DESIGNING A MANUFACTURING SYSTEM TO REDUCE PRODUCTION LEARNING CURVE

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by

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ABSTRACT

The goal of this project was to design a new manufacturing system for Patio Pacific that would reduce the learning curve and the skilled labor required in the production process. Multiple ideas to decrease the scrap rate in the vert manufacturing process were tested. It was determined that outsourcing the manufacturing of the vertical frame piece was the most optimal because it would reduce overall cost and increase product quality. A new facility and production layout were designed in order to accommodate the new pre-manufactured parts. The approved facility design included a new production flow that transitioned manufacturing from single employees performing batch production methods to a component based manufacturing system. This included the introduction of job shops around the facility to reduce distance travelled by employees. To further increase standardization within the production process, the work benches were redesigned using 5S methods. The design was aimed to reduce strain on the employee during production and increase flexibility in the workplace. Many secondary results came from the start of implementation of these changes, such as: increased throughput, increased product quality, increased inventory accuracy and a reduced employee training time. Moving forward, Patio Pacific will continue to implement these designs and train their new employees accordingly.

1.0 INTRODUCTION

The subject of this report is the manufacturing process of the most requested products sold by Patio Pacific, the door/wall mount. Patio Pacific is a small e-commerce based company that manufactures their products at their facility in San Luis Obispo. The vision of the company is to sell the highest quality pet doors in the market. This requires an amazing product with no defects and great customer support in order to account for their high market value. The current issue that Patio Pacific is facing is their inconsistency in the product quality. Since the products are manufactured from start to finish in house, Patio Pacific takes on a lot of the products' risk. This is an issue for the company because the process in which the company currently uses to produce door/wall mount products requires a high level of skill. Due to this, there is a high defect rate for the product that requires an excessive amount of time to fix as the reworking process is not time efficient. The rework process and the implementation of batch production limits the company's ability to respond to market demand and has resulted in an extensive back order list. Furthermore, since the company is located in the college town of San Luis Obispo, students make up a large portion of the labor force and consequently the company has a high employee turnover rate, hindering the ability to retain this high skilled labor once employees reach production expectations. In order to improve the quality of their product and reduce the need for skilled labor in the manufacturing process, the steps taken to produce the door/wall mount products requires a complete overhaul. The objectives of this project improve the manufacturing process at Patio Pacific through:

- Improving product quality
- Standardizing procedures and processes
- Decreasing scrap rate
- Increasing manufacturing throughput
- Reducing the company back order list
- Simplifying the manufacturing process

Achieving these goals requires meetings with the COO of Patio Pacific regularly to discuss new processes the company can implement. Discussion and analysis of facility designs and standardized processes will be evaluated during these meetings. The manufacturing process will be broken down into simpler tasks in order to allow employees to master them in a short time frame and reduce defects. In order for this project to be completed, a new manufacturing process as well as any facility changes that need to be made in order to facilitate the new process must be designed, prototyped and approved by the COO and the head manufacturers. This entails any processes that involve materials handling through out the production area and processes. The designed process and facility must lead to the above objectives but will be difficult to measure as the implementation will not be completed until later in the year. That being said, time studies, 5S, ergonomic and economic analyses will all be assessed during the design of the new protocol to determine its effectiveness.

2.0 BACKGROUND

Patio Pacific is an e-commerce company that has been in business since 1976. It is a small company with a high employee turnover rate with an average of about fifteen employees at any given time. The company of Patio Pacific has an expensive product in which the employees rightfully feel should reflect the cost put into it. Customers value the out of box experience of the product in addition to the functionality, therefore there should be no cosmetic or mechanical defects. As mentioned before, there is a high employee turnover rate in the manufacturing department due to the number of students working for the company, paired with a high learning curve for the skilled labor required in the processing of the door/wall mount products. It was estimated that the average time it takes for an employee to reach standard proficiency in production was at least six months if working part time. During this period of time, not only were build times slow and scrap rates high, but there was also a large quantity of defective product that were shipped to customers. This is in part due to the fact that there are no clear quality standards for the products and there is no cross examination of the products manufactured. One employee will take the product from raw materials all the way to boxing without anyone else laying eyes on the product. Metal extrusions are selected from the front of the shop, cut and drilled, then taken to a workbench in which they are assembled with the preassembled flaps and locking covers and finally boxed for storage in the warehouse. This not only allows for defective products being shipped to customers, but also creates a lack of consistency in quality as the product standards are determined by whoever manufactures the item.

The heart of the defects lies in the processing of the metal sides of the door frames, also known as the verts, specifically drilling out the holes on the front face. The current drill and jig setup uses a step drill bit allowing two holes of different sizes to bet made with one motion through the front and back of the metal vert. If this process is done improperly, flash on the top hole can remain stuck to or between the drill bit and the jig, creating rings around the drilled hole. These scratched verts must then be cut down to a smaller size and set aside for another manufacturer to use or scrapped all together. These errors are not only frustrating for the workers, but also drive up material and labor costs due to the increased scrap rate and manufacturing time. This is a main point of concern for the company as material costs are the highest percentage of their costs of goods sold by far. The current process also uses batch production in which anywhere between five and eight doors are produced in one cycle. Having this many products in front of the manufacturers at one time makes difficult to notice some of these defects right when they happen, if at all.

Previously, testing has taken place in order to solve this problem but with little avail. The first test involved drill rpm speed. This test failed because there was no significant difference between the tested drill speeds and when a new drill speed was set, there was a high increase in the scrap rate of the metal verts. This was due to the fact that the drill speed was a crucial part of skilled labor required to produce the part. When the drill speed changed, it took a long time for the manufacturers to adapt and therefore was not worth the investment for the company. Another test to mitigate the defects to the product was increasing the paint thickness on the metal verts. This idea was attempted on the white metal verts and did reduce the scrap rate. While the cost of the material did increase, it was a temporary solution to the problem. However, this did not last because when the company contacted the suppliers to change to the paint thickness of the other colors of the extrusions, the suppliers were unable to fulfill the requested change. This resulted in the revoking of the changes to the paint thickness of the white verts because it was not an absolute solution to the issue and increased material costs. Patio Pacific has since been looking for an alternate solution to their process problem.

LITERATURE REVIEW

In order to familiarize with the topic as well as discover possible solutions to the problems currently faced at Patio Pacific, many peer reviewed and journal articles were examined. These reviewed article will present feasible options that can be used as recommendations or design opportunities to be taken under consideration during the design, methodology or results sections of the project.

At Patio Pacific, the production process consists of many product families with a large amount of variation within each family. In order to accommodate the wide amount of products, the production process is set up to manufacture products in small batches. Ning (2014) talks about this topic in her article, “Production Planning Optimization Method in the Same Assembly Line Based on Discrete Random Demand”. Ning identifies the most costly point in processes that accommodate multiple manufacturing lines as set up or transition times in machines. In order to plan around this problem and avoid possible bottlenecks, a production schedule should be established that aims to reduce the set up times between products by manufacturing one product at a time [9]. This information could be very helpful in the manufacturing process at Patio Pacific as there are few lead time issues associated with production. A large majority of product are made to restock inventory at e-commerce warehouses to be shipped for the future. With proper notice, these shortages can be avoided while also implementing a single line system with minimal change over time.

Another change that can take place in the production area, as pointed out by Liu (2014), is the lack of line balancing in the system. There are many small tasks that go into one process of the production cycle that may not make sense to separate and be too hard to work around in a line balancing scenario, losing the efficiency. In addition to this, scheduling conflicts due to the high number of part time employees also makes line balancing a less feasible option to implement. Liu (2014) discusses a new option for production line balancing through a system called the "bucket brigades assembly line" [7]. In this assembly line, workers are organized in the production line from least to most efficient/experienced with newest employees at the front. In this system, the slowest employee starts the process and finishes whenever the second employee in line is free. This is a very straightforward pull system that allows for no employee to be free of time and optimize the work force. The line will also balance itself as it goes on due, ending with a very structured time as to when each employee's process will be picked up by the next person in line. This process also allows the most seasoned manufacturers to get the final check on the product without having to rely on the inspections of the newer employees.

Quality is one of the main issues Patio Pacific faces in their manufacturing process. Moving away from batch production could be an initial step to solving the issue, but it is not enough. Kiselev (1995) discusses a production process implemented at an engineering plant, Mytishchinskie, in which quality checks were required at each step in the manufacturing process and signed off by a manufacturer verifying the products meet the standards [6]. The written out standards required for the products of each process give manufacturers a very clear idea as to what needs to be accomplished for the product to pass. This standardization of quality can help to reduce the need for skilled or experienced employees in production process. In addition to this, forcing employees to sign off on quality standards gives responsibility to those performing the product inspections and help gather data as to whether standards are not shared between inspectors, requiring further quality standardization, or there is an area in which product rejection is noticeably high, indicating an opportunity for process improvement.

When comparing the quality check and assembly line process to the current batch process, it becomes apparent that straying from batch production will result in an increase in work in progress materials around the facility. Fang discusses a possible solution to this problem by using a flexible kanban system designed around multi-stage manufacturing [4]. This kanban system aims to optimize the manufacturing process by calculating the exact time in which raw materials should be ordered and how manufacturing schedules should be developed in order to keep the least amount of work in progress material in the shop without creating bottlenecks. This process allows certain lines to build up stock while other lines are running and shifting process timing so every previous process is a step ahead of the next. The work in progress material created by the assembly line will need to be stored around the facility. Given that no part numbers are currents given to these new products, a kanban system suck as the one described above could be implemented to facilitate the production process change with minimal set up time. The kanban system can also be improved to create a lean, just in time process throughout the process.

As mentioned before, the production process at Patio Pacific has a large learning curve that makes it difficult for new employees to make an impact and cost the company a lot of money. Champney (2013) discusses the balancing point of training in the article, “A Method to Determine Optimal Simulator Training Time: Examining Performance Improvement Across the Learning Curve” by analyzing the optimal time of simulation training. In reference to the workplace, simulation training could be any training that results in no product being developed whether it be through watching videos or making test parts to be scrapped [1]. Typically the amount of training allowed is based on how much training the company can afford. Ideally any trainee would be performing at a high rate once introduced in the workplace in order to minimize time spent by other manufacturers training the new employee as well as a reduction in defective products. The result of the analysis to optimize training is to do so until the new employee begins to plateau, therefore utilizing their ability as much as possible as soon as they are introduced. This reduction in cost of training time and learning curve will can help resolve one of Patio Pacific’s greatest obstacles.

During discussion of this project with the COO of Patio Pacific, they company mentioned their openness to outsourcing some of the production processes. As Mokhtari point out in his article “Manufacturing Operations Outsourcing Through an Artificial Team Process Algorithm”, by outsourcing labor and raw materials, Patio Pacific will be extremely reliant on their suppliers. So, when a large order comes in to Patio Pacific, it is important for them to decide early on whether they would need to outsource some of the manufacturing. There is no single best solution to this issue as it is influenced by many different variables and based on the specific company in question. Mokhtari claims the team process algorithm (TPA) will help to combat this issue [8]. Since TPA is a computational algorithm, it can factor in production needs, capacity while also researching supplier constraints and capabilities based on location. This could be a worth investment for Patio Pacific if their manufacturing capabilities are unable to meet customer demand.

If changes are made to the current production process, it is important that there is a facility design to supplement the changes. The goal of a new facility design is to ensure the new process increases manufacturing throughput at Patio Pacific. Duggan recommends the proper way to go about process of designing a facility in his article, *Facilities Design for Lean Manufacturing*. The process must begin with constructing a facility map that highlights process relationships in the workplace. Next, shared resources between processes should be recognized as they will need to be accessible to multiple areas in the facility. Lastly, organize the facility processes as fitting and determine whether it is a bulk product cell, small product cell, new product cell or a mixed model cell [3]. By identifying the cell type and value added processes, a new facility design can be created to streamline production flow.

The production system at Patio Pacific may require a total overhaul and focus on lean manufacturing. But, as Gomez point out in his article, *Complementing Lean Manufacturing with Quick Response Manufacturing: Case Studies*, it can be difficult to implement an effective lean system in high variety and low volume production. Quick response manufacturing systems aim to reduce the critical path of production which can help to alleviate some of the pains of implementing lean manufacturing in this type of system [5]. This can be accomplished by focusing on lead time management, production batch sizing and the addition of cellular manufacturing. The results of this study showed an increased machine utilization and decreased lead times in the manufacturing facility which can both benefit Patio Pacific.

One metric of the effectiveness of the production changes is product quality. While many of the manufacturing changes may be designed, customer feedback will not be available to Patio Pacific for quite some time after the implementation. That being said, it is important to identify the customer needs based on the feedback they give. By interacting with the customers, product value to the consumer can be identified to create goals for the manufacturing process. This can be done as Wei has in his article, *An Evaluation Method of Comprehensive Product Quality for Customer Satisfaction Based on Intuitionistic Fuzzy Number*, using the Delphi method. This is done by acquiring customer feedback on what they expected compared to what their perception of the product is. Each of the categories are weighted by the company and rated by the customer based on the value it is to them [10]. This gives an overall rating for each category that can be used to prioritize future projects.

Knowing that Patio Pacific is a small company without a lot of extra capital, there may not be a lot of opportunity to introduce heavy machinery into the workplace. In addition to this, investing in a costly decision that the company is not sure will pay off will can prevent Patio Pacific from taking some opportunities. Dance and Jarvis tackle this issue by introducing the use of yield application models, specifically SEMATECH [2]. This software can be integrated into the company to collect data and use it to model the manufacturing system and help make decision. While there is a high cost to implementing the system itself, it all pays off. With the data collected and a data relationship set up between the influencing factors and the company goals, areas of improvement can be easily identified and pointed out to industrial engineers that can help to come up with solutions and once again use the software to model the possible solution. Using this type of software can help engineers design around the need for skilled labor, resulting in a decrease in both defect rate and training time.

3.0 Design

As previously stated, the vert manufacturing process was required the highest level of skilled labor in the production process, therefore creating the highest scrap rate and cycle times. In order to design and implement the most effective changes to the production process, multiple aspects of the manufacturing process would also be affected as the entire process is tied together. Consequently, in this project there were a few different designs implemented at Patio Pacific: a new vert manufacturing process, an updated facility design as well as standardization for the new manufacturing process.

Vert Manufacturing Process

The original vert manufacturing process had excessive scrap rate and cycle times which increase material and labor costs for Patio Pacific due to the skilled labor necessary in the process. Based on data taken from the company's previous process analysis, over 4% of all raw material extrusions for the verts were calculated to be scrap, and this number was estimated to be lower than the actual scrap rate, resulting in an additional cost of 19 cents to the company for each vert produced. On top of this, reworking the part also added another two to four minutes each. The quality of the vert piece used in the final assembly varied a lot and was not consistent with the company standards. The goal of the company was to implement a new process that would make it easier for employees to produce high quality products. There were two main errors that were identified when this process was analyzed. The process that drilled the holes on the front face of the verts used a jig and step drill bit in the drill press. Occasionally during this process the flash metal from the drill would get caught in the jig or get so hot it would stick to the drill bit and scratch rings around the hole. Because this hole is on the front of face of the final product and will be facing the customer when the product is unpackaged and after installation, it is important that there are no cosmetic defects to the part. The other issue that was recognized after analyzing the process was the inconsistency in the material quality of the raw material extrusions for the part. Because the raw metal extrusion were packaged and shipped in bundles there tended to be bent and damaged extrusions that would not be discovered until it was too late to return to the supplier for a refund. The most frustrating part for the employees was when the parts were not bent enough to notice until the final assembly, forcing them to scrap the piece and redo all the previous steps in the process.

To solve the problem with the drill press, a few separate attempts were tested. The first was to change the RPMs on the drill press and see if it affected the scrap rate. This required minimal investment to the company and could result in major savings. The second attempt was to require manufacturers place masking tape over the holes before they were drilled in order to reduce the scratching by providing a protective layer to the metal. This would also be easy to implement but would add extra time to the process, increasing the labor costs to the company. The next two ideas both had the potential to solve both the manufacturing and material problems faced by the company. First was the idea to increase the thickness of the paint on the extrusions to make it more difficult to scratch. This would increase material costs and may also need to be paired with one of the previous process changes to eradicate the problem. The second is the most expensive which involved having the verts cut and drilled by the supplier, eliminating the labor aspect of the process but increasing the materials costs dramatically. While this idea required the most intense changes to the current process, a quick calculation of labor cost and material cost was determined by speaking with the company's suppliers and employees proved the change to be feasible and worth further investigation. Another positive aspect that could come from the implementation of outsourcing the manufacturing was the reduction in batch size. Due to the lack of extrusions, the manufacturers could assemble products one at a time as opposed to the previous batch production of six at a time. This would increase the product quality as employees could focus on manufacturing one product at a time, and increase the market responsiveness which is important because some of Patio Pacific's online distributors have a two day demand for their products. As this process change would eliminate the extrusions in inventory and cutting and drilling in the manufacturing process, there were a few other changes that would need to be made throughout the production facility to make sure it was implemented smoothly.

Facility Layout

After speaking to the COO at Patio Pacific, another problem was identified with the current system. A Pareto chart used to track the reasons why items were returned was created and lead to the discovery that domestic flaws from the very manufacturing process was not the only reason products were being returned, as shown in the figure below (Figure 1). Another reason, which

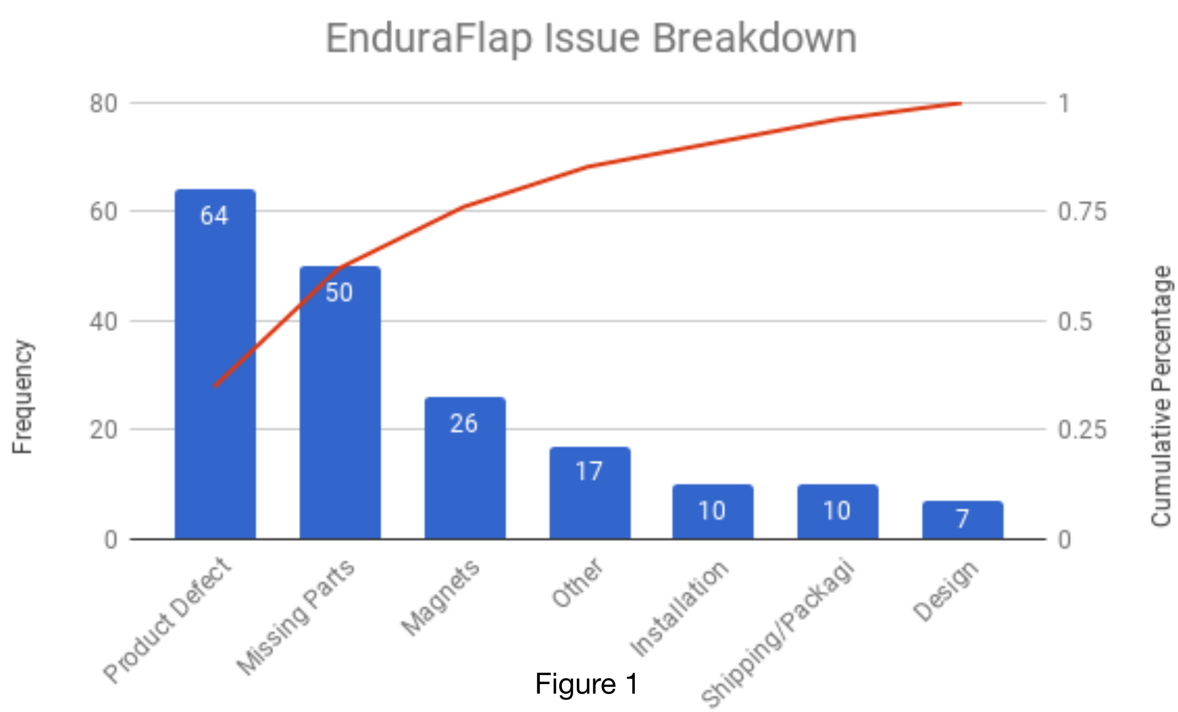


Figure 1

accounted for over a quarter of the returned items, were missing parts. The reasoning behind this became very apparent after analyzing the company's current process. When the batch manufacturing process was used, the employees would each manufacture six entire products from start to finish on their own. This is strenuous for the employees and can cause things in the process to be overlooked because there are over fifty individual parts that go into the assembly of the final product. If any of these parts are missing, it creates a defective product for the customer. In order to reduce the Muri in the process, also known as overburdening the workers, a new facility design was created in order to break down the current process into smaller steps.

In order to design the most effective facility for the company, the process needed to be broken down into its most crucial parts. Because materials handling is so important in a product with such high quality standards, a diagram of the manufacturing process was created and analyzed to determine which subassemblies would make the most sense for the company. The machines required in each process were assembled in a relationship diagram, as shown in appendix F, to determine which machines needed to be next to each other as to minimize travel around the workplace. The result of the charts and diagrams showed that all cutting and drilling of metal extrusions could be completed separately from the construction of the flap, then both subassemblies could be joined for final assembly, inspection and packaging at a separate workbench. A new facility design was then created by measuring the manufacturing facility and the areas allotted to each of the raw materials for each process, as shown in appendix B. The flap assembly process was allocated to the back corner of the building next to where all the machines for the process were currently located. A bench was added to the metal room in the front of the structure to keep all metal processes in one area, reducing the flash metal at the workbenches that lead to scratched parts during final assembly. Both these subassemblies were then given space to be stored in one of many of the storage shelves around the final assembly station, allowing easy access for the employees. The shelving for the units was based on the space and accessibility required for each SKU which can be identified in appendix E. This facility design can lead to many potential benefits such as: standardized product quality due to multiple employees being involved in the same production cycle, simpler tasks for the employees making them easier to learn and perfect, fewer defective parts due to separation of processes and implementation of inspections, and helping to facilitate the new vert processing changes.

Workbench Standardization

The last issue that Patio Pacific requested to be resolved synonymously with the other changes is their lack of standardization at their workbenches. With the current process, each manufacturer had their own workbench in which they would take their parts to for deburring, assembly and packaging. This was a problem for the company because there were a limited number of workbenches and based on the schedules of the part time employees, some were left with nothing to do if they were all taken, or they were placed at a workbench in which they were unfamiliar with. Each employee placed the parts around their workbench in a different manner and would slowly adapt it until they felt comfortable. Many times, with multiple people working at the same bench at different times, employees would place parts in different places, causing the next user to waste their time looking for the part. In addition to this, the workbenches were designed for people that were at least six feet tall, making it difficult for some of the employees to reach the items in the third level of bins or know how many are left in the bins. This resulted in a lot of time being wasted refilling parts in the middle of the manufacturing process.
In order to solve this issue, there was a lot of discussion with the senior manufacturers at Patio Pacific. A list of all parts and tools necessary at each workbench was created. Each part was labeled with where it needed to be on the bench for the employee to have the easiest access to it during the assembly process. This process was the same with all employees, regardless of the workbench, in the current production cycle with work in progress on the right side of the bench and finished goods on the left. With this, and the discussion with the lead manufacturers in mind, a new bench design was created that took into account all the actions of the employees during the final assembly process as shown in appendix A. Each bin is labeled in the front with the parts it contains and the tools are outlined on the backing board. This 5S tool will make it so everyone knows where they go and exactly what they are missing at a quick glance. The new model limited the number of bins to two rows to account for shorter employees, eliminated excess space underneath the workbenches in which trash would be stored, and decreased the movements required for the assembly of the final product. These changes also allowed more flexibility for employees in the workplace. Since all workbenches are now standardized, there is no preference to any specific one, and employee throughput should increase.

4.0 Methods

In order to make sure the changes taking place in the company were actually effective, a few measurements needed to be taken to prove the investment would pay off. That being said, many of the designs that are in the process of being implemented required very little investment and instead focused on reallocation of current materials. As stated previously, each of these changes had their own set of obstacles and reasoning behind the decision making so they will be discussed as separate entities below.

Vert Manufacturing Process

In order to determine which option would be the most fitting to solve the issues associated with the vert processing, simple tests were designed to evaluate the options effectiveness. The first test that was performed was changing the RPMs of the drill press. This test was executed by one of the current employees. The drill was tested at two RPM speeds, the original 2540 RPMs and the speed on level down, 1630 RPMs. Each speed was tested four times and forty eight holes were drilled each cycle. The number of defects created on each test speed were measured by counting the total number of circular rings created around the drilled hole at both speeds. The processing time was also measured using a stop watch to analyze the effect of speed on the number of scrapped parts created.

The second process tested was taping the verts before drilling in order to provide a protective layer. One of the newer employees, who consequently had a higher scrap rate than most employees, was instructed to drill out a batch of verts with masking tape over the holes. It took the employee and average of five minutes to tape over all forty eight holes to be drilled, an average of just over six seconds each. This added another step in the process and therefore increased the cycle time. The process was repeated over five batches and the course of two days to determine whether or not the employee had a lower scrap rate using the masking tape before drilling than his scrap rate without the tape.

The third analysis to be performed was the possibility of increasing the paint thickness on the vert extrusions to reduce scratches during packaging, shipment and the drilling process. This idea came about because the SKU with the lowest defect rate was the tan metal, which also had the largest paint thickness over the metal, and the SKU with the least paint thickness, black, had a much higher scrap rate. Paint thickness was useful because minor scratches could be buffed out later in the production process by scrubbing the material with lacquer thinner to even out the paint. The buffing process had the ability to cover the defects as long as there was no color variation or exposed metal on the surface of the product. Unfortunately for this process, tests could not be executed because the supplier of the material was unable to increase the paint thickness to all of the colors to that of the tan metal. In fact, the supplier stated that the black metal had the maximum paint thickness possible for the extrusion, making this option unfeasible for Patio Pacific.

The final process change evaluation to take place was investing in pre-manufactured parts. In order to determine the effectiveness of this option, two separate tests needed to be performed. The first was an economic analysis of the cost, and the second was a quality check of the products. The economic analysis required monetary values to be assigned to multiple components in the process: the labor costs of the process, the cost of scrap rate produced, and the cost of the new materials. For the labor cost of the process, a stopwatch was used to time an average employee to pull the metal extrusions, cut, drill and deburr the verts. It took the average employee twenty six minutes to complete the task. This time was divided by the twenty four verts in the batch giving an average of just over one minute per vert. The time per vert was then multiplied by the pay rate of what Patio Pacific considered to be a proficient manufacturer to give a final labor cost per unit. The scrap rate was determined by taking the difference between the actual material required per vert, and the material required as listed in the inventory manager. This calculated out to be 0.077 feet of scrap metal for every vert created, and this was estimated to be on the lower end. Multiplying the scrap rate by the cost per foot of raw material, to give a total cost of scrap per unit. Summing these two number together gives a total cost per vert that would be saved if the parts were pre-manufactured by the supplier. After discussing with the supplier, it was discovered the pre-manufactured part would have a lower material cost but have an additional tooling charge attached. Ignoring the scrapped raw material due to the mitigated risk of the process and adding in the tooling charge resulted in two fully allocated costs to company the current and proposed process. After the economic analysis was complete, Patio Pacific order a set of sample parts. Once the fifty pre-manufactured verts were received, the parts were placed in the current jigs and drill presses to make sure all cuts and holes were in the proper locations. Next, the test parts were assembled into a final product and brought given to the manufacturing employees and administration for review.

Facility Layout

Designing and testing the new process breakdown and facility design was an iterative process. Multiple drafts were created and analyzed by the manufacturers at the facility who gave feedback as to what they liked and disliked. During this time, design constraints were made apparent, such as the restrictions on having shelving in front of a bay door. All the designs were tested by measuring the distance employees travelled around the workplace in order to complete their tasks. Breaking down the process into smaller tasks gave the opportunity to consolidate all machines associated with each process to a specific location where the task would be performed. The main focus of the analysis was to minimize the movement within each of these job shop locations due to the fact that Patio Pacific encouraged investment in safety stock of their subassemblies. The storage bin capacity of thirty six components for the operation was used to determine how often the employee needs to travel across the facility to restock the parts. Each design developed had a spaghetti chart associated with it to highlight the reduced and localized travel of each employee throughout the system. Once a facility design was approved by the senior manufacturer, the distance travelled between machines in each job shop was measured and compared to the distance travelled by a single employee attempting to produce the same total number of products using the original facility design and manufacturing process. The test compared the distance travelled for both a single build and for three separate builds.

Workbench Standardization

The workbench standardization was theorized to allow more flexibility in the workplace and ease of use for the employees performing the final product assembly and packaging process. In order to ensure this process was efficient for the workers, the 5S methodology was implemented into the design. Due to the limited numerical and statistical data associated with this change to the facility, many of the result were tested theoretically and once again after the prototype was built. The reach requirements necessary for each piece were tested against the current process method and placed according to where along the workbench they would need to be and how often the parts needed to be accessed to put the least amount of strain on the employees during production. Multiple drafts of the design were created and given to the lead manufacturers. The manufacturers then implemented these changes to their own desks and tested the changes themselves. Every few days a discussion was held in order to determine what changes needed to be made. Slowly, the design evolved into what the lead manufacturers thought fit best for them and made them the most proficient. Once the final design was approved, a prototype was built and implemented on a separate desk as shown in appendix A. Each of the other employees that had not yet tested the final design were all asked to take turns on the new workbench layout over the next few weeks to identify any problems they faced with the new design and how they would change the workbench to better suit their production needs. As mentioned before, another issue involved with the workbenches was personal preference by the employees based on the layouts they ad become accustom to. Problems arose when two part time employees who preferred the same workbench layout were assigned overlapping shifts, as they were mostly students who's schedule changed every quarter. The increased flexibility was planned to be tested around employee downtime while waiting for a preferred desk or employee reduction in productivity when at an unfamiliar desk, but the limited data and extensive testing required to determine the results man the test unfeasible for this project.

5.0 Results & Discussion

In order to determine what was the most feasible and profitable solution for Patio Pacific each of the changes proposed to be implemented were tested separately. For the changes to be deemed worthy of implementation they needed to be individually justified. As mentioned before, many of the changes proposed require a long lead time before they are completely implemented in the process. Many of the results discussed below for each design are based on a limited number of runs and compared back to the current process to rationalize the decision to implement. Therefore the results discussed below will have the largest impact once fully integrated into the manufacturing process at Patio Pacific. While some of the results have not been given numerical or quantified values as to their effect on the company, whether it be due to a lack of previous data or lack of ability to measure new data, they were justified by the theory in the design and/or discussion of the deign with the COO and lead manufacturers of Patio Pacific.

Vert Manufacturing Process

The test of the drill speeds gave surprising results. The original drill speed of 2540 RPMs was counted to have an average total of 1.5 complete rings per experimental run. The slower drill speed of 1630 RPMs was counted to have an average total of one complete rings per experimental runs. On the other hand, the faster drill speed had a processing time that was over a sixty seconds less than that of the 1630 RPMs. In addition to this, the slower drill speed had an higher chance to break the drill bit as it had an increased torque. Patio Pacific decided to implement the lower drill speed in an attempt to reduce the scrap rate. Unfortunately, when the drill speed was changed, many of the employees did not adapt to the slower processing time required to achieve the reduced scrap rate. Consequently the scrap rate skyrocketed and multiple drill bits were broken. This lead to the company returning to the previous drill speed of 2540 RPMs.

The implementation of a new process to cover the verts with masking tape before drilling was tested by a newer employee through multiple production batches. Over the course of multiple trials, the new employee typically scratched only one or two verts in each process which was lower than his previous scrap rate of four or five. While the tape did deter some of the minor scratches, the deeper cuts to the metal still damaged the part. The process did add an extra few minutes to the total manufacturing process therefore it was determined that this method would not be beneficial to the senior manufacturers. This is due to the fact that their scrap rates were much lower than that of a new employee and their defects were typically caused by the much deeper scratches from the flash that the masking tape was unable to prevent.

The outsourcing of labor for the pre-manufactured verts had to be justified by its new cost and quality. The current material cost for a part was calculated using the $2.43 per foot of material multiplied by the total material used (including scrap) of 1.91 feet, resulting in a total material cost of $4.64. In addition to this was the cost of the labor used to process the parts in house. A batch of twenty four verts could be pulled, cut, drilled and deburred in twenty six minutes. With the salary of an employee with a standard performance level of $20 per hour, this equated to a total labor cost of $0.36 per vert. The sum of the labor and material costs gives the total cost to manufacture the part in house, which is an even $5 per vert. The new supplier of the material was able to sell the company the metal at a lower rate of $1.92 per foot. This supplier is not Patio Pacific's first choice because the metal extrusions received from them had the thinnest coating of paint, resulting in excessive scrap rates when the material was processed in house. This material cost multiplied by the length of extrusion per part (without scrap) of 1.83 feet gave a material cost of $3.52. In addition to this cost was the tooling cost of the part for the outsourced labor at a rate of $1.42 per unit. This summed to a total cost of the new material to be $4.94, saving Patio Pacific $0.06 per vert, as shown in the figure to the right (Figure 2). Over 40,000 vert are used by Patio Pacific each year. With the implementation of outsourced manufacturing, Patio Pacific could result in an annual savings of $2,400. Once the prototypes were received and multiple test frame was assembled and reviewed by the employees to see if the verts met the high quality standards of the company. The employees were not only happy with the product's high quality but also its quality consistency . Since the approval, orders have been placed and received for the pre-manufactured parts, but only for their most popular frames, large white frames. The pre-manufactured parts have also proved to be beneficial to individual employee throughput, increasing the total number of manufactured products in one shift by 50%. In addition to this, the variation in quality of the products produced has been greatly reduced because using a single unit system gives Patio Pacific the opportunity to returned defective parts, which could not not previously done with the metal extrusions. Therefore, any vert that is not up to the quality standards of the company does not result in extra material costs to the company. Further implementation of the pre-manufactured parts is in progress. The medium size white verts have just arrived to Patio Pacific the first week in June 2018, and discussion with the supple of the extra large white vert shipments are in place. Patio Pacific would also like to start receiving pre-manufactured verts in other colors, but this process will take a bit longer as the new supplier needs to find a color match to vert extrusions currently being purchased. Patio Pacific plans to restock their pre-manufactured vert inventory every four weeks and keep the leftover extrusions to mitigate the risk of production delays in the case of the supplier of the new verts cannot fulfill Patio Pacific's order or meet the expected lead time or shipment date. Another result from this process change was the was the materials were ordered. In addition to the pre-manufactured parts increasing throughput, quality and reducing cost, this process change also made it easier to keep track of inventory. When extrusions were being used, scrap was not measured but estimated and every part that had to be reworked was not always for the same reason. Some of the extrusions received by Patio Pacific had surface scratches or dent that needed to be cut out of the raw material extrusion adding an element of randomness to the

Cost to Manufacture Single Vert		
Process Type:	**Current**	**Outsource**
Vert length (ft)	1.833	1.833
Material Cost ($/ft)	2.43	1.92
Scrap Rate (%)	4.014	0.00
Tooling Costs	$ -	$ 1.42
Total Material Cost	$ 4.63	$ 4.94
Processing Time (hr)	0.018	0.00
Labor Rate ($/hr)	20.00	0.00
Total Labor Cost	$ 0.36	$ -
Total Cost	**$ 4.99**	**$ 4.94**

Figure 2

inventory tracking system. As mentioned before, the current scrap rate of material was uniform for all sizes of the same color, even though it varied heavily in practice. By purchasing parts in pre-manufactured units, an exact number can be counted as opposed to trying to convert scrapped units to feet of material. This will in turn make it easier for Patio Pacific to implement a just in time manufacturing system and decrease the frequency and duration of inventory counts in the facility.

Facility Layout

The new facility design and vert processing changes were not something that could talk place overnight. The new vert processing system alone requires a long time to scale up and take over the entire manufacturing system. On top of this, the facility changes that have been approved for implementation by the COO of the company have yet to be integrated into the manufacturing facility at Patio Pacific. Due to this lack of implementation, the results from the design tests have been mostly theoretical. That being said, there are still some calculations that can be made to determine the effectiveness of the new system. The first of these is to compare the distance traveled by employees around the workplace during the production process. As mentioned before, due to the fact that the new vert process will have a long lead time before it becomes the standard for all variations of the door/wall mount products sold by Patio Pacific, it is important to account for the in-house manufacturing of the verts for both the facility design and processing breakdown. Consequently, the vert manufacturing process will also be a part of the distance traveled analysis. As you can see in the spaghetti diagram for the facility design of the current process in appendix C, one employee will travel to almost every corner of the workplace in order to acquire all the parts they need to complete the manufacturing process. For the single employee to complete three builds worth of products (each build is six products in the current batch production process) they will need to repeat the same production cycle three separate times. Each production cycle requires the employee to walk 186.5 feet to retrieve all the parts for the process. Repeating this process for three builds totals 559.5 feet, and that doesn't account for any defective material reworks or other delays in the process. The second spaghetti diagram shows the distance traveled by three separate employees who all work synonymously, as shown in appendix D. Using the job shop method where two employees work on a separate parts of the manufacturing process, flap assemble and metal processing, in order to stock parts for the employee performing the final assembly process, it is clear that there is much less total distance traveled. In fact, to complete three builds worth of production the employee performing flap assembly only travels 126 feet, the employee performing the metal processing only travels 162.5 feet, and the employee performing final assembly only travels 49.5 feet. This results in a total of 338 feet traveled by the employees. When compared to the current manufacturing process, the total distance traveled to complete eighteen products is reduced by 221.5 feet, or 39.59%, as displayed in the figure below (Figure 3).

Distance Traveled Due to Process & Facility Design			
Distance Traveled to Manufacture 6 Products			
Current		New	
Single Cycle	186.5	Flap Assembly	126
		Vert Processing	162.5
		Final Assembly	49.5
Total Distance Traveled (ft)	186.5	Total Distance Traveled (ft)	338
Distance Traveled to Manufacture 18 Products			
Current		New	
Single Cycle	186.5	Flap Assembly	126
Single Cycle	186.5	Vert Processing	162.5
Single Cycle	186.5	Final Assembly	49.5
Total Distance Traveled (ft)	559.5	Total Distance Traveled (ft)	338

Figure 3

After seeing these results, further analysis was performed in order to determine the savings in labor cost that would ensue from the implementation of the new facility which, as shown in the figure to the right (Figure 4), came out to be $0.095 per build.

Distance Traveled Economic Analysis	
Difference in Distance Traveled (%)	39.59
Difference in Distance Traveled (feet)	221.50
Walking Speed (feet / hour)	15540
Walking Time Saved (hours / build)	0.00475
labor rate ($ / hour)	20.00
Total Savings per Build	$0.095

Figure 4

Since the there is an annual number of batches produced equaling 2,250, the new facility design could save Patiot Pacific over $200 in travel time alone. In addition to this is the amount of time saved between processes. While it is not a number that has been able to be quantified, it is known that employees in the workplace will take longer to perform their tasks if they have to continuously leave the place in which the tasks are performed. Implementing the new facility in part with the new job shop process flow will decrease manufacturing time, therefore increasing throughput and reducing labor costs.

From this new facility and process layout come four other profitable results for pet Patio Pacific: increased accuracy in inventory tracking, a reduction in the learning curve for the manufacturing process, increased market responsiveness and an increased employee capacity in the facility. With the process breakdown and focus on component manufacturing as oppose to the current batch production comes an increase in WIP. While this is normally viewed as a problem to most industrial engineers, it is a step in the right direction for Patio Pacific. The current process makes it difficult to track inventory. In order to convert raw materials into final production, from an inventory tracking standpoint, the supply chain and logistics manager needed to estimate the amount of scrap produced. On top of that, there was no way of accounting for the amount of reworked parts that sat on the shelf, usually left until they were too damaged to be used, and then thrown out. This method of estimating scrap was recognized by Patio Pacific as being inefficient and to account for the error in the estimation, the company required monthly inventory counts by someone in the production facility. This was not only a time sink for the company but also easily avoidable. Transferring to a component based system, supplemented by the new facility and production layout, the time to count parts will not only be reduced, but make the need to convert raw materials to WIP obsolete in the system. The second profitable change that derived from the new system was a reduction in the learning curve for a new employee. As mentioned before, the company hires a fair number of college students who can only work for the company for a few years before they graduate and leave the company. This means there is a high employee turnover rate in the manufacturing facility and in turn, a need to train new employees as quickly as possible. With the current manufacturing process, a single employee needs to be able to perform all of the tasks in the production of the product in order to contribute to the manufacturing throughput. The COO of Patio Pacific estimated the time it takes for a new employee to meet the standard performance level of production to be anywhere between six and twelve months, which is a huge investment to make in an employee that may leave shortly thereafter. As mentioned previously, there are not only over fifty parts and a complex process involved in the production of the door/wall mount products, but there is also no standards in place for inspection of the products a new employee packages before they are sent out to a customer. This forces the administration at pet Patio Pacific to put a lot of trust in their employees, which is not always the best for their customers. With the new facility and job shop flow of production, an employee can focus on learning one part of the process until they master it, while still contributing to the total manufacturing throughput. Specifically, a new employee can start working at flap assembly, as there is virtually no defects that can come from this process without being noticed later on in the production process. After becoming efficient at constructing the flaps, they can move on to metal processing which has also been made easier for employees due to the new electronic interface that has been added to the chop saw. Once again, any sub assemblies made here will be inspected at final assembly by another manufacturer to ensure its quality. Lastly, the employee can move forward to final assembly once the administration and lead manufacturers at Patio Pacific feel the new employee understands what the quality standards are at the company. By breaking down this long and complex process into smaller, less daunting tasks, new employees will be able to produce the high quality products Patio Pacific expect with less training time and with higher success. The third effect of the new process and facility is an increase Patio Pacific's ability to respond to the market demand. The new job shop flow allows for a component based system to be integrated into the production process, which is crucial in any manufacturing facility, especially Patio Pacific. Because Patio Pacific sells expensive, high quality products, production volume should not be their only focus. There are a wide variety of products that need to be produced, and estimating this is difficult. In addition to this, many of their distributors, such as amazon and home depot, will place large orders for various products that require a lead time of two days or less. The current batch production process used requires a build of six products to be constructed at once, even if only one product has been ordered, which takes three hours to make from start to finish. Using the job shop production method will allow Patio Pacific to have components readily available to be assembled, so if an order is placed for one product, only one will be produced, and will take employees less than thirty minutes to do so. This will not only allow the company to meet these lead times, but overall have more on time deliveries to all their customers and less inventory invested in their finished goods. Lastly is the increased employee capacity in the production facility. With the current process, most of the time spent in production takes place at one of the workbenches. In fact, over half of the production time is spent there. This means that there is no possibility of two employees sharing the same workbench during the course of a shift, making this the bottle neck in the facility. With the new system, employees are less reliable on the workbenches to fulfill the production needs of Patio Pacific. Whereas before only four employees could be effective on the production floor at once (because there are only four workbenches) the new process will allow employees to be stationed throughout the facility. Just based on speculation at this point, if one employee is to produce flaps, one to process metal, and the rest to assemble and package products at the workbenches, that allows six employees to be involved to production at once. When compared to the previous limitation of four employees effective in the workplace, that is a fifty percent increase in production capacity. With these results from the new production process, the company will be able to adapt to their production demand without having to hire or fire employees and instead reallocate them to either a different process in the production cycle, or help on other administrative projects as the company sees fit, in essence utilizing the employees even when production demand is low, which can happen in a seasonal market. This issue was not addressed previously and would result in a long back order list for products in the peak season of the market, causing Patio Pacific to deal with angry customers or even lose their orders due to the long lead time.

Workbench Standardization

Of all the designs and changes that have been approved to be implemented, the redesign to the workbench has been the most challenging to justify numerically. Currently, the prototype workbench was approved and already implemented to the rest of the workbenches in the manufacturing facility. Implementing the process breakdown has allowed for simplification of the workbench design. Through the constant discussion with the lead manufacturers in the facility and extensive knowledge about the production process, the new workbench design has been tailored to hold exactly as much as is needed for the final assembly process and nothing more. This has been executed by following the steps in the 5S methodology: sort, set, shine, standardize and sustain. Following this process resulted in a multitude of changes aimed to streamline the final assembly process. The first is the reduction of parts required at the workbench. Removing unnecessary materials makes the area less overwhelming to the employees. This step was accompanied by labeling all tools and materials that the employees would need to access for the final assembly process. In addition to this, the tools and parts needed in the final assembly process were strategically placed to require the least amount of movement necessary from employees to complete the task. Once the prototype was approved, the other workbenches followed suit, allowing standardization across the facility. The standardization will allow employees to work at any of the workbenches available, while still feeling comfortable and maximizing throughput which is important to a company with many part time employees. To promote sustain in the new design, all bins were labeled and tools outlined as to where exactly they needed to go. This not only allows employees to know exactly what is missing or what they need, but encourages them to keep the workbench in accordance with the standard.

As of now, the changes to the workbench design have been very successful. That being said, one obstacle has challenged the current design. The workbench was designed around the new weatherstripping. The weatherstripping was previously ordered as individual parts but excessive scrap encouraged Patio Pacific to order the raw material in a large roll. As shown in Appendix A, the new weatherstripping roll was to be mounted on the left side of the workbench and drawn from as needed. No problems were expected from this as it is the same way in which the thermo panel glaze is drawn, as shown on the right side of the workbench as it is also on a roll.

Unfortunately, the employees have reported it difficult to draw the weatherstripping from the wheel because it gets tangled and knotted together. One idea to solve this problem has been to construct or order a housing for the material to regulate how the weatherstripping is dispensed from the wheel but no research has been done to determine if this is a viable choice.

5.0 Conclusion

The problem Patio Pacific faced was that any of their products did not meet the company's quality standards which stemmed from the need for skilled labor in their manufacturing process. Due to this, employees who were not as familiar or comfortable with the manufacturing process tended to have higher scrap rates, slower processing times and would produce lower quality products. Consequently, the objectives of this project were to implement a system that would ultimately:

- Improve product quality
- Standardize procedures and processes
- Decrease scrap rate
- Increase manufacturing throughput
- Reduce the company back order list
- Simplify the manufacturing process

In order to accomplish this goal, the current production process was measured, recorded, analyzed, and performed multiple times until the specific tasks that required skilled labor to execute were identified. Once these steps were highlighted, solutions to the reduce the skilled labor needed were deigned and tested. The goal of these tests was find a new process or system design that would make it just as easy for a new employee at Patio Pacific to build a quality product as an experienced manufacturer, effectively reducing the learning curve. The most influential results that came from this project were:

- Outsourcing vert processing is cheaper than in-house processing
- Component based manufacturing increases throughput by 50%
- Job Shop manufacturing and facility layout reduces distance travelled by 39.59%
- Job Shop manufacturing and facility layout increases facility capacity by 50%
- Breaking down the production process can make a new employee effective almost immediately

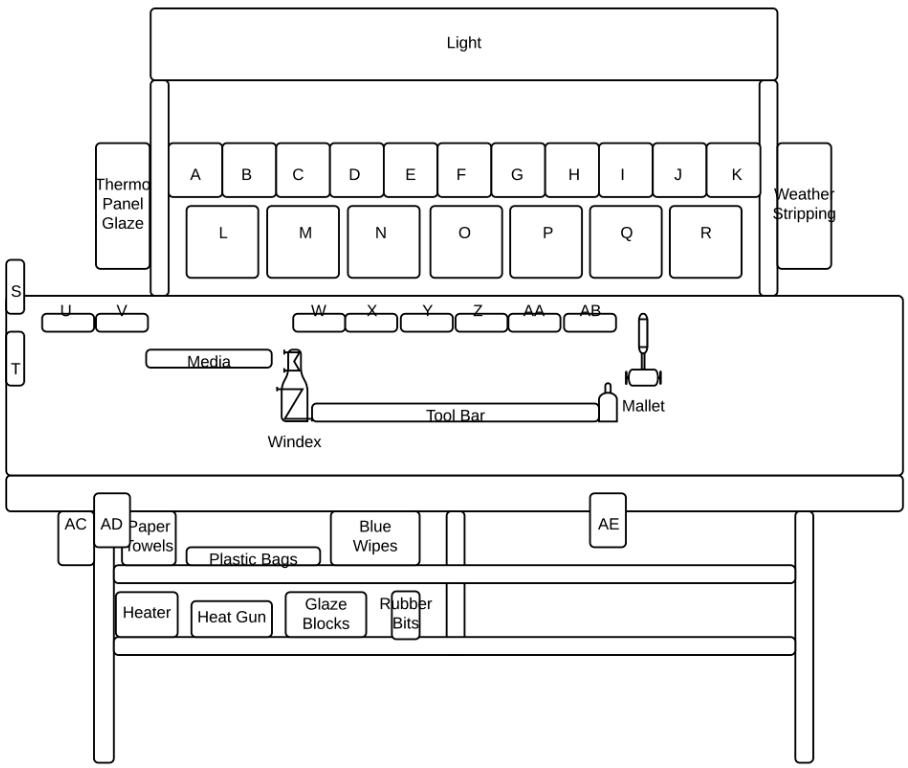
As stated previously, many tests and designs did not yet have quantifiable results to justify their worth to Patio Pacific. To make sure these changes were valuable to the company they were backed through standard industrial engineering practices and experience in the production process. Any process standardization was encouraged by pet Patio Pacific and process changes aimed to increase product quality were justified by the mitigation of risk to Patio Pacific. All objectives listed above were confirmed to be accomplished through statistical and economic analysis or discussion with employees working at Patio Pacific. Procedure standardization and process simplification was accomplished with the new workbench design, improved quality and decreased scrap rate were accomplished by outsourcing vert processing, and throughput was increase with the new job shop manufacturing facility design, effectively reducing the company back order list.

This project has shed light on how important it is to encourage change in the manufacturing facility and the company culture simultaneously. Having a company culture that is opposed to change, whether it be in the administration or on the manufacturing floor, will stunt a company's progression. It is crucial that everyone in the company is open and able to accept and adapt to changes that are for the good of the company. If anyone is unable or not willing to do so, they will not only be an obstacle to the implementation of the change, but may even be costly to the company. Moving forward, there will be a stronger focused placed on encouraging change in the company by getting everyone that will be effected by it involved in the design process. Getting them involved early on will not only give insight from another perspective, but also help mitigate any concerns, and make them more comfortable with the changes.

As for the future of Patio Pacific, the company should look to complete the task of outsourcing their vert processing by expanding it to all SKUs. In addition to this, Patio Pacific should look into ways to integrate the thermo panel production process into the new, or a similar, job shop manufacturing process. In addition to those recommendations, pet Patio Pacific should also place a larger focus on gathering data about their manufacturing facility, specifically employee throughput by product to highlight any possible issues. Based on the new manufacturing process, it is recommended Patio Pacific update their training process to utilize the new process breakdown and reduce their learning curve. Lastly, and possibly the most important, Patio Pacific should develop a way to measure product quality and implement a quality standard based on the decided metrics. Generating a way to measure quality and making it known to the manufacturers will ensure a reduction product quality variation. If Patio Pacific feels it is necessary, the company could require that any employee performing the task of final assembly (the process where all final inspections take place) must be "certified/approved" by lead manufacturers or administration. This approval would be based on the employees familiarity with the quality expectations of the company and ability to reject products or components that do not meet the standard and produce product that do.

APPENDIX A

Workbench Design



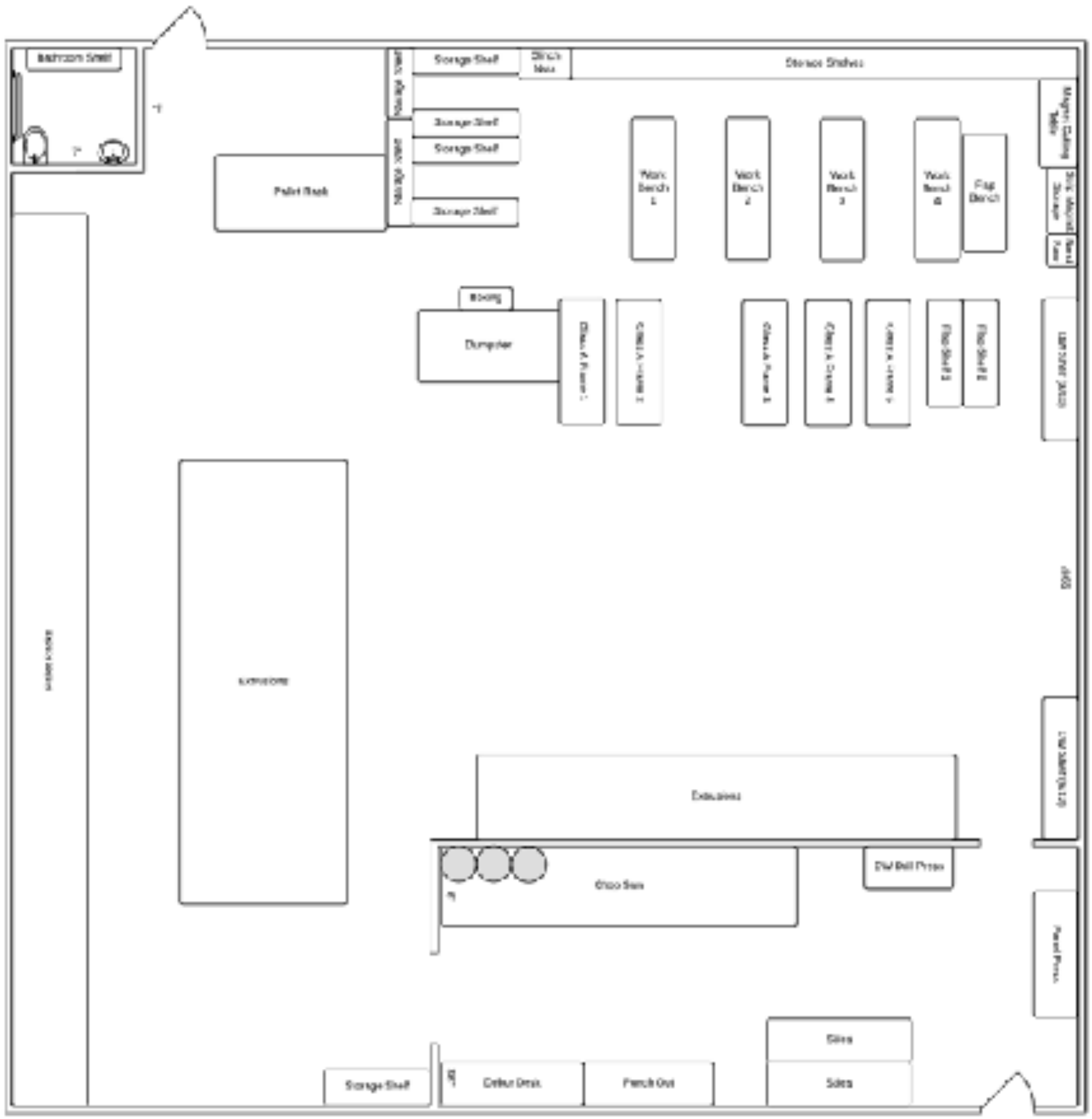
Bins:
A: Black Trim Frame Corners (Left, Right)
B: Black Flap Frame Corner: Top Left
C: Black Flap Frame Corner: Bottom Left
D: Black Flap Frame Corner: Bottom Right
E: Black Flap Frame Corner: Top Right
F: Rubber Bits
G: Tan Flap Frame Corner: Top Left
H: Tan Flap Frame Corner: Bottom Left
I: Tan Flap Frame Corner: Bottom Right
J: Tan Flap Frame Corner: Top Right
K: Tan Trim Frame Corners (Left, Right)
L: White Trim Frame Corners (Left, Right)
M: White Flap Frame Corner: Top Left
N: White Flap Frame Corner: Bottom Left
O: White Flap Frame Corner: Bottom Right
P: White Flap Frame Corner: Top Right
Q: Pivot Washers, Flap Frame Panel Corners
R: 1.5 Connectors, 2.0 Connectors

S: Clamp
T: Topper Screwdriver
U: Topper Screw, Topper Washer
V: Nylon Washer, Nylon Screw
W: Panel Screw
X: Plastic Bushing
Y: Flap Frame Screw
Z: Middle Panel Screw
AA: Sectional Screws and Screwdriver, Retainer Rings and Tool
AB: Sash Guide
AC: Small Deburr
AD: Large Deburr
AE: Drill

Tool Bar:
1. Manual Deburr
2. File
3. Whiteout
4. Glaze Stick
5. Cover Strip Stick
6. Scissors
7. Sharpie
8. Needle Nose Pliers
9. Wire Cutter
10. Pen
11. Strike Magnet Pusher
12. Allen Wrench
13. Glass Razor Blades
14. Windex
15. Lacquer Thinner

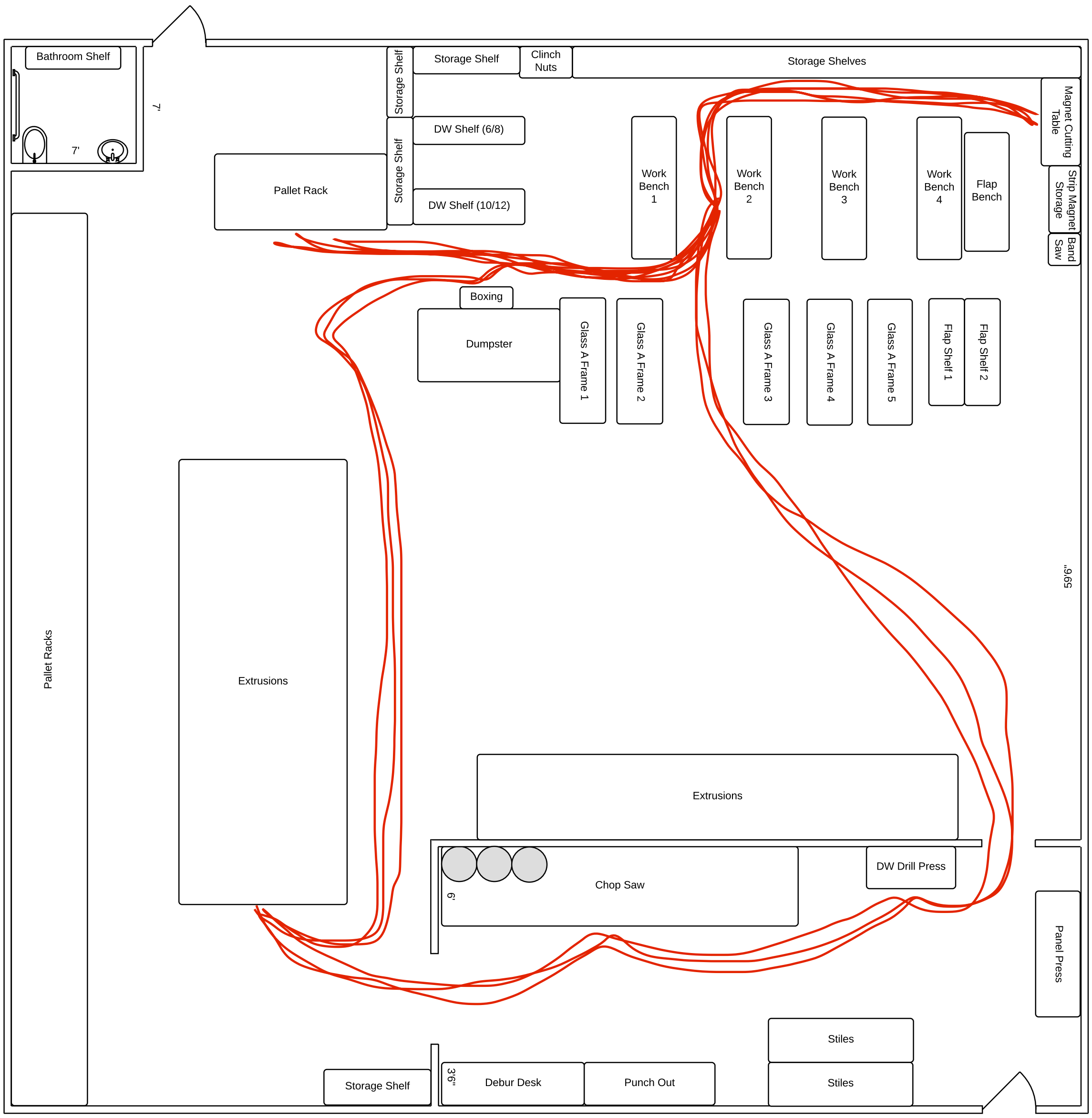
APPENDIX B

Proposed Facility Design



APPENDIX C

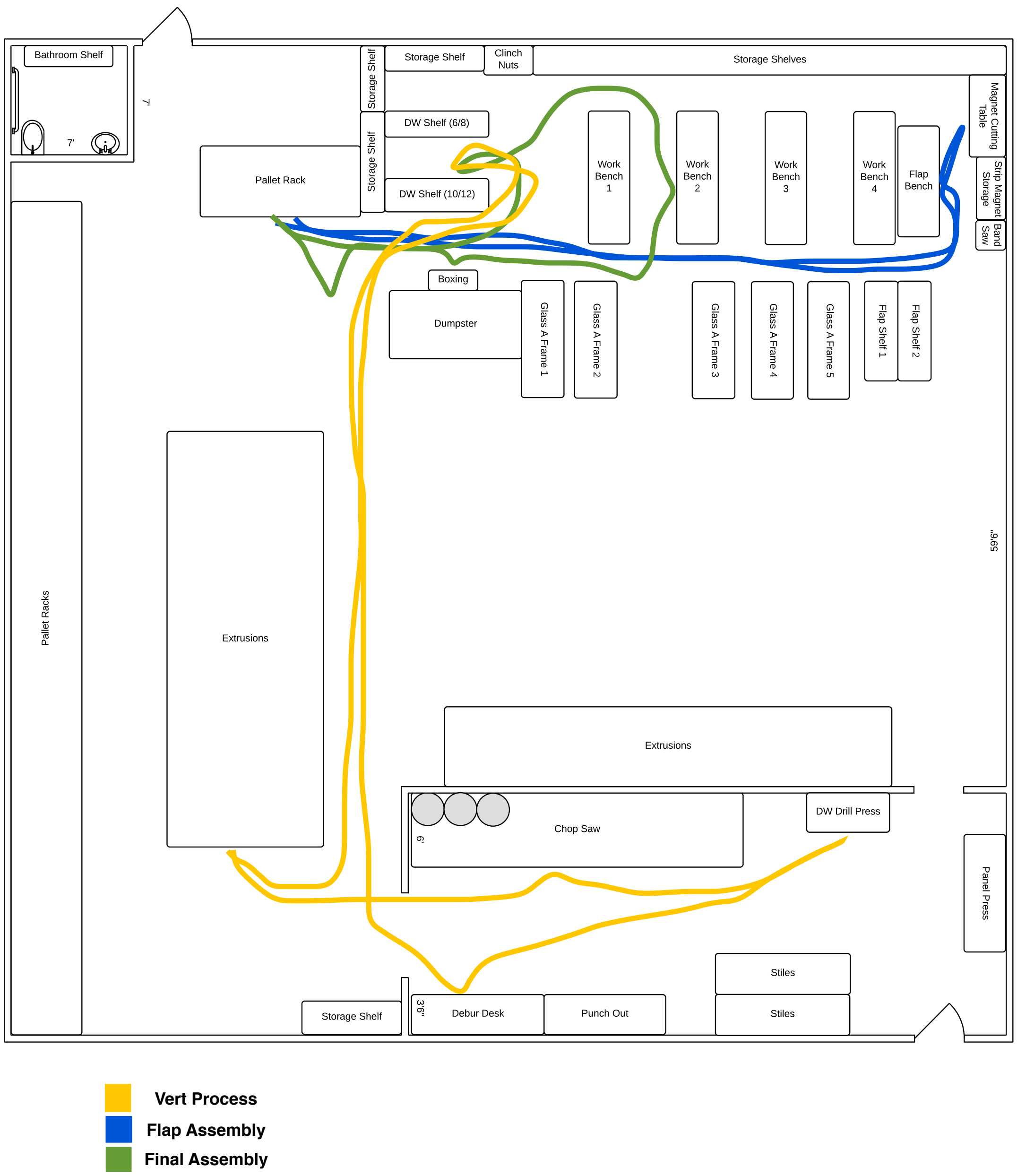
Current Facility Design Spaghetti Chart



Current Process

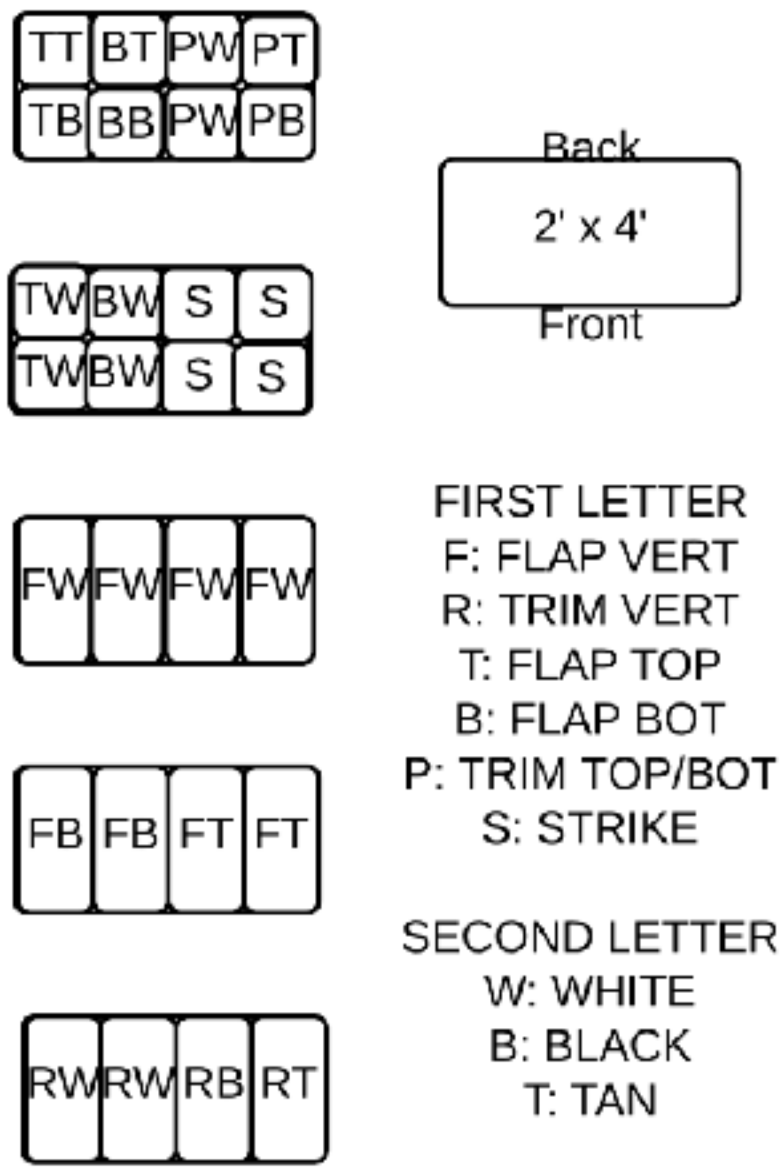
APPENDIX D

Proposed Facility Design Spaghetti Chart



APPENDIX E

Materials Handling Shelving Design



APPENDIX F

Vert Processing Relationship Diagram

Relationship Diagram						
To/From	Metal Extrusions	Chop Saw	Drill Press	Tape Dispenser	Storage Area	Deburr Station
Metal Extrusions						
Chop Saw	I					
Drill Press	O	I				
Tape Dispenser	U	E	A			
Storage Area	U	E	E	O		
Deburr Station	U	U	I	E	I	

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