Engineering Management
Field Project

Battery Stack-on Process Improvement

By

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Executive Summary

Imagine yourself in a job in which you stack 10,000 batteries onto a conveyor for eight hours. Each battery weighs about 22 pounds. The work is completed in an acidic environment where temperatures can peak in the summer as high as 100 degrees Fahrenheit. This is the normal experience for a XXXXX, Inc. stack-on operator in

XXXXX is the global leader in lead-acid batteries and is dedicated to continuous improvement. This report examines a battery stack-on process and provides the optimal solution that is derived from research that is supported by process models and data collection.

By collecting baseline data, identifying root causes for issues and confirming all necessary work to be completed in the area, a robotic work cell will be designed that is capable of meeting the customer's expectations. This report will have a strong focus on communicating what additional machinery and controls are necessary to operate a battery stack-on robotic work cell. If used incorrectly, these controls and machinery may yield devastating results and huge financial losses. The key metric in the process will be battery gaps and through-put. The author will track this continuously after the project has concluded to hold the gains in the area and understanding any further opportunities available.

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Chapter1

Introduction

XXXXX is a global diversified technology company that serves customers in over 150 countries. XXXXX creates quality products, services and solutions to optimize energy and operational efficiencies of buildings; lead-acid automotive batteries and advanced batteries for hybrid and electric vehicles; and interior systems for automobiles (XXXXX Web).

The Power Solutions division is where this project is centered. It is the global leader in lead-acid starter batteries, advanced lead-acid batteries for start stop vehicles and Lithium-ion batteries for hybrid and electric vehicles. The 35 manufacturing facilities supply more than one third of the world's lead-acid batteries to major automakers and aftermarket retailers. One of the lead-acid battery plants, where the manufacture and distribution takes place, is located in . The facility is separated into two plants, the manufacturing facility and the distribution center. At the assembly plant, the batteries are manufactured through a

battery is shipped across town to the DC (distribution center) plant. There, batteries go through a forming process and are decorated for each customer. The DC plant is the focus of the project.

Currently, when DUF batteries are received, they are brought to the DC facility and manually stacked onto a conveyor system by operators. The current labor cost includes $500,000 per year to complete stack-on operations at this facility. Lowering costs is important to the business because the overall vision for the Battery Division is to reduce the direct labor to produce a battery. The through-put is also affected in the current process because of the several different operations needed in the area in addition to stacking on batteries. Increasing through-put is important to the process because customers would like to receive their product in a timely fashion. The work in the area also requires lifting and extensive walking, which may cause long term injuries to operators.

Robotic Material Handling is a widely used solution in the facilities. However, in the North American facilities, it has yet to be used in the DC stack-on area. The facility and several other plants have implemented the use of stack-off robots, which is a similar process. Robotics offers several opportunities for cost savings and increases in through-put in the area.

The vision of the XXXXX Power Solutions Division is to reduce the amount of direct labor required to produce a battery. In addition, it is important to assess improvements in through-put and reduction in downtime. Robotic Pick & Place is the key to optimizing the formation stack-on area and providing improved efficiency, increased safety, increased through-put and reduced downtime in the area.

Chapter 2

Literature Review

Robots have existed in manufacturing for several years. The challenge is integrating the multiple functions and machinery necessary to complete an entire robotic work cell. This study first will address automation and how it was introduced to manufacturing. Next, the several mechanical additions to a battery robotic work cell will be examined. Finally, the logic and electrical controls necessary to control the machinery put in place will be discussed.

Automation

There are extensive amounts of literature on automation and its use in manufacturing facilities, particularly in the automotive industry. The automotive industry has enjoyed the benefits and cost savings of robotics and has used this technology to provide quality products to its customers. For years, humans were known to be the only manufacturers of goods. Toyota Motor Corporation has excelled in manufacturing for decades. For manufacturing products, Toyota uses a unique approach called the TPS Toyota Production System. Shimon explained that JIDOKA is one of the two main pillars of the TPS.

JIDOKA has been translated into English in several ways. It was translated in Standard and Davis as “quality-at-the-source. ”In addition to its multiple meanings in English, it also has two different meanings in Japanese, one being “automation,” which was simply described as changing a manual process to a machine process (Monden). The second is “automatic control of defects,” which was described as incorporating the mind of a human to troubleshoot and correct errors (Thomas).

JIDOKA is described by Toyota as automation with a human mind. This process incorporates techniques used for identifying and correcting defects in a process. This includes mechanisms to identify irregular or defective product and also controls for stopping the process when those situations occur (Thomas).

End of Arm Tooling

This project focuses on robotic pick-and-place applications. As described in *Plastics Manufacturing Engineering Systems*, most designers and manufacturers focus on providing an end of arm tooling design that is sound enough to ensure consistent performance across the life of the application (Kazmer). End of Arm Tooling (EOAT) can be a very complex application, especially when secondary operations are involved. In the facility, handling batteries becomes intricate with the different sizes and weights involved. Sound EOAT must be complementary of the Robot, and for most applications, it must be able to handle multiple tasks and have precision pick and placement (Petz). As explained in an article on Manufacturing Technology, several factors weigh in on the overall results of a successful design. The handling and the placement of the part is a significant factor in the success of the tooling, including the security of the part once inside the EOAT. Consistency is also very important. Historically, poorly designed tooling has cost companies thousands of dollars in scrap from damaged product. Lastly, the reliability of the tooling and each individual component is vital to measuring the longevity of the equipment (Petz).

Cost efficiency is also important when it comes to robotic EOAT. The combination of capital investment, labor content and the speed of operation will result in a cost effective EOAT design and build (Petz). While EOAT is a fraction of the overall robotic work cell cost, it is crucial that the design of the EOAT minimize risk of damage to the finished product

An EOAT tooling specialist is very good at helping companies select the proper tooling needed for the application. Although XXXXX has specialized and highly experienced engineering staff, custom applications similar to what is described later in this paper will require an EOAT specialist who can handle complex jobs. A company that can provide customer tooling and sound technical support will be pivotal when searching for competitive bids.

End of Arm Tooling Construction and Build Requirements

As discussed in the *Guide to Robotic Gripping,* the basis for any modular system of EOAT components is how it interfaces with the Robot (Fisher and Westbeld). Numerous articles and books discussed the importance of several concepts when designing EOAT. Modular EOAT is an effective way to resolve any tooling issues because they are adjustable, and often inexpensive. How it interfaces with the robot is also a key aspect of modular tooling.

The weight of the tooling is also important because if defines the size of robot for the application. All weight suspended from the robot needs to be taken into consideration. Excess weight can cause issues during a collision as more energy is present during the event. While less weight will minimize the work cell area and reduce the overall investment. The tooling must adjust for all product types without losing precision and accuracy.

EOAT can be constructed with many different components such as vacuum suction cups or actuators and multiple gripping solutions. The complexity of constructing tooling can often be determined by the product. Pick and place tooling is one of the simplest applications, but its success is still dependant on reliable EOAT. In this application, the robot does most of the work and the tooling simply secures the part (Fisher and Westbeld). Motion and functionality of the EOAT is often necessary in certain applications. Good tooling designs can minimize some robot movements.

Sensory Devices

Robotic work cells function in a sequence that is driven by events. Sensors, such as a battery in place photo eye are one example of a trigger for a robot pick event. For most pick and place applications, grippers are mounted on the tooling using suction cups to pick and place the part. Many robotic grippers consist of two or three single and double acting parallel fingers (Kimon). The parallel fingers or parallel gripper is typically operated by pneumatics. In higher speed robotic applications the control of the pneumatic valve is not adequate to insure the correct position of the parallel gripper. The delay for pressure to build within the cylinder to translate to movement, and time to extend or retract is important. If the parallel gripper is closed when it should be open, the tooling and/or product can be damaged. These conditions are typically resolved by the use of sensors to detect component and product positions. The use of a cylinder reed (proximity) switch to indicate the actual parallel gripper position would resolve the prior example. Logic within the robot would examine the status of the parallel gripper prior to executing the move to pick. If the robot examined the status to be open then the robot would be clear to pick the product. However, if the robot examined the parallel gripper to be closed prior to the pick, the robot can be programmed to pause and execute alarm logic that would require operator or maintenance intervention. Sensors allow for an event driven sequence of operation that minimizes damage to product and equipment.

Vision systems and software are widely used in robotic material handling. A grayscale camera is often used to perform image processing, to locate objects and an area, as well as to track moving product (Kimon). When first implemented into a robotic operation, the vision system must be trained on what and how to recognize each part. This is called "Prototype Training," which is important for automatic and split second component recognition. After taking, digitizing, and processing the photo image, the system performs system based object recognition, displaying the features as pieces of image boundaries (Kimon). The vision system stores prototypes during the training and recognizes them when the new photo appears.

The vision system needed for this application will be a very costly investment for the project, but will be proven as a required function of the robot cell order to pick and place the product accurately and correctly.

Conveyors

The use of conveyors can be traced back to the 1700s. Many researchers have communicated that the use of conveyor belts can be traced back in history to the major construction projects of ancient civilizations (Guglielmo). Early conveying systems were simply belts covering flat wooden beds for the use of carrying bulky items. Hymle Goddard was awarded the first patent for roller conveyors in 1908 (Guglielmo). By the 1920s, conveyors were seen more and more in manufacturing facilities, specifically in the automotive industry.

Every design of roller conveyors encompasses a single rotating motor power source that gives mechanical drive through a connection. The connection that drives the conveyor can be rope, leather belting, synthetic belting, or most commonly, a chain. This linkage makes contact with the rollers to help allow continuous movement of the conveyor sections. The number of motive power sources for a conveyor system is generally the most expensive and complex section of the conveying system (Knapke).

The basic design of the motorized conveyor has not changed since its invention. A large multi phase electric motor and gearbox rotates a shaft that turns a sprocket, which then moves a chain or pulley/belt combination (Knapke). This is a description of a conveying system that would convey items in a continuous direction. Most systems require products to accumulate on the rollers with small gaps and allow the final items to discharge onto the next item in the queue while other items continue to accumulate. Knapke believes that most people want this done without their product bumping into one another and without the conveyor rollers tuning and grinding causing damage while the conveyor is accumulating (Knapke).

Accumulation

Accumulation conveyors are systems that have release signals that hold products in place for a given time period. These systems also incorporate zero pressure accumulation conveyors, which involve a product stopping caused by a photo eye. The photo eye senses the presence of the product and sends a signal to the trailing conveyor zone. Once the product moves into this zone, the drive belt is lowered away from the tread rollers, causing the product to stop. All products behind this zone will transition forward once this area is clear. For zero pressure accumulation conveyors to be successful, solenoid valves and compressed air hookups are needed with a motorized drive chain that operates the entire conveyor (Knapke).

<u>Pallet Collectors</u>

Once pallets are emptied by the robot, they must have an area to be diverted to. Pallet collectors are built to handle multiple types of pallets and collect them at one to two pallets per minute to ensure continuous flow of product in and out of the robot cell. In most cases, the pallet collector will be quoted as a separate device from the robot cell. In addition to the robot itself, micro logic micro-processors and panel will be necessary to control the collecting of the pallets.

Retracting forks will operate on one side of the magazine as cylinders raise and lower them. A power conveyor will feed pallets into the machine, which may reach a 24” to 34” elevation. As product is completely emptied from the pallet and it transports into its first area, a signal is sent to the machine. When the pallet approaches, the forks raise the already accumulated pallets in the machine. The pallet is conveyed into the stack, and the forks retract out of the second pallet into the stack.   Then the forks enter into the new pallet for preparation of the next pallet to transition into the machine.

Motor Control Circuits

Complex machinery similar to what will be used in Pick & Place Robotics will be controlled by electrical circuits. These machines and applications, which need electrical control circuits, often require greater speed, higher efficiency, and greater versatility than manually controlled operations (Bartelt).

Wiring diagrams, which are made up of lines connecting certain symbols, are a major part of electrical circuits. They serve the purpose of giving written communication to the technician and are used as a troubleshooting guide when issues arise. The best wiring diagrams include a physical layout of all electrical devices, how devices are physically connected to one another and finally information that communicates how all the controlled devices operate (Bartlet). Familiarity with symbols is an important part of understanding and successfully working with wiring diagrams. Electrical Control Circuits use wiring circuits known as relay ladder logic diagrams to display information about the layout of a device. Figure 1 shows an example of a simple ladder diagram for turning on a light bulb (Bartelt).

In the Ladder Diagram in Figure 1, L1 and L2 noted as rails are the differences in voltages that supply power to the circuit. A Ladder Circuit consists of 4 elements, a power source, an input control device (ex. push button), a load device at the output (ex. motor, buzzer, light), and interconnecting wires (Bartelt). To achieve an energized circuit, there must be a continuous unbroken path from the one side of the power source through the load device and to the other side of the power source. Figures 2-6 are a series of charts that show the most common wire diagram symbols used in ladder diagrams (Bartelt).

Figure 1: Ladder Diagram

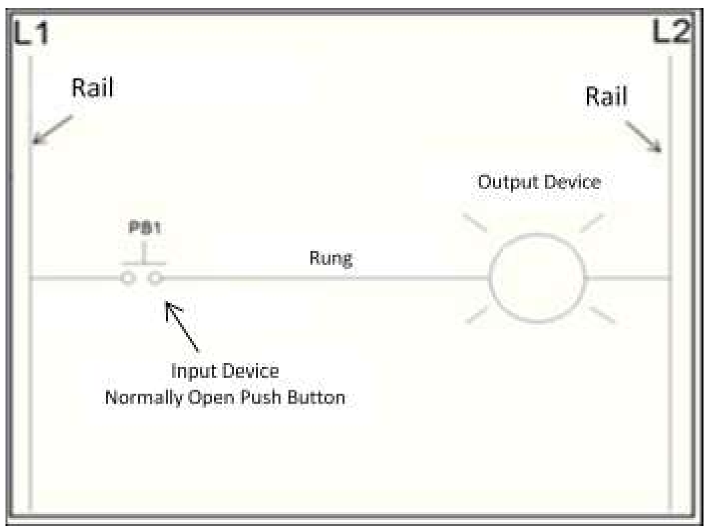


Figure 2: Manual Switches

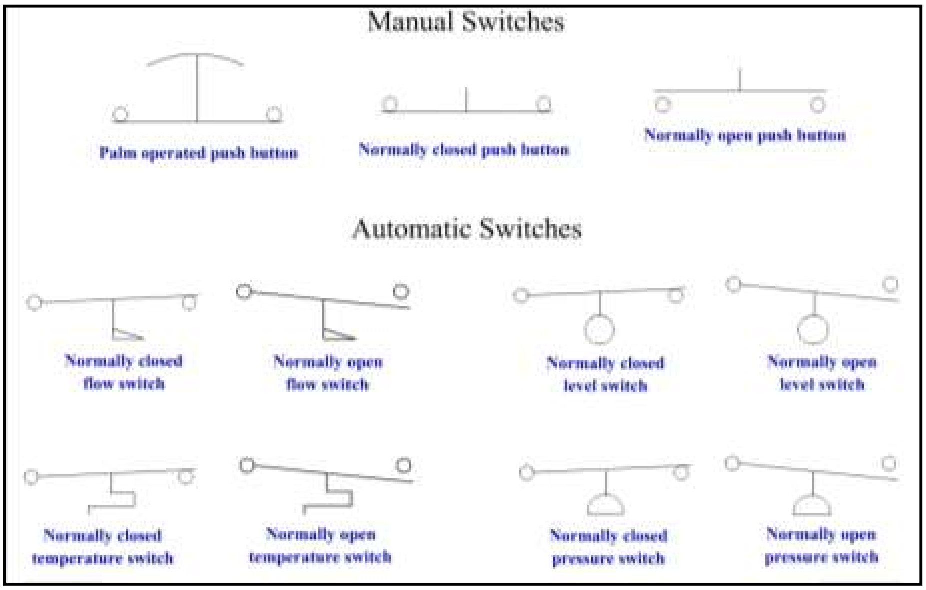


Figure 3: Limit Switches

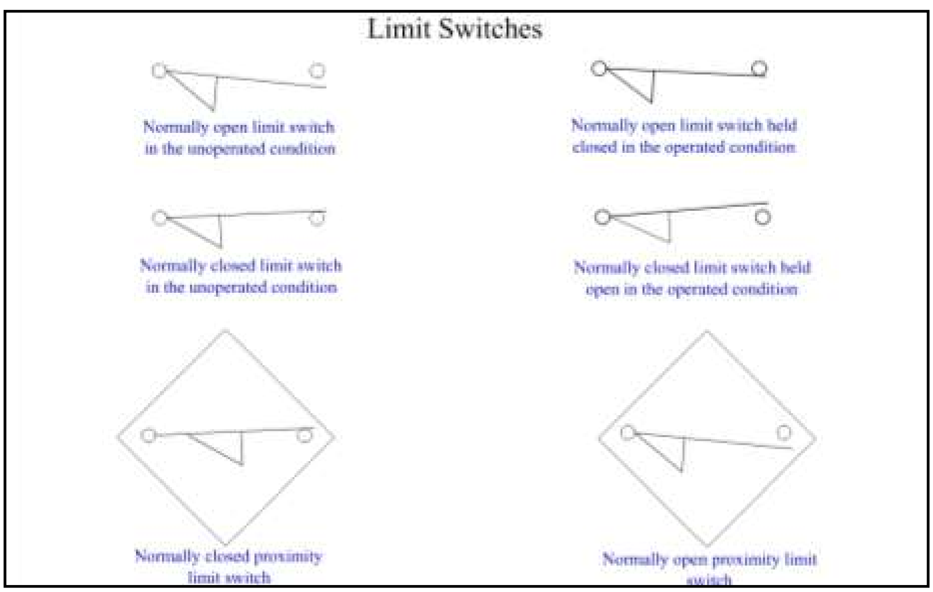


Figure 4: Output Devices

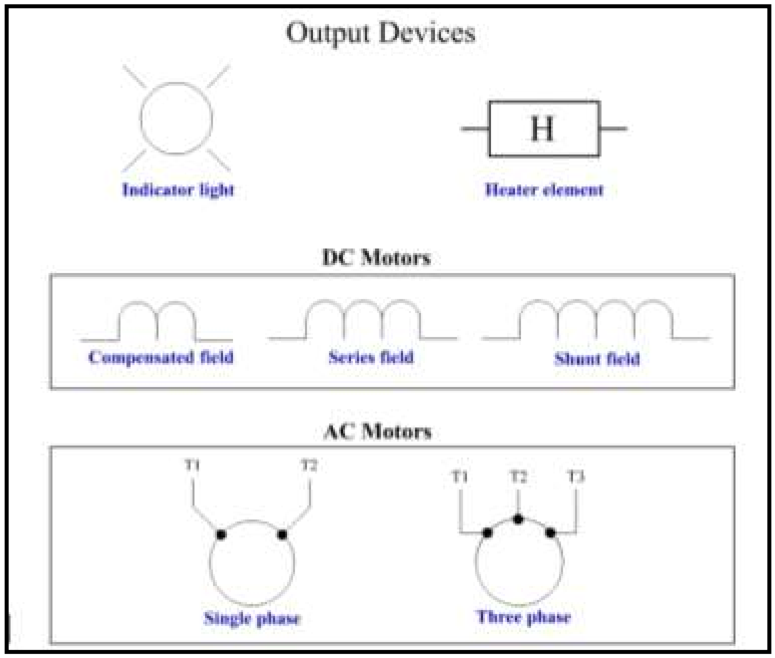


Figure 5: Indirect Devices

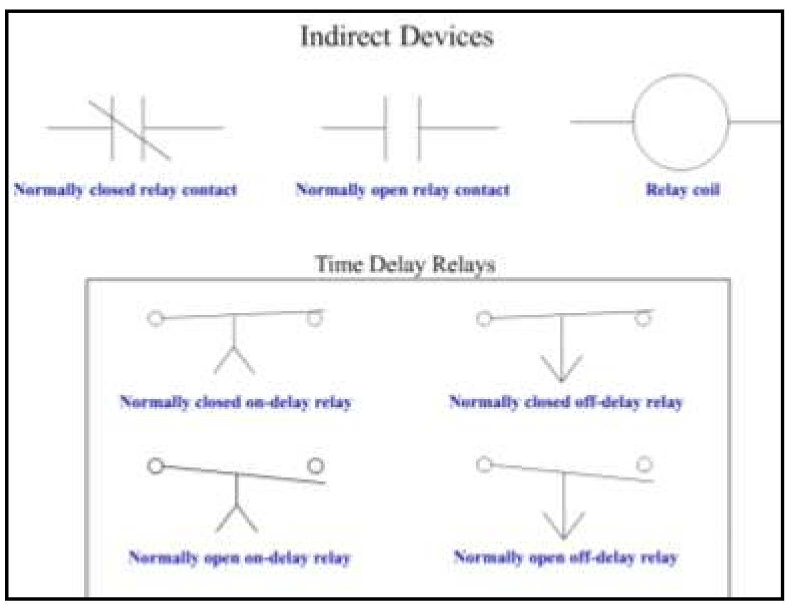
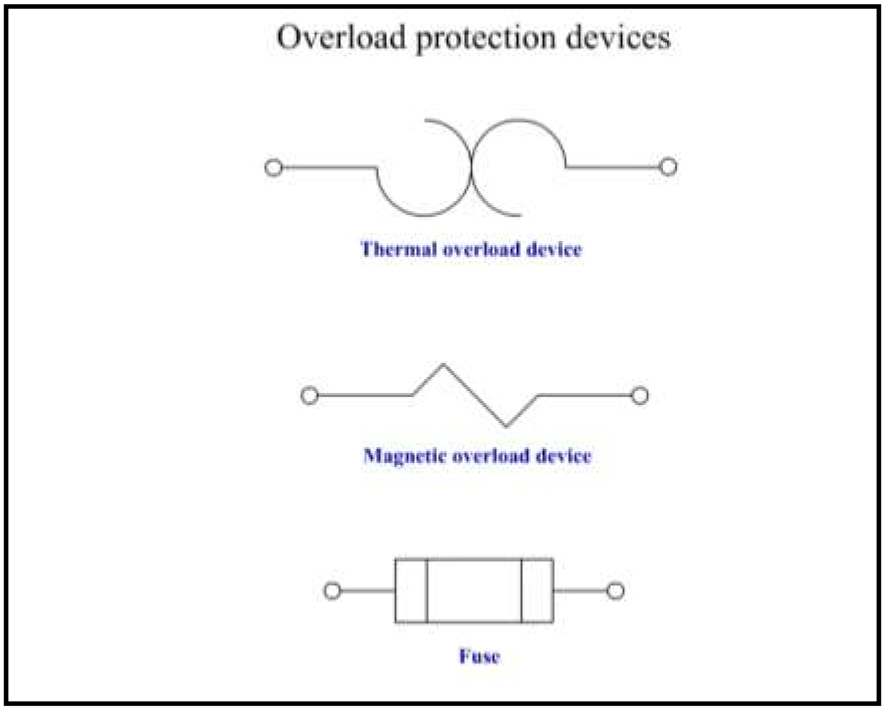


Figure 6: Overload Protection Devices



Relay Ladder Logic Circuit

Relay Ladder Logic circuits perform a variety of functions. When these circuits are in operation, input devices are coded with a 0 input when not activated; while activated input devices are coded with a 1 input. Similarly, outputs devices are in logic 1 state when activated and logic state 0 when not activated.

Boolean Logic & Logic Functions

Boolean Logic & Logic Functions are performed frequently when programming machinery and robotics. Boolean Logic was developed in the 1800s by George Boole. It allows a variety of items to be mapped into bits and bytes (Brain).

Figure 7 shows an example of using the OR function. When using OR Functions input devices, if any of the two switches are closed, the output device will become energized. If both switches are open, the output device will turn off.

Figure 7: Circuit Using OR Function

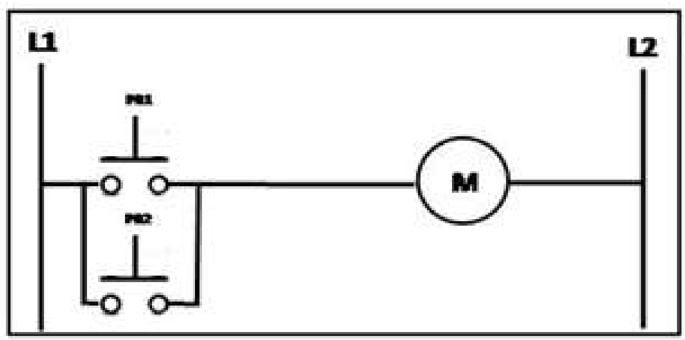


Figure 8 shows an examples of using the AND & NAND functions. When using the AND functions, two switches or input devices must both be in logic state 1 or remain active to power the output device. If either switch has the opposite condition of the other, the output device will turn off.

Figure 8: (Top) Circuit Using AND Function
(Bottom) Circuit Using NAND Function

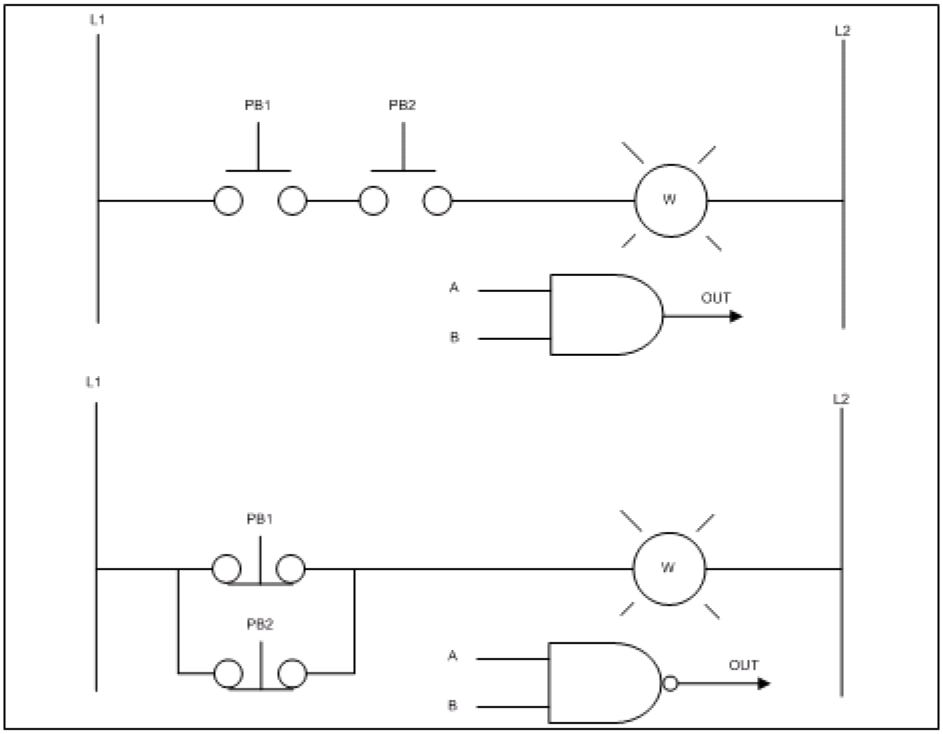


Figure 9 shows an example using NOT Functions, if the push button is not activated, the output device will be energized.

Figure 9: Circuit Using NOT Function

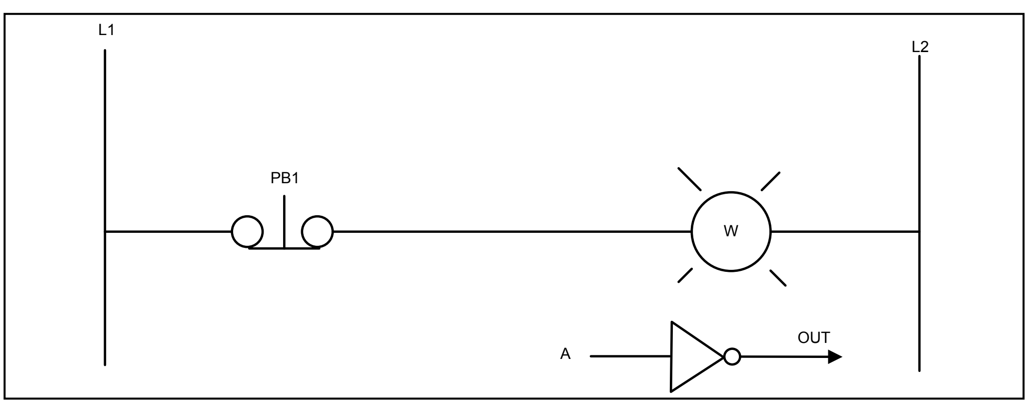
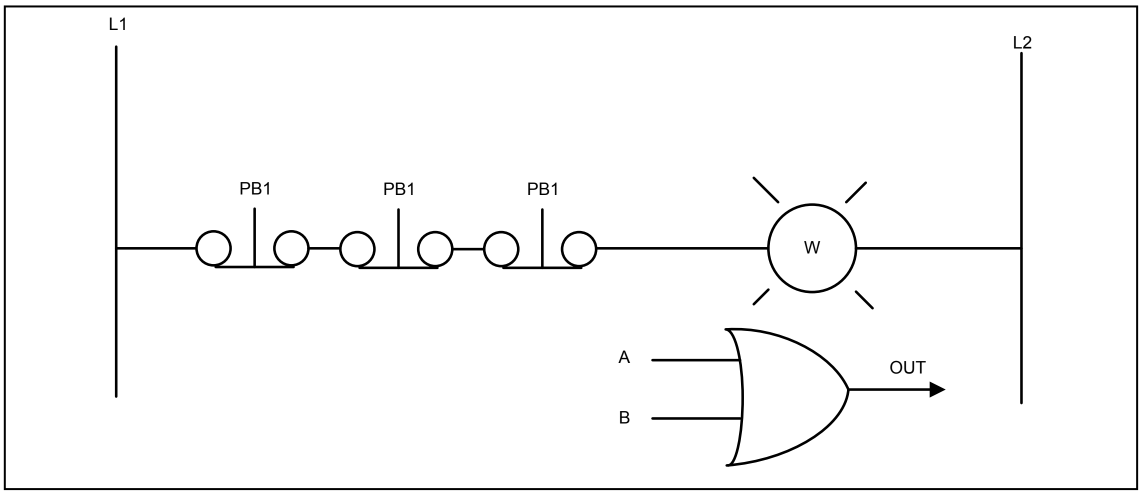


Figure 10 shows an example of using the NOR function. When using NOR Functions, if all input devices are not activated, the out device will energize. If one or more of the inputs are activated, the circuit will turn off. The following charts show examples of the functions previously described.

Figure 10: Circuit using NOR Function



Start and Stop Interlocking Circuits

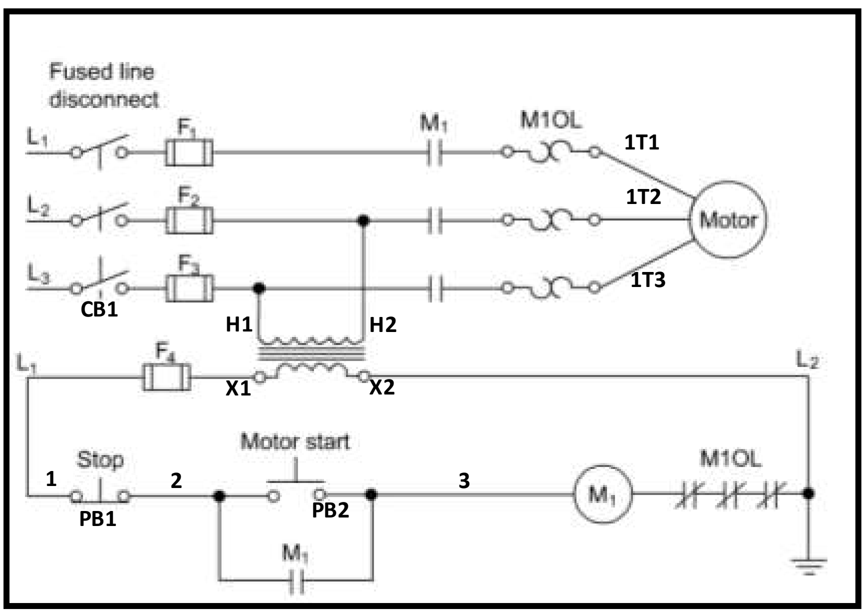
Starting/Stopping and interlocking circuits are very important in ladder circuits. The circuits have N.C. (Normally Closed) start and stop buttons, controlled relay coils, and N.O. (Normally Opened) contacts started by a relay (Bartelt). The connections that are in parallel with the start button are known as branch connections (Bartelt). When there are incomplete paths in the circuit, no power is given to the relay coil.

Motor Control Starter Circuits

Motor controllers are used in many different ways in controlling motors. Three phase motors generally include two functions, starting and stopping a motor and overload protection (Bartelt).

Figure 11 shows three phase power lines that supply power to the conductors labeled L1, L2, and L3. The circuit is protected by a line disconnect that includes a single-throw/triple pole switch with fuses, circuit breakers, and overload heaters, which are placed between the motor and the line connection (Bartlet). Each power line includes normally open contacts shown as M1. Once these contacts are closed by the relay coil or motor starter, current will flow through the motor windings.

Figure 11: Example Motor Control Circuit



Two of the three phase lines are connected to the lead of transformers labeled as H1 and H2. They will transfer electrical energy from each circuit with coupled conductors known as the transformer's coils. Keeping the line disconnect closed will continue to supply AC power to the circuit. Secondary coils at the terminal labeled X1 and X2 will transfer the voltage for the control circuitry location of the circuit (Bartlet).

Once the start button is pushed and the contact is closed, current will flow through M1. When the start button is disengaged, the contact will keep the coil energized, allowing the contacts in the three phase circuit to close also. Closing these contacts gives connection of the three phase power to the motor (Bartelt).

Programmable Controllers

In the past, programmable controllers served as a separate function that controlled process components of the Robot cell such as conveyors, pallet dispensers, and operator control panels. Today, PLCs have been integrated into the Robot cell to communicate with the Motion Controller and the vision system to help complete operations.

Before the 1960s, controlling automated equipment involved hardwired relay panels. Any changes or additions to these programs involved physically removing wires, which became very expensive and time consuming.

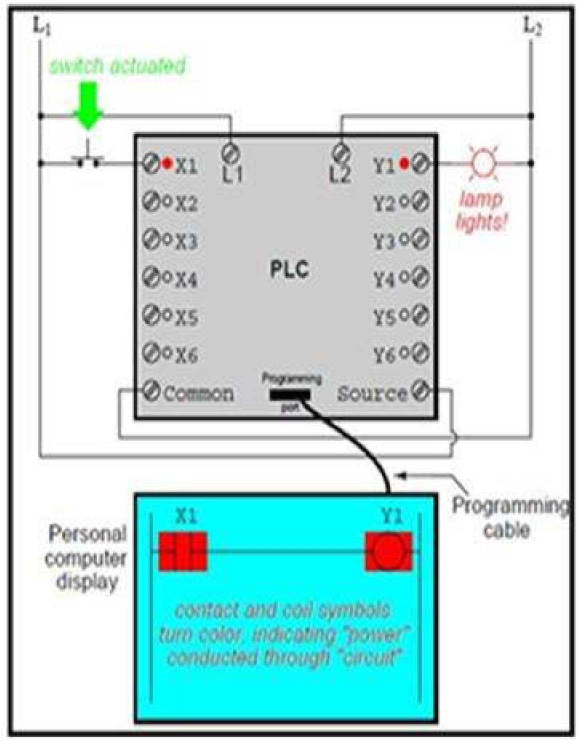
Later in the 1960s, a company named Bedford Associates created a computing device called a MODICON (Modular Digital Controller). Other versions of this device were soon created that came to be known as a PLC (Programmable Logic Controller).

With the introduction of the PLC, any changes could simply be made from a computer without physically changing anything inside the control panel.

Programmable controllers also are digital computers used for automation of electromechanical processes such as controlling machinery conveyors and many of the components of the robot. As technology advanced, controllers were restricted to relay comparable on/off functions. Moreover, with improvements made in hardware, software, and micro-processor developments, the abilities of the PLC have increased dramatically. Specific modules are now required to perform certain tasks for multiple motion and process control applications (Bartelt).

PLCs have many input terminals to interpret logic states from sensor switches. They also have a variety of different output terminals to different signals to power many of the devices discussed above, such as motors, power lights, solenoids, and several other devices that have on/off controls. For ease of programming, PLCs were created with programming language that resembles ladder logic diagrams. Figure 12 is an example of a simple front view of a PLC. L1 and L2 are shown as screw terminals connecting the mostly common 120 volts AC for powering the internal circuitry of the PLC. Screws to the left with "X" labels are input devices, each with different channels above a common connection generally connected to the L2 power source (Hollingsworth).

Figure 12: PLC Front View



Between the input terminals and the common terminals inside the housing of the PLC is an opto-isolator device, which provides a signal to the computer when power is applied between the terminals. A visual indicator is displayed when an input is energized.

A switching device is activated by the computer circuitry; this switch connects the source terminal to any of the labeled "Y" input terminals. The source terminal is usually connected to the L1 side of the power source. Again, indication is given when an output is energized.

Interfacing with real world devices is done with actual logic of the control system established inside the PLC through communication with a computer program. The computer program communicates which output should be energized and under what input conditions (Hollingsworth). As mentioned earlier, the design of the program is similar to a Ladder Logic Diagram in that the PLC does not involve any relays, coils, or switches, only symbols. All symbols are viewed through a personal computer connected to the programming port into the PLC.

This overview is but a small overview of programmable controllers. PLCs as real world applications can have very advanced functions, having far more than six inputs and outputs. Figure 13 shows an example of this kind of application. It includes sixteen input and output terminals with the ability to monitor and control several devices.

Figure 13: PLC Panel

Motion Controllers

Motion Controllers control machinery using digital computers or analog components. They are automatic control systems that control the physical motion and position of objects (Bartelt). Motion controllers all have three common characteristics to successfully control objects:

1. The control of speed, acceleration, or deceleration of a mechanical object.
2. Sensors to detect motion, position, and examine the robot.
3. Controls to give intelligence to the robot to respond to input commands within a fraction of a second and be able to pick various objects.

Servo Controls

Motion control systems are also known as servo mechanisms. Positioning servo mechanisms were first developed for military use. Today, they are mostly used in automated machine tools. Servos are devices that use error sensing to correct the performance of a mechanism. Most common servomechanisms control position using electric motors as a primary means of creating mechanical force.

Chapter 3

Research Procedure

The initiation of this project emerged from multiple issues in the formation battery stack-on area. Six sigma tools will be used to conduct research and understand the current problems in the area. Chapter 3 will give a description of the methods used to collect and analyze data for the project to drive towards a decided solution for issues in the area.

The first section of research began with a meeting with all operators in the area. The purpose of this meeting was to collect information from the process experiments to understand true causes for issues in the area. Notes were taken as each operator explained their concerns and issues in the area. A summary of the questions asked can be seen below:

1).What is the main causes for downtime or large gaps between batteries in your area?

2).At what point during the day do you begin to feel tried for stacking batteries?

3). Are you stacking batteries, slower, faster, or the same by the end of a shift?

4).What tasks take you the longest time to complete?

5).Which of your job task would be helpful to be removed from your job description?

6). Are there any safety concerns in the current area?

All noted causes and feedback was discussed with other team members. This eventually allowed us to construct a Cause and Effect Diagram (C&E), which will be explained in further detail later in chapter 4.

The second section of research was the collection of data to support issues that were identified in the C&E diagram. To collect data, sensory devices and cameras have been setup to monitor the area for several days. After several days of collection the video was reviewed by team members. It was confirmed that items noted in the C&E where in fact true causes for issues in the area. In addition, battery gap information from the sensory device gave baseline data to allow the team to understand the current performance level of the area.

The third section of research involved an internal or external search of any manufacturing facilities with a similar operation as the SJDC facility. The goal was to understand their strategies for reducing issues in the area and possibly benchmark there process to help eliminate the current issues that are seen today.

During a plant visit to a XXXXX facility in Germany, it was seen that they used a robot to eliminate issues in their stack-on area. It was noted that their robot was not the ideal setup for the SJDC process, but it added great value and information for the team to build on. Drawings, video, pictures, and contractor information was passed on to the team for further discussion.

Chapter 4

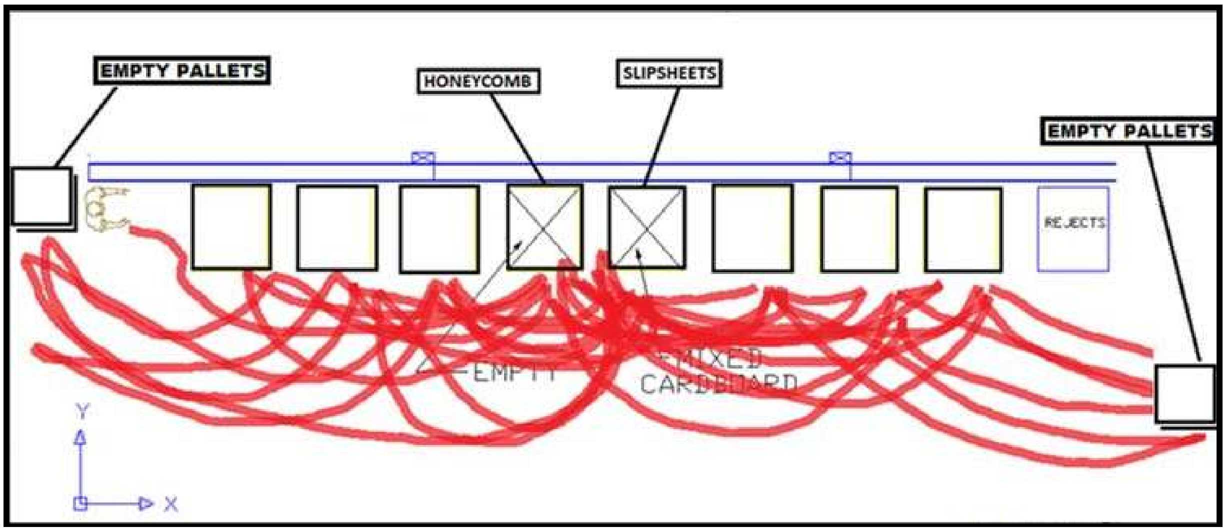
Results

To completely optimize the area and receive required returns on the investment, the installation of a robot will be chosen to improve this process and eliminate issues in the area. First, the author will display the agreed problems in the area. Next, the customer concerns and the current capability of the process will be shown. Understanding this is vital to confirming these concerns are addressed and the improvement is capable of meeting the customer expectations. Finally, the improvement process will be discussed, and an analysis of the gains from the robotic implementation of the project will be provided. The improved process can become very lengthy, which includes the approval of a Capital Appropriation Request (CAR), the examination and exchange of pertinent information with contractors, new layout identification, and finally a display of the overall improvements to be seen once the area is improved.

Stack-on Process Problem Analysis

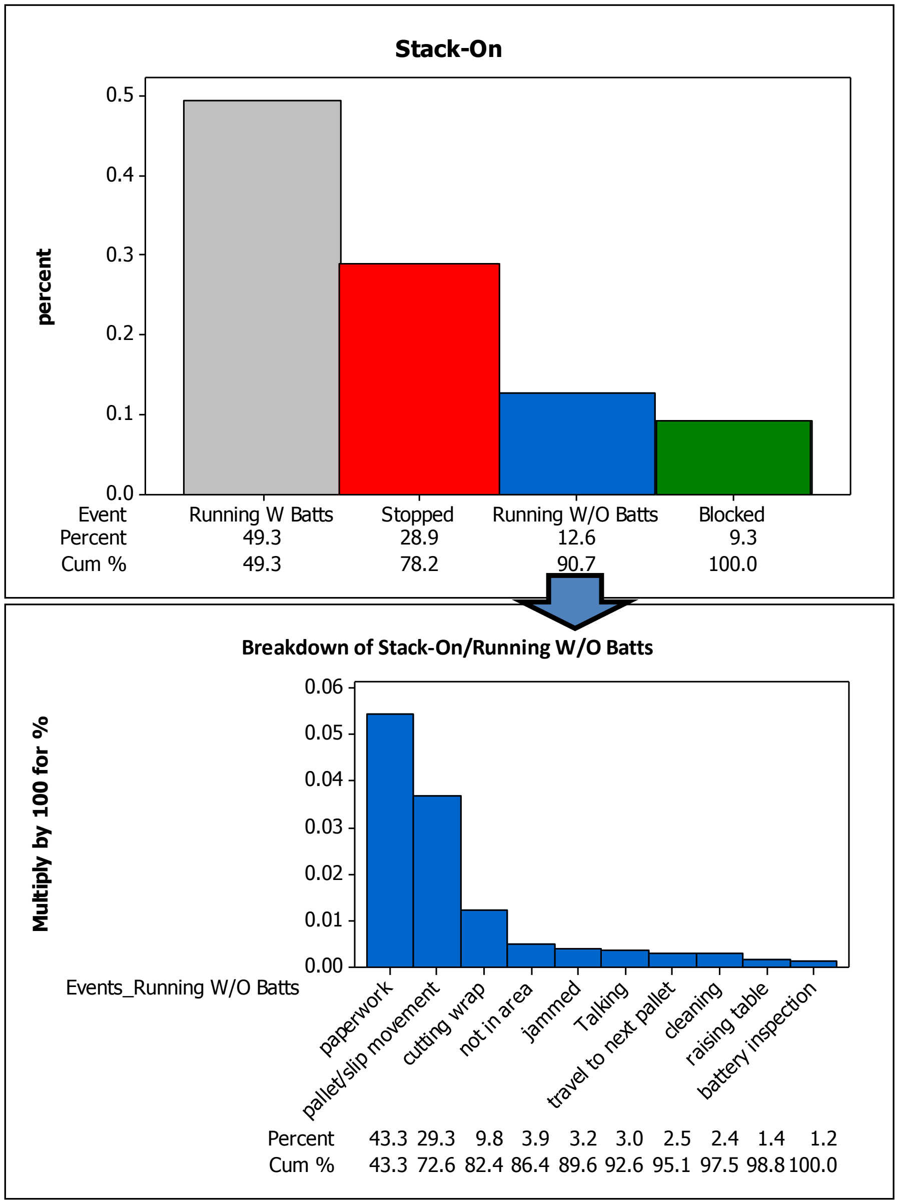
Figure 14 shows a spaghetti diagram of the current formation stack-on area. There are several jobs that an operator must complete in the battery stack-on process which is shown in the diagram above. Currently seven lift tables set beside the conveyor. A fork-truck driver sets a pallet of batteries on each lift table and an operator will walk to each table and manually stack on batteries onto the conveyors. Between each layer of batteries is a piece of cardboard that must be removed after each layer is stacked off. Each piece of cardboard must be taken to a nearby storage location that is generally 10 – 20 steps one way. After the final layer of batteries is stacked on the operator must remove the pallet from the lift table for a new set of batteries to be placed on the table. Pallets must be carried 10 – 20 steps to their storage location.

Figure 14: Current Formation Stack-on Layout



Since these pallets weigh 35 lbs each it can be very dangerous and cause injury over time. Operators must also scan batteries into the process and do additional paperwork. Finally operators must also check for damaged product that arrives at the facility. These batteries are manually stacked off at the end of the line. This required them to walk the entire length of the line, which can be up to 50 steps one way. Figure 15 shows the stack-on process problem analysis break down.

Figure 15: Stack-on Problem Analysis



An attempt was made to understand all tasks in the area and examine which cause the most delays and down time. A Six Sigma Black Belt completed a study which provides significant data that shows the various task in the area and the time lost due to completing these task. As seen in the chart above, completion of paperwork, pallet/slip-sheet movement, and the cutting of stretch wrap are the main contributors that prevent the operator from stacking off batteries.

<u>Customer Concern</u>

When an operator is unable to stack off batteries because of other duties in the area, this affects through-put and causes gaps in the line. This lost through-put cannot be re-gained and has a direct impact on the operators in next areas downstream. Figure 16 shows a moving range chart that gives a snapshot of the gaps seen over a three day period.

Figure 16: Battery Gap Daily Average

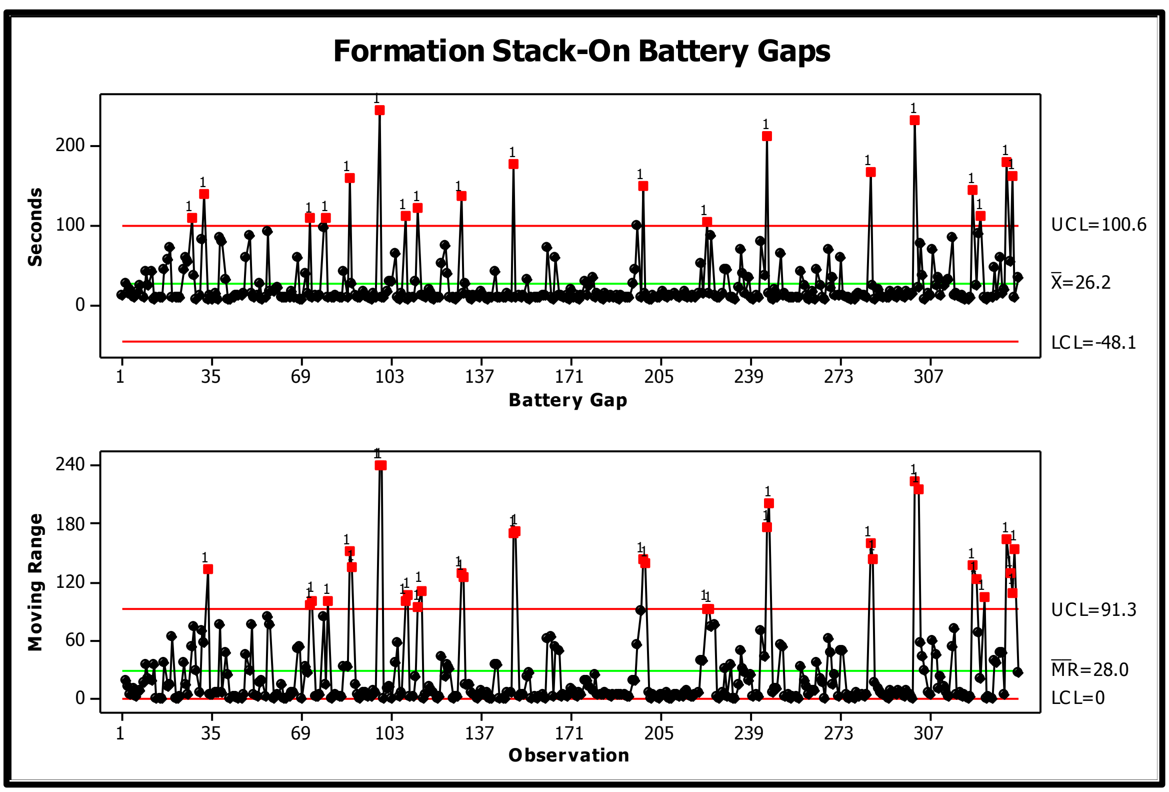


Photo-eyes and logic were programmed to track gaps on the line in this area. There is an average of 26.2 seconds for gaps between batteries. A number of gaps were above the 29.3 second control limit, which shows that this process is out of the control limits. Several of these gaps were caused by an operator task being completed in the area.

Capability

Next, a capability analysis was conducted on the data retrieved. A normality test was conducted first. To check Normality, the Minitab program was used, as seen below.

Figure 17: Normality Test

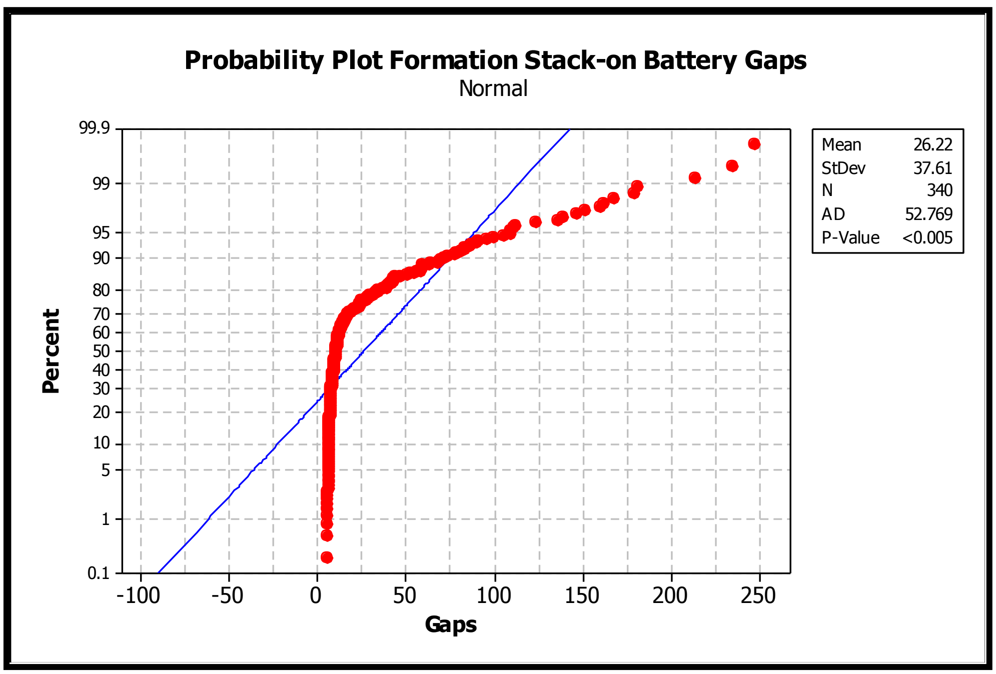
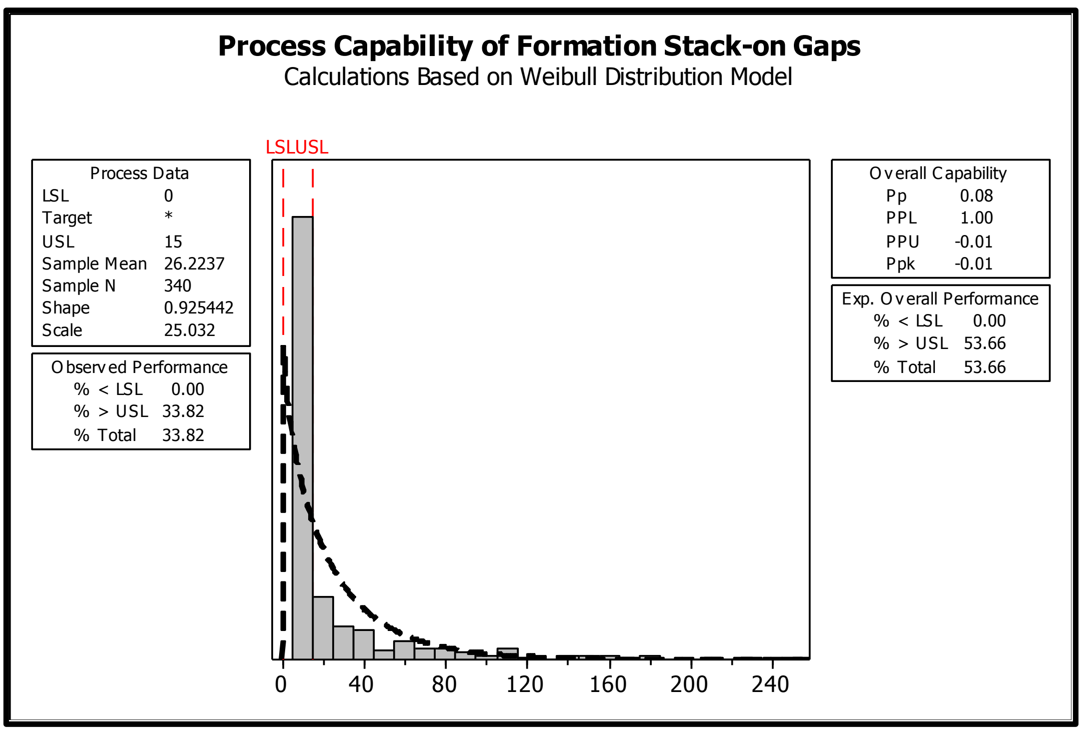


Figure 17 shows a normal probability plot using a hypothesis test to examine whether or not the data follows a normal distribution. When testing for normality, the primary concern is the P-Value in the bottom right corner of the data box. This indicates whether the data is significantly different from the line. Since the P-Value was < 05, it was concluded that this was non-normal data.

With the non-normal data, a capability analysis can be conducted to visually show a distribution of the process relative to the target. This analysis will also display whether the data follows a particular distribution and if the process is capable of meeting the conditions consistently (Joiner).

Figure 18: Process Capability



As seen in the Figure above, 53. 66% of the overall process was defective and not capable of meeting standards.

Analyzing Root Causes

A widely used tool in the DMAIC process is a Cause & Effect Analysis (C&E). A Cause and Effect Diagram is a useful tool that involves a team collaborating together to find causes behind known issues in a process. How do people, machines, materials, and methods cause high battery gaps and affect through-put in the area? Each area has specific factors that may cause the known problem being analyzed. The interviews in the previous chapter where incorporated into the C&E. Below the four areas are discussed in detail and how each has an effect on the process.

People

The operators in the area have a huge effect on the process. Multiple factors may cause the identified problem in this area.

1st Cause Identified: Shift Change

The facility operates on five shifts. On every shift, there is a tool box meeting with the operators and supervisors to communicate issues, goals, and problems. During this period of time, the line generally does not run. This was identified as one of the causes behind battery gaps and the effects on through-put.

2nd Cause Identified: New Employee Training

Stacking batteries on a conveyor may seem like an easy task, but actually it is one of the hardest jobs in the facility. Several tasks must be completed in addition to stacking batteries. An extensive training program is required in order to eliminate issues with through-put and remain consistent in minimizing battery gaps in the line. If the optimal technique in the area is communicated and trained to the new operators and also the existing work force, problems can be eliminated in the area. This drives towards the issue of standard work, which will be discussed later in this section.

3rd Cause Identified: Breaks/Lunches

Recently, rolling breaks and lunches have been implemented in the area. This generally means an operator relieves another operator in order to keep the line running. Often times it is not possible to keep the line running because there is not enough staffing available. When the line runs dry, no batteries are stacked on the conveyor.

4th Cause Identified: Pertinent Information Not Passed On from Shift to Shift

Generally, on every shift there is information that needs to be communicated from supervisor to supervisor. Often times, supervisors become busy and forget or may not be able to pass the pertinent information to the next shift supervisor. If an approaching shift supervisor is not aware of any issues beforehand, this could cause issues and may affect the production on the next shift.

5th Cause Identified: Heat/Environmental Conditions

Extremely hot conditions throughout this past summer have shown the facility how the environment affects the process. As temperatures rise, through-put decreases and cost increases. Fatigue affects how product is built; as operators become tired from high temperatures in the area, the process slows and production is lost.

Materials

The materials used to build the product in the area have a huge effect on the process. There are multiple factors that may cause the identified problem seen in the area.

1st Cause Identified: Returning Reject Pallets

Often times, product arrives to the operators in the area already damaged. This defective product must be separated from good product and placed on a separate skid. To achieve this, operators pull the battery from the line and walk the battery to a reject pallet. When this happens, the line is stopped and production is affected.

2nd Cause Identified: Returning Cardboard Material

Most batteries arrive to the operator in layers of three or four. In between each layer is a piece of cardboard material that is removed. This material is stacked off into a bin in a nearby location. Operators are instructed to remove the material and stack the cardboard in this location. When the operator does this, no batteries are stacked on the line and production is affected.

3rd Cause Identified: Cutting Stretch Wrap

Each pallet of batteries that arrives to the operator is wrapped in stretch wrap. The operator must cut the stretch wrap, remove it from the stack of batteries and throw the wrap away. When this happens, no batteries are stacked on the line and production is affected.

4th Cause Identified: Returning Empty Pallets

Once an operator completely stacks off all batteries from a pallet, the empty pallet is carried to a location for retrieval. When this occurs, no batteries are being stacked on the line and production is affected.

5th Cause Identified: Returning Damaged Cardboard and Pallets

All material including cardboard and pallets that are damaged during transportation must be separated out and stacked off in a separate location. When this occurs, no batteries are being stacked on the line and production is affected.

Machines

The machinery used to build the product is important because without its adequate performance, operations will not meet its daily demand. There are multiple factors that may cause the identified problem seen in the area.

1st Cause Identified: Lift Table Maintenance

As mentioned earlier, there are several lift tables in the work area that the operator stacks off from. Each table has weekly maintenance that is completed to ensure it performs to standard. In addition, these lift tables may require un-planned maintenance during periods of production. During both planned and unplanned maintenance, no batteries are being stacked on the line, which affects production.

2nd Cause Identified: Lift Table Operation

The lift tables discussed above must be operated and move up and down to stack batteries off pallets. During the operation of the lift tables, the procedure of stacking on batteries is halted for a split second while the lift table moves upward to stack off each layer.

3rd Cause Identified: Stack on Conveyor Maintenance

All batteries are stacked onto a conveyor that transports the batteries to the next work location. Each conveyor section has weekly maintenance. This may include sprocket, motor, and belt changes, which are completed to ensure each section performs to standard. In addition, these conveyor sections may require unplanned maintenance during periods of production.

Methods

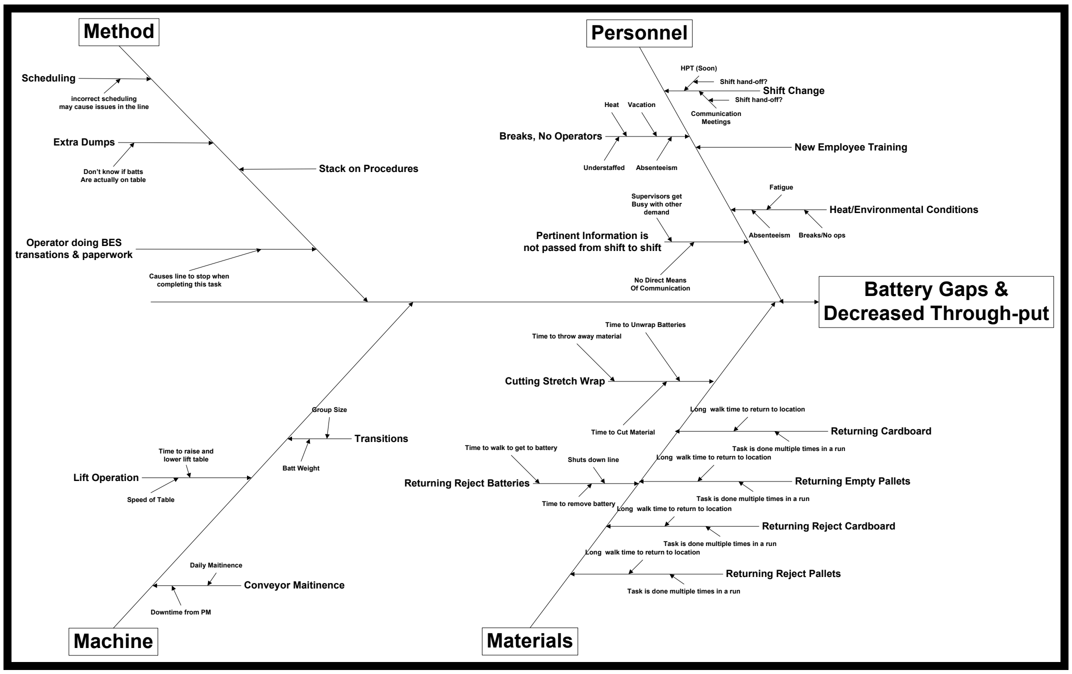
The methods used to perform tasks in the area can become direct causes of issues in stacking on batteries. It is important that all workers use their best judgment in the area to complete all tasks to ensure high production numbers daily.

1st Cause Identified: Stacking on Batteries

The method in which the operator stacks on batteries is important. There is no SOP (standard operating procedures) in this location so operators must use their best judgment to complete the work. Any new or less experienced operators may cause losses in through-put due to incorrect work habits in the area.

Figure 19 shows the Cause & Effect diagram that was recently directed towards explaining the identified problem in battery gaps and decreased through-put.

Figure 19: Stack-on Problem Analysis



The key items noted in the Cause & Effect diagram prompted a discussion between engineers that allowed us to highlight key causes that directly affect battery gaps and through-put in the area.

Capital Appropriation Request

The purpose of the CAR form is to document and authorize purchase of the fixed assets. The form is to be filled out by the project manager and then sent to upper management for approval. Most capital requests similar to this one have high upfront cost but generally have a large payback in the future. Most companies put restrictions on payback periods, limiting projects to 2-3 years. XXXXX has established an internal checklist for CARs that is used before sending them for approval, which can be seen below:

Installation Cost

A preferred vendor will be utilized for this project. The following items will be included in the cost to complete the robot installation:

Two (2) Integrated Robotic Battery De-Palletizes

- Paint/Color Finish
- Controller
- 480 VAC/3 Phase /60 Hertz Power
- Standard Protection
- Connection to Manipulator
- Connection to Cabinet
- Connection Kit
- Bus Communication
- Lower Arm Harness
- Device Net Cables
- UL Approved Safety Lamp
- Brake Release Unit on Base with Cover
- Fork Lift Device
- UL/UL Canada Safety Standards
- Operator Panel on Cabinet
- Door Keys
- Operator Mode Selector
- Controller Cooling
- Lighted Teach Pendant Unit
- English Language for Lighted Pendant Unit
- Main Connection Type – Cable Gland
- Main Transformer
- Flange Disconnect
- Service Outlet
- Power Supply
- Floppy Drive
- Base Ware OS 4. 0
- I/O Plus for Device Net
- Load ID and Collision Detection
- CD-ROM Software
- Software Installation
- Multi Function 1 Package
- English Documentation

Vision Inspection System

- Integrated Battery Inspection Vision System

Pallet Conveyors

- ¾ hp AC motor (conveyor speed 30 FPM)
- 2 ½” galvanized rollers on 3 1/4” centers
- 52” effective roller width
- Every roller driven loop to loop
- Includes photo eye and sequencing control
- +/- 1” leg height adjustment

Conveyor Brakes

- Electric brake for more precise positioning
- Releases when power is applied to conveyor motor

Honeycomb Cardboard Bins

- Mounts to floor inside robot cell
- Paint color/finish

Cardboard Slip-sheet Bin

- Mounts on floor inside robot cell
- Paint color/finish

Standard Safety Fencing

- 1 in / 1 out layout configurations
- Out (1) double door and two (2) access doors

Robot End Effectors

- Pick up 4 to 6 batteries

Electrical Installation

- Labor
- Hours
- Motors
- Devices
- Motor Control
- Machinery

- Conductors

The contractor will require certain information in order to accurately give quotes for installation. Contractors will meet with the team and discuss the project and all operations required in the area. All layout, design options, and constraints will be discussed. Below is a description of some of the information that will be needed by the contractors to move forward with quoting the project.

Part Sizes and Weight

A list of different sizes and weights is also important. This list is also important when designing the EOAT tooling. Contractors must design tooling to handle a variety of different weights and sizes. Depending on the design of the robot head, existing stack patterns may need to be adjusted to allow the robot to pick batteries from different locations.

Battery Types & Stack Patterns

When the team meets with contractors to implement and design the robot cell, one of the key items that will be requested is product part numbers. Generally, the larger the number and variety of part numbers, the more complicated the design will be, which also affects cost. Contractors will request a list of part numbers for all products that will be picked and placed in the cell. These part numbers will be input into the logic of the robot to recognize changeovers and the size and weights of the batteries.

Figure 20 shows and example of XXXXX battery stack patterns. Stack Patterns are very important to the design and build of the robot. Existing stack patterns may not allow the robot to pick certain batteries that are in certain locations. The team must find a pattern that can be consistent and allow the robot to perform fewer moves to retrieve the product. It also must be taken into account how these changes affect other facilities. The facility receives batteries from many other facilities. These changes must be made across the board to ensure product arrives in the agreed pattern.

Figure 20: Pallet Stack Patterns

Layouts

The robot cell layout involves several improvements to the current process. Installation of the Robot removes five operators from the process. Figure 21 shows the robot being setup to the east of both the stack-on conveyor and also the pallet conveyor.

Figure 21: Robot Cell Layout

Logic will be given to the motion controller to complete moves over the pallet conveyor to the stack-on conveyor. Full Battery pallets will be loaded to the east of the Robot by a driver using a fork-truck. Ninety-five percent of the pallets arriving at formation stack-on will arrive covered in stretch wrap. This material will be removed by the driver and disposed of before conveying the pallets forward. Once the stretch wrap is removed and batteries are placed, the motorized pallet conveying system will transport batteries towards the robot to be stacked off. When the batteries arrive at the stacking location, the robot will stack-on up to five batteries at a time depending on size. As each layer is stacked off, the piece of cardboard material will be removed and placed in the cardboard holder cells. After the last row is completed, the empty pallet will convey forward where it will eventually arrive at the pallet retrieval location for empty pallets. Often times to complete a customer order, only partial pallets are needed. Partial pallets are pallets that only require a certain number of batteries off the skid to complete the order. When a partial pallet is required, that pallet once completed will stop before arriving at the pallet retrieval location, where it will wait until a driver removes it.

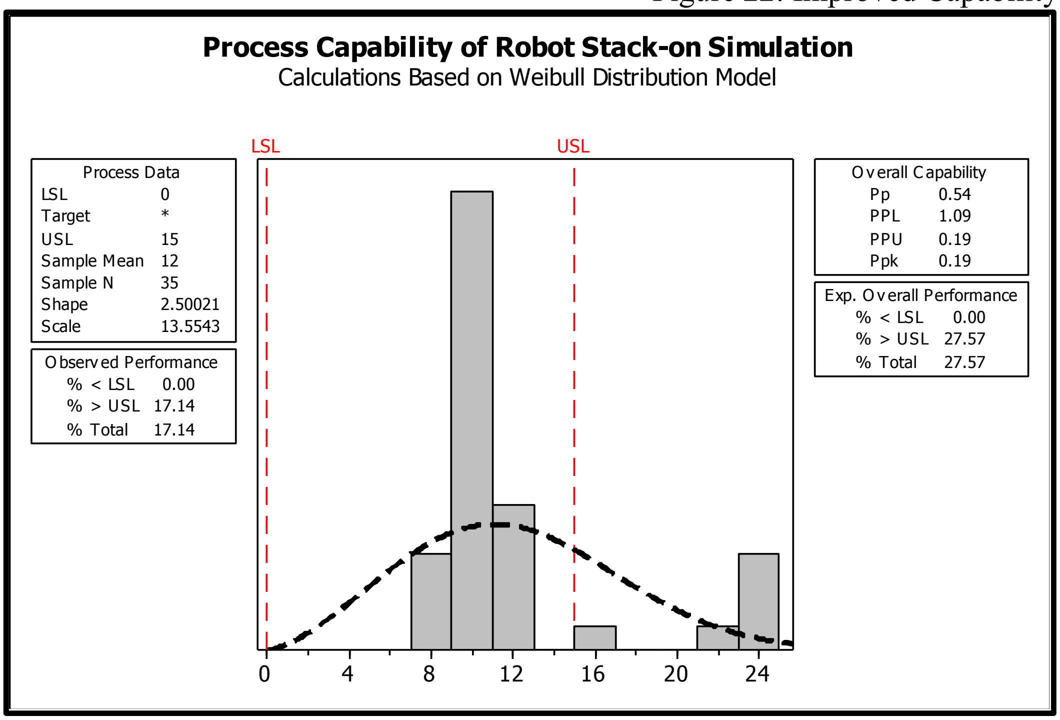
Once batteries are on the stack-on conveyor, they will be transported to the first station where an inspection will be completed by a newly installed vision system. The vision system will check batteries for damage that occurred at the previous facility or in transit. Any defective product will be pushed off the line to a gravity conveyor to be retrieved by an operator, as shown in the figure. Normally, all batteries are inspected by the stack on operator during normal duties. There is a high risk that the operator may miss defective product while trying to handle so many other tasks. As shown by the Cause & Effect Diagram, checking defective product also causes the line to shut down in order for the defective product to be removed by the operator. In the newly improved layout, the line will continue to run while any defective batteries are kicked off to the side.

Often times, the robot will be shut down for un planned maintenance or repair. For these situations, emergency stack-off locations were created so that production can continue to operate during these periods.

Improved Capability

A simulation of the Robotic Stack-on Operation indicated that 27.57% of the overall process experience gaps were longer than 15 seconds. The capability analysis in Figure 22 shows a 49% improvement from the current manual process. To resolve remaining gaps in the area from the robotics stack-on operation, we will adjust the conveyor speeds to recover time lost.

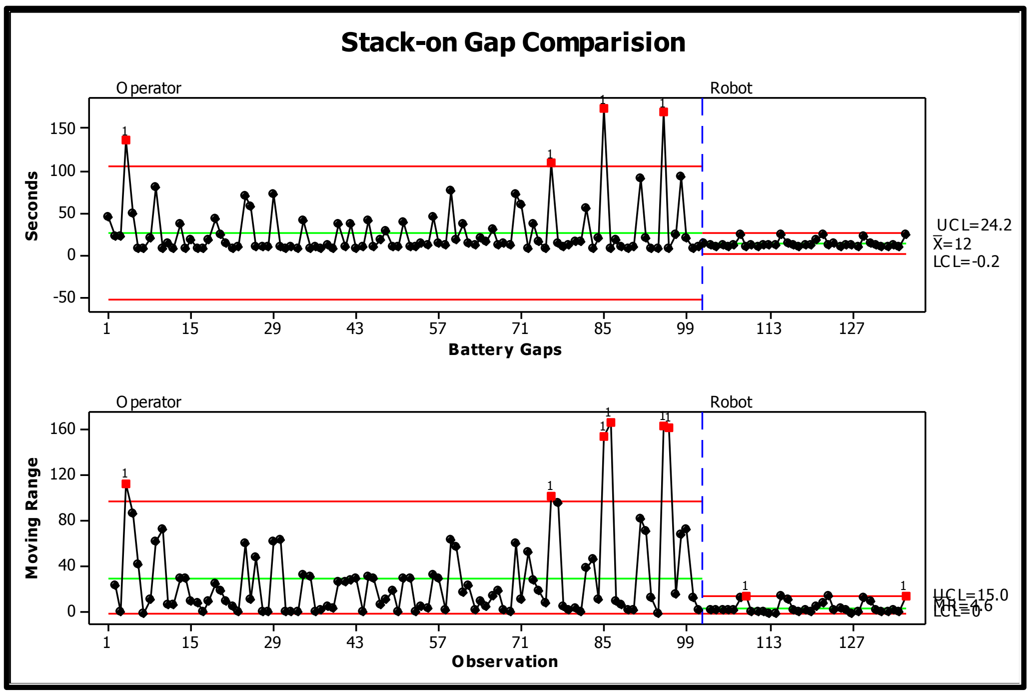
Figure 22: Improved Capability



Improved Moving Range and Gap Average

Figure 23 shows a new sample of data for gaps in the current area. An average gap of 26 seconds was seen in the Formation Stack-on area. In the new simulated robotic stack-on, an average gap of 12 seconds is seen in the area.

Figure 23: Moving Range Improvement



Labor Reduction and Return on Investment

The formation department currently run five shifts in this area, utilizing ten operators to complete the work. With the installation of the Robot and reducing the manpower in the area to zero, an annual savings of $500,000 per year is expected. This savings includes the annual wages and benefits of all five operators from our formation stack-on area.

Necessary Battery Gaps

Earlier, battery gaps in the line were seen due to the return of cardboard material, and the walking from lift table to lift. These conditions will still exist due to the robot still needing to handle cardboard material and also pallets transitioning in and out the work cell, which is comparable to operators walking to each table. The goal is to minimize this time as much as possible to reduce the gaps this operation creates.

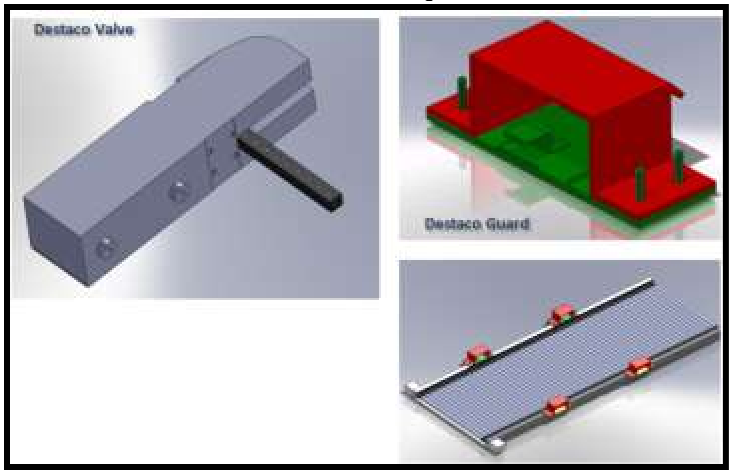
Scrap Prevention

Previous projects have shown that although automation is an improvement and reduces variation, there are still possible risks to damage product. As a result of this project, I recommend certain items to be included into the Robot Cell to help prevent scrap. Below is a list of suggested items to include in a work cell.

Pallet Location

Consistent pallet position is a significant factor when preventing issues at the robot cell. All pallets must arrive in the same location every time to prevent crashes at the robot. Implementing a hard stop using a Destaco valve will eliminate variation with pallet location when transferring into palletizing location. It is also smart to design guarding as seen in Figure 24 to prevent damage to the valve and any other sensory implemented into the cell.

Figure 24: Pallet Location



Instant Replay Stations

Figure 25 shows a picture of an instant replay station developed in our facility. The "Instant Replay Station" was created in a previous project as a maintenance tool that allows the maintenance team to replay incidents at the Robot to find accurate causes. As a result, the Robot scrap has decreased by 62% since June 2010.

Figure 25: Instant Replay Stations

Conclusion

Robotic stack-on is the optimal condition for the formation stack-on area. For several years, automation has been successfully implemented by several manufacturing and automotive industries. Adequate tooling is one of the most important considerations for successful implementation of robotics. Tooling should be built to safely handle various weights and heights. Sensor and vision is also a key component of the robot cell. Several sensors will be programmed and put in place to sense product and help the robot react to situations and various stack patterns. Conveyors will be the piece of machinery that encompasses most of the area of the cell and will need to operate consistently for product to move safely in and out of the robot cell. Controlling these conveyors and several other machinery in the cell will require several logic to be written. An introduction and brief overview of wiring diagrams and ladder logic gives a small but accurate idea of the amount of programming that must be completed to control machinery in the robot cell. In addition, a short introduction into programmable logic controls gives a unique persepective on how ladder logic is used in programmable controllers and how this all ties to pick and place robotics.

The introduction of six sigma methodology plays a huge role in identifying root causes and ensuring the project is successful and holds gains in the future. Several charts and data are developed to communicate where the project is, where it is going, and the tools that will be used to get there. Utilizing the DMIAC process ensures gains will be held after completion.

Robotic Implementation is never easy. All items discussed in this field project will play major roles in the success of the project and will be needed to assurance upper management that their investment will see true gains and hold still for several years to come.

Chapter 5

Suggestions for Additional Work

Robotic Material Handling has provided major gains for several manufacturing facilities. The final item and the often missing piece from the implementation process is a preventative maintenance program.

Preventative maintenance is essential to maintaining the equipment at the robot cell. This program is essential to maximizing the useful life of the robot. Preventative maintenance in a robot cell can range from multiple levels of visual inspections to performance testing and small adjustments.

The center of any preventative maintenance program is a complete physical inventory of all mechanical and electrical parts in the cell. A schedule for cleaning, adjustments, lubrication, minor repairs, and any other necessary task needed will be included in the program.

Most preventative maintenance programs are now managed through software. These programs are used to design, implement, and administer a program using a calendar to manage current and future activities. While robotics is a sound investment with major gains, without a strong preventative maintenance program it may cause a process more damage than good.

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