

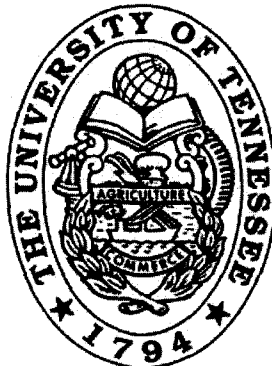
Senior Honors Project:

**Implication and Analysis of Lean
Manufacturing for Senior Design Project
with Sea Ray Boats**

Bethany Denise Gregory

**The University of Tennessee
Honors Program**

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Abstract:

Every student in the College of Industrial and Information Engineering is required to complete a senior design project. The purpose of these projects is to enhance and integrate the industrial engineering educational experience and prepare senior industrial engineering students for transition for professional practice. The project's "real world" application is assigned in conjunction with an outside company and is conducted by a three member team. My senior design project involves the cabinet building department at Sea Ray Boats, where process capability is limited by space, clutter, and disorganization. As the concepts and principals related to lean manufacturing systems provide many solutions to these problems, my primary research consists of the tools and methodologies specifically related to lean manufacturing. From this in-depth study, I individually apply these tools and studies towards the Sea Ray project through the creation of a unique implementation model. This model is followed throughout the design project to the benefit of the design team and is reflected by my design and contribution of a new process layout design, lean audit sheet, simulation model, and value stream maps.

This report consists of three parts. The first part is a detailed collection of researched lean tools and concepts to serve as a reference my proposed lean model, which constitutes the second part. The lean model incorporates the tools with my own theories regarding the implementation of a sustained lean production system. Finally, the third part incorporates these concepts and principals into the Sea Ray Senior Design Project. The full body of the Sea Report is included, along with my specific, individual contributions.

PART I

Tools for Lean Manufacturing: **A Cumulative Summary**

Executive Summary:

This report contains all of the information received in my experiences and lessons learned as a result of research regarding Lean Production Systems. Although this summary report includes detailed explanations of the lean tools addressed in the course, the main emphasis study was not to simply memorize how to use the tools but to achieve a deep understanding of what lean actually is and to change the way I think about a process or a system. Therefore, I decided to create a unique, individualized definition of lean to accompany the research. Once this definition was established, I could proceed to define lean tools in terms of my personalized conclusion and meaning of lean with metrics relative to this definition. These efforts would later be applied towards the Sea Ray senior design project and guide the team into creating a lean manufacturing system with the Cabinet Department.

The topics addressed in this summary are explanations, descriptions, and applications of specific lean tools and include: Definition of Lean, my Model Blocks of Lean, GT technology, A3 report, 5S audit sheet, Leadership, Cellular manufacturing: Cell Design, Standardized operating procedures, and Setup Reduction. Also, case studies are included, with topics such as how to develop current and future state value stream maps.

The compilation of these tools will serve as a reference to both my unique model for implementing lean in Part II and to the Sea Ray Boats senior design project.

Introduction to Lean Manufacturing: What is it?

In today's manufacturing world, industrial engineers will undoubtedly have experiences with the concepts and methodology surrounding lean manufacturing and are likely to implement directives associated with this ideology. The term "lean" in a business or manufacturing environment describes a philosophy that integrates a collection of tools and techniques into the business processes to optimize time, human resources, assets, and productivity. In other words, lean means reducing the timeline from customer order to building and delivering a product by eliminating waste. Waste can come in various forms, some of which include: over-production, time on hand (waiting), transportation, processing, stock on hand (inventory), movement, and making defective products.

One way to conceptualize this waste could be following a piece of material from the start, through the manufacturing processes, through the assembly, into a product, and then delivery to the customer. Lean practices evaluate how long the total process takes, how much of the time the product is actually being processed, and how much time the product is simply waiting. Processing small batch sizes and reducing setup times are two examples of factors that often aid in creating a "lean" system.

Although a primary purpose of lean is to eliminate waste, lean systems also direct efforts towards improving the quality level of products and services to their customers. While inventory levels could be low and waste is decreased, companies should still maintain a high standard of quality to meet both company and customer expectations for

the product. Lean “outcomes” would prove to be worthless if bad product were still flowing through the system.

Experts suggest that becoming "lean" is a commitment to a process and a tremendous learning experience. When a company is attempting to implement lean principles and practices, the entire organization must be involved. The principles and practices of lean are simplistic and have been developed over a 90-year period of time. The first “lean-based” production strategies were introduced by Toyota, who is considered by many to be the model for successful lean manufacturing.

While lean practices have evolved by trial and error over many decades, and many prominent men have contributed to their development, many companies seem to agree that the principles are somewhat difficult to implement. Implementation requires a commitment and support by management, and participation of the all personnel within an organization to be successful. Furthermore, once the new practices are implemented, the system must continue to be utilized and successful in the long term.

As previously mentioned, Toyota has been a leader in lean systems and strategies, and the company is accredited with the creation of kanbans. The automotive industry seems to have embraced these concepts, as Henry Ford also is accredited with creating lean practices. However, the applications of lean are broad and diverse, appearing in many manufacturing and service industries. Gulfstream, an airplane manufacturer, has enjoyed successful results after implementing lean strategies by increasing yearly production from 73 in 2001 to 80-90 today at their Mexicali plant. Parker Hannifin (PH), the world's leader in motion-control products, experienced a great turnaround when they moved to lean strategies such as “just in time” and cellular manufacturing. The

company has freed 25-30% of the plant's floor space while increasing revenues by nearly 10% with signs of future growth. Companies who can not only understand lean principals but also implement them for a long term period of time successfully seem to find greatly beneficial results and outcomes.

In summary, lean manufacturing is a way to improve a system as a whole by locating means of decreasing what is to be considered useless or unvaluable by all members of the system. Through lean methodology, changes and improvements lower the amount of time and resources that are wasted during the process. However, the entire society surrounding the system must be considered, as each entity should benefit and view the changes as valuable, reasonable, and justifiable in order for implementations to be successful and endure.

Establishing the Model:

After a definition for lean was created, the building blocks of my unique lean model were to be designed. The model can be thought of as four subsequent blocks which include: 1) Definition of Lean, 2) Concept, 3) Tool to visualize concept, and 4) Tool to test concept. As my own definition has already been addressed, the concept block was the first focus and is described in terms of lead time, which can show the total time spend and gives an idea of how long the entity is in the system versus process time. This can help locate levels of WIP and time spent in queue. Next, my first understanding of tools to visualize these concepts included: value stream maps, process flow diagrams, pareto charts, and simulation models. From these tools we then can test the concepts in terms of my metrics, which include time (lead time, takt time, reaction time to change, differences in expected time versus scheduled time), money (cost of inventory, cost of

lost resources, cost of produced parts/service, personnel), and communication. My metrics are what will be used to measure the performance of the system in terms of lean.

Group Technology and Product Families:

Now that preliminary definitions of lean and metrics are established, the first set of a series of tools can be introduced. The first of these tools is a popular and widely recognized concept called group technology. Group technology is a concept used in lean manufacturing that involves forming clusters of processes and parts based on similarity. After studying a large population of different work pieces and then dividing them into groups of items having similar characteristics and necessary process requirements, each such group is classified as a *product family*. Defining a product family involves grouping work pieces into logical families so that they can be produced by the same group of machines, tooling, and people with only minor changes on procedure or setup.

Once product families are defined, they are placed into *cells*. A cell consists of the processes necessary to produce the product family. With this arrangement setups and changeovers are faster because the same tools and fixtures can be used for similar parts. All workstations, machines, or equipment are arranged such that a product can be processed progressively from one workstation to another without having to wait for a batch to be completed or requiring additional handling between operations. Each cell might be designed to handle a specific process, or the cell could be a flexible multi-operation design. Group technology can be applied to eliminate inventory and work-in-progress while decreasing lead time, all of which are advantageous in terms of lean manufacturing.

Clustering Algorithms and Methods:

Before a group or cell is organized, the best combination of machines and products must be studied and decided. Several methods exist for finding the optimal arrangement for a product family. Utilizing these tools allows the engineer to group processes into cells logically and efficiently. The clustering algorithms first consider each part and each process required through the creation of a part and process matrix, with "X" representing a positive instance or match of a part and process. This type of matrix will be used in each of the following methods.

Manual Approach:

This method works well for smaller, less complex matrixes. First, one draws a line through the first column. For each "X" the line intersects in the first column, another line should be drawn horizontally through that row. Next, these same steps should be repeated by looking in the first row and drawing another vertical line in the column containing the next "X." The horizontal lines should be added in the same manner as previously executed. This process should be repeated until every "X" has either two lines intersecting it or none at all. Using this distinction, one can then separate parts into product families and cells.

King's Rank Order:

This method begins by assigning columns and rows values of 2^n , with n being equal to the column number. For the columns, one must take the summation for each instance of X and the corresponding 2^n value. Next, he or she should rearrange the

columns according to this summation value in ascending order. Then, the same method is repeated for the rows as well. This pattern is repeated until both rows and columns have summation values in ascending order. At this point, the engineer must analyze “emerging clusters” and subjectively place them into cells.

Direct Order Clustering:

In direct order clustering, the first step is adding up the number of X's in each row and then rearranging the rows in descending order based on this value. The same process is repeated for the columns but this is done in ascending order. This pattern is repeated until rows are descending and columns are ascending in order. Next, one should look at the first row and circle every column that contains an X in the first row. These columns should be moved to the far left of the matrix. At this point, rearrangements are made in the columns until X's are weighted in the upper left corner, going down to the bottom right corner. The same process is repeated for the rows, with the greatest weight going to the bottom right. At this point, each of the mentioned steps is repeated until a lower right triangular matrix is achieved. From here, a subjective arrangement of cells can be created, with good judgment being applied to potential overlaps. Either repeating a process in multiple cells or moving parts between cells might be required at the discretion of the engineer.

Similarity Coefficient:

Jaccardi's method analyzes the matrix by considering the similarity of pairs of processes and parts. A similarity coefficient is used to quantitatively decide if certain

machines should be paired. The equation for the coefficient is a fraction. The numerator is the number of parts requiring both machines being considered. The denominator is a summation of the instances of both machines required and instances where either machine is being used. This value is compared to a subjectively defined similarity coefficient (Example = .6), and if the value is greater than or equal to the coefficient, then the two machines should be grouped together.

VSM Case Study

To illustrate the next lean tool, my lean manufacturing class was assigned the task of applying the tool in a “real world” system or process. This tool, the value stream map, is another frequently used tool by lean engineers, and I believe this case study deserves mention. Value Stream Mapping helps to identify the current flow of material and information in processes for a family of products, highlighting the opportunities for improvement that will most significantly impact the overall production system.

Implemented at the beginning of a lean improvement strategy, VSM has been shown to increase the chance for lean success if changes are sustained by the workers. Mapping out the activities in your production process with cycle times, down times, in-process inventory, material moves, information flow paths, helps the company visualize the current state of the process activities and guide them towards the future desired state. Value Stream Mapping can be a communication tool, a business planning tool, or a tool to manage change progress. The process includes physically mapping your "current state" while also focusing on where you want to be, or your "future state" map, which can serve as the foundation for other lean improvement strategies. As with lean

manufacturing, the goal is to identify and eliminate waste in the process. Waste being any activity that does not add value to the final product in terms of the customer's needs.

My value stream maps for the current and future state were conducted at Moe's Southwest Grille on the Strip. The project slides, VSM's, results and explanations are attached.

A3 Report

Just as the focus of a VSM would suggest, lean methodology involves studying a process with the intention of reducing wasted resources. This waste can take on many forms, and several plans of action must be created so that changes in the system can actually take place. In other words, when one wishes to carry out a "lean analysis," he or she primarily pinpoints problem areas and concrete ways the system can improve. However, lean alone does not actually include a specific action plan of how these changes might occur and who might manage them. For this reason, constructing A3's is a vital step that must transpire so that individuals will be held accountable for the changes that should be occurring.

A3 is a management summary and problem solving tool utilized by Toyota Motor Corporation and a growing number of other companies in industry. The first A3's were constructed as part of the TQC programs implemented by Toyota in the 1960's. These A3 forms originated from the storyboard process used in the report out phase of TQC problem solving activities. In time, the storyboard process was condensed to a single A3 size sheet of paper. This simple and visual method is used by Toyota as part of problem solving activities, general management reports, as well as the policy deployment process.

The benefit of A3 reports is that they objectively identify and design projects that lead to a transition from the current state to the future state. They are designed to solve specific problems, usually on a small scale. After completing the lean study, the organization must consider and plan the levels of projects that entail the implementations that must take place. This means that a hierarchy of projects will develop as well as the delegation of time-lines, project leaders, and projects. Since these projects are interdependent, the A3 builds accountability and encourages communication between workers and departments. The A3 clearly shows who is responsible for what as well as specifying how one project depends on another in order to be completed. Along with using metrics, A3's are a simple and effective way to understand the process, organize the best way to redesigned it effectively, and measure the degree to which change is taking place.

5S and Lean Audit Sheet

While it must be noted that clearing out clutter and organizing the workplace does not necessarily mean that the process will become "lean," the changes instituted in a 5S certainly promote lean principals and will allow the metrics of lean, such as takt time, lead time, on time delivery, and cost of quality, to become more visible and manageable. Sustaining the changes implemented in a 5S obviously is the most important step and factor in encouraging a leaner process flow and production system for workers in the department. Therefore, we researched a way to help a company be accountable to these changes.

After researching methods and tools concerning 5S, we created a customized audit checklist for inspecting a department or system. This checklist is unique in that it

involves 5S principals with a lean perspective. The checklist contains several sections that combine the steps of 5S with lean principals, and each checkpoint contains a corresponding field for rating that particular checkpoint on a scale of 1 to 5. These ratings are added together and compared to the optimal value to rate the performance of the system in terms of lean and 5S principals. The audit sheet is attached to this report.

Teamwork and Leadership

A crucial aspect of lean and of assigning A3 projects is teamwork and leadership. Teamwork is the process by which a group of people work together to reach a common goal, to solve a particular problem, or to achieve a specified set of results. Working in a team usually includes the division of tasks among members based on relative skills. Some of the benefits of teamwork are ease of computer and informational access, global influence, and deregulation. Along with the idea of teamwork is leadership. Leadership provides direction for the team and manages thought and vision of future possibilities. Some important roles that the leader must play are to ensure the teamwork and elicit employee participation in the creation of the vision rather than “force” the ideas of vision onto the team. Each member of the team must be motivated and engaged in the process in order to produce great results. People are more willing to support an effort that they have helped to develop.

Teams can bring talent, experience, knowledge and skill to the problem situation. Teamwork can be more satisfying and morale boosting for people than working alone. For this reason, every member of the team must be committed to soliciting and utilizing the skills, ideas, and opinions of team members. Ensuring that others are informed and

up-to-date about any relevant or useful information is imperative to effective teamwork. Keeping in mind the concerns of other members as well as your own concerns is another dynamic that must be present to bring out each persons strengths and abilities.

In order to produce results with clarity and insight, a group or team demands an effective leader. Sometimes this leader naturally emerges; at other times, the role is predefined. In any case, the characteristics of an effective leader are vast and broad, depending on the environment and nature of the task to which the leader is assigned. For example, a military officer would likely possess a set of leadership qualities that are very different than a kindergarten teacher. However, many traits are independent of the environment and will be discussed below.

A leader must possess good communication skills so that his or her followers understand the goal of the group and realize each person's individual responsibilities. Furthermore, the leader must motivate the group and engage them in working towards to goal. This inspiration can come through desirable incentives, positive and negative reinforcement, appropriate punishment, and even simple actions such as verbal praise. The followers must trust in the leader's expertise and knowledge, viewing the leader's decisions valid and reasonable. For this reason, a leader must be decisive and engage others in following the decisions. The leader must be dependable and assertive as well.

An effective leader must be courageous and willing to take risks for the sake of achieving the goal. Because reaching this goal might require extensive time and effort, a leader must have tremendous endurance and determination. Obstacles will certainly arise for the leader, so he or she must exercise sound judgment and integrity. The leader must

also maintain a strong sense of justice and know how to treat others fairly with respect, tact, unselfishness, and loyalty. He must “walk his talk” in order to gain respect as well.

Cell Design and Variability

The key to lean manufacturing is to compress time by eliminating waste and thus continually improving the process. An organization can achieve a “leaner” process through many different methods. Someone who wishes to apply lean methodology can approach the topic through tools such as value stream mapping, work place organization (5 S’s), standardized work, plant layout, quality, batch reduction, pull systems and the use of Kanbans, quick changeover, one piece flow, producing to Takt time, and several other methods.

In other words, a “set” or definite way of becoming more lean does not exist, and I am finding out the variety of ways that lean can be reached. In particular, I am realizing that the reduction or variability in the process and moving to a cellular layout or “focused factory” can greatly improve vital metrics to determine performance of the process. Although many people do not realize how variability can affect a process or a system, cell design and reducing variability can lead to great results.

In many processes, the flow of material goes continuously from machine to machine. This type of layout is considered to be “process focused” and can lead to problems such as bottlenecking. Moreover, this configuration limits the flexibility of product types being produced and results in higher setup times. On the other hand, a more flexible, “leaner” approach would be a cellular design, which is considered to be “product focused.”

Cellular layouts organize departments around a product or a narrow range of similar products, called product families. Once processing begins, material and products move directly from cell to cell. Each cell can be thought of as a mini-factory or a “focused factory” responsible for a specific set of tasks or products. The results are very fast throughput, better communication since operators are physically closer than they might be otherwise, and reduction of the wasted time that had originally been lost due to transportation between machines or processes. This improves quality and coordination and leads to a greater sense of teamwork. Overall, cellular design is one way to focus on reducing setup and achieving single-piece flow for one product since each product is broken up into families.

Another important element of lean manufacturing that goes along with cellular design is the reduction of variability in all processes. Process variability significantly affects production throughput, delivery, quality, costs and customer satisfaction. A considerable interest in understanding the factors that contribute to process variability should be taken. Through case studies in class, 403 students found that reducing variation leads to a reduction in flow time and WIP. Although pull systems also benefit from the change, reduction in variation has the most significant impact in a push system. Therefore, the engineer must analyze the process to find ways to cut down variation through methods such as standardization for process steps and work methods. Processing that is accurate, precise, and repeatable will lead to a leaner environment.

Setup Time Reduction

Many of the previous tools address reducing cycle time within the process. However, as I continue to investigate ways to introduce and implement lean methodology, I learn that reducing set up time directly lowers the lead time of a process and can be a relatively simply way to become more lean. Reduction can come through various forms, such as standardization, better tooling, and simple organization. With this lesson, I performed a setup time reduction project to illustrate the concept. For this project, we were told we must reduce “setup time” of a process by 50%. Although the project is a simulation of a setup, the actual process will be assembling a product. In other words, this assembly is considered to be the actions necessary to setup a machine for production. Reducing the time it takes to do this assembly will represent a reduction in setup time.

For my project, I studied the assembly of a wooden bedside table. I began the project with only the tools I owned, which is not many, and without much preparation or study of the instructions. This situation simulated an unstandardized setup by a worker with little experience in a poorly designed work environment. Not only did I not have the right tools, I had no bench or table to build the object, which created an awkward work positioning and actually lead to injury.

The bedside table that I built came in a package bought at Home Depot. The kit contained all the wood pieces, parts, and fasteners needed for the assembly. The wood pieces were pre-drilled so that most of the screws and bolts could be tightened easily and so that all the parts could be mated together and aligned correctly. To begin the project, I first dumped out the pieces of wood from the box and opened the bag of bolts, hinges, knobs, and screws. All these pieces came in one large plastic bag, which made it difficult

and time-consuming to sort through when selecting an appropriate screw. Also, a couple of the screws were almost identical, with only subtle differences in shape. I did not realize this until I had screwed in some of the wrong pieces and had to go back and unscrew certain fasteners and start over. Clearly, locating the appropriate part could be an arduous task for me and actually led to mistakes.

In addition to having trouble with the many bolts and screws, I did not have all the tools I needed when I began. I started with the first steps in the assembly and realized that I would need a Philip's head screw driver. This meant that I had to get up, go down to the garage, and rummage through the tool drawer. Even when I returned with the screwdriver, I realized that the size was too small. I tried using this screwdriver anyway, which led to me stripping some screws. Finally, I went and retrieved the appropriate screwdriver, which helped speed up the process to a small degree.

One frustrating aspect of the bedside table assembly was that many of the pieces were similar looking in size and shape. Actually, a couple of the pieces were identical but were to be assembled as mirror images to one another. Finding the correct piece of wood in my pile was not always easy, and the correct part was not always obvious. As I was looking through the stack of wood pieces, I caused them to fall over on the ground. One of the pieces was scratched as a result, meaning that my poor working conditions and extra tasks were leading to a decrease in quality.

The first couple of steps in the assembly involved tightening the metal runners for the drawer to the long side pieces of the cabinet. The metal runner had to be tightened with two screws, but the runner had five identical screw holes on each end. These extra holes were confusing and difficult to line up perfectly. Plus, if the runner was screwed

into the wood through the wrong holes, the drawer would not shut in the last step. I actually ran into this problem at the end and had to take some pieces apart to be able to reach the runner for adjustments. In fact, all the larger wood pieces contained multiple screw holes for various fasteners, but I found difficulty in knowing which hole was the correct fit. I had to consult the directions many times to verify that I was placing the screw in the appropriate hole, and I often used the wrong hole and had to go back and repeat the action correctly.

When I finally finished the assembly, I was frustrated and had many ideas for improvement. The first assembly took me approximately one hour and 45 minutes to complete, but I could easily see many opportunities for time saving. First, I created a supply box to hold and separate all of the screws and bolts. Each compartment in the box was color coded and labeled. To aid in knowing where to place each type of screw, I drew a small ring around the corresponding hole with a magic marker of the appropriate color. While I had out my markers, I used a tape measure and ruler to draw lines and dots to indicate the appropriate location for holes that were not predrilled into the wood. These mistake proofing steps cut down on time spent searching for the correct parts and kept me from tightening screws or nailing holes in the wrong spot like I did in the first assembly.

To avoid injury and decrease the chances of drilling screws at an angle, I set up a work bench in the driveway. This way, I also could assemble the parts with my tools and supply box within easy reach. Another change that I made in the second assembly was arranging the wood stack and labeling the pieces. Assigning a number to each wood piece, I ordered them according to the point in the assembly when they were needed. I

attached a sticker for each piece with a number and stacked the pieces neatly, with the parts needed first on the top. This change cut down the time spent searching for the right part and also kept me from knocking over the stack. Additionally, I placed the sticker on the side of the part which faced the center so I would immediately know how to orient the piece.

One of the biggest and most time-saving improvements was the use of more sophisticated tools. A cordless, power drill reduced my assembly time significantly. After visiting the hardware store, I had standardized the screw head size so that I only had to use one drill bit instead of two for all the fastening tasks. Only one of the screws was unique in that it could only be tightened with a standard screwdriver. However, this did not effect the total time greatly because this specialized screw only required three turns for tightening.

When all these changes were added, I reduced the time needed to assemble the table drastically. With my improvements, the time was cut down to 28 minutes, less than a third of the original time. I also reduced my frustration, which kept me from making as many hurried mistakes. Having the correct tools within arms reach saved time, and using a power drill significantly reduced the time. This illustrates the advantages of acquiring more technologically advanced tools. In this case, I believe the time reduction justifies the cost of the new equipment. Organizing my methodology as well as my workplace enabled me to tackle the project with greater ease and with greater speed. Planning ahead and standardizing the work tasks and tooling not only simplified the process but also caused the environment to become more “user-friendly” for a new worker. All of these

simple actions proved to be effective means of reducing setup time and certainly be related to improvements for an actual “real life” set up.

A video of the actual procedure was turned into instructor as a CD file.

Creation of Pull System: Case Study

Many of the lean methodology discussed point towards a pull manufacturing system rather than push. In a push manufacturing system, production is pushed from one station to another as materials flow from start to finish. The push system receives a signal to begin production at the starting workstation and does not recognize whether or not the next process necessary needs or can accommodate more entities. Unlike a push system, a pull system only produces when a downstream signal triggers production. In other words, the process at one station only begins when the next station sends a signal upstream requesting the part. These signals are sometimes called kanbans.

The most obvious or traditional applications of pull systems exist within the context of a manufacturing environment. However, the dynamics of this production system can be exhibited in many other situations and circumstances. When a person wishes to trigger a desired behavior or outcome, he will send a signal, and this signal can be as subtle as a raised eyebrow or as tangible as a note to a student’s parents. So long as people send either literal or social signals, pull systems will be created.

In this case study, I decided to analyze a process that would be of particular personal interest: stocking our refrigerator with milk. I would argue that few things are worse than stumbling into the kitchen in the morning and pouring a bowl of cereal only to find that all the milk is gone. Cereal is my equivalent to morning coffee—I must have it. Often, this frustrating occurrence is intensified by the fact that I had just visited the

grocery store the day before and could have picked up a gallon of milk if I knew the supply was short. It makes me want to cuss and starts my morning off on a sour note.

To remedy this problem with a pull system, a profile of my roommates and subsequent milk consumption must be constructed.

“Customer” Profile

I have three roommates and consider them my closest friends. The system we have used for the past three years of being roommates is to share both the milk and the responsibility of buying it. My roommates are very unselfish and the least stingy people I know so conflict over who buys what and how much rarely arises. We trust each other to do her part and this has historically been true with little or no communication to sustain the system.

However, the dynamics of our milk system have recently shifted. The stresses and effects of upcoming graduation have played a global impact on us seniors, but these impacts magnify themselves differently among each roommate. This semester, two of my roommates (we'll call them A and B) quit going to the grocery store. They never cook and literally go out to eat for every meal. Since they never cook, they never go to the grocery store. However, they *do* tend to still eat breakfast at the apartment.

Roommate C has been trying to lose weight and skips meals, including breakfast, and she seemingly feels no obligation to buy milk despite the fact that she still drinks a glass a day. These factors have contributed to the shift in the system's paradigm and result in a refrigerator void of milk.

Demand

Most mornings, Roommate A drinks a chocolate instant breakfast made of milk and a powder mix. Regardless of what this beverage calls for, Roommate A adds three cups of milk (24 ounces) to the shake. If she were the sole customer of the gallon of milk (128 ounces), she would be able to make 5.33 servings of her breakfast. At the same time, we other roommates still use the milk to pour over our cereal, which requires about 10 ounces apiece. If the cereal-eating roommates were the lone consumers of the milk, our demand would be $10 \times 2 \times 5 = 100$ ounces per week, assuming that each of us eats breakfast meals that require milk 5 times a week. When the Roommate A's instant breakfast shake is considered, approximately 31.5 ounces of milk are used each day. This means that a gallon of milk is used up in about four days, and therefore, our apartment's weekly demand is 1.75 gallons per week.

Signal and Response

Now that the demand is defined, the ability to support this demand must be considered. I go to the grocery store every week, while the other roommates rarely visit the store. However, each roommate fills up on gas each week, usually at the gas station nearest our apartment, which just so happens to carry the best deal on milk in town (Weigel's: \$2.69). Therefore, despite the defense plea of the roommates, the problem is not a matter of going to the grocery store. If each roommate knew when milk was needed, she could buy milk at the gas station or the grocery store.

The new pull system for our milk is simple and addresses the need for a signal. When the milk level in the jug falls to the bottom of the round, circular indentation on the jug, a fifth of the milk remains. This is about a days worth of milk, on average. When this level is reached, a Mayfield milk magnet will be placed on the Area of Moo, a newly

Conclusion:

The tools described in this summary do not stand alone as a “lean solution” for a process or system. These tools must be applied in terms of a global definition of lean manufacturing and the subsequent implication that this definition plays on metrics and values. However, if a deep understanding of lean “logic” is achieved, these tools can more effectively influence the improvement of the system by helping us visualize and test our pre-established lean concepts.

designated signal area. Once the signal is placed, the apartment members have one day to buy the milk. This will not be a difficult time restriction, since each of us either stop to get gas or groceries every day--not to mention each day we pass a Weigel's that is fifty yards from our apartment for easy "emergency" purchases.

Under the Area of Moo is a list with each roommate's name on a dry erase board. When a roommate replenishes the milk supply, she can draw a smiley face out by her name. Each roommate frequents the refrigerator daily and can effectively monitor her status as milk maid. Knowing my roommates, nobody would want to be seen as not pulling her weight. From experience, we know that this could create animosity and we wish to avoid this so close to graduation. The roommates who consume more milk for cereal and cooking (A and myself) have agreed to expect to buy two times as many gallons as the other roommates in order to be fair. Now that we have a system to clearly monitor the milk level and signal the need for more, we can know when milk is needed. Each roommate will treat the signal as a personal request, but if one roommate has not bought the milk lately, she will be held accountable on the list and shamed to try and be the first to replenish the supply.

This pull system for the milk is similar to a supermarket in a manufacturing pull system. If two roommates buy milk on the same day, our refrigerator can usually accommodate the buffer stock. My hope is that this system will prevent another morning without cereal and without wanting to cuss.

PART II

Model of Lean Implementation:

Steps and Strategies for Creating a Lean Manufacturing System

Using Concept and Tool Definitions

Executive Summary:

Throughout the Industrial Engineering curriculum, my courses have addressed the topics and principles of lean manufacturing. In addition to these methodologies and tools, the courses combined with my individual research challenge the implications of lean towards the individual worker and society, constantly considering the effects of lean at the “people” level.

The objective of this unique model is to combine all of these principles and create a personalized strategy for implementing lean that can be used to guide and sustain improvements in both for Sea Ray and for any company. The model encompasses not only the researched lessons of lean but is based upon my own vision and understanding of how to go about creating a lean system. With this in-depth model, the Sea Ray team can direct efforts towards achieving lean methodology, but the model also greatly benefits me personally, as I am prepared to apply lean any place I go to work as an employee or as a self-employed Lean Consultant.

Step 1: Establish Definition of Lean and Lay Foundation

In typical manufacturing environments, it is easy to find waste and identify the sources of these wastes. This “waste” can come in many forms, such as defects, transportation, inventory, overproduction, or motion. These wastes can often result from outdated or incorrect notions such as batch and queue models that do not accurately consider the relationships between production costs, quality, efficiency, and demand. However, other sources of waste can simply stem from neglect, apathy, lack of ownership, or lack of accountability to unreliable machines and processes. In this case, a culture of “solving problems” and actually fixing them usually is not fostered.

While lean manufacturing focuses on reducing and eliminating wastes through the use of tools and concepts, ultimately the goal of lean is to create a facility and system where *everybody benefits* (workers, customers, society, etc) from the outcome. When all workers participate in the lean improvements, they will recognize potentials for improvement on every level and direct efforts towards reaching perfection.

A: Become the change agent.

- Confirm that the company is willing for a fundamental change in thinking, strategy, and culture.
- Tear down fear and uncertainty through strong leadership. Fear can be greatest cause for hesitation and reluctance to change. A strong leader builds confidence in his or her followers by creating a clear vision and a plan for reaching that goal.
- Cultivate a mindset that “we will make something happen.” Make it your passion.
- Utilize every resource to get the knowledge you need to make confident decisions towards change.
- Find justification and support for change from an outside source or case study.
- Enlist the support of a plant manager or even a president to increase your authority and influence.

B: Create urgency; an unavoidable reason to change (a lever)

- Crisis can be an incredible opportunity. Desperation can work in your favor to motivate and bring focus to the need.
- Competition can also be an outside factor of motivation and urgency.
- Suppliers or customers who depend upon your product create a level. The company must be held accountable to deliver and receive on time; hold up their role in the supply chain or face penalty.

C: Forget about the “grand business strategy.”

- Remember spending huge amounts of capital is *not* lean
- Think of long-term, transition to lean in effective but incremental steps
- Don't turn lean into a “business scheme” which implies the short-term, or “fad,” solution

D: Involve and excite every employee. This is crucial for success.

- Empower each individual by delegating ownership and responsibility. Be specific in order to eliminate confusion and conflict over who is supposed to what and how.
- Train every worker on the concepts of lean so they can eventually sustain lean system and continue to locate ways to improve for themselves. Teach them how to think. This will drive culture towards lean culture.
- Emphasize and practice good communication. Elicit ideas, hold weekly team meetings.
- Take feedback seriously.
- Make a program for recognizing significant, beneficial suggestions. Reward them publicly, perhaps with a parking space, free meal, etc.
- Propose an egalitarian system rather than the traditional inegalitarian organization. Treat everyone as equals.
- Success begins with each employee trusting and understanding that they will directly benefit from the changes. Clearly communicate those benefits and follow through.
- The only way the system can flourish is if everybody along the value stream is treated fairly and believes that the new system will go the extra mile to deal with dilemmas.
- Ease the fears of reluctant workers. Get permission to make promises you can keep. [No lay-off's will occur as a result of changes, Bonuses or raises in response to increased profitability]

Step 2: Learn the Organization

Before making changes in the organization or the system, one must develop a deep and detailed understanding of the way the company works. The products and product lines must be defined and identified so that the effects of changes to these items can be considered. Knowing these products and processes will be crucial in later phases of the model. In addition to understanding the layout and process flow, realizing the values of the company is crucial. What a company values drives their metrics and typically demonstrates where they pour most of their resources. Redirecting these values and metrics in a way that supports lean principals is a challenge that should be accomplished before moving into phases of physically changing the system.

A: Observe and gain an understanding of the organization.

- Layout of the plant and system.
- Processes and flow; product lines.
- Inventories
- Demand
- Takt time
- Scheduling
- Lead time

B: Learn and Establish the values of the company.

- My values: People, Safety, Quality, Customer Satisfaction. These values dictate what metrics we use to measure performance.

C: Define the objectives of the project by creating metrics to measure effectiveness and performance. Metrics include:

- On-time delivery: schedule deviation.
- Cost of Quality. Consider the implications of each category. For example, preventative costs should be higher than others, such as internal or external. Otherwise, we can suggest that the system is highly reactive and variable.
 - Preventative: PM, Predictive M, training, study, standardization, new technologies
 - Appraisal: auditing, inspection
 - Internal: scrap, rework
 - External: recall, lost customers
 - Wastes: transportation costs, inventory for nonconformance
- Lead Time (CTU); Days to produce
- Inventory (WIP)
- Efficiency: contact time vs. lead time. Efficiency is not synonymous with speed but combines aspects of rate, speed, performance.
- Safety: can be quantified:
 - Lost time accidents
 - Protective gear available. Safety budget.
 - Safety violations per year
 - Costs related to health and safety.
- Employee satisfaction with work, job, or company. This is an important indicator of whether or not lean systems will be sustained. Can be quantified through surveys or interviews, measured by:
 - Degree to which company will address “human dilemma”
 - Number of cross functional meetings, representation
 - Employee turnover

D: Define product families

- Find an initial product family whose problems you want to tackle first.
- Begin with production or another area that has good visibility and manageable, easy solutions.

Step 3: Create current value stream map.

Value Stream Mapping helps to identify the current flow of material and information in processes for a family of products, highlighting the opportunities for improvement that will most significantly impact the overall production system. Implemented toward the beginning of a lean improvement strategy, VSM has been shown to increase the chance for lean success if changes are sustained by the workers. Mapping out the activities in the production process with cycle times, down times, in-process inventory, material

moves, information flow paths, helps the company visualize the current state of the process activities and guide them towards the future desired state. Value Stream Mapping can be a communication tool, a business planning tool, or a tool to manage change progress. The process includes physically mapping the "current state" while also focusing on where you want to be, or your "future state" map, which can serve as the foundation for other lean improvement strategies.

- Follow chosen product family through the process.
- Identity customer and requirements for this product
- Use the VSM to pinpoint what adds value to the product.
- The VSM also demonstrates other flows, such as supplier information, delivery times, daily orders and forecasts, which departments or machines get the schedule.
- Find the lead time and takt time to baseline.

Step 4: Create an A3

From the current VSM, the company will be able to pinpoint problem areas and concrete ways the system can improve. However, lean alone does not actually include a specific action plan of how these changes might occur and who might manage them. For this reason, constructing A3's is a vital step that must transpire so that individuals will be held accountable for the changes that should be occurring. The benefit of A3 reports is that they objectively identify and design projects that lead to a transition from the current state to the future state. They are designed to solve specific problems, usually on a small scale. As they conduct a lean study, the organization must consider and plan the levels of projects that entail the implementations that must take place. This means that a hierarchy of projects will develop as well as the delegation of time-lines, project leaders, and projects.

- Define specific improvement goals
- Start to organize the tangible plan of attack
- Display current VSM.
- Locate waste in the process and how to eliminate
- Begin creating A3's within departments and groups as the Future VSM is constructed.
- More A3's will be continually created as project progresses and the depth of the plan expands.
- Always assign a specific manager or contact for a project with an appropriate due date.

Step 5: Create the Future Value Stream Map

Once the value stream map for the current system has been created, the A3 will state that a future value stream map must be built. This VSM is based on the new values and metrics that have been defined for the company. The future VSM analyzes the system and locates all necessary steps of the process and sets them in sequence, eliminating

unnneeded items or processes considered to be “waste” according to the pre-established definition of lean. The creation of the future value stream map incorporates several of the core tools used in lean implementation to improve performance based on the metrics. However, the tools serve as a means of visualizing, measuring, and administering our concept of lean, which primarily focuses on people.

Although the following steps provide detailed, in-depth steps for creating the future VSM, it must be noted that the first phases of implementing lean and project A3’s must be manageable and reasonable. Every requirement listed below will not be met initially, and the expectation is that making all of these changes will take a significant amount of time, resources, and perseverance. Easy and obvious changes with visible results should be chosen first to build optimism and momentum. The nature of lean elicits continuous improvement and never-ending opportunities for making the system better. While perfection is the ultimate goal of lean, the paradox of its nature is that you never plan to reach perfection--the company must endlessly search for ways to improve. In other words, do not stop until its right and then repeat. Never give up.

A: Produce to takt time

- Consider the demand. Takt time should be whatever demand requires.
- Keeps flow steady and predictable
- Regularly stimulates standardization; operators get into routine quickly and ideally speed up the process.

B: Develop continuous flow. This is *fundamental* to our lean manufacturing system. Smoother, steadier flow is achieved because the number of stops, starts, and changeovers are reduced. This improvement addresses variability, a curse manifested by waste and poor quality.

- Design layout based on products and processes, using group technology algorithms such as Hollier’s Method, Job Sequencing, etc.
 - Cellular Manufacturing – Focus factories reduce lead time, WIP inventories, and floor space. They increase flexibility, ownership of tasks and functions by workers, reducing boredom. Special fixtures and tools within the focus factory speed up the process. Production efficiency increases because more attention, knowledge, and skill are directed at a smaller number of different things.
- Link operations to reduce lead time. Turn multiple operations into one and eliminate inventory and transportation waste.
- Less variability means reduced lead time and the freedom to reduce buffer stocks, assuming you have reliable delivery. Variability comes from many sources such as the worker (skill level, motivation, abilities, attendance) or equipment (cycle time, setup times, reliability, schedule of raw materials, batch sizes). Standardization is a key remedy to this ailment [See Step 5E].
- The ultimate goal is to institute single piece flow with each item passed immediately from one process to another, banishing all queues, batches, inventory and waste.

C: Utilize supermarkets – only if continuous flow is not possible. This is a compromise.

D: Send Customer schedule to one production process: the bottleneck since this particular process determines the throughput pace.

- Make the schedule visual to employees, clearly posted for all to see.
- Maintain a buffer of jobs ahead (upstream) of bottleneck to ensure that it is never starved.
- In a push system, place the bottleneck at the start of the process if possible. Opposite is true for a pull system. Earlier operations are less influenced by variability in other operations and are therefore easier to control.

E: Make every part, every day.

- Reduce setup times through standardization.
 - Reduce the differences in product design. Study the consumer market to find most profitable degree of options or product features in terms of manufacturing complexity. The more complex, the greater the number of setups.
 - Make multiple kinds of products in one step or one stroke.
 - Dedicate a machine to making just one item. This action is only practical with inexpensive machines and with an item that requires a small number of operations.
 - Transition from internal to external setups
 - Create equipment checklists and repair sheets. Monitor equipment functionality; performance of machine should be checked at setup, avoiding reactive maintenance.
 - Setup schedules should be visible and operations should be standardized. Operators should be trained and prepared for setup in advance. This way appropriate workers and tools will be there when needed.
- Produce in small lots if system has improved equipment reliability and performance. This increases flexibility and speed.
 - *Must* be accompanied by reduced setup times.
 - Reduce the cost of order placement and processing by moving responsibility from purchasing department to production or even the shop floor, where workers place orders. Along with supporting our philosophy of employee empowerment, this method reduces purchasing overhead costs and order lead times.
 - Work with suppliers to find ways of increasing frequency of deliveries, reducing the need for incoming inspection, and reducing the costs and shipping and handling.

F: Level the production mix: if setup times are short and standardized

- Ensure appropriate product mix through department based on due dates.
- Avoid large costs associated with large batches of defected product

G: Initialize a Pull System; level the production volume

- Consider Conwip: combination of push and pull. If resources are not available to completely shift to a pull system, conwip is a good compromise. Pull to the bottleneck.
- Producing must shift from producing for production's safe to producing to meet demand; no overproduction.
- Preventative maintenance efforts should be aimed at eliminating breakdowns, which halt operation.
- Production plans and schedules must be somewhat uniform. Pull systems cannot absorb variation like a pull system can.

Step 6: Simulate the system

Simulation is a great way to model the effects of the improvements made on the system. Once the model is verified and validated, the output can provide feedback that guides decisions on whether or not the changes should be implemented. These outputs also quantify the degree to which changes have taken place in terms of WIP, lead time, takt time, production capability, and other important metrics. Variation should be included to prove that future state works and validate the impact of the critical metrics

Once it is agreed that the changes are beneficial towards our lean system, an A3 should be created to implement them.

Step 7: Sustain changes through work fundamentals and strategies.

Transforming a process into a successful lean system is quite a challenge. However, the greatest challenge is sustaining these changes—that is why laying the foundation at the beginning is so crucial. Employees must have involvement and ownership in all these changes, as well as strong leadership to give them confidence. The managers must provide workers with the opportunity to develop and expand their skills and utilize their potentials, all while showing respect and recognition for the ability as problem solvers. Training, job descriptions, and compensation of workers must be directed toward developing cooperative work attitudes and teamwork since much of the planning and control decision making is done by worker teams on the shop floor in lean systems. These teams should have all the power they need to fix their problem and will be responsible for sustaining their own area. If rearrangement of the process leads to having excess workers, create a team for them to support the lean changes. Nobody should suffer from the improvements. As mentioned, **standardization** is a key element of sustaining changes, serving as a guiding principal and baseline for operations and tasks. If a process is standardized, workers who switch tasks can easily perform new functions without greatly affecting the system.

Visibility and **cleanliness** are aspects of 6S that should be incorporated into an A3 as lean projects are being designed. However, these efforts do not make a system more lean or cause the organization to work better; they simply support the changes and help to sustain them. In lean implementation, cleanliness is a good starting point to develop and

reinforce skills and attitudes towards continuous improvement. Workers do not lose time looking for needed tools, and they can see cracks, leaks, contamination, and defects more easily. Order and structure in an organization will improve moral and boost a greater sense of discipline—both of which affect turnover and productivity.

Visibility means organizing the way a system is “seen” and plays a pivotal role in sustaining lean improvements. If a worker can literally see how the system is performing, she can receive the feedback she needs to respond quickly with the appropriate action. Information should be redirected so it is visible and transparent to the shop floor. Some manifestations of this concept are posting a daily production schedule with charts to know who is on schedule or not, installing signal lights on machines, or turning the process line into a U-shape so that workers in the subassembly process can see the final assembly. Being able to see what he is making boosts moral and feelings of satisfaction in his work. Kanbans are ways to signal immediate action or create immediate feedback. With these signals, workers do not rely of supervisors or managers all the time to take action or make decisions.

As lean is being implemented, one must remember that there is no worker, machine, or process that does not, on rare occasion, do something incorrectly. A worker should not be punished for these rare mistakes or pushed to high utilization or the company risks sapping the soul from its workers. However, steps can be taken to avoid making mistakes or allowing defects to pass through the system. A combination of **inspection** self-checks and successive checks should be instituted, but the workers must know from the managers that the inspection process is not used as a tool to evaluate them but as a means of identifying places where errors occur and procedural improvements can be made. Also, workers must be given a time allowance to improve quality in the form of extra time or end of the day or week meetings to discuss problems. Another tool to prevent defects is called **pokayoke**, where product designers should think of ways to build features in a way that will prevent the risk of mistakes in assembly. Pokayoke also incorporates devices that control a process, give warning about it, or check for proper settings in a process. These devices take on the form of automatic switches or buzzers or can simply be fixtures or procedures that do not involve any automated or electronic objects.

If so much responsibility and expectation is placed on the individual worker, clear **rewards** and **incentives** must be established to motivate employees to act. The company can become creative with these benefit programs. A basketball goal can be installed or so that if a team reaches a production goal early, they can go play ball if they choose. A walking track might also be paved so workers can take a break but still stretch their legs if they wish. In other rewards program, daily performance is recognized. A supervisor gives verbal praise or positive feedback to a deserving individual or team and keeps track of these “perk points” by numerically tallying a score for that person. This total can be kept on a pay stub or individual weekly report, for example. Team members can also get approval to hand out points to other team members. After a certain number of points are achieved, that individual can visit a type of “treasure chest,” a box of prizes such as gift certificates to restaurants, movie theaters, grocery store, gas station, etc. Regular bonus

programs such as profit sharing should already be in place, but this new program serves as a way to stimulate daily motivation and performance. The program might seem juvenile, but anytime a reward is desirable, a person will be interested in receiving it regardless of age. One other manifestation of this concept can be more immediate: when a supervisor sees outstanding performance or effort, he or she can slap down a \$20 or \$50 bill in the hands of the deserving. If granted in the appropriate frequency and amount, these incentives will support sustaining the system.

Conclusion

Requiring total dedication to success and perfection, implementing lean is certainly a challenge, but certainly not an impossible one. A definition of lean must first be established to guide the process of defining values and subsequent metrics. The underlying focus of these efforts should be directed towards the worker, who will ultimately dictate the success or failure of every effort to become more lean. These workers must all be trained in lean thinking, be ensured of how changes will benefit them individually, be granted power and responsibility, and feel welcomed by managers and supervisors when offering suggestions.

After the workers embrace the concept of lean, the next steps of understanding the organization and creating value stream maps follow. The creation of the future VSM incorporates many tools and possible means of improvement, but the easiest, most manageable projects with the greatest return on investment of resources should be selected first to build momentum and morale. Sustaining these changes is the most important step, or else all the efforts will have been labored in vain. Standardization, visibility, mistake-proofing, and rewards systems are examples of strategies that can significantly increase the likelihood of success. The benefits of implementing lean must be expressed and reflected at all times so that everyone will realize the vision and be encouraged and devoted in reaching the goal.

Notes for “fun”

As the popularity of lean grows, interesting manifestations of its concepts are appearing in other aspects of manufacturing. These influences are imperative, as lean should affect the entire culture of a company. In the maintenance organizations of many companies, maintenance procedures and downtimes are performed based on a schedule that likely is not justified statistically. Maintenance usually follows a blanket routine that checks or fixes system components without really knowing if these procedures are truly necessary. Combining predictive and preventative maintenance with design of experiments could lead maintenance to become a less wasteful endeavor and could support the shift away from reactive maintenance. Squeezing the ultimate potential from equipment depends on how well the equipment meets requirements such as availability, efficiency, and quality.

Ergonomics is another aspect that should be incorporated with the application of lean. Lean manufacturing seeks to reduce waste in key areas and achieve great cost savings, but unfortunately, lean processes can make jobs highly repetitive while eliminating

critical rest time for employees. If ergonomics and human factors are not integrated into the process, the repetitive tasks take their toll of workers as stressful postures and high forces are repeated continuously throughout the day. This dynamic defies lean principals because in the long run, the financial savings from the productivity gains and quality improvements may be erased by the cost of injuries, lost time, and insurance claims. To ensure that ergonomics is a key consideration in the lean implementation, lean leaders and team members should understand the role of ergonomics by including metrics that evaluate the impact of lean improvements on safety risk factors associated with each job. Lean teams should focus on ergonomic design concepts by considering how employees interface with workstations, tooling, parts, and environmental factors will reduce costly errors, improve productivity, and reduce injury risk factors that lead to higher workers' compensation costs.

PART III

A Lean Work Cell for Sea Ray Cabinets

Sea Ray Knoxville-Riverside Plant

Bryan Robertson-Fabrication Manager

5502 Island River Drive

Knoxville, TN 37914

By:

Marcus Greene

Bethany Gregory

Neil Howerton

University of Tennessee

Department of Industrial & Information Engineering

416 East Stadium Hall

Knoxville, TN 37996-0700

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Executive Summary:

This final report contains all of the information from our first visit to Sea Ray until the last days of our project. In our Senior Design Project, we have been working with Sea Ray Boats to study and provide recommendations for improving the current state of the Cabinets division of Fabrication. The Cabinets division is responsible for building cabinets that are installed within the cabin of large sea cruisers, which include the 260, 270, and 290 models of galleys, gunnels, dinettes, headliners, and mdp's.

Although the Cabinet group usually meets weekly production demands, the current layout of the department possesses many space constraints. This lack of available space restricts product flexibility as only a limited number of workers can fit into the current layout. We have also found problems with obtaining required wood, access to glue booth, access to flormica, organization, and others, which we will discuss in this report.

In order to utilize the available space most effectively, Sea Ray asked that our team use lean methodology and other industrial engineering tools to analyze the current process and reduce the amount of waste. To simultaneously benefit our team as well as fulfil her senior honors project requirements, Bethany Gregory conducted extensive background research into Lean Production Systems and related tools. These additional efforts resulted in a cellular layout designs along with value stream mapping. These contributions are two tools that affected our analysis by directing our efforts towards a significant result. These applications also lead to the proposed use and her subsequent design of a Lean Audit sheet, simulation model, and A3 reports.

Since the scope of the project was considerably open-ended, our original objectives of simply reducing clutter expanded and grew throughout the project period. With the implementation of a work cell, the cabinet group has experienced changes in production dynamics, and our group has been able to study these changes and analyze additional opportunities for improvement in the physical layout and in the system methods with IE tools. With the outcome, Sea Ray will be able to utilize their space more effectively and follow lean manufacturing principals while we as a team gain insight and knowledge of practical engineering.

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Introduction:

Company Profile

As the world's largest manufacturer of superior quality pleasure boats, Sea Ray now produces more than 40 models ranging from 18 to 68 feet in length. Sea Ray Boats leads the marine industry in the manufacture and sale of an extensive line of superior quality fiberglass boats and maintains a reputation for producing luxury boats of the highest standard of excellence. The global company finds pride in making products that combine innovative styling, design, and advanced engineering concepts with distinct and prestigious brand images. Sea Ray is a forty-four year old company whose corporate headquarters is located in Knoxville, Tennessee, a placement that benefits both the corporation and the University of Tennessee's Industrial Engineering students who have the opportunity to analyze a manufacturing environment and provide relevant recommendations for improvement.

Project statement and objectives:

The term "lean" in a business or manufacturing environment describes a philosophy that integrates a collection of tools and techniques into the business processes to optimize time, human resources, assets, and productivity. This semester, every member of our project team has undergone extensive training in lean methodology and principals in our senior level Lean Manufacturing course. In this course, we have been challenged to develop a deep understanding of lean manufacturing and create our own personal definitions of what "lean" means in practical applications.

For our project, we have been working at the Riverview plant, where we focused on the department that produces the cabinets in the 260, 270, and 290 luxury boat models with the intention of implementing the lean principals that we are learning and

researching because of our coursework. At the time of our arrival to Sea Ray, the Cabinet group expressed concerns over the utilization of floor space in the work area. Although the Cabinet group usually meets weekly production demands, the current layout of the department possesses many space constraints. Firsthand, we have seen that this lack of available space restricts product flexibility as only a limited number of workers can fit into the current layout. Movable racks and storage bins clutter the work area and occupy a great amount of space, which creates a cramped work environment.

Sea Ray is currently trying to make the lean transition and improve this current situation, but continuous value flow, pull production, working toward perfection, and just in time, deliveries are difficult to plan and achieve. The supervisor of the Fabrication Department, Bryan Robertson, opened the door for our team to analyze the process of cabinet building and utilize our industrial engineering knowledge to recommend solutions that may improve the layout and create space through lean manufacturing principals such as cellular design and value stream mapping with the added verification of simulation modeling.

As improvements in this work area were greatly needed, any suggestions and improvements we presented throughout the project were eagerly received and valued by management. Cabinet builders in the group also expressed the need to improve the system, although some of these workers might have to be trained for a different operation based on the design of cells. However, the highly visible project presents the potential of favorable change for both management and the workers. With our recommendations, workers will be able to move more freely and safely without overlapping paths and

bumping elbows as much. Furthermore, if more space is available, production capabilities will increase and fall in line with other lean principals in which the management of Sea Ray desire to embrace, such as 5S and workplace organization.

Scope and limitations

Initially, both our team and Sea Ray wish for us to explore the potentials for improvement in the Cabinet Department through lean methodology in order to improve the process in the cabinet building department. As we discussed the project objectives, our Sea Ray correspondent clearly indicated that we could apply whatever tools and methods we decided to be most fitting and provided us with the freedom to pursue limitless possibilities. This degree of freedom did provide many chances to practice Industrial Engineering skills but also presented the challenge of directing our focus and narrowing down our observations.

The scope our project was restricted to a certain degree by the amount of time we had to conduct time studies and watch the various processes, as cycle times are relatively long and product types are unique. To greater benefit the client, the scope expanded from simply designing a new work cell for the department to suggesting multiple recommendations including layout, workplace organization, and process improvement. However, the aspect of the scope that remained consistent was that we wanted to become more “lean”. In other words, lean is among other things to reduce the timeline from customer order to delivery by eliminating waste. Waste can come in various forms, some of which include: under or over-production, time on hand (waiting), excessive transportation, processing, stock on hand (inventory), movement without purpose, idle

workers, lack of worker creativity and responsibility, and making defective products. Each of these wastes is evident in the cabinet department and our mission is to reduce these factors through group technology, cell design, and performing 5S audits with a lean perspective. To support our mission, we are providing additional resources such as value stream maps and simulations of both the initial and future processes.

Description of the Total System

Sea Ray produces fiberglass boats in an assembly type line in three rows. There are two different buildings. The first one is where the molding of the fiberglass hulls takes place, and the second is where all the parts are put into the hollows to make a complete luxury boat. In the second building, Sea Ray contains a warehouse in which they stock all the parts for the boat that they do not make. The two buildings are to be joined in the future, which will provide more space and likely relocate the cabinet process to another area. Currently, one line consists of the smaller boats, and the other two lines are for the larger boat models. The cabinets are installed on the larger boats, which are the two closer lines to the cabinet making area. Sea Ray plans to outsource the smaller boats and only produce the bigger models in the future. In the molding building, there are many boat shells taking up floor space, and the work environment is extremely unpleasant, as fiberglass clings to worker's skin and the odor released by the laminating materials is quite repulsive, in the opinion of both the workers and our team members. For these reasons, Sea Ray plans to make this process mostly robotic within a year.

Initial Steps and Progress

Before we could make any valid recommendations, we first had to become familiar with the plant, process, employees, and even the corporate culture. Touring the facilities and specifically observing the cabinet fabrication process was essential to this phase of the project. Inside the cabinet department, the first thing that we recognized first-hand was the need for space along with the cramped storage areas, which gave us a greater appreciation for the scope of our project. Our project facilitator described to us how the cabinet process begins all the way through to the end process where the finished Cabinet comes out.

As we observed the system, members of our team interviewed the cabinet builders about their impression of the system and recorded their feedback. As expected, we found that they could quickly give suggestions and opinions about improvements. Although some of the workers expressed reluctance to change for fear of “having more work”, each admitted that the process would benefit from a change. We attended two cabinet team meetings where ideas for a new cell were discussed, and we became familiar with the plant and product terminology. Understanding the environment and attitude has aided us in interacting with workers and knowing how to ask questions and get information. We have made it clear that through process redesign, the workers’ job will be more easy, productive, and enjoyable because waste will be continuously removed. A major conflict of Lean principles is that workers fear losing their jobs due to changes and improvements. The way Toyota dealt with this problem was trimming their workforce, then, guaranteeing employees jobs and giving workers more responsibilities.

Overview of the Process Flow and Plant Layout

Once we understood the current cabinet making process in a general sense, we could gather detailed specifics with the production. Currently, the cabinet section is making a wide range of models and designs, so we decided that it was necessary to identify a particular product family to focus on. After analyzing the throughput and questioning workers, we have come across valuable information that can be used to improve the baseline metrics for the 260 and 270 model cabinets. We made the decision to focus on these cabinets because of the production data, which revealed that these models are in the highest demand at 17 per week. Furthermore, we realized that the 260 and 270 building processes are nearly identical. When we spoke with the cabinet supervisors, they agreed that arranging a single cell for both assembly processes would be an effective and efficient design for consideration. However, the 290 is still being produced in the cell because the process is relatively similar and produced for a much smaller demand.

In the initial visits, we identified the different tools and materials needed to make the cabinets such as the wood router, sanders, edge banding, saw, drills, glue, mica, carpet covering, brackets, latches, muffs, staples, and screws. All of the hand tools are air driven and connected to lines that run overhead. Understanding the setup and purpose of these tools was vital for planning future layouts and cellular workstations. Three primary subcomponents compromise the cabinets and are separately assembled before the final assembly. Becoming familiar with each part of the cabinet took some time but helped our understanding of the current methodology. The three assembled, the upper galley, lower galley, and the MDP (the cabinet that houses the electrical circuit box), each have a set of similar processing steps. Workers have to walk around their stations to

work on various parts of the cabinet, and the space is so limited that they can easily run into each other. At first, the cabinets were being made by one worker from start to finish, and then two people assemble the three parts together. Last, the entire cabinet is dollied to the boat for installation.

The workers voiced that the finishing process--where edges are banded, mica sheets are glued to sides, and hardware is installed--is the bottleneck, and we have verified this in our observations and time studies. From the production scheduler, we have found out that the desired takt time, the time it takes for a boat to be ready for a cabinet, is 2 hours based on the weekly demand. We have also constructed a process flow diagram of the current situation, which reveals a lot of waste. (See Figure 1)

Initial Process Layout

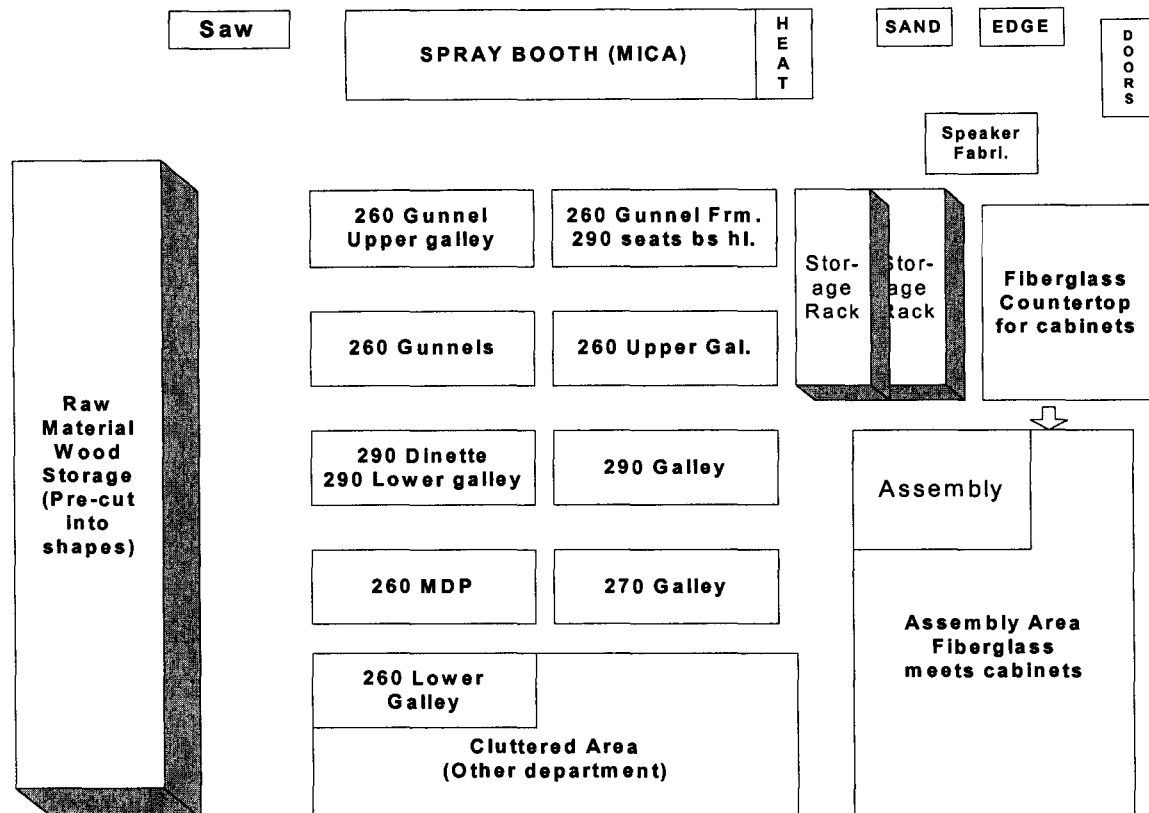


Figure 1

The flow of material is very excessive. For example, the worker travels without the main assembly from workstation to raw material, back to his workstation to frame the cabinet. Then, he will travel to the glue booth and back to apply flormica finish, then to the edge banding and back, to the saw and back, etc. The process is not organized so that the resources (glue booth, raw material) are available when the worker needs them. If all the arrows were included in current layout drawing, it would look like spaghetti. All of the seven deadly wastes, as defined in the book Lean Thinking and listed in Figure 2, to be were initially identified as we observed the process. At this point, it was time to take action.

Figure 2: Seven Deadly Wastes

1. Overproduction – Production more than production schedule
2. Waiting – Poor balance of work; operator attention time
3. Transportation – Long moves; re-stacking; pick up/put down
4. Processing – Protecting parts for transport to another process
5. Inventory – Too much material ahead of process hides problems
6. Motion – Walking to get parts because of space taken by high WIP.
7. Defects – Material and labor are wasted; capacity is lost at bottleneck

Value Stream Maps

Once we obtained an understanding of the process, completed the process flow diagram, and performed non-value added analysis, we could analyze potential waste reductions and basic improvement ideas. In order to do this, we first constructed a present value stream map Phase 1 (See Figure 3) to understand the current cabinet-making process as it relates to the individual product and its associated values. From the value stream map, the cycle time of each operation plus the inventory wait times are clearly stated. Next, we made a future value stream map (See Figure 4) to show the process in an improved, Lean perspective. Our future value stream map emphasized a cellular layout with single piece flow, balanced operations, and the capacity to increase productivity by giving more problem-solving responsibility to the shop-floor workers. The workers in the cabinet area were involved in our quest to create an efficient work cell and are encouraged to recommend solutions to problems along the way.

Figure 3

Initial Value Stream Map

Sea Ruy Cabinet Current Value Stream Mapping

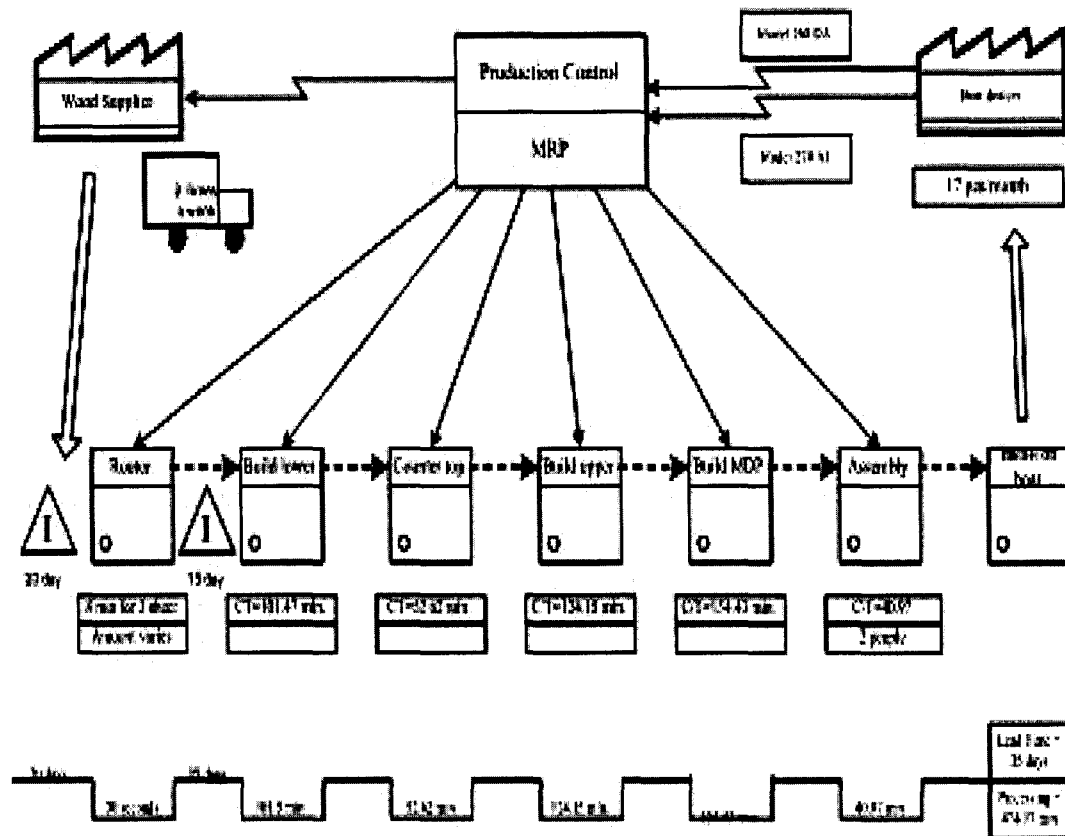
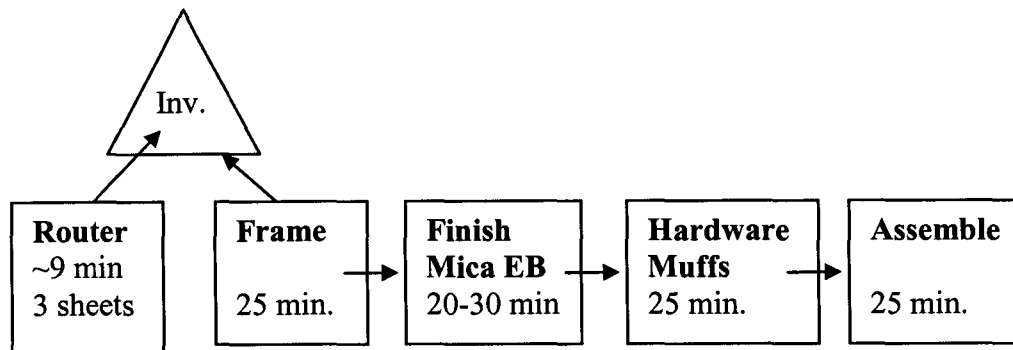


Figure 4

Future Value Stream



This future state value stream emphasizes single-piece flow to minimize lead time, cycle time, needed space, and inventory. This design alternates between MDP, LG, and UG, so that three pieces arrive every 1.5 hr to be ready for assembly. The worker can produce the cabinet from start to finish, or there can be one worker at each station. Balancing the operations is necessary for each of the three sub-assemblies to prevent waits and standard operations can help accomplish this. This model requires that raw materials and resources be readily available and delivered on time with 100% quality. We intended this design to be for the 260/270 model cabinets. Sure, there are problems with it such as: What if a worker is absent? Or What if the glue booth is being used? Another good thing about single piece flow is that more waste in the process will be revealed, and the workers can solve the problems with balancing, delays, and quality.

The Cell Layout: Phase 2 (current)

After constructing our value stream maps, the next step was to evaluate time studies created collaboratively with Sea Ray co-ops to help us understand each element of the operation and the time involved to complete a task to assist with line balancing and the best location of resources. The time studies divided each part assembly into tasks and

defined these tasks as either value adding or non-value adding. At this point in the project, the cabinet workers had actually followed up a cell meeting by changing their work stations around to test a work cell layout defined as Phase 2. This phase is the current layout of the cabinet department right now.

Although the lead time was slightly decreased, we observed the implementation of the Phase 2 cell and found problems such as workers unsure of their role in the cell and extended traveling lengths to flormica material and the glue booth. We proceeded to produce a process flow diagram of the current cell so that we could visually have a tool to show these problems to the upper management at Sea Ray during a progress presentation. Bryan Robertson and Colby Foster were pleased at our findings and agreed that these problems needed immediate solutions. Last, we discussed as a team what we could do to help Sea Ray address critical problems in a Lean context.

(See Appendix D)

Unfortunately, it was around this time that the router had technical difficulties and obtaining crucial raw material for the new cell layout was a major problem. The workers were behind schedule and somewhat stressed. This made it more difficult to evaluate cell operations because under normal circumstances the router would work properly and supply the needed wood pieces. An inventory problem in the cabinet process is also caused by the CNC wood router programming. This CNC router has many programs stored in its memory bank. Anything that is cut out of plywood goes through this machine. Three sheets of plywood are pre-stacked onto the router table. Once on the

table, the router begins to cut out the parts needed, obtaining 3 pieces of every part that is on that particular program.

The cabinet department has a rough storage area that houses the wooden parts from the router. When this inventory area gets low, one of the cabinet team members signals the router operator. The router operator has to go through the stacks of router programs to find the specified parts needed. When the programs are executed, he puts the milled parts onto a cart where they are transported to the rough storage area.

The router programs for the wooden parts are designed to eliminate the waste of wood. Trying to utilize each sheet of plywood is not an easy task, but it is needed in trying to minimize waste. Each router program can consist of multiple parts that are not going into the same style of finished cabinet. The randomization of these programs can cause a delay on the assembly of the cabinets and increase inventory. Any given program will take around nine minutes to execute. So it is obvious that if the cabinet team members are waiting on a certain part and the router is already running a program, it may take between nine to twenty minutes to get the needed part milled.

Our team feels that Sea Ray should address this issue, because to get the process “Lean” we must be able to supply enough parts to the cabinet assembly area in a timely manner without building unnecessary inventory. An idea would be to use a kanban signal when the last piece of wood is taken from inventory.

New Cell Layout: Phase 3

As previously mentioned, we feel that the current Phase 2 layout (Figure 3) could still use some improvements to increase the flow of the operation. Therefore, a Phase 3

layout design was created by our project team to present to Sea Ray. The Phase 2 and Phase 3 process layouts can be seen in Figures 5 and 6.

Figure 5

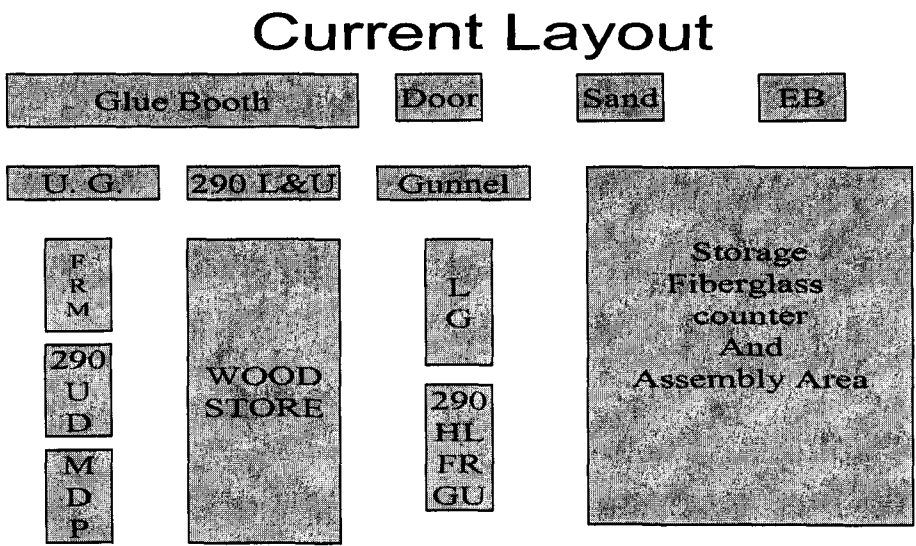
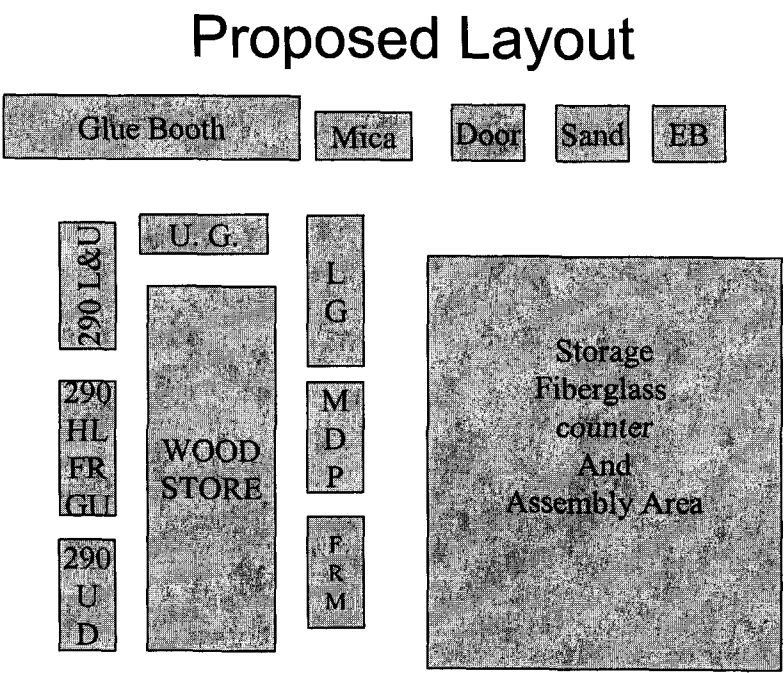


Figure 6



By having single piece flow throughout the cell, productivity would increase. This set up would eliminate the excessive travel, crossing, and backtracking in the flow. This idea is explained in more detail on the future value stream map. Typical results found in the book Lean Thinking are: Continuous single-piece flow with pull by customer will double labor productivity throughout the system, reduce throughput by 90%, errors, scrap, and job-related injuries will be cut in half, time-to-market will be drastically decreased, and a wider variety of products can be offered. Inventory holding costs are significantly reduced, and the focus is on elimination of all waste.

Potential for Greater Improvements

Although the Cabinet Department at this point has undergone steps towards becoming a work cell design, several improvements can be still be made. The individual workstations for each operation remain cluttered and unorganized. When the worker is performing the tasks to build each part of the cabinet, he picks up and sets down many tools without placing them back in an organized method or container. The drills and staple guns often pile on the side of the work table, which could lead to damage of the tool or injury of the worker. Providing tool belts for each worker could alleviate some of the disarray as well as help the worker keep track of his tools, equipment, and safety gear. At this point, the screws are being tightened down on the new cell layout. It is a great time to get the workers to write down their problems, discuss the problems that are having the most impact on the cell output in a team meeting, and work together to solve these crucial problems.

Through observing the process, our team has produced many simple suggestions that we wish to organize and give to Sea Ray. This way they can in turn assess whether or not these suggestions are feasible. Placing individual glue booths each workstation would greatly reduce travel time during the operation. These glue booths can be made by the workers to save money. Initial ideas are to have glue access at the workstation by glue bottles, building special fixtures (mini-glue booths at the station), and obtaining or designing self-adhesive flormica (eliminating the need for the glue booth altogether). Eliminating this travel need would decrease the cycle time, reduce transportation waste, and improve safety. Looking at the time studies, it is apparent that most of the non-value added time is spent going to and from materials and resources. As this example illustrates, many of our improvement ideas relate to 5S, which focuses on maintaining a clean, stable, and safe work environment. Combining these concepts with lean principles would provide a means of improving the cell, which is a primary focus of our project. With these suggestions in mind, we plan to make a lean audit or scorecard to rate the performance of the cell once implementations are complete.

Lean Audit Sheet:

As we have studied ways to make the cabinet department at Sea Ray more lean, we have noticed the great need for workplace organization and clean-up. Cleaning up the work area would certainly promote worker moral and an attitude of pride, but organizing the department would lead to more significant changes relating to the process flow. Disorganization of tools, materials, and work-in-progress blocks walkways and leads to increased travel times because workers must take alternative routes to arrive at

the glue booths and sanding machines. Furthermore, this clutter could lead to injury, which clearly slows down the building process.

After speaking with managers, we realized that performing a 5S in the cabinet department with steps including Sort, Straighten, Shine, Standardize, and Sustain is an important recommendation that our team suggests for Sea Ray. This action could be considered a “low-hanging fruit” and would produce extremely visible results. While it must be noted that clearing out clutter and organizing the workplace does not necessarily mean that the process will become “lean,” the changes certainly promote lean principals and will allow the metrics of lean, such as takt time, lead time, on time delivery, and cost of quality, to become more visible and manageable. Sustaining the changes implemented in a 5S obviously is the most important step and factor in encouraging a leaner process flow and production system for workers in the department. Therefore, we researched a way to help Sea Ray hold the Cabinet Department accountable to these changes.

After researching methods and tools concerning 5S, we decided to create a customized audit checklist for Sea Ray for inspecting the cabinet department. This checklist is unique in that it involves 5S principals with a lean perspective. The checklist contains several sections that combine the steps of 5S with lean principals, and each checkpoint contains a corresponding field for rating that particular checkpoint on a scale of 1 to 5. These ratings are added together and compared to the optimal value to rate the performance of the system in terms of lean and 5S principals. (Table 1)

SCORE CARD FOR EVALUATING IMPLEMENTATION OF 6S and Lean MethodsPerson Preparing this Score Card: **Cabinet Team**Company/Division : **UTK**Will be reviewed again on : **4/26/05**

	QUESTIONS	ANSWERS	POINTS	PREVIOUS SCORE	STATUS
I	First Impression				
1	Overall organization of the department	1 2 3 4 5			
2	There is a standardized place for all materials, tools, and equipment and everything is in its place.	1 2 3 4 5			
3	Production and support areas are clean from unnecessary materials, items, or scrap	1 2 3 4 5			
4	Workstations have clear distinction between production material, maintenance & support tools.	1 2 3 4 5			
II	Cleanliness				
1	The production and support areas clean from unnecessary materials, items, or scrap.	1 2 3 4 5			
2	The plant floor have lines or signs that distinguish work areas, material drop, and inventory staging areas	1 2 3 4 5			
3	The Equipment is clean,painted and working as per requirement.	1 2 3 4 5			
4	Cleaning equipment is stored in a neat manner, handy and is readily available when needed.	1 2 3 4 5			
5	It is established practice to check for leaks, overflows, etc., on the equipment & fix them	1 2 3 4 5			
6	All the employees aware of good housekeeping practices and how often do they follow them	1 2 3 4 5			
III	Workplace organization				
1	There is a standardized place for all materials,tools,equipment and is everything in its place	1 2 3 4 5			
2	Every necessary item, tool, material, container, or part rack labeled and easy to find.	1 2 3 4 5			
3	The employee know where to find the required tools or machine parts and does he replace them on to their original position.	1 2 3 4 5			
4	Part numbers are assigned to tools, jigs & fixtures to be placed at specified location.	1 2 3 4 5			
5	The workstations or cells regularly audited for 5S.	1 2 3 4 5			
IV	Visual Factory				
1	All workers aware of schedule for production	1 2 3 4 5			
2	Everyone can make suggestions to supervisor	1 2 3 4 5			
3	Suggestions are made on a weekly basis in clearly designated box or book	1 2 3 4 5			
4	Maintenance requests are made on a weekly basis in a clearly designated method or location	1 2 3 4 5			
5	The 5S responsibilities posted in a visible manner near their respective cells or work areas.	1 2 3 4 5			
6	There is a sufficient production data, job descriptions, safety, and operation instructions included in the site management boards.	1 2 3 4 5			
7	These boards readily visible at each production line or process.	1 2 3 4 5			
8	All the employees familiar with these boards and do they follow the instructions written on them.	1 2 3 4 5			
9	These boards regularly updated and maintained.	1 2 3 4 5			
10	The entire manufacturing process in this department be controlled visually.	1 2 3 4 5			
11	The entire production is designed ergonomically,to access all the material, fixtures and other tools				
V	Safety and Quality				
1	Products go to scrap or rework are rare (example: defect)	1 2 3 4 5			
2	Inspections made throughout your group's portion of the process for safety and quality regularly	1 2 3 4 5			
3	Lost time due to injury is rare	1 2 3 4 5			
4	Safety training is given on regular basis	1 2 3 4 5			
5	The emergency accesses are unobstructed and predominantly visible	1 2 3 4 5			
6	Stop switches and brakers are marked and color coded for visibility	1 2 3 4 5			
7	storage boxes, containers and materials are always neat at right angles	1 2 3 4 5			
8	Protective guarding are provided to enhance the safety of employees	1 2 3 4 5			
9	workers are encouraged to practice safety procedures	1 2 3 4 5			

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9	workers are encouraged to practice safety procedures	1 2 3 4 5			
VI Training and Audit					
1	Have all the employees been trained and aware about 5S and Visual control practices	1 2 3 4 5			
2	Are all the check sheets describing inventory and tracking quality defects being updated regularly at each workstation	1 2 3 4 5			
3	Is there a standard procedure for passing the information between shifts and how smoothly does it work	1 2 3 4 5			
4	Does the team of office and production members conduct weekly audits to monitor the entire process of 5S and visual control implementa	1 2 3 4 5			
VII Internal Flow					
1	Travel outside your workstation to complete your task is uncommon	1 2 3 4 5			
2	Traveling outside workstation do not account for a significant amount of time	1 2 3 4 5			
3	Workers rarely wait on someone else before they can do their job	1 2 3 4 5			
4	Workers rarely wait on something(materials,tools, etc.) to do job	1 2 3 4 5			
5	The department is producing to takt time	1 2 3 4 5			
6	Continious flow	1 2 3 4 5			
7	Is the work in the department being balanced	1 2 3 4 5			
8	Are the operators performing preventative maintenance	1 2 3 4 5			
9	Impact of setup times on flow	1 2 3 4 5			
10	Impact of quality on flow	1 2 3 4 5			
11	Is the layout based on continious flow	1 2 3 4 5			
12	Supermarkets available to link operations	1 2 3 4 5			
13	Does the department have apporiate lot size	1 2 3 4 5			
VIII Supporting Flow					
1	Utilization for mistake proofing to eliminate errors	1 2 3 4 5			
2	Utilized layout of the department	1 2 3 4 5			
3	Utilize critical metrics to manage the department	1 2 3 4 5			
4	Development of visual management boards	1 2 3 4 5			
5	Standardized the work in the department	1 2 3 4 5			
6	Visual work procedures	1 2 3 4 5			
7	What kind of inventory levels	1 2 3 4 5			

IX: Manage Flow									
1	Each tool and workstation item is used within a month's time	1	2	3	4	5			
2	Workstation is orgainzed and set up the same way as other stations in the department	1	2	3	4	5			
3	Maintenance requests are acknowledged or answered within 4 hours	1	2	3	4	5			
4	Workstation is reorganized on a regular (bi-monthly or monthly) basis	1	2	3	4	5			
5	Communication plan	1	2	3	4	5			
6	Program to monitor progress	1	2	3	4	5			
7	Program to provide feedback	1	2	3	4	5			
8	Training plan	1	2	3	4	5			

Standard Operations

We also looked at standard operations. Standard operations employ the best method currently available of performing a specific task, so that the right levels of quality, cost, delivery, and safety can consistently be achieved. With this method, all of the steps in the operation will be documented so that the workers can see what exactly is expected of them. This will also allow the workers to switch workstations smoothly since they will know the various tasks from beginning to end. The procedure for standardizing the operations is timely, but when properly implemented, it can be seen as a success. The variation of making cabinets from worker to worker would be decreased because the best methods of production will be documented and the workers would have the ability to update and improve the standard for a particular cabinet. To conclude, after we determined the required cycle time, standard task time, completion time per unit, production capacity, standard operation routines, and sequence, standardizing has the ability to improve the process flow and to reduce variation in the process.

The benefits of standard operations are dynamic. Standard operations will allow the workers to share responsibilities in the manufacturing process, and will allow the workers to help each other with problem areas. When performed on the shop floor, problems are easily spotted and corrections can be made immediately when the change occurs. Standard operations also allows for identification of safety hazards and procedures that lead to or permit defects, so that when a quality problem occurs it can be traced back to a particular task, and the workers can learn from the mistake to prevent it in the future. Standard operations also allow the workers and supervisors to check their

standards vs. the current state. This will let the employees and management have a way to measure performance. (See appendix E)

Simulation

We felt like the best way to test our proposed ideas would be to try simulation modeling. We used arena simulation software to test our theories. We first modeled the current process to identify potential problems with three separate process lines making the parts needed for a final assembly (See Figure 7). A match block combined these pieces into a new entity. The process pushed the product through the system with the assumption of an infinite demand and available resources and materials. The delays for the resource seizures were based on the data provided in the time studies. After running a replication length for a workday, we found that in a ten hour day the process could produce four complete cabinets. There is also a significant amount of waiting time.

- Avg. takt time from 1.91 to 1.25 hrs.
- Avg. lead time from 5.49 to 4.97 hrs.
- Avg. Work in process from 58 to 23 pieces
- Output from 4 to 6 cabinets

With the proposed Phase 3 cellular design, pieces that flow through the ten hour period produced six complete cabinets. The parts flow through the cell in a single piece fashion, with workstations for each assembly (see Figure 8.) Since the new cell layout eliminates significant travel times, the times for these delays did not include the wasted time that currently exists due to traveling to the glue booth. We feel that this information that we obtained from the software is very useful.

Figure 7

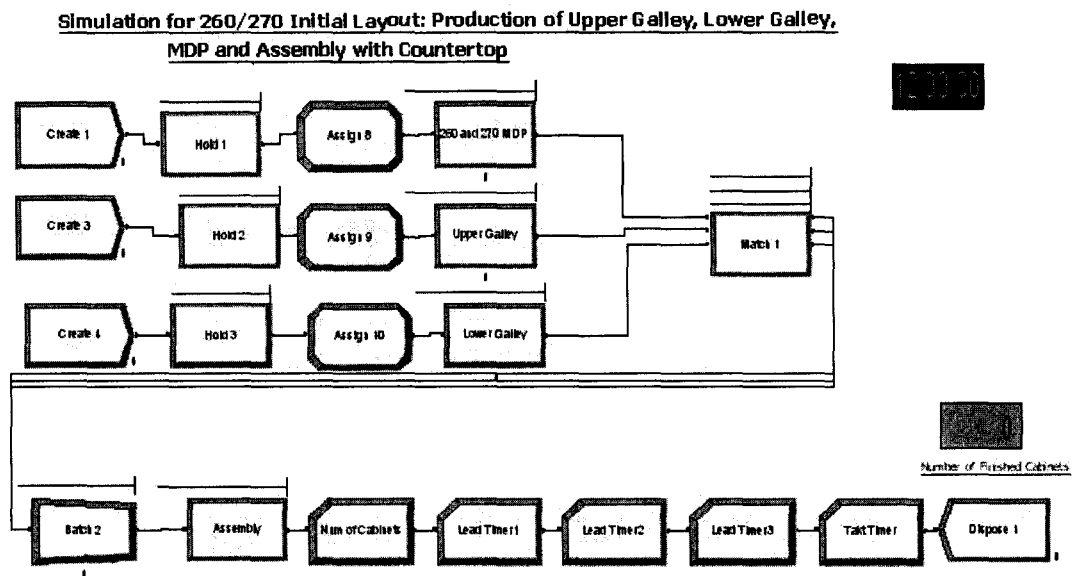
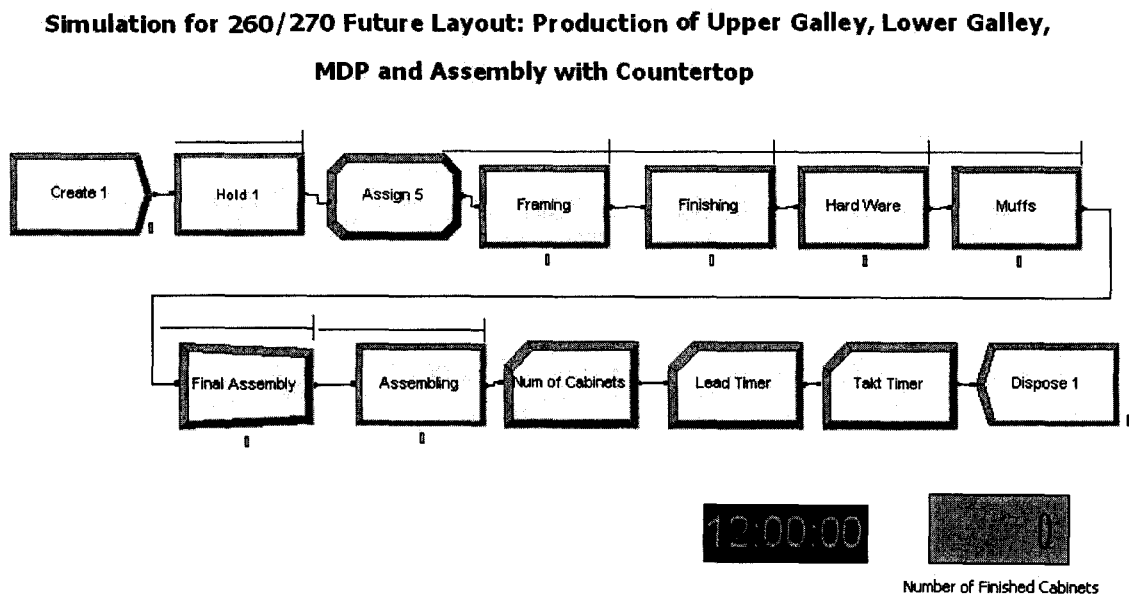


Figure 8



A3 Report

The A3 report is used to show the important information associated with LEAN project improvement. It shows four pages that add value to the company. The first page (top-left) shows the data of the current process. The product family of concern is introduced, an improvement strategy is identified, and the elements that are important to the company (metrics-cost of quality, on-time delivery, cycle time) are identified and measured. The second page (bottom-left) shows the current value stream map of the process, which tells the current cycle times of processing, inventory wait times, push/pull status, and information flow. The third page (top right) is the future value stream map that is proposed to improve the system based on the data and knowledge of the improvement team. During this step, a lot of waste is removed by combining operations, producing to takt time, placing supermarkets, establishing continuous flow where possible, continuous improvement, line balancing, creating work cells, and various other waste eliminating strategies. Finally, a hypothesis is given to show the proposed improved metric of concern. The last page shows the implementation plan to help get the show on the road. Individual projects and their timelines, as well as project leaders, are identified and proposed metric improvements are revealed. See Appendix G for an example of an A3 report.

Cost benefit analysis

The cost of this cabinet project is primarily associated with paying for labor and materials used to make the cabinets. By finding a way to use one less worker in the cell, the company can save approximately \$30,000 per year. Giving more responsibility to the

worker to problem solve can eliminate the need for a process engineer, saving \$50,000 per year. Sending the schedule to only one workstation and pulling from that station can eliminate time needed for mass scheduling within cabinet production. For material costs, we will be using a value of \$500 per cabinet. So, if a cabinet needs rework because of poor quality, Sea Ray has to pay double that amount because of labor and lost production. We are not directly affecting the budget for materials or changing the process in a significant financial manner. In fact, we are trying to save the company time, which in return would be money. This project cannot only affect the budget, but we are hoping it will help the employees perform their job at an easier, more pleasant, safer, and more successful rate. To achieve even higher profits, the boat output per week should be increased using Lean principles along the entire value stream of raw material to finished boat. In return, our studies will help the company be able to manufacture cabinets more efficiently and meet the increasing demand associated with such improvements.

Through the workers rearrangement of the work cell, transportation time to raw material has decreased. This in itself has led to more satisfied workers and less non value added time. However, there are still ways to increase productivity, including closer location of flormica, less travels to glue booth, and well defined work breakdowns. We explored bill of materials to get actual numbers on the cost benefit of these various improvements, but the material costs were estimated based on the limited data that was provided at our requests. Perhaps next semester the students should get with the company accountant to get a better idea of cost data. We truly believe that overhead costs can be reduced drastically through more Lean process improvements. This will reduce the time needed from raw material to finished boat, as well as customer order to

delivery, and product design to launch. We hope that the improvements we accomplish can spread from the cabinet area to every aspect of production and beyond. We do not see our suggested improvements costing a significant amount of money. The point of Lean is that it is possible through teamwork, communication, efficient use of resources, and continuous improvement to use half the space, effort, engineering hours, investment tools, and time to develop new products. In the future, we would like to see the process improved to the point where the 260/270 model boats are affordable to the middle class, thus increasing demand and profits.

Deliverables

The deliverables for this project are a final presentation, along with various tools that can be used to achieve Lean production. These tools consist of Value Stream Mapping, Cell Design principles, 5S/Lean Audit Sheet, Standard Operations, and the use of A3 reports to define projects to achieve Lean goals. We feel that this is a good project to get some hands on experience and are thankful that Sea Ray gave us the opportunity to work with them. Through this project, we improved our teamwork, communication, and analytical skills. This is also a good way to see how it actually is in the workplace. We want to thank everyone at Sea Ray for being so kind and helpful to us throughout this entire semester. Hopefully, this project was more of a success than we realize and Sea Ray will be able to use our ideas to improve performance, save time, and lower costs. The goal for our team is to turn the Sea Ray cabinet department into a well organized team that will utilize their resources to produce on-time quality products and solve their own problems to the point where no more problems exist. We want to spread the faith

that perfection can be achieved through continuous improvement. Our team observed some signs of high worker morale, which showed that most of the workers show enthusiasm and enjoy the work they do. This high morale is very helpful to an organization and can be increased by using Lean principles to have the right persons doing the right jobs.

Summary

This project can make some very important improvements to an existing process. By reducing some of the congestion, it would create more available workspace, allowing the worker to have more freedom to implement his skills on the work. The use of group technology is the realization that many problems are similar, and that by grouping similar problems, a single solution can be found to a set of problems thus saving time and effort. The work cell in the cabinet division has endless opportunities for improvements in productivity, elimination of waste, quicker problem solving, and higher levels of worker satisfaction. Through improvements, lead time and takt time will decrease significantly as already observed through changes in the cell and as evidenced in simulation modeling, floor space and workers will be freed up, and the business can use these resources to develop new products, or in Sea Ray's case, produce more components in house.

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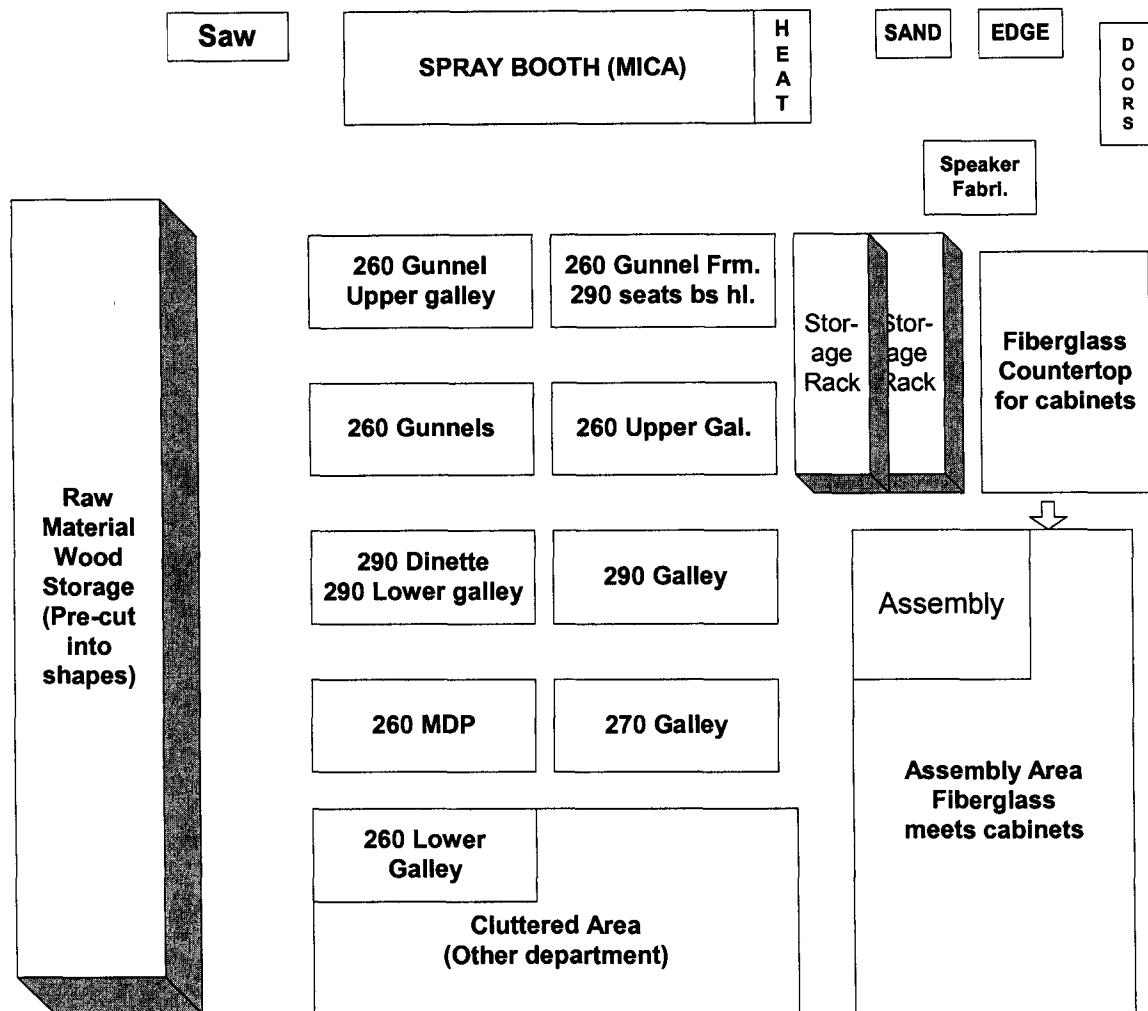
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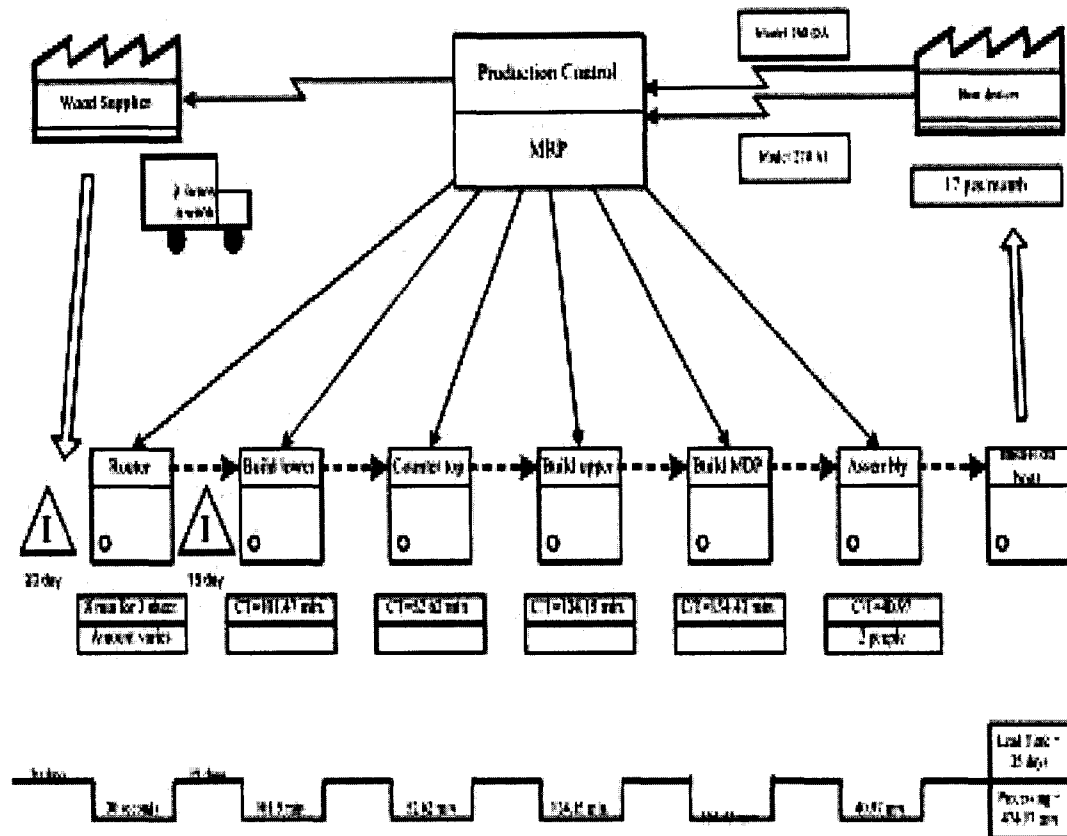
Appendix A

Initial Process Layout

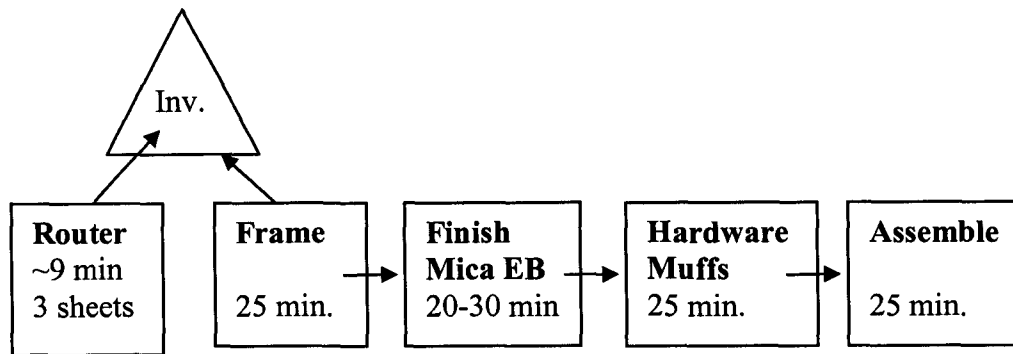


Initial Value Stream Map

Sea Ray Cabinet Current Value Stream Mapping



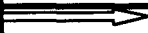
Future Value Stream



This future state value stream emphasizes single-piece flow to minimize lead time, cycle time, needed space, and inventory. This design alternates between MDP, LG, and UG, so that three pieces arrive every 1.5 hr to be ready for assembly. The worker can produce the cabinet from start to finish, or there can be one worker at each station. Balancing the operations is necessary for each of the three sub-assemblies to prevent waits and standard operations can help accomplish this. This model requires that raw materials and resources be readily available and delivered on time with 100% quality. We intended this design to be for the 260/270 model cabinets. Sure, there are problems with it such as: What if a worker is absent? Or What if the glue booth is being used? Another good thing about single piece flow is that more waste in the process will be revealed, and the workers can solve the problems with balancing, delays, and quality.

Appendix C

PROCESS ID : MDP 260		STANDARD WORK			DATE : 4/14
OPERATOR : 2					TAKT TIME
SEQ. NO.	TASK DESCRIPTION	TIME		TIME SCALE	
		MAN	MOVE	10	20 30 40
1	GET MATERIALS		9.93		
2	MEASURE	2.87			
3	CUT WOOD	1.43			
4	SECURE BRACKETS	7.77			
5	APPLY GLUE	2.57			
6	SECURE WOOD	12.52			
7	CUT WOOD	5.76			
8	SAND WOOD	12.14			
9	PAINT WOOD	1.23			
10	CLEAN WORK STATION	2			
TOTAL		48.29	9.93	UTILIZATION = 58.22/120 = 48.51%	
				MANUAL  MOVE 	

PROCESS ID : MDP 260 OPERATOR : 3		STANDARD WORK		DATE : 4/14 TAKT TIME	
SEQ. NO.	TASK DESCRIPTION	TIME		TIME SCALE	
		MAN	MOVE	5	10 15 20
1	WALK		5.48		
2	DRILL HOLES	5.96			
3	INSTALL HARDWARE	5.82			
4	SPRAY GLUE	5.4			
5	WAIT	1.27			
6	LAY FLOOR MICA	1.34			
7	TRIM FLOOR MICA	1.91			
8	EDGE BANDING	2.2			
9	TRIM EDGE BANDING	2.77			
10	PLACE CONDUIT	1.18			
11	APPLY VELCRO	1.47			
12	CHECK FIT	0.77			
13	WRAP BOARDS	0.62			
14	SWEEP WORK AREA	0.57			
TOTAL		31.28	5.48	UTILIZATION = 36.76/120 = 30.63%	
				MANUAL  MOVE 	

PROCESS ID : UPPER GALLEY.1		STANDARD WORK		DATE : 4/14	
OPERATOR : 2				TAKT TIME	
SEQ. NO.	TASK DESCRIPTION	TIME		TIME SCALE	
		MAN	MOVE	20	30 40 50
1	GET MATERIAL		12.55	→	
2	MEASURE	4.41		→	
3	CUT WOOD	2.17		→	
4	REMOVE PLASTIC	7.71		→	
5	SECURE BOARD	13.31		→	
6	SECURE BRACKETS	0.73		→	
7	SECURE BOARD TO BOARD	12.57		→	
8	SAND BOARD	6.36		→	
9	SPRAY PAINT	3.43		→	
TOTAL		50.69	12.55	UTILIZATION = $63.24/120 = 52.7\%$ MANUAL → MOVE	

PROCESS ID : LOWER GALLEY 260 OPERATOR : 1		STANDARD WORK				DATE : 4/14 TAKT TIME	
SEQ. NO.	TASK DESCRIPTION	TIME		TIME SCALE			
		MAN	MOVE	20	30	40	50
1	GET MATERIAL		9.42				
2	MEASUREMENTS	0.67					
3	MARK WOOD	2.45					
4	WALK		3.24				
5	CUT WOOD	3.9					
6	DRILL HOLES	9.64					
7	SECURE BOARD TO BOARD	16.31					
8	SAND BOARD	6.36					
9	SPRAY GLUE	1.84					
10	GLUE BOARDS	1.69					
11	SAW	1.25					
12	EDGEBANDING	5.87					
13	TRIM EDGEBANDING	8.64					
14	SPRAY PAINT	3.22					
15	INSTALL DOORS	2.98					
16	ADJUST DOORS	3.91					
17	INSTALL HARDWARE	5.45					
18	WIPE DOWN	0.93					
19	HUNT DOLLY		1.2				
20	PLACE ON DOLLY	0.6					
TOTAL		75.71	13.86	UTILIZATION = 89.57/120 = 74.64%			
				MANUAL MOVE			

PROCESS ID : UPPER GALLEY 260 OPERATOR : 4		STANDARD WORK		DATE : 4/14 TAKT TIME			
SEQ. NO.	TASK DESCRIPTION	TIME		TIME SCALE			
		MAN	MOVE	10	20	30	35
1	WALK		9.2	→			
2	APPLY TRIM & EDGEBANDING	6.01		→			
3	SPRAY GLUE	4.64		→			
4	LAY TRIM& FLOOR MICA	6.43		→			
5	DRILL HOLES	10.32		→			
6	INSTALL HARDWARE	4.04					
7	INSTALL DOORS	0.23					
8	ADJUST	1.12					
9	APPLY VELCRO	2.48					
10	TAPE	2.8					
11	WRAP BOARDS	0.37					
TOTAL		38.44	9.2	UTILIZATION = 47.67/120 = 39.7%			
				MANUAL → MOVE			

Appendix F

Figure 1

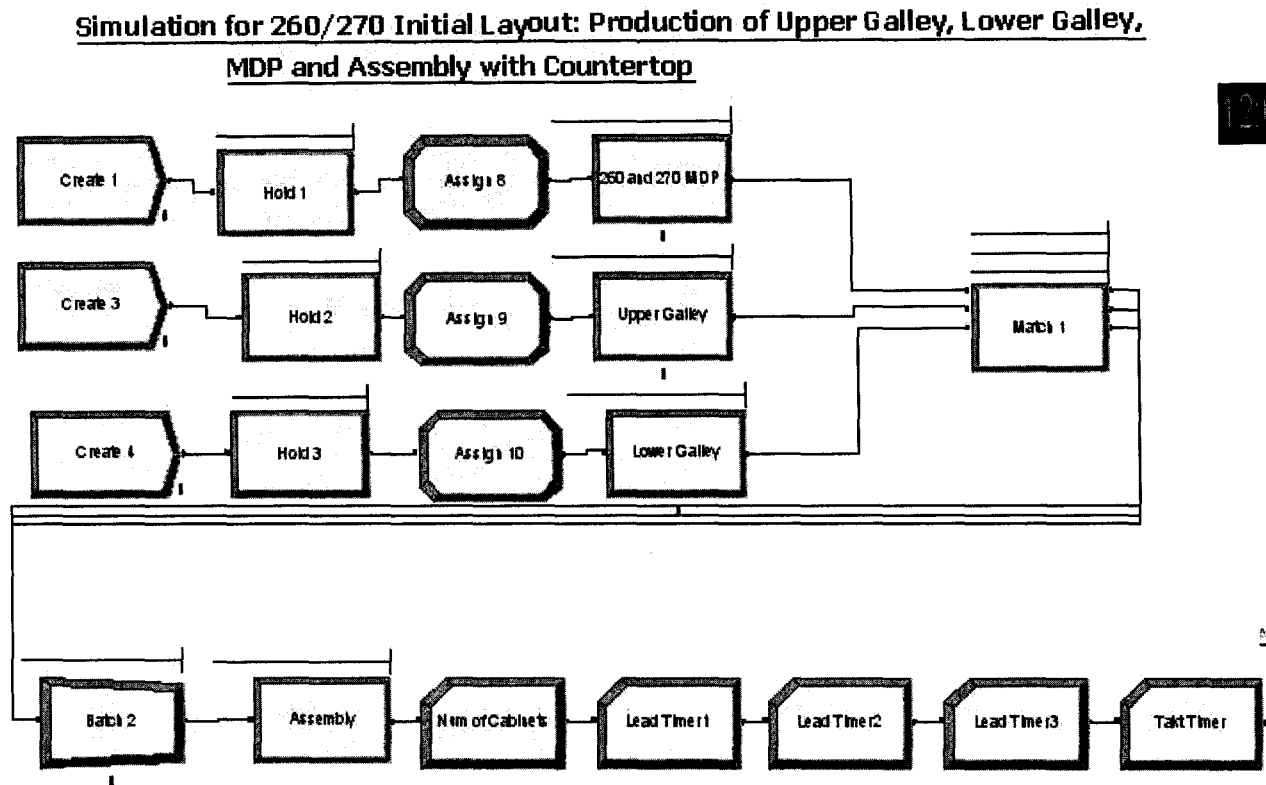
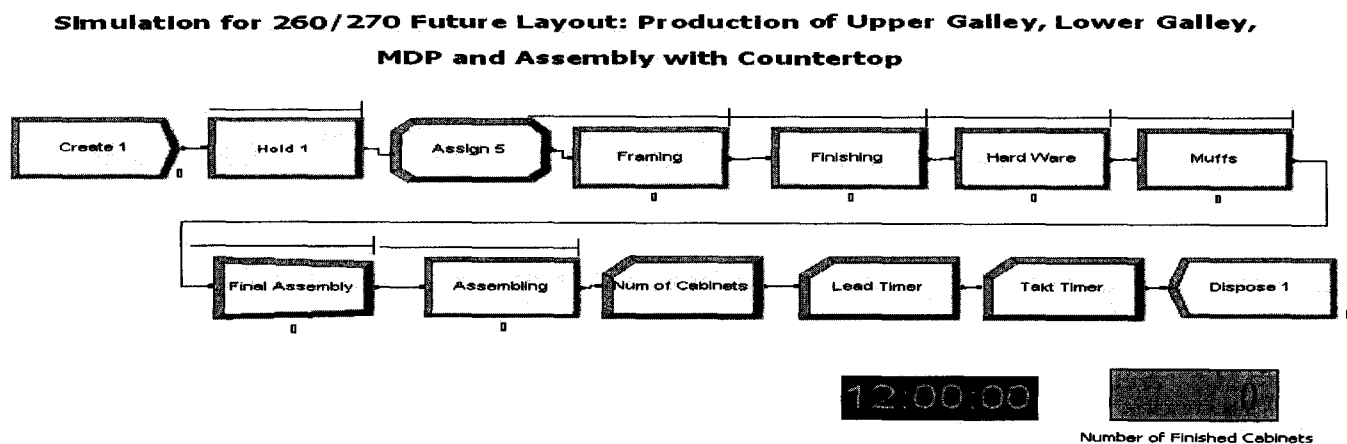


Figure 2



Appendix G

Sample A3 Report.doc (Read-Only) - Microsoft Word

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Sample A3 Report

Business Case Product A represent about 25% of one organization and a high Profit Margin. An improvement to capacity to process Product A is critical to the future profitability. The primary improvement needed is in Delivery and Quality to the customer. We will ensure the improvements to the entire value stream of six different type of Product A utilizing the principles of Lean Six Sigma to stay competitive, improve profit and position ourselves to take advantage of present and future opportunities to increase our market share. Current trends and forecasts indicate a significant increase in demand. Baseline Metrics <table> <tr> <td>OTD</td> <td>69.7%</td> </tr> <tr> <td>COQ</td> <td>\$\$\$\$\$\$ / month</td> </tr> <tr> <td>COY</td> <td>\$\$\$\$\$\$ month</td> </tr> <tr> <td>DAYS TO PRODUCE</td> <td>12</td> </tr> <tr> <td>INVENTORY TURNS</td> <td>3.6</td> </tr> <tr> <td>MARGIN %</td> <td>35%</td> </tr> </table>	OTD	69.7%	COQ	\$\$\$\$\$\$ / month	COY	\$\$\$\$\$\$ month	DAYS TO PRODUCE	12	INVENTORY TURNS	3.6	MARGIN %	35%	Future State: Hypothesis: By implementing the changes outlined here associated with pha Lean Six Sigma strategy, Product A production is expected to increase 30%.																								
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MARGIN %	35%																																				
Current State:	Implementation Plan: There will be 9 interdependent projects all directed at achieving the above. Individual projects, time-lines, project leaders, are also identified. <table> <thead> <tr> <th>Title of Project</th> <th>Date</th> <th>Project Leader</th> </tr> </thead> <tbody> <tr> <td>1. Isokhron</td> <td>mm/dd/yy</td> <td>Name</td> </tr> <tr> <td>2. Engineering</td> <td>mm/dd/yy</td> <td>Name</td> </tr> <tr> <td>3. Changeover Reduction</td> <td>mm/dd/yy</td> <td>Name</td> </tr> <tr> <td>4. Maintenance PM</td> <td>mm/dd/yy</td> <td>Name</td> </tr> <tr> <td>5. Press Production</td> <td>mm/dd/yy</td> <td>Name</td> </tr> <tr> <td>6. Organizational Changes</td> <td>mm/dd/yy</td> <td>Name</td> </tr> <tr> <td>7. Process Improvement</td> <td>mm/dd/yy</td> <td>Name</td> </tr> <tr> <td>8. New Equipment</td> <td>mm/dd/yy</td> <td>Name</td> </tr> <tr> <td>9. Review Customer Requirement</td> <td>mm/dd/yy</td> <td>Name</td> </tr> </tbody> </table> METRICS <table> <tr> <td>OTD should increase to 90-95%</td> <td>Days to Produce should decrease by 50%</td> </tr> <tr> <td>COQ should decrease by 50%</td> <td>Inv. Turns should increase by 25%</td> </tr> <tr> <td>COY should decrease by 25%</td> <td>Margin % should increase by 10%</td> </tr> </table>	Title of Project	Date	Project Leader	1. Isokhron	mm/dd/yy	Name	2. Engineering	mm/dd/yy	Name	3. Changeover Reduction	mm/dd/yy	Name	4. Maintenance PM	mm/dd/yy	Name	5. Press Production	mm/dd/yy	Name	6. Organizational Changes	mm/dd/yy	Name	7. Process Improvement	mm/dd/yy	Name	8. New Equipment	mm/dd/yy	Name	9. Review Customer Requirement	mm/dd/yy	Name	OTD should increase to 90-95%	Days to Produce should decrease by 50%	COQ should decrease by 50%	Inv. Turns should increase by 25%	COY should decrease by 25%	Margin % should increase by 10%
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