



WPI

Process Improvement at Source International

A Major Qualifying Project

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Abstract

The objective of this Major Qualifying Project was to help Source International to improve their manufacturing process for the Modular product line while reducing costs, non-value added time, and employee motion within their work area. The purpose of this project was to reduce operational costs to remain current in the custom furniture market. The methods used to accomplish this included axiomatic design matrix, lean methodologies comprised of value stream map, spaghetti diagram, DMAIC, 5S methodology, 7 Wastes, and Arena® Simulation. The team's recommendations included implementing these lean methodologies tools in order to improve the Modular product line in the form of a manufacturing cell. In conclusion, the application of lean analytic tools would yield substantial savings in time and money, and increasing efficiency of the manufacturing process that Source International uses.

Acknowledgments

The team would like to thank Source International, our sponsor, and everyone at Source International's Sutton, MA facility for the amazing opportunity to apply our knowledge acquired during our college career. Being able to collaborate and learn while working at Source International was an invaluable experience for our future career development. We also want to acknowledge the welcoming environment in which this project was developed. The experience was a pleasant one because the doors were always opened to new ideas and changes throughout our project time. This was a great chance for learning and professional development.

We would like to give a special thank you to Dennis Kamfonik for being our main point of contact and mentor at Source International. The knowledge and experience he provided helped the project development and completion.

Finally, we would also like to thank our advisors at Worcester Polytechnic Institute, Professor Walter Towner and Professor Helen Vassallo for their dedication, flexibility, and feedback throughout our project. Our project would have never started if it was not for their prior communication with Source International as well as their trust believing we would be able to represent Foisie Business School outside of WPI. We thank them for their support and guidance in all of our ideas and changes throughout the project

Chapter 1: Introduction

1.1 Problem Statement

Source International produces a wide variety of custom luxury furniture for their consumers. Due to the variety of customization, the manufacturing process has faced some challenges as they try to optimize and standardize their cycle process, and employee training. Currently, the main focus is the Modular product line that Source International produces. This Modular line includes different types of furniture styles which vary when it comes to building them, making each furniture unique.

1.2 Project Goals and Objectives

After observation and evaluation of three different production areas at Source International our team’s goal is to optimize the Modular Manufacturing process line, the team decided to focus on the following objectives, shown in Table 1 below, to reach our goal.

Optimize cycle process of Modular furniture manufacturing
Improve process efficiency of Modular furniture manufacturing
Improve employee work condition and accountability

Table 1: Objectives established after observations at Source International

1.3 Project Scope

This project mainly focuses on Source International’s Modular product line which goes through a different manufacturing line than their other merchandise. The Modular line consists of different products, however, the team focused on three products: *Scape, Lore, and Reveal*. These models are on the luxury end of Source International’s vast product selection. When working on the floor, the team focused on the following manufacturing cells within the Modular line: cutting, sewing, wood assembly, gluing, upholstery, and final assembly. The team did not focus on the shipping cell of the manufacturing process due to time constraints and out of scope elements. Overall, the team focused on the efficiency and improvement of the Modular product line.

1.4 Project Deliverables

Our project deliverables for this MQP include:

- A system design methodology using an Axiomatic Design of the functional requirements and design parameters of the manufacturing process using Acclaro®] Software
- A current state Value Stream Map
- A current state Spaghetti Diagram Map
- An Arena® Simulation that models the Modular line production process
- A current and future state of the manufacturing floor layout
- Recommendations of lean Methodologies to be implemented in the production process

Chapter 2: Background

2.1 Company History

Source International was established in 1982, focusing on the creation of custom made furniture with a wide variety of styles (Mueller, 2014). They focus on innovative products composed by designers around the world in order to have a portfolio able to meet each of its customer's needs and demands. These product lines seek to include comfort along with a sophisticated design, environmental responsibility, and realistic pricing (Mueller, 2014). Different product lines vary in style and purpose, including multi-use, lounge, and stackable furniture ("Products - All Products", 2014). Not only does Source International have a large variety of products, they also have the capacity to customize every single part of a custom order such as the type of wood, fabric, and shape of each piece. This allows customers to express themselves through their furniture and make their space unique. These furniture pieces are inspired by the scandinavian style trend, characterized by minimalism, and functionality.

Furthermore, Source International is committed in becoming an environmentally-conscious company by manufacturing their products with sustainable materials. Throughout their time as a manufacturing company, they have been focused on acquiring high standard environmental certifications, in order to comply with environmental standards. Their chairs are certified by the Greenguard Environmental Institute, guaranteeing indoor air quality for human health. Their wood is Forest Stewardship Council certified providing wood from responsibly managed forests that provide environmental, social, and economic benefits, their wood stains and paints are free of volatile organic compound emissions. Among other environmentally conscious initiatives, Source International recycles overspray from their taint processes, and their foam is CertiPUR-US made without harmful chemicals ("Company - Sustainability", 2014). Their product lifetime structural warranty guarantees durable pieces that minimize the burden on landfills ("Company - Sustainability", 2014).

2.2 Pre-Project Status

2.2.1 Cultural

Throughout the course of the project, we found that the manufacturing facility of Source International had a distinctive company culture. This was important in order to understand the constraints of our research, analysis, and recommendations. The following are aspects of Source International's culture on the manufacturing floor.

2.2.1.1 Labor experience

While working with Source International, the team started a dialogue with the workers on the floor as well as management. During the different conversations about the

manufacturing process, the team noticed the differences in labor experience within the manufacturing floor. This means that some employees had been working for Source International over a decade while some other employees had just recently been hired. These variations in labor experience brought up some concerns due to the fact that employee awareness of the products and processes are drastically different. Moreover, many of the workers are unaware of what product they are actually working on, its previous steps, as well as the completion deadline. The lack of product awareness has an effect on the manufacturing floor because floor managers, the liaison between departments, are left solely responsible for work-order information as well as front office communication (Personal Interview, 2018). When the team talked to the floor manager he expressed that all the responsibilities lie on him and many of the orders would not be on time, lack of materials would not be reported, and communication between the manufacturing floor and offices would be minimal if there was not a floor manager. This is due to the fact that he is the only person in the production floor with the required knowledge to meet all of these demands. However, one of the problems observed was that it takes employees a long time to learn all of the skills the floor manager has since they do not have a proper background on the products. This could be improved by giving the workers more responsibility and information instead of solely depending on the floor manager. The information given to the workers could include work order, shipping deadlines, specific manufacturing cell deadlines, and product characteristics.

2.2.1.2 Language

Communication is key in any work environment. This aspect is especially important in a manufacturing facility such as Source International, where there are a lot of variables regarding the products. However, communication is challenging because most of the manufacturing floor workers are primarily Spanish speakers. This creates miscommunications that lead to errors in the process, which could delay product delivery or increase lead time. Even though this language barrier could create problems in communication between cells and offices, Source International makes an effort to create an inclusive work environment. The company has created a friendly and multicultural environment for its employees by hanging flags of the different nationalities alongside the United States flag on the manufacturing floor and letting workers speak their native language amongst themselves.

2.2.1.3 Education

Since the salary of a manufacturing job at Source International is minimum wage it is not necessary for the manufacturing employees to obtain an education higher than a high school diploma. However, according to Mr. Kamfonik, employees developed specific skills through their work on the manufacturing floor, which add values to their work experience. Although it takes multiple workers to manufacture any piece of furniture, the employees complete their daily tasks independently. Mr. Kamfonik mentioned how

employees are not earning much money and work alone, which results in production floor workers not viewing their position as a long-term career. Source International employees follow a daily routine at work and thus, notice changes made on the manufacturing floor. Most of the changes that have been implemented by the operations manager, Dennis Kamfonik, were done without prior notification or consultation on the floor. Therefore, changes are seen as executive decisions and not a general consensus for the well-being of the floor.

2.2.2 Layout

During the span of our first visits at the manufacturing floor, the team was able to observe the manufacturing process and dissect each manufacturing cell. Source International has six manufacturing cells and can be classified in the following ways:

1. Cutting
2. Sewing
3. Wood Assembly
4. Gluing
5. Upholstery
6. Final Assembly

The manufacturing floor is split into two main sections, the back stores inventory and the front (shown in Figure 1) contains the production line. Currently, cutting is positioned in the back of the manufacturing floor line with sewing directly in front of it, which gives the sewer a clear path to access the newly cut fabric. Opposite of the cutting cell is wood assembly and gluing where gluing combines padding to the wood structures. In front of wood assembly is upholstery, which takes the product from gluing and attaches the sown fabric. Lastly, the final assembly puts the finishing details on the chairs as well putting the chair together. Because there are no fixed cells in the manufacturing floor, this allows management to physically rearrange the order of the cells in order to experiment with different layouts.

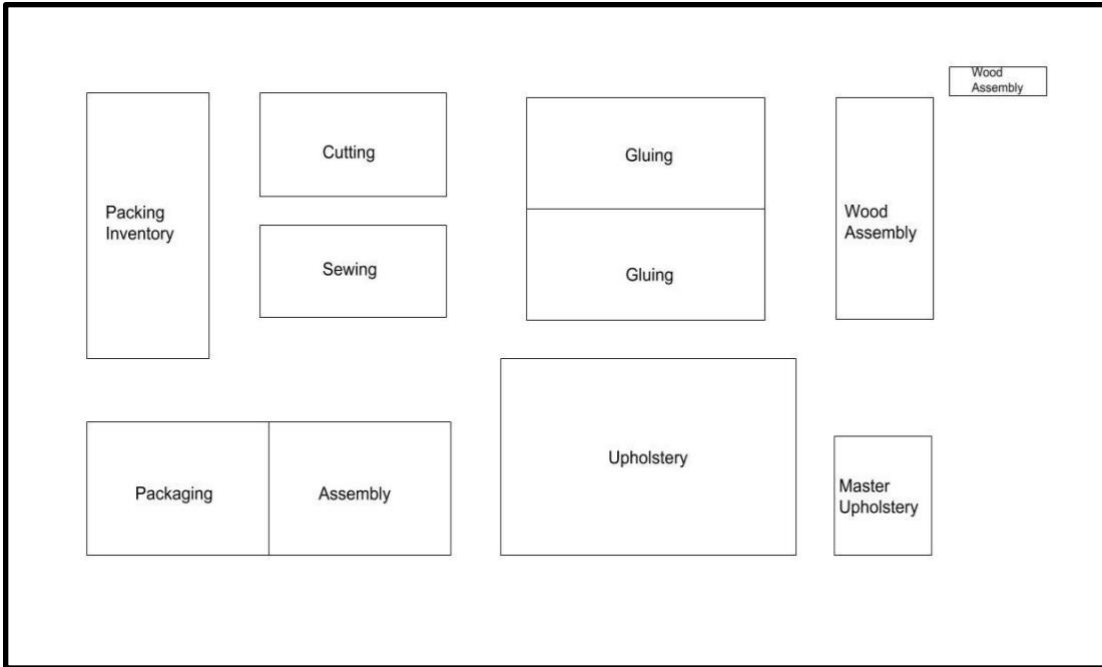


Figure 1: Current Layout of the Manufacturing Floor at Source International

2.2.3 Prior Organization Efforts

Before the team’s first visit, Source International was able to establish a successful company without an Industrial Engineer. However, steady growth had created some challenges due to lack of process flow, inventory control, and floor management. Source International CEO, Erik Mueller, was conscious that even though the company was profitable, the manufacturing process could be improved. During the summer 2018, Source International decided to hire their first on-site Operations Manager, Dennis Kamfonik. Mr. Kamfonik has been the team’s main point-of-contact since the start of the project and has been able to guide the team through the main problems we tackled in this report. The collaboration between our team and Mr. Kamfonik was a valuable experience that can lead to more WPI projects opportunities at Source International.

2.3 Axiomatic Design

Axiomatic Design (AD) is a hierarchical problem solving method that can be applied to solve technical and complex problems. AD was developed by Nam P. Suh in the mid 1970’s in order to create a “scientific, generalized and codified” systematic procedure that would be able to decompose a problem and re-designing a system by making a complex problem into “smaller and manageable work packages” (Suh, 1998) (Rauch, E., et al, 2016, p. 1). In order to begin an AD, a high-level goal must be defined. After this goal is defined, the problem is broken down and sorted

into functional requirements (FRs) which describe how a system should work. In order to fulfill the defined-high level goal, FRs are later complemented by design parameters (DPs) which outline how a system would achieve the previously defined FRs (Rauch, E., et al, 2016). The decomposition is leads to a complex matrix mapping how the FRs and DPs interact, these interactions highlight problems and show the order of adjustments of the system to achieve goals (Suet, 1990).

2.4 lean Methodology

lean Methodology techniques emerged after World War II, when Eiji Toyoda and Taiichi Ohno experimented with the idea of lean manufacturing and applied it to Toyota's Production System (Rufe, 2013) . The concept of lean manufacturing can be simplified to eliminating waste in order to achieve a desired ideal state using different tools such as 5S, Value Stream Map, 7 Wastes, and Spaghetti diagram among other tools, which will be used in this project.

2.4.1 Value Stream Mapping

Value Stream Mapping (VSM) is the method of outlining material and information flow that are part of the observed manufacturing process (Sundar, et al., 2014). VSM aims to locate the source of waste in order to find opportunities that can be improved through lean Methodologies as well as eliminate non-value added time movements. VSM outlines bottlenecks by highlighting lead time, waiting time, process time, and creates a visual process flow of the current system state and an improved system state (Sundar, et al., 2014).

2.4.2 Spaghetti Diagram

A Spaghetti Diagram is a visual representation that traces the path of an item or activity throughout a process with a continuous flow line (Bialek, R., Duffy, G.L., Moran J.W., 2009). By analyzing a Spaghetti Diagram, redundancies within the workflow can be detected and optimized.

2.4.3 DMAIC

DMAIC is a systematic methodology that aids problem solving and is often used to optimize supply chain operations (Mast & Lokkerbol, 2012). DMAIC defines the problem statement, its metrics, required actions, improvements, and how to maintain the efforts done.

2.4.4 5S

5S is a lean Manufacturing technique that is used in order to visually organize a working space (Rufe, 2013). 5S stands for: sort, set to order, shine, standardize and sustain, Figure 2 below shows the continuous improvement of applying 5S. 5S allows the elimination of waste motions by reducing time that takes for employees look for materials and tools (Liker, et al., 2006).



Figure 2: The 5S Process

2.4.5 Seven Wastes (TIMWOOD)

The 7 wastes of lean Manufacturing aim to remove waste from the production process. The acronym TIMWOOD can be used to focus on the 7 forms of waste: Transport, Inventory, Motion, Waiting, Over-Processing, Overproduction, and Defects (Earley, n.d.). These are different areas that can be focused on to eliminate waste, which does not add any value to the manufacturing

process. However, Source International could utilize this for their Modular product line to improve profits for their company.

Chapter 3: Methods

3.1 Design of Methods

The team designed a methodology as a sequential systematic process in order to achieve the overall project goal. This systematic process included suggestions to optimize the production of the Modular product line at Source International. For each method defined in Table 2, the team's purpose was to ensure that all methods were beneficial to achieving the project goal.

Methods	Purpose
Collect relevant data	Understand the current manufacturing processes as wells as past processes
Generate current value stream map	Outlines the current process in order to identify the flow of materials including non-value added time.
Generate current spaghetti diagram	Outlines the material movement in order to reduce waste motions.

Table 2: Design of Methods Table

3.2 Problem Diagnosis

To analyze the current state of the Modular product line, the team utilized an axiomatic design in order to decompose the process' non-functional requirements to identify customer needs.

3.3 Axiomatic Design

Axiomatic design was used to reveal opportunities in the manufacturing process flow of the Modular product line. After multiple visits to Source International, the team was able to develop the Functional Requirements (FR) pictured in Figure 3. Each one of the top tier FR's was split into sub FR's which when summoned, equal to their preceding FR's. The team was able to identify decomposed Design Parameters (DP) that enable fulfillment of the FR's.

To analyze the current state of the manufacturing process of the Modular product line, axiomatic design was utilized to decompose the process into functional requirements to identify customer needs. The team identified the top level functional requirement, FR0, as optimize process

of Modular product line. To address FR0, the team developed DP0 to implement manufacturing processes for optimizing the Modular product line.

#	[FR] Functional Requirements	[DP] Design Parameters
0	Optimize manufacturing process of "Modular" product line	Implement manufacturing processes to optimize "Modular" product line
1	Optimize cycle process of "Modular" furniture manufacturing	Optimize cycle process of "Modular" product line using Lean Methodologies
1.1	Improve the flow of materials required to produce "Modular" product line	Reduce non-value added time using value stream map
1.2	Optimize material movement of "Modular" product line	Reduce waste motions using spaghetti diagram
1.3	Evaluate manufacturing cycle time of "Modular" product line	Analyze manufacturing cycle time using Lean formulas
2	Improve process efficiency of "Modular" furniture manufacturing	Improve process efficiency of "Modular" furniture manufacturing using Lean Six Sigma tools
2.1	Improve organization of manufacturing cells for "Modular" product line	Systemize organization of manufacturing cells using 5S
2.2	Reduce manufacturing wastes of the "Modular" product line.	Reduce manufacturing wastes tackling 7 Wastes through manufacturing process
3	Analyze how Source International can adapt our recommendations	Creatae a plan of action to maintain our recommendations
3.1	Improve worker engagement on the floor	Observing and understanding Source International culture
3.2	Provide financial analytics	Estimate financial impact

Figure 3: Axiomatic Design for Modular Product Line at Source International

3.4 Value Stream Map

The value stream map was used to understand the flow of materials within Source International’s manufacturing process. This analysis was able to be done by collecting data through several visits to the manufacturing floor in order to include information such as number of workers per cell, lead times, and process times.

During the observations, the team identified the areas included in the value stream map. Once observations were made, it was noted the wood assembly and gluing were being done using a push process where furniture skeletons were built and inventoried by batches as shown in Figure 5. On the contrary, the processes of cutting, sewing, upholstery, and assembly were done by the pull process where work was done based the demand of orders being placed as shown in Figure 6. These differences are the reason why there are two value stream maps for the same manufacturing process. The process times on the value stream maps are the average of the three furniture types, Scape, Lore, and Reveal, that for part of the Modular product line. Figure 4 shows the overall perspective of the manufacturing process, where two parallel processes are carried out and then join in upholstery. Moreover, Table 3 includes data of the current and average run times of each manufacturing process respective to each furniture model in the Modular line. Lastly, Table 4 shows the overall summary results from both the push and Pull Value Stream Maps.

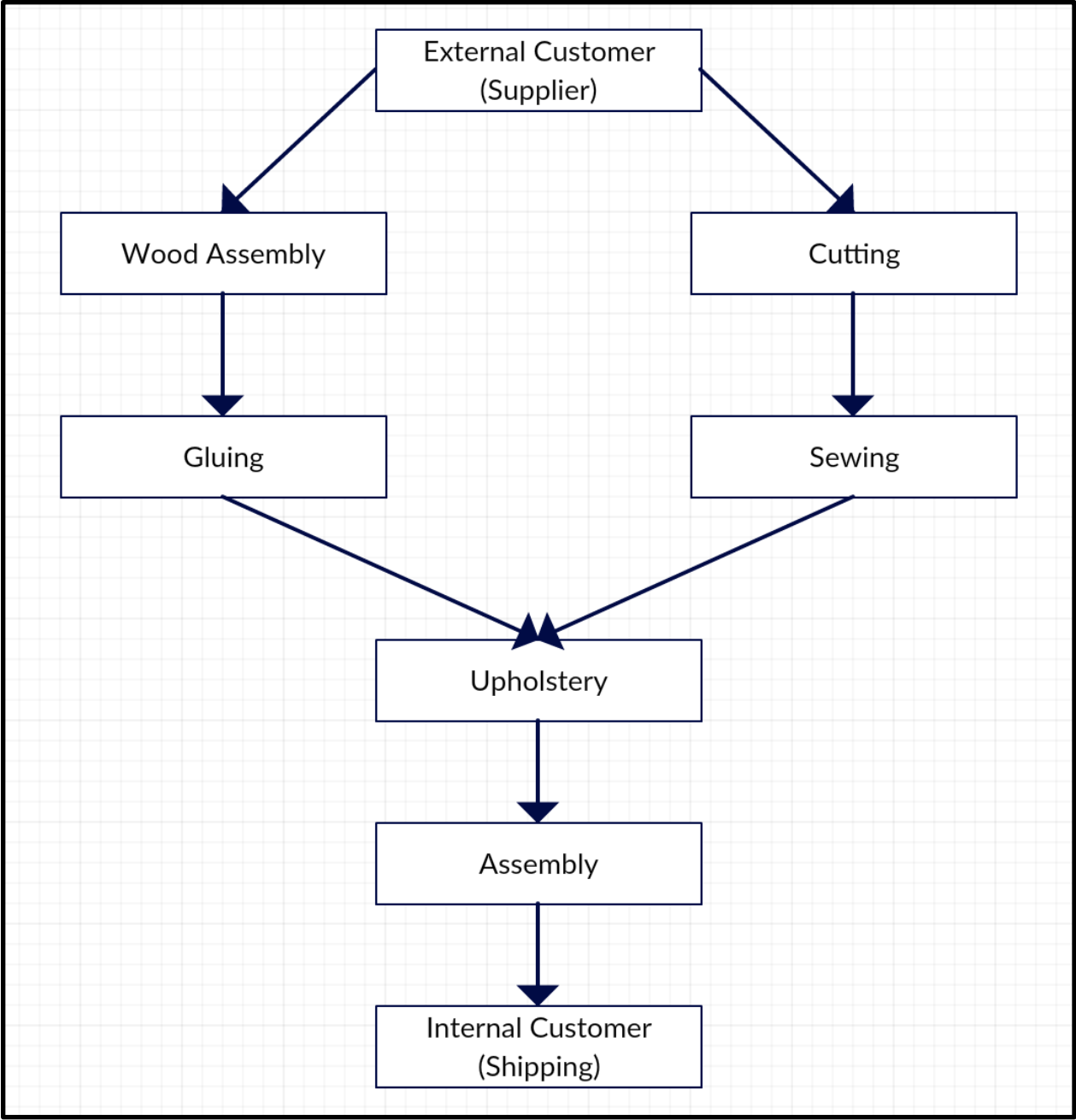


Figure 4: Visual Aid for the Furniture Manufacturing Process of Source International

	Scape	Lore	Reveal	Average
Wood Assembly	-	0.0667 HR	-	0.0667 HR
Cutting	0.600 HR	0.0333 HR	0.5000 HR	0.3778 HR
Sewing	0.7000 HR	0.0833 HR	0.5000 HR	0.4278 HR
Gluing	0.8000 HR	0.1000 HR	0.5000 HR	1.4000 HR
Upholstery	0.9000 HR	0.1667 HR	0.5000 HR	0.5222 HR
Assembly	1.0000 HR	0.5000 HR	0.5000 HR	0.6667 HR

Table 3: Current and average run times of each manufacturing process respective to each model

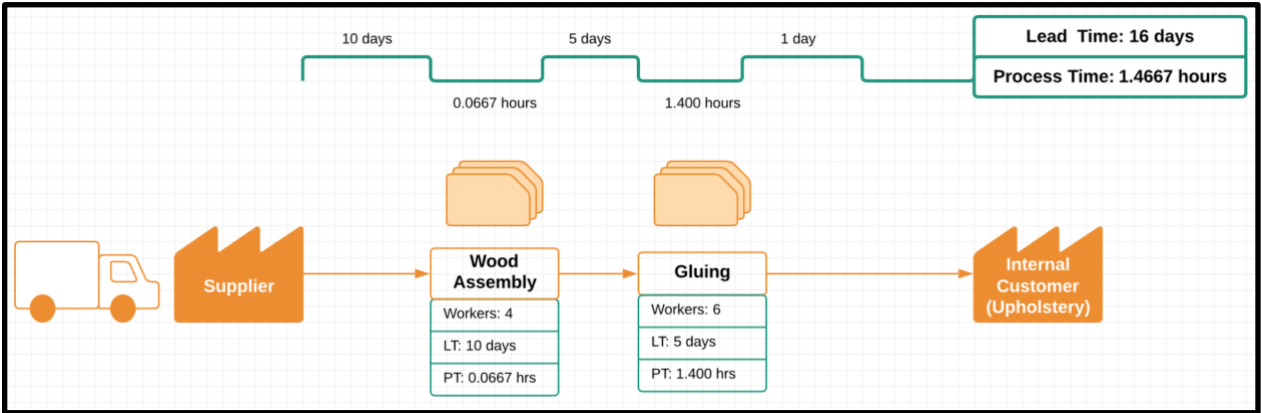


Figure 5: Value Stream Map for Push Processes

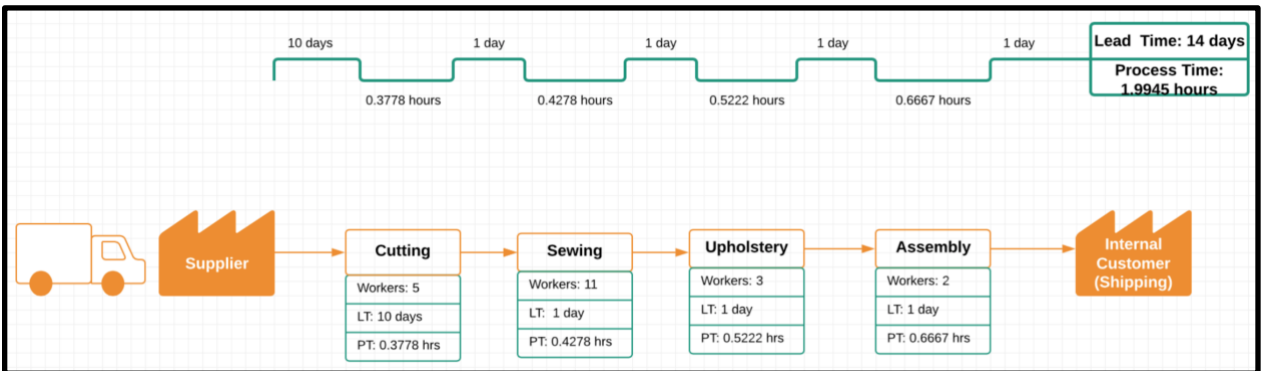


Figure 6: Value Stream Map for Pull Processes

	Push VSM	Pull VSM	Total Process
Lead Time	16 days	14 days	30 days
Process Time	1.4667 hours	1.9945 hours	3.4612 hours

Table 4: Summary of Results from Push and Pull Value Stream Maps

Based on the observations made and the financial analysis, the team decided to create a future state value stream map where we observed where times could be decreased. The pull value stream map had a decrease of 30 minutes overall, making the process time 1.4945 hours. Since the push value stream map is systematic and repetitive, the team did not consider there would be a decrease of time. The future pull value stream map can be observed in Figure 7.

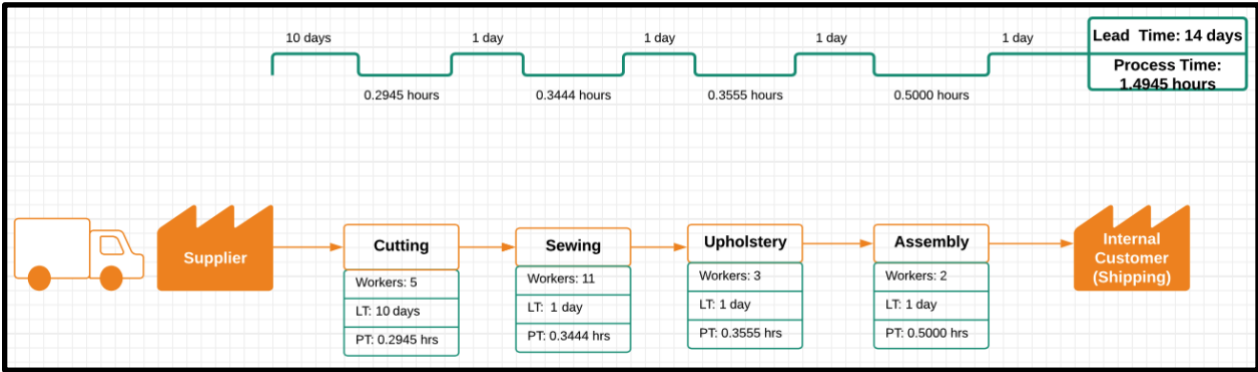


Figure 7: Future State Pull Value Stream Map

3.5 Spaghetti Diagram

A spaghetti diagram is a visual aid that traces a path of activity through a process (Bialek, et al., 2009). At Source International, this tool can be utilized to track an employee’s activity throughout Source’s process of manufacturing furniture. Using the spaghetti diagram, Source International will be able to look at the six manufacturing cells of their process and how much activity was recorded. Some of the activities are vital to the process, such as obtaining the proper template from a shelf in the Cutting process. Other activities are inefficient, such as an employee in the sewing manufacturing cell walking across the floor to the upholstery manufacturing cell.

The team gathered data from each manufacturing cell at Source International in order to create a spaghetti diagram, which can be seen in Figure 8 below. We visited the manufacturing floor during September of 2018 in order to observe employees working on the Modular product line. The employee’s activity was tracked when they were working on the Modular furniture. Most

of the activity tracked in the Spaghetti diagram occurred when the employee left their cell to find specific materials or equipment that was necessary to complete the chair.

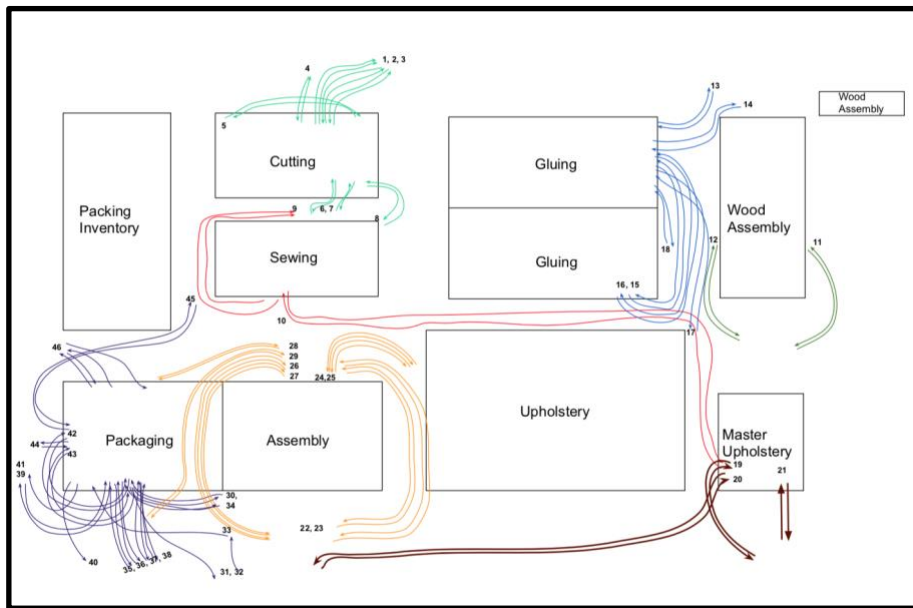


Figure 8: Spaghetti Diagram of manufacturing's Current State

The Spaghetti diagram that was created in September 2018, had a key for each activity corresponding manufacturing cell. A step-time conversion was created by the team calculated as seven second per 10 steps, which can be found in Appendix A. With the 46 lines of activity on the diagram, shown in Figure 8 above, there are a total of 1613 steps taken. With the steps-time conversion, the team calculated the total time of activity to be 18 minutes and 48.5 seconds.

3.6 Formulas

In order to see where Source International could make improvement, a few calculations were needed. The formulas used were throughput, takt time, and cycle time. Throughput is the amount of material passing through the production line. From takt time, the team was able to find the time between starting to work on one unit and starting the next. Lastly, cycle time provides the average time it takes to complete one unit.

To calculate throughput the team added up the wait time, product time, and move time. Wait time is the the it takes from when an order is placed and when productions starts. Production time is how long it takes to produce a product from start to finish. Move time is how long it takes to produce a product from start to finish. After talking with Mr. Dennis Kamfonik, we estimate that the wait time is on average four weeks, production time is on average two weeks, and move time is same day. When added all up throughput is on average six weeks long.

$$\begin{aligned}
\textit{Throughput} &= \textit{Wait Time} + \textit{Production Time} + \textit{Move Time} \\
\textit{Throughput} &= 4 \textit{ weeks} + 2 \textit{ weeks} + \textit{same day} \\
\textit{Throughput} &= 6 \textit{ weeks}
\end{aligned}$$

Equation 1: Throughput Formula applied to Source International

Takt time is the net available time divided by customer demand. Source International starts production at 8:00 A.M and ends production at 4:30 P.M with a half hour unpaid lunch as wells as two fifteen minute unpaid breaks. From this we can see that the total amount of net available work time in a day is 7.5 hours. However, after talking to Dennis Kamfonik, the operations manager, the estimated time spent working on producing furniture is closer to six hours when taking into account lavatory breaks, fraternizing, and delays coming back from breaks. From our conversation with Dennis Kamfonik we estimate that that there are six work orders produced each day. With six work orders produced in a six hour period we found that it takes one hours on average to produce one work order.

$$\begin{aligned}
\textit{Takt Time} &= \frac{\textit{Number of work hours}}{\textit{Number of work orders}} \\
\textit{Takt Time} &= \frac{6}{6} \\
\textit{Takt Time} &= 1
\end{aligned}$$

Equation 2: Takt time formula applied to Source International

Cycle time is calculated by summing the time between the start of production and the end including delay time. By taking the duration time from each cell in the production process along with the value added and non-value added time collected from the spaghetti diagram we are able to find the cycle time. From the bill of materials which provides the duration time from each cell the total time is 6.3 hours (6 hours and 18 minutes) long. Total value added and non-value added time equates to 18 minutes and 48.5 seconds (~19 minutes). This brings cycle time to a total of 6 hours and 36 minutes and 48.5 seconds (~6 hours and 37 minutes).

$$\begin{aligned}
\textit{Cycle Time} &= \textit{Process Time} + \textit{Delay Time} \\
\textit{Cycle Time} &= 6.3 \textit{ hours} + 0.3133 \textit{ hours} \\
\textit{Cycle Time} &= 6.6133 \textit{ hours}
\end{aligned}$$

Equation 3: Cycle time formula applied to Source International

3.7 DMAIC

When solving a problem, there is always a methodology to follow in order to be organized and tackle different aspects of the challenge at hand. In this case, according to an academic article by Smętkowska & Mrugalska published in 2018, DMAIC is a Six Sigma concept used for quality management. This technique goes through five consecutive stages, analyzing different problems, solutions, and controls. Stated below are the five stages, with their respective definition from the previously mentioned article, targeted to Source International.

3.7.1 Define

“Define the goal and its requirements.” The challenge presented at Source International was to improve the manufacturing line of the Modular products. The team needed to define the resources and responsibilities, the organizational structure, and the scope of the project with Source International. We received the assistance from management by working closely with the operation manager, Dennis Kamfonik.

3.7.2 Measure

“Measuring the current process.” In order to improve the Modular product line, the team needed to understand the current manufacturing process and metrics that could be improved. After understanding the process, the team checked if there was enough data to measure, as well as documentation of the current performance and effectiveness. Some of the metrics included product time, workers movement time, and throughput. However, the team was not able to compare prior time metrics at Source International due to the fact that the metrics started to be collected shortly before the project started.

3.7.3 Analyze

“Analyzing the results of measurements, determining the causes of process imperfections and possible solutions for them.” Possessing the current data and being on the floor helped the team analyze key aspects to improve Source International’s manufacturing process. The team demonstrated the current state through value stream maps, spaghetti diagrams, and an Arena simulation. In order to achieve this ideal state, resources, and obstacles needed to be defined as well.

3.7.4 Improve

“Improving the process, implementing the changes, which eliminates the imperfections.” In order to improve the manufacturing process, potential solutions were recommended based off of the team’s calculations, observations, and Arena simulation. Due to the scope and time constraints of this project, the team did not implement any suggestions. However, the team constructed recommendations as implementation plans.

3.7.5 Control

“Controlling of the improved process, monitoring the results in a continuous way.” The control of the different improvements throughout the manufacturing floor rely heavily on Source International’s employees and management. That is why the team suggested a plan for standardization and process monitoring improvement through the use of centralized training, layout improvement, and communication.

3.8 5S

In today’s market, it is critical for businesses to strive and increase their profit margins. One way to do this has been through the 5S methodology, which comes from the Japanese word “muda” (Al-Aomar, 2011). The translation of this word in english is waste, however, its meaning encompassing a broad range of aspects such as excessive material, rework, and delay. The 5S acronym can be broken into 5 aspects which will be developed below based on the team experience at Source International.

3.8.1 Sort

“Removing wastes and clearing the work area.” On the manufacturing floor, there are designated spaces for each of the manufacturing cells required to create a piece of furniture. This allows for a lean floor with contained activities in a specific area, which in turn reduces movement on the manufacturing floor. Within the cells, workers have their tools in areas of easy reach, going back and forth between their table to equip with the proper tools.

3.8.2 Set in order

“Designating and labelling locations of work tools.” The workers have areas designed for their tools. However, there is no labelling of their locations or what each tools is used for. The manufacturing process should be able to have visual aids indicating the flow of products for different production lines. This will allow workers to have a clear knowledge of the process, even without years of experience. Moreover, within the manufacturing cells, visual aids could be helpful to determine where tools should be placed, used, and returned to. Organization will allow a more efficient process.

3.8.3 Shine

“Cleaning and improving the appearance of a workplace.” Walking into the manufacturing floor, there is an open space with mostly cleared pathways. The appearance is lean and organized from afar.

3.8.4 Standardize

“Documenting the work method, using standard tools, and populating the best practices.” Standardization at Source International is a difficult task due to factors such as customization of furniture and high workforce turnover. When furniture orders are customizable, the lead times and process times vary and the fabric process changes. Even though, the process as a whole cannot be standardized, tasks such as assembly and gluing already have a standard procedure. One aspect that impedes the standard process from being effective is the employee turnover rate of nearly 40% of the total workforce on the manufacturing floor. Best practices for each of manufacturing cells might vary with the experience of each worker. Repetition makes expertise in this environment; unless there is the time dedicated to the process it is difficult to standardize the process.

3.8.5 Sustain

“Maintain improvement, controlling work methods, and integrating 5S’s into culture.” The manufacturing floor underwent changes in order to improve the layout depending on the seasons of production demand. This has brought necessity to develop methods of quality control, such as manuals, easy to understand for any new employee at the manufacturing. With the help of the new floor manager, integration and improvement of 5S would be feasible.

3.9 Seven Wastes (TIMWOOD)

Seven Wastes is a lean manufacturing method that allows activities to be analyzed as either Value-Added or Non Value Added. These activities can be broken down into a seven letter acronym “TIMWOOD” which stands for Transport, Inventory, Motion, Waiting, Overproduction, Over-Processing, and Defect (Earley, n.d.). The following analysis breaks down the seven different wastes during the manufacturing process at Source International.

3.9.1 Transport

There are six different manufacturing cells that the product goes through before it is packaged and shipped to the customer. The product is handed off to each cell when the previous cell is finished with their work. Employees sometimes walk across the manufacturing in order for the product to move along the manufacturing process.

3.9.2 Inventory

Source International makes customizable furniture and offers a lifetime warranty on their products. If a chair is sent back to Source International for repair and is older than

10 years old, Source offers the customer a new chair of similar price and style. The lifetime warranty causes them to hold onto too many different types of fabric and wood structures for the chairs. Also, the inventory part of the manufacturing is not organized as items are placed on shelves wherever there is an opening.

3.9.3 Motion

When looking at the “Modular” product line, there is one point in the manufacturing process that can be improved through a layout change. The sewers in the manufacturing process have to bring the fabric across the entire manufacturing floor to the master upholstery cell. Looking at the spaghetti diagram, the action of delivering the fabric to the master upholsterers was the second longest action with 184 steps. The time sewers spent walking across the manufacturing floor could have been spent working on the next work order. This problem can be reduced by moving the master upholstery manufacturing cell closer to the sewing cell. This would reduce the amount of time employees spend transporting the product.

3.9.4 Waiting

The six manufacturing cell process Source International utilizes both a push and pull system. The push system can be seen in the wood assembly and glue manufacturing cells. Employees assemble the bases of furniture and those bases wait until the upholstery cell is ready with the fabric for the given piece of furniture. The part of the manufacturing process that utilizes a pull system starts with the first cell (cutting fabric) and is passed along to each cell until the product is assembled and ready to be packaged. Although there are multiple employees in each cell working on different work orders, there is potential for the products to be waiting to be worked on in any given manufacturing cell. The same can be said for an employee waiting for the work order to be handed to them in their cell, but this is less likely to happen at Source International.

3.9.5 Overproduction

Due to the fact that Source International makes custom furniture, there isn't that much overproduction. Overproduction can be seen with the wooden and metal bases of different product lines. Often the bases of Modular chairs are produced in advance because Source International is waiting for the fabric to arrive to the manufacturing. This is an example of bottlenecking occurring on the manufacturing floor. Custom fabrics have different lead times that are often weeks after the order was placed. Having these chairs ready to be assembled shortens the time it takes to complete the order, but also takes up valuable space on the manufacturing floor.

3.9.6 Over-Processing

Since Source International utilizes both a push and pull system manufacturing process, over-processing doesn't occur as often as other types of procedures. This is indeed a problem that is faced in the packaging cell which is not within our scope.

3.9.7 Defect

Source International has a lifetime warranty on their products. This means that any customer since 1982 can call to have the furniture they purchased repaired. Since the company has been established, they have used different ways to track work orders. Now, when a product is returned to be repaired, it is placed into the manufacturing floor to be repaired which do not produce any profits while they are on the manufacturing floor. Not only does Source International not make money off of these repairs if there are no longer any replacement parts for the product the entire chair will be replaced with a similar chair at no cost.

Chapter 4: Results

4.1 lean Implementation at the Modular Product Line

The focus of our visits at Source International were spent viewing the manufacturing cells while they were producing furniture from the Modular line. We observed and recorded times and movement of employees on the manufacturing floor working on the Modular furniture. It was necessary for us to observe how this furniture line was produce for us to further understand the problem statement. By viewing the process of making the Modular furniture line. We were then able to use our observations to make viable recommendations.

The team identified that reducing throughput times, takt times, and implementing lean Methodologies on the manufacturing floor can help Source International produce their Modular furniture more efficiently. Adjusting the manufacturing floor layout could also benefit the company to improve the efficiency of the manufacturing process. These are changes that would not only affect the manufacturing workers, but the administration and management as well.

4.1.1 Throughput times

Throughput times were analyzed by the team to see how long the manufacturing floor takes to produce a piece of furniture. To conduct throughput, wait time, product time, and move time is added up. The sum of all three is the calculated throughput time, which the average was six weeks. The result was calculated as the average wait time being four weeks, product time being two weeks and moving time happening the same day. Source International could reduce their throughput time by following lean Methodologies or adding more employees to each manufacturing cells. If the throughput time could be reduced, it would result in Source International completing their work orders faster. If Source International can reduce their throughput time, they can use the excess time to take on more work orders. More work orders means more sales. Having a reduced throughput time would result in Source International operating more efficiently.

4.1.2 Takt times

The team analyzed takt times to see how quickly Source International completed customer's request. Takt times are the quotients of all available time divided by the customer's demand. the team calculated the average takt time for one work order was one hours. Source International's manufacturing is open from 8am to 4:30pm Monday through Friday. Each employee is scheduled a 30 minute paid lunch break and two 15 minute (30 minutes total) paid breaks. This leaves an employee with a maximum of 7.5 hours of work in their work day. According to the operations manager, Dennis Kamfonik, it can be assumed that employees produce six hours of quality work during their eight-hour work day. The rest of the time is spent on returning from breaks, going to the lavatory, taking

water breaks, fraternizing with fellow co-workers, and getting ready to either start or finish their shift. One idea that has been discussed in the past is having two groups of workers, one group opening the manufacturing and working their eight hour and another coming in a few hours later and closing the manufacturing after their day. This would allow Source International to extend their company's production time by being open longer during the day. Also, this would keep the employees more focused on their work as there would be less people fraternizing in the break room, which can delay how quickly employees return to their work station. This would reduce the average time it takes to complete each work order.

4.1.3 lean Methodologies

Recommending the use to lean Methodologies is simple. Just about anyone can look at a company and find little changes that could be recommended to make the manufacturing process more efficient. From the team's analysis, two techniques we believe could be implemented more are following 5S and 7 wastes. Both techniques are acronyms that stand for different forms of waste. The technique, 5S represent Sort, Set in order, Shine, Standardize, and Sustain. The 7 forms of waste can be referred to as TIMWOOD, which stands for Transport, Inventory, Motion, Waiting, Overproduction, Over-processing, and Defect. These techniques are already being practiced without any focus on lean. Now that the company has an operations manager on site every day, putting a focus on implementing lean Methodologies would not be too challenging. When looking at 5S, Source International would gain the most by focusing on set in order, and standardizing. Right now, Source International has maintained staying organized (sort and shine) and the ability to maintain a lean focus (sustain). If the company could standardize part of their work process, it would make life easier for their employees. According to the operations manager, they suffer from having a workforce turnover rate of about 40%. A standardized process could make it easier for the newer employees who struggle with the challenges that come with starting a new job. Although, making custom furniture can cause standardizing more difficult to obtain, it seems beneficial for Source International, especially for their employees on the manufacturing floor.

The 7 forms of waste are similar to the 5S method, except there are more forms of waste to look at. Due to a dual push/pull-system that Source International utilizes on their manufacturing floor, they do not need to focus on waiting, overproduction, or over-processing if they were to implement TIMWOOD methodology. These areas of waste are already being addressed through the process of manufacturing furniture. The areas in which Source International could benefit from are transport, inventory, motion, and defect. Transport and motion can be addressed with an adjustment to the floor layout that Source International uses. During the production process of the Modular product line, there is one point where employees need to walk across the floor from the sewing manufacturing cell to the master upholstery manufacturing cell. With this more expensive, Modular product

line, Source International wants their best upholsters working on the Modular product line. This could be rectified by moving the location of the master upholsters to a more centralized location where the gluing and sewing department can be accessed easier by the master upholsterers. Source International struggles to organize their inventory in the manufacturing. As most products are customized, it is rare to have the same product on the shelves multiple times. If there was an inventory system in place, there would be a record of where items are located. Source International currently has a system trying to be implemented. By improving these issues Source International would be able to focus more on their defects. Source International has a lifetime warranty policy on their furniture. This means that at any time a customer can have their chair sent back to Source International to be repair or replaced with a product of equal value if the original chair is over 10 years old. These chairs are just thrown into the flow of the manufacturing floor and are expected to be repaired and shipped back to the sender as soon as they enter the building. There is limited ways to track these repaired chairs are not being sold, thus not producing revenue for Source International.

4.2 Financial Analysis

Throughout the course of this MQP, the main goal has been to improve the Modular product line. The reason for this improvement is to reduce costs or increase revenue, which would benefit Source International. In the case of this MQP, the team focused on the use lean methodologies on the manufacturing floor as well as an Arena Simulation to understand the different proposed solutions and its outcomes. In turn, the team was able to decrease time of the production process as outlined in the following sections.

The team approached the financial analysis with calculations of how many hours per year were saved. First, the team needed to define how much was an hour worth for Source International. The team calculated the hours based on a 40 hour per week for each employee as well as a quarter system of 13 weeks. The overhead, occupancy cost, and profit were considered fixed costs for the shop rate costs. The total cost of one hour per employee is about \$110.00 for the Modular product line. The calculations can be observed in Figure 9. The total cost of one hour with 31 employees in the Modular product line is \$860.00. The calculations can be observed in Figure 10. The cost of the hour would be considered the shop rate for the Modular product line at Source International.

	Salary	Benefits	#of Employees	Total per hour	Week	Quarter
Cost of Employee	\$12.00	\$13.00	1	\$25.00		
Overhead (Rent, utilities, insurance, salaries that aren't job- or product-specific, office equipment such as computers or telephones, office supplies)				\$15.00		
Occupancy cost				\$20.00		
Profit				\$50.00		
				\$110.00	\$4,400.00	\$57,200.00

Figure 9: Shop rate cost per employee for the Modular product line

	Salary	Benefits	#of Employees	Total per hour	Week	Quarter
Cost of Employee	\$12.00	\$13.00	31	\$775.00		
Overhead (Rent, utilities, insurance, salaries that aren't job- or product-specific, office equipment such as computers or telephones, office supplies)				\$15.00		
Occupancy cost				\$20.00		
Profit				\$50.00		
				\$860.00	\$34,400.00	\$447,200.00

Figure 10: Shop rate cost per 31 employees for the Modular product line

The second step of the process was to calculate the cost of implementation of the potential change proposed by the team. Changing the manufacturing floor would take approximately 5 hours and affect 9 employees in upholstery and master upholstery manufacturing cells. Considering this, the team was able to calculate the cost for the change would be of approximately \$1,550. Source International would not need major internal costs such as new pipelines or electric lines which maintains the cost of the change to wages and shop rate costs. The calculations for the cost of implementations are shown in Figure 11 below.

	# of Hours	Number of Employees Unable to Work While Implementation is Done	Shop Rate (Cost of Overhead, Occupancy and Profit) per Hour	Salary Cost per Hour	Total Cost
Cost of Implementation of Change	5	9	\$85.00	\$25.00	\$1,550.00

Figure 11: Cost of implementation of change for Source International

The third step of the financial analysis process was to calculate the total worth of the shop rate hour on a quarterly basis. According to Mr. Dennis Kamfonik, the manufacturing floor completes a minimum of one work order or a maximum of eight work orders per day. Each of the work orders take an approximate time of 6.85 hours. Based on these numbers, the team did calculations based on the completion of 6 work orders per day. The current total worth per quarter

of the manufacturing process is approximately \$2,297,490.00. The calculations can be observed in Figure 12. Assuming the change can save 0.5 hours per work order in the Modular product line, the process would take 6.35 hours. The future total worth per quarter of the manufacturing process would be approximately \$2,129,790.00. The calculations can be observed in Figure 13. This would mean the team would be saving an approximate of \$167,000.00 per quarter. This results can be observed in Figure 14.

Current Time per Work Order	Work Orders per Day	Work Hour Value with 31 employees	Total Worth per day	Total Worth per Week	Total Worth per Quarter
6.85	6	\$860.00	\$35,346.00	\$176,730.00	\$2,297,490.00

Figure 12: Current total worth for the Modular product line at Source International

Saved Time per Work Order	Current Time per Work Order	Work Orders per Day	Work Hour Value with 31 employees	Total Worth per day	Total Worth per Week	Total Worth per Quarter
0.5	6.85	6	\$860.00	\$32,766.00	\$163,830.00	\$2,129,790.00

Figure 13. Future total worth for the Modular product line at Source International

Savings per Day	Savings per Week	Savings per Quarter	Savings per Year
\$2,580.00	\$12,900.00	\$167,700.00	\$670,800.00

Figure 14: Approximate savings for the Modular product line after implementation of change

The fourth step was to create a cash flow diagram outlining the initial investment for the change and the savings per quarter after its implementation. This cash flow diagram can be observed in Figure 15. However, the team needed to consider time value of money. This means that money is worth more in the present than in the future. In turn, the money saved in quarter 1 would be less in quarter 2, 3 and 4. That is why the team used a Present Value calculation to estimate how much would savings in the future quarters would represent currently. The team used an Excel Formula Builder where the annuity value (A) over payment (pmt) was represented per quarterly savings of \$167,000.00. The interest rate per year used was 10% which was equally divided between the number of four period which represent the four quarters to equal 2.5% interest. This calculation resulted in a present value of approximately \$66,633.00 in savings due to the change implementation. The calculations can be observed in Figure 16.

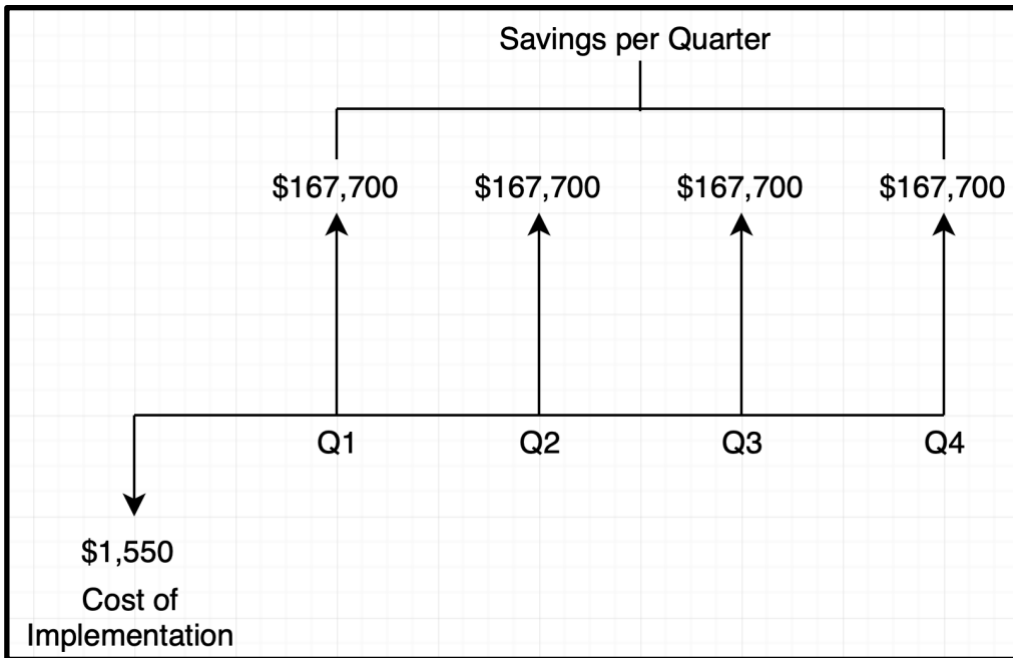


Figure 15: Cash flow diagram for Modular product line

Annuity Value (A) / Payment (pmt)	-167,700.0
Interest (i)	2.5
Number of Periods (n)	4.0
Present Value (PV)	66,633.0

Figure 16: Present value of savings for the Modular product line

Chapter 5: Discussion and Production of Data

5.1 Impact

During the course of our MQP, the team was able to gain real world experience in a manufacturing environment and learned how to decompose problems in order to isolate errors. Through the use of lean Manufacturing techniques, such as axiomatic design, 7 Wastes, and 5S, the team gained a new perspective of evaluating and recommending process improvements more efficiently.

Learning and utilizing axiomatic design as a process improvement strategy was a major benefit to the completion of this MQP. Applying axiomatic design methods to the Modular product line's manufacturing process provided the team with the opportunity to understand its functional requirements, design parameters, and process variables in relation to how they interact.

The majority of this project was dedicated to the technical aspects, such as conducting time studies, tracing the flow of the manufacturing process, and interviewing front-end management and manufacturing workers on their experiences in the production process.

5.2 Challenges

During the course of the project, the team was able to identify challenges surrounding the Modular product line. The team found difficulty in standardization of the manufacturing process. This is due to the fact that the process includes both push and pull systems of production. For the push system, standardization is likely to happen because they are repetitive actions in batches with no customization. However, the pull system is done through steps that require customization which involve specific actions depending on the size of the furniture and fabric. This makes standardization difficult because each step is different based on the customer's demand.

Moreover, the Modular product line requires experienced workers, especially in upholstery in order to deliver a quality product. These "Master" upholsterers are seldom met with which makes them extremely valuable members of Source International. Without these Master upholsterers, Source International runs the risk of substandard production of the Modular products.

The work experience of the employees varies drastically. Some employees have been working for Source International for decades while others have been working for a few days or weeks. This in turn, presented challenges of product knowledge, as well as the process of production. The team also took into consideration that the level of education required by employees was very minimal, due to the fact that the tasks at hand were based on repetition or prior experience. There are no incentives to encourage employees to do additional tasks outside of their job description, making changes in the manufacturing floor difficult.

Lastly, one of the biggest detriments to the manufacturing process was the high employee turnover. This is due to the fact that most of the tasks do not require prior knowledge and the

compensation is minimum wage. Therefore, employees tend to leave Source International when an opportunity for a better job arises. According to Mr. Kamfonik, 40% of the workforce is seasonal while only 60% are full-time.

5.3 Managerial Analysis

5.3.1 Addition of operations manager at Source International

Source International tried to improve their manufacturing processes this summer by hiring operations manager, Dennis Kamfonik. The hiring of an operations manager represents Source International trying to utilize an engineer's mindset to improve their process. Although he is ambitious to improve the company, he is a new hire which makes it more difficult for him to implement any improvements. Employees may not 100% agree with any improvement Mr. Kamfonik makes because some of them have worked for Source International longer than Mr. Kamfonik and may not find the improvement necessary. It's important for Mr. Kamfonik to find employees who will not only support any changes he makes, but also enforce the improvements on the manufacturing floor.

5.3.2 SWOT Analysis

Our team conducted a SWOT analysis on Source International. The intention of this SWOT analysis is to study Source International internally and determine their strengths, weaknesses, opportunities and threats of the company.

5.3.2.1 Strengths

Source International is a furniture company that manufactures high quality products. They are involved in a unique market and differentiate themselves from their competitors by giving their customers the opportunity to customize their desired product. Customers can choose any fabric they'd like to apply to their furniture, even fabric not offered through Source International. Source International is flexible with their furniture because they want to their customers to have the best piece of furniture for a low cost.

5.3.2.2 Weaknesses

Source International offers high quality products for a low cost because the company manufactures furniture with minimum wage employees. Although they are able to utilize cheap labor to manufacture their furniture, the decision comes with its own risk. Source International suffers from having a high turnover rate. According to Mr. Kamfonik, there is a 40% turnover rate

on the manufacturing floor. This means that there is a large percentage of Source International's workforce that has little to no experience on the manufacturing floor. These new hires received hands-on training from experienced employees, but this takes the experience employees away from their work, slowing down production on the floor. Training new hires who aren't in the company's long-term future has potentially to negatively affect work production at Source International.

5.3.2.3 Opportunities

There are opportunities for Source International to complete more work orders per day if they can reduce their takt times, throughput times, and cycle times of their manufacturing process. Our team observed the manufacturing process at Source International to determine these time studies. If Source International can reduce non-value added activities on the manufacturing floor, they can use the extra time to complete more work orders daily.

Another opportunity that Source International has to increase their number of work orders is by adding a second shift of manufacturing employees. By utilizing a second shift, employees would no longer be working the same eight hour shift as their colleagues. Half the employees would arrive in the morning while the second wave of employees coming into Source International in the afternoon. This means Source International could extend their daily hours of operation, so they would have additional time to complete more work orders.

5.3.2.4 Threats

There are two types of threats that Source International face: internal and external threats. The internal threat that Source International faces are works not adopting the newly implemented methods. The external threat that Source International faces is tariffs on foreign parts.

The main threat to making changes to the way Source International operates on a day-to-day basis is not having the workers adopt the new methods. Without full cooperation and support of the workforce new implementations will slow production down and result in higher throughput, takt times, and cycle times. To limit the threat, it is imperative for management to obtain feedback from the workers and empathize with their concerns. Rewarding those who adopt the changes without issue is crucial as it will reinforce good behaviors and positive work performance.

With tariffs on Source International's imported good prices will be increased to accordingly. This threatens the sales on Source International's Modular product line as businesses may not want to pay the additional fees associated with the tariffs. In order to reduce the likelihood of lost sales, Source International can show "good faith" by splitting the cost of the tariff with the customer. Initial glance may make it seem as if Source International is losing money on sales, however, they put themselves at a greater risk of losing more money in sales by deterring potential customers by increasing the prices of the Modular produce line to the cost of the tariffs.

5.3.3 MOST Analysis

A MOST analysis is a structured method that our team used on Source International. MOST is an acronym that stands for Mission, Objective, Strategy and Tactics. Our team utilized a MOST

analysis is to demonstrate how Source International can take their business to the next level, through improving their manufacturing process, to all their employees.

5.3.3.1 Mission

Source International is a company that creates customized furniture with high-quality designers. They want their furniture to be comparable to other top of the line furniture companies but can be purchased at a reasonable, affordable price. In order for Source International to maintain this mission, they will need to make sure that all of their product lines, not just the modular line, are being manufactured at optimal efficiency. The less efficient their manufacturing floor is, the less time they can spend producing customizable furniture.

5.3.3.2 Objective

The goal of Source International's business is to specialize in quality, sophisticated furniture through the use of designers located across the world. This goal acts as a roadmap for all of the employees that work for Source International, no matter if they are manufacturing or administrative employees. When analyzing ways to improve the company in any way, the objective of the company is something that needs to be considered at all times. Source International will not improve anything if these improvements do not follow the objectives of the company.

5.3.3.3 Strategy

As Source International improves their manufacturing process of the modular product line, a predetermined strategy must be in place in order for them to effectively achieve their goal. Changes are easy to make on the manufacturing floor, the difficult that comes with any change is the analysis of the change. After making an adjustment on the floor, it is crucial to analyze it to see if the adjustment is an improvement or a regression from the current system in place. Source International can do this by conducting more time studies on their manufacturing process after an adjustment on the floor occurs. These adjustments can be compared to the time studies and simulation of the current floor layout.

5.3.3.4 Tactics

Source International can be tactical with their approach to improve the manufacturing process of the modular line by being accountable and responsive to changes on the floor. By making any adjustments to their manufacturing floor, it is vital for Source International to act quickly and efficiently to limit the distractions to the workforce. If an adjustment has more of a negative impact than a positive one on the workforce, management must work effectively to amend the problem by empathizing with the workforce's concerns and making adjustments based on their feedback.

Chapter 6 Recommendations

After our team's observations at Source International's manufacturing floor, we have decided to focus on standardizing work, improving the manufacturing floor layout, implementing 5S, and doing an Arena® Simulation as part of our recommendations. The following subsections encompass detailed explanations of each recommendation.

6.1 Standard work

The team's first recommendation for Source International is to utilize standard work which is the act of documenting the best practice of a certain action and enforcing this method to be utilized. Standard work "ensures execution of standardized processes" and "ensures performance-tracking data for problem solving and corrective action" (Mann, 2009). In Source International's case, standard work would create more consistent practices among workers when building Modular products. Standard work would also allow for management to closely track quality of products and custom specifications. This allows for a calculated approach to problem-solving, as there are consistent actions being taken that can be measured without the possibility of extraneous errors. Standard work would also create ease of turnover if Source International is to add additional shifts to production.

6.2 Improved Layout

Source International has six different manufacturing cells that utilize a pull system on their manufacturing floor. The cells are located strategically for the furniture to be passed along in the manufacturing cell. The manufacturing floor is open and has very little immovable objects that give Source International the ability to place their manufacturing cells wherever they choose to. This allows the furniture to be built in all six manufacturing cells efficiently. When looking specifically at the Modular product line, the manufacturing layout of the manufacturing cells are located in sequential order, but the layout is not the most optimal design.

Since the Modular product line needs the labor of the master upholsterers, the furniture is moved across the manufacturing floor from one cell to another. Once the sewers complete sewing the fabric, they walk across the floor to give the fabric to the master upholsterers. These are the employees that provide seating, cushions, and fabric to the wooden base of the furniture. By looking at the Spaghetti Diagram the team generated in Figure 17 below, employees have to walk 184 steps before they can handoff the furniture and start the next work order. A recommendation that Source International could consider is moving the master upholstery manufacturing cell closer to the middle of the manufacturing floor. This would allow the same flow for the other product lines, but eliminate the long walk across the manufacturing floor when a Modular product is being

produced. By eliminating the time it takes to transport furniture from one manufacturing cell to another, it would give Source International’s employees more time towards the next work order.

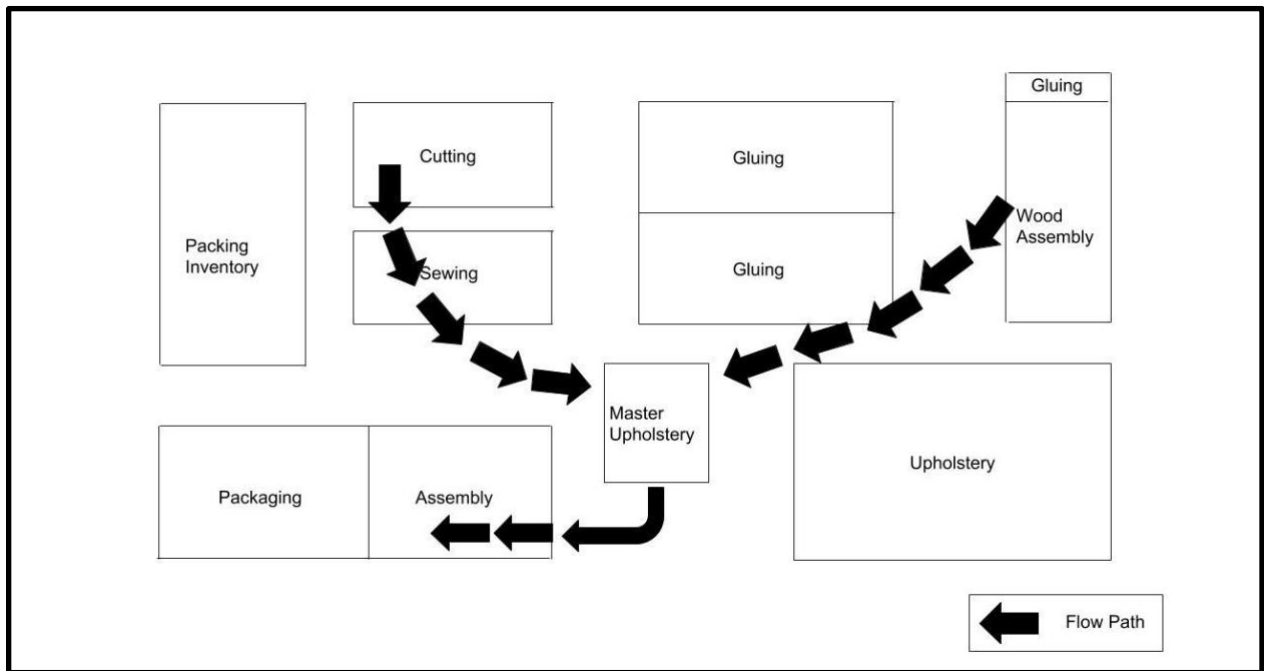


Figure 17: Future Layout of the Manufacturing Floor at Source International

6.3 Expanded 5S

After the team’s observations on the manufacturing floor, we noticed that 5S methodologies could be applied to the fabric inventory shelves. As seen in Figure 18, the fabric shelf does not have a standard order. In order to address this issue, our team recommended the implementation of subsections within the shelves. These shelf divisions would categorize the fabrics based on the last digits of their work orders. For example, if the last two numbers of the tracking number on the work order was 38, then the employee would stock the fabrics on the shelf, in the section labeled “30-40”. This organization can be observed in Figure 19. The implementation of shelf divisions for different orders would reduce non-value added time searching for fabric.

This lack of organization was also present in the inventory racks where the wooden furniture pieces are stored. The staff allocates the assembled wooden pieces based on space available. This has caused Source International to have problems with inventory count as well as problems locating the specific items needed for orders. That is why one recommendation would be to designate areas for the different current product lines and discontinued product lines. Once the areas are designated, numerically representing each of the racks would be a beneficial addition

to the production floor. Numbering these designated areas creates a simple and common way to bypass language barriers. Overall, Source International would be able to Sort, Set in order, Shine, Standardize, and Sustain a naming system for the different products at hand.



Figure 18: Fabric Inventory Rack in Sewing Manufacturing Cell at Source International

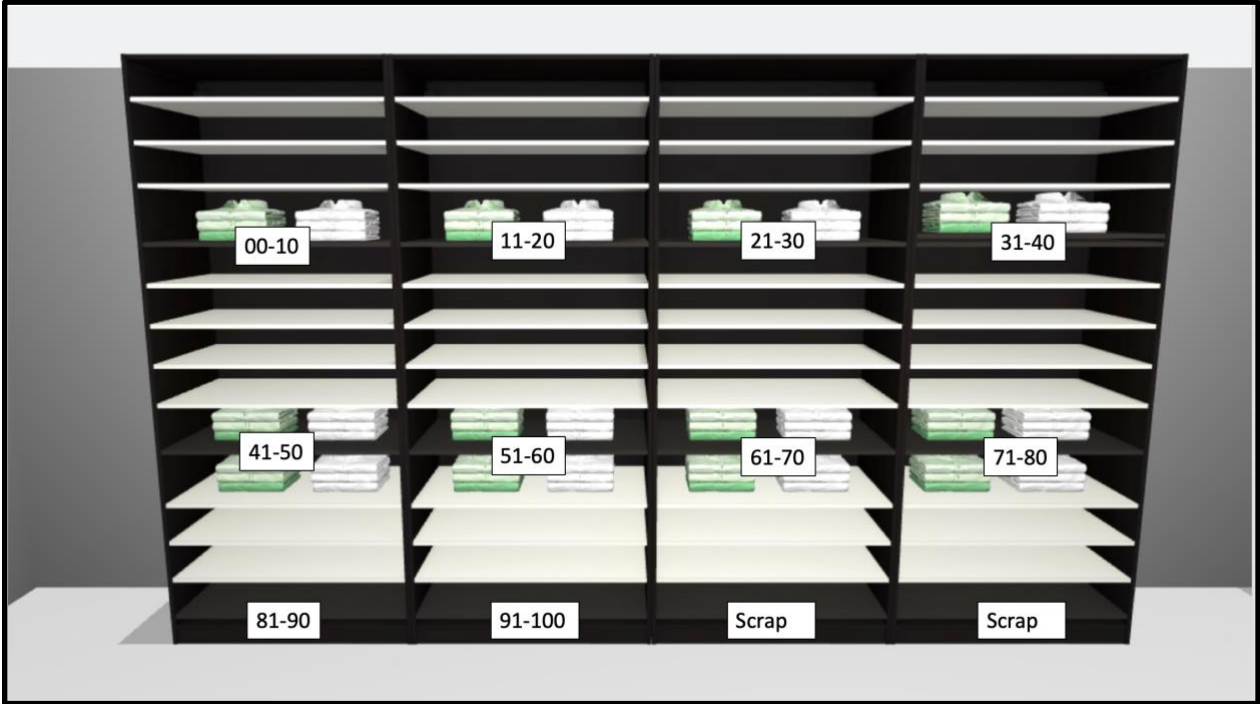


Figure 19: Future organization fabric racks using 5S

6.4 Arena® Simulation

Arena® is a computer simulation software that allows users to model and visualize the behavior of different systems over a desired period of time, which enables users to analyze and optimize a system before applying changes to the physical system (Kelton, W.D., et al, 2015). With Arena® simulation, users are able to visualize bottlenecks, make changes to the process being modeled, and compare and contrast different versions of the same model in order to increase efficiency (Elam, M., et al, 2011). After a model is created, it needs to “run” in order to obtain different key performance indicators such as queue times, average time spent in the system, work in progress, and throughput.

In order to create an Arena® simulation, certain parameters have to be defined. The team decided to use the Basic Process Template Panel in order to model Source International’s manufacturing process because it fits the model’s needs more accurately than the other Template Panels. Figure 20 below shows each parameter and its icon that can be used in a model. Models are created by dragging “modules”, which represent different processes within a simulation. Below these modules are grid boxes that contain properties of each modules.

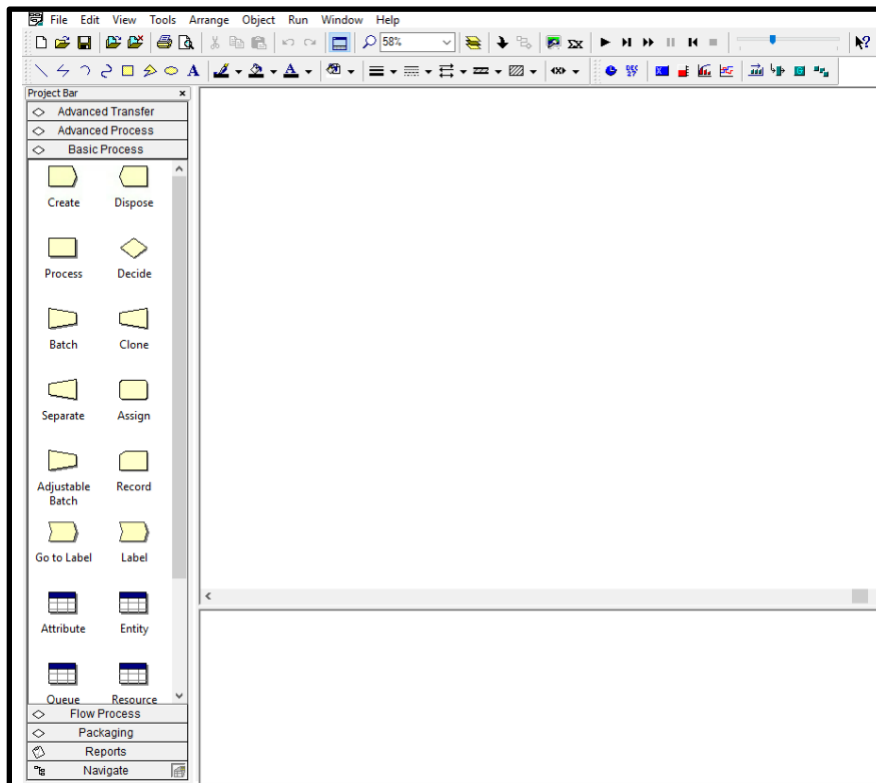


Figure 20: Basic Process Template Panel

As mentioned before, Arena® simulations contain modules which can be broken down as seen in Table 5 below:

Create	Produces arrival rates of entities which can entail product/customers etc.
Process	Carries on entities' process
Entity	Edits properties of the entities
Schedule	Edits schedules that different resources will follow
Resource	Edits each resources properties
Decide	Allows for decision making within the process
Dispose	Indicates entities that the process ends
Create	Produces arrival rates of entities which can entail product/customers etc.
Process	Carries on entities' process

Table 5: Arena® Simulation Modules (Kelton, W.D., et al, 2015).

The “create” module starts the simulation by determining the arrival rates of “entities”, in our model these entities are the types of furniture orders. The entities will then follow into different process modules that will represent the different stages that the furniture’s go through, each process module will have different “resources” or workers that can work on each furniture. After the processes have been completed, the items will then exit the simulation. The simulation stops when the furniture is assembled rather than being boxed and shipped, since the scope of our project stops at the completion of the products.

The team used data obtained from our value stream map in order to accurately simulate Source International’s current state of the process for the Modular furniture line. The model considers the number of workers per process, workers schedule, hours of operations, as well as the number of incoming orders in order to accurately model the manufacturing process. The team was

able to analyze the process flow, potential bottlenecks that could arise, employee addition or relocation and evaluated changes that could be implemented for a future state of the process.

Figure 21 shows the Arena® Simulation for the Modular furniture manufacturing line. The differences between our current state and future state models is the addition of a second shift as well as an addition of 2 extra upholsters that work only one shift. The three models were simulated for 260 days, which is an average work year. The times for each process were taken from the value stream map that was mentioned previously on the paper. The arrival rates of the Modular furniture were averaged from all three furniture lines and according to the data given by Source International, the minimum order per day would be 1, the mean order per day would be 3 and the maximum order per day would be 8.

The current process was simulated for 260 days and the output showed that total production of Modular line chairs would be 5774 and it would spend an average time of 78.36 hours in the system. The future state model with two shifts would produce an average of 5774 Modular line furniture and the product would spend 78.36 hours in the system. Ultimately, after noting that there was a bottleneck at the upholstery station the addition of 2 extra upholsters was considered and after the system was run the throughput decreased to 5,526 and product time in system decrease to 78.23 hours, the throughput difference between the current state and adding 2 new upholsters was 248 hours monthly. The team believes that the current state and future state with second shift had no change due to the fact of the order constraints, meaning that no more than 8 orders would be received per day so the second shift would not have any orders to work on because the day shift had already completed them.

Changing shifts and adding employees are one of the basic and less complex models than can be simulated in Arena®; it has the ability to simulate different approaches and scenarios in order to improve a manufacturing process. The addition of supplemental data of the manufacturing process would make the Arena® model more accurate and representative of the current process. If data was collected over the span of one year, this would allow the model to have data regarding Modular line order surges, this would allow Source International to analyze the different trends in order and how to allocate their workers which will increase the . This data would also aid in analyzing bottlenecks and creating a more accurate future model since the amount of orders does not stay uniform throughout the year. If Source International were to invest in purchasing a commercial license for a simulation modeling software like Arena, this would allow engineers to model and tests different future scenarios before applying them into the manufacturing cell.

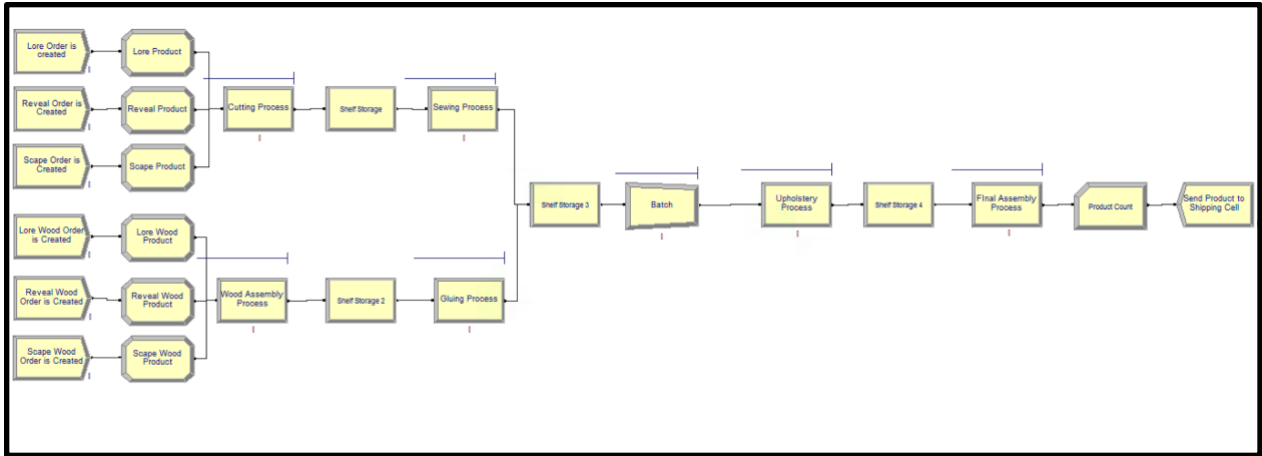


Figure 21: Arena® Simulation model of Modular line Manufacturing line

Chapter 7: Conclusions

Our team worked alongside Source International’s Operations Manager, Dennis Kamfonik, in order to improve production manufacturing process of the Modular product line. Using lean Methodologies, our team was able to pinpoint opportunities for process improvement that could impact the reduction of throughput time and cycle time for the Modular line. Furthermore, in order to understand the challenges, the team created an Axiomatic Design Decomposition where we developed functional requirements to be understood for the improvement of the process.

Based on the data collected, the team was able to create a future state map of the manufacturing floor layout and an Arena® Simulation model. The impact of the future state layout of the manufacturing floor will reduce non-value added time by rearranging the manufacturing cells and thus, improve the flow path of the entire process. Moreover, the Arena® Simulation model provides an insight into the possible changes that could be made within the manufacturing floor by modifying variables such as the number of employees and shifts. Having these models, Source International will be able to experiment with different models before implementing the future changes on the manufacturing floor.

The team also considered various management tools in order to improve employee’s work conditions and accountability. The first is to improve workers’ engagement on the floor through the use of standard work and training. These could be done by implementing procedures for manufacturing employees on the floor to assist them in their daily tasks. New employees are often overwhelmed and subsequently underperform, thus an organized training seminar could be helpful to everyone at Source International. Also, Source International could invest in a safety orientation for all of their employees. Safety is often overlooked until a detrimental situation occurs. This can compromise the company employee’s health and also impact the efficiency of the manufacturing process.

The team’s time at Source International was a valuable work experience in a manufacturing environment. The team will take these skills that we have learned and apply them into our future endeavors and career paths. We have been exposed to real world industrial engineering challenges where we used our academic knowledge gained from our time at Worcester Polytechnic Institute.

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Appendices

Appendix A: Spaghetti Diagram of Modular Product Line Key

Cutting - Turquoise

Sewing - Red

Gluing - Blue

Wood Assembly - Green

Upholstery - Brown

Assembly - Orange

Packaging - Purple

Conversion: 10 steps = 7 seconds

Footnotes

Cutting

1. Getting template for cutting - 24 steps
2. Getting template for cutting - 24 steps
3. Putting away template - 24 steps
4. Grabbing fabric for cutting - 20 steps
5. Non Value added time (talking to coworkers) - 22 steps
6. Getting tool for cutting - 24 steps
7. Speaking to supervisor at desk - 24 steps
8. Finishing product and delivering to sewing - 20 steps

Sewing

9. Getting fabric from cutting - 68 steps
10. Finishing product and delivering to master upholsterers - 184 steps

Gluing

11. Obtained materials in front of Wood Assembly - 28 steps
12. Obtained materials in front of Wood Assembly - 28 steps

Wood Assembly

13. Non-value added time (took a water break) - 28 steps
14. Obtained materials from the back - 42 steps
15. Grabbing tool from coworker - 50 steps
16. Returning tool - 50 steps

17. Obtaining fabric/foam for gluing - 56 steps
18. Obtaining fabric/foam for gluing - 40 steps

Master Upholstery

19. Obtained materials from front of Wood Assembly - 28 steps
20. Non-value added time (took break to get food) - 186 steps
21. Obtained materials from front of Wood Assembly - 20 steps

Assembly

22. Obtained materials from front of Assembly - 44 steps
23. Obtained materials from front of Assembly - 44 steps
24. Borrowed tools from coworker - 16 steps
25. Borrowed tools from coworker - 16 steps
26. Obtained materials from front of Assembly - 44 steps
27. Obtained materials from front of Assembly - 44 steps
28. Borrowed tool from packaging cell - 28 steps
29. Helped package product - 40 steps

Packaging

30. Moving couch from assembly to packaging - 12 steps
31. Non value added time (stepped into break room) - 20 steps
32. Returned from break room, walked immediately to wrapping station - 8 steps
33. Wrapping station to products - 8 steps
34. Moving couch from assembly to packaging - 12 steps
35. Building box for packaging - 20 steps
36. Building box for packaging - 20 steps
37. Building box for packaging - 20 steps
38. Building box for packaging - 20 steps
39. Bringing mobile wrapping closer to the products - 42 steps
40. Additional wrapping - 8 steps
41. Additional wrapping - 8 steps
42. Additional wrapping - 20 steps
43. Additional wrapping - 20 steps
44. Additional wrapping - 14 steps
45. Obtaining small boxes for packaging - 60 steps
46. Bubble wrap - 35 steps