AIS MQP

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Authors:

Kaitlyn Byrum, Industrial Engineering
Benjamin Chaves, Industrial Engineering
Haley Gilbert, Industrial Engineering
Raman Kaushik, Industrial Engineering
Matthew Wofford, Management Engineering

Advisors:

Professor Walter Towner Ph.D.

Sponsors:

Affordable Interior Systems, Inc.

Authorship & Acknowledgements

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Abstract

In pursuit of enhancing the efficiency of CNC router tooling processes at Affordable Interior Systems (AIS), our project focused on three key objectives. First, we dove into a comprehensive investigation and modeled the CNC tooling process to identify potential areas for improvement. By employing a value stream analysis, axiomatic breakdown, and root cause analysis we facilitated a complete understanding of the existing challenges. Additionally we identified opportunities for the implementation of lean processes through simulation modeling in ARENA as well as talking with operators and stakeholders. Next, we began to evaluate and determine where lean processes could be optimally integrated. This involved conducting time studies of the router process and extensive interviews with operators and stakeholders to identify the most impactful areas for improvement. Based on our findings we provided AIS with recommendations for preventative maintenance techniques, as well as ways to improve and develop standardized tooling training and education.

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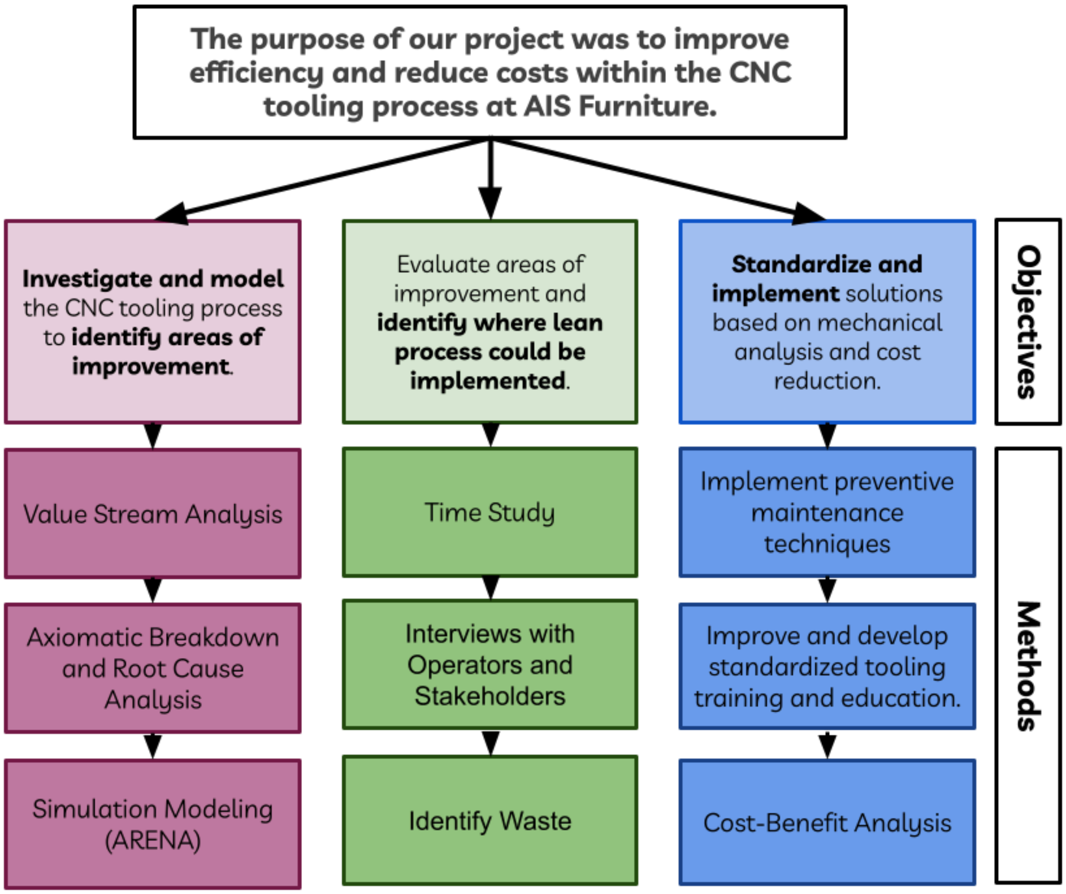
Introduction

In the ever-evolving landscape of manufacturing, one factor remains constant, the pursuit of efficiency. Our research has shown that improving operational efficiency in manufacturing can reduce costs by 4-7% annually and increase global GDP by trillions. It is clear that embracing efficiency is no longer a choice but a necessity (Link Source).

Therefore, the purpose of our project was to improve operational efficiency and reduce costs within the CNC tooling process at AIS Furniture. To accomplish this our team developed and executed three objectives. First, we investigated and modeled the CNC tooling process to identify areas of improvement. To accomplish this we used a value stream analysis, conducted an axiomatic breakdown and root cause analysis. Then, we evaluated areas of improvement and identified where lean processes could be implemented. We identified where lean processes could best fit using Simulation Modeling in ARENA, conducting a time study and interviewing operators and stakeholders. Lastly, we standardized and implemented solutions based on a mechanical analysis and cost reduction. A summary of our objectives and the methods we completed them by using can be seen in the following figure.



Background

AIS Furniture

About AIS Furniture

Affordable Interior Systems (AIS) is a prominent furniture manufacturer headquartered in Leominster, Massachusetts, specializing in customized office furniture solutions. Their emphasis lies in employing lean manufacturing techniques and a made-to-order system, ensuring efficient production and tailored solutions for each client. With an expansive catalog boasting over 50,000 unique furniture pieces, including panel systems, desks, tables, storage units, seating, dividers, and worktool accessories, AIS offers comprehensive options for modern workspaces. With a workforce of over 800 employees nationwide, AIS is dedicated to upholding its corporate values, achieving excellence in product design, and recognizing employee achievements. With annual sales exceeding $220 million, AIS is certainly a leader in the office manufacturing industry. They maintain their position by using cutting edge technologies not only on the manufacturing floor but on their design teams being awarded the NeoCon Silver Award and an Innovation Award for their designs of PET Wire Managers and Enclosures. Embracing diversity, AIS values employees from various backgrounds, including a significant representation of Hispanic or Latino heritage, and ensures inclusivity for those with limited English proficiency. As the company continues to grow, AIS remains committed to maintaining integrity in all aspects of its business operations, with a focus on efficient manufacturing practices, competitive pricing, and aesthetic furniture.

Work Surfaces & Materials

(Reference 1.) AIS purchases high volumes of particle board for manufacturing “work surfaces” (tabletops and desks). Particle board (Not to be confused with plywood) is made by fusing wood particles with resin in 3 layers.The outer layers are made from smaller wood particles and the center layer is made from larger wood particles. This results in a sheet with hard, dense “surfaces” and a lighter, porous “core” as seen in figure X. (Citation would go here)

(Reference 2.) To turn a plywood board into a durable, usable, and visually appealing work surface, decorative paper is adhered to the surfaces. TFL (Thermally Fused Laminate) is made when paper is saturated in resin and heat pressed onto the plywood. HPL (High Pressure Laminate) is a more expensive and durable material made by adhering multiple layers of resin saturated paper to the particle board under high pressure. The most common material cut for work surfaces is TFL followed by HPL.

The structure of TFL and HPL gives them unique properties that impact how it is cut with a cnc router. The resin saturated paper layers are far tougher than the wood, causing uneven wear on the top and bottom of the tool. Poorly manufactured plywood can have large clumps of hard resin in the core that causes additional wear to the router bit and sometimes causes the bit to fail dramatically. Since HPL is stronger than TFL, it is causes more wear to the router bit

Furniture is constructed from cut pieces of particle board. Each material is cut into shape using CNC Routers. AIS currently houses 9 routers.

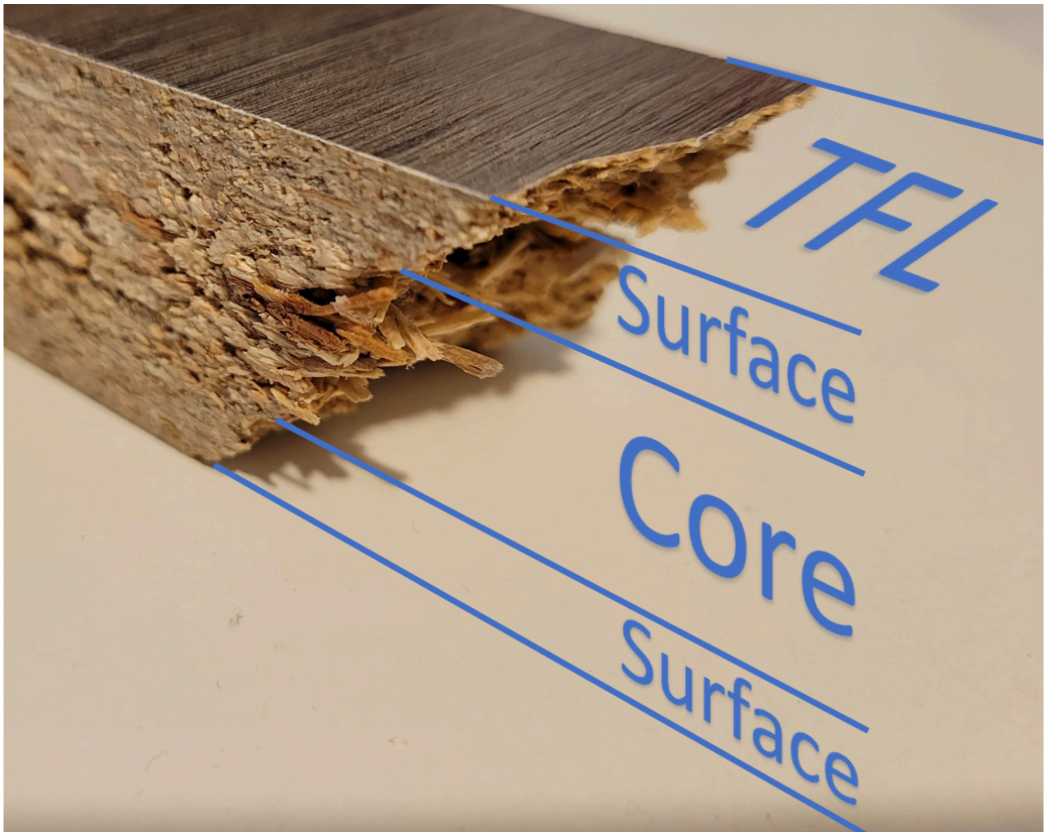


Figure X: Anatomy of a Particle Board

Note. TFL (Thermally Fused Laminate) consists of multiple layers. The surface layers are made of small, densely packed wood particles. The core is made of larger wood particles. Paper is adhered to the surface to give the board hard, decorative faces.

Lean Manufacturing

AIS is committed to implementing lean practices throughout their operations to maximize value for their customers while minimizing waste and improving operational efficiency. Lean practices were initially developed by Kiichiro Toyoda in the 1950s in the automotive industry and have since been implemented in various fields such as healthcare, software development, retail, defense, government operations and services. Lean practices are founded on five key principles, value, value stream, flow, pull and perfection.

AIS adheres to the 5 principles of lean in their production system. AIS creates value for their customers by providing high quality, customizable, low lead time office furnishings. They map the entire value stream for a product or service and understand each step's contribution to value. They minimize delays and interruptions to ensure a continuous flow of work. AIS operates on a customer pull system, orders are custom cut to customer specifications soon after an order is placed. Finally, AIS strives for perfection through continuous improvement and fostering a culture of learning and adaptability.

There are some key concepts within lean that encompass the five key principles such as waste reduction, Kaizen, 5S Methodology, Just-in-Time (JIT) and Visual Management. Waste reduction focuses on identifying and eliminating sources of waste and inefficiency such as overproduction, waiting times, transportation issues, excess inventory, overprocessing and defect. Kaizen is a Japanese term meaning continuous improvement that focuses on small continuous change over time, the involvement of all employees, standardization and quality enhancement. 5S stands for five S's Sort (as in organization), Set in order, Shine (as in to keep clean), Standardize and Sustain procedures and improvements. Just-in-Time refers to producing and delivering services and goods just in time to meet customer demand and minimize inventory and carrying costs. Lastly, Visual Management refers to the use of visual cues, charts and displays to make information easily accessible and understandable, while enhancing communication and transparency in the workplace.

AIS furniture utilizes a few of these concepts deep into their business model such as, continuous improvement, waste reduction, value stream mapping and Key Performance Indicators (KPIs). They foster a culture of continuous improvement where they encourage employees in all business areas to identify areas and opportunities for improvement. They also recognize that employee involvement and skill development are crucial for continuous improvement so they invest in employee training programs and improvement initiatives to enhance the skills, knowledge and problem solving capabilities of their employees. AIS also strategically identifies and eliminates waste such as overproduction, inventory, motion, waiting time and defects. They do this by producing furniture based on real customer demand, implementing just-in-time inventory management, optimizing facility layouts, streamlining processes and emphasizing quality control. The company also utilizes value stream mapping to optimize its process to help identify bottlenecks, non-value added time and areas for improvement. Lastly, AIS utilizes KPIs to monitor and measure the effectiveness of its processes by measuring metrics such as cycle time, on time delivery, defect rates and customer satisfaction.

The company's use of lean practices demonstrates its commitment to operational excellence, waste reduction and continuous improvement. Their practices allow them to enhance productivity, optimize processes and deliver high quality furniture in the most efficient customer centralized manner.

Value Stream Mapping

Value Stream Mapping is a diagramming tool utilized to understand the necessary components and information to bring a product from its initial stage of being ordered by the customer to when the delivery is completed. In creating a value stream map, the organization can have a better idea of identifying all the necessary employees, resources, inventory and processes needed to produce a product. Subsequently, lean manufacturing principles such as continuous improvement and waste elimination can be identified and efficiently implemented by using value stream mapping.

Axiomatic Design

Axiomatic design is a structured and systematic methodology that serves as a decomposition for complex systems into smaller and more manageable components based on axioms, or fundamental principles. The goal of axiomatic design is to analyze and optimize the design of industrial systems. This methodology lists Functional Requirements (FR) and Design Parameters (DP). Each Functional Requirement is an objective, and each Design Parameter is directly related to its corresponding Functional Requirement, and serves to achieve the objective. Within the structure, there are levels of FRs and DPs that are intended to help break down each larger statement with smaller ones. In the AIS model, axiomatic design was used to analyze the manufacturing process of the CNC routers.

Simulation Modeling (ARENA)

Rockwell Arena Simulation Modelling software is a leading simulation technology for manufacturing and business operations.It is useful in analyzing the efficiency and productivity of an operation’s workflow. With Arena, it is possible to model a precise replication of a manufacturing plant with distinct specifications a process might have such as the number of employees, resources, cycle time etc. Consequently, this model can run through distinct simulations to find possible bottlenecks and subsequently alternatives to the process for more efficiency.

There are a range of modules available for modeling the process and workflow of a certain operation. Some fundamental ones which will be used in the AIS model are:

- Create - This module is used to identify the beginning of the workflow. It includes vital information such as the specific products going through the operation and how often an order for this product is placed.
- Process - A process module will be created for every process involved in the manufacturing plant. Vital information like the number of employees working at a process and process delay information can be added to this module.
- Decide - This module serves as a decision step, where the results of a certain process can be accepted or, for example, due to quality issues be rejected and reworked.

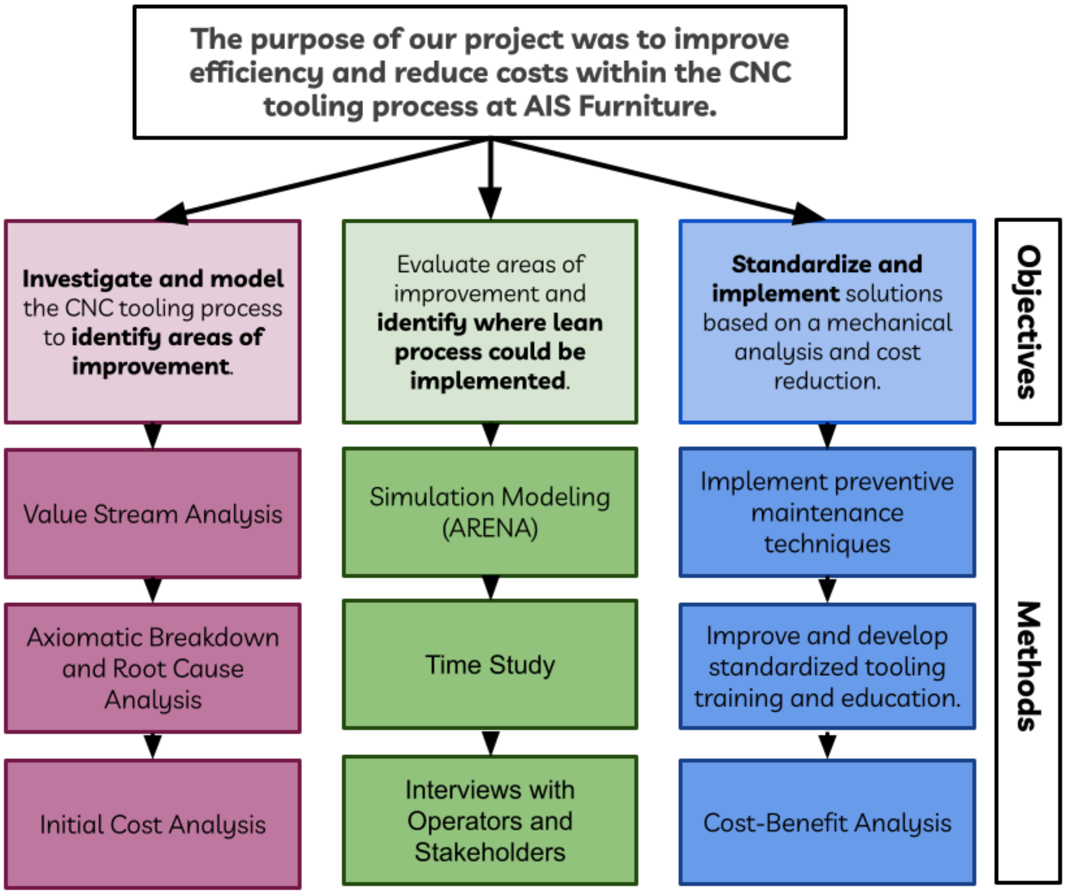
By utilizing these modules and ultimately other features of Arena, we will be able to create an accurate representation of the AIS manufacturing operation and identify bottlenecks or alternatives to the current process.

Standard Work and Training

Standard work presents many benefits in manufacturing, including improvements in quality, decreased defects, predictable and measurable results, and general streamlining of processes. In the context of a manufacturing facility and more specifically for AIS, standard work refers to the set of procedures and practices that guide a worker when completing a task, ensuring a streamlined and efficient process. By maintaining a constant set of procedures through the implementation of standard work, there is reduced variation and a decrease in defects. From the beginning of the process when receiving materials throughout the end of the process when orders are shipped, adhering to standardized procedures allows optimization of workers' skills and a high degree of accuracy. Consistency within a manufacturing facility not only enhances product quality, but it facilitates continuous improvement by allowing the facility to easily pinpoint inefficiencies and areas for improvement.

Methodology & Results

The purpose of our project was to improve the efficiency and reduce costs within the CNC tooling process at AIS Furniture. This section of our report explains the methods and tools we used to evaluate our objectives and report our results.



Before being able to collect data at the AIS Manufacturing facility our team had to participate in a safety training with AIS's safety manager. Which included an explanation of what to do in the event of an emergency, safety protocols of machines used on the production floor, and other general safety information. The data we collected onsite was through interviews with personnel and observing the process. Interviewed personnel were given release forms so that they understood that the information they were giving us was going to be published and that they were being recorded. When observing any given process a video was recorded along with a group member recording information by hand.

Investigating and Modeling

Gantt Chart

The objective of a Gantt chart is to visualize the timeline and schedule of a given project. By utilizing this visual tool, our group is able to systemize the tasks we need to complete in the twenty-one week time constraint. Additionally, we are able to provide an organized and illustrative view of our progress to stakeholders in the project such as our advisors and sponsors.

As seen in Figure A, the Gantt chart is categorized by the three terms we have to complete our project: A, B and C. Term A was primarily utilized to understand the different processes in AIS's manufacturing plant and then more specifically into the routing process. By observing the process consistently throughout the first two weeks of the term, we were able to brainstorm different visual and lean manufacturing tools that we could use to identify inefficiencies and wastes in the routing process. Ultimately, we decided to utilize tools such as: Axiomatic Design, ARENA simulation modeling software, Value Stream maps, Time Studies and etc. to identify and implement changes to make the routing process more efficient.

In Term B, we had a clear understanding of the routing process and had started implementing our different tools. We created an Arena model and Value Stream map to establish the connection different processes in the manufacturing plant such as Kitting and Edgebanding had to the Routing process. Additionally by utilizing axiomatic design, we were able to establish an efficient system to maximize the value-added time and minimize costs associated with the routing process. Furthermore, we made use of time studies to find distinct inefficiencies and lean wastes in the routing process. Combining these tools, we were able to identify areas of improvement and present our findings to the AIS team. This allowed us to get valuable feedback on our progress and make relevant changes.

In the initial weeks of C term, our focus was to use the feedback given by our advisor and the AIS team and improve our methodology to complete our project. When we were able to modify our data and findings we could ultimately use cost-benefit analysis to quantitatively determine if our implementations and recommendations were financially viable and optimal for AIS. Ultimately, we presented our findings from lean manufacturing tools and cost-benefit analysis to the AIS team.

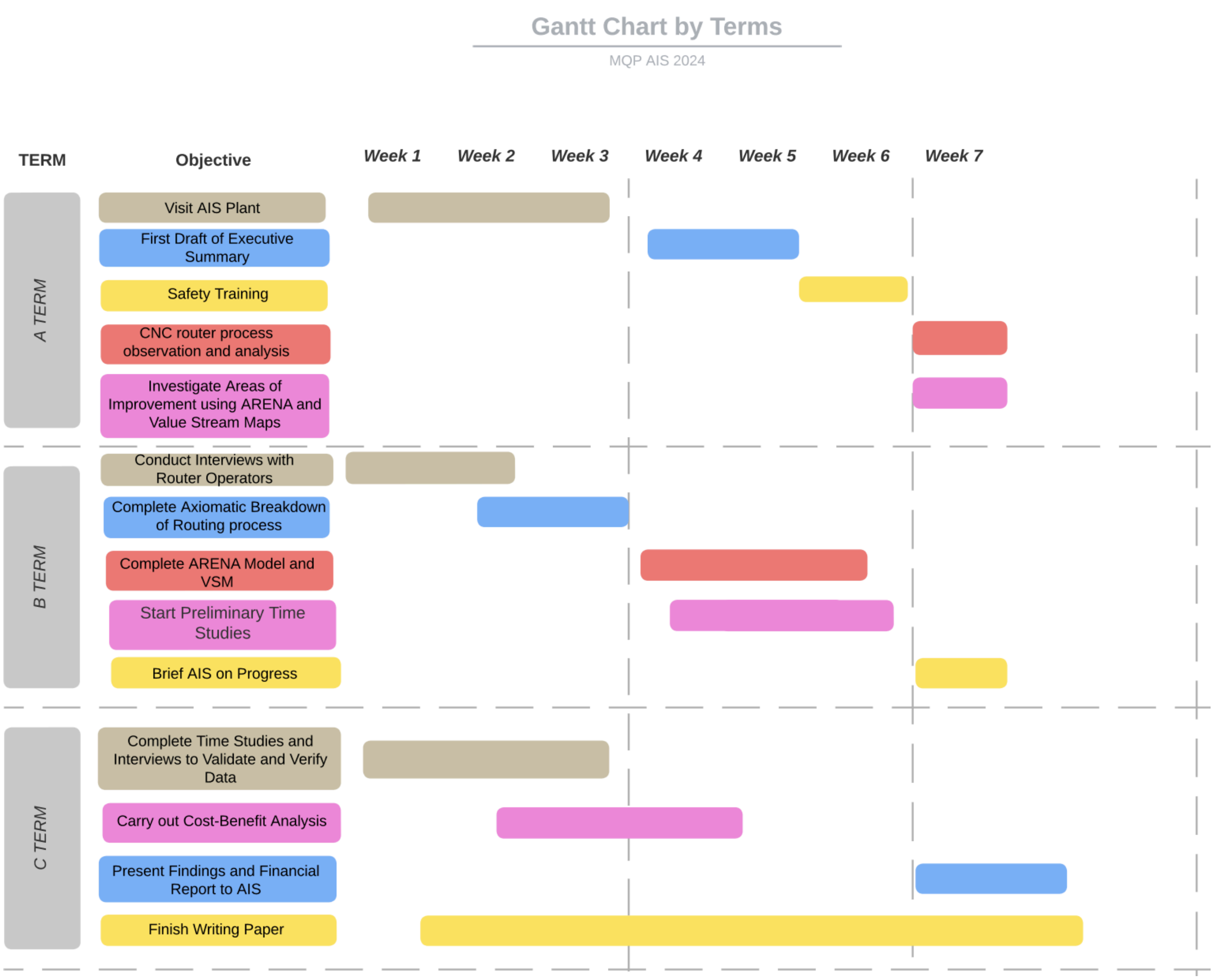


Figure X: Team Gantt Chart

Modeling The Entire Process

To properly model the work surface manufacturing process our group was tasked with investigating the overall operation as well as the upstream and downstream processes.

When investigating the upstream process we began looking into inventory and kitting. The kitting process has an important role in the operation and efficiency of the routing process and subsequently the succeeding process, edge banding. The kitting process is an essential step in a manufacturing plant as it involves the gathering and delivering of necessary components required for assembling a product. In the case of AIS, the kitting operators are responsible for selecting the most suitable router for a packet, a certain stack of wood boards, to be transported to. Logically, the manufacturing support team maintains and adheres to a set of criteria which determines the order and timing of packet boarding the routers.

The manufacturing support team utilizes a customized algorithm to create packets, strategically determining which wood pieces need to be prioritized. This algorithm takes into account various constraints, such as delivery date, and physical attributes such as type of wood surface and color etc. Subsequently, this algorithm can organize these wood pieces into pallets, which can then be transported to the routing process.

The group leads in the kitting operation act as intermediaries between the manufacturing support and the forklifts. They decide the precise order and timing for dispatching pallets to the routers and accordingly communicate this information to the forklift operators. Furthermore, group leads utilize decision-making in how they select the appropriate router for each pallet. The most prevalent determinant in this decision-making process is the number of pallets stationed at a given router. For example, a router running low on pallets takes precedence in receiving new ones. The optimization of this system helps keep a steady and standardized operation.

Other factors such as unique capabilities of each router also contribute to the router selection process. For example, Router 9's specific capabilities make it an ideal choice for boards designated for desking customizations. In contrast, Router 4 may not be the optimal choice for processes involving drilling or cutting knife-edge wood surfaces. Subsequently, team leads might prioritize Router 9 for desking operations, while directing all routers except Router 4 for tasks involving drilling and knife-edge boards.

In summary, the kitting process is an essential step in the AIS manufacturing plant, specifically for the routing process as it is responsible for maintaining an efficient and smooth workflow of designating packets to routers. By utilizing this customized algorithm, criteria and decision-making, kitting ensures an optimal utilization of resources and equipment within the manufacturing plant.

For the downstream process our group investigated the edgebander and contour processes. All of the cut parts with square edges get sent to edge banding and all of the parts with curved edges get sent to contour. The edge banding process by nature is more efficient, due to the manual steps required in the contour process. An edge bander is a machine commonly used in the woodworking industry to apply a thin strip of material, called edge banding, to the exposed edges of panels or boards. This process enhances the appearance and durability of the furniture by covering the raw edges. The edge banders consist of a roller system that transports the panels through the machine, a glue application system, the actual application of the edge banding material and a trimming unit to trim the excess banding material. The contour process involved a few more steps: edge preparation, measuring and cutting, applying adhesive, placing and trimming and finishing. Edge preparation ensures the edges of the furniture component are clean, smooth, and free from any dust and debris. Measuring the length

Simulation Modeling (ARENA)

Modeling the AIS manufacturing plant on Arena was helpful in understanding how each distinct process relates to each other in the plant. For example, our focus was on the routing process but with Arena we could see how resources and inventory interacted with the process preceding and succeeding the routing process.

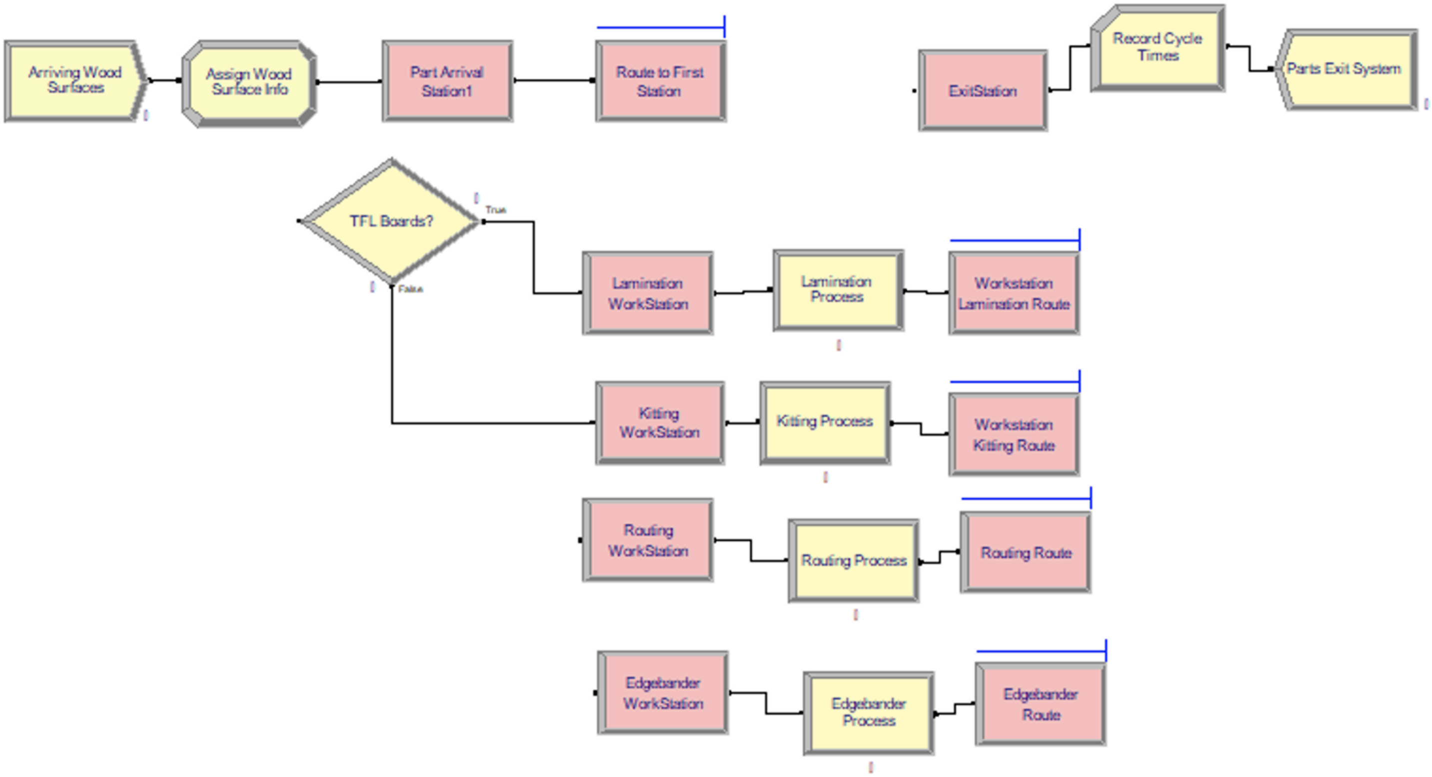


Figure X: AIS Manufacturing Plant Model in Arena

In figure X, the arena model shows each distinct step involved in the plant. After the particle boards arrive at the plant, they are assigned based on the specific type of board they are. This is important as based on the type of board, it might get laminated. For example about 30% of the particle boards are laminated and therefore sent to the lamination process. After this all boards follow a similar sequence as they are sent to kitting.

Utilizing Arena, we can determine the number of resources or employees involved at each step and possible bottlenecks that could occur. However, as each process has an independent inventory, any minimal delays or inefficiencies in the routing process does not have any impacts on the edgebanding process.

Value Stream Mapping

A vital tool in investigating and understanding the complete operation at AIS is using Value-Stream mapping. This visualization allows a structured illustration of every process which exists at the manufacturing plant from when the supplier provides the wood surfaces to when the final product is delivered to the customer.
Value streaming allowed us to identify that AIS utilizes the combined principles of Assembly Line Production, Just In Time and Lean Manufacturing in its production line. This means that a series of operators complete a specific process in a sequential order in order to assemble the product. Furthermore, JIT and Lean Manufacturing are used to reduce lean wastes by producing based on the specific demand time they are needed by. Figure X shows the distinct processes involved in the manufacturing plant.

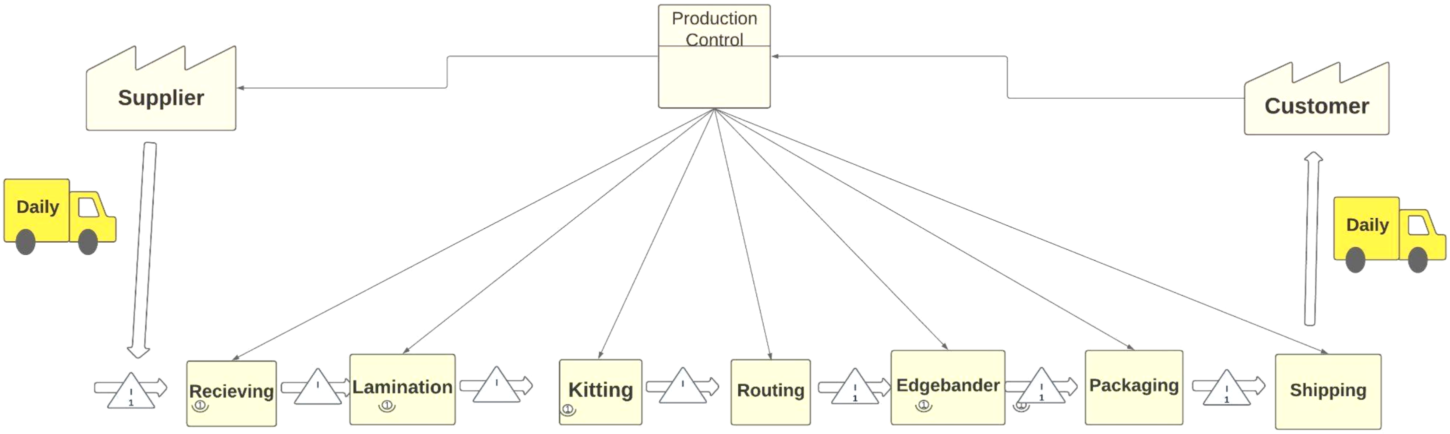


Figure X:Value Stream Map of Entire Process

As the project's focus was primarily on the Routing process, a detailed value stream map of this process was created. Utilizing simple observations and a preliminary time study, we were able to divide the routing process into: pulling stock, the CNC machine cutting, labeling and ultimately pushing stock. Furthermore, we recorded the cycle time of each step and the non-value added time in between each step in order to calculate the total processing time for one wood surface. We then also calculated the takt time based on the available time in a given shift and the average demand on a specific router for that shift. The objective of calculating the processing time and takt time is to compare these values and see how efficient the process could be ideally.

As shown in Figure X, with the routing process having an approximate 345 second takt time and a processing time of 453 seconds, there is a 109 seconds of time waste. Therefore, we are able to summarize there is room for improvement in the process.

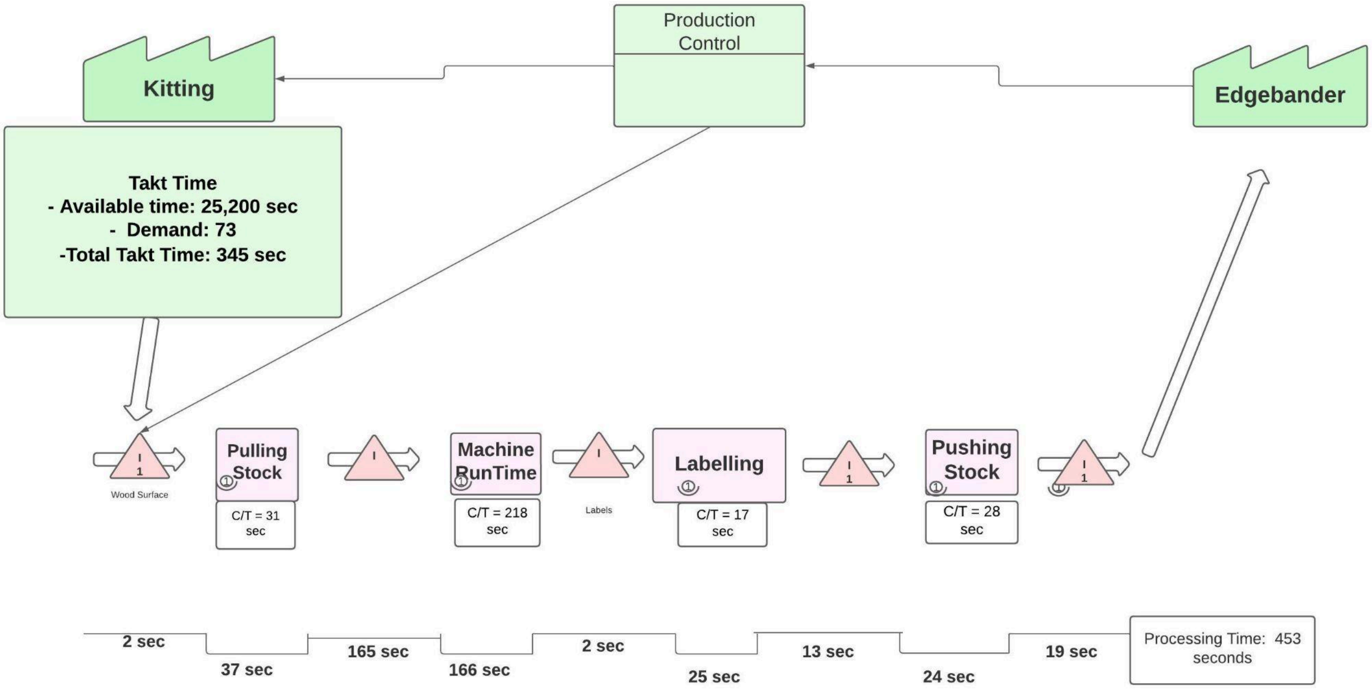
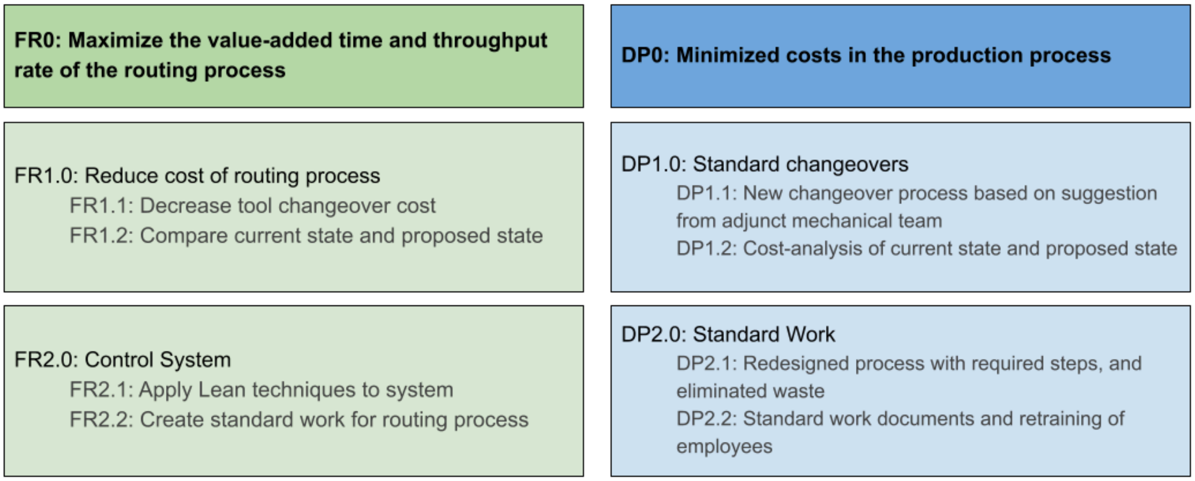


Figure X: Value Stream Map of Routing Process

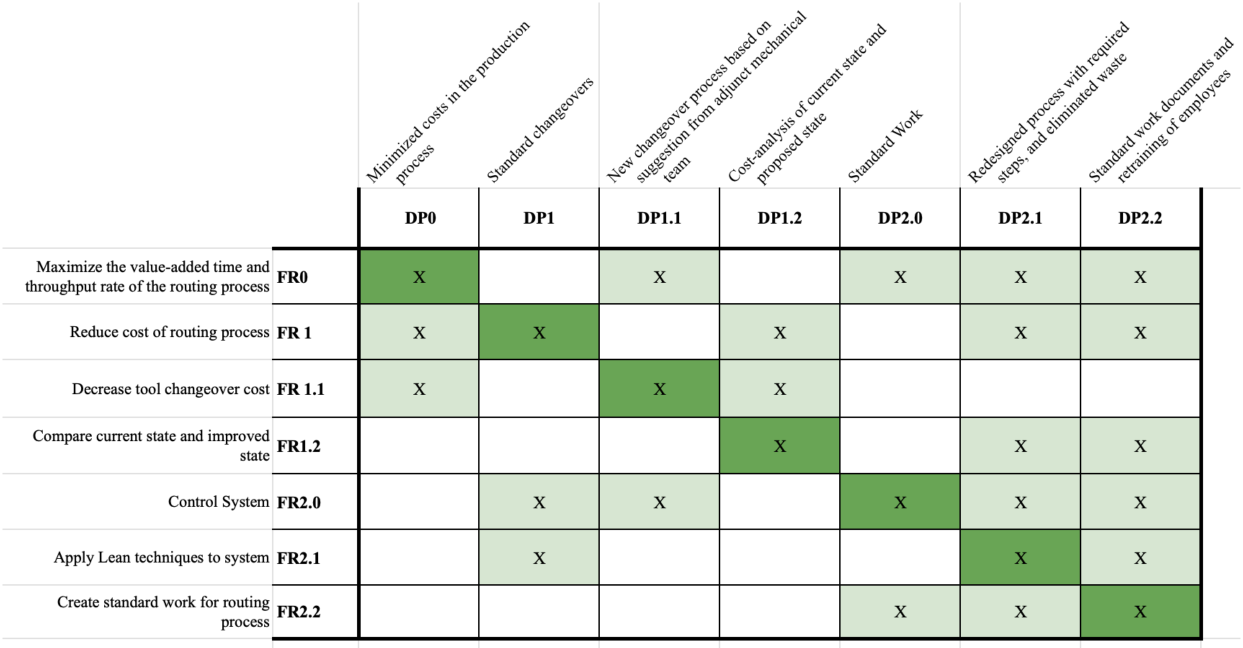
Axiomatic Design



FR0: Maximize the value-added time and throughput rate of the routing process	**DP0: Minimized costs in the production process**
FR1.0: Reduce cost of routing process FR1.1: Decrease tool changeover cost FR1.2: Compare current state and proposed state	DP1.0: Standard changeovers DP1.1: New changeover process based on suggestion from adjunct mechanical team DP1.2: Cost-analysis of current state and proposed state
FR2.0: Control System FR2.1: Apply Lean techniques to system FR2.2: Create standard work for routing process	DP2.0: Standard Work DP2.1: Redesigned process with required steps, and eliminated waste DP2.2: Standard work documents and retraining of employees

Figure X: Functional Requirements and Design Parameters

Our group further developed our goals and project steps using axiomatic design. The main goal of our process was to maximize value-added time and throughput rate of the routing process at AIS furniture, which is attained with minimized costs in the production process. This was broken down into reducing the cost of the routing process and controlling the system, matches to the corresponding parameters, standardized changeovers and standard work. In order to reduce the cost of the routing process, we created the goals of decreasing the tool changeover cost and then comparing the current costs of the routing process at AIS with our proposed state of the process to be completed by the implementation of the new changeover process as modeled based on the suggestion from our adjunct mechanical team, and completion of a cost-analysis of the current state and proposed state. To control the system, we created the goals of applying Lean techniques to the routing process with a redesigned process with required steps, and eliminated waste, and then creating standard work to model our suggestions with standard work documents and retraining of employees.



		Minimized costs in the production process	Standard changeovers	New changeover process based on suggestion from adjunct mechanical team	Cost-analysis of current state and proposed state	Standard Work	Redesigned process with required steps, and eliminated waste	Standard work documents and retraining of employees
		DP0	**DP1**	**DP1.1**	**DP1.2**	**DP2.0**	**DP2.1**	**DP2.2**
Maximize the value-added time and throughput rate of the routing process	**FR0**	X		X		X	X	X
Reduce cost of routing process	**FR 1**	X	X		X		X	X
Decrease tool changeover cost	**FR 1.1**	X		X	X			
Compare current state and improved state	**FR1.2**				X		X	X
Control System	**FR2.0**		X	X		X	X	X
Apply Lean techniques to system	**FR2.1**		X				X	X
Create standard work for routing process	**FR2.2**					X	X	X

Figure X: Axiomatic Design Matrix

While each FR and DP with corresponding numbers or levels were designed to be directly related, there were inevitably connections between other FRs and DPs. Figure X shows the Functional Requirements and Design Parameters that are directly and indirectly related.

Evaluating Areas of Improvement

Time Studies

We conducted two rounds of time studies to comprehensively evaluate the machining of work surfaces. In the initial round, our objective was to list the steps involved in the machining process, distinguishing between value and non-value-added time. The operators and machines were observed to map the process in detail before the time study was conducted. We established predetermined "checkpoints" to objectively pinpoint the beginning and end of each process, ensuring a consistent and accurate recording of time. All recorded time data was documented in a spreadsheet. The time study specifically measured the duration of the following six steps:

1. **Pull Stock:** The start time was recorded when the operator hit a button that signals the turret to pull the uncut particle board onto the router table.
2. **Cut Stock:** The start time was recorded when the stock was secured to the table via vacuum, as indicated by the pressure gauges on the side of the table. At this point the cnc router begins cutting.
3. **Vacuum Dust:** The start time was recorded when the router lowered the vacuum. The turret made a pass over the router table removing sawdust.
4. **Labeling/Idle:** The start time was recorded when the turret returned to the rightmost side of the table. The operator applied a label to the cut particle board and then waited for the next step.
5. **Push Stock:** The start time was recorded when the turret began moving toward the left. The turret slid the cut pieces off the table onto the conveyor belt.
6. **Idle/Blow:** The start time was recorded when the turret returned to the rightmost position. The operator blew the table with a long barreled airgun to remove remaining debris before starting the next cycle.

Only the critical path operations were measured. Certain steps that were performed by the operator while the router was performing operations such as moving the stock and printing labels were not recorded.

#	Step	Average Time (m:ss)	Standard Deviation (ss)	Qualitative Observations
1	Pull Stock	0:35	5	This is an automatic process. It takes longer when the board is placed farther away from the turret.
2	Cut Stock	2:00	40	This is an automatic process. Depending on what is being cut, this could take anywhere from 1 to 15 minutes.
3	Vacuum Dust	0:20	0	This is an automatic process with a fixed time. It triggers as soon as the cutting stops.
4	Labeling/Idle	1:10	35	This step is manual. While the cut boards are on the router table the operator applies a label and the machine waits for the catcher to advance the line.
5	Push Stock	0:30	5	This step is triggered by the catcher pressing a button. That button has problems. Sometimes It takes 15 to 20 seconds to activate.
6	Idle/Blow	0:35	35	Sometimes the operator is assisting the catcher causing high variability.

Figure X: Results from the first time study

For the second round of time studies, we wanted to expand our data set and collect a more holistic view of the routing process. To achieve this, we completed the studies on 3 of the work surfaces routers and during both first and second shift. We wanted to track the full process for each board, from the second it is pulled onto the router, to when it is pulled off of the router. To clearly define the difference between value added and non-value added time, we incorporated idle space between steps. We restructured the steps within the time study:

1. **Pull Stock:** Starts when the operator pulls a board from the stack, and ends when the board is on the conveyor.
2. **Pull Idle**
3. **Machine Runtime:** Starts when the suction of the router pulls the board, and ends when the router has completed the vacuum process and is stationary.
4. **Machine Idle**

5. **Labeling:** Starts when the operator places a label on the boards and ends when the operator restarts the machine.
6. **Label Idle**
7. **Push:** Starts when the router begins pushing the board down the conveyor.
8. **Push Idle:** Sometimes is zero; only occurs when catcher does not immediately take the pieces off the conveyor.
9. **End:** Defined as the moment when the catcher removes the first piece from the conveyor.

R2	**Cycles**									
Steps:	1	2	3	4	5	6	7	8	9	10
Pulling Stock	40	35	25	29	20	36	27	34	23	98
Idle	199	169	23	192	181	187	171	156	192	181
Machine Run Time	200	78	199	200	155	157	151	156	182	178
Idle						31				10
Labeling	31	21	39	23	15	24	20	19	31	22
Idle	9	40		12	41		93		21	
Push	26	23	24	19	26	29	18	25	22	26
Idle	10	18	34	60	0	16	0	32	0	22
Total Time (sec)	516	386	347	539	443	486	487	430	480	547
Total Time (min)	8.60	6.43	5.78	8.98	7.38	8.10	8.12	7.17	8.00	9.12
Percentage of time Spent Cutting	38.76%	20.21%	57.35%	37.11%	34.99%	32.30%	31.01%	36.28%	37.92%	32.54%

Figure X: Ten cycles for round 2 of time studies

The chart above shows 10 of the completed time study cycles. During both the first and second shift of production, 25 cycles were completed. We found that the average total cycle time for a board was 8.15 minutes. From that, we calculated the average percent cut time as 39.55%. This value represents the percentage of time the router is physically cutting the board, and would then be used by our team for the standardized tooling model and cost-benefit analysis.

Group Interviews & Surveys

Group interviews were held in English and Spanish with all of the first and second shift operators and their supervisors. We began the session with a view questions to help guide the conversation:

- What are some causes that lead to time waste at a router?
- Which cause of time waste is the most frequent?
- Why do these problems occur?
- How do you resolve it? Based on your training/standard work, based, or from experience?

The purpose of this line of questioning was to isolate the most frequent, highest time wasting, easiest to prevent problems that lead to machine downtime. Addressing such problems should be prioritized.

One of the most frequent problems discussed was when defective boards arrive at the router station. If the operator sees scratches or blemishes on the board, or the board is bowed, they will have the forklift driver take it away and grab a new one. The amount of time lost due to this problem depends on the availability of the forklift driver. The root cause of this problem is boards not being rejected at the kitting phase. One potential solution discussed was improving the lighting in the kitting department to make it easier to see defects on the boards. If kitting is able to reject the boards before they get sent to the routers, time will be saved and escape will decrease.

Another big impact to machine time is planning and changing the spoil board. The spoil board serves two purposes. It allows the workpiece to be held in place by suction, and it protects the router table from being machined. Every cut made takes a small amount of material off the spoil board, this is necessary to get a good bottom edge on the workpiece. Eventually these cuts become so deep that it impairs the suction, leading to increased risk of parts disconnecting from the table. To keep the spoil board smooth, it is planed. This process takes around 15 minutes because the router has to pass over the entire area of the board. This is done multiple times a shift at the operators discretion. When the spoil board wears down enough, it must be replaced entirely. This process takes 30 to 45 minutes and is done 2 to 3 times a week per, certain routers needing to be changed more often than others. There are many factors that impact the lifetime of the spoil board. The operators calibrate the z height of the tool to minimize the consumption of the spoil board. Sometimes, when a hole is being drilled, the machine plunges too far and makes a deep hole in the spoilboard. The more experienced operators can manipulate the relative position of the parts on the board to maximize suction since the spoilboard wears unevenly. The solutions discussed involved standardization of when to change the spoilboard and the appropriate z height and continued operator training.

The labeling process was discussed at length. While labeling is necessary, it is currently being done manually while the machine idles. (This does not apply to the routers attached to the automated board picker, those boards are automatically labeled before they are even cut. It is the only cause of machine downtime that happens with every single board, taking anywhere between 10 to 30 seconds, depending on the complexity of the parts. The solution to eliminate this downtime is to have the board labeled while another board is being cut. This solution has been tried in the past however it caused other problems. The operator could label the parts while the board is sitting on the rollers waiting for its turn, however it is difficult to judge where the labels should go before they are cut. This resulted in the machine cutting through labels, ruining the part. At one point there was a projector that would display where to place the labels, but that came with its own set of challenges. The lens would quickly get covered in sawdust and become unusable. It is also difficult to synchronize the multiple independent computer systems, so sometimes part orientations get changed or flipped leading to incorrect labeling (and mirrored parts, however that is a separate issue).

Surveys were created both in English and Spanish, and issued to first and second shift router operators. The goal of the survey was to gain a better understanding of the changeover process the operators follow. The questions asked the operators how they decide to change the router bit, how often they do so, and how long it takes to replace. It was found that the operators were mostly following the same process with little variability; the tool is changed every 2-3 hours, or every 15-30 boards. There were a multitude of responses for the indicators that are used to determine when to change a board, including a change in color of the tool, a different cutting sounds, a rough cut or chips in the board, an odor, or the amount of time that has passed since replacing the tool last.

Standardization and Implementation

Cost Benefit Analysis

The cost benefit analysis of AIS's manufacturing process comes in two parts, first looking at the dollar value of time, and secondly, the costs of replacing the router's bit. We decided to initially focus on the money value of time as it would give us the ability to give a monetary value to the process improvements our team is suggesting in relation to the operators cutting and labeling process. To find the dollar value of time within the router cutting process our team found the costs and the revenue generated by a given machine and compared the two. The costs included, maintenance costs, electricity costs and operators salary, while revenue was harder to quantify for a specified router but was found using the cumulative revenue from the worksurfaces department. Comparing the two gave us our dollar value of time within the routing process TBD.

The next cost benefit analysis portion came from the data collected by the other team working at AIS who found the maximum utilization capacity of routers cutting bits whether new or resharpened. Using a calculator created in excel we were able to predict the number of tool changes needed for a given day on any given router as long as 6 different values were imputed those being, the meters to be cut of TFL or HPL, on a given router with the ability to put a mix of both, and then the expected distribution of new tool bits to resharpened bits on a given router ranging from their new to their 3rd resharpen. With this data inputted we can then give a prediction for the number of tools that will be needed to make those cuts for a given day. This optimized result has then been compared to the large 3 month long data set of every tool change that has happened and gives our group the ability to show that they are changing their tools too often. This system does not offer the ability for AIS to predict exactly when to perform tool changes but can be used to compare the expected results to the actual number of tool changes that are happening within a given day.

Standardized Tooling

In order to standardize the tooling changeovers, we used information collected by our adjunct mechanical team. With the metrics they discovered on the capacity of a new tool and after each resharpen, we were able to map our proposed changeover model to their current changeover model.

Currently, the changeover schedule is unstandardized, and the time between tool changes varies from one to four hours, or is measured by the number of boards cut, ranging from ten to twenty boards. As found in direct interviews and surveys, the time between a tool change is typically 2-3 hours, or is based on the number or boards cut.

Using data records of logged tool changeovers on a single router from July 2023 to October 2023, we calculated the average time between changeovers. For the purpose of representing a holistic view of the current state, values that were outside of a reasonable data range, under 1 hour, or above 6 hours were not included in the calculation. We found the average time between tool changes to be approximately 2 hours and 17 minutes.

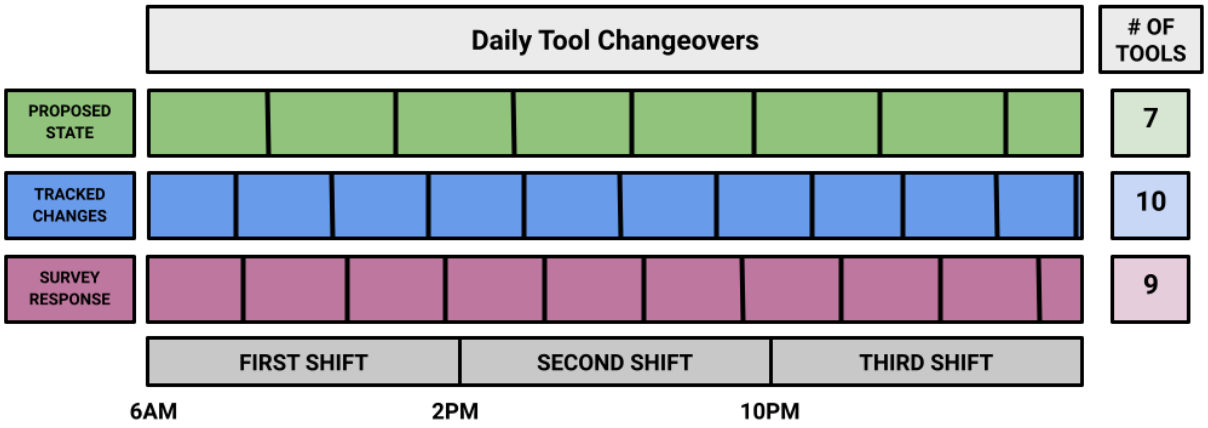


Figure X: Tool Changeover Timeline

To model the current tool changeover process and our suggested standardized tool changeover model, a timeline was constructed, as shown in Figure X. Each of the three states are represented as different colors, and the different tools are shown by the blocks within each color. For the survey response model, we used the average of 2.5 hours, as the responses were almost unanimously “2-3 hours”. The 2 hour 17 minute calculation was used for the tracked changes.

To calculate the time between changeovers for the proposed state, we used metrics provided to us by AIS Furniture for an estimation of the distances cut by the routers coupled with the metrics provided to us by our adjunct mechanical team to calculate the average time a tool can be used before needing to be changed. Since it is known that the tool life decreases with resharpens, it was assumed that the tools modeled in the timeline were new tools, but the average time before a change for the new state was completed for 3 resharpens.

Using the average of 12.7 meters cut per board and the average number of boards cut per day in the work surfaces department as 400, as given to us by AIS Furniture, it was calculated that each of the 4 worksurfaces routers cut approximately 1270 meters per day, and 53 meters per hour. The mechanical analysis done on the tools themselves discovered the following capacities, both in meters, and cut time in hours for a new tool, and 3 resharpens.

	Capacity (m)	Average Cut Time Capacity (hrs)
New Tool	130	2.46
Resharpen 1	100	1.89
Resharpen 2	90	1.70
Resharpen 3	80	1.51

Figure X: Capacities of Tools

To calculate the time between changeovers, we used data found during our time studies. The average percentage of cut time was found to be 40%. Using this, we found the time between changeovers to be approximately 3.45 hours, represented as 3.5 hours in the timeline model.

For each of the models, the number of tools used during a singular 24 hour period was found, and estimated on the timeline. Modeling the survey responses, a singular router would need 9.6 tools during this period, rounded down to 9. For the tracked tool changes, the router would need 10.5 tools, rounded down to 10. For the proposed state, there would be 6.8 tool changes during this period, which was rounded up to 7 for the model.

Following these calculations, there is a 28.6% percent decrease in the number of tools used by a work surface router.

Recommendations & Conclusions

This project has given our team the opportunity to take all of the skills learned throughout our industrial engineering courses and apply them in a real world setting giving us an unforgettable educational experience. Working at AIS Furniture exposed us to a professional working environment, where you must meet deadlines, manage conflict and practice clear and concise communication. The ability to adapt to changing circumstances and unforeseen challenges is also a key aspect of professionalism. Along the way we realized that every member of our team has very different backgrounds and expertise and learning to understand and listen to each other is crucial to working well together. This experience taught us how to adapt, be flexible, and solve problems together. Our diverse skills and backgrounds weren't a challenge; they were the key to our success.

In addition to our findings and suggested implementations, there is still more work we did not have the time to help improve the operational efficiency of the work surfaces manufacturing process. Below is a list of these recommendations:

- Investigate the root cause for material defects in the HPL and TFL boards or conduct an inspection before the boards are brought to the routers. As a result of our group interviews with all of the operators we concluded that defective material is a big time waste for the CNC routers.
- Bring back the visuals on the labels as a guide for the operators.
- Implement the feature of distance cut that is installed on router 2 on the other routers as a way to track the distance before a tool changeover for more accurate readings.

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Appendices