Tool Change Process Improvement at AIS

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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

Advisor:
Professor Walter Towner Ph.D.

Sponsor:
Affordable Interior Systems, Inc.

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Authorship & Acknowledgements

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Abstract

The objective of this project was to improve the efficiency and subsequently reduce the costs of the CNC routing process at Affordable Interior Systems (AIS). To achieve this objective, we first investigated and modeled the routing process to identify areas of improvements. This entailed value stream mapping and creating a simulation of the process on Rockwell Arena. Our next step was to evaluate areas of improvement and determine where LEAN tools could be implemented. We utilized time studies and conducted root cause analysis with the operators using interviews and surveys. Lastly, we determined solutions based on our findings and conducted a cost-benefit analysis to quantify the effects of our results. Our findings revealed that the current time between tool changeover at routing varied and was unstandardized. With the combination of the various LEAN tools utilized and the results from the tooling team, our suggested implementation would decrease the number of tool changeover by 29% approximately at every work surface router. Furthermore, from the cost-benefit analysis of our implementation, the team established that by using a distance tracking software on all the routers and a calculator created by the tooling team, AIS could save approximately $12,000 annually on just tool bits. In summary, our project was able to leverage LEAN technique to determine areas of improvement and provide a quantifiable outcome from our suggested implementations.

Introduction

In the ever-evolving landscape of manufacturing, one factor remains constant, the pursuit of efficiency. Improving operational efficiency in manufacturing can reduce costs and increase global GDP. It is clear that embracing efficiency is no longer a choice but a necessity.

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.

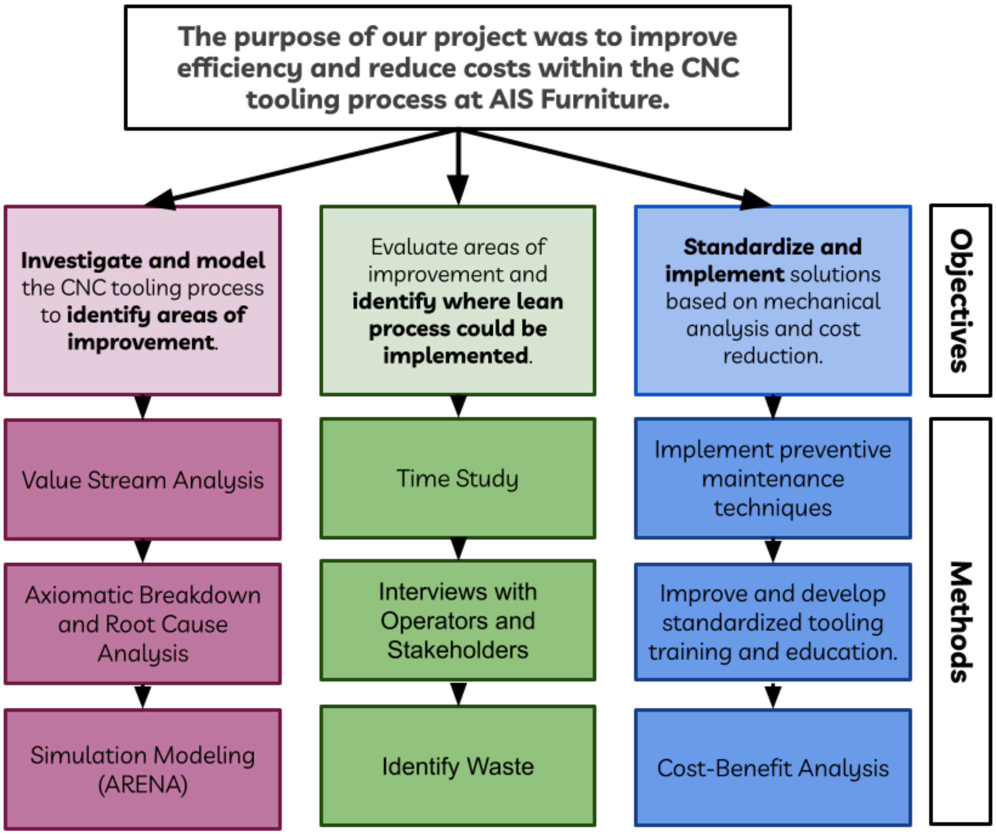


Figure 1. Objectives and Methods Summary

Background

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

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. (ES Shelf, 2024)

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. (Material Bank, 2024) 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 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.

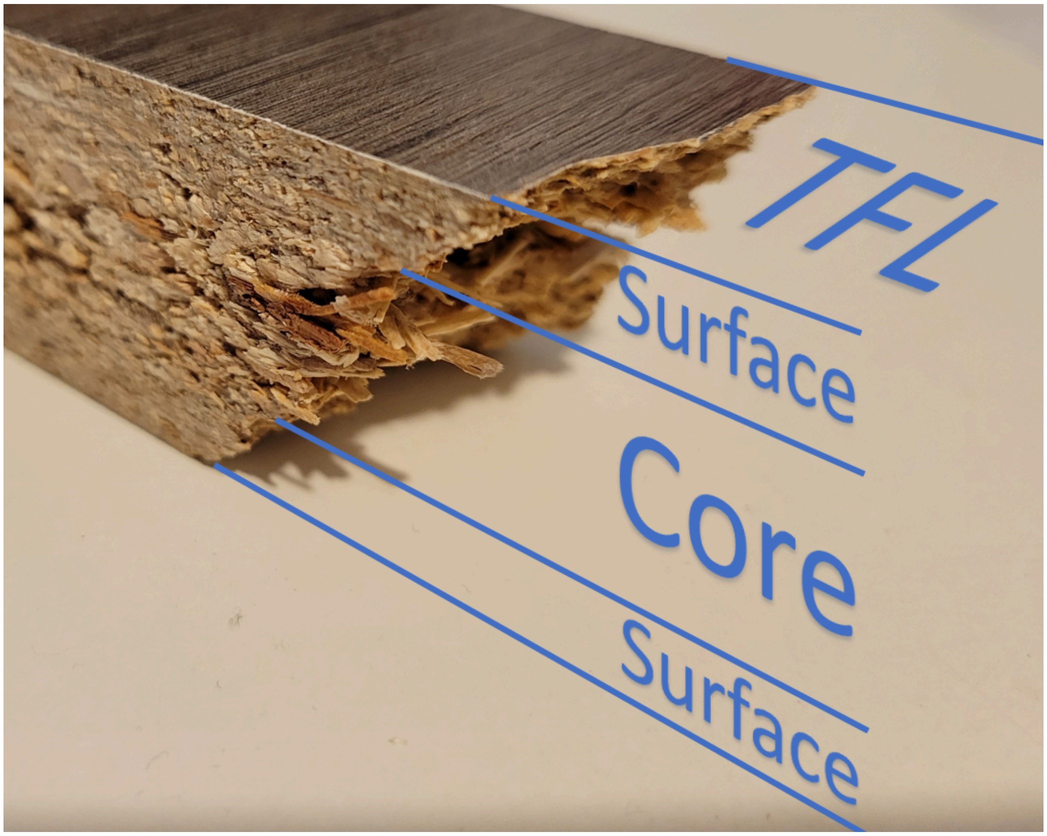


Figure 2: Anatomy of a Particle Board

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. (Hessing, T. n.d.)

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.(Lean Enterprise Institute, 2024) 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.(Purdue University, 2021)

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.(Rauch et al., 2016, pg 1) 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..(Rauch et al., 2016, pg 2) 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.(Kelton et al. 2015, pg.2)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.(Kelton et al. 2015, pg.11) 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.(Graupp, TWI Institute) 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.

Methods & 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.

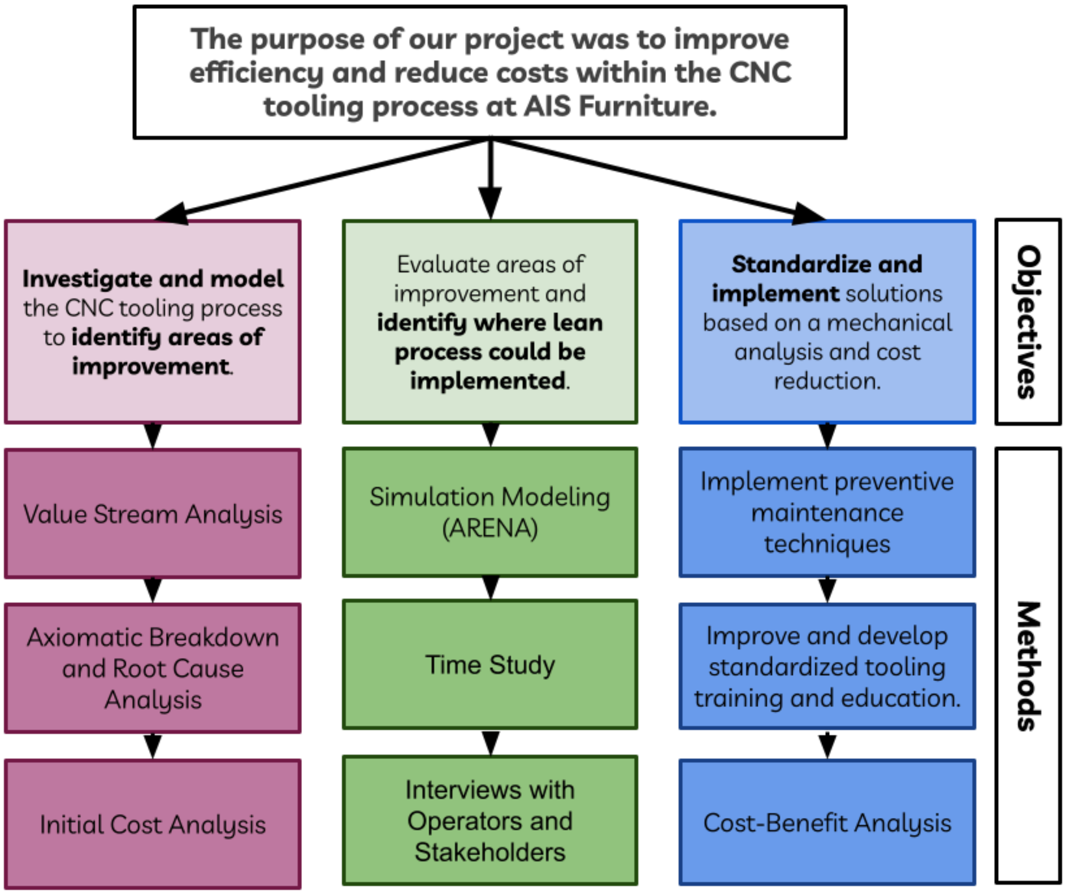


Figure 1: Objectives and Methods Summary

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.(Lutkevich 2021, TechTarget) 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 and Time Studies 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.

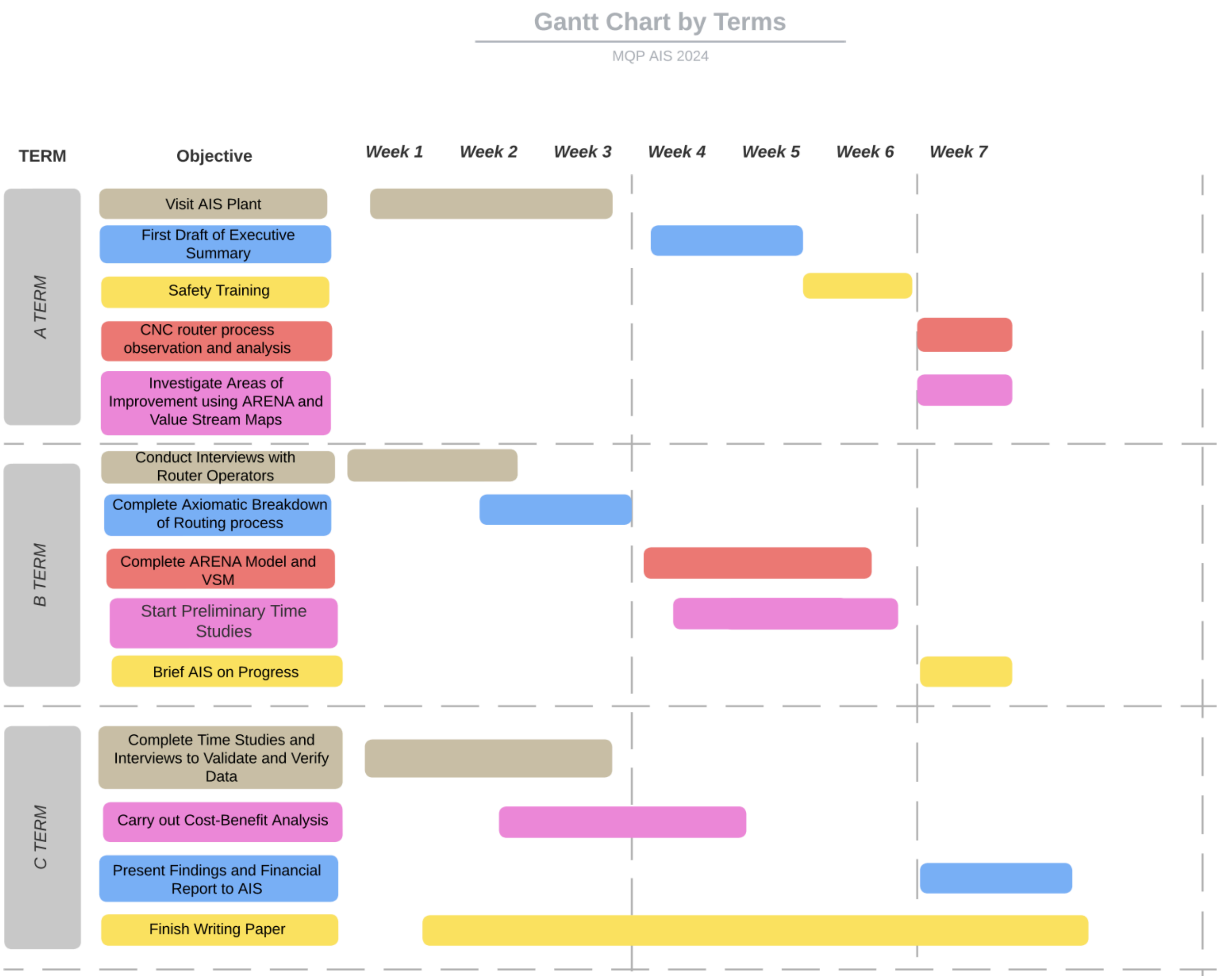


Figure 3: Team Gantt Chart

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.(Affordable Interior Systems 2024)

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.(Affordable Interior Systems 2024)

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 the unique capabilities each router has 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.(Affordable Interior Systems 2024)

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. (Affordable Interior Systems 2024)

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.

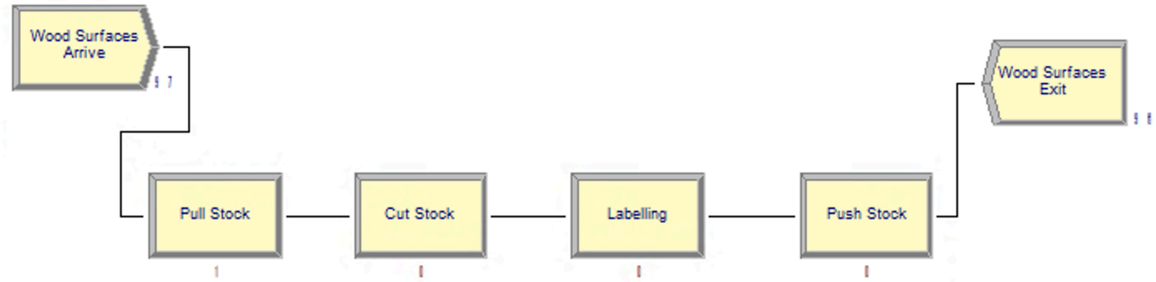


Figure 4: AIS Manufacturing Plant Model in Arena

In figure 4, the arena model shows each distinct step involved in the routing process. After the particle boards arrive at the routing step, they go through a sequence of steps namely: pull stock, cut stock, labeling and push stock.All types of boards go through the same steps and in that specific order. The main difference between the type of boards is the cutting time as more pieces might be cut from a specific board. Accordingly, a triangular time distribution is utilized for all the steps in the routing process as this distribution acknowledges outliers which may exist throughout the shift.

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 5 shows the distinct processes involved in the manufacturing plant.

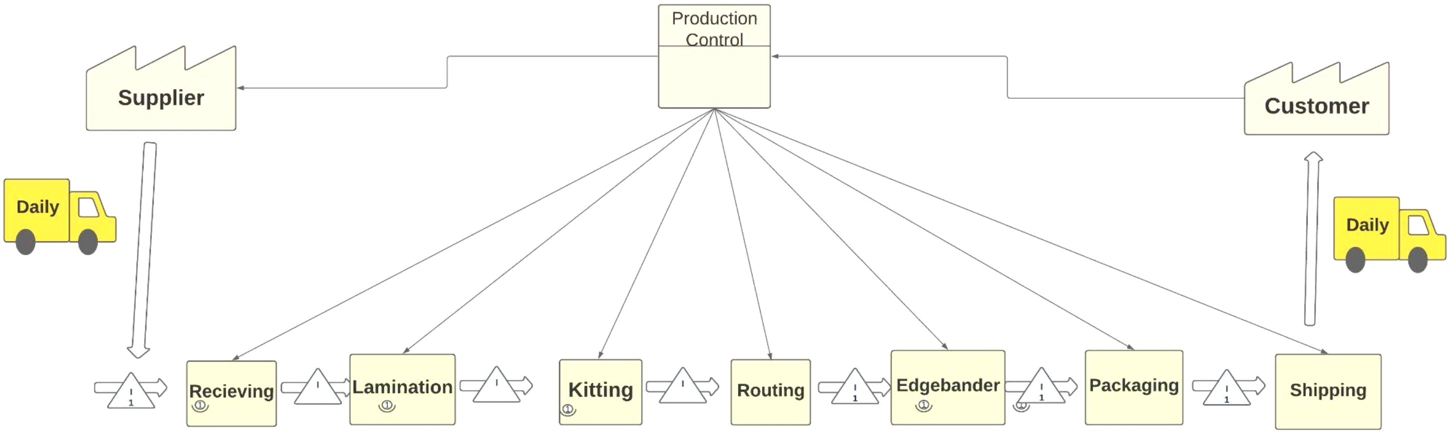


Figure 5: Distinct Processes in AIS Plant

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 6, 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.

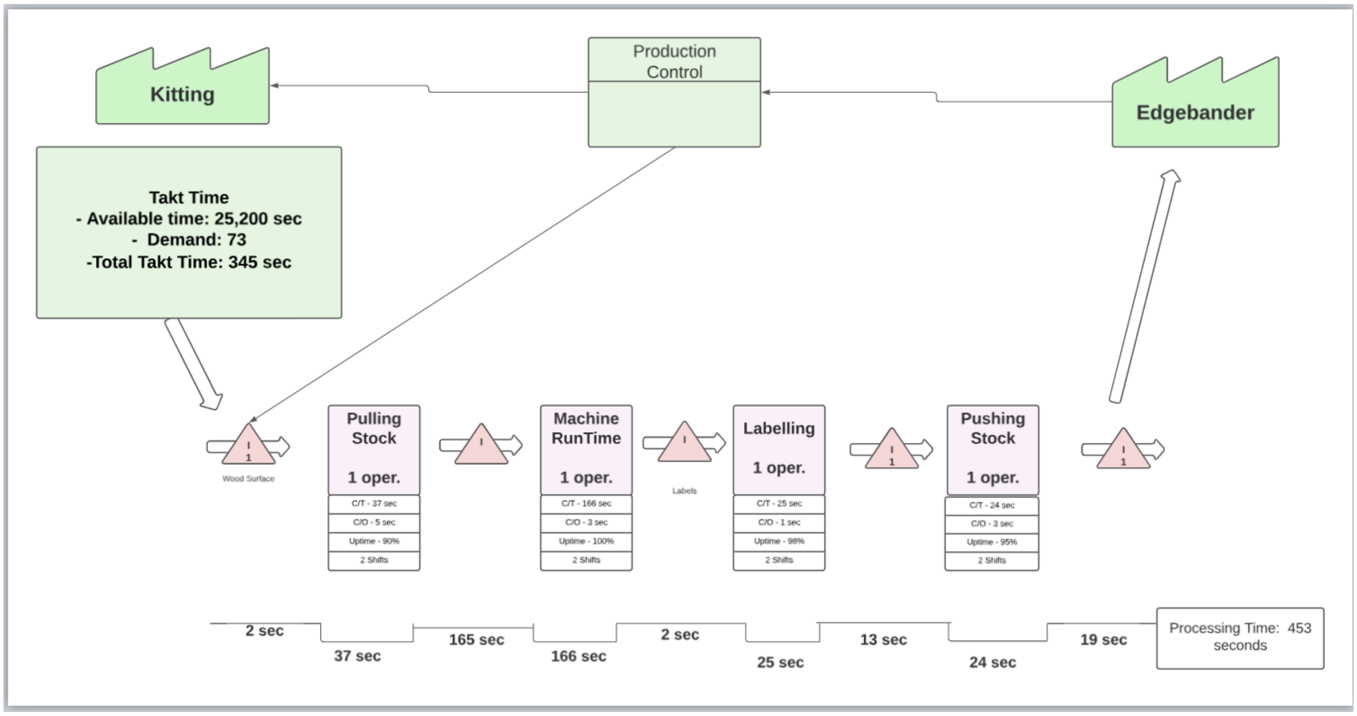
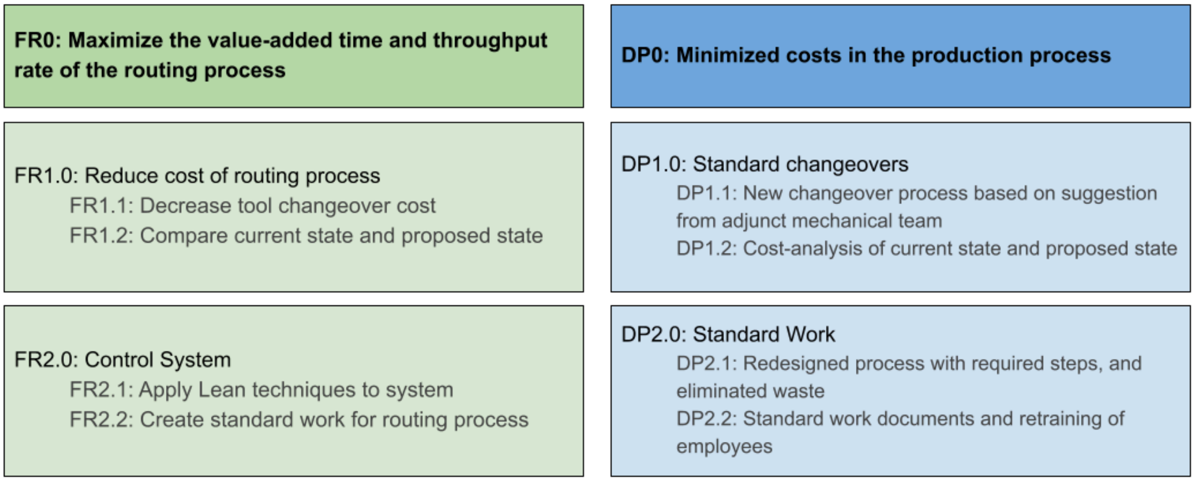


Figure 6: Value Stream Map of Routing Process

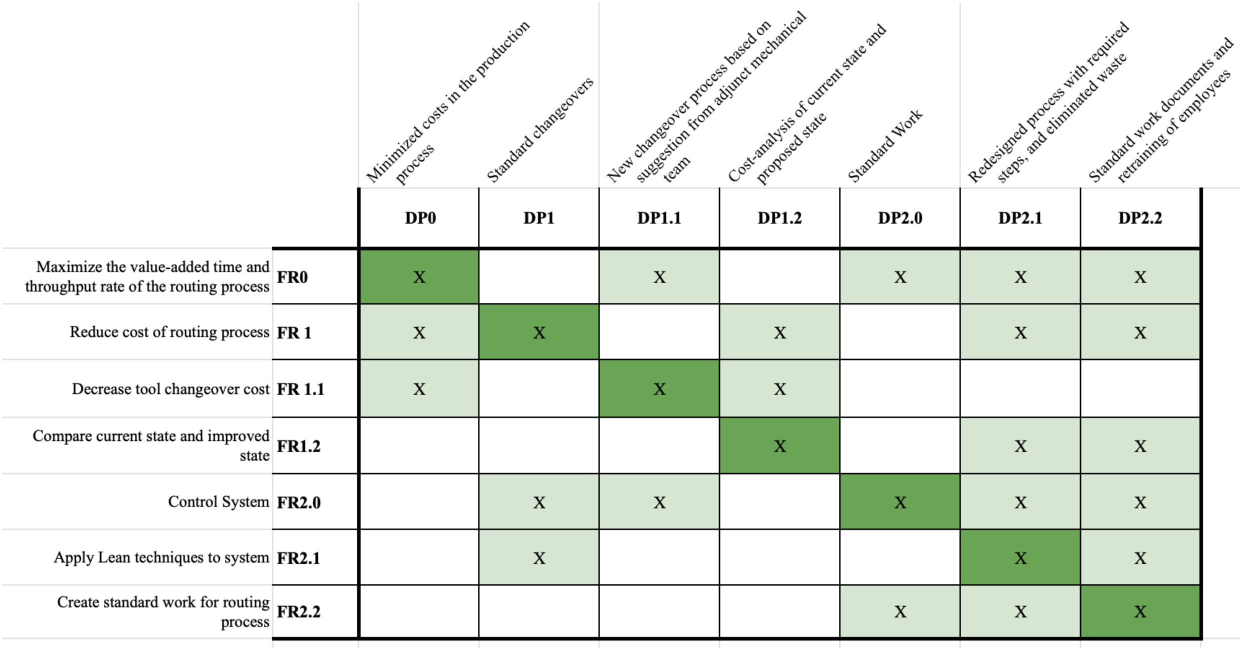
Axiomatic Design



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 7: 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 8: 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 8 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 slides 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.

Table 1: 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%

Table 2: Ten cycles from 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 planned. 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 deep 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 and the value of implementing our new system. We decided to initially focus on the dollar 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 over a period of time and compared the two. The costs we found included, material costs, electricity costs, replacement parts, and operators salary. Revenue was harder to find since the routing process only produces parts of a finished project, however with an assumption of the number of parts that go into a finished piece of furniture we can find the value of a given board after it has been cut. The data we were given in relation to the costs are given below.

Cost of Material per sf.	$1.34
Average Board	32 sf.
Boards per day per machine	100

Table 3: Given cost data for Particle Boards

Using the data provided above we came up with the following, and under the assumption that there is a 16 hour shift.

Average board cost	$42.85
Boards per hour	6.25
Total Cost per hour: (Average board cost) x (Boards per hour)	Roughly $268

Table 4: Material Cost per Hour Calculation

The next cost benefit analysis portion came from the data collected by the other team working at AIS who found the standard utilization capacity of routers cutting bits whether new or resharpened. Using a calculator created in excel by the tooling team 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 them being 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. The cost associated with these tool changes was found using the data below, gathered from the 3 month long data set on tool changeovers.

Tool Type	Distribution %	Cost
New	26.76%	$110
Resharpen 1	14.10%	$15.5
Resharpen 2	45.83%	$15.5
Resharpen 3	13.31%	$15.5
Average cost for a given bit		$41

Table 5: Average Cost for any given tool bit

Within the data set we also found that the tools were changed every 3.5 hours. To find the average cost per hour spent on tools, we found that tool changes happened about .29 times per hour, multiplying this by the average cost for a given bit gives us our cost per hour spent on tool bits. This comes out to around $12 an hour spent on tool bits.

The next two costs considered were the hourly salary of the operator working the CNC router, and electricity costs to run the machine for an hour. Within our own calculations we used arbitrary numbers as this was information specific to AIS that they can change as they see fit. We decided that the hourly wage of an operator would be $20 an hour and the hourly electricity cost was $50 an hour to run a given CNC machine. These give us the total costs given below.

Type of Cost	Hourly cost in dollars
Materials	$268
Tool Bits	$12
Operators Salary	$20
Electricity	$50
Total	$350

Table 6: Total Costs

This data shows that it costs AIS around $350 an hour to run a given CNC machine.

To find revenue we used the data provided by AIS along with some assumptions that can be changed to better fit the actual numbers. The data provided as well as the assumptions are listed below. Please note any number marked with an asterisk is subject to change and an assumption by our team.

Number of pieces created per board	2.5
Number of pieces per piece of furniture	5*
Number of boards per piece of furniture	2
Boards cut per hour	6.25
Finished furniture per hour	3.125
Gross Revenue per finished furniture	$400*
Total Gross Revenue per hour	$1,250

Table 7: Revenue generated per hour

To get net revenue per hour we subtract the Gross Revenue created per hour, $1,250, by the total costs per hour, $350, which gives us an estimated net revenue of $900 an hour created by any given router in the worksurfaces department of AIS.

To calculate the average cost of a given tool bit we first found the usage distribution of the bits, at AIS. The tool bits that AIS use to cut the boards within their work surfaces department come in 4 different sizes, all beginning as new bits but are resharpened for further use subsequently after the edges of the bits are dulled. AIS provided us with a 3 month long data set with timestamps and sizes of tool bits when they are replaced. The sizes, type of bit and distribution can be found in the table below. (Cass, P., Martin, R. 2024)

Tool Bit Type	Size in inches	Distribution
New	.500	26.76%
Resharpen 1	.490	14.10%
Resharpen 2	.480	45.83%
Resharpen 3	.470	13.31%

Table 8: Tool Bit Types and Distribution

Finding the tool bit distribution was important to find the average cost of a given bit because the costs associated for each bit differ. That data can be found in the table below.

Tool Bit Type	Cost
New	$110
Resharpen 1	$15.5
Resharpen 2	$15.5
Resharpen 3	$15.5

Table 9: Tool Bit Costs

To find the average cost of a tool bit we can multiply the cost of a bit by its distribution at AIS and sum all of those products together. This can be done and represents the average cost of a tool bit because each bit represents its own tool since the preceding costs had already been covered. This data gives us an average tool bit cost of $41.

The tooling team created a calculator that by measuring the wear a bit experienced over a given distance will create an output of how many tools should be needed to cut a given distance. Currently at AIS each router uses 4.6 bits a day however this number is higher than it should be. Using the average distances cut of each type of material within a day the tooling team was able to find that AIS should only be using 4.4 bits a day. This gives a difference of 0.2 bits per router per day, spread across 4 machines that is a total of 0.8 bits a day that AIS is not using to their full capability. If a given bit costs $41, and there are 0.8 bits a day that could be saved over 365 days AIS could save $11,972 a year on just tool bits alone. This would be if AIS was to implement a system that would track the distance each router cuts and would give the operator feedback as to when they should change their tool bit. This software exists and is priced at around $3000, this was information that AIS provided for us, this would give AIS startup costs of $12,000 across the 4 cnc routers in the worksurfaces department to implement this software. However, it would garnish returns of $12,000 every subsequent year. A cash flow diagram showing the upfront cost and subsequent savings adjusted for inflation may be found below.

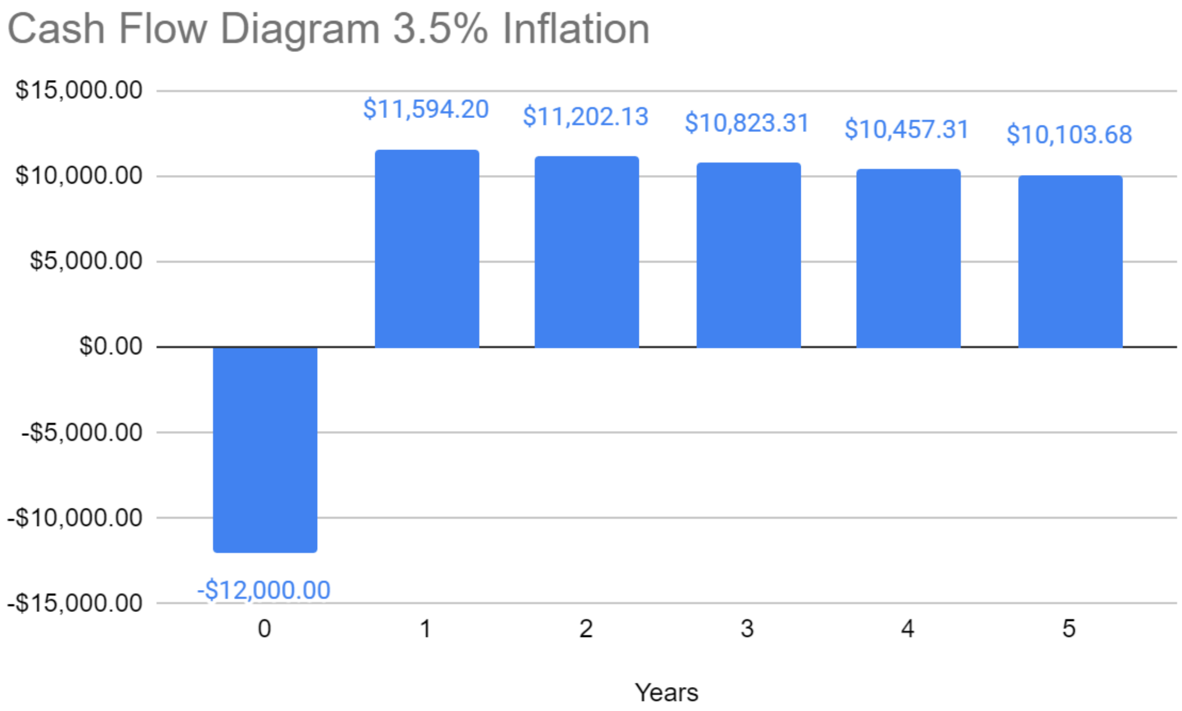


Figure 9: Cash Flow Diagram Predictive State

The total revenue AIS would save after the implementation of this process ranges from $48,000 to $68,000 depending on the depreciation rate that the process experiences. Ultimately our team recommends that they purchase the software that tracks distances being cut so that they may use their tool bits to their full capability.

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.

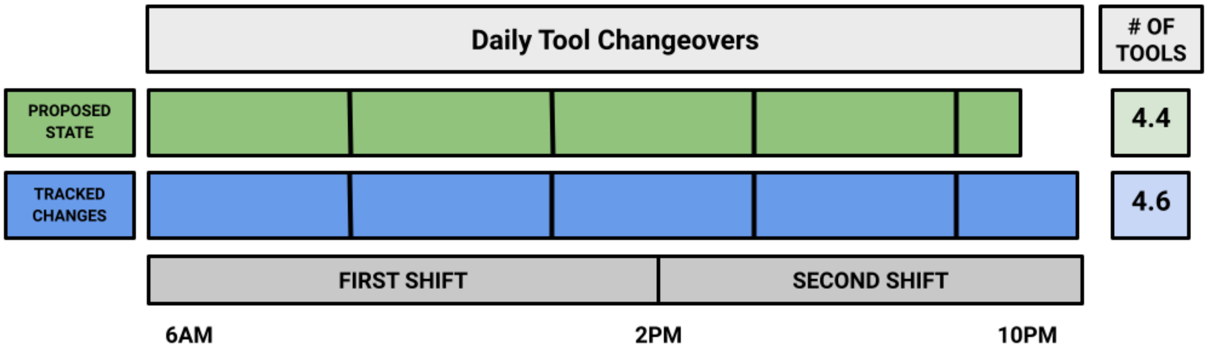


Figure 10: Tool Changeover Timeline

To model the current tool changeover process and our suggested standardized tool changeover model, a timeline was constructed, as shown in Figure 9. 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 (Cass, P., Martin, R. 2024)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

Table 10: 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 roughly 10 tools. For the tracked tool changes, the router would need roughly 10 tools. For the proposed state, there would be about 7 tool changes.

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

Future Work

In addition to our findings and proposed implementations, there is additional work we did not have the time to help improve the operational efficiency of the work surfaces manufacturing processes.

Firstly, we recommend investigating the root cause for material defects in the HPL and TFL boards. One of the insights from our time study was instances where the operator would have to wait several minutes due to a damaged board being in the inventory and consequently having to wait on another board. Additionally, this was further corroborated in our group interviews as defective pieces from the kitting station seemed to be a frequent time waste for routing operators. A potential recommendation that was discussed in the operator meeting was adequate lighting levels at the station to improve visibility in order to detect defects before they reach the routing station. Another solution includes comprehensive and standardized training to operators on identifying defects.(Automotive Quality Solutions) For example, visual documentation like quality alerts could be utilized to illustrate a wood surface which is “OK” and “Not OK”. Feasibly, with such documentation and training, the time waiting on replacement boards will be reduced.

Another time-waste that was talked about during the operator meeting was in the labeling step. Specifically, sometimes new operators might have some confusion on correctly labeling the wood surfaces. In the meeting, operators did remark that with experience, it becomes less of an issue. Regardless, a potential recommendation to this issue would be to investigate the visuals on the labels as a guide for the operators. Another solution might be assessing the feasibility of a projector guide at the CNC routers. This would involve finding suitable software and additional operator training and integration. However, this could be useful in decreasing process time and errors in the labeling process.

Lastly, we recommend looking into implementing the distance cut software, found on router 2, on the remaining 3 routers. As this feature allows the routers to measure precisely the distance traveled by the cutting tool before every changeover, the operator has a better understanding of when the tool wears. Currently, operators, based on their training or experience, have different ways of deciding when to change the tool. To mitigate that and simultaneously utilize the tool bit more efficiently, the distance cut software could be helpful for operators. This recommendation would involve a major implementation phase and additional operator training and standard work documentation, but in the long term it could help decrease the number of tool bits used while maintaining high quality.

Since we were not able to assess these recommendations in our time constraint, there is a need for a root cause analysis and subsequently verification and validation in order to determine the efficiency of these proposed solutions. Regardless, we suggest considering these recommendations as they have the potential to significantly improve the efficiency of the routing process.

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. Toward the beginning of our MQP we believed we fully understood what the task was at hand and ran with it. However, along the way we realized how important it is to have check-ins with our sponsor as we were initially on different pages and had to work together to get the desired end result. This allowed us to step back and look at the processes from a broader perspective and gain new insights. Throughout this project, we encountered challenges that tested our adaptability and problem-solving skills. Despite our diverse backgrounds and expertise, we learned to leverage our differences as strengths rather than obstacles. Working in a group environment taught us the significance of effective communication, active listening, and mutual respect. Moreover, we gained insights into the necessity of evaluating situations objectively, making informed assumptions, and maintaining transparency about our methodologies. Overall, this project was more than just a culmination of our academic journey, it was a transformative experience that equipped us with the practical skills and professional mindset essential for success in our careers. As we move forward, we carry with us not only the knowledge gained but also the invaluable lessons learned from overcoming challenges and collaborating effectively as a team.

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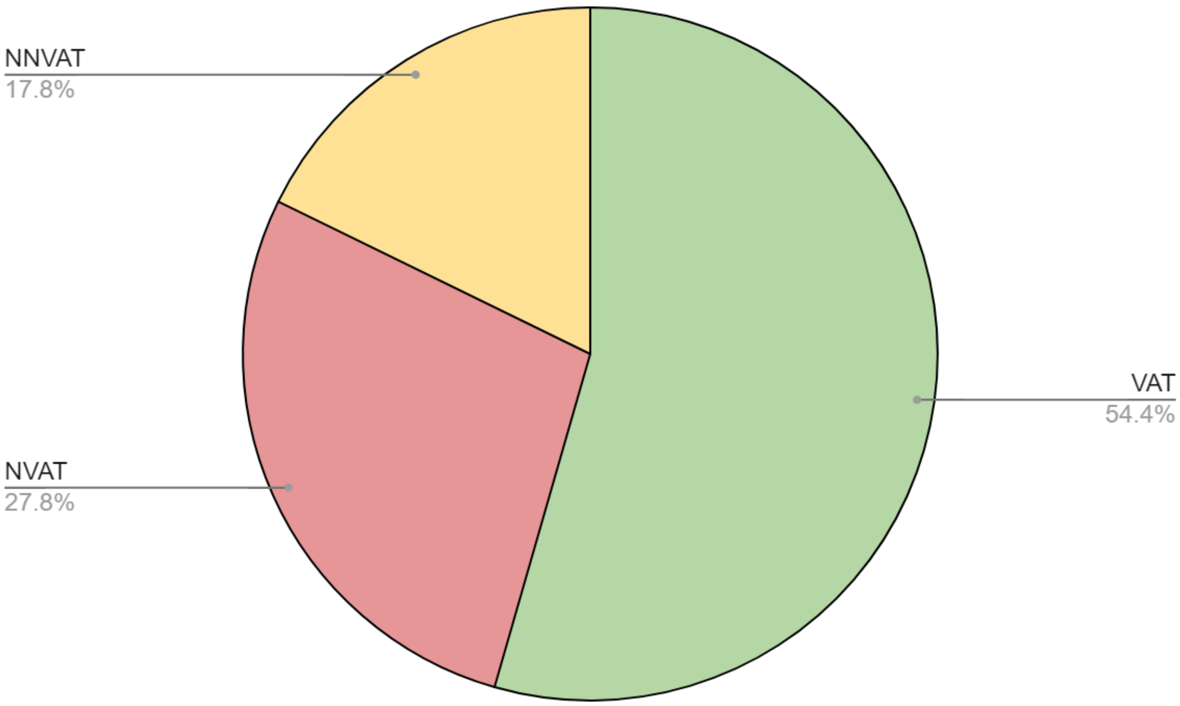
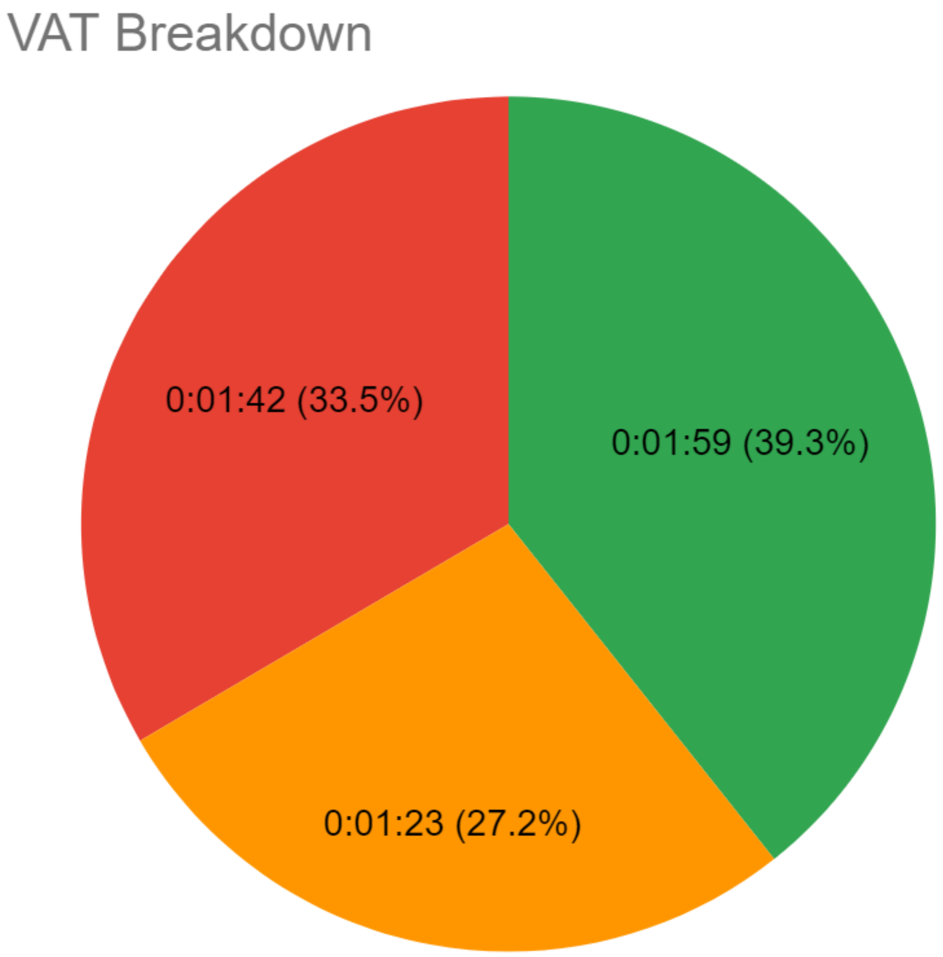
Appendix

1. Preliminary Time Studies Router 2

	Cycle								Average
Step	1	2	3	4	5	Avg		VAT	0:04:25
Pull Stock	0:00:33	0:00:30	0:00:33	0:00:28	0:00:33	0:00:31		NVAT	0:02:15
Cut Stock	0:03:38	0:04:22	0:06:52	0:05:29	0:01:44	0:04:25		NNVAT	0:01:26
Vaccum Dust	0:00:17	0:00:17	0:00:29	0:00:20	0:00:19	0:00:20		Utilization	54.44%
Labeling/Idle	0:01:24	0:00:59	0:02:25	0:01:58	0:02:57	0:01:57			
Push Stock	0:00:28	0:00:28	0:00:55	0:00:17	0:00:45	0:00:35			
Idle	0:00:15	0:00:36	0:00:24	0:00:00		0:00:19			
Sum	0:06:35	0:07:12	0:11:38	0:08:32	0:06:18	0:08:03	Cycle average		



Step	Trigger	1	2	3	4	5	6	7	8	9	10
Pull Stock	Op Presses Button	0:00:34	0:00:35	0:00:37	0:00:32	0:00:33	0:00:31	0:00:30	0:00:44	0:00:40	0:00:34
Cut Stock	Vacuum Gague	0:01:41	0:02:03	0:03:41	0:01:58	0:02:12	0:01:41	0:01:44	0:01:37	0:01:36	0:01:40
Vaccum Dust	Whiskers Down	0:00:17	0:00:18	0:00:21	0:00:15	0:00:17	0:00:17	0:00:20	0:00:21	0:00:16	0:00:17
Measure/ Label	Turret Right	0:01:23	0:01:32	0:02:04	0:00:43	0:00:54	0:01:15	0:01:08	0:00:30	0:01:42	0:00:18
Push Stock	Turret Moves	0:00:43	0:00:27	0:00:29	0:00:29	0:00:30	0:00:32	0:00:30	0:00:27	0:00:24	0:00:26
Idle/Blow	Turret Right	0:00:41	0:00:19	0:00:17	0:00:14	0:00:33	0:00:21	0:00:16	0:00:19	0:00:17	0:02:09



2. Time Study Results 2/2/24

R2	**Cycles**													
Steps:	1	2	3	4	5	6	7	8	9	10	Notes			
Pulling Stock	40	35	25	29	20	36	27	34	23	98	- Any Idle time after labeling is occuring based on the downstream process - Tool changeover after cycle 3 - before cycle 10 there was a 10:48 pause for material issues - this operator was very eficient			
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	7.77			
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%				

R9	**Cycles**						
Steps:	1	2	3	4	5	Notes	
Pulling Stock	62	86	53	199	55		
Idle	89	87	108	42.5	182		
Machine Run Time	163	153	164	179	324		
Idle							
Air Blowing						- For Cycle 4, pullisng stock was lower than average as there was no work in progress delaying the board to be cut	
Idle							
Labeling	12.6	14	17	18	25.4		
Idle	14.3	11	14	52	5.7		
Air Blowing							
Idle							
Push	27	27	27	29	27		
Idle	10	8	11	12	16		
Total Time (sec)	377.9	386	394	531.5	635.1		
Total Time (min)	6.30	6.43	6.57	8.86	10.59	7.75	
Percent cut time	43.13%	39.64%	41.62%	33.68%	51.02%		

3. Time Study Results 2/14/24

R4	**Cycles**										
Steps:	1	2	3	4	5	6	7	8	9	10	Notes
Pulling Stock	31	11	65	40	20	45	24	23	22	19	2/14 - 10AM
Idle	203	217	167	211	205	200	185	212	217	220	
Machine Run Time	227	226	227	224	223	224	222	225	226	223	
Idle											
Air Blowing											
Idle				16							
Labeling	13	15	12	12	14	15	18	12	13	15	
Idle											
Air Blowing											
Idle	10	6	5	8	8	6	7	8	6	7	
Push	16	22	25	24	23	22	24	21	29	18	
Idle	25	10	34	39	25	23	21	20	26	27	
Total Time (sec)	525	507	535	574	518	535	501	521	539	529	
Total Time (min)	8.75	8.45	8.92	9.57	8.63	8.92	8.35	8.68	8.98	8.82	8.81
Percent cut time	43.24%	44.58%	42.43%	39.02%	43.05%	41.87%	44.31%	43.19%	41.93%	42.16%	