Abstract—In all types of manufacturing, firms value the effective utilization of resources like raw materials, employee time, and machine labor. The Lean Manufacturing Methodology (Lean) is a philosophy of waste minimization that increases the efficiency of modern factories [1]. The 5S system (5S) is a subset of Lean that provides concrete steps to implement Lean [2]. The goal of this research was to implement 5S in a window screen production process to increase screens made per minute. Surveys of line operators, distance measurements, and time studies revealed that the production process was inefficient. This implementation took place in the Screen Room at the Silverline Building Products (Silverline) production facility in New Brunswick, NJ. The proposed change, a reorganization of the materials needed to produce a screen, reduced production time per screen and decreased the distance traveled by each worker during their shift. It is also projected to save Silverline up to $45,000 annually. These results demonstrate that applying the Lean framework improves manufacturing processes that rely on human factors.

I. INTRODUCTION

Silverline is a subsidiary of Andersen Windows that specializes in affordable and low-maintenance windows and patio doors. The windows come with insect screens which are produced in the Screen Room. This paper addresses the inefficiencies of this specific room at the Silverline production facility in North Brunswick, NJ. The screens produced are either sent to assembly and paired with a window or shipped out individually as a replacement. Many of the production issues in the Screen Room stem from the complexity born out of the higher levels of customization Silverline offers in its windows. This necessitates many variations in screen dimensions and type. Therefore, it is difficult to refine the manufacturing process, as traditional assembly lines are usually specialized to produce one specific product.

II. BACKGROUND

A. The Lean Manufacturing Methodology

Lean is a systematic method to reduce waste of all forms in an assembly line in a practical, reliable, and cost-effective way. It identifies waste as anything that adds cost to the product, such as wasted worker hours, excessive movement, or unnecessary steps in the manufacturing process [3], [4]. Implementing this methodology has been shown to have a number of potential benefits such as shortening the time taken to produce each screen (lead-time) and reducing work-in-process inventory (partially finished goods awaiting completion) [5].

1) Toyota Production System: Lean is widely agreed to have been developed by Toyota Motor Corporation (Toyota) after World War II, in order to increase efficiency. Since Japan's production capabilities, raw materials, and resources had been extensively damaged by the war, the then-standard manufacturing methods produced products with high prices. Thus, Toyota created a system to continuously improve their factories' productivity, which they called the Toyota Production System (TPS). Implementing TPS helped the company lower their prices to compete with comparatively inexpensive German and American cars [6]. It is from TPS that the principles of Lean Manufacturing Methodology were later derived.
In 2007, MIT researchers found that TPS was much more efficient than traditional mass production in that it represented a “completely new paradigm” and a “radically different approach to production” [6]. After this report, TPS gained substantial popularity and was emulated in the factories of many other companies. In fact, Silverline uses a system modeled after the Toyota Production System in their North Brunswick location. Due to TPS’ inherent compatibility with Lean principles, implementation of the solutions described in this paper were significantly easier.

To be successful, TPS requires a foundation of “stability,” which is defined as “bring[ing] process variability under control” [6]. Essentially, all activities must be standardized and every worker should do their job the exact same way. In a factory, this is both practicable and desirable, because the production process reliably produces quality products. Additionally, a manager can easily adjust a stable production process to meet demand; for example, operating half as many lines will always lead to exactly half as many units produced.

The system itself relies on two pillars, Jidoka and Just-in-Time Inventory [7]. An overview of TPS can be seen in Figure 1.

Fig. 1. An overview of the Toyota Production System and its two pillars, Jidoka and Just-in-Time Inventory

a) Jidoka: According to Toyota Global, the Japanese word Jidoka means “automation with a human touch” [6]. It represents the concept of a well-designed machine that can make certain decisions for itself, and thus requires less human supervision. It originates from the automatic loom, which was designed by one of Toyota’s engineers to automatically stop when a broken thread was detected. With this type of machine, less human supervision is required since one man can keep track of several looms. This is a crucial pillar of TPS because it dramatically reduces the need for human labor, which helps a firm save on wage costs.

b) Just-in-Time: Just-in-time (JIT) inventory is a way to organize production by delivering and receiving materials and parts “right when they are needed” [8]. At Toyota, materials are not only prohibited from being on the production floor until they are required, but also kept away from stations until production is active. This results in decreased inventory, and thus lower storage costs.

Beginning the implementation of JIT is a multi-step process. The first step is to assess and document current inventory. Then, managers use these results to determine what the firm will need in the future. Finally, managers set up JIT in a workplace setting by stocking up on only what is needed and buying new materials only when a particular order from a customer requires it. Since factories have to store less materials, logistical costs and inventory waste are reduced. Additionally, a flexible inventory that is based on the orders that customers give allows for customer responsiveness. A drawback, however, are that any delays from the suppliers of a factory’s parts can seriously bring down the factory’s bottom line. In addition, any fluctuations in the market price of certain parts impact JIT systems more because they are more reliant on other companies and so less on their own stock of these parts.

B. The 5S System

One method of identifying and addressing areas of inefficiency in manufacturing is the 5S system. Originally conceived as part of the Toyota Production System, the 5S system provides multiple benefits to the function of a workplace, including improved performance, better health, and increased safety [9]. Each “S” in 5S represents a step in a process that improves the function of a business. Translated to English, the five “S”s roughly stand for Sort, Set in Order, Shine, Standardize, and Sustain [10]. Sorting the inventory of a workspace serves to remove all surplus items from the workstation. This includes putting less used items in a different area while keeping the more important items in closer proximity. Similarly, Set in Order is devoted to arranging materials in the most logical way, taking into consideration the role of every item in each step of the process. Shine establishes the responsibility of the company and of each individual employee to clean up his or her workspace. After implementing Sort, Set in Order, and Shine, a firm needs to standardize the process so that the workplace does not revert to its original state. Standardization includes assigning regular tasks, creating schedules, and posting instructions to habituate these activities. Sustain, the last step of the 5S system, refers to keeping the entire process running smoothly and keeping everyone in the system involved; it cements 5S as a long-term program and not just a short-term fix.

With 5S principles, companies in Hong Kong have successfully increased product quality and employee satisfaction. The implementation of the 5S system has also been shown to allow for easier integration of other management tools. In their studies, Ho and Fung (1994) stated that 5S was one of the strongest tools for enhancing the success factor of Total Quality Management implementation, which is another lean manufacturing principle [11]. 5S has also been shown to be a
driver for the successful implementation of other quality tool applications [12].

C. The Seven Types of Waste

The seven types of waste in a factory, according to the 5S System, are the following [13]:

1) **Overproduction**: Overproduction is the continued manufacturing of an item above the necessary demand for it, and in the process, creating a build-up of unused product. This creates waste as the product accumulates at a faster rate than it is transported out and can generate high storage costs and reduce product quality as quality control checks become more difficult at larger scales.

2) **Waiting**: Waiting is the period of time when a product is not being transported or undergoing a transformational process. Much of a product's life in an assembly line system is spent waiting to be processed further, contributing to wasted time. Ideally, processes should feed directly into one another so that it flows from one step to another smoothly.

3) **Transportation**: Transportation is an inherently wasteful practice as it requires time, energy, and money to move a product, yet adds nothing to a product's value. Manufacturing processes should be compact such that the product does not need to be transported long distances during or upon the completion of the process. Furthermore, handling and transport create opportunities for damaging and reducing the quality of the product.

4) **Inappropriate Processing**: Inappropriate processing represents the improper utilization of assets to perform tasks. Tools and machines should be specialized to the necessary task they perform, so when a machine is capable of doing far more than what it is being used for it is an example of inefficiency and waste. It is thus preferential to invest in smaller, more specialized equipment, and take advantage of a more powerful machine for appropriately difficult tasks.

5) **Unnecessary Inventory**: Unnecessary inventory often goes hand-in-hand with Waiting and Overproduction. Having excess inventory wastes money and space, as well as cluttering the production area which hinders further production. All unnecessary inventory is waste, and one should look to avoid it or remove it.

6) **Excess Motion**: Excess motion is an example of operator waste; unnecessary movements require time and energy, which contribute to overall inefficiency in the manufacturing process. This is related to ergonomics, and can create health and safety issues over time as excess motion builds up to cause fatigue and injury.

7) **Defects**: Defects are an easily quantifiable and direct form of waste. Every defect found is one fewer product being sold, and every defect not found harms brand image and reputation. It is thus imperative that defect frequency be reduced at every step in the process and wherever possible.

D. Screen Manufacturing Process

At Silverline, one of the main issues impeding efficiency in the Screen Room is the complexity which stems from the variety of styles of screens offered. This variability is particularly evident among the corner pieces used to assemble the screen frames. There are different screen corners for each of the four colors produced by the factory: white, sand, beige, and dark bronze. This is further complicated by the fact that each line in the room produces screens for multiple series of windows (3000, 3000 Oriel, 3000 Reverse Oriel, 8500, 8500 Reverse Oriel, 8500 Oriel, 9500, and 1200). The default screen color is white; other colors are produced for specific orders and are very rare. However, only one shelf in the Screen Room contains white pieces, making it difficult for employees to get the parts they need. Efficiency can be greatly improved by making the white pieces more easily accessible to all lines in the room.

First, flat metal stock is run through a machine known as a flatroller, which presses the stock into metal rods that provide a frame for the windows. These rods are passed to the frame assembly, where operators piece them together with screen corners to form the frames. At this step in the process, operators also add labels with barcodes and identification numbers to indicate when and how the screens need to be processed. [Figure 2]

The frames are then taken to a second workstation where another set of operators use spline machines to attach the screen mesh to the frames. At this step in the process, operators also add labels with barcodes and identification numbers to indicate when and how the screens need to be processed. [Figure 2]

The frames are then taken to a second workstation where another set of operators use spline machines to attach the screen mesh to the frames. Finally, the excess screen mesh is cut out. Finished screens are placed in carts of fifty and sent to the assembly room, where they are paired with a window or packaged individually for a replacement order and shipped.

This study focuses on the supermarkets in the Screen Room, where screen corners and other necessary parts are stored. These supermarkets supply operators at the frame assembly workstation. According to analysis of the Screen Room, the poorly-organized supermarkets were the most serious constraint, or bottleneck, in efficient production.
E. Purpose

The purpose of this paper was to improve worker efficiency in the Screen Room at Silverline by implementing 5S to eliminating wasteful practices in production. Specifically, the goal was to reduce the time workers took to gather parts for their shift, as well as the distance they needed to walk. To achieve this, this paper focuses on optimizing supermarkets by moving the parts that operators need closer to their respective workstations.

F. The Thinking Processes

According to the principles of Lean, the four trees of the thinking process encompass the problem-solving process in a greater manufacturing setting. The Current Reality Tree [Figure 7] is performed first, and establishes the undesirable effects present in the status quo and attempts to discover their root causes. This is crucial to determining what needs to be addressed and how the solution should be found. Then, the Evaporating Cloud Tree [Figure 8] is constructed, in which several solutions to an objective are determined along with the prerequisites to those solutions. This tree helps to determine the efficacy parallel solutions and which is preferred. It can also help discover which are mutually exclusive and which are not. One such solution is then chosen from the Evaporating Cloud Tree and used in the creation of a Future Reality Tree [Figure 9], in which a given solution is tested by determining its impact and desired effects, as well as diagramming unwanted impacts that may arise to create a cohesive, holistic picture of the plan’s impact. Finally, a Strategy & Tactics Tree [Figure 10] is made to determine the best way to carry out the plan and achieve the desired outcome at every level. Each of these charts for the proposed solution are given in the Appendix.

III. Experimental Methods & Procedure

A. Survey

Each frame assembly operator was asked a series of four questions in their native language (Spanish, English, or Hindi) concerning their experiences with the supermarket and their work habits. These questions are given in the Appendix [Table 1]. The responses were recorded and then used to identify and quantify the magnitude of several issues. In total, six frame assembly employees during the second shift were surveyed and the results were recorded. These results supported our conclusion that the current organization of the supermarket is an area of interest to be addressed.

B. Spaghetti Diagram

A spaghetti diagram is a map of individual or department-based movement throughout a process and aids in identifying areas of waste. It focuses on a single affected section to see movement of material within it. In this case, the affected section of the Screen Room was the route between the frame assembly and the supermarkets, so only the movement of those operators were recorded with a measuring wheel. In the affected area’s current operations, every frame assembly operator goes to one supermarket shelf [Figure 3]. In the proposed path, however, Lines 2 and 7 would go to the supermarket on the far left of the factory while Lines 1 and 6 would go to the supermarket in the top right of the Screen Room. Then, these routes were recorded onto a floor plan to create current and proposed spaghetti diagrams, both of which are illustrated in Figure 3.

C. Measurements

After identifying the distance and organization issues with the supermarkets, an organization method was developed. Then, measurements of the current path as well as the proposed path from each frame assembly workstation to its respective supermarket, shown in Figure 3, were recorded with a measuring wheel. For each line's frame assembly workstation, the difference between the current and proposed paths were calculated. Supermarket and box dimensions were then recorded along with an inventory list to compile a directory of which parts should go where. These parts were sorted by color first, placing white parts in the two new allocated supermarkets, and each of the other colors in the rest of the supermarkets.

D. Time Studies

A time study was taken to determine an approximation of the time it took operators to go from their workstations to the supermarkets and back with the appropriate screen corners and product labels. In the Screen Room, there are seven screen assembly lines, each consisting of a flat roller, frame assembly station, and spline machine. Three of the seven lines would be affected by our proposed change, so the walking time between the workstations of these lines and the supermarkets were recorded. This was repeated twelve times for each line.

IV. Results & Analysis

A. Reasoning for Proposed Changes

During the several observational visits conducted of the Screen Room area, potential areas of improvement were identified and recorded. When questioned, frame assembly operators revealed that most lines only used white parts and only the second shift of Line 1 produced any colored screens. Due to the standard white screens being ordered more often than the colored screens, there are instances in which the second shift of Line 1 is assigned to producing white screens instead of the colored screens.

Within the supermarket system, the most prominent problems concerned wasteful practices such as incorrect labeling of boxes, placement of parts into the wrong boxes, long walking distances between employee workstations and supermarkets, and ineffective usage of shelf space [Figure 4]; among these, the distance traveled to each supermarket stood out as the most important. As shown in Figure 3, all workers currently travel to a single supermarket area to obtain white parts. Certain shelves were much closer in proximity to the workstations that required white parts; however, the shelves were reserved for
colored parts, forcing the workers to travel across the Screen Room to obtain the necessary parts.

Given the infrequent use of colored parts and relative distances from each workstation to these existing shelves, new routes were created by redistributing the white parts from the central supermarket to periphery ones. In the proposed arrangement, the supermarket to the right of Line 2 as well as one of the two supermarkets to the bottom of Line 2 would be dedicated solely to holding white parts. The sand, beige and dark bronze parts would be sorted into the remaining shelves. Materials such as screen labels, which are stickers that the workers place on each white and colored frame as it leaves the flat roller, would remain where they currently are in the supermarket. It would be inadvisable to distribute these across several locations, for it could potentially increase the disorder of the shelves and confuse employees.

This proposed arrangement makes use of existing shelf space and required only a rearrangement of box location. Though concerns were raised regarding the negative impact of moving the rack location on workers who are already accustomed to their current location, the workers are expected to quickly adapt to this new change as such procedural changes are not uncommon, and its positive benefits (including improved health and safety, greater monetary savings, and increased production rate) will quickly emerge in the long-term despite potential short-term difficulties. As the new arrangement would make necessary parts closer to each frame assembly operator's workstation, it would make it simpler for employees to do tasks such as refill and return their parts.

The following calculations are based upon existing information and are intended to offer an estimate as to the impact of the proposed solution.

B. Time Study Data

Figure 5 shows the average time taken to travel from the frame assembly to the supermarket and back in one full cycle, and represents the time it takes for a worker to travel to the supermarket to refill his or her bins and back. The timing does not include refill time while at the supermarket, as this remains unchanged. Distance measurements for Line 6 revealed that the proposed change would have increased the distance to the supermarket by 10'10" in a round trip (51'6" to 62'4"), so the proposed change was not implemented in this line, and further time measurements were not recorded for it.

Each affected line demonstrated substantial changes in time difference between the current arrangement and proposed arrangement. Lines 1, 2, and 7 would experience time decreases of 5.06, 20.30, and 30.22 seconds respectively on each round trip as a direct result of the proposed change. The magnitude in which the proposed change affects each line depends largely on the original distance the line was from the central supermarket. For all three of the affected lines, the
propose route would decrease the amount of time needed to get the necessary parts. Incorporation of this rearrangement would serve to optimize the employee refill process.

C. Monetary Savings

In order to better evaluate the impact of the proposed change, several Screen Room-wide constants were collected and the expected deviance from this value was determined. First, the variable \( X \) was collected as seconds saved/trip, and can be found in Figure 5 for each line. Observation and timing of various workers revealed that they all walk at slightly different paces due to varying height and age. To account for this, the value for \( X \) was assigned an uncertainty of \( \pm 2 \) seconds. Consultation with the Screen Room team leader at Silverline provided the schedule for the three daily shifts. On weekdays, the first shift always works eight hours with an additional two hours of overtime, while the other two shifts always work eight hours. On Sundays, the factory is closed (0 shifts), while on Saturdays it is only open part-time from 5:00 a.m. to 7:00 p.m. (2 shifts). Given their yearly schedule, it was determined that approximately 856 shifts would be worked in a given year. This shift count was assigned an uncertainty value of \( \pm 20 \) shifts to account for potential stoppages due to mechanical issues or additional overtime to meet unexpected demand.

Surveying of workers indicated that 67% of surveyed workers took two to three trips to the supermarket in a single shift and 33% took more than three trips to the supermarket per shift. Averaging these values together gives three trips per shift on average, with an estimated increase or decrease of one trip per shift depending on volume of screens produced and material already available at the workers’ stations at the beginning of their shifts. Using all of this information, the total annual hours saved by the proposed change can be calculated in Equation 1 (\( Y \) hrs saved/yr).

**Equation 1:**

\[
\frac{X \text{ seconds saved}}{\text{trip}} \times \frac{3 \text{ trips}}{\text{shift}} \times \frac{856 \text{ shifts}}{\text{yr}} \times \frac{1 \text{ hr}}{3600 \text{ s}} = \frac{Y \text{ hrs saved}}{\text{yr}}
\]

Given a representative sample of screen production for one week, which was what the team leader deemed a standard working week, 250 screens were produced in an average work hour [14]. An uncertainty value of \( \pm 50 \) screens was added to account for the large variance in hourly production recorded due to training of new workers, workplace injuries, mechanical failure of machines, and other unexpected potential issues. It was assumed that any time saved in walking distance would be used to produce additional screens at the same rate as they are currently produced. Given this, the additional screens produced annually can be calculated in Equation 2 (\( Z \) screens produced/yr), assuming all of the additional walking time is used to produce excess screens to be sold.

**Equation 2:**

\[
\frac{250 \text{ screens/hr}}{\text{yr}} \times \frac{Y \text{ hrs saved}}{\text{yr}} = \frac{Z \text{ screens produced}}{\text{yr}}
\]

Finally, Silverline screens were found to be sold for approximately $2.50 per screen online, with negligible variation. This allowed us to find the final total additional profit in Equation 3 ($\( W \) earned/yr), given that all the time saved from shorter refill times is used to produce additional screens.

**Equation 3:**

\[
\frac{Z \text{ screens produced}}{\text{yr}} \times \frac{\$2.50 \text{ screen}}{\text{screen}} = \frac{W \text{ earned}}{\text{yr}}
\]

This combined formula provides the average expected additional money earned on a yearly basis. An upper and lower bound for this estimate were also calculated using the upper and lower bounds of each uncertainty value, respectively.

Average: = $24,779.42 saved annually

Upper Bound: = $44,953.40 saved annually

Lower Bound: = $11,513.58 saved annually

Ultimately, the proposed change is expected to earn Silverline an estimated $24,779.42 in additional production revenue.

D. Health & Safety Impacts

**Length of Path Taken from Frame Assembly to Supermarket**

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<th>Current</th>
<th>Proposed</th>
<th>Difference</th>
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<tr>
<td>Line 1</td>
<td>70’4”</td>
<td>59’0”</td>
<td>11’4”</td>
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<tr>
<td>Line 2</td>
<td>142’2”</td>
<td>43’10”</td>
<td>98’4”</td>
</tr>
<tr>
<td>Line 7</td>
<td>145’4”</td>
<td>31’2”</td>
<td>114’2”</td>
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Fig. 6. Measured distances of paths for lines 1, 2, and 7 as walked by the workers in a single round trip. Exact paths taken can be seen in the spaghetti diagram [Figure 3].

Given the data in Figure 6, Equation 4 can be used to arrive at a cumulative total of 108.9 miles saved per line annually, with a lower bound of 70.9 miles and an upper
bound of 148.5 miles.

\[ J_{ft \ saved}^{\frac{trips}{trip}} \times 3_{\text{trips}}^{\frac{trips}{shift}} \times 856_{\text{shifts}}^{\frac{mi}{shift}} \times 856_{\text{shifts}}^{\frac{mi}{yr}} \times \frac{1_{\text{mi}}}{5280_{\text{ft}}} = K_{\text{miles saved}}^{\frac{yr}{yr}} \]

Furthermore, whenever walking around the factory a risk of injury is always present given the large machinery that must often maneuver around the same areas as the workers. This change would then decrease worker fatigue, as a result of the shorter distance walked, and lower the probability of movement-related injuries, positively impacting the health and safety of each worker.

V. Conclusion

The organization method described previously cut the time it took operators to refill the bins at their workstations and reduced the confusion caused by disorganized racks. The proposed change also makes it easier for new employees to learn the locations of various pieces, thereby decreasing the time it takes for them to become accustomed to their workspace.

The implementation of these methods, which focus on minimizing waste, would save Silverline an estimated $11,500 - $45,000 annually. The frame assembly operators’ movement lines were all centralized towards only one supermarket, which was not the closest supermarket for some lines. By placing the white parts, which were used the most often, at two locations instead of one, the optimized spaghetti diagram would have each operator going to the nearest shelf to refill his or her parts, instead of having to move across the entire room.

The Screen Room makes up a relatively small part of the window manufacturing process, and so it has not been the primary focus of the operations engineering team at Silverline. For the most part, little work has been done in optimizing the Screen Room. The development of a new shelf organization system through the collection of quantitative data as well as employee responses serves as an important step in the optimization of the production process at Silverline.

VI. Future Improvements

Due to time constraints and a narrow scope, the authors of this paper could not implement related changes within the factory. If given more time, a similar solution could be implemented in other rooms in the factory as well. Additionally, the machines in the Screen Room are not organized in the most optimal way, according to measurements the authors took over the course of their research. They would like to further explore this challenge and implement a more efficient room layout, if possible.
ACKNOWLEDGMENT

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[14] Silverline Building Products, MINUTES PER UNIT, P-7 datasheet, July 2018

TABLE I

<table>
<thead>
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<th>SURVEY QUESTIONS</th>
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<tr>
<td>Questions</td>
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<tr>
<td>How often do you use colored parts?</td>
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<tr>
<td>How often do you refill per shift?</td>
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<td>Are boxes always on the same place on the rack?</td>
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<td>Do you see parts in the wrong box?</td>
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