Abstract

In industry, it is essential to focus both on goods and processes. In the window making business, refining the process to maximize profit and customer satisfaction becomes an essential part of making a successful product. In the case of Silver Line Industries, the window making process involves numerous steps that can be improved such as the data collecting process and glass cutting process among others. The improvements to these processes can result in additional efficiency for Silver Line and a higher quality product for the consumer. After identifying potential areas of improvement, potential solutions were determined to minimize glass breakages such as chemical solvents, reduced thermal shock, and fractography. These solutions require additional research, however, because there is a lack of data to choose a best approach and some approaches may require large monetary investments such as new pressure reading machines and other automated devices.

1. Introduction

The main goal of industrial engineers is to improve what already exists. Improvement, however, is a vague term. It can mean slashing costs, expediting processes, or incorporating safety checks, among others. In the end, an industrial engineer must balance all these developments and revisions to maximize profit for a business while satisfying the customer. Industrial engineers play a key role in economic and engineering progress. By creating and refining techniques they can ensure that new and old products reach consumers in a timely and cost-effective manner.

This project requires taking on the tasks of an industrial engineer at Silver Line Industries. Silver Line Industries is the leading manufacturer of vinyl windows in the United States. Silver Line is limited to national and local levels because of overseas shipping prices and foreign building codes and operates four facilities in Ohio, Illinois, Georgia, and New Jersey. Each facility provides windows to broad surrounding regions; the facility in New Jersey has sent products as far south as Florida. Specifically, the facility in New Jersey is able to produce 7,000 windows a day in two shifts with about 1,000 employees involved in direct labor and 300 employees involved in indirect labor. [1] Silver Line offers various types of glass in
addition to the custom shapes they make, including tempered, green tinted, LoE2, and laminated glass, among others. It produces 463 different configurations of windows which fall at the lower end of the industry’s pricing spectrum ranging from $250 to $350 per window. [2]

On-site visits are essential to developing the familiarity needed for producing process maps. By taking into account the metrics and defect potential in each step of the process, areas in need of change are identified. Once possible changes are acknowledged, they can be ranked by importance based on the turnover involved with making the changes and the long term benefits. When these factors have all been weighed, an informed recommendation can be made to the company. The Industrial Engineering in a Major Manufacturing Facility project aims to propose alterations to Silver Line Industries’ window manufacturing process to increase efficiency at the factory and thereby decrease expenditure and increase profit margin.

2. Background

The method used during this experiment was the Six Sigma analysis of Silver Line’s glass manufacturing, specifically the ‘Define Measure Analyze Improve Control’ (DMAIC) problem solving strategy. Six Sigma analysis allows one to put a number value to the process performance. This DMAIC strategy encompasses defining the problem, measuring the current process, analyzing the data to postulate the origin of the problem, improving the process by proposing modifications, and then controlling the long term-effects by updating data and monitoring the success of the company. [3]

Investigation of Silver Line’s glass cutting process began with setting a project scope; boundaries were placed on a specific sector of the overall process for studying. By setting these boundaries, straying from focus was avoided and measurement of the specified part of the process began. Specific metrics that were collected included time, distance, temperature, pressure, and more.

2.1 Suppliers, Inputs, Processes, Outputs, Customers (SIPOC) Diagram

To fully explore the manufacturing process, visual diagrams can be utilized to further analyze and interpret individual details and steps of the overall process. One such diagram is the SIPOC diagram. A SIPOC diagram represents the suppliers and inputs of a certain process. Next, the process is listed. After that, the outputs and customers of the process are listed. This diagram is especially beneficial as it exemplifies the transition between starting and finishing materials and aids the viewer in understanding additional information about what exactly is needed to begin a certain process. The SIPOC diagram depicted below summarizes Silver Line’s window making process from glass cutting to window assembly. [3]
2.2 Value Stream Map

A value stream map is a diagram that shows the flow of materials and information of a process from beginning to end. It is used not only to map out the completion of an order from customer request to product shipment, but also to indicate which steps of the process are value added. Value added steps can be defined at steps that alter the final product in a way that the customer is willing to pay for. [3] The value stream map for Silver Line depicted in Figure 3, which demonstrates one window’s progression through an assembly line at the factory; there are four assembly lines working simultaneously on various thicknesses and types of glass. The value stream map includes the initial order from the customer, the supplies, and each macro process. Under each macro process the value added steps are shown. The times on the peaks of the lines show the times of the value added steps. The times on the bottom of the line indicate the time the non-value added steps of the process take. This is important to consider because it can display how much time is wasted between steps that does not add value to the product. After the value added steps, shipment and delivery are shown.

Data was also organized using visual aids in the form of process maps. Process maps depict the various stages of a procedure in the order that they occur, and can also include metrics about each step. The following processes were observed.

2.3 Floor Plan

Depicted below is the floor plan for Silver Line’s window manufacturing process. The macro processes that were studied in detail during this project are color coded to make the process order easily identifiable. The layout of the factory is carefully designed to minimize downtime during the manufacturing process. Additionally, utilizing a compact layout reduces the distance glass has to travel on carts and thereby reduces the chance of accidental breakage during

*Figure 2 Value Stream Map*
transportation. Silver Line’s current layout, as depicted in Figure 3, results in glass having to travel no greater than fifty feet between stations through the first five defined macro-processes. However, when moving to the final step, assembly, glass needs to move over 200 feet. The traveling distance between butyl application and assembly may not be ideal, but it is currently necessary and unavoidable due to the dimensions of the factory.

2.4 Cut Glass Process

The glass cutting process is shown in Figure 4. The primary input to the process is the raw sheets of glass. The sheets are typically 72 inches by 84 inches and come in two thicknesses: 2.2 and 3 millimeters. Typically, 65% of Silver Line’s orders are for 2.2mm (single strength) glass, and 35% are for 3mm (double strength) glass. [1] The glass is supplied by Guardian, a private manufacturer of glass and other building products. Due to the pressure from the other glass sheets and jostling during handling, both the front and back pieces of raw glass per pallet are assumed to be unusable and are scrapped immediately. Aside from looking for apparent visual cracks or damage, Silver Line does not currently check the inbound raw glass quality.

The glass cutting process begins when a forklift takes the glass pallets and places them upright on the side of the glass cutting table. The glass is then pushed over sideways onto a table that streams a cushion of air to protect the fragile glass. Before the machinery begins cutting the glass, the orders are put into an optimizing software that looks three orders ahead to make cuts that minimize scrap glass. After the orders are processed,
the glass cutting machine uses a rotating diamond blade to score 1/10 of the glass’s thickness. [1] Using a conveyor belt, the glass slides over the snapping area, where typically one or two operators are standing ready to snap the glass into the scored shapes.

Based on the order number, the glass is then divided into three batches. Each batch is placed into a cart that can hold up to 100 pieces of glass [1] and has a paper attached for identification. The operator scans the barcode on the paper attached to the cart. Once the cart is filled it is pulled over to a designated area where it waits to be taken into the next process of edge deletion and spacer attachment. Another empty cart is then brought over to replace the full cart.

2.5 Edge Deletion

Figure 5 describes the edge deletion process that only pieces of glass with coating undergo. The glass is placed on a bed of rollers coated side up. A worker then slides it under a wheel made of Scotch-Brite, an abrasive material, which rotates at a high speed. Each edge of the glass is slid under the wheel to remove the coating so the glass can stick to the spacer. It is slid under the wheel in a certain direction in order to put less pressure on the glass which alleviates further scratching and cracking. When this is finished, the glass is put on a rolling conveyor belt and advances to the spacer attachment process.

2.6 Spacer Attachment

After edge deletion has occurred or if the glass has no coating, it is pushed onto a bed of rollers into a washer. The movement of glass through the washer can be controlled by the operators that assemble the module by pressing a switch that halts the movement and cycle of the washer. When this button is pressed, a red light will notify the operator working the edge deletion process to stop sending glass through the washer. When the red light turns off, he will resume the process. Additionally, there is a sensor that detects which side of the glass the LoE is on. The washer uses deionized tap water and a heat source between 130 and 140 degrees Fahrenheit to wash each piece of glass before it is formed into a module. [1] Brushes are used to clean the glass, yet they don’t scrape the surface enough to cause cracking. The glass exits the washer and is pushed out on a plane of wheels to two operators while the spacers and grilles are delivered by another operator. The operators take the piece of glass and sets it before them. One worker

![Figure 5 Edge Deletion Process Map](image-url)
receiving the spacer from the spacer assembly line and examines the joints to make sure they have been correctly aligned. Using his pointer finger and thumb, he forms the two bottom edges of the spacer into right angles and places them on their respective corners on the glass pane. The operator across from him lines his two corners up with the remaining corners on the glass. Next, the top pane of glass is fitted on the spacer, and the module is complete.

The operators then proceed to roll the glass modules on a roller bed into an oven with a range of 150 to 160 degrees Fahrenheit. As the module passes into the oven, a small wheel is pushed down and registers that another module has been manufactured. This number is displayed on a screen above the assembly line. The module enters the oven where the heat from the machine activates the adhesive and creates a bond between the sheets of glass and the spacer. The window then rolls out of the machine to two other workers. Labels corresponding to window orders are printed from a computer. One worker sticks a small label on the spacer and another puts a bigger label on the top of the window. The small label contains the order, size, model, argon option, and line the window was produced on. The larger label color codes the windows which require argon, providing a visual for easy reference. Next, one of the two workers puts the window onto a cart, which has slots for 50 windows. A third worker verifies that the labels have been correctly placed and runs a quick visual scan for any obvious defects that the module might have. The cart is then pushed off to the argon station.

### 2.7 Apply Argon

After the sheets of glass are attached to the spacer, the next macro-process is insulating the window with argon (only if ordered by the customer). Silver Line gives its customers the option of filling the spacer in between the sheets of glass with argon, which helps to insulate a home and thus helps to lower a customer’s power bills over time. The label applied during the spacer attachment process identifies if the window module will receive Argon. A green label indicates that Argon is required.

The windows are brought on a cart to the room where machines insert Argon. The windows on each cart are mixed between receiving argon and not being filled with any gas. It is important to note that the workers closely monitor the air temperature inside the windows and the temperature of the glass and compare it to the factory air temperature. The
glass is not durable when it comes to dealing with extreme temperature changes, and the windows must be allowed to cool to within five degrees of room temperature [1] before they are filled with gas or sealed in order to prevent the expansion of air and possible glass breakage due to thermal shock.

There are four argon machines and four corresponding operators. Each machine has four needles connected by tubes to a tank of argon, and the operator sticks the needle into the hole in the spacer which has been previously punched by the uncoiling machine. The operator then turns the machine on with the push of a button and waits for the window to fill with argon. The amount of time needed for a window to fill with argon is dependent on its size. Once the window is filled with between 92 and 99% argon, [1] the machine beeps and turns off. The operator then seals the spacer with a screw using an air gun. The air gun stops when it reaches the correct torque. If the windows are to be left with just air, the operator simply screws the screw into the spacer. A gold screw is used to signify an argon filled window and a silver screw is used to signify a non-argon window. The operator then repeats the process until all windows in the cart have been filled with argon.

2.8 Apply Butyl

The next macro-process is the application of butyl. Provided by HB Fuller, [1] the butyl is a sealant that helps to keep the argon and air from escaping the spacer. Although the main purpose of the screw is to keep the argon from escaping, the butyl is a reinforcement that seals the rough corner of the window, regardless of whether or not it has argon. The butyl operator applies the substance from a hose to five windows on
the corner that has the screw. He then uses a smoothing tool to make sure that an even, flat coating has been applied. Any bumps or irregularities will put added pressure onto the glass once the window is in the frame. Because the module has a snug fit in the frame, dried butyl protruding from the smooth surface of the module will alter its shape and therefore make it a poor fit for the frame. After application of the butyl, it is given time to cool down and solidify, and workers push carts with completed butyl application to the other side of the room. With the completion of this process, the mainframe of the window is completed, sealed, and protected, and only aesthetic details are left to be completed.

2.9 Assembly

The final step in the manufacturing of the window is assembly. In this process, the completed window module, the sash, and the frame come together to form one final unit. The sash and frame are inputs into the process, and their suppliers are the vinyl assembly line. The vinyl assembly line makes the vinyl needed for the accessories to the window module out of a powder that comes from an outside supplier. The line then shapes the vinyl and then welds the pieces into a sash or frame. A completed frame has a protective foam covering attached to the outside and then waits for the placement of windows in sashes. In the meantime, a sash is placed into a machine that removes any imperfections along the inner edge of the sash that would put additional pressure on the window. Next, setting blocks are placed inside the sash to reduce pressure on the window when it is placed in. Then the operator puts the window module into the sash. The operators secure the module in the sash by hammering in side supports. The window, now completely in the sash, is folded by another worker into the top half of the frame. The process is repeated again until the window is completely into the sash, and then the second window is folded into the bottom half of the frame. At the completion of this process, one unit has been completely manufactured and now only needs to be packaged and then shipped to a customer or retailer.

3. Discussion Analysis and Proposals

The current window manufacturing process at Silver Line Industries puts value in mass production over attention to detail. While Silver Line certainly recognizes details that are damaging to long-term profit such as defective windows, solutions to problems plaguing the process have been put off due to the belief that the fixes would be too time consuming or would not be cost effective.

However, in spite of these apparent drawbacks, Silver Line still manages to effectively execute certain factors of their
They are able to manufacture a substantial amount of vinyl windows, enough to generate a profit and maintain their business. Windows and window parts move along the assembly line with relative ease; there is little inventory buildup between steps of the process. Furthermore, the parts of the window module are built in various locations, yet are assembled in one location. All of those examples show Silver Line’s ability to correlate these processes and ensure the module parts line up with their respective customer orders. In addition they reflect Silver Line’s ability to coordinate the components of their processes.

Despite these positive aspects of the manufacturing process at Silver Line, there are many current problems that inhibit optimal production of glass. The most prominent of these problems is glass breakage. An Ishikawa, or fishbone diagram, can be utilized to outline the causes of a certain problem. Once the problem is defined, the possible causes of that problem branch off under six categories: measurements, machines, man, environment, methods, and materials. [4] Figure 9 shows an Ishikawa Diagram for glass breakage.

### 3.1 Measurements

Silver Line’s current lack of data collection regarding the metrics of their process has prevented them from exploring and evaluating the true extent of their problems and also from probing their full potential to solve those problems. Without full knowledge of a problem itself, a solution cannot be formulated. For instance, if Silver Line recorded the frequencies of broken glass at each process step, it would be able to identify the step that caused the most breakage. Moreover, analyzing glass breakage is difficult due to this lack of measurements. The glass cannot be traced back to the location on the raw sheet of glass it was cut from. This would allow analysts to answer significant questions about the origin of glass breakage. For example, this information would allow analysts to determine if four cuts to a piece of glass make it more prone to cracking than glass with only two cuts.

![Glass Breakage Fishbone Diagram](image)

**Figure 10**

*Glass Breakage Fishbone Diagram*
3.2 Machines and Man

Machines and man are prone to malfunctions and errors which induce glass breakage. Machines themselves may make microscopic scratches on the glass that, with other applied stresses, may propagate into a visible crack. For example, the diamond cutting blade may cause cracks in the glass other than the intentional marks. Furthermore, the metrics of the rotating Scotch-Brite wheel used to scrape off the LoE coating are not controlled, so it could potentially scratch into the glass itself if the operator runs the glass under the wheel for an elongated period of time or if the wheel has too much pressure. Additionally, the glass enters a heated washer immediately following edge deletion which could cause the microscopic cracks to widen if the heat is strong enough to cause the glass to experience thermal shock. Next, many of the carts and conveyor belts that move the glass down the assembly line have rough or uneven surfaces, which could jolt the glass and cause damage. Lastly, the optimization software only operates at 85% glass yield, which produces too much scrap. The software could be modified to improve the glass yield and minimize scraps. Human error is also a dominant problem and is similar to machine error; dropping and mishandling during relocation can cause glass breakage.

3.3 Environment

In addition, the environment on the factory floor is not always consistent. The setting and temperature fluctuations may harm the glass. Glass is susceptible to thermal shock, and differing temperatures on the surface of the glass compared to the inside of the glass can make the glass more shatter prone. Thermal shock can also affect the glass through high temperatures used in the washing and pressing processes. The washer functions at 150 to 160 degrees. During the winter months, the raw glass from Guardian is stored adjacent to the delivery door. When glass is delivered, the glass waiting in the inventory is swept with cooled air. This repeated heating and cooling process can add stress to the glass. Additionally, the actual factory floor also affects the glass breakage. Silver Line’s floors are inconsistent, which can make the carts bump and jostle the glass on its corners and edges. Moreover, the moisture inside the factory increases during the hotter months. These increased moisture levels cause the anti-moisture material applied to the inside of the spacers to be compromised more quickly; if the spacers wait on the overhead conveyor for too long, then they may be rendered useless.

3.4 Methods

Many of the methods that may cause glass breakage are related to the fact that much of the process is implemented by human labor, which is vulnerable to human error. For example, the operator who snaps out the pieces of glass from the raw sheet does not consistently snap the glass the same way: sometimes he snaps it length-wise, sometimes width-wise, sometimes against the table, and sometimes in the air. These differing methods may put the glass at different risks for breakage. In addition, the operators do not apply the butyl on the window the same way for each window. Varying length of the butyl, bumps, and amount can change the pressure on the glass when it is fit into the frame. An uneven fit is sometimes a precursor to glass breakage.

3.5 Materials

Finally, errors in the raw materials can contribute to glass breakage even before they enter the factory. The glass from Guardian is not currently sampled to ensure
consistent quality glass, which allows glass with previously existing imperfections to enter the window-making process unchecked. Conducting inspections on inbound glass from Guardian would additionally verify that the glass is as thick as Guardian claims it is. Deviations from indicated material standards such as a different viscosity of butyl or an incorrect pressure of Argon could influence the glass negatively.

4. Results
To determine the problems that were the best candidates for upheaval, the significance of the problem, the benefits of the solution, and the cost of the solution had to be taken into account relative to each problem. A Pugh Matrix, as seen in Figure 10, allowed for the evaluation of the potential actions taken. By using this method, criteria was weighed and then each problem could be valued with respect to the criteria. The weight of the criteria was multiplied by each

<table>
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<td>Severity of Problem 4</td>
<td>High 3 4x3=12</td>
<td>Medium 2 4x2=8</td>
<td>High 3 4x3=12</td>
<td>High 3 4x3=12</td>
<td>Medium 2 4x2=8</td>
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<td>Long Term Benefits 4</td>
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<td>High 3 4x3=12</td>
<td>High 3 4x3=12</td>
<td>High 3 4x3=12</td>
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<tr>
<td>Cost Effectiveness of Solution 2</td>
<td>High 3 2x3=6</td>
<td>Medium 2 2x2=4</td>
<td>Medium 2 2x2=4</td>
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of the heating process (150-160 degrees Fahrenheit). Some of the data that Silver Line does collect is used as a motivator for improvement among its employees. The company has a basic tracking system, and although it appears to be used only when a broken order needs to be reproduced, the ability to trace a breakage back to an operator is certainly a motivator. Additionally, the company has charts throughout the manufacturing floor that display the day’s actual progress relative to the day’s goals. The charts are not visible to all workers, but they are a reflection of the company’s belief in the kaizen system, the desire for continual self-improvement. In some of the workers’ perspective, these charts are the only important data. Relevant to the actual glass efficiency, one striking datum that demonstrates the severity of the glass breakage issue is that 12 cubic yards of glass, equivalent to two garbage trucks, out of 64 total cubic yards used are discarded daily. Silver Line already uses data for causes important to its manufacturing process, like keeping up with window orders and assuming possible causes of damage, but the potential for detailed data examination is endless. By analyzing breakage data, Silver Line would be able to determine the glass types, manufacturing steps, and operators who were prone to the highest volume of errors. Silver Line would then be able to identify the greatest causes of glass breakage and revamp its process. [5]

By analyzing glass breakage, Silver Line would be able to define the most problematic areas in the manufacturing process. There are plentiful changes that could be made in the process or measurements that could be taken with the potential to increase profit margin over time. Conducting fractography tests would be an indirect aid, as it would enable Silver Line to identify the reasons of glass breakage and would allow them to decide what changes to implement.

4.1 Fractography

Luckily, the breakage itself can tell a story about how and where glass breaks, thus allowing analysts to trace the cause of breakage. Fractography is the study of the patterns involved in breakage. Glass tends to have what is known as brittle cracking. Brittle cracking is cracking that does not need large amounts of elastic deformation. The glass warps in such a way that the cracks propagate in an identifiable pattern without much ‘bending.’ For example, when the breakage is due to thermal shock the initial crack is perpendicular to the original stress point and then branches out into an extensive networks of cracks. Similarly, all types of breakage follow a pattern. A breakage from impact (a large amount of force on a relatively large area) results in damage with cracks branching from the outside of a large concentric circle. Edge or surface damage is a result of a point of stress in the form of cracks, nicks, or scratches. These points first result in a mirrored elliptical shape with a clouded edge. The cracks essentially point to the initial stress fracture which is typically at the center of the elliptical. Furthermore the actual damage correlates to the size of the fault and both the stress applied and the stress at the edge of the crack. There are many more types of breakage such as gas pressure, acid corrosion, etc., that can all be detected using fractography. [6] [7]

Aside from characterizing the type of breakage and severity, fractography also tells us an important detail about edge/surface damage. Griffith’s formula for cracks and crack propagation is \( m=2a (a/p)^{1/2}=mKt \) where \( p= \) radius of convergence, \( m= \) stress at crack tip, and \( o= \) applied stress. [6] Based on this formula a nick on the side of a piece of glass that has the same stress variable will
be as important as a crack in the center of the glass that has double its length because the radius (a-value) is the same. In Layman’s, the edge and surface is very important to maintain. Silver Line could conduct fractography tests to determine what step in their process makes glass most vulnerable. With that information, they could make informed changes and reduce glass breakage.

4.2 Traceability

Silver Line currently has a tracking system in place, but it is limited in what it collects and how it is used. Silver Line uses bar codes when carts of glass move through a process, but it only reports breakages so that the order can be fulfilled. Since data regarding breakages is already being entered into the company’s database, obtaining statistics about the breakages would only be a matter of installing software. This software would depict any correlations between glass breakage and a particular operator or step in the manufacturing process, and Silver Line would be able to increase its production efficiency by addressing individual operators or by reevaluating the proper steps in their processes. Additionally, Silver Line could reduce problems created by others outside of the factory through inbound inspection. Silver Line is supplied with 72 inch x 84 inch sheets of glass by Guardian, [1] but they do not currently conduct any inspection on these sheets before they are cut into individual pieces. Silver Line purchases glass from Guardian because they offer lower prices than other suppliers, but if the glass is of poor quality than the low price loses it benefit to the operating margin. Silver Line already loses the front and back piece in almost every package of glass from Guardian due to damage during transportation, and although they are not charged for these pieces, individual sheets of glass are often rendered unusable before they are even cut. By recording how often they lose a whole sheet of glass, Silver Line would be able to make the determination of whether or not they should spend more money for a higher quality glass that would fare better in the manufacturing process.

Aside from software and inbound inspection, if Silver Line put a bar code on individual pieces of glass and entered them into the system immediately after they were cut, rather than adding them after the spacers were attached, the company would be able to see if the position of the cut piece in the original sheet had any effect on the risk of breakage. For example, a piece cut out of the middle of a raw sheet would have had four edges cut by Silver Line, while a piece cut out of the corner of a raw sheet would have had only two edges cut by Silver Line. If Silver Line’s cutting process proved to be stressful relative to the cutting process of Guardian, a higher rate of breakage would be seen in pieces of glass with four sides cut by Silver Line. The glass cutting optimization system could then be adjusted accordingly to position as many cuts as possible along the edges of the sheet. By tracing glass back to the inventory stage, Silver Line would be able to address worker inefficiency, uncover hazardous manufacturing steps, and reduce the rate of failure during the rest of their process.

4.3 Butyl Application

The overarching drawback of Silver Line’s butyl application process is that it is not mechanized. The application of the butyl is a creative technique, interpreted differently by each operator. Because of this, different lengths and amounts of butyl are applied to each window module. This haphazard application has varying effects on the modules; too much butyl causes spillage onto the glass pane and too little risks gas leakage. To overcome this uncertainty,
numerous solutions are proposed. Metering the butyl can be considered; when a button is pressed on the applicator, a precise amount of butyl would be released. This method would have to take the two different glass depths into account. This ability to control the optimal amount of butyl would be a beneficial modification for Silver Line. Not only would this decrease butyl on the glass panes, but it would also decrease the non-valued added time extra butyl causes in the manufacturing process. If the butyl spills onto the pane, it must cool before it can be removed with a razor blade further down the line. Extra clean up steps, such as these waste productive time, decrease the yield of the line and therefore decrease Silver Line’s profit. An addition to this technique is applying the butyl as a stamp. This would decrease the time and further standardize the process.

Despite concentrating on metering butyl, different techniques can be applied to sealing the spacer that effectively eliminate the use of butyl. The screw currently used does not form an airtight seal with the spacer, necessitating the butyl application. A more tightly threaded screw that forms a complete seal with the spacer would eliminate the need for butyl. Another option is sealing the hole in the spacer by welding on an additional piece of tin. This method would form a complete seal and would remove the chance of any air escaping the seal of a screw. Additionally, an expanding chemical seal could be sued to create an airtight barrier without requiring the use of butyl.

4.4 Glass Handling

Another inherent flaw in the problem arises due to the amount of variation possible during glass handling, particularly the glass-scoring and edge deletion steps. One crucial step is when the initial incision is made into the large 72in x 84in sheets of glass. The tiny 3/8” (diameter) [1] diamond wheel is rapidly spinning in order to get a precise cut with minimum damage to the glass edge. During this step a very important metric is the pressure that the diamond wheel exerts upon the glass. The pressure is indicative of numerous factors including glass structure and the depth of the incision. Currently Silver Line leaves this pressure up to the discretion of the operator. The current average pressure of the blade is 50 Newtons but the fluctuation is anywhere between 30 Newtons and 80 Newtons. Because of this large fluctuation, the glass may be cut too deep resulting in edge damage. Similarly, if the wheel is not applying enough pressure then the glass will not be cleanly cut with an optimal depth and when the glass is snapped by an operator it may experience minor brittle fractures. The solutions to this problem are quite simple. One solution would require a standardized pressure measurement in which the operator inputs the depth of the glass and the blade goes down to a predetermined pressure in order to prepare the cut. One drawback of this solution is that if the glass varies in depth or structure then the pressure reading varies as well, causing an inefficiency of cuts. On the other hand it would be equally as feasible to allow for a number to pop up while the operator lowers the blade that states the pressure. As the operator lowers the blade, the amount of pressure changes until it reaches the desired value. In this way the operator still has the ability to modify the blade depth but understands the approximate value that should be reached.

Other areas of variation include the actual snapping process. Although Silver Line promotes a specific method for snapping, the workers tend to use their own various methods, and even the current method is not definitively correct. The first step to overcoming this obstacle is to designate a well-defined methodology to the snapping process. Once traceability of the
worker’s performance becomes available, that minimizes varied worker practices.

Another macro-step subject to variation is edge-deletion. During the edge-deletion process the worker slides the glass against rolling wheel and removes a small amount of coating from the glass. This coating has to be rubbed away because the spacers attach more feasibly to the raw glass than to a coated glass such as glass with LoE. The operator has total control of the process. He/She has the ability to move the glass at different velocities through the rotating brush that deletes the edges. This can result in variation in the amount of coating actually rubbed away and can easily cause damage to the glass that lies beneath it. Furthermore, as the glass thickness varies from 2.2 millimeters thick to 3 millimeters. [1] There can be significant amounts of abrasion from the coarse wheel. As the wheel becomes duller and duller throughout the shift, the operator is even responsible for moving the coarse material up or down leading to additional error. Sometimes the operator can even have the glass going through the edge deletion process upside down meaning the glass is under direct contact of a coarse wheel going 2,000 RPM’s. [1] This can result in significant edge damage. Shortly after the glass goes through an oven at nearly 160°F that can magnify any edge damage by the application of thermal shock. A workaround for these problems is a chemical solvent. Instead of abrasion the chemical solvent can dissolve the coating without reacting to glass, such as Cellulose Acetate or a similar solvent. By dissolving the LoE coating one does not add any microscopic fractures that can be magnified throughout the process.

5. Conclusion

By touring Silver Line and analyzing the window-making process, the team was able to identify four areas for improvement: fractography, butyl application, glass handling, and traceability. By conducting fractography tests, the company would be able to determine what caused the majority of their glass breakage and then would be able to reduce these problems to a minimal amount. Changing the application of butyl would help to avoid pressure-related breakages during the assembly process, save time spent removing dried butyl that erroneously ends up on the glass, and help preserve the argon inside of the window module. Changes to glass handling would positively impact operating margin, as the changes would lead to reduced breakages before, during, and after manufacturing. Implementing a tracking system would provide further uses for data that Silver Line already collects, which when applied would increase the manufacturing efficiency. In addition to the long term benefits that all these changes would have on processes that are causing problems for Silver Line, the changes are not particularly costly and the money saved after implementation would justify the expenditure.

Silver Line Industries is currently taking the solutions presented into consideration to improve their current efficiency rate. In the future, the company may decide to implement the changes, but only after realistically comparing the costs associated with any purchases to their current budget for expenditure. The solutions presented address many different aspects of Silver Line’s process, allowing Silver Line to attack its current problems from a variety of angles.

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