

ECONOMIC ANALYSIS AND JUSTIFICATION FOR AUTOMATED WELDING SYSTEMS

A Senior Project submitted

In Partial Fulfillment

of the Requirements for the Degree of

Bachelor of Science in Manufacturing Engineering

California Polytechnic State University,

San Luis Obispo

by

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June 2015

Graded by: _____ Date of Submission: _____

Checked by: _____ Approved by: _____

Abstract

Economic Analysis and Justification for Automated Welding Systems

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This report looks at designing a new welding process for a company in the Oil & Gas industry, ensuring method consistency and performance quality of their steel drill bit while increasing overall production. The current product is welded manually with a flux core wire, resulting in high cycle times and numerous cases of required rework.

The use of automation systems will be analyzed for their increased consistency, quality, safety, and production estimates. Specifically robotic cell design will be considered, since it can work on more parts with fewer operators, adding efficiency and flexibility to the production floor. Other areas of researched covered in this report include welding parameters and methods, fixture use in relation to automation, preheating and material properties of steel, and investment justification of automated systems.

The design will be modeled and simulated in a 3D environment, and analyzed with economic considerations in the form of payback period and return on investment. All calculations, given values and assumed values will be stated and explained. Results include an estimated payback period of 2.14 years, a 34% ROI, and savings of \$ 13,140.00 per year from the robot alone, with capacity for additional savings analysis based on use of the design.

Recommendations to go forward with prototype testing on actual weld quality and efficiency improvements as well as cell design finalization.

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Introduction

This report will describe the justification of using automated systems for welding by comparing the manual and automated setups of a steel pipe welding operation. Automated systems for welding processes, specifically those utilizing industrial robotics, are increasingly common in manufacturing environments as they offer increased production, consistency, and quality while decreasing labor costs, re-work, and human exposure to hazardous environments. Industries experiencing major growth, such as the Oil & Gas industry in the United States, are starting to utilize automation for simple or hazardous tasks; however it is important to analyze the each operation individually to mesh production styles and successfully integrate an automated system. This project aims to design an automated welding production cell and prove its economic advantage over a manual set up.

The defined problem will assess the welding operation of a steel drill bit used by a large company in the oil and gas industry, who need to ensure method consistency and performance quality. To consider automation for this process, the following objectives must be completed:

- Analyze the current process and its associated costs.
- Consider welding techniques and fixtures for the material and quality requirements.
- Design an automation setup of the welding operation and analyze its associated costs.

These objectives will be achieved by implementing the engineering knowledge and skills learned from research and the curricula for the Bachelor of Science in Manufacturing Engineering provided by California Polytechnic State University in San Luis Obispo, CA. Tools and knowledge that will be applied include: automation of industrial systems, material joining by welding, engineering economics, and lean manufacturing.

Background

The Oil & Gas industry is one of the largest and most powerful industries in the world. Fossil fuels, which include oil, coal, and natural gas, are refined into fuel to provide electricity, heating, and transportation. In recent years, technological innovation in the form of horizontal drilling and hydraulic fracturing has dramatically increased energy reserves in the United States. Fracking involves water, sand, and chemical fluids being injected underground at pressure to fracture the shale rock and release gas and oil. In 2006, 1 trillion cubic feet (tcf) of shale gas was produced in the United States; by 2010 it had increased to 4.8 tcf with the increased use of fracking (Dunn & McClelland, 2015). This rapid expansion of available resources has generated growth in nearly all sectors of the Oil & Gas industry and in October 2013, the United States domestic oil production exceeded crude oil imports for the first time since 1995 (Utech, 2013).

To keep up with this growth, companies are looking for ways to increase and streamline production. This project looks at improving the manufacturing process for a steel bit used in drilling for oil and gas, justifying the chosen method, and economically analyzing the process. Currently the product is manually welded using flux-core arch welding (FCAW) and rotated in a lathe chuck. The product use two different steel alloys for mechanical strength and must be preheated with a gas torch to avoid cracks in the weld. The difficulty with flux core wire is that each pass must be cleaned to remove slag build up, extending the time needed for the process and increasing the possibility of defects if the steel temperature drops too low or slag build up is missed. Automation is an ideal way to improve the process and involves changing the welding parameters, preheating operation, and fixtures; however it also requires a significant financial investment. The following literature review will look into key concepts related to developing and justifying an automated process.

Literature Review

Automation

As defined by the International Organization for Standardization (ISO), specifically ISO 8373, an industrial robot is “an automatically controlled, reprogrammable, multipurpose manipulator, programmable in three or more axes. The field of robotics may be more practically defined as the study, design and use of robot systems for manufacturing” (ISO, 1994). Robot systems can also include any devices required for the robot to perform tasks, or sensors for sequencing and monitoring communication interfaces.

In 1954 George C. Devol revolutionized the industrial robotics world with his mechanical arm, Unimate. It relied on digital control, magnetic drum memory, and solid-state control components, making it the first digitally operated and programmable robot. A General Motors plant in Trenton, New Jersey, was the first to install one of these robots in 1961, using it to assist a hot die-casting machine (Malone, 2011). Modern day industrial robots are generally used to perform unsafe, hazardous, highly repetitive tasks. They have a huge range of functions such as material handling, assembly, arc welding, resistance welding, machine tool loading and unloading, painting, and spraying; and are used in nearly every industry. Outside of manufacturing plants, robots are used for anything from care of the disabled to space and deep sea exploration. An important argument to consider is that robots do not have to directly remove labor. Implemented correctly, workers of the old process would be assigned new tasks such as a different process, quality inspection, supervision, support technician work, and similar changes.

Looking specifically at welding robots, automated welding systems have the potential to increase productivity by increasing speed while decreasing scrap and rework rates, improve visual and mechanical weld quality, reduce labor and materials costs, mitigate the welder

shortage, and increase a company's overall profitability (Summers & Stevens, 2008). The potential downsides to the system include that shop-floor personnel must be able to provide the robot with a consistent supply of material and work to perform. Since the efficiency of a robot far exceeds that of a human worker, increased production may accumulate in another part of the plant, shifting the bottleneck and not truly improving productivity.

When looking at automation options there are two basic types for welding systems: robotic and fixed. Robotic systems are more expensive and more complicated than fixed automation systems, but they can be reprogrammed to accommodate different product lines which can prevent shifted bottlenecks. Fixed automation systems usually involve the welding gun or the part is fixed in place, making it a single setup operation. A product that requires only straight or curved welds along a single plane is usually a good candidate for a fixed automation system, while complicated and multiple path welds are best under a robotic system.

Welding

The use of welding robots has become a common means of industrial automation for manufacturers of steel products. Shown alongside other operations in Appendix A, manual welding operations have an efficiency of roughly 20-30% while an automated welding process has an efficiency of 90% or higher. The increase comes from more control and consistency in the wire feed rate, pulse waveform, and arc stability combined with robotic movement within a single tightly integrated system (Groover, 2007). Other parameters of the arc process include: peak current, base current, arc voltage, pulse mode, and pulse frequency ("Automated MIG Welding of Aluminum," 2004). Some of these parameters are set within the welding equipment while others are dependent on the welder's skill and repeatability. Typical weld joint variations can be seen in Figure 1 below (Kou, 2003).

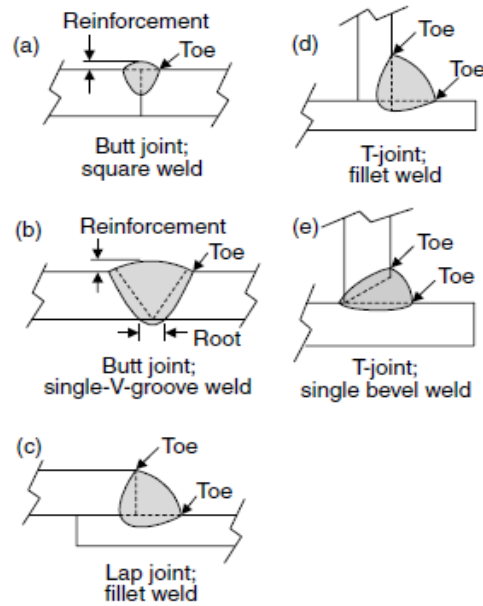


Figure 1 Typical Weld Joint Variations

There are three major types of fusion welding processes as follows: gas welding, arc welding, and high-energy beam welding. Gas-metal arc welding (GMAW) is the most widely used arc welding process, especially for aluminum alloys, and uses an electric arc established between a continuously fed filler wire electrode, and the metal work piece. Shielding the arc and the molten weld pool is often done with inert gases such as argon and helium. Flux-core arc welding (FCAW) is similar to GMAW, but the electrode is a metal tube with flux wrapped inside. The functions of the flux include protecting the molten metal from air and allow the use of additional shielding gas to be optional. The downside is the molten flux floats to the weld pool surface and solidifies into a slag layer which must be cleaned off (Kou, 2003). Comparatively GMAW is a more economic process because it has higher speeds, higher deposition rates, few to zero stops to change electrodes, and needs minimal post weld cleaning. The electrode wire is fed automatically and a self-adjustment mechanism maintains the arc length. These advantages make the process very well suited to being automated, particularly to robotic welding systems (Pires, Loureiro, & Bölmsjö, 2006).

When considering weld quality outside of weld parameters, cracking from improper temperature levels and potential warping from the heat affected zone (HAZ) are mainly material dependent. High carbon steel, for example, has a tendency to form martensite (a hard crystalline structure) in the HAZ and therefore create hydrogen cracking. A hydrogen crack occurs when a hard microstructure (in this case martensite) cools too quickly from around 800°C to 500°C. Cooling can be slowed down by applying preheat, maintaining a high weld inter-pass temperature, increasing welding power and reducing travel speed (Economic Commission for Europe, 2001). In order to determine what preheating level is needed for a given carbon content, the following equation is used (Yurioka & Kasuya, 1995):

$$CE(IIW) = C + Mn/6 + (Cu + Ni)/15 + (Cr + Mo + V)/5 \text{ [wt\%]}$$

Preheating is commonly done by a gas flame, usually a hand torch or furnace. Open flames however, have a very inefficient energy use to heat input ratio. A more efficient option is electromagnetic induction, or simple “induction,” which is a method of heating electrically conductive materials. Considering the diagram in Appendix B, induction uses alternating electrical currents to internally move through the material to be heated (Zinn & Semiatin, 1988).

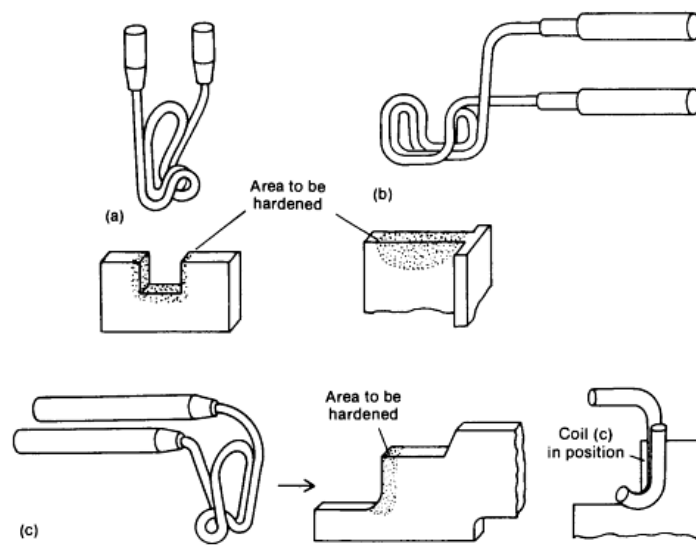


Figure 2 Induction Coil Shape Variations

The coils can be bent and turned into a variety of shapes as seen in Figure 2, as long as the metal being heated is between them. This offers a new flexibility to heating specific zones of a material for various operations.

Fixtures and Future Trends

The use of fixtures is very important when working with automation and robotics; the program will run to the exact same location every time therefore it is important for the part and work piece to also be in the exact same place each time. In short a fixture provides proper position and rigidity of work piece for ease and safety of operation. There are three main structural components in a fixture: a locator, clamp and support. A locator is generally an immobile unit, such as a pin or surface, which constrains freedom of movement. Clamps constitute the mobile part of fixture and apply forces to grab the work piece. Support is mostly stable, holding and facilitating the work piece to maintain its geometry under thermal stresses (Vural, Muzafferiglu, & Tapici, 2007). A well designed fixture will reduce the amount of distortions by accounting for welding forces, thermal expansions, and position consistency. As part of position consistency, the fixture should account for movements of the work piece, such as rotations on any axis, so that the entire operation can be performed in with ideally a single set up.

One of the most time consuming components of creating a robotic welding system is programming each new weld that needs to be performed and determining how that plays into external features such as preheating operations and fixture choice. Recently, research studies have focused on the increased use of sophisticated 3D CAD/CAM systems and combining them with robot simulation systems. One such method is case-based reasoning (CBR); a memory based system that reflects how humans remember old problems and solutions and use them as a

starting point for solving a new problem. Aamodt and Plaza's classic model of the problem solving cycle in CBR had four main modules (Wang & Rong, 2008):

- Retrieve: Given a target problem, retrieve relevant cases from memory to solve it. A case consists of a problem, its solution, and annotations about how the solution was derived.
- Reuse: Compare the solution from the previous case to the target problem and adapt the solution as needed to fit the new situation.
- Revise: Test the new solution in the real world (or a simulation) and, if necessary, revise.
- Retain: Store the resulting experience as a new case in memory.

Using a system such as CBR would allow companies to generate welding parameters, cell set ups, and fixture choices for new products based on ones they, or others, have previously devised and found successful. By increasing the number of products a robotic system can work on, production can increase across operations, instead of in just one area, creating a more flexible and economically beneficial system.

Return On Investment

A major part of justifying an automated system, or any new process, is the calculation of the potential economic benefits. The two main measures of how well a system will benefit a company are the payback period and the return on investment percentage (ROI). The payback period is a measure of time, usually month or years, for how long it will take for the system to generate enough savings to overcome the investment costs. Factors that go into the calculation include: direct wages saved by removing labor, savings from robot such as scrap or energy use, depreciation of value, new maintenance costs, and new staff and supplies costs. For welding operations specifically, payback starts with determining the current product cycle times and comparing those values to the cycle times an automated system can achieve. Since automated

systems can produce parts in roughly a quarter of the time manual welding can, lost time costs are greatly reduced. Approximately 70% of a welding operation's costs are for labor since manual work includes weld time, rework, injury compensation, slower cycle times, and more material waste (Summers & Stevens, 2008).

Payback period is just one measure of ROI, a full ROI consideration takes into account the lifespan of the system, inflation and deflation rates, future value of money and more. A positive ROI shows that the investment generates successful gains over the costs. Factors such as reduced labor, inventory, and operating cost are generally easy to calculate and consider, but more complex considerations that are harder to measure, such as capabilities return on investment (CROI) and total cost of ownership (TCO), are equally important to a company (Beretta, 2015). CROI looks at the economic value of being innovative, that is are there opportunities in marketing, award recognition, or employee inspiration that could also benefit the company. TCO looks in depth at accounting for all direct and indirect costs, including possible ecological and social costs that might be associated with implementing the system. These risks and more are just as important to consider as direct investment costs. One example is to consider the constant increase of labor costs alongside the decreased cost of technology over time. A graph representing these trends in relation to robot prices can be seen in Appendix C.

Ron Potter of Factory Automation Systems in Atlanta, Georgia, explains “Justification should be a strategic decision made by informed management that balances short-term goals of survival with longer-term goals of growth, to posture the company to have competitive advantage. It should not be relegated to an accounting function without foresight of long-term strategy” (Beretta, 2015). Looking purely at the “headcount” of labor reduction an automated system will reduce will fail most project proposals, there needs to be a more positive attributes

that can be applied. Employee mentality and acceptance is another risk that is hard to measure, but the culture and atmosphere of a work environment is extremely important for a prosperous company.

Design

For this design, the company has asked that the new welding process for their steel drill product ensures method consistency and performance quality while increasing production. There are multiple ways to consider and potentially improve the process, such as applying lean principles to worker operations, however to increase production by a significant amount, the process as a whole will need to be adjusted. For this design, the mechanical weld properties will be looked at as well as the option of automation, as a method for increasing production.

To better understand what changes need to be made, the following is an outline of the current set up. The product being analyzed consists of two different steel alloy pipes, 4140 and 8620, which are screwed together and have a diameter of about 8 inches, but changes depending on the various product models. The part is loaded into a lathe chuck and able to support its own weight without additional fixtures. It is slowly rotated while the operator preheats the weld groove with a gas flame torch. Once heated to 500°F (260°C), the rotation is slowed and continued manually by the operator, who welds the V groove where the two steels meet with a flux core wire for four passes. Between each pass, the slag must be cleaned from the weld and the part reheated to temperature before the next pass can begin. The overall cycle time is 50 minutes, and any rework that needs to happen due to quality issues, takes the welder 1 hour. Additional variables and costs provided by the company can be seen in Table 1 below, these include the available work hours, current production, worker pay rates, and estimated training costs associated with moving to an automated robotic system.

Table 1 Given Variables and Costs

Given Variables		Given Costs	
Shift length	8 hours	Operator	\$ 34.00 /hour
Days worked	5 /week	Robot Work	\$ 0.40 /hour
Weeks worked	50 /year	Maintenance staff	\$ 40.00 /hour
Available hours	4000	Current Staff Training	\$ 5,000.00 one time
Current cycle time	0.83 hours	Continued Education	\$ 2,000.00 yearly
Current Production	4100 units/year	Maintenance Training	\$ 2,500.00 one time
Target Payback	2 years		
Robot life	8 years		

Any design generated is required to overcome the costs given as well as any costs associated with that new design. Beyond the investment cost of the physical system, implementing an automation process requires initial and continued staff training, as well as hiring new staff specialized in that field. To avoid some of these costs, one initial design idea was to simply have the welding operator use a non-flux wire to remove the need for cleaning between passes and increase the overall cycle time. While it increases efficiency, this method does not meet the requirements of consistent method and performance quality due to the natural variation of a human operator. Even at a highly skilled level, each weld will be unique in position, speed, and angle which could lead to quality issues and is hard to troubleshoot. The only way to truly ensure method and quality would be to automate the system.

When considering automation, fixed and robotic systems are the two main options. Since the operation is fairly simple (the weld torch stays in same position for nearly the entire weld), a fixed option seems ideal. While it certainly would ensure method and quality, the production levels would only increase for that one operation. With the increased speed of production, any automated system used will be left with time to spare in the work day and to run it all day would

risk an inventory backlog. To meet this new dilemma, a flexible system is more appropriate and would allow multiple products to be worked on throughout the day. Only a robotic system, with a multi-axis design, can offer a heightened level of flexibility and will be the system looked at for this design.

With the automation choice determined, the next design steps need to look at the process layout and details. Design options will be modeled in simulation software called WeldPro, provided by FANUC Robotics alongside Lincoln Electric welding. Where possible, pre-built or off the shelf parts will be used. This decision is justified by the fact that a fully custom set up is much more expensive on a monetary level, increases the time frame to implement the system, and requires additional testing before operations can begin. The same rules govern the new fixture design and preheating methods needed to assist the new system. The ideal layout will follow lean principles, by not wasting space or movement, and will allow for quick set up changes to match the flexible capabilities of the robotic welder.

Assumed variables and costs based off previously given variables and costs, general company information, and industry accepted estimates can be seen below in Table 2. The values take into consideration both manual and robotic processes.

Table 2 Assumed Variables and Costs

Assumed Variables		Assumed Costs	
Operators	2 /shift	Robot System Cost	\$ 250,000
Shifts	2 /day	Robot Upkeep	\$ 500 yearly
Manual Efficiency	0.3	Daily Labor Cost	\$ 1,088
Robot Efficiency	0.95	Annual Labor Cost	\$ 272,000
Time decrease	1400 hours	Daily Robot Cost	\$ 6.40
Manual Scrap Rate	0.05 /hour = \$6,800.00 /year	Annual Robot Cost	\$ 2,100
Robot Scrap Rate	0.01 /hour = \$1,360.00 /year		

Methods

Taking into consideration all areas of research and the design considerations, the following cell layout and process for the welding operation was developed. Below, Figure 2 shows the modeled setup, a larger version can be viewed in Appendix D. The design uses a six axis FANUC robot with Lincoln Electric welding capabilities. Wire type, welding method, and torch shape are interchangeable within the system through programming and accessories. For this simulated setup, a standard MIG operation using non-flux, solid wire will be used. The robotic arm has a large movement envelop allowing it to reach forward to weld the parts as well as retract far enough to avoid collisions.

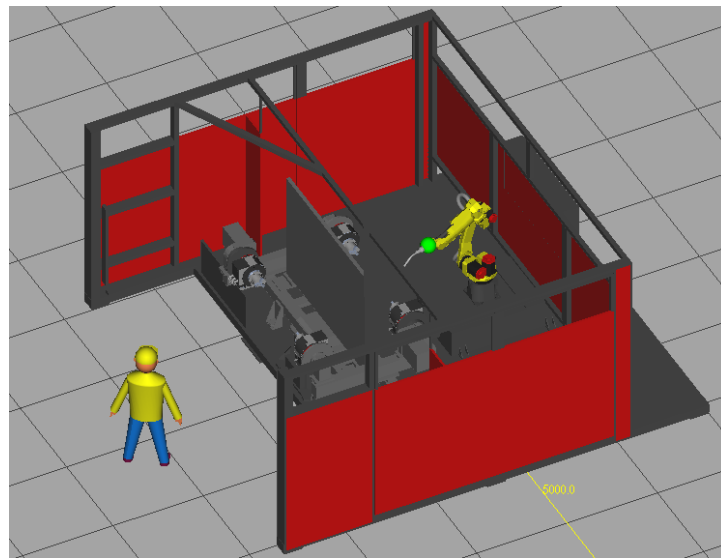


Figure 3 Robotic Weld Cell Model

Each work piece will be mounted to one of four individual positioners, all connected to a turntable with a divider allowing different sections for work and preparation to be possible. The positioners will be equipped with a base plate for mounting various fixture types; for this design and operation, the fixture plate would feature a three jaw lathe chuck. The overall cell could be operated by one worker trained to inspect weld quality and understand basic robot operations,

and preheating would be performed by induction coils instead of a gas flame; moved in and out of position automatically in relation to the robot and turntable.

In the above design, the table has two sides: one for two parts to be welded by the robot, and the other for two parts to be prepared and loaded before the operation, and cleaned and unloaded after the operation. This set up allows for work value to constantly be added to the parts, there is little waiting time where the robot or operator is not able to do anything. A potential improvement to this design would be to have the divider separate the four positioners individually, since the robot and human operator can each only work on one part at a time. An individual division would create four stages: loading and unloading, preheating, weld operation, and post heat or cool down time. Both possible set ups present more efficiency than a manual operation and the turntable utilizes the available space well. Prototype testing would be needed to fully examine the success rates of each set up.

Other considerations of the above design include that the cell could be run by a single operator who could inspect and clean the welds once the robot has finished. This job would be an easy transition for the current welding operator and a suitable match in terms of skill and ability. Additional training would be needed for the operator to understand potential problems the robot could run into and how to solve them. A separate robot and automated system maintenance employee would also need to be added. This worker would not be needed full time however and can be used in other areas of the company.

To analyze the potential success of the new system, general calculations will be used to find the payback period and ROI percentage. Variables and equations were generated within Microsoft Excel to allow for quick adjustments as assumed values become more accurate. Table 3 below shows the general equations and associated variables used in the calculations.

Table 3 Equations and Variables

Equations	Variables
$P = \frac{C}{W + I + D - (M + S)}$ $ROI = 100 \times \left[\frac{W + I + D - (\frac{C}{N} + M + S)}{C} \right]$ $D = \frac{C}{N}$	<p>P = Payback period ROI = Return on Investment</p> <p>C = System Cost M = New Maintenance Cost</p> <p>W = Direct Wages Saved S = New Staff/Supplies Cost</p> <p>I = Savings from Robot N = Useful Life of Robot</p> <p>D = Depreciation</p>

The payback period looks at the overall system cost, including equipment, tooling, installation, and testing, divided by the savings that system will provide. Direct savings must be balanced with costs and are usually self-explanatory. To clarify however, “Direct Wages Saved” is the savings associated with removing an operator such as their hourly pay and any insurance or compensation amounts. “Savings from Robot” on the other hand, can be harder to quantify, but looks at savings associated with tooling, energy reduction, saved floor space, scrap reduction, and lost time reduction. Different from operator removal, “lost time” relates to the costs of an operator being slower in their movements or completely absent from work due to minor or major injury.

Results & Discussion

Going back to problem defined by the company, the results of the simulated design will be tested against their need for ensured method consistency, performance quality, and increased production in relation to the welding operation of their steel drill bit. All three of these areas are improved upon by the use of an automated, robotic system.

Automation ensures a consistent process through programming, identifying specific parameters for the welding material feed, travel speed, and weld angle. Consistent parameters make it easy to troubleshoot quality issues since changes can easily be seen in reaction to updates. The efficient movement and maintained parameters will also reduce variability in each weld pass. Including increased speed and deposition rates associated with solid wire welding, switching the weld wire decreases cycle time removing the cleaning time usually associated with flux core wire and the re-heating needed when the part cools during the cleaning. Without these delays, the four weld passes can be performed in a single continuous movement.

With use of the rotating platform, parts can be heated directly before welding with little to no down time in-between. While more than four work pieces could potentially be loaded onto the design, this design allows for quick inspection of each finished product and can identify potential quality problems before they affect multiple parts. In conjunction with the turntable, induction coils would be used for preheating, providing a more effective heating system than a gas flame. Electrical heat uses less energy resources and applies heat to the work area with less diffusion than open flames. Additionally, induction increases safety with the removal of open flame exposure to the operator and environment, and the electrical current only effects electrically conductive materials inside the coils.

In terms of fixtures, due to the variety of diameter sizes in the product and the need for it to rotate to access the weld grooves, the current use of a lathe chuck works well. Modifying the classic three jaw chuck to fit a mountable plate that can be bolted individually to the four positioners would allow for easy use and flexibility. With a mountable plate setup, different fixtures can be installed for different products, adding to the system flexibility and increased production capability value for the company as a whole. As mentioned previously, this is an important aspect when considering the long term growth and strategy of the company. Simply increasing production in one area will create problems with inventory back log and not using the robot to its full work potential is a waste of time and lost value added.

Moving forward to calculation analysis, Table 3 shows the calculated and estimated savings gained by using a robotic system. The values for safety, lost time, and tool savings are harder to measure and estimate from outside of industry, and the present values are general estimates based on the company size, difficulty of work, process operation, and current production rate. The “Removed Labor Savings” estimate is based off the removal of one welder per shift and the addition of one robot maintenance worker. It is important to note that the removal of the welder should be considered in the frame of the operation under scrutiny and if possible, the employee should be relocated to another area of the company where their skills can be utilized appropriately.

Table 4 Calculated and Estimated Savings

Savings		
Removed Laborer Savings	\$ 80,000.00	/year
Scrap Savings	\$ 5,440.00	/year
Safety	\$ 2,700.00	
Lost time	\$ 3,000.00	
Tool Savings	\$ 2,000.00	

Applying the above savings to the previously established equations, the below economic calculations in Table 4 were generated. The results show a payback period of 2.14 years and a ROI of 34%. For a system of this large of a capital investment, a period of 2 to 4 years for the payback is expected and accepted as good option for the company to move forward with. Similarly a positive ROI shows that the system will generate value over its lifespan that exceeds its investments by 34%. Considering that these savings only analyze the direct use of the automated system in the single operation and not the added capabilities to work with multiple operations, an automated robotic welding system would be an excellent choice of process improvement for the company to follow through with. Were the system to be used full time on the defined operation, production would increase from 4,100 units per year to just over 11,700 units per year.

Table 5 Economic Calculations

Variable	Unit	Values	Calculations
P = Payback period	Years		2.14
C = System Cost	\$	\$250,000.00	
W = Direct Wages Saved	\$/year	\$ 80,000.00	
I = Savings from Robot	\$/year	\$ 13,140.00	
D = Depreciation	\$/year		\$ 31,250.00
M = New Maintenance Cost	\$	\$ 2,500.00	
S = New Staff/Supplies Cost	\$	\$ 5,000.00	
N = Useful Life of Robot	Years	8	
ROI = Return on Investment	%		34%

Conclusion

This report focused on the economic analysis and justification of design for a simulated layout of an automated robotic welding process. As presented, the numerous benefits of switching to a robotic system from a manual one are worth a long term investment by the company. These benefits include increased weld efficiency and consistency which lead to higher quality, reduced rework, and overall production increase, as well as reduced employee exposure to hazardous environments.

Estimated savings, calculated from given and assumed values, resulted in a payback period of 2.14 years and an ROI of 34%. Both of these values fall well within the accepted range of the company and it is highly recommended that they move forward with moving to an automated process for this product's welding operation. To fully analyze the potential benefits of the system and prepare it for industry implementation, a testable prototype would need to be set up and analyzed for actual efficiency and production values. Further research and testing on induction coils would also be valuable, especially when integrating with the robotic arm and turntable positioners described in the suggested design.

In the event that another analysis of this type should be performed, it is highly recommended that the operation being analyzed is studied in person and with close and open communication between the researcher and company representatives. This would allow for more accurate data variables and for more thorough economic analysis.

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Appendices

Appendix A

Robot Industry Association, 2013

Typical Efficiency Ratings by Application for Manual vs. Robotic		
Robot Industry Association Data 2013		
Application	Manual Efficiency (%)	Robotic Efficiency (%)
Welding (Mig)	30 - 35	90 +
Material Removal (de-burring, polishing, grinding, sanding)	25 - 30	90 +
Machine Tending (CNC lathe and Mill all styles)	55 – 60	90
Press Tending	40 – 50	90
Pick/Place	70 – 75	90
Palletizing	70 – 75	90
De-Palletizing	65 – 70	90

Appendix B

Zinn & Semiatin, 1988

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Elements of Induction Heating: Design, Control, and Applications

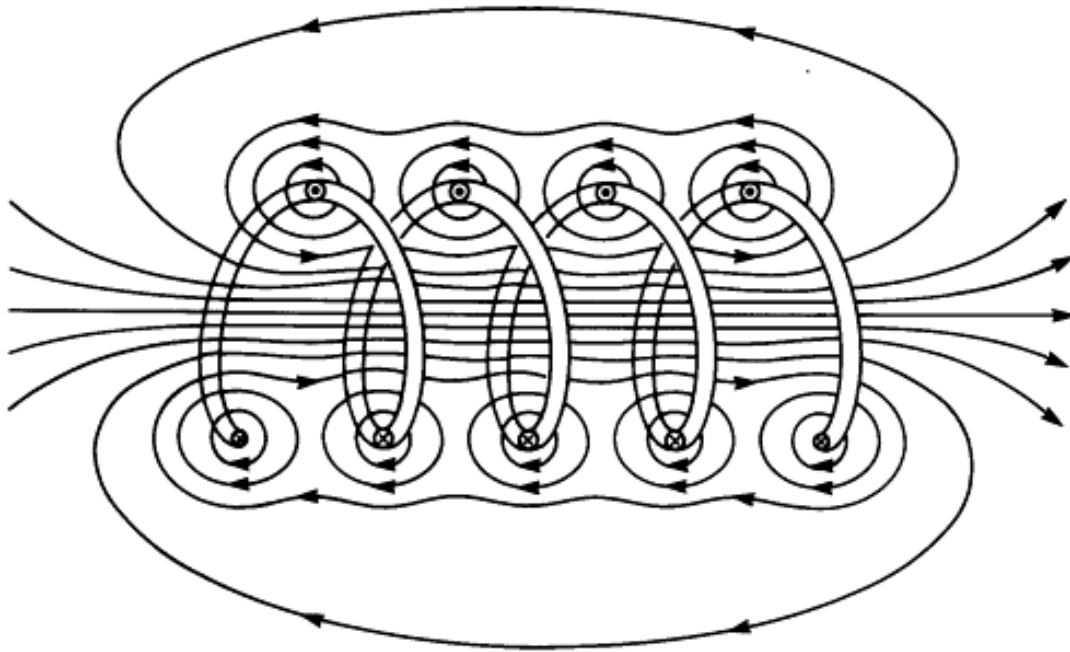
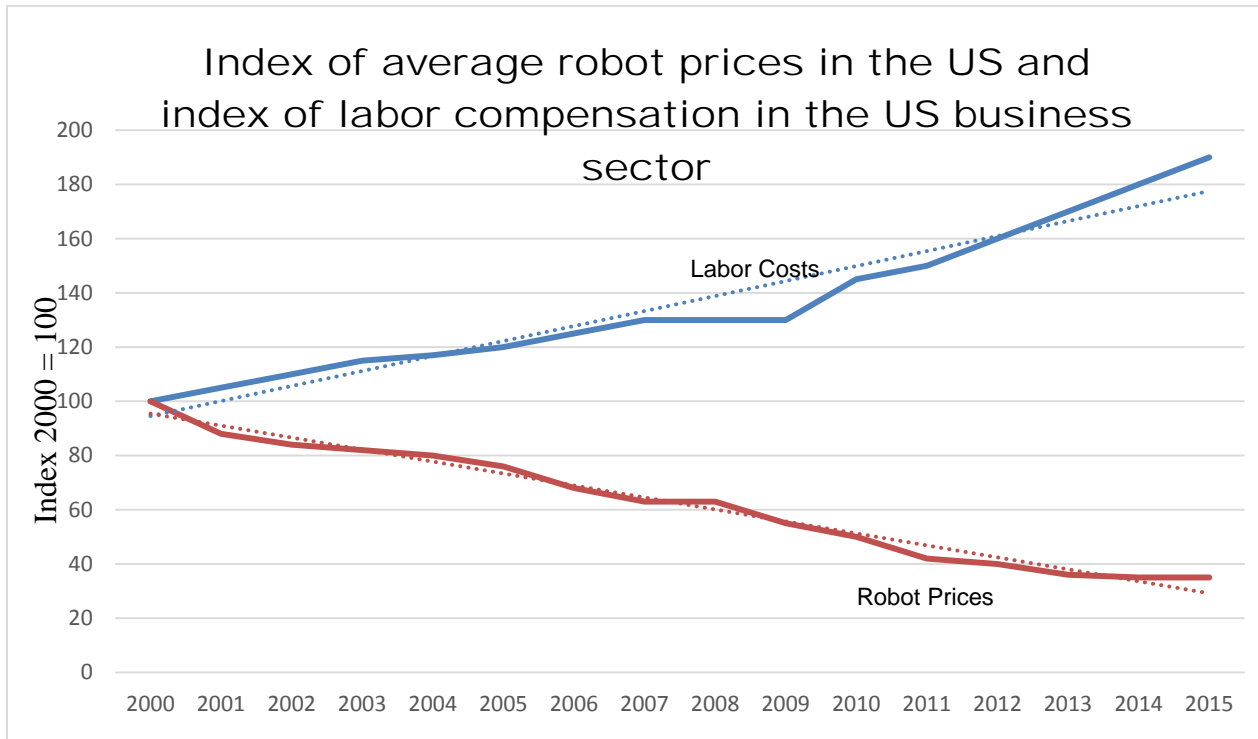


Fig. 2.2. Schematic illustration of the field of magnetic induction associated with a solenoid coil carrying an electric current (from D. Halliday and R. Resnick, *Physics*, Wiley, New York, 1966)

Appendix C

Economic Commission for Europe, 2001



Appendix D

