Lean Manufacturing Work Station Design in Silver Line

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Abstract
Modern manufacturing companies aim to increase efficiency and to protect the health of their workers. Silver Line by Andersen is one such company that utilizes lean manufacturing methods to reduce waste and increase production of their windows [1]. In order to identify problems in the 2300-1 Single Hung window line, the latter half of the line was analyzed using cycle time observation charts. Various solutions ranging from new work standards to reorganization of work station elements that reduce the cycle time of the stations are proposed in this paper. These solutions make the six stations’ cycle times more balanced and therefore more efficient. In total, streamlining the assembly process could save Silver Line an estimated $82,418 annually.

1. Introduction
Lean manufacturing aims to reduce the total amount of waste in a system to promote efficiency and conserve resources [2]. By reducing waste, industrial companies are able to increase product output and profit.

Silver Line by Andersen constantly seeks solutions that reduce waste throughout their assembly lines while minimizing worker strain [1]. This project focuses on the optimization of the second half of the 2300-1 Single Hung window line at the North Brunswick, NJ location of Silver Line. The solutions developed had to be implemented without major disruptions to the current configuration of the 2300-1 line in order to increase its efficiency without sacrificing profit or customer satisfaction. Every work station on this line was recorded and its respective times analyzed in order to obtain a better understanding of the work flow and cycle times of the line. Ergonomic studies and layout analyses were conducted for each station’s operator in order to integrate the concepts of the 5S methodology and minimize the eight wastes of lean manufacturing.

2. Background

2.1 Assembly Process of the 2300-1 Single Hung Line
The 2300-1 Single Hung window line begins with the assembly of vinyl window frame pieces. The window frame and the sash are assembled in separate work stations and are joined halfway down the line. This paper focuses exclusively on the final six parts of the assembly line, from the installation of the glass to the packaging of the windows. Procedures performed outside
of the 2300-1 line, such as the creation of vinyl parts and glass, are not included in the proposed lean solutions because they are outside the scope of this paper.

Fig. 1. This diagram is a general window that Silver Line produces on their 2300-1 line.

As shown in Fig. 2, glass is installed into the window frame. At this station, glue is applied, glass inserted, and siding hammered in. Next, the assembled sash is walked over to the window and attached (Fig. 2). Here, the head and screen are also fixed to the window frame.

Fig. 2. At these stations, the glass, siding, sash, screen, and head are attached to the window frame.

The operator passes the window down to the exterior cleaning station, where the window is washed (Fig. 3). Exterior cleaning also scrapes off any excess silicone glue remaining from previous stations. Then, the window is passed to the interior cleaning and quality control station. Here, the operator cleans the inner side of the window and performs quality control inspections (Fig. 3). This operator also removes any excess glue and scrapes off all stickers and leftover residue. The window is thoroughly sprayed with a cleaning spray and wiped with a paper towel. Afterwards, the sash is checked and the vinyl siding is hammered in one final time. This step also includes the application of multiple window stickers which display barcodes, names, and labels. Finally, sash stoppers are hammered into the sides, which prevent the sashes from sliding during packaging and shipping.

Fig. 3. The windows are cleaned on both sides and their quality is ensured before they are sent off to packaging.

After interior cleaning and quality control, the window is pushed down to packaging (Fig. 4). Windows that are four feet by eight feet or smaller in size are packaged by a machine, while the rest are packaged manually.
After packaging, the window is unloaded from the machine and placed on a cart to be shipped (Fig. 5).

2.2 The 5S’s of Lean Manufacturing
Silver Line embraces the 5S lean manufacturing methodology that focuses on reducing waste and increasing productivity. Each of the five S’s corresponds to a distinct pillar of manufacturing: sort (seiri), set in order (seiton), shine (seiso), standardize (seiketsu), and sustain (shitsuke) [3]. Some companies, such as Silver Line, include an additional ‘S’ for safety. The 5S methodology is often used as a general guideline to help maximize a company’s resources, profit, and productivity [4].

1. Seiri
The first S—Sort or Seiri—is the idea that an assembly line should remove all unnecessary materials, leaving only those that are critical to production [3]. Reducing clutter allows operators to concentrate on their tasks, since less time is wasted searching for their tools [4].

2. Seiton
The second S—Set in order or Seiton—stresses efficient material organization based on ergonomic principles [3]. Strategic arrangement of materials allows operators to gather supplies more quickly, reducing their cycle times [4].

3. Seiso
The third S—Shine or Seiso—represents the idea that tools must be cleaned regularly to ensure that equipment functions as smoothly as possible [3]. Unsanitary materials hinder the production process. Additionally, having a clean workspace has a positive effect on human psychology and allows operators to stay relaxed and focused [4].

4. Seiketsu
The fourth S—Standardize or Seiketsu—ensures fewer variations for each manufacturing process by creating a specific set of instructions [3]. Work standards reduce the chance that an unnecessary step is performed at a station, increasing its efficiency [4].

5. Shitsuke
The fifth S—Sustain or Shitsuke—is the idea that companies must continually
conducted audits and studies based on the 5S manufacturing principles [3]. Silver Line follows this procedure by having employees perform studies periodically throughout the year.

6. Safety
The sixth S—Safety—is often included in the 5S methodology [4]. Companies such as Silver Line emphasize safety in the workspace in order to reduce injury to the workers.

2.3 Ergonomics
Ergonomics is the study of human capabilities and efficiency relative to their body positioning and work requirements [5]. While redesigning an assembly line, industrial engineers consider a worker’s body posture and strain to prevent injuries [6]. For example, if a worker has to repeatedly bend down to lift a product, an industrial engineer should redesign the workstation to eliminate the action. Ergonomic improvements help prevent a worker from developing various musculoskeletal disorders (MSDs) [7]. There are ranges of motion that dictate optimal zones of movement for an operator and provide ratings for a variety of motions [8]. A poorly rated motion indicates increased strain on the operator, which is amplified through repetition. This increases risk of developing an MSD in the workplace and forces the line to compensate for an absent operator, reducing the efficiency of the line [9].

2.4 The Eight Wastes of Lean Manufacturing
The minimalistic ideology of lean manufacturing emphasizes the importance of customer satisfaction. Therefore, processes and actions that do not benefit the consumer are considered non-value added and wasteful. There are eight wastes recognized in lean manufacturing that detract from the overall efficiency of the assembly line [10].

1. Transport
Transferring parts in the assembly line to their next location increases risk of damage or deterioration of the product. Therefore, truncating the distance between elements in the production line saves time, energy, and capital [10].

2. Inventory Excess
One piece flow, the idea that there should be no more than one unit at a station at any given time, is disrupted by inventory waste [11]. It often manifests itself on the window production line as a bottleneck. If an operator works on multiple windows simultaneously, one piece flow is disrupted and cycle time is increased [10].

3. Motion
Unnecessary motions made by operators in the product line do not add value to the product and place strain of the operator. Therefore, they should be excised from the manufacturing process [10].

4. Waiting
Waiting typically occurs if a bottleneck forms in the manufacturing process, which is usually a result of mismatched cycle times along the production line. Like inventory excess, waiting is a strong indicator of inefficiency [10].

5. Overproduction
Although it may seem counterintuitive, overproduction does not benefit manufacturing companies and is considered the worst waste of production. By producing more goods than the demand, companies waste time and money on products that will eventually be discarded rather than sold to the consumer [10].
6. **Excess Processing**

Excess processing refers to repetitive and unnecessary tasks that waste resources. Although quality checks are necessary, certain elements in the production line undo the actions of previous elements and therefore, must be eliminated [10].

7. **Defects**

This waste is very closely related to customer satisfaction. The imperfections that result waste operator time and company resources [10].

8. **Under-Utilized Talent**

Although not initially recognized as a waste of lean manufacturing, it is now included as one of the eight wastes because it negatively affects output. Company practices that do not maximize value and consider consumer needs waste resources [10].

2.5 **Takt Time**

Takt time is used in manufacturing to determine the production rate required to match customer demand [2]. This value is calculated by dividing the total amount of work time by the demand for the product (Fig. 6) [11].

\[
\text{Takt Time} = \frac{\text{Working Time Available}}{\text{Customer Demand}}
\]

Fig. 6. Takt time is calculated by dividing the amount of work time available by the customer demand for the product.

For example, if a company has five hours of work time per day and the daily consumer demand is 10 units, then the takt time is 0.5 hours or 1800 seconds. Takt time is a theoretical value, whereas cycle time is the observed amount of time that each station’s operator spends on a unit.

In order to reconcile takt time with cycle time, maintenance checks, as well as other random occurrences along the line, must be considered when predicting the ideal cycle time for a production line. According to Ortiz, the actual cycle time should not exceed 85% of the predicted cycle time to ensure that the operator does not become overstressed by his or her workload [12]. This percentage allows for regular maintenance checks, non-cyclical tasks, and other day-to-day occurrences that interrupt the expected workflow.

In order to maintain one piece flow, cycle times across all stations should be similar. Cycle times that are out of sync increase inefficiency in production [11].

3. **Methods/ Experimental Design**

3.1 **Data Recording Methods**

Two types of time studies were conducted: cyclical and non-cyclical steps. Cyclical steps are repeated for every window produced, while non-cyclical steps are only performed periodically throughout the shift. There are two types of non-cyclical work: value added and non-value added. Value added steps are necessary to the production of the window, such as refilling a cleaning spray bottle or refilling the sticker dispenser. Non-value added steps are tasks that are unnecessary or redundant, such as cleaning a window twice at two different points in the line.

The order of the steps for each work station was first determined. Then, cycle times were recorded by either taping videos of the operators or manually timing the tasks that they performed. A minimum of ten observations were required for each station. The data was used to identify which stations’ cycle times could be reduced. This procedure was done only for cyclical tasks. Non-cyclical tasks were timed and their frequencies were recorded, which was used to calculate the total time per shift spent on specific tasks. The purpose of these time
studies is to reveal any discrepancies between work station times.

3.2 Calculated Takt Time

The 2300-1 line takt time is 132 seconds. In other words, a new window should be produced by the line every 132 seconds. Line 2300-1 consists of three eight hour shifts. Each shift has two fifteen minute meetings and one ten minute break, which results in a total of 440 minutes of working time per shift, or 1,320 working minutes per day. The daily consumer demand for the windows produced is 600 windows. When the working time is divided by the consumer demand, the resulting takt time is 2.2 minutes, or 132 seconds.

3.3 Discrepancies

There are currently three eight-hour shifts on the 2300-1 manufacturing line. On average, this line produces 496 windows daily.

![Current Number of Windows per Shift](image)

Fig. 7. The target number of windows manufactured per shift is 200, but even the most efficient shift is still short of this demand. As a result, this line is 103 windows short of their daily production requirement of 600 windows.

This discrepancy between shifts shown in Fig. 7 is due to the fact that later shifts have less experienced workers. Since the demand is 200 windows per shift, Silver Line is currently producing 104 fewer windows per day than what its demand requires. Operators often have to work overtime on Saturday to meet the full demand of Silver Line’s customers. A standard work procedure, which is an ordered outline of steps detailing how the operator should complete the tasks, could help alleviate this issue. With the implementation of proper standard work procedures, the variation between shifts should be reduced.

3.4 Tool Belt

Many stations include tasks that require operators to turn around often to pick up or replace tools. At the interior cleaning and quality control station, the operator must turn around six times per window. During three of those six times, the operator turned in order to get the spray bottle, get a paper towel, and get the window locks. Two of those three materials could be placed in a tool belt that the operator would wear. If the paper towels and locks were readily accessible, it would reduce the number of times an operator would turn, and therefore, decrease the cycle time. On average, a full turn takes about 7.6 seconds, and for each window, the operator turns about two times to retrieve tools. With a tool belt, the operator would not need to turn around as often and could reduce the cycle time by 15.2 seconds per window, or 50.7 minutes per shift. If they save 15.2 seconds per window and they make 600 windows per day, they will save 2.53 hours daily by not having to turn around as often. Based on the average operators’ salary of $11.89 [14], this will save the company $30.08 per day and $7821 per year. This can be implemented in the interior cleaning and quality control station. Since this project proposes splitting this station, Silver Line would only need to buy two tool belts for these two stations. Since the cost of purchasing two tool belts would be around $50 annually, it is insignificant compared to the net savings due to the implementation of the tool belt.
3.5 Glue and Glass

At this station, one operator installs the glass and the siding into the frame of the window.

The average cycle time for this work station is 81 seconds, which is under the takt time of 132 seconds. Since this station requires glass and siding, the operator cannot complete the job unless all his materials are available. During the earlier cycles, the cycle time was longer than the later cycles because there were glass and siding delivery issues. Resolving problems with materials that originate outside of the six stated stations is not within the jurisdiction of this paper. Therefore, there is no change to the layout or the cycle time of this station.

3.6 Assembly

At the assembly work station, the operator’s average cycle time is 65 seconds, which is under the takt time. However, there is frequently a bottleneck at this station because window parts are inconsistently provided by other stations that are outside the scope of this paper. Another source of bottleneck resulted from the way the operator performed his tasks; he would often complete two or more windows simultaneously before passing them to the next station, which is out of line with the concept of one-piece flow. Since a cycle is completed when a unit is passed along to the next station, the cycle time is doubled whenever the operator completes two-window batches because he only passes one window along for every two he completes. In order to resolve this, management should emphasize to the operator the importance of one-piece flow in lean manufacturing and ensure that he only works on one window at a time in order to maintain the work flow.

3.7 Exterior Cleaning

<table>
<thead>
<tr>
<th>Step</th>
<th>Operation Description</th>
<th>Manual Time</th>
<th>Walking Time</th>
<th>Total Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Pull window to station</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>Remove labels and silicone</td>
<td>15</td>
<td>15</td>
<td>30</td>
</tr>
<tr>
<td>3</td>
<td>Grab window cleaner and paper towel</td>
<td>3</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>4</td>
<td>Spray window with window cleaner</td>
<td>6</td>
<td>6</td>
<td>12</td>
</tr>
<tr>
<td>5</td>
<td>Wipe window with paper towel</td>
<td>20</td>
<td>20</td>
<td>40</td>
</tr>
<tr>
<td>6</td>
<td>Push window to next station and return</td>
<td>3</td>
<td>3</td>
<td>6</td>
</tr>
</tbody>
</table>

Fig. 8. The new suggested standard work document aims to reduce discrepancies in cycle time between the shifts.

For the exterior cleaning station, the operator cleans and prepares the window for delivery and sale. Some of the inefficiencies at this station were due to the operator not following the designated steps to complete the task. The current work standard for the station keeps the station within the takt time only if consistently followed. With the implementation of a new work standard, each operator, no matter how experienced, can perform the steps in a similar time, helping increase overall efficiency (Fig. 8). The current layout of the exterior cleaning station, shown in Fig. 9, is designed for the operator to turn around, grab the magnet, check the window material, turn around, place the magnet on the paper towel roll, grab paper towels, walk to the table, grab the window cleaner, and clean. After video analysis, it was determined that the operator spends an average of four seconds per window turning around and getting the paper towel and magnet. To reduce walking time, a rearrangement of the work station elements is suggested.

Fig. 9. The current floor plan of the exterior cleaning station requires the operator to turn around to reach supplies.
For every window produced, an operator must turn around from the operator pad and grab paper towels before moving to the tool table. By moving the paper towel roll above the tool table and the trash underneath the tool table, the cycle time will drop an average of four seconds per window because walking distance and turning are reduced. In addition, the establishment of standard work procedures will allow each shift operator to perform the steps in the correct order, limiting mistakes and saving time. For the exterior cleaning station, as with all stations, it is important to maintain balance with other stations. In order to increase efficiency, the operator must be aware of the assembly line and how quickly it is moving.

3.9 Interior Cleaning and Quality Control
An important aspect of lean manufacturing is reducing waste, or muda [10]. By doing unnecessary tasks or repeating tasks, time and material were wasted. Excess time is a significant problem because this waste causes an imbalance between the stations and can lead to bottlenecks throughout the line. An example of a non-value added step would be washing the same window repeatedly. This is a waste because the time that was spent on that window is essentially useless. However, by creating a work standard for this station, the non-value steps will be eliminated which will help balance the cycle time between the different work stations.

3.10 Timed Cycles for Interior Cleaning and Quality Control
The window is first scanned and cleaned thoroughly. Then, the operator inspects the window to ensure that all components are functional. The proper stickers are placed on the glass pane. Finally, the operator uses a hammer to insert the sash stops to the sides of the window. These steps prepare the window for the final packaging station, which wraps the window in plastic and places it in a cart to be shipped. There are many problems regarding this station, which have reduced the efficiency of the entire line (Fig. 11).

Fig. 10. The new floor plan of the exterior cleaning station eliminates the need for the operator to turn around, improving the ergonomics of this station.

Fig. 11. This is a typical bottleneck at the interior cleaning and quality control station.

This station had large time discrepancies between the first and second shift (Fig. 12). In order to address this issue, a work standard was created for the interior cleaning and quality control station to minimize the variation between the first and second shift.
The difference between the two shifts is explained by the lack of a work standard. The second shift takes almost twice as long as the first shift. By standardizing both shifts, the time difference between them should decrease. If the operators follow this new work standard, then the station’s cycle time should be reduced (Fig. 13).

The new work standard that the group proposes includes a total of eight steps. However, these steps will be split between two different operators. Adding another operator helps create a balanced workflow in the line. When the window is pushed down to the first operator, the operator will first scrape off the indicator stickers on the window. Then, the first operator will open and close the sash. The operator should not close the window during this step. The first operator will then spray the window. Two to three sprays is the optimal amount that minimizes wasted cleaning fluid. After spraying, the first operator will wipe the window with a different cleaner. Then, he or she will scrape and wipe the window. Then, the first operator will push the window down to the second operator. This operator will scan the barcode and print out a sticker. They will then apply the sticker to the window. After the sticker is applied, the second operator will close the bottom sash. Finally, the operator will hammer in the locks and push the window down to the packaging station. By following this standard, the operators should be able to clean the window efficiently without repeating any steps.
3.11 Packaging
Silver Line uses a machine to package its windows for shipping. Before the windows enter the machine, one or two operators prepare the windows’ packaging and feed the windows into the machine. There are two types of packages. The first package covers the jambs of the window. This packaging is used for displays in stores. The second packaging consists of four white cardboard covers for the window corners. Windows packaged this way are shipped to houses under construction.

3.12 Timed Cycles for Packaging
Both types of packaging require securing the cardboard pieces with plastic zip ties. The first type of package requires 104 seconds to complete on average, while the second type only requires about 74 seconds. Both processes’ average cycle times are under the takt time. When the operators are working on the first type of packaging, they were able to complete their tasks within the takt time during nine of the eleven observations. The cycle time was greater than the takt time when only one operator was present. Two operators are able to complete the job faster. When they are able to prepare the cardboard pieces ahead of time, the cycle time for the station decreases to about 80 seconds.

3.13 Safety of Packaging
The work at the packaging station prevents any major changes to its layout because any change would create an imbalance in work between the two operators at the station. However, a new work standard should be established for packaging for safety reasons. Operators tend to follow procedures that are most convenient for them, but these procedures are not necessarily safe. In particular, some operators have bent over into the packaging conveyor so that they can place the last sticker before the window was packaged. Therefore, the operators should place the sticker on the window before placing it in the zip tie machine. This work standard guarantees that the placement of the sticker is done before the last cardboard piece is secured with a plastic zip tie. By switching the order of the last two steps—securing the corners and placing the sticker, the operators will not have to stretch themselves into the machine.

3.14 Adjusted Computer Monitor Height
Many of the operators had to strain their necks in order to look up at the computer monitors. The height of the top of the computer is 6’ 4” and the height of the top of the keyboard is 4’ 6”. However, since the workers in the stations that use computers are women, the average height of these workers is only 5’4”. This means that the workers have to constantly strain their necks in order to see the screen. This can cause musculoskeletal disorders that force the operators to take time off work. In order to reduce the likelihood of injury, the computer monitor should be lowered to eye level.

3.15 Unloading for Shipping
After the windows go through the packaging machine, they are unloaded by an operator and put onto either wood pallets or carts. Currently, there is a lack of wood pallet and cart organization. The operator would often have to move the large windows to the farthest wood pallets. The more efficient and ergonomic procedure is to have a designated area for each window size next to the packaging machine. The largest windows will be put on wooden pallets closest to the machine, while the smallest windows will be put on the wooden pallets that are farthest from the machine. With this configuration, there is less stress on the operator because the larger windows
require less transportation. This creates a safer work space for the worker and helps reduce operator strain at this station.

4. Results

4.1 Interior Cleaning and Quality Control

By creating a work standard, the cycle times for these stations can be reduced. The average cycle time of the new work standard was calculated by averaging the spray times of the current configuration and applying those times to the projected cycle times of the new work standard. The benefits of the new work standard would be amplified if the station was split into two stations: interior cleaning and quality control. An additional operator would be needed. The new cycle times for these stations would be 84.5 seconds for interior cleaning and 68 seconds for quality control. The previous average time for these stations from the first and second shift was around 135 seconds. Therefore, by implementing a work standard as well as adding an operator, the cycle times across all stations have a lower standard deviation.

4.2 Adjusted Computer Monitor Height

Currently, the operator bends his or her neck back an angle of 43.3° for approximately four seconds in order to view the computer screen. However, the optimal range of motion for neck extension is 0° to 16°, and a neck extension of 43.3° puts intense stress on the neck (Fig. 14).

This strain is compounded because the operator viewed the computer screen 64 times during a typical shift. Multiplied out over all the shifts for a year, workers at the packaging station spend 53 hours looking up at the computer, which can lead to musculoskeletal disorders.

Currently, manufacturing operators across the country who are recuperating from work-related injuries spend on average nine days away from work. At the frequency that the packaging station operators extend their necks, it is possible that musculoskeletal disorders will result and force them to take days off from work. Silver Line does not employ “floater” workers who can fill in for an operator if that worker is absent, so the line will have to compensate for the absent worker in other ways. This will increase the average cycle time significantly for the day and further decrease the line’s window output.

The packaging station’s computer is not the only object that should be lowered. The printer that produces the sticker is also at the same height. Therefore, the operator must extend his or her arm up to reach the sticker. The optimal range of shoulder flexion is 0° to 47°. Currently, the operator must rotate his or her shoulder 142° in order to take the sticker from the printer. The operator must perform this for every single window produced. If the line produces an average of 496 windows per day, the packaging workers across all shifts must flex their arms over 42,000 times per year. Therefore, the printer should be lowered to keyboard height (54 inches off the ground) so that instead of straining the shoulder to reach the sticker, the operator can simply move his or her hand across from the keyboard to the printer and grab the sticker.

Fig. 14. This diagram depicts the safe zone for neck strain in green, between 0° and 16°. The unsafe zone for neck strain is shown in red from 16° and 46°.
4.4 Cost Benefit Analysis

Since the highest cycle time of the line limits the rate of window production, the fastest a window can currently be produced is once every 135 seconds. Assuming that operators during each shift work for 440 minutes and there is one overtime shift every Saturday of the year, Silver Line should be producing 160,249 windows annually at its current rate. However, based on actual window production rates, Silver Line is only producing 136,676 windows annually, which is approximately 85.3% of the highest cycle time estimate. This is in line with Ortiz’s claim that the actual window production rate is 85% of the predicted window production rate in order to account for maintenance checks and other disruptions to the daily work flow.

The changes proposed by this paper suggest that the highest cycle time will be reduced to 104 seconds, which is well below the takt time. With this reduced highest cycle time, 198,000 windows could be produced annually without the need for overtime. Even after accounting for daily fluctuations in the work flow, this lowered highest cycle time still allows 168,873 windows to be produced annually by the 2300-1 line, which is 32,197 more windows than the current annual window output that includes overtime work (Table 1).

Currently, the 2300-1 Single Hung assembly line works overtime on Saturdays for one eight-hour shift in order to meet its current demand. In the past month, the four overtime shifts with an average of 20 operators per shift produced 643 units. New Jersey state law requires companies to pay an overtime wage 1.5 times their normal wage provided that the operator works a 40-hour work week, which applies to Silver Line’s operators [13]. Based on a average union operators’s wage of $11.89, the overtime salary is $17.84 [14]. If this cost is spread over 20 operators working every Saturday of the year, the overtime shift costs Silver Line $148,429 annually.

| Cost additional worker | -$74,194 |
| Cost tool belts         | -$50     |
| Savings with tool belt  | +$7821   |
| Overtime                | +$148,429|
| Net Savings             | +$82,006 |

Table 2. The improvements outlined in this paper will lead to a net savings in the 2300-1 assembly line.

The improvements outlined in this paper reduce all of the stations’ cycle times to below the takt time, meaning that the line could potentially fulfill its quota of 200 windows per shift (156,000 windows annually) without the need for overtime hours. The sum of the salaries of the three new workers that Silver Line would employ for the proposed station is $74,194 per year. Combined with the money saved from eliminating the overtime shift and the savings from implementing the tool belt, the net profit from these changes is $82,006 in operator wages (Table 2). This number does not include the amount of money that could be saved if the management placed a heavier

<table>
<thead>
<tr>
<th>Current Annual Window Production</th>
<th>132,676 windows</th>
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<tbody>
<tr>
<td>Projected Annual Window Production</td>
<td>168,873 windows</td>
</tr>
<tr>
<td>Net Increase</td>
<td>+32,197 windows</td>
</tr>
</tbody>
</table>

Table 1. There could be an increase in annual window production in this line.
emphasis on one-piece flow to reduce bottlenecks, nor does it include the sales profit the company would receive from the increased window production.

This project recognizes that overproduction is the worst waste and that the current projected output with the recommended modifications would place this line’s output over its demand by 12,873 windows. However, the scaling factor of 85% is imperfect because it assumes that the maintenance times and day-to-day interruptions in the work flow during window production can also be scaled down, which is not necessarily true. In reality, the true annual window production with these improvements will likely be lower than predicted, placing it closer to the window demand.

5. Conclusion

There are many areas in which Silver Line can make minor changes that result in major improvements in cycle times and savings for the company. At the assembly station, management should promote one piece flow ideology to the operator in order to prevent bottleneck formation in the line. The external cleaning station should undergo a relocation of work elements and an implementation of a new work standard that will reduce cycle times. Interior cleaning and quality control should receive an additional operator to split the tasks. Combined with the implementation of a tool belt and a new work standard, this change will improve efficiency at this station, eliminating the current bottleneck in the latter half of the 2300-1 line. A work standard was established for packaging in order to improve the safety of the workers. Overall, with these solutions, this half of the 2300-1 line’s production time is reduced by 54 seconds. Because all stations are under takt time now, Silver Line should be able to save $82,418 a year. In total, this paper proposes solutions that increase the efficiency of the line while promoting the wellbeing of the workers.

5.1 Future Work

The layout of the line could be modified so that there is less traffic between the gluing station and the assembly station. Currently, when both stations are working simultaneously, the operators have to pause briefly to allow each other to pass. However, eliminating that traffic requires major redesign of the floor plan that includes relocating stations not within the scope of this paper.

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References


