Silver Line Extrusion–Improving Quality through Six Sigma Methods and Ergonomic Analyses

Franchesca Doell
fndoell@gmail.com

Luke Magette
qwak051502@gmail.com

Jason Maytin
j.maytin20@student.rih.org

Alex Zhang
alex.lx.zhang@gmail.com

Wanda Duran*
wanda.duran@plygem.com

Kunjan Rana*
kunjan.rana@plygem.com

New Jersey’s Governor’s School of Engineering and Technology
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*Corresponding Author

Abstract—In industrial processes, both the physical process of creating products and the safety of employees must be closely monitored to ensure that the operations of the facility are running smoothly. Six Sigma, a set of techniques used by businesses to reduce the number of defective parts, and ergonomic analyses are applied in tandem to control the quality of production processes. The application of quality control techniques in the PVC extrusion process, specifically in the production of window and patio door frames, was explored. Profile 5531, a piece of a patio door frame with a significant defect rate, was investigated by analyzing numerous samples produced at the Silver Line window facility in North Brunswick, New Jersey. After process capability reports were run on the analyzed samples, dimensional offsets and variability within the production process were found to be the root cause of the defects. Additionally, the width offset introduced ergonomic strains for the punching machine operators, so a force study was conducted to analyze injury risk. To address the extrusion issue, various quick solutions were proposed and implemented using the Six Sigma methodology, including increasing the PVC hopper feed and adjusting the dry calibration rails. These changes were shown to significantly improve the efficacy of the production process and reduce ergonomic strains for the operators. Potential long-term solutions such as changing the factory environment and automating the punching machine were also devised to improve both the extrusion process and worker safety for companies like Silver Line.

I. INTRODUCTION:

Located in North Brunswick, the Silver Line window company produces their products from start to finish. The creation of these windows involves many different departments, including glass-making, assembly, and extrusion sections. As part of this process, the window frames, which are made up of polyvinyl chloride (PVC), are produced in many different forms through the dozens of extruders in a dedicated portion of the factory. These extruders each produce about 3800 feet of PVC every day. However, as in many factories, this process is not entirely automated, as there are some jobs that machines are unable to replace. One such job occurs after the PVC is extruded, when factory employees must transport the PVC parts to a punching division of the extrusion facility [1]. The employees at this part of the factory must insert the PVC parts into punching machines in order to develop the profiles. Due to the fact that the punching machines provide very little room for variability, any parts that are even slightly off dimension from the width of the punching machine will reveal themselves to the workers working at this section of the factory. When a worker has trouble inserting a part, they alert their team leaders, who report the problem to the quality control technicians at Silver Line. Two different aspects of the extrusion process were investigated: ways to improve the physical extrusion process through an analysis of Six Sigma, and ways to improve the ergonomics of the punching process when defects inevitably appear during production [2]. Profile 5531, the patio door component shown in Figure 1, was the specific piece with a significant defect rate that was investigated in this study.

Fig. 1. A digital scan of the cross-section of Silver Line’s profile 5531.
II. BACKGROUND:

A. Quality Control

One of the most important departments at Silver Line and other industrial companies is the quality control department; they continuously monitor the production process to make sure that all products are being made to dimensions within allowances that will result in little to no complaints from consumers or other assembly line operators. At Silver Line, proper documentation is essential for the assurance of an efficient and smooth output. Throughout the day, operators will perform checks on the dozens of extruders that populate the extrusion area, verifying that all quality zones are within their normal operating limits and monitoring aspects such as temperature, hopper feed, and length. During every shift, operators check the weight of the parts to make sure that they are close to their required value and sample a piece of the product by scanning it into a Promex machine, which measures the deviation from the specification limits. Once 30 of these samples are taken, they are compiled into a set for data analysis. Extrusion support then searches for possible causes of the problem, and implements solutions to try to return the profile dimensions back to their normal values.

![Promex Machine Scanning](Image)

Fig. 2. Samples of profile 5531 being scanned using the Promex Machine.

B. Six Sigma

Six Sigma is defined as a set of tools and methods used in the manufacturing industry to improve the quality of products and limit variability during the production process. A “Six Sigma process” is an ideal process in which there exists six standard deviations between the process mean and the nearest specification limit. Such a process would have a 99.99966% success rate in producing products free of defects [3]. However, since windows do not require this level of precision, a sigma level of five or even four is satisfactory. The Six Sigma methodology is currently being employed by large corporations to save hundreds of thousands of dollars each year by reducing waste and improving efficiency [4].

In order to achieve a Six Sigma process, a company must look closely at the variation between products along the production line. Manufacturing processes inevitably contain some variability, which can lead to dissatisfaction from both consumers and assembly workers on the product line. The simplest way that companies study this variation is through process monitoring, which studies every part of the production line to find the source of flaws [5]. Process monitoring is infrequent and manual in nature, as an automatic process often cannot solve the problem without human interference. Capability and performance indicators are another set of measurement tools that calculate the rate at which a process meets customer requirements [6]. Performance indicators measure a complete set of data, while capability indicators measure a subgroup.

Some of the most useful tools that Silver Line and quality control analysts use to discover flaws and abnormalities in the production line involve control charts. These charts display and detect unusual variability in the data. On these plots, there is often a display of each individual data point, as well as the mean, control limits, and specification limits. The limits of the data involve both upper and lower values, but differ immensely in their meaning and importance. Control limits are limits directly calculated from the process data in the control chart. On the other hand, specification limits are targets set for the product by the customer, as an overarching, industry-wide limit that must be met in order to be sold to a consumer [7].

The upper specification limit (USL) and lower specification limit (LSL) are utilized to calculate two of the most important values in quality control: $C_p$ and $C_{pk}$. Both of these values are a measure of data variation; the main difference is that $C_{pk}$ also takes into account the ability of a process to remain within control limits [8]. $C_p$ thus is a good measure of whether or not variation is an issue in the production process, while $C_{pk}$ is a good indicator of the efficacy of the production process. $C_p$ is calculated through (1), while $C_{pk}$ is calculated through (2).

$$C_p = \frac{(USL - LSL)}{6\sigma}$$ (1)

$$C_{pk} = \min\left(\frac{USL - \bar{X}}{3\sigma}, \frac{\bar{X} - LSL}{3\sigma}\right)$$ (2)

C. PVC Extrusion Process

Profile extrusion is a process used to construct the framing of window products at Silver Line. The first step in this process is the pulverization of PVC chips, which are ground to a powder. Specifically at Silver Line, a portion of these chips are recycled from excess plastic at other areas of the factory, decreasing overall waste. In fact, Silver Line produces PVC with either 100% pure PVC vinyl, or a mixture of 75% pure and 25% recycled PVC. The ground powder is then moved through a feeding system, consisting of a tubing network and a hopper, into the barrel of one of the dozens of extruders in the factory. Next, a specified amount of PVC is dropped from the hopper into a barrel, where it is moved through the apparatus by a large, metal screw. Because of PVC’s high viscosity, the material heats itself and becomes a putty-like substance in the channel. Silver Line uses a twin screw extruder, which passes the PVC through a set of two screws, doubling the friction...
within the material. This allows the company to save money by avoiding the cost of applying external heat to the material.

Once the material has reached a certain temperature and malleability, it is passed through a die. These large metal molds, which cost around $90,000 per unit, shape the PVC to be transformed into framing for windows. There are hundreds of types of dies that are used in the factory, each of which creates their own unique PVC part. After passing through the die, the malleable PVC travels through templates of the profile’s cross-section in a process called dry calibration. Dry calibration involves creating a vacuum within the die, while surrounding the die with cold water. This allows the material to completely fill the die, while also beginning the cooling and hardening process. Afterwards the PVC is submerged into cold water through wet calibration in order to make the PVC solidify. Extrusion chained pads pull the PVC out at a constant rate in order to prevent deformation from affecting the material. Finally the PVC is cut into specific lengths using a saw and is moved to another area of the factory to be formed into windows.

Fig. 3. A network of tubing carries the pulverized PVC to hoppers on the extrusion line.

Fig. 4. PVC exits the wet calibrator as it solidifies and takes form.

D. Punching Machine

When an issue in the PVC extrusion process arises at Silver Line, the first individuals to notice are often the operators at the punching machines. Located a few steps away from the PVC extrusion line, these operators are tasked with pushing the PVC forms into machines that punch out holes into the parts. These holes will later be used for the assembly of the window frame and are essential for producing a well-made finished product. The workers at this location often work quickly and efficiently, meaning that only a few workers are at this location at any given time. However, problems emerge when these workers have trouble inserting the PVC parts into the punching machine. Very few quality problems appear from customers, or even other parts of the factory; a majority of them arise in this station, due to the tight limits of the punching machine. The machine has very specific constraints, as the part must be positioned perfectly for the holes to be punched out properly.

Fig. 5. Profile 5531 is pushed through a punching machine.

E. Ergonomics

Ergonomics concerns how workers are affected by their work, taking into consideration the discomfort and possibility of injury that arises from different working environments. The end goal of ergonomics is to design a task fit for a human to safely work in. There are three main aspects of a job that may be evaluated by an ergonomist when investigating a line of work, which are collectively known as Ergonomic Stressors [9]. The three stressors are repetitiveness of a job, the force needed to complete this job, and a number of postures developed by a worker that pose a risk of awkwardness or uncomfortability. These stressors are important to maintaining a healthy working environment, ensuring the employee can protect their health, as well as protecting the company from any repercussions that may arise from an injured employee.

At Silver Line, there are five main factors that safety engineers consider when analyzing ergonomics: repetition, force, contact stress, vibrations, and awkward postures. If any of these factors are happening in conjunction, the associated risk grows exponentially. Additionally, ergonomics engineers must consider the psychological problems that occur due to these stresses. Silver Line has adopted safety techniques so that their equipment and processes are safe for at least 75% of the female population [10]. Ergonomics at Silver Line are aimed at improving morale, but first and foremost, lowering the cost resulted from potential injuries may cost the company. A number of injuries may arise from the aforementioned factors, but the most common injuries include sprains, carpal tunnel syndrome, back pain, and hernias. Each of these conditions can be detrimental to a company, as injured employees...
may be absent from their jobs for many days, leading to lower productivity and workman’s compensation expenses for the company. Therefore, it is in the best interest of companies to reduce the risk of injury of an employee, while still maintaining high profits and low spending. To do this, companies generally employ three main solutions: engineering controls, administrative controls, and personal protective equipment [11].

1) **Engineering Controls:** These controls involve designing a job in order to consider the abilities and limitations of workers. This often involves changes to the physical machines and layouts of factories. Automatic devices may be used to reduce the load on workers, though simpler solutions, like placing handles on equipment, may be used as well. Engineering controls also involve changing the layout of the workstation, which may involve the implementation of benches that are adjustable in height.

2) **Administrative Controls:** This type of control does not involve a physical change in the factory, but instead seeks to reduce the risk of injury until engineering controls can be applied. There are many types of administrative controls, but some of the most common include job rotations, worker training, and changing shift times.

3) **Personal Protective Equipment:** These solutions are mandatory in factories around the world, as they provide essential protection to the human body. They include ear plugs, hard hats, and safety goggles.

**F. Methods**

When Profile 5531 was first identified with a quality issue, the first step taken was the creation of a flow chart (see Appendix, Figure 12). Flow charts are important in identifying the potential steps to solving a problem, and the possible outcomes that can appear from the steps taken in the process. Two problem areas were initially identified in the flow chart: problems with the physical extrusion process, and problems with punch operation. First, the extrusion process was investigated to see if any physical changes to the machine or process could help reduce the variability in the data. A fishbone diagram (see Appendix, Figure 14) was developed to try and identify the reasons why the width of the profile was too large, which involved looking at five different possible categories where problems may have appeared: material, machine, methods, man, and environment [12]. This diagram helped identify the problem areas, which allowed for the profile to eventually be reduced by the quality control engineers. However, while the problem was not caused by improper punch operation, the ergonomics of the punching process needed to be investigated, as another defect could arise at any time, and ergonomic concerns were needed during normal operation as well. To address these problems, a Baseline Risk Identification of Ergonomic Factors (BRIEF) and BRIEF Exposure Scoring Technique (BEST) diagram were created together [13]. First, the punch process was investigated by observing an employee carry out the process. The BRIEF diagram allowed the concerns to be identified for specific problem areas of the body, assigning numerical values to each body part based on severity. Next, the BEST Diagram took the values from the BRIEF diagram and converted them to a risk factor for how hazardous the job may be, which was determined to be a medium risk (see Appendix, Figure 13). These diagrams were used to assess the hazards for workers in order to come up with possible solutions.

**G. Purpose**

The Silver Line production line requires thousands of complex steps to run smoothly and efficiently for the process to function correctly. During Silver Line’s production process, a variety of issues arise in different products, with multiple problems possible in one single part. For the company, quality control in manufacturing ensures that its products are satisfactory for its customers. The purpose of this project is to analyze the methods used to improve the PVC extrusion process. By using quality control methods, the production process will be streamlined, reducing overall waste, increasing efficiency, and increasing customer and worker satisfaction.

Ergonomics is another aspect of quality control that analyzes and addresses people’s efficiency in their working environment. It is often used to increase savings, enhance morale, and prevent musculo-skeletal disorders from occurring (e.g. carpal tunnel syndrome, epicondylitis, and rotator cuff tendinitis). In Silver Line’s case, Six Sigma can be enforced within the PVC extrusion process to prevent hazardous working conditions which can cause such injuries. Overall, following the Six Sigma methodology enables companies to raise quality standards, reduce costs, and increase profits.

**III. EXPERIMENTAL PROCEDURE**

A. **Solutions to Dimensional Offset and Variability**

Selected samples of profile 5531 were run through a Promex machine to determine the error and variability of the extrusion process. A Promex machine is a device that gathers the precise dimensions of a piece using a set of cameras. After running through 30 samples, the Promex machine determined that the dimensions of the piece was significantly out of its specification limits. For a company like Silver Line, it is necessary that solutions be implemented quickly to maximize the number of produced goods. Several plausible solutions were hypothesized to return the dimensions to within their specification limits, such as changing the water levels of the tanks used in wet calibration, increasing the feeder rate, calibrating the rails, cleaning the PVC templates used during dry calibration, and increasing the vacuum strength in wet and dry calibration [14]. It was determined that increasing the hopper feeder rate would be the most time effective solution.

To track how the changes to the extrusion process affected the sample variability, the samples were analyzed through a capability analysis in a program called Minitab, which is used for statistical analysis. A Gage R&R study was also conducted within the Promex machine to ensure the repeatability and reproducibility of any collected data. A capability analysis is
used to determine whether the data can meet the specification limit, while a Gage R&R study is used to validate the accuracy of the Promex machine. It was concluded that an additional action was needed after the hopper feed changes: adjusting the rails on the dry calibrator, then cleaning the rails and PVC templates. Each of the rails were calibrated by 10-15 thousandths of an inch using an offset key to make the width of the PVC smaller. Moreover, the rails of the calibrator were ground down until they were level with one another. This adjustment enables the PVC to better maintain its shape as it is cooled down during the calibration process.

![Fig. 6. Image of the calibrator where rails were adjusted.](image)

B. Ergonomics Analysis: Force Study

As a result of the improper sizing of profile 5531, Silver Line operators were having difficulty pushing the part into the punching machine. A force test study was conducted to determine the risk of injury with this added strain. An employee at the company was first tasked with conducting her normal operations while being recorded, allowing her actions to be monitored and viewed for any potential sources of injury. Next, five trials were conducted, with two separate conditions. The first trial involved a control PVC profile with a value that was in the specification limits. This part was inserted into the punching device and measured with a force gauge in order to determine the amount of force needed to push/pull the device. Next, a defective PVC part was tested in a similar manner, and the average of both pieces were found and compared.

IV. Results

A. Process Capability Report of Profile 5531 Before Changes

In the case of Profile 5531, a number of pieces were unable to fit properly into the punching machine. The average width of the piece was 0.03 inches above the specification limits, suggesting a critical inefficiency in the extrusion process. A Minitab analysis was run on 30 samples for profile 5531, as well as a process capability report, which is shown in Figure 8 [15]. The lower specification limit was set at 4.785 inches, while the upper specification limit was set at 4.815 inches, meaning the limits were 15 thousandths of an inch from the ideal measurement. The average for this data was 4.837 inches, which is 0.022 inches away from the upper specification limit. For each graph, the data was assumed to be a normal distribution, with the $C_p$ and $C_{pk}$ values calculated from this assumption. For Figure 8, before any changes were made to the extrusion process, a $C_{pk}$ of -1.30 was recorded. Silver Line keeps very tight specification limits, even though window frames do not require a high degree of precision. As a result, any values that are at least within a certain range out of the specification limits are acceptable to the company. A $C_{pk}$ value of -1.30 reflects a mean that was considered too far from the specification limits to be considered comfortable, which needed to be amended.

![Fig. 7. A force study is being conducted using a force gauge on the punching machine.](image)

B. Process Capability Analysis After Hopper Feed Changes

The hopper feed rate was increased for two primary reasons: first, increasing the amount of PVC flowing into the extruder helps to balance the width of the product. Second, feeding more PVC into the hopper makes each piece of PVC heavier. The additional weight prevents the PVC from expanding during the cooling process in wet and dry calibration, decreasing the overall size of the profile. Furthermore, solutions with
short implementation times are crucial for the Silver Line company because the Profile 5531 problem occurred during “door season,” the period of summertime when people are most likely to make home renovations. It is important to note that this change, while effective, was only a temporary fix that needed to be revisited in the future. A Minitab analysis was run on 30 new samples, as represented by Figure 9. While the data was still not within the specification limits, the mean of the data had noticeably moved towards the specification limits, to a value of 4.825, just 0.01 inches away from the upper specification limit. Additionally, the $C_p$ increased from 0.88 to 1.55, demonstrating a reduction in variation to 4 sigma levels. This change to the mean, as well as less variation between the data points, was reflected by a change in the $C_{pk}$ value to -1.03, as opposed to the original -1.30. This change in the $C_{pk}$ value towards a value that was more positive means that the data had reduced in variability, and had reached a value that was acceptable to the company, having taken into account the tight schedule and with the understanding that more work needed to be done to achieve an overall width closer towards the specification limits.

![Process Capability Report for 5531 Overall width after data](image)

Fig. 9. A Process Capability Analysis of the production process of profile 5531 after the hopper feed was increased.

**C. Process Capability Analysis After Dry Calibration Rail Adjustments**

After the increased hopper feed had produced positive results, adjustments were made directly to the dry calibrator to reduce the width offsets. Changes were made to the dry calibration rail, which works by running the PVC along metal plates under cold water that allows the PVC to cool. The PVC is held tightly within the dies, allowing it to cool in a dry environment, while also becoming smooth and filling the die completely using vacuum tubes. In this case, the dry calibrators were taken off of the extruder, where they were taken to a die shop and adjusted using keys. The keys adjusted the railings on the sides of the dies; when they were inserted, it brought the railing in 10 thousandths of an inch, which allowed the PVC profile to reduce in width as well. After this change, 30 more samples of Profile 5531 were tested and measured, represented by Figure 10. As compared to Figure 9, the data in this new set showed many more data points that were nearly within the upper specification limit, as opposed to only about two or three that were within this limit in the previous set. The sample mean reduced to a value of 4.821, which is 0.004 inches closer to the specification limit than the data after the hopper feed increase, and only 0.006 inches away from the upper specification limit. While this value is not within the specification limits, it shows a promising trend that the part is reducing steadily towards the specification limit. Even more encouraging is this dataset’s $C_{pk}$ value, -0.44. The “Before” data set had a $C_{pk}$ value of -1.30, while the “Hopper Feed Increase” set had a value of -1.03. This change to -0.44 means that the data is both more closely aligned together, and also nearer to being within the specification limits. This change was much greater than the change from the “Before” data to the hopper feed increase, meaning that the hopper feed increase and dry rail adjustment in conjunction were very effective in reducing variability within the data, and in bringing the data towards a level that is acceptable to the company.

![Process Capability Report for 5531 Overall Width After Dry Rail Adjustment](image)

Fig. 10. A Process Capability Analysis of the production process of profile 5531 after calibrator rails were adjusted and the calibrator was cleaned.

**D. Force Study Data**

When the workers at the punch machine at Silver Line complained of trouble pushing and pulling Profile 5531 into and out of the machine, it was imperative to investigate both ways to solve the defective product and also reduce the stress on these employees when these problems inevitably arose. Even on a normal day, pushing and pulling the PVC parts into and out of the machine can cause a strain on the body, as this task is quite repetitive, made significantly worse by a defective part. In fact, the Health and Safety network reports that one in ten accidents that are reportable by the Reporting of Injuries, Diseases and Dangerous Occurrences Regulations are caused by pushing or pulling tasks [16]. Pushing and pulling cause strain on many parts of the upper body, including the arms, shoulders, chest, and back.
When the primary arm and shoulder muscles are fully extended, the Eastman Kodak Company recommends that the maximum force exerted on the body is 24 force-pounds (lbf) [17]. The process of using the punching machines, from receiving the part, to punching it, to placing on the finished rack, takes approximately 68 seconds. The orientation of the part in respect to the worker appears awkward; the worker must grab the profile by the hands and pull horizontally by extending their arms in front of them, grasping onto the profile, and sliding the profile in or out with a sweep of the arms. This type of motion does not utilize the whole body, and the position of the worker presents possibilities for injury to arise. According to the Eastman Kodak Company, exerting a force at an angle that is not directly in front of the body, like the situation described at the punch machine, is a possible hazard to an employee [17].

At the Silver Line factory, a five trial study was conducted for both the control and defective parts in the punching machine, as shown in Table 1. After these trials, a mean of 1.10 lbf was determined for the control part. After this control value was established, a defective PVC sample was tested in the same way as the control. After multiple trials, the mean value for force was determined to be 12.93 lbf. This value is 11.7 times the amount of force needed to push in the control product, a substantial increase. While this value does not approach the maximum value of 24 pounds that is recommended, an increase of more than 11 times is clearly a present burden to the workers. Nevertheless, the results of the force study indicate that the punching machine offers minimal risk to the operator, even when defective parts are produced.

<table>
<thead>
<tr>
<th>Part Type</th>
<th>Trial 1 (lbs)</th>
<th>Trial 2 (lbs)</th>
<th>Trial 3 (lbs)</th>
<th>Trial 4 (lbs)</th>
<th>Trial 5 (lbs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-Defective</td>
<td>1.20</td>
<td>1.03</td>
<td>1.30</td>
<td>1.00</td>
<td>0.95</td>
</tr>
<tr>
<td>Defective</td>
<td>14.00</td>
<td>12.45</td>
<td>12.60</td>
<td>11.70</td>
<td>13.90</td>
</tr>
</tbody>
</table>

V. Conclusions

For a company like Silver Line, it is imperative that the PVC extrusion process meet certain specification limits to avoid ergonomic issues while also maximizing the efficacy of the production lines. After the aforementioned solutions were implemented, it was determined that the $C_p$ and $C_{pk}$ value increased in comparison to the original values, indicating a decrease in variability around the target specifications and an increase in the number of parts falling within an acceptable range of the specification limits. The initial state of the production process, which led to ergonomic strains for the punching machine operators due to an abundance of defective pieces, was improved to a state where defects were lessened and complaints from operators reduced. Overall, the solutions implemented by Silver Line to improve their extrusion process, as guided by the Six Sigma principles, were effective in increasing the quality of the production process for Profile 5531 without disrupting any part of the process.

A. Future Improvements and Solutions for PVC Process

While the overall process was improved in the short term, further refinement of the PVC extrusion process could potentially yield less defects and improve profit margins for Silver Line and other companies that apply extrusion processes in the future.

In some cases, the tank plates or dry calibrator are the causes for undesirable measurements. According to the Silver Line company, a set of tank plates can cost around $6,000, a new dry calibrator can cost $13,000-$20,000, and a die can cost upwards of $90,000. For the company, these investments are rare, as dies and calibration equipment can last anywhere from 10-40 years. Normal wear does make this equipment a worthy investment at times, as equipment can not always be fixed. One way to prolong the lifespan of this equipment is to purchase wear packs. About once a year, the equipment must be milled to account for any sharp edges that may shape the profiles improperly. While a new die could be purchased, a more practical solution would be to buy a wear pack. Wear packs are specific parts of the die that may wear more often than others, allowing the die to be fixed, not completely replaced. Wear packs cost roughly $30,000, which is significantly less than the $90,000 price-tag that Silver Line pays for a new die.

![Fig. 11. Images of components of the extrusion process. Top left: die; Top right: tank plate; Bottom left: side view of dry calibrator; Bottom right: dry calibrator](image-url)
the width in a controlled manner. The vacuum power may also affect the product, as increasing the vacuum would lead to a smoother and less jagged edge to the PVC profile. These changes do not come without risk, as changing any environmental factors could have an adverse effect on another part of the process. While these may be risky, though, studies could be done to see how changing these factors changes the PVC profile, as well as parts of the PVC extrusion process, to test the effectiveness of the changes.

B. Future Improvements and Solutions for Ergonomics

There are a variety of possible solutions that may be effective in reducing the problems accompanied by defective parts. When workers at the Silver Line punching machine were asked if they felt any discomfort while working, they complained that defective parts would cause shoulder and back pain. One possible cause for this is that workers are not working in their optimal power range. The height of the punching machine was measured to be 40 inches, the optimal height for the average individual. However, some of the workers at the company were significantly shorter or taller than the average individual, meaning that their power range is at a different level than the punching machine. One solution to this problem would be a height-adjustable punching machine. With a machine this large, however, it would not be practical for a worker to physically adjust the height of the machine, even with a mechanism that lessened the load on the worker. Making an intuitive series of individual adjustable legs without causing physical strain on the operator would be infeasible. Hypothetical alternatives such as a pneumatic device or hydraulics system with adjustable controls could be implemented so as to not demand significant efforts from the operators. However, these solutions could cost thousands of dollars, and some resilient employees may not even utilize the changes, suggesting that simpler solutions could be employed to aid their workers.

Two other simpler solutions that are less expensive are the implementation of rollers or lubricants on the punching machine. For defective parts, rollers would help reduce the force needed to push the profile in, reducing friction and strain on a worker’s arms, back, and shoulders. Rollers are quite cheap, costing only a few hundred dollars, meaning that this change may be a very cost-effective way to improve the working environment for the employees of the factory. Lubricant could reduce friction on the punching machine’s metal tracks significantly, and one coat could be applied to the punching machines without changing hardware at all. However, most lubricants could leave residue on the punch machines which could cause issues later on in the assembly process.

Finally, a more radical solution to the punching machine issue at Silver Line would be the implementation of an automatic punching machine that would require only machine operators to run, instead of employees physically pushing the parts into the punching machine. An automatic machine would clearly reduce the manual impact that a defective part would have on a worker and would be much safer than the manual punching machine that Silver Line currently uses. However, these machines are expensive, often costing hundreds of thousands of dollars. An investment in a punching machine would need to be carefully considered by Silver Line, as this is a very large investment that involves company money, worker safety, and the potential loss of jobs. In any case, the ergonomic concern at the punching machine in Silver Line is an important part of quality control within the company.

APPENDIX

Fig. 12. A flow chart for relating the Six Sigma method analysis to ergonomics.

Fig. 13. A BEST sheet used to determine the ergonomic risk for an operator.
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