Birdhouse Factory Simulation
Project Report

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Introduction

Large scale manufacturing is difficult to do consistently and quickly. The drive of lean manufacturing is to reduce production times, waste and variation in products being produced. The nebulous of lean manufacturing principles employed in many manufacturing settings are extremely varied without a one size fits all fix for production problems. Every manufacturing setting has its own unique set of problems and constraints meaning that a solution that works for one product in one setting may not be applicable to the same product in another setting or different products in the same settings. Early in the development of these lean principles several companies would blindly copy strategies being used at their competitors without fully understanding the reasoning behind the decisions being implemented resulting in poor performance gains. Understanding the nuance of the situation at hand and applying the concepts of lean manufacturing appropriately is the key to success, however it is difficult to fully understand some of these principles without examples about their implementation. To this end all of the lean manufacturing principles discussed in this paper will be contextualized through the lens of a birdhouse factory.

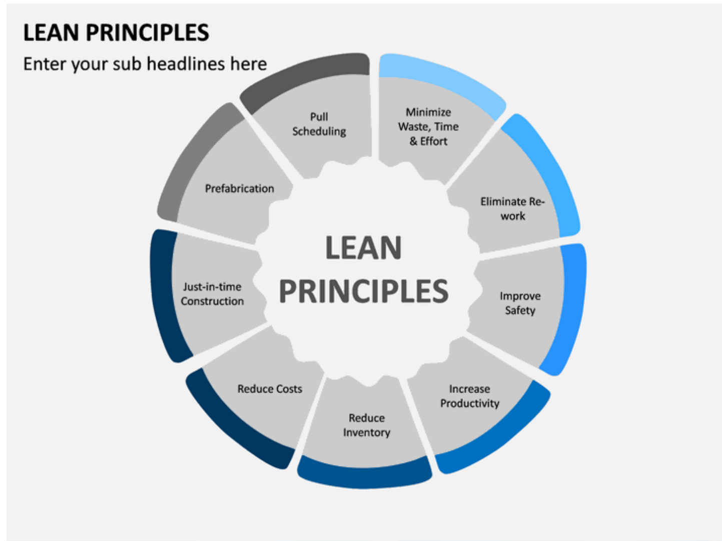

Figure 1: Lean Principles

The birdhouse factory example will allow us to examine a high volume, low margin manufacturing setting where creating a product quickly and consistently is the only way to stay profitable. We will examine the process of designing and refining our birdhouse factory and the lean manufacturing principles that guide it through its four developmental stages: Proof of Concept, Prototyping, First Article Development, and Production.

Proof of Concept

Proof of concept is a presentation of a feasible design concept, which determines the foundation of the entire project. At this stage, we will demonstrate our purpose and goal of this project, product quality, and the value stream map of the manufacturing process.

Problem Statement

A problem statement addresses a statement about what should be focused on, what is the situation, how to eliminate a difficulty, or what should be solved. It highlights the major purposes, helps understand how the problem causes, its condition, and situation, and provides primary solutions. The problem statement is significant to manufacturing because it decides what should be done. The entire manufacturing process will build up based on the problem statement.

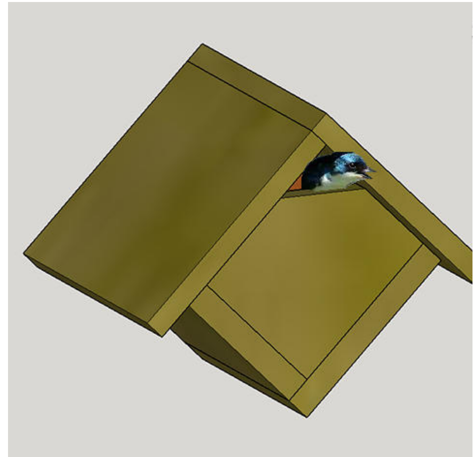

Figure 2: Design of Birdhouse

In the project, we define what is going to be produced, what are the customers' requirements, and how are we going to provide the product that customers desire. Our manufacturing process and products are the ways to answer the problem statements. Based on the determined customer' requirements, we will manufacture birdhouses in various qualities, aesthetically pleasing, easy mounting, and customizable. We design birdhouses that can host multiple birds.

Goal Statement

A goal statement defines the direction a company or process improvement should be moving towards. It outlines decisive, measurable goals and should be focused on the goals alone and not how they will be achieved, nor mention what may be a cause or solution a given goal is addressing. Each goal needs to have a clear indicator as to when it has been achieved. A goal statement is important in manufacturing as it provides a clear and definite indicator if the work being done is moving toward the goals set forth.

In the case of our birdhouse company, we can set goals for what we would like our facility to produce on a weekly, monthly, and yearly basis. The goal statement should also state how the design and layout of the facility should be improved to increase productivity. We will set a yearly production goal of 30 thousand high-quality bird houses per year.

Figure 3: Goals

Critical to Quality

Items that are critical to quality allows the company to not only satisfy customer demand and desires but also helps to set the company apart from the competition. Generating a critical to quality (CTQ) tree like the one shown in figure 1 can aid in this process. First, the needs of the customer, or what is critical for the product or service to be successful, should be defined in broad terms. After the needs have been defined you must identify what is driving those needs, known as quality drivers are factors that must be present for the consumer to believe you are offering a quality product or service. After defining the quality drivers it is essential to identify the minimum performance requirements for each driver to deliver the quality product or service the consumer is looking for.

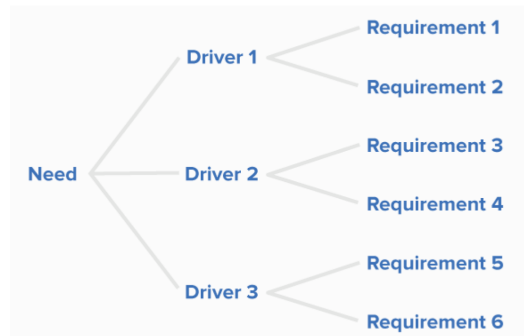

Figure 4: Example of a blank (CTQ) Tree

The CTQ tree can be applied to the birdhouse company, to identify what we must do to offer the consumer a quality product. Knowing exactly what the consumers want for your product to be considered quality is vital in identifying what must be done while producing the products and what processes are not critical. Our customer needs are that we must produce a birdhouse that can house at least one nesting bird. Based on this need we can generate the birdhouse critical to quality trees seen in figure 2.

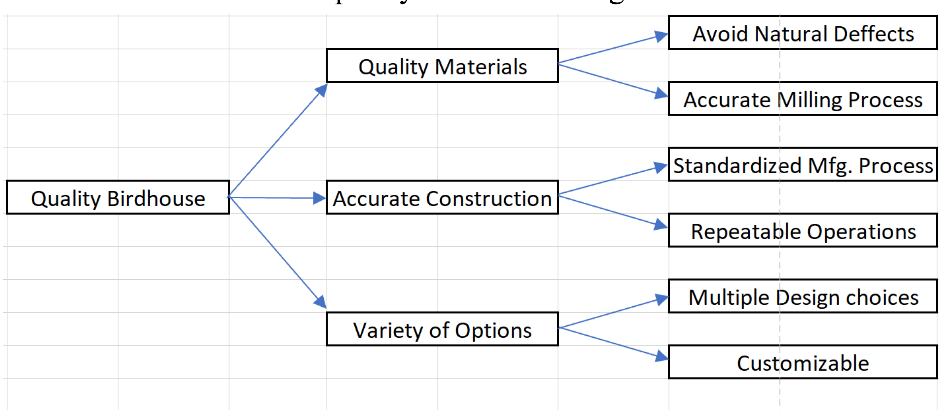

Figure 2: Birdhouse CTQ Tree

Cost of Poor Quality

Cost of poor quality is an extra cost resulting from using or manufacturing defective materials, it is considered as the offsetting cost filling the gap between expected and actual quality of products. The cost includes rework cost, material cost, shipping cost, workers cost, and additional cost will be added on to the manufacturer after the products are manufactured. It is determined as a negative outcome. It is crucial to manufacturing because it helps manufacturers decide the final value of products, and avoid poor quality in the future. In our birdhouse company, we can predict the possible failures and defective products that would be manufactured by our workers and predict the additional costs that are generated by those. Having the possible cost of poor quality, we can accurately establish the price for birdhouses and forecast the expected profit. Besides, we can reduce the costs of poor quality through reviewing the previous financial period, and according to the information, we can improve the manufacturing process and avoid the cost from happening again.

Figure 5: Cost of Poor Quality

Value Stream Map of Current Production Environment

The greatest challenge in creating the value stream map was not being able to physically go to the shop. Ideally, we would be able to go to the shop and time ourselves making a birdhouse or at least running through the steps to get the most accurate time estimates. Therefore, the value stream map below is generated based on the experience of a member and reasonable imagination.

As seen in figure 3, our build process has a lot of steps, this is primarily due to purchasing rough cut lumber, which not only will lengthen our production times but also increase our profit margins on each birdhouse. Based on our goal and predicted efficiency, the lead time will be less than three days. The value-adding time will be 50 minutes and the non-value adding time will be 2905 minutes.

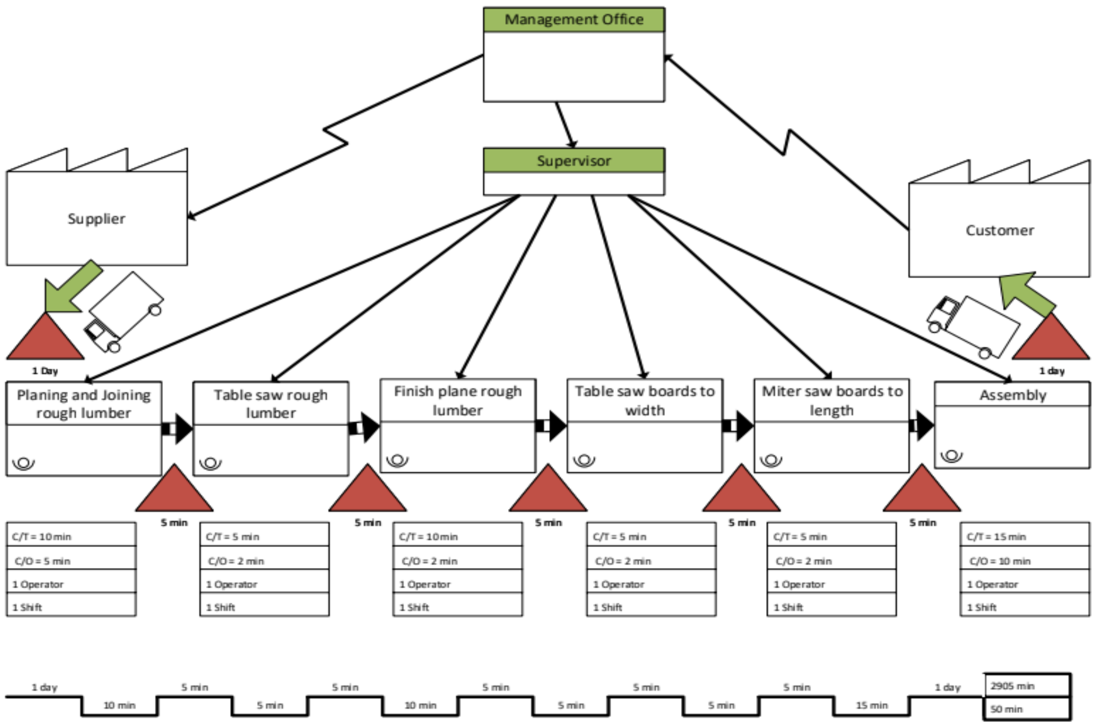

Figure 6: the value stream map of our birdhouse company

Prototyping

Prototyping transfers a product design to a primary product and varies the design with different purpose and quality, the essential processes will be determined as well. In this step, we will present a product family that is diversified from the primary design, and the key processes and metrics that are significant to diverse products.

Product Family

A product family is a series of products that pass through similar or the same processes in their creation. By producing a variety of products we can ensure that we are capturing a larger share of the market and increasing our profits. By diversifying our output we can capitalize on high-profit designs that may not have the demand to support a shop dedicated only to its production full time. In our factory, we will produce a variety of birdhouse designs made of varying material quality. By capitalizing on the shared manufacturing requirements of these products we can design a versatile shop that can produce a wide range of birdhouses that can appeal to a variety of customers. Figure 4

Figure 7: Product Family

shows just a few of the designs our birdhouse factory plans to produce.

Product/Process Matrix

The product/process matrix is a tool used to show graphically what processes are required to produce differing products. Visualizing the manufacturing process in this manner, various product families or products with similar process requirements can be grouped together. This grouping facilitates the design of the manufacturing cells required to meet customer demand.

In the example birdhouse facility, the product process matrix can be seen in table 1. We can clearly define two groupings of products. The pine and cedar birdhouses all require the same processes and can therefore be manufactured in the same flow line cell. The premium birdhouse will be low in demand and can thus be made in a job shop production cell.

Table 1: Product/Process Matrix for birdhouse manufacturing

	Birdhouse Process Requirement					
Product	Ripping	Cross Cutting	Miter Cutting	Sanding	Assembly	Weather Proofing
Pine	x	x	x		x	
Cedar	x	x	x		x	
Premium	x	x	x	x	x	x

Manufacturing Method Recommendations

Recommending manufacturing methods is an important part of reducing the time it takes to manufacture products. This is because there may be multiple processes which can achieve the same result but only one method is the most efficient. Selecting the correct method can greatly reduce the time required to manufacture a product.

The birdhouse example has a few different processes that require a dedicated tool to perform. The ripping process is best achieved using a table saw with a 24-tooth ripping blade. Cross cutting will be performed using a dedicated miter saw with an 80-tooth cross cutting blade. Another miter saw is required to create the miter on the front of our birdhouse. Sanding will be done using a drum sander to sand panels quickly. Pneumatic nail guns will be used to affix the components to each other.

Figure 8: Miter Saw

Estimated Process Times

Figure 9: Time

Understanding process times is critical to reducing waste and ensuring that maximum time is spent working on value-adding processes. The most ideal method for determining process times is to simply observe the process and time it using a stopwatch. It is critical that during this observation the operator performs the process as they normally would and does not attempt to speed up their normal pace in an attempt to “get a good score”. This analysis only works if it reflects the true rate at which the process is performed. Unfortunately, due to limitations brought on by the global pandemic we are unable to physically produce our product and time how long each step of production takes. To compensate, estimates for all process times have been made and included in table 2. All processes will have a transfer of materials that happens between each of the processes and is represented below as material transfer. All of these estimates are assumed to be taken in the Oregon State Rogers woodshop which has not been optimized for the production of our birdhouses and therefore all process times are meant to be conservative estimates that could be severely reduced in an optimized shop.

Table 2: Process Time Estimates

Process Name	Process Time
Joining Rough Lumber	25 minutes
Table Saw Rough Lumber	2 minutes
Planing Rough Lumber	10 minutes
Table Saw Boards to Width	2 minutes
Miter Saw Boards to Final Shape	5 minutes
Birdhouse Assembly	30 minutes
Material Transfer	5 minutes

Cell Design Considerations

There are two primary production cell types, job shop production cells and flow line production cells. A job shop production cell is a versatile production cell that can handle different types of products flowing through the cell. This is an advantage that it has over the flow line cell. Though it is capable of producing a multitude of products, it does so at a cost to manufacturing efficiency. A job shop production cell, by design, cannot produce a large amount of products quickly and is not suited to handle a large influx in demand. A flow line production cell, on the other hand, is designed with a large production volume in mind. This is achieved by optimizing placement and setup of each machine. While the flow line production cell excels at mass production, it's main disadvantage is that the cell is optimized for producing a single or family of products. Changing what the cell produces entirely will result in a long changeover time which is not ideal for a large production volume.

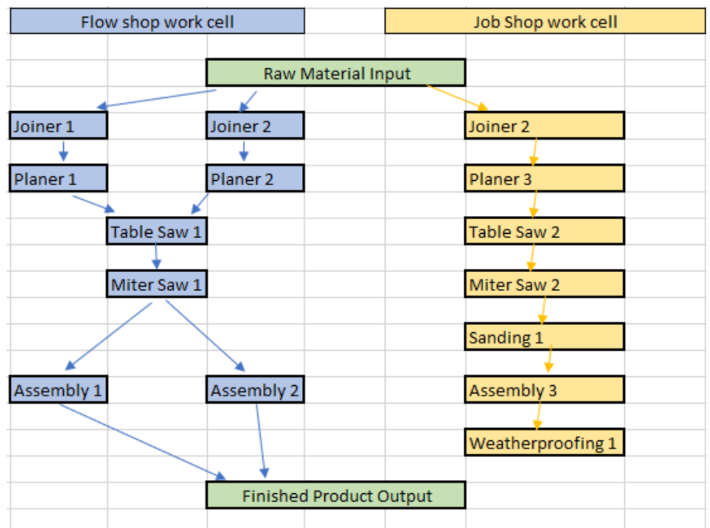

Figure 10: Possible Work Cell Layout

Based on the required processes and estimated demand for our products we would recommend the construction of two work cells; a high volume flow line cell and a low volume job shop cell. The lower quality pine and cedar birdhouses require the same processes and will be in the highest demand so being able to produce a high quantity of parts in a short period of time will be crucial. The premium quality birdhouses will require additional process steps to manufacture as well as having more design options that may involve more complicated construction. This low volume and highly variable production are perfect for taking advantage of the versatility of the job shop configuration.

Both the flow shop work cell and the job shop work cell will require jointers, planers, table saws, miter saws, and assembly stations including tables and pneumatic nail guns. Additionally, the job shop work cell will require a sanding station and a weatherproofing station. Joining, planning, and assembly are time-consuming processes that will likely require additional stations in the flow shop work cell. Figure 5 illustrates one potential layout for the work cells that allows the work cells to share the same input and output nodes.

8 Wastes

The 8 wastes of lean manufacturing, as seen in figure 6, are Defects, Overproduction, Waiting, Non-utilized Talent, Transportation, Inventory, Motion, and Extra Processing. There are many ways that these forms of waste can manifest themselves in any manufacturing process. One of the goals in lean manufacturing is to reduce these forms of waste to optimize the production process and workspace.

In the example birdhouse facility, there is ample opportunity for waste to happen. A few examples are listed in table 3. By identifying different types of waste we can increase profits and optimize production.

Figure 11: Eight Waste in Manufacturing

Table 3: Examples of waste in birdhouse production

Type of Waste	Example 1	Example 2
Defects	Knots or checking present in products	Misalignment of assembled products
Overproduction	Producing more premium birdhouses than demand requires	Producing more birdhouses than can be sold
Waiting	Waiting for adhesizes to set	Work in progress waiting for assembly
Non-Utilized Talent	Talented craftsman working in flow line cell	Talented designer not allowed to ideate new design concepts
Transportation	Sourcing stock from distant vendors	Workstations far away form each other when they could be next to each other
Inventory	Large amount of rough stock being stored	Large amount of stored work in porgress
Motion	Placing a tool far away from where it is needed	Unnecessary bending to pick up stock onto work surface.
Extra-Processing	Hand planing rough stock	Appling finish to lower quality birdhouse that will likely be painted by consumer

Key Metrics and Methods

Key metrics and methods for measuring and reporting are crucial when you measure length of products and report a manufacturing process. Choosing a key metric will decide how accurate to manufacture and uniform all productions. A tiny difference in the metric scape will hugely change productions, and furtherly, it will impact the assembling and create cost of

Figure 12: Metrics in Engineering Design

failure. On the other hand, a key method reports manufacturing progresses will help manufacturers understand the situation of manufacturing. Correctly using a method to report the production will indirectly benefit improving the manufacturing process, cut the wastes, and increase efficiency.

Since our birdhouse produce can be done in a short time, we will use “minute” as the primary time metric unit to measure the value adding time, lead time and other time related systems. We use “inch” as the primary length metric to measure the product length, width, and height. To report the manufacturing condition, we will tend to use graphs and diagrams to present the manufacturing condition and demand. Paper report is necessary if we need to report a failure or problem in the manufacturing process.

Consequences of Failure Demand

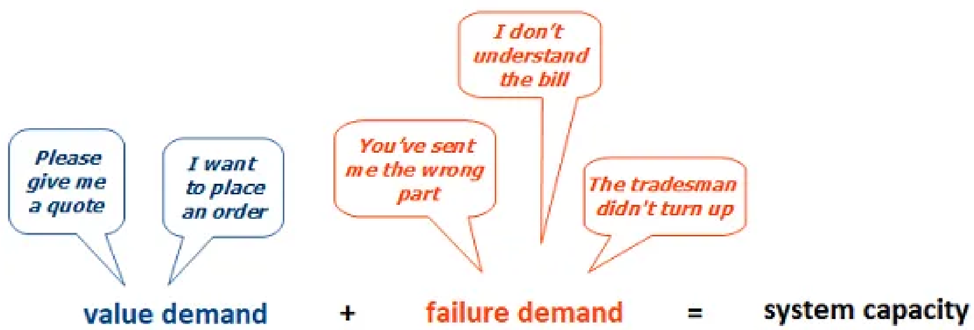

Figure 13: Value Demand and Fail Demand

The purpose of all businesses is to fulfill a demand. Demand occurs in two parts; value demand and failure demand. Value demand is the demand generated by the value of the service or product provided. This is the kind of demand that businesses strive for as they generate the greatest value for all parties. Failure demand on the other hand is the demand generated by failing to do something correctly for a customer. Failure demand could include needing to rework out of spec parts, unnecessary process steps, or issues with digital ordering systems. All of these things take away from our shop's capacity but not in a way that generates income for the company. To this end we will strive to reduce failure demand so that most of our capacity is used addressing value demand by implementing inspection stations between process steps to ensure that value-adding work is not done on parts that need to be thrown away, products are manufactured in the fewest possible process steps ensuring that time is not wasted on unnecessary steps and that work cells are laid out efficiently ensuring minimal time is spent in the nonvalue adding transfer of materials.

First Article Development

First article development introduces lean manufacturing tools that are related to early product production with an emphasis on work stations and cells. In this step, we will present lean manufacturing tools such as DMAIC, Standard Operating Procedure and else, and develop our workstations based on the essential processes and design a rational layout for work cells.

DMAIC

DMAIC is a problem-solving approach, depicted in figure 1, which contains five stages to solve problems with unknown causes. The five stages are: define, measure, analyze, improve, and control [2]. In the beginning of solving a problem, define the problem with a project charter, a document that highlights the presenting problems with problem statement, business case, goal statement, timeline, scope and team members. After the project charter is defined, the process knowledge would be built and the needs of process customers will be defined. Second stage is to measure, the lead time and the quality of the process are measured. Third stage is to analyze, study the process walks and charts, develop and confirm theories about the root cause of the issue. The fourth stage is to improve, in this stage, the team will structure the improvement effort with refining the countermeasures, try the process changes and primary solution, and finally collect data to prove the improvement. Lastly, the develop a monitoring plan and response plan to maintain the updated process is on track and avoid dip in the performance. This concept is significant because it systematically introduces a process to solve problems with unknown causes, and track the success of the process with a monitoring plan. It increases the chance of success for solving a problem, and the experience can be deposited as an experience in case the problem occurs again.

Figure 14: The phases of Lean Six Sigma

This concept is meaningful to our birdhouse factory because we never run a business like this before, so there are some issues that we may not know how to solve. Using this concept will help us understand the process of problem solving, and increase the rate of success for implementing solutions to fix the problem. Defining the root of causes in the problem would also understand the process better and refresh the goal of the manufacturing process, and the data from the improvement would make our manufacturing process mature and skillful.

Visual Control

Visual controls remove ambiguity and allow for quick communication. When implemented correctly visual controls will give clear signals to operators and management on if workflow is being disrupted or if operations are continuing as planned. A good example of visual control that most people interact with on a daily basis is the traffic signal. A green signal means that all is well and traffic should continue to flow. A red signal indicates that traffic should not continue to flow until some criteria is met (Cross traffic ceases). These simple visuals communicate all of the necessary information to the relevant parties in a matter of seconds, if we can bring this level of efficiency to our birdhouse then we can reduce bottlenecks and machine down times. A few simple visual controls we can implement are Andon lights which allows operators to quickly communicate workcell issues with management, color coding workcells making it obvious which machines and tools belong to which area, and product flow lines that clearly indicate the path between processes that each product must make.

Figure 15: Visual Controls (Andon Lights)

Standard Operating Procedures

Standard operating procedures are a series of written instructions that members of the organization have to follow while they are in the manufacturing activity [1]. A well-documented SOP will reduce human error and improve the quality of the manufacturing process. Standard operating procedures include but are not limited to preparations before manufacturing, detailed procedures of manufacturing, and performance measurement of products. One of the critical advantages of SOP is it is easy to be read and understood by members who are not familiar with the process or the relevant background. Compared to the manufacturing process, members who understand the SOP of the manufacturing activity will have a faster production rate and lower production error and waste. SOP unifies the standard of products. Because of the procedure's consistency, if different people are doing the same work, though the production may have insignificant differences, the overall quality will be the same. To our birdhouse facility, we need SOP for unskilled workers. Having less adept workers and more unskilled workers will save the cost of laboring fee, and SOP will educate workers for a certain part of birdhouse manufacturing. Following the SOP will also reduce the human errors and risks that may happen during manufacturing.

Figure 16: SOP

Automation

Automation in a production environment reduces or eliminates sources of possible manufacturing errors. This is done by introducing robots, computer controlled machines, or anything as simple as a jig to eliminate ambiguity in the process. The introduction of automation in the manufacturing process can also decrease the cycle time and number of required operators for the operation being automated. Automation has a great beneficial effect on manufacturing and should always be looked into if the cost of implementing the automation is reasonable.


Figure 17: Ideal automation

The manufacturing process could make use of automation or jigs to make quick work of a given manufacturing task. To partially automate the board ripping process a feed roller can be added to the table saw so that it feeds the stock into the blade at a constant feed rate to ensure the table saw doesn't burn the wood and creates a clean cut. The fence of the table saw could also be actuated electronically to ensure repeatable width on each board. Once the board has been ripped to width, it can be cross cut to the required length. This could be accomplished with a linearly actuated stop block that moves to the correct location for the component being cut. The same actuated stop block could be implemented for the mitered front of the birdhouse to ensure it is a repeatable process. For the assembly of the birdhouses we can create a few jigs that accurately and repeatedly locates each component and can then be fastened in a controlled manner.

Point of use material storage


Figure 18.1: Point of use material storage at our station

Point of use storage is a concept about all essential supplies are located or organized in the arm reach area or in the logical order in the work station. The foundational idea would be what are needed? How many of them are needed? And how to organize them in the process to create efficient work. It is important to the manufacturing process because a well organized storage use will help workers reach and operate supplies in the shortest time, or report the shortage immediately. Point of use storage also reduces the internal setup time

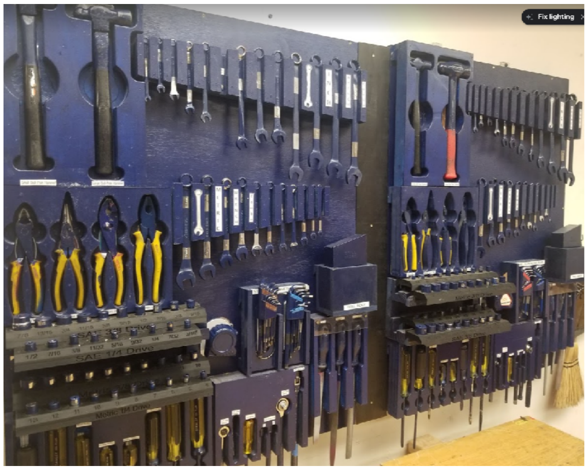

Figure 18.2: Point of use material storage at our station

during manufacturing so that more inventory can be produced and work efficiency will go up. This concept is crucial to our birdhouse factory at Oregon State University has little space, so we do not follow the point of use storage, we will spend more time on taking and placing supplies so that the lead time will be extended and work efficiency will go down, as a result, the entire manufacturing process will be impeded.

Work cell design

To design a facility optimized to generate birdhouses we will require multiple cells. One of those cells needs 4 workstations in the cell that produces the front and back of the birdhouse. In the first station milled lumber will be ripped to the correct width. The stock will be left on a table until the next operation can be performed. Entering the second workstation the boards will be crosscut to the correct length and placed on another table awaiting the third operation. If this batch is destined to be fronts the third workstation will cut the miter required for the bird to enter. If the part being made is meant to be a back then the third workstation will be skipped and moved onto the Inspection table where the part is inspected and moved onto the assembly cell.

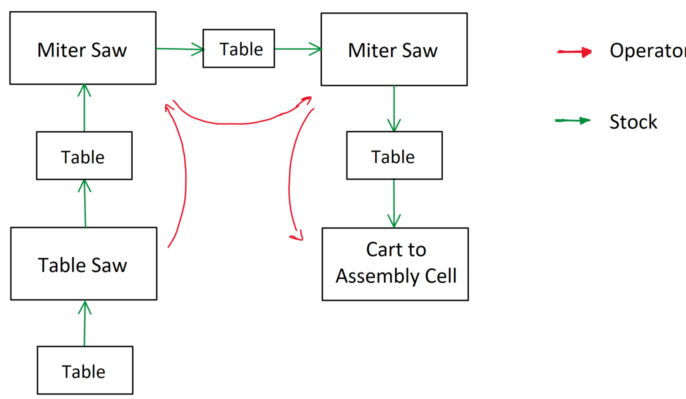

Figure 19: Workcell Flow

Production

The production development phase focuses primarily on maintaining and refining existing production plans. In this section we will introduce several lean manufacturing principles that allow us to analyze and understand our processes like basic charts and analysis. Additionally we will discuss several principles that aim to increase communication and organization such as 5S, point of use storage, visual controls, Kanban, standard operating procedures, and more.

Basic Charts and Analysis

Basic charts and analysis is the essential method for engineers to summarize and demonstrate the development performance of manufacturing. There are many types of basic charts such as line, bar, column, and pie, which present relationships between time, production rate, demand, cost, and else. One of them that was applied in this course is the Pareto chart, which exhibits that 20 percent of demand or quantity takes over 80 percent of cost or value. Basic charts are powerful in presenting results and supporting a conclusion, sometimes they are more useful than a verbal explanation. For example, a linear chart plots and connects data along a certain sequence, readers can understand the previous performances and predict the future developing trending. An analysis is the process of understanding and concluding the presentation of a chart, its result impacts the further decision of activity. We will use many basic charts to present the performance of our birdhouse manufacturing and reveal potential errors. For example, we use a pie chart to demonstrate the percentage of each cost in a single birdhouse product. Analyzing basic charts not only summarizes the insufficiencies in the manufacturing process, but also helps us better manage the factory and reduce unnecessary error and cost in the future.

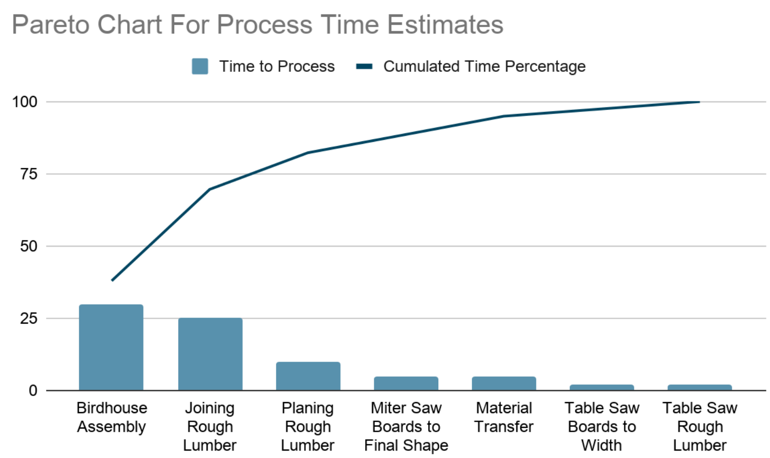

Figure 20: Pareto Chart For Time Estimated

5S

5S is a lean system designed to reduce waste and increase productivity while trying to increase consistency in operations outcomes. Implementing this method typically involves "cleaning up" and organizing existing workstations and can easily be performed by already well established shops. The 5S's for which the methodology is named are sort, set in order, shine, standardize and sustain. Sort means that we are identifying which items are needed for a process and which are not, and removing the latter. Set in order

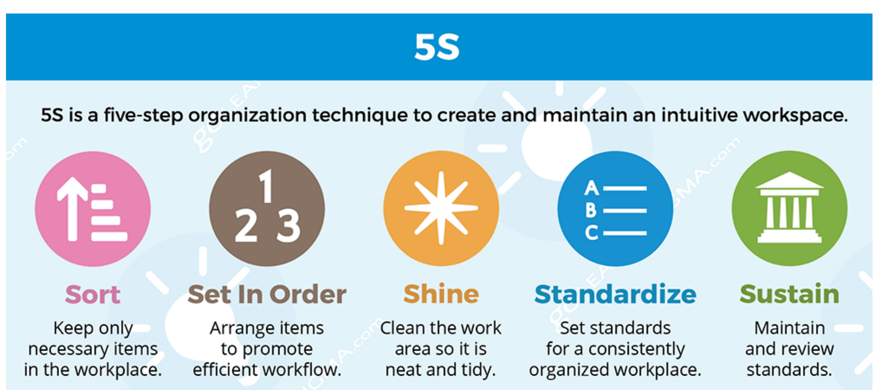

Figure 21: Workcell Flow

means to set out your required tools or materials in the order in which you need them to maximize workflow. Shine means to keep the workstation clean and clear of debris like cutting fluid and chips. Standardize means setting a precedent for how processes are done and sticking to it, reducing variety in manufactured parts. Finally sustain means that once you have implemented the other S's, keep doing them. Following all of these procedures will help a disorganized shop to flow smoothly and consistently. Figure 1 below succinctly describes the 5 S's and this graphic will be displayed near workstations in our birdhouse factory as a reminder to operators about the principles that keep our factory operating efficiently. Additionally we will make routine workcell checks to ensure that 5S principles are continuing to be utilized across all workstations.

Poka-Yoke

Poka-Yoke is a Japanese phrase that means mistaking-proofing. The principle is simple, remove any opportunity for a mistake to occur. This is usually accomplished by setting up an environment in which the only way to get a task done is to do it correctly. This removes any ambiguity between the operator and the process they are working on and should immediately draw their attention to any mistake they have made. In our birdhouse factory this could mean designing jigs and fixtures to only allow parts to be made in a specific way and order. Additionally bins that carry work in process materials from one cell to another will be shaped in a way that ensures only the correct number of appropriate parts is being moved from one station to the next.

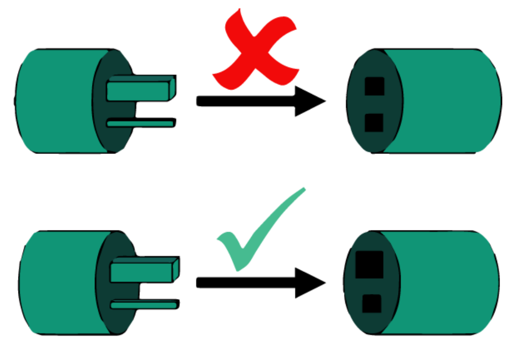

Figure 22: Poka-Yoke mistake-proofing

Value Stream Map of Upgraded Production Facility

As previously mentioned the starting production facility used as our birdhouse factory was woefully inadequate for our needs. Once production began to stabilize and cash flow allowed we moved from the Oregon State Roger's wood shop to our factory specifically laid out for our birdhouse production needs. Gaining full control of the floor space allowed us to orient and place workcells so that products follow a well marked and short path from one station to another. New machines were purchased to fill the new facility that have improved capabilities over the originals allowing for shorter production times. Additionally the new facility has increased access to shipping areas, which when combined with our increased demand makes it both possible and feasible to receive and send out multiple shipments a day. All of these improvements can be seen in Figure 14 which shows the value stream map for the new production facility.

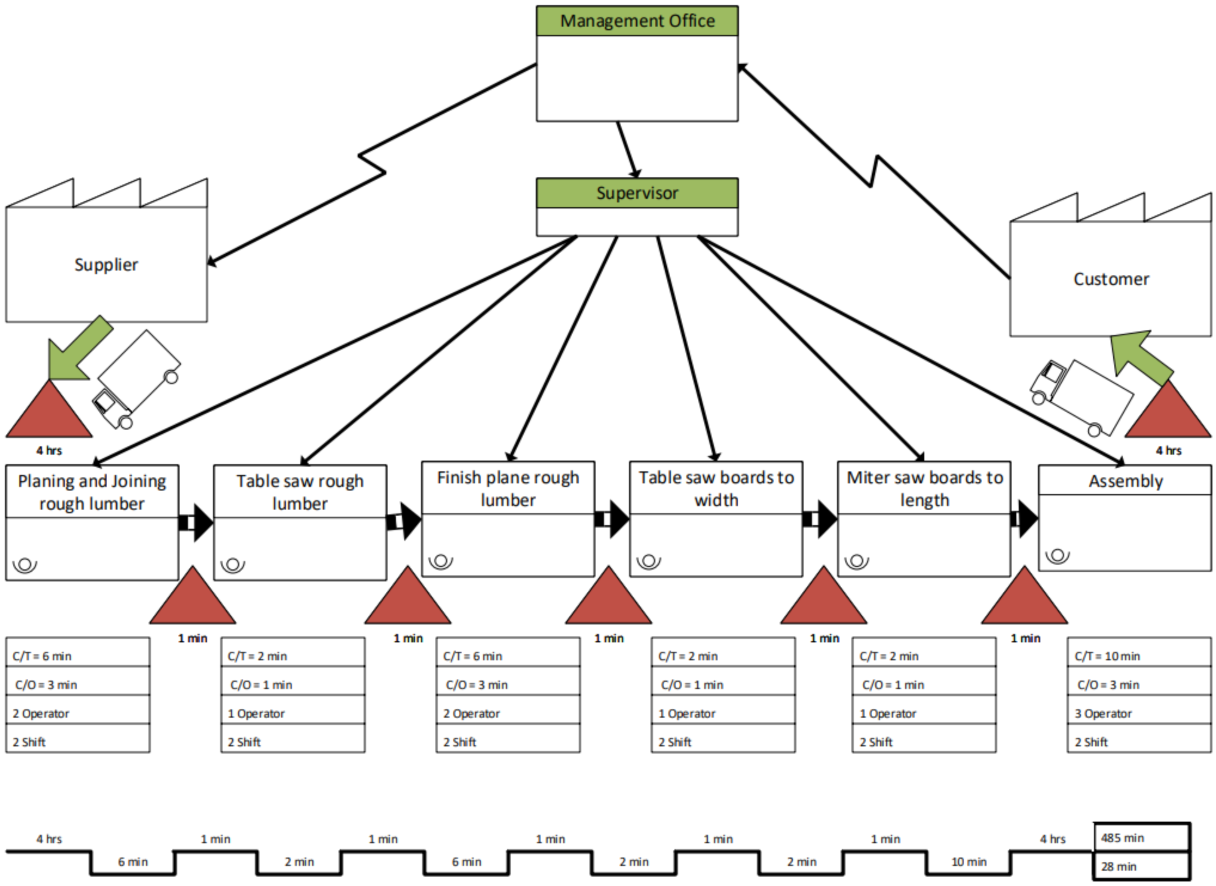

Figure 23: Value Stream Map of improved production facility

Table Saw Workstation

Point of Use Storage

In this workstation the primary machine would be a professional cabinet saw by SawStop. This saw will be used for its quality build and built-in safety features. To the right of the table saw cabinet another cabinet will be built under the saw top to store the required ripping blades, feather boards, push blocks, saw brake cartridges, and house various jigs that would be required to make any other bird houses in the product line which can be seen in figure 1. Wrenches to replace the saw blades will also be stored in the cabinet on the right. An outfeed table will be installed behind the saws iron top to act as WIP storage for the next operation.

(a) (b) (c) (d)

Figure 24: (a) SawStop professional Cabinet Table saw, (b) 24 tooth thin kerf ripping blades, (c) table saw feather board, (d) replacement standard brake replacements.

Visual control

We will use Andon lights, pictured in figure 2, in the workcell to alarm operators to quickly communicate workcell issues with management. Color coding workcells making it obvious which machines and tools belong to which area, and product flow lines that clearly indicate the path between processes that each product must make. In the table saw station the andon light system will be used to notify the area of its current state as outlined in table1.

Figure 25: Visual Controls (Andon Lights)

Table 4: Definition of andon light system

Light Color	Definition
Green	Machine is operating as intended
Yellow	Machine is experiencing excessive cutting loads (blade pinching)
Red	Machine brake has been activated and requires immediate service

Kanban

The table saw station will require an incoming kanban from the milling work cell. This kanban will hold boards roughly 8 feet in length and will be stacked in a cantilever storage rack as shown in figure 3. A kanban of this design can hold a lot of lumber to ensure that the table saw is in constant operation. Once the kanban is emptied another will be wheeled in to take its place and the empty one can be moved to the milling work cell to be replenished.

Figure 26: Double sided Cantilever kanan for incoming milled lumber

The outfeed table attached to the end of the table saw will act as the kanban for the miter station within the same work cell. It will have some extra features which will be discussed in the automation section.

Table Saw Standard Operating Procedures

1. Grab the board in the top most position on the kanban to ensure the kanban doesn't become top heavy.
2. Place the board onto table saw in preparation for rip cutting
3. Engage feather board to apply constant pressure onto the fence. This ensures the board is fed straight into the table saw and not at an angle.
4. Feed board into the blade of the table in a smooth motion. Using a push block once the end of the board is approached for safety.
5. Push the ripped board clear of the table saw onto the outfeed table for the next workstation in the cell.
6. Pull the rest of the board back and repeat steps 3 - 5 until the board is to narrow to make the intended component

Figure 27: Wood Sawing

Automation

The table saw can use automation to aid the lone operator of the saw. The first thing that can be installed on the table saw is a featherboard that is computer controlled and dynamically applies constant pressure up against the table saw fence. This is so the operator doesn't have to actively set the location of the featherboard and can just press a foot operated button to activate the featherboard. The next step in the automation of the table saw would be to add feed rollers to the saw much like those on a thickness planer. This will feed the board through the blade at a constant feed rate for the given species of wood being ripped. This will also aid in mitigating possible kick-back situations. The outfeed table will also have some automation as well. Sensors will detect once the board has been completely fed through the rollers of the table saw and activate the automation of the outfeed table to move the ripped board off to the side onto rollers clearing the path for the next board through the saw. The rollers will enable the board to be pulled onto the miter saw with minimal resistance to minimize the effort required by the miter saw operator.

Figure 28: Power Feed Roller

Conclusion

Through the example of the birdhouse factory, many lean manufacturing tools and principles are demonstrated in this paper, and we have learned their importance in real-time manufacturing. When starting a product planning, determining what is the product and goal is the foundation of the entire manufacturing. It is not a simple process because many factors should be considered such as the cost of poor quality and critical quality, on the other side, determining them will be beneficial to maintain quality in production. Value Stream Map is the keystone to outline the entire manufacturing process and total lead time for customers. Product family presents other similarities of a design to diverse the product's category and impacts the essential process and time-consuming. However, 8 wastes and failure damned should be considered during the manufacturing in order to minimize the production of wastes. Many lean principles optimize the manufacturing process. Visual control and standard operating procedures make sure operators are safely operating machines. Point of use material storage and work cell design maximize the utilization of space and effectiveness. Poka-Yoke and 5S maintain the sustainability of the production and reduce the risk of making mistakes. Each step in manufacturing needs the lean manufacturing tools and principles to make manufacturing organized and managed. They are the key to mass production, quality standardization, and manufacturing management.

Figure 29: Ideal Factory

Applying these lean manufacturing principles to the problems facing our birdhouse factory provided us with a great deal of insight into just how important these principles are. Initially we were clueless on how to quickly and effectively mass manufacture birdhouses in a competitive nature. Our production shop was chaotic with machines and tools in seemingly random places around the room. Additionally storage space was limited and often occupied by other projects, and access to shipping was difficult. This resulted in extremely slow production times, taking just over 2 days from material drop off to finished products shipping out. Once we understood our products, their markets we were better able to conceptualize what was critical to the final quality of our products and what the costs of poor quality would be. With our goals well defined we moved on to prototyping our birdhouses. We identified the manufacturing techniques that would be appropriate for our designs and then examined which designs had similar requirements so that they could be manufactured in the same workcells. With this information in mind we began to strategize on how to most effectively use the production space that we have. By grouping similar products we are able to reduce the total number of machines needed in our shop and by optimizing their positioning we are able to reduce wait times between production steps. By upgrading our shop space from the rogers basement to a dedicated production facility we were able to increase our access to shipping, reducing the wait times between material drop offs and finished product pickups. In our new facility we heavily emphasized the use of visual controls to streamline production. Tools are organized on tool boards where they can be easily seen with painted outlines showing which tools belong where, reducing operator time spent looking for the appropriate tool. We also installed Andon lights on the machines so that management can quickly identify workstations that require attention. Finally we drafted sets of standard operating procedures for each workstation so that every part is produced consistently. Once we were able to operate profitably we just needed to maintain the course. This was done through regular 5S checks of workstations where we examine the organization of the stations and through the addition of Kanban carts that allow us to efficiently provide necessary materials to each workstation while also reducing the amount of inventory needed on site. All of these changes managed to reduce our production time to just over 8 hours from material drop off to finished product pickup. Moving forward we plan to continue to improve our production facility under the principle of Kaizen, or constant improvements. Lean manufacturing is best thought of as a slow and steady progression towards improvement and not a quick one time permanent solution and to this end we will continue to push our factory forward in any way that we can.

Figure 30: Customer Satisfaction

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