The results of the study was intended to assist future investment decision makers in maximizing the return on capital expenditures. It was proposed that the labor time differential determined by this study be applied to the future labor and overhead rates in determining the return on investment for a robotic weld cell purchase. The variability of labor time differential between part numbers is intended to provide a sensitivity index for the future investment decision makers.

Statement of Need

This study was done to provide data for evaluating future robotic justifications. Manufacturing firms required increases in productivity to remain competitive. A productivity increase provided the opportunity to gain a pricing advantage over competitors. Robotics have been implemented in welding operations to reduce direct labor cost resulting in improved productivity. U.S. industries lagged the Japanese in robotic purchases.

The labor time savings that result from the replacement of manual welding methods with a robot weld cell was the key element in the financial justification of a robotic weld cell. Several methods were analyzed that predict the labor savings from a robot weld cell. There was a wide variation in reported productivity increases resulting from robot weld cells. Additional data was needed for robotic investment decisions.

Statement of Hypothesis

It was hypothesized that there was no difference between the labor time required to produce weldments using a robot weld cell and the labor time required using manual welding methods at a large midwestern manufacturing firm.

Assumptions

The following assumptions were made in pursuit of this study:

1. The weld operations performed by the robot weld cell were typical of those done in industry.

2. The process parameters, such as amperage, wire feed, and travel speed, for both the robot weld cell and the manual weld method were suitable and typical for the operation that was performed.

3. The time values acquired historically from the manufacturing firm were accurate.

4. Both the robot and manual welding methods produce acceptable levels of product quality.

Limitations

This study was limited to the welding operations performed by a robot weld cell, consisting of a General Electric robot model P50 and related equipment, in current use at a large midwestern manufacturing firm. The research was further limited to the welded assemblies that had direct labor time standards established for both robot weld cell and manual weld methods.

Definition of Terms

The following terms were defined to clarify their use in the context of the study:

1. Direct labor: The labor time directly associated with the conversion of raw materials into finished products. (Maynard, 1963).

2. Manual weld method: A welding operation which requires a human to manipulate the electrode, also referred to as semi automatic welding when using a gas shielded metal arc welding process. (Kerns, 1978).

3. Predetermined time standards: Established times for small basic motions, which are used to estimate direct labor time without performing a stopwatch study. (Heizer, and Render, 1991).

4. Productivity: A comparison of input resources as compared to the production output. It is normally expressed as a percentage. (Heizer, and Render, 1991).

5. Robot weld cell: A computer integrated manufacturing unit consisting of a robot, a number of work stations, welding equipment, and the related material transport mechanisms that interconnect them. (Adolfson, et al, 1983), (Mangold, 1989).

6. Standard minutes: The time value, in minutes, assigned to each task element, including factors for operator performance, delays, and personal and fatigue time. (Heizer, and Render, 1991).

7. Stopwatch study: The establishment of the direct labor time required to perform a task by observation and timing of the worker. (Heizer, and Render, 1991).

Chapter 2

THE REVIEW OF LITERATURE

The history of robotics, the use of robots for welding processes and why robots are needed were discussed. Also covered was information on the financial justification of robots, previous research on their performance, and historical data from industrial applications.

History of Robots

The first machines to be considered robots were devices such as the Jacquard loom and the Babbage differential engine in the nineteenth century. An industrial robot, by definition, consists of a manipulator arm with a gripper or tool holder, that can be programmed to repeat a cycle of operations. (Todd, 1986). The loom and the differential engine had their motions controlled by punched cards. (Scott, 1984). The term robot was first used by the playwright Karl Capek, in 1921, to mean forced labor. (Todd).

During World War II, a programmable paint spraying machine, a crude robot, was patented. However, because robots were controlled by numerical data, it wasn't until electronic computers were developed that industrial robots became practical. (Scott, 1984). In 1954, George Devol applied for a patent on the first industrial robot, which consisted of a general purpose manipulator with a playback memory and point to point control. Devol teamed up with Joseph Engelberger, an aerospace engineer, in 1958 to build machines that could be easily taught a new job without physical revisions. (Scott). The patents were sold to a company called Condec, which later became Unimation Inc. The first commercially available robot was marketed in 1973 by Cinncinnati Milacron. (Dorf, 1983). Robot development has continued to progress steadily and now included features such as tactile sensing (touch sensing probes) and machine vision (digitized optical data that the robot controller can process). (Dorf).

Robots and Welding

Welding was one of the early successful applications of robots. (Stonecipher, 1985). Resistance spotwelding was the predominant use for robots in welding. Arc welding was not initially successfully accomplished with robotics because the accuracy required to position the arc was greater than the early robots could obtain. (Stonecipher). Another problem with robotic arc welding was that the weld joint would vary, both in position and in gap size. While a human could adapt the welding parameters, such as travel speed and amperage, a robot would repeat the exact same pattern, creating quality problems. (Groover, Nagel, Odrey, Weiss, 1986). Advances in the numerical controls and electromechanical devices have increased the positional accuracy of robots, which along with improvements in unit part fabrication processes have allowed arc welding to be successfully done with robots. (Groover, et al).

A robot weld cell was a computer integrated manufacturing unit consisting of a robot, a number of work stations, welding equipment, and the related material transport mechanisms that interconnect them. (Adolfson, Blackmon, Park, Tanner, and Topperwein, 1983). The robot, by itself, cannot accomplish a task. The auxiliary equipment allowed the robot to interface with humans and perform useful work. (Stonecipher, 1985).

Need for Robots in Welding

Robots did not entirely replace humans on the job; companies still needed human operators to load raw parts for the robots, unload the finished parts, and monitor the finished quality. (Koop, 1991). Since robots cost more than $100,000, they had to be able to perform the tasks with less human input than manual methods in order to justify the acquisition cost. (Brennan, 1992).

Companies needed to invest in robots to increase productivity and improve competitiveness. Increasing productivity (the production output per cost input) was a way to decrease costs. A lower production cost enhanced a manufacturer's competitive position by providing the opportunity to gain a price advantage over competitors. (Adolfson, Blackmon, Park, Tanner, and Toepperwein, 1983). A price advantage provided increase sales volume or higher per unit profit margin. (Adolfson, et al). Therefore, if robots were justified and purchased, a company could produce its product for less cost, thus increasing profits.

U.S. companies did not pursue robots as aggressively as other nations. U.S. industries purchased only 600 arc weld robot cells in 1990, while Japanese industries procured more than 5500 of these systems. (Monnin, 1991). Even though robots provided increased profits, there were unused opportunities for robotic applications that would have yielded the competitive advantage for companies. Koop (1991) corroborated this position by stating that "Less than 10% of the industrial concerns that could benefit from robots have even one" (p. 32).

Financial Justification of Robots

Because of the high investment level ($100,000 or more), it was important to properly assess the potential financial benefits that a robot was to generate. (Brennan, 1992). An example of this close scrutiny was that a robot investment justification at a midwestern manufacturing firm required a one year payback period to be approved by the financial managers. (Mitchell, 1993). Most companies used cost savings as the primary financial justification for purchasing a robot. (Koop, 1991). Abundis (1986) supported this position: "Most robot applications, when cost justified, are evaluated on the basis of the number of employees directly replaced by the robot" (p.17). Accurately estimating the labor time differential between a robot process and the manual method that it was meant to replace was the key to a financially successful robot implementation. (Mitchell, 1993).

Previous Research on Robotic Time Performance

Previous research was done to quantify the difference in task performance between humans and robots. That study was related to the proposed research in that task performance is a key element in the welding time for both humans and robots. Both robot and manual work methods were studied by Nof and Paul (1979) during the development of predetermined time data for robots. Predetermined time data for manual work, called method time measurement (MTM), was used to evaluate an established task - the assembly of a water pump. An alternative system of predetermined time data, called Robot Time and Motion (RTM), was used to evaluate accomplishing the same task using a robot. A comparison was done on the relative performance of both task methods.

The study examined the assembly of a water pump assembly by both a human operator and a robot . The study showed that the robot took eight times longer than the human to assemble the water pump. (Nof and Paul, 1979). The factors that affected the robot's performance were the lack of finger dexterity, limited part sensing capability, and only having one arm. Nof and Paul stated that proper methods and part design changes would overcome these limitations and result in improved robot performance.

During the study, Nof and Paul (1979) found fundamental differences between the capabilities of humans and robots. There were five major differences between a human operator and a robot in the performance of a task (Nof and Paul):

1. Humans possessed a set of accumulated and unconscious skills.
2. A robots abilities could be optimized for a given task.
3. Robots were unaffected by social and psychological effects.
4. Humans are harder to train and retrain than robots.
5. Robots can be built to have no individual differences.

The study also discovered information about comparative physical abilities of robots. Nof and Paul found out that for very short reach motions, the robot was inefficient when compared to a human. This was due to the slow acceleration and deceleration rates that could be acheived and still maintain accuracy. Another difference in physical attributes was the ability of a robot to accurately and repeatedly manipulate a tool, such as a flame cutting torch, in a absolute path, while the human cannot. There was a grasping motion that the robot could accomplish which was impossible for a human operator. This motion involved grasping an object while simultaneously measuring its width, without the need for special tooling.

The results of the study by Nof and Paul (1979) have also shown that the RTM estimating approach was accurate to within -2% to +3% of actual time, as compared to a stopwatch study. This measure of accuracy was needed to establish the confidence level of the estimating approach. Nof and Paul's RTM data provided a means to evaluate robot task time without physically installing a robot. This allowed a potential robotic application to be evaluated for labor time savings, and hence the financial return on investment. Nof and Paul further stated that RTM could be used to evaluate the performance of different robot models.

Historical Robot Performance Data

The examination of historical data from existing robot weld cells was another way to improve the accuracy of the robot labor time estimates. By examining previous installations, a company can gain insight on the abilities of robots that other companies have experienced. (Hibben, 1993). The review of literature showed a wide variation of reported direct labor time savings. Table 1 listed the labor savings reported by 14 manufacturing firms that implemented robot weld cells. The manufacturer of the robot, if known, was also listed. The savings, normally reported as a percentage of productivity improvement, ranged from 30% to over 500%. The firms were listed in the order of productivity improvement.

Table 1 Range of Productivity Increases Reported

Firm	Make of Robot	Productivity Improvement
Steel Case, Inc.	Unknown	30%
SMT, Inc.	ESAB	40%
Maysteel Corp.	Asea	44%
Litton Automated Systems	Mac	45%
VME Co.	Cybotech	45%
Falk Corp.	Asea	35 - 75%
Holland Hitch Co.	Hitachi	82%
Budd Co.	Unknown	100%
Ransomes, Sims, and Jefferies	Asea	100%
Weightronix	ESAB	100%
GKN Axles	GEC	225%
Toro Co.	Unimate	240%
Feterel Mfg.	GMF	300%
Cybex Co.	General Electric	480 - 660%

Source: Listed in appendix A.

The review of literature has shown the development of robotics and robotic welding. There was a need in industry for robots because of the competitive environment of the world economy. Robots provided a productivity improvement by reducing direct labor. Robots had to be financially justified by estimating the direct labor difference, as compared to manual labor.

There was a study done on robot time performance as compared to humans. The study showed that a robot took eight times longer than a human to assemble a water pump. Historical data was discussed that showed the range of the productivity improvements experienced by companies that have implemented robot weld cells.

Chapter 3

METHODOLOGY

This study used the experimental research method. This method was chosen because the purpose of the research was to determine the relationship of variables - the labor time differential of robot welding as compared to manual welding - for the benefit of future investment decision makers. The causal - comparative research method was deemed unsuitable by the researcher because the reason for the existing differences between the variables could not be determined. The other types of research - descriptive, historical, and correlational - also were not applicable to this study.

Population and Sample Description

The population of the research was all the part numbers that had operations performed by the robot weld cell, with the exception of those that did not have manual welding operation data established. There was a total of 14 part numbers that were welded by the robot weld cell. Of these, only eight had manual welding operation data established. The six part numbers that had no manual data available were not used in this study.

The population size was eight. The sample size used was equal to the population. Due to the population size, a smaller sample size was deemed to be statistically invalid.

Collection of Data

The data was collected from a midwestern manufacturing firm. The firm used an incentive system that required time standards to be set on each operation, of each part number. The time standards were developed by either stopwatch studies or predetermined time data. Each operation was broken down into steps, called work elements, which then were assigned time values. Miscellaneous adjustment factors were added to allow for personal fatigue and job delays. This adjusted time was called standard minutes. Each operations total time was converted arithmetically to standard hours per 100 pieces, also known as the operation standard. An example of a time study form, called a Job Detail and Standard Sheet (JDSS), was shown in appendix B.

Ron Hibben, Industrial Engineer for the donor manufacturing firm, provided assistance in obtaining the Job Detail and Standard Sheets that contained the robotic and manual weld time data. The JDSS's for each part number were analyzed to determine the work content of both robotic and manual welding methods. The time alloted for work elements that were done with one process but not the other was noted. This data was needed to obtain equivalency between the two groups under examination. A listing of the work content, with disallowed elements, was shown in Appendix C.

The reasons for disallowing the work elements were discussed with Ron Hibben. The JDSS for the robotic weld process for part number AR 73982 included several work elements for part measurement. Ron Hibben stated that this work was added after the robot weld cell was implemented, and was measuring a variable not related to the welding process. The JDSS for the robotic weld process for part number AR 73983 had the same part measurement elements, and they were disallowed for the same reason.

The JDSS for the manual weld method of RW 16801 included an element for the grinding of welds. This element was not disallowed, because, according to Ron Hibben, the weld size was not adequately controlled by the manual weld method, but was acceptably controlled with the robot weld process. Mark stamping was an element on the manual weld method for RW 16801 that was disallowed, because this work was done as an operator convenience, and was not related to the weld process. The adjustments made to the manual labor time for part number RW 16802 were made for the same reasons as part number RW 16801.

The manual weld method for part number RW 19218 included elements to position and remove a copper shield. This work was not disallowed, because it was needed with the manual method to protect from weld spatter, but was not needed with the robot weld process because that process is spatter-free. Another disallowed work element was for loosening the door hinge. This work was not associated with the welding process.

The work elements disallowed under the manual weld method for part number RE 24361 were for hole sizing and weld grinding. The hole sizing was done to improve the fit of a bushing. The weld grinding was done for clearance in assembly. An engineering change to the part design during the implementation of the robot weld cell eliminated the need for this element. Part number RE 24361 also had a work element to remove spatter. This work was not disallowed, for the same reason that was outlined under RW 19218.

A recording form was developed for organizing the data. The form, shown in appendix D, had space provided for operational inconsistencies between robotic and manual welding. The data was arithmetically manipulated to provide equivalent operational content between the two processes.

The data was divided into five groups and was listed by part number:

1. The robot weld cell labor time.
2. The robot weld cell labor time, adjusted for disallowed work elements.
3. The manual weld method labor time.
4. The manual weld labor time, adjusted for disallowed work elements.
5. Disallowed labor time.

The adjusted robot weld cell labor time and the adjusted manual weld method labor time were established by either using the JDSS time, expressed in standard hours per 100 pieces, or by subtracting the disallowed work element time from the appropriate JDSS if work content needed to be deleted for equivalency of data. The recording form and the accuracy of the data were validated by Ron Hibben, Industrial Engineer for the donor manufacturing firm.

Analysis of Data

1. For each welded assembly, the productivity change ratio was computed. This ratio was the difference between the manual and robotic labor times compared to the original manual labor time.

Productivity change ratio =

$$\frac{\text{Difference between adjusted manual and robot labor times}}{\text{Adjusted manual labor time}}$$

2. The mean productivity change ratio was calculated.

3. For each welded assembly, the deviation from the mean productivity change was determined by subtracting the individual productivity change ratio from the mean productivity change ratio.

4. The standard deviation for the sample was calculated with the following formula:

$$\text{Standard deviation} = \sqrt{\frac{\Sigma(X - \overline{X})^2}{N}}$$

Where: X = Each part number's productivity change ratio.
$\overline{X}$ = The mean productivity change ratio of the sample.
N = The sample size.

5. The statistical information was listed in tabular form.

Chapter 4

REPORT OF THE FINDINGS

Information About the Study

This study examined the difference in direct labor time between robotic welding and manual welding methods. The robot weld cell chosen for this study was in use for production operations at a midwestern manufacturing company. A floor layout of the robot weld cell was shown in appendix B. Photographs of the robot arm, positioner, and a typical weld fixture were displayed in appendix C.

There were 14 welded assemblies at the manufacturing firm with operations performed by the robot weld cell. Of these, eight weldments were processed with both robotic and manual welding methods.

The manual and robotic welding processes were evaluated for the difference in time performance by the human operator. The data was collected from historical records provided by the midwestern manufacturing company. The data, obtained from time study forms called JDSSs, was analyzed to determine the work content of both robotic and manual welding methods.

The work elements for both weld processes and the unique work elements that are done with one process but not the other was identified and recorded on a data collection form. Ron Hibben (1993), Industrial Engineer for the donor manufacturing company, provided guidance as to which work elements needed to be excluded to obtain equivalency between the two groups under examination. Some elements were not excluded, even though they were unique to one process. The data was adjusted by subtracting the standard minutes required for the disallowed work elements from the appropriate weld process labor time.

A statistical analysis was done to provide the following parameters:

1. The productivity difference of each welded assembly, in the units of standard minutes per piece.

2. The productivity change ratio of each part number, using the manual weld method labor time as the basis.

3. The mean productivity change ratio of the sample.

4. The deviation from the mean productivity change ratio for each welded assembly.

5. The standard deviation for the sample.

Results

The direct labor times for both weld processes were listed in appendix D for each welded assembly. The direct labor times were expressed in standard minutes per piece. The disallowed work content time was listed, along with a brief description of the reason for the exclusion of the work element. The results of the statistical analysis was displayed in table 2. The first column of table 2 listed the part numbers of the sample. The second column listed the labor time for the manual welding method. The manual weld method time was adjusted for disallowed work elements so that equivalency of groups could be obtained. The third column listed the labor time to weld each part number using the robotic process.

<u>Table 2 - Statistical Analysis of Data.</u>

Sample	Adjusted Manual Labor Time (Std. Min. per Pc.)	Adjusted Robot Labor Time (Std. Min. per Pc.)	Manual Minus Robot Time (Std. Min. per Pc.)	Productivity Change Ratio (X) (Std. Min. per Pc.)	Deviation from Mean $(X-\bar{X})$	Deviation from Mean² $(X-\bar{X})^2$
AR84566	1.924	1.695	0.229	0.119	-0.293	0.0856
RW19218	2.59	1.59	1	0.386	-0.0255	0.00065
AR73982	2.293	1.392	0.901	0.393	-0.0187	0.00035
RW16801	3.484	0.994	2.49	0.715	0.303	0.0918
RW16802	3.484	0.994	2.49	0.715	0.303	0.0918
RE24361	6.164	3.37	2.794	0.453	0.0417	0.00174
AR73983	2.293	1.392	0.901	0.393	-0.0187	0.00035
AR84567	1.924	1.695	0.229	<u>0.119</u>	-0.293	<u>0.0856</u>
			Totals -	3.293		0.358
			$\bar{X}$ =	.4116		

As with column two, the robot labor time was adjusted to provide equivalent data. Both the adjusted manual labor time and the robot labor time were expressed in standard minutes per piece.

Column four listed the arithmetical difference between the adjusted manual and robot labor time values. Column five listed the productivity change ratio, in which the difference between the manual and robotic labor times was compared to the original manual labor time. The productivity change ratio was calculated with the following formula:

$$\text{Productivity change ratio} = \frac{\text{Difference between adjusted manual and robot labor times}}{\text{Adjusted manual labor time}}$$

The mean productivity change ratio, $\bar{X}$, is shown at the bottom of column four. This value was the statistical average of the productivity change ratios of the sample. It was calculated to determine the amount on change, on average, that can be expected when a robot weld process is used to replace manual weld methods. The mean productivity change ratio was calculated by summing column four and dividing by eight, the sample size.

The fifth column of table 2 displays the deviation from the mean productivity change ratio of each part number. This is an intermediate step that is necessary to calculate the standard deviation, a measure of the data dispersion. The deviation from the mean productivity change ratio was calculated by subtracting the mean from each part number's productivity change ratio.

The sixth column of table 2 listed the squared deviation from the mean. This is also an intermediate step that is necessary to calculate the standard deviation. The sum of the squared deviations from the mean was shown at the bottom of column six.

The standard deviation of the productivity change ratio between the manual weld methods and the robotic welding process was calculated to determine much variation from the mean productivity change ratio can be expected when manual weld methods are replaced with robot weld processes. The standard deviation was calculated with the following formula:

$$\text{Standard deviation} = \sqrt{\frac{\Sigma(X - \overline{X})^2}{N}}$$

Where: $(X - \overline{X})^2$ is the deviation from mean, squared.
N is the number of samples.

The mean productivity change ratio, as shown in Table 2, was .4116. This value signified that the operation of the robot weld process, on average, required .4116 less labor time produce weldments than the manual weld methods it replaced. The range from the highest productivity change ratio to the lowest was .596. The standard deviation of the productivity change ratios was .2115. Three standard deviations of variation equaled .6345. Plus or minus three standard deviations from the mean productivity change ratio equalled -.2229 to 1.0461. Plus or minus three standard deviations provided the range in which 99.7% of the population fell, providing a measure of the variability of the productivity change ratios.

Part numbers RW16801 and RW16802 each had a productivity change ratio of .715, which were the highest results of the sample. Each of these two assemblies had 2.49 minutes of direct labor reduction from the original labor time of 3.484 minutes, which was a 71.5% improvement in productivity.

Part number RE42361 had the next highest productivity change ratio, .453. This part number had 2.794 minutes of direct labor reduction from the original labor time of 6.164 minutes, which was a 45.3% improvement in productivity.

The next lower productivity change ratios were part numbers AR73982 and AR73983, with .393 each. These part numbers had a direct labor reduction of .901 minutes from the original labor time of 2.293 minutes, which was a 39.3% improvement in productivity.

Part number RW19218 had the next lower productivity change ratio of .386. This part number had a 1.0 minute of direct labor reduction from the original labor time of 2.59 minutes, which was a 38.6% improvement in productivity.

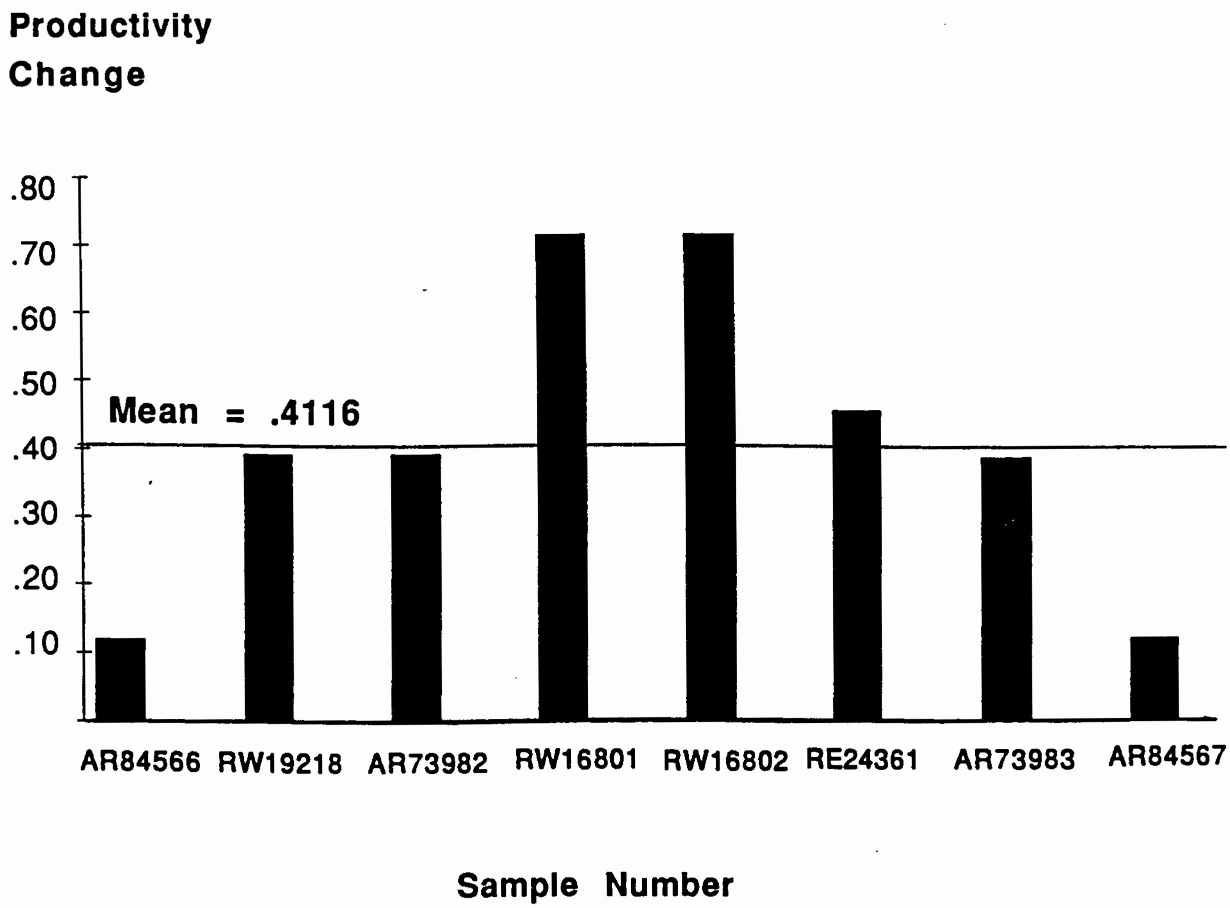
Part numbers AR84566 and AR845677 had the lowest productivity change ratios, .119. These part numbers had direct labor reductions of .229 minutes from the original labor time of 1.924 minutes, which was a 11.9% improvement in productivity.

Only two part numbers (RW16801 and RW16802) had productivity change ratios higher than the mean. These two part numbers represented 25% of the population. The part numbers RW16801 and RW16802 also had the highest deviation from the mean productivity change ratio, .303.

There were six part numbers with productivity change ratios lower than the mean, representing 75% of the population. These part numbers were AR84566, RW19218, AR73982, RE24361, AR73983, and AR84567. Part numbers AR 73982 an AR 73983 had the lowest deviation from the mean, .0187.

A histogram was constructed to display the range of the data and was shown in Figure 1.

Figure 1. Histogram of Productivity change ratios.



Chapter 5

SUMMARY, CONCLUSION, AND RECOMMENDATIONS

Summary

This study was conducted to investigate the labor time differential between robot and manual weld methods. The study results were intended to assist future investment decision makers in maximizing the return on future capital equipment expenditures. Manufacturing firms needed to increase productivity in order to survive in todays world economy. Robotics were used for welding operations as a way to obtain these needed productivity increases. The direct labor savings that result from replacing manual weld methods with a robotic process were the primary financial justification for a robot purchase.

A related study was perused during the the literature search for this project. That research (Nof and Paul, 1979) focused on the task performance of robots as compared to humans, and found that there were major differences between human and robot capabilities. The study also resulted in the development of predetermined time data for robots, called RTM. Historical data was found to show that fourteen manufacturing firms had reported labor savings that resulted from robotic welding installations. The productivity improvements reported ranged from 30% to over 500%.

This research, using the descriptive method, studied a robotic weld cell that is in current use at a midwestern manufacturing firm. All of the weldments that had operations performed by the robot weld cell were examined, with the exception of those that did not have manual welding operations established. The data was collected from time study forms . The work content listed for each method of each welded assembly was analyzed to determine unique work elements. The data was adjusted by subtracting the disallowed work elements to obtain equivalency between the comparison groups. A statistical analysis was performed on the adjusted data to obtain the mean productivity change ratio, and the standard deviation.

The statistical analysis showed that the lowest productivity change ratio that resulted from the change from manual welding methods to a robotic process was +.119. The highest ratio was +.715. The mean productivity change ratio was found to be +.4116. The standard deviation was calculated to be .2115.

Conclusions

It was concluded that because the null hypothesis was rejected by the data from this study, there was a difference between the labor time required to produce weldments using a robot weld cell, as compared to the use of manual welding methods. Furthermore, the data indicated that the robotic welding produced a productivity improvement over manual welding. The productivity improvement allowed more production output per unit of input labor.

The statistical analysis performed on the data suggested that the implementation of a robot weld cell provided a .4116 productivity improvement over manual welding methods. Three standard deviations of variation equals .6345. Therefore, 99.7% of the productivity change ratios resulting from the replacement of manual weld methods with robotic welding could be expected to fall between -.2229 and 1.0461.

The General Electric P-50 robot weld cell examined in this study resulted in a 1.5 year payback period, according to Mitchell (1993). The cost calculation could not be presented in this study for confidentiality reasons. The actual return on investment is below the 1 year payback minimum that was earlier stated by Mitchell, suggesting that the robot would not be economically feasible under the current financial justification guidelines.

Recommendations

The conclusions reached in this study suggest that additional samples of manual and robotic welding be evaluated for productivity change ratio. The wide dispersion of data (three standard deviations equal to .6345) indicates that there is a possibility of a negative productivity change ratio (-.2229), which would result in higher production costs and lower profits for the manufacturing firm. However, there is potential for high productivity improvement (+1.0461), which could provide increased profitability and an improved competitive position for the manufacturing firm. Future investment decision makers should note that the wide dispersion of data indicates a high sensitivity of the return on investment.

The high sensitivity of the productivity change ratio found by this study indicates that further research should be conducted on the correlation between the amount of work content, which may include clamping, non-welding movements, and welding movements, and the productivity change ratio. This correlation information could aid robotic weld cell investment decision makers by allowing them to concentrate on the welding applications that have high return on investment potential.

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Appendix A.

Sources for Table 1.

Company	Source
Budd Co.	Bennington, (1986).
Cybex Corp.	Robot cuts costs, (1986).
Falk Corp.	Robot boost, (1986).
Feterel Mfg.	Arc time increases, (1988).
GKN Axles	Robot welding, (1988).
Holland Hitch Co.	Robotic arc weld, (1984).
Litton Automated Systems	Robot cuts welding, (1987).
Maysteel Corp.	Melton, (1986).
Ransomes, Sims and Jefferies	Welding combine, (1987).
SMT Inc.	Welding robot increase, (1991).
Steelcase, Inc.	Robotic arc welding, (1986).
Toro Co.	Schack, (1985).
VME Co.	Kuvin, (1988).
Weigh-Tronix Co.	Robots lend, (1987).

Appendix B.

Sample JDSS Form.

JOB DETAIL AND STANDARD SHEET (PAGE 1 OF)

Operator JOE   Engineer ANDY

Part No.	Oper. No.	Dept.	Machine No.	Machine Code	Date
SAMPLE	10	200	451		1MAR93

Part Name

Operation Description: MANUAL WELD

D.P.T.	New	Rev.	R.P.	Rck.	Withdrawn Std.	Date

Occ. Code	L. G.	Std. Hrs/100 Pcs.	S. U. Hours	T. O. Hours	W.A.F.

Reason for Change

Remarks:

Cal. Code

Acct. No.

Prod. Code

Card Color

Group

Battery

Crew

Material: Size   Weight   JDM   Part: Size   Weight

* ______ Pcs

Equipment   IDA   TSM

Mach. Work Std.

Op. No.

Part No.

ELE No.	Data Code	Elemental Description	R/MT	Std. Min./Cycle	Occ/Cycle	Observed Time in Decimal Minutes	Avg.	Perf.	Norm.	P & F	Std. Min.	Bound By
1		PLACE PART IN FIXTURE		XX								
2		LOWER HOOD		XX								
3		WELD 1" LONG FILLET		XX								
4		RAISE HOOD		XX								
5		REMOVE PART		XX								

Sketches, Layouts, etc.

Number of Pcs./Cycle ______

Standard "D" Work Minutes ______

Standard "R" Work Minutes ______

Inherent Delay Allowance ______

Total Standard Minutes ______

Total Std. Min. / Pcs./Cycle: XXX × 1.0 (Job Delay) = XXX × 1.667 = Std. Hrs./100 Pcs. XX.XX

NOTE. The approved method is as shown on this form and no change in method may be made by the employee without securing approval of the company as indicated by the issuance of a revision

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Appendix C.

Work Content of Operations.

Legend
Work elements that were disallowed for equivalency of data were marked *.
Work elements that were unequal but allowed were marked **.

AR73982 R. H. Battery box assembly - Manual method

Open manual clamps
Push power clamp release buttons
Hammer and remove weldment
Hang part on paint rack
Load latch part to fixture
Load end plate to fixture
Push buttons to power clamp
Rap with hammer
Close manual clamps
Load end plate to fixture
Index rotation of fixture
Pry side into position
Manual weld
Clean gun nozzle

AR73982 R. H. Battery box assembly - Robot Method

Open manual clamps
Push buttons to open power clamps
Hammer and remove weldment
Load assembly to paint rack
Load latches to fixture
Load end plate to fixture
Push buttons to power clamp
Rap with hammer
Close manual clamps
Load end plate to fixture

Push cycle ready button to robot weld
*	Transfer part to inspection bench
*	Measure width
*	Test weld
*	Enter data onto SPC chart

<u>AR73983 L. H. battery box assembly - Manual method</u>

Open manual clamps
Push power clamp release buttons
Hammer and remove weldment
Hang part on paint rack
Load latch part to fixture
Load end plate to fixture
Push buttons to power clamp
Rap with hammer
Close manual clamps
Load end plate to fixture
Index rotation of fixture
Pry side into position
Manual weld
Clean gun nozzle

<u>AR73983 L. H. Battery box assembly - Robot Method</u>

Open manual clamps
Push buttons to open power clamps
Hammer and remove weldment
Load assembly to paint rack
Load latches to fixture
Load end plate to fixture
Push buttons to power clamp
Rap with hammer
Close manual clamps
Load end plate to fixture
Push cycle ready button to robot weld
*	Transfer part to inspection bench
*	Measure width
*	Test weld

* Enter data onto SPC chart

RW16801 R.H. Rollgard plate assembly - Manual Method

Push Buttons to release power clamps
Unlock and open hinged gates
Unload assembly
Place assembly in basket
Load outer plate to fixture
Load reinforcement to fixture
Load 2 end plates to fixture
Push power clamp buttons
Close hinged gates and lock
Manual Weld
* * Grind Welds
* Stamp

RW16801 R.H. Rollgard plate assembly - Robot Method

Push Buttons to release power clamps
Unlock and open hinged gates
Unload assembly
Place assembly in basket
Load outer plate to fixture
Load reinforcement to fixture
Load 2 end plates to fixture
Push power clamp buttons
Close hinged gates and lock
Push cycle ready button to robot weld

RW16802 L.H. Rollgard plate assembly - Manual Method

Push Buttons to release power clamps
Unlock and open hinged gates
Unload assembly
Place assembly in basket
Load outer plate to fixture
Load reinforcement to fixture
Load 2 end plates to fixture

Push power clamp buttons
Close hinged gates and lock
Manual Weld
* * Grind Welds
* Stamp

RW16802 L.H. Rollgard plate assembly - Robot Method

Push Buttons to release power clamps
Unlock and open hinged gates
Unload assembly
Place assembly in basket
Load outer plate to fixture
Load reinforcement to fixture
Load 2 end plates to fixture
Push power clamp buttons
Close hinged gates and lock
Push cycle ready button to robot weld

AR 84566 R.H. Mounting Bracket - Manual Method

Pull locating pins
Open manual clamps
Unload assembly from fixture station 2
Place in basket
Transfer assembly from station 1 to station 2
Load hex nuts to station 1
Load bracket to station 1
Push locating pin
Clamp
Manual weld

AR 84566 R.H. Mounting Bracket - Robot Method

Unscrew locating pins
Unclamp
Unload assembly

Place in basket
Load bracket to fixture
Clamp
Load hex nuts to threaded pins
Push cycle ready button to robot weld

AR 84567 L.H. Mounting Bracket - Manual Method

Pull locating pins
Open manual clamps
Unload assembly from fixture station 2
Place in basket
Transfer assembly from station 1 to station 2
Load hex nuts to station 1
Load bracket to station 1
Push locating pin
Clamp
Manual weld

AR 84567 L.H. Mounting Bracket - Robot Method

Unscrew locating pins
Unclamp
Unload assembly
Place in basket
Load bracket to fixture
Clamp
Load hex nuts to threaded pins
Push cycle ready button to robot weld

AR19218 Service access door - Manual method

Unclamp
* * Remove copper shield
Unload assembly from fixture
* Place assembly on bench
* Wiggle hinge 3 times to loosen
* Grind clearance for seal
Place in basket

Load door panel into fixture
Clamp
Load hinge into fixture
Clamp
Load latch bracket into fixture
Clamp
Load brace
* * Position copper spatter shield
manual weld

RW19218 Service access door - Robot method

Unclamp
Unload assembly from fixture
Place in basket
Load door panel into fixture
Clamp
Load hinge into fixture
Clamp
Load latch bracket into fixture
Clamp
Load brace
Clamp
Push cycle ready button to robot weld
* Preposition door panels next to fixture

RE24361 Control Support Assembly - Manual weld Method

* * Scrape Spatter with blade
* Ream hole to size
* Grind weld for clearance
Load assembly to paint rack
Procure tack welded assembly from conveyor
* * Place on bench
Assemble rubber sleeves
Assemble capscrews
Manual weld

RE24361 Control Support Assembly - Robot weld Method

* * Push buttons to release power clamps
* * Unload assembly from fixture
Load assembly to paint rack
Procure tack welded assembly from conveyor
* * Load to fixture
* * Push buttons to activate power clamps
Assemble rubber sleeves
Assemble capscrews
Push cycle start button to robot weld

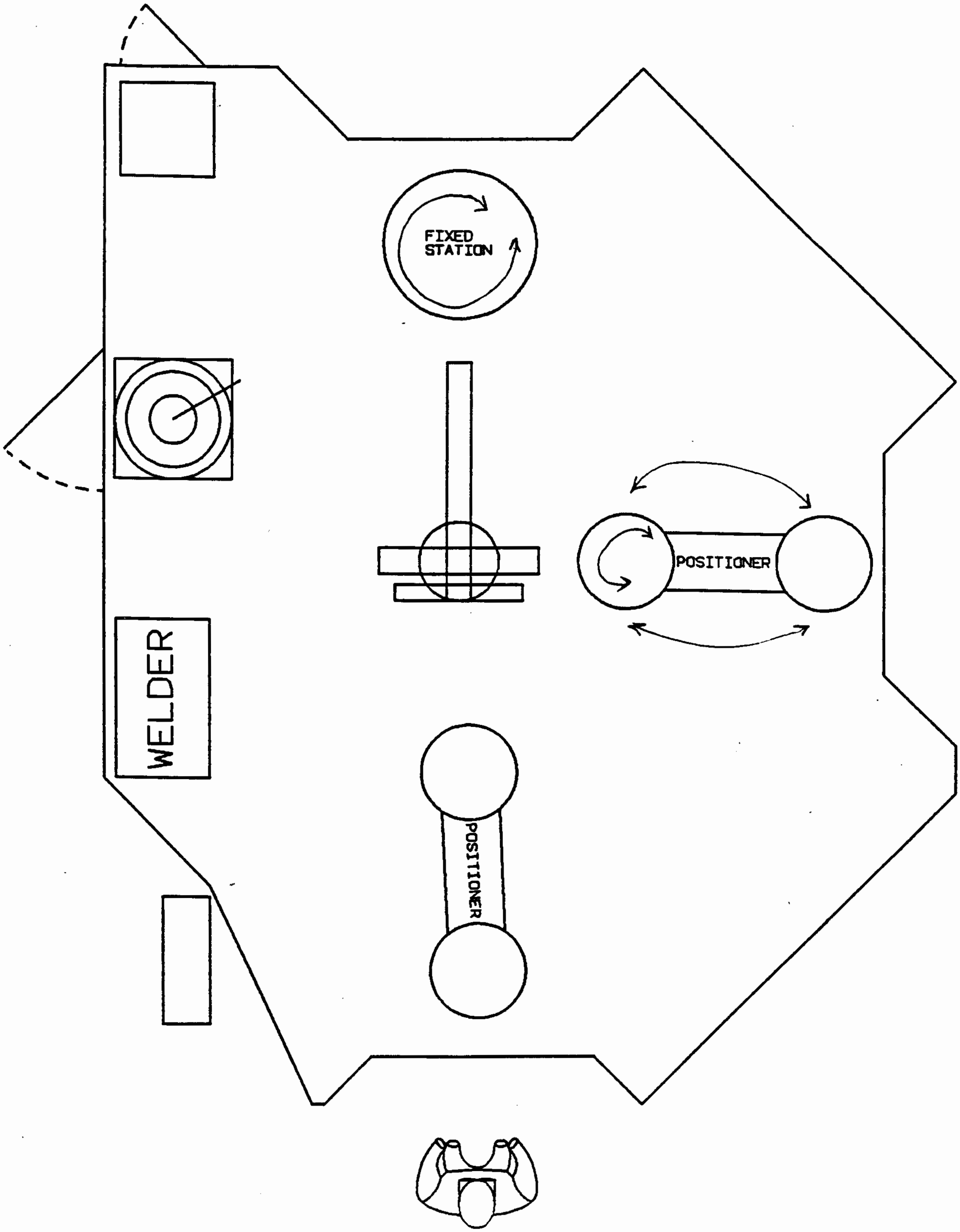
Appendix D.

Recording Form.

Part Number	Manual Weld Time Std. Min./Pc	Robot Weld Time Std. Min./Pc	Disallowed time Std. Min./Pc	Reason for Disallowment
AR 73982	2.293	1.5 Adjusted 1.392	0.108	Inspection work added after manual operation was discontinued
AR 73983	2.293	1.5 Adjusted1.392	0.108	Inspection work added after manual operation was discontinued
RW16801	3.571 Adjusted 3.484	0.994	0.087	Mark stamping Eliminated as unneeded work
RW16802	3.571 Adjusted 3.484	0.994	0.087	Mark stamping Eliminated as unneeded work
Ar 84566	1.924	1.695	0	
Ar 84567	1.924	1.695	0	
RW 19218	2.615 Adjusted 2.59	1.59	0.025	Hinge movement eliminated due to Improved raw material
RE 24361	6.39 Adjusted 6.164	3.37	0.226	Hole reaming eliminated due to change in raw material

Appendix E.

Floor Layout for Robot Weld Cell.



Appendix F.

Photographs of Robot Weld Cell.

Robot Arm

Positioner with Fixture