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Application of SLP Layout Optimization with Lean Tools for Enhanced Performance in Metal Manufacturing Facility

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Abstract

This project delves into the optimization of facility layout in a metal fabrication plant through the application of discrete event-based simulation and Systemic Layout Planning (SLP), aiming to enhance production efficiency. This case study endeavor sets out to better manufacturing performance at Progressive Metal Manufacturing Company (PMMCO) in Warren, Michigan, with the guiding principles of lean manufacturing, aiming to strengthen its production system. Employing an array of lean tools such as optimization, statistical process control, process mapping, flow optimization, 5s, and Muda's 8 wastes. The primary objective is to identify an optimal plant layout that maximizes machine utilization and execute an ideal solution for space allocation. Analyzing the different sequences of operations and cycle times for each metal fixture product will be key inputs for the applied plant simulation. PMMCO is identified as a high-mix, low-volume job shop, splitting operations into two facilities. The existing plant layout holds several limitations on manufacturing production due to the machine quantity in the plant and current spatial relationships. The new layout considers four new machines to be relocated from one facility to the other, expanding the range of operational abilities in the Warren facility.

Keywords:
Optimize, Simulation, SPC, SLP, Production.

1. Introduction
The progression of the manufacturing industry in the current day and age has cultivated innovative methods of production. Technological advances within the industry are moving towards automation and lean practices within production. This paper explores the implementation of automation, lean techniques, and optimization within a metal manufacturing fabrication facility. Progressive Metal Manufacturing Company (PMMCO) is a metal fabrication company that specializes in producing and supplying metal fixtures for a variety of customers. PMMCO is identified as a high-mix, low-volume job shop. The company splits its production between two facilities, the main production takes place in the Ferndale, Michigan facility. The accompanying facility is located in Warren, Michigan, specializing in first-run production, assembly, shipping, and receiving. The company's initiative to integrate automation within their production encouraged the motive to redesign and optimize the current layouts. Collaborative robot (Cobot) was installed in the Ferndale facility which kick-started the relocation of current machinery to the Warren plant.

1.1 Objectives
Optimize the plant layout in the Warren facility via systematic layout planning (SLP) and simulation techniques. The redesign aims to maximize machine and space utilization. A new layout can potentially reduce cycle times for products.

1.2 Problem Statement

The existing layout is not optimal and doesn't consider the flow of products and personnel. The departments are scattered and fail to reduce unnecessary movement within the facility. The main motive behind the optimal facility layout redesign is to combat the following concerns: inefficient use of space, excessive movement of personnel, and idle machinery. The plant layout optimization should have a smoother flow between departments. Arranging the departments closer together while also maintaining enough distance for clearance and avoiding a dense area should improve the flow and production.

1.3 Research Questions

How can the integration of Systematic Layout Planning (SLP) and discrete event simulation improve machine utilization and reduce idle time in a high-mix, low-volume manufacturing environment?

What impact does reconfiguring layout have on production flow, worker movement, and overall facility efficiency?

How can simulation-driven layout redesign incorporate lean principles and OSHA standards to balance productivity improvements with workplace safety?

2. Literature Review

2.1 Systematic Layout Planning

Optimizing plant layout is essential for achieving lean manufacturing. It aims to decrease non-value-added activities that could potentially be triggered by inefficient layout design and management. Performing optimization can cut manufacturing throughput time, enhance productivity, and promote cost-effective decisions. Systematic Layout Planning (SLP) may improve efficiency and maximize space utilization in production facilities (Sutari and Rao 2014). Facility layout not only influences production planning but also plays a major role in manufacturing execution (Wang et al. 2008). Production improvement can be accomplished through plant layout. This improvement starts with identifying the problems of the current plant layout to maximize productivity. SLP provides a multi-criteria decision-making framework that is used to evaluate the developed alternatives which are compared with the existing layout. The SLP method derives an improved layout that improves the flow of materials, utilizes space effectively, and provides a flexible solution (Desai and Madhale 2019). SLP is a systematic and structured approach that helps to minimize the material flow while considering the relationship between departments, the special requirements, and the available space (Kasemset et al. 2023). The SLP consists of 4 crucial phases covering the location determination, data collection, and analysis, proposing the layout designs, and the evaluation of the layout designs. Phase I involves determining the area where the departments will be laid out. Phase IV deals with the physical relocation of the departments to the new site (Heragu 2018). Drafting and designing an efficient plant layout can lead to considerably lower expenses, typically fluctuating from 10-30%. Assessing and optimizing the layout can aid in reducing cross-traffic within the facility and maximize utilize production floor space to the fullest capacity (Suhardini et al. 2017). An effective layout of any manufacturing system often results in better space utilization, reduction in cycle time, trimming down the inventory costs, proper on-time delivery, efficient management, and better transparency of roles and responsibilities to the employees and workers (Singh and Khanduja 2019).

2.2 Simulation

Discrete Event Simulation (DES) models a system via discrete time steps created by state changes. Each event triggers a change within the system, which follows a random distribution. Corresponding DES simulators are frequently used to model operations in many industries. DES helps to identify operational characteristics (time & number of entities in queue, service & system at each process stage) and to simulate existing and alternate scenarios (Turner and Garn 2022). As a modeling technique, simulation can reflect the behavior of any system, allowing the simulation model to be manipulated rather than an analytical model to study the behavior of a system. The simulation also allows for testing various scenarios, detecting bottlenecks, and improving manufacturing performance. The ruling behind a simulation approach towards optimization is that the analytical objective function and constraints are substituted by simulation models. The decision variables are the predefined conditions that simulation is run under, and the simulation generates performance metrics based on the model's behavior (Wang et al. 2008). Many researchers have noted that DES simulations can be extended by, or integrated with, Digital Twins. To express the changing dynamics of real-time industrial material flows and internal transportation issues external data can be integrated with the simulation model to achieve optimization for further context (Turner and Garn 2022). Simulation models can pose as analytical tools when systematically planning alternate layouts and to better decision-making when eliminating inefficiencies within the layout (Suhardini et al. 2017).

2.3 Optimization

Previous research reveals that combining Systematic Layout Planning (SLP) with a simulation approach is a highly effective approach for optimizing manufacturing layouts. Applying SLP to design layout alternatives and simulation to evaluate their performance ensures data-driven decisions that improve efficiency and operational effectiveness (Liu et al. 2019). Optimization can be achieved through various approaches, including simulation. Traditionally an analytical model is employed to find the optimal solution for the optimization problem. However, this method isn't practical to perform in a real-life scenario, instead, a simulation model can act as an analytical model (Wang et al. 2008). Optimization can be achieved through statistical process control (SPC), which is composed of a set of techniques and statistical tools, organized to provide, through their application, the maintenance and improvement of the quality levels of a process. SPC assesses the quality process among the many existing processes via statistical tools and methods. Applying the SPC processes can be evaluated, and waste can be reduced through the constant process evaluation (Silva et al. 2021).

2.4 5s Methodology

5S was coined in 1970 by Takashi Osada and later implemented by Toyota engineers, Sakichi Toyoda and Kiichiro. They found that inherent benefits of the 5S methodology are employees' high motivation, a clean and tidy workplace, and easy detection of defects on regular maintenance of machines (Patel and Kiran 2022). The concept of 5S originated from the five Japanese words; Seiri (Sort), Seiton (Set in order), Seiso (Shine), Seiketsu (Standardize), and Shitsuke (Sustain). This technique is often misunderstood as merely a cleaning technique for shop floors and workshops. However, 5s entails more than simply tidying the area, rather it is a set of techniques to maintain orderliness and cleanliness, reduce wastage, and enhance efficiency and productivity. 5S aims to improve productivity and efficiency by reducing factory chaos, reducing the tool and material search time, and arranging the workplace for better visibility of the machines, equipment, and items (Monnanyana and Gupta 2021).

3. Methodology

This study utilizes systematic layout planning (SLP) as the main framework to optimize the plant layout. Simulation is employed to analyze the current plant flow and process sequence for selected product productions. This involves several data input metrics such as machine distance and cycle times for every operation. The collected data was then transferred onto a simulation model through Simio to generate potential outcomes of alternate layouts. Utilizing statistical process control to analyze and measure the quality of products.

4. Data Collection

The production process for the steel bracket arm was used to evaluate the general flow of the Warren plant facility. The engineering drawing for the bracket is illustrated below in Figure 1. This case study focuses on the crucial flow for a product, as it was impractical to conduct this study of flow for approximately 20,000 different products produced in this high mix, low volume job shop. Shown in Figure 2 below is a flowchart for the bracket production flow at PMMCO.

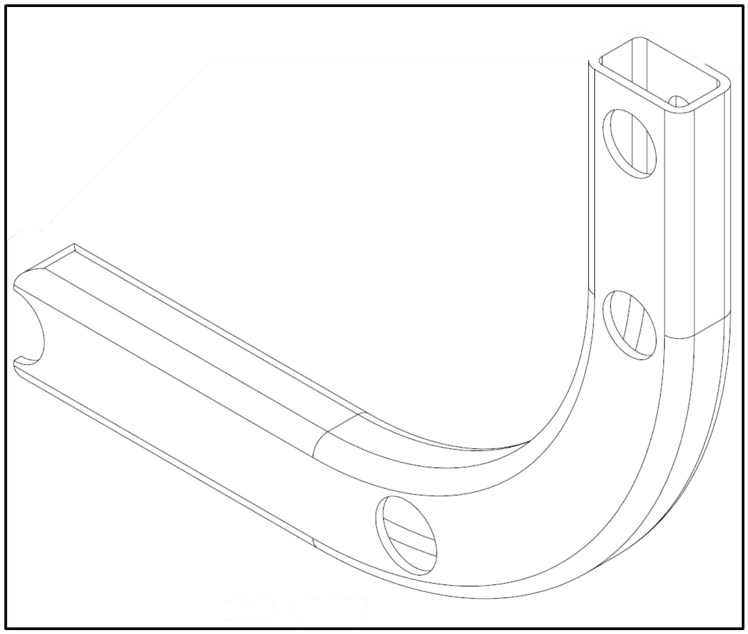


Figure 1. Steel Bracket Arm Engineering CAD Drawing

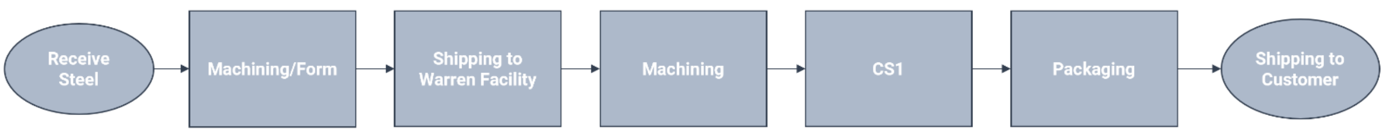


Figure 2. Steel Bracket Arm Production Process Flowchart

4.1 Time Study

A time study was conducted to identify the processing times for each operational task during the production of the steel bracket arm. A cycle of 30 runs for each step was recorded and analyzed. A histogram for the Machining CNC processing times is displayed in Figure 3. Stat::fit software was employed to determine the best-fit distribution for the processing times. Figure 4 below visually represents the following distributions: lognormal, normal, triangular, uniform, on a histogram graph of the processing times for the bracket machining operation. According to the graph, a triangular distribution (160, 171, 166) seconds best depicts the cycle times recorded to machine the bracket on the Mazak CNC machine.

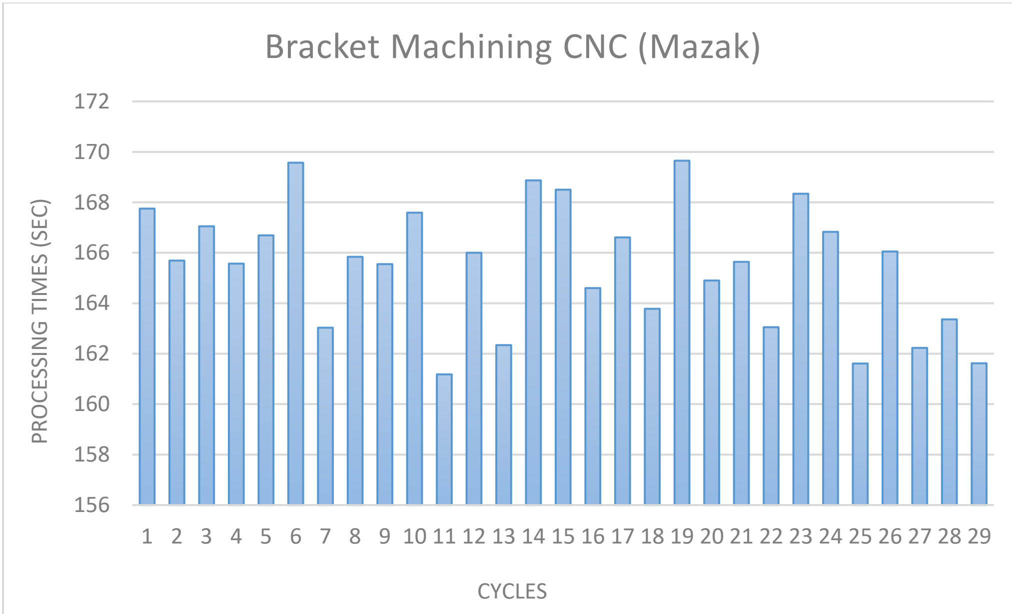


Figure 3. Histogram of Time Study for Steel Bracket Arm Machining CNC Processing Times in Secs

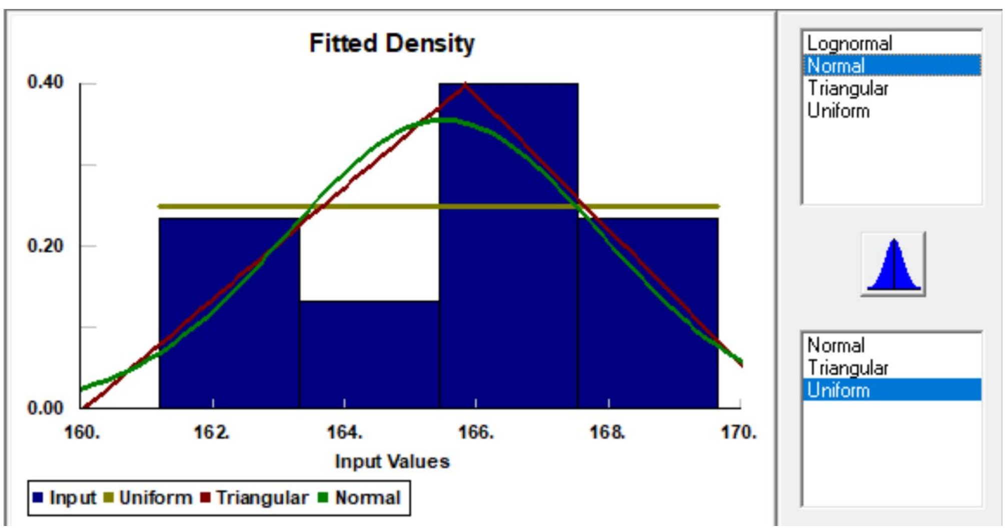


Figure 4. Processing Time in Secs for CNC Machining Best Fit Distribution

A comparison of the varying distributions was repeated for each machining step to establish the most accurate patterns in processing times. Considering multiple distribution patterns was necessary to simulate the routing logic in Simio. The forming operation cycle times are displayed as a histogram in Figure 5 and the best-fit distribution is in Figure 6 below. According to the flowchart for the steel bracket arm quality inspection and packaging are operational tasks to deliver the product to the customer. The recorded processing times and their distributions are shown in Figures 7-10.

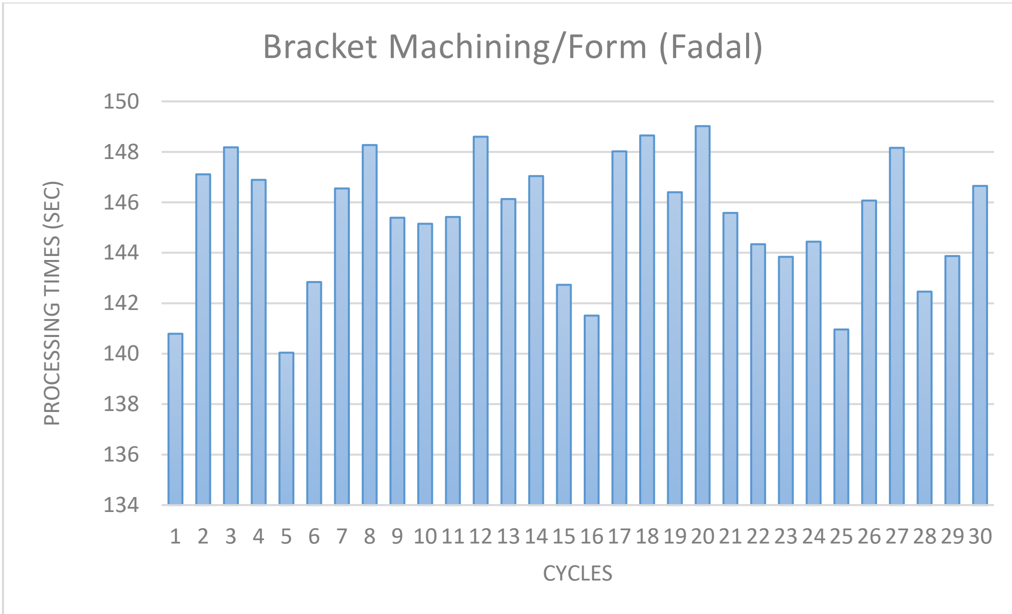


Figure 5. Histogram of Time Study for Steel Bracket Arm Machining/Forming Processing Times in Secs

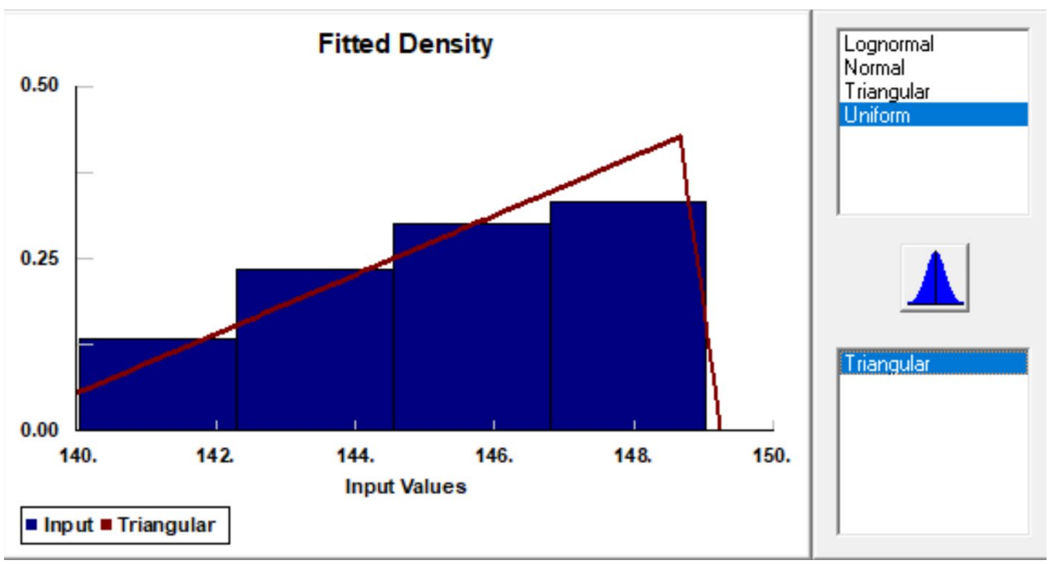


Figure 6. Processing Time in Secs for Machining/Forming Best Fit Distribution

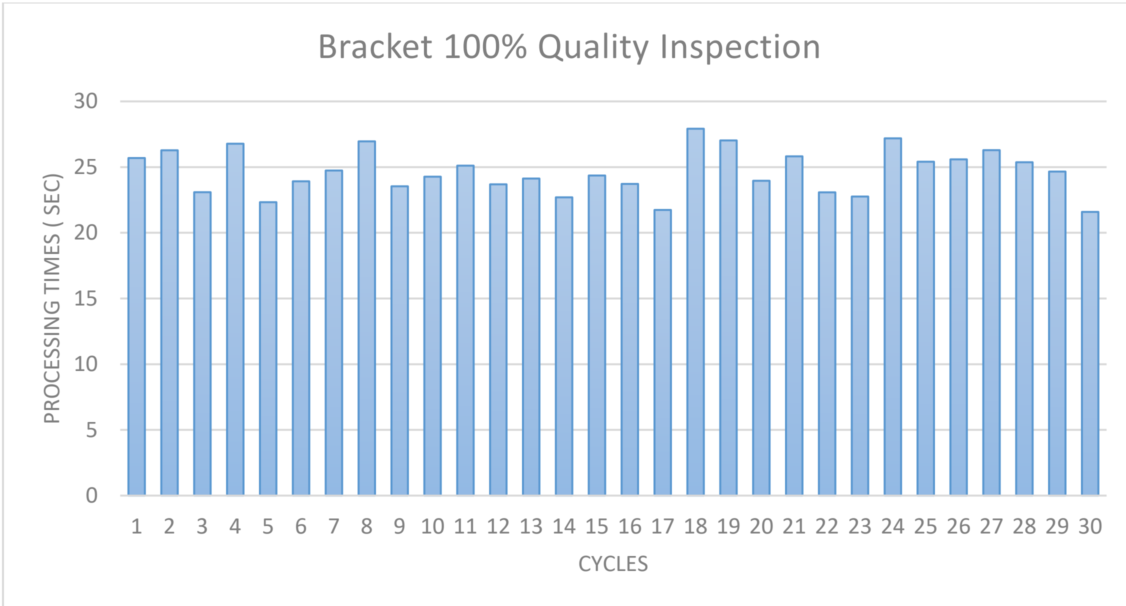


Figure 7. Histogram of Time Study for Steel Bracket Arm Quality Inspection Processing Times in Secs

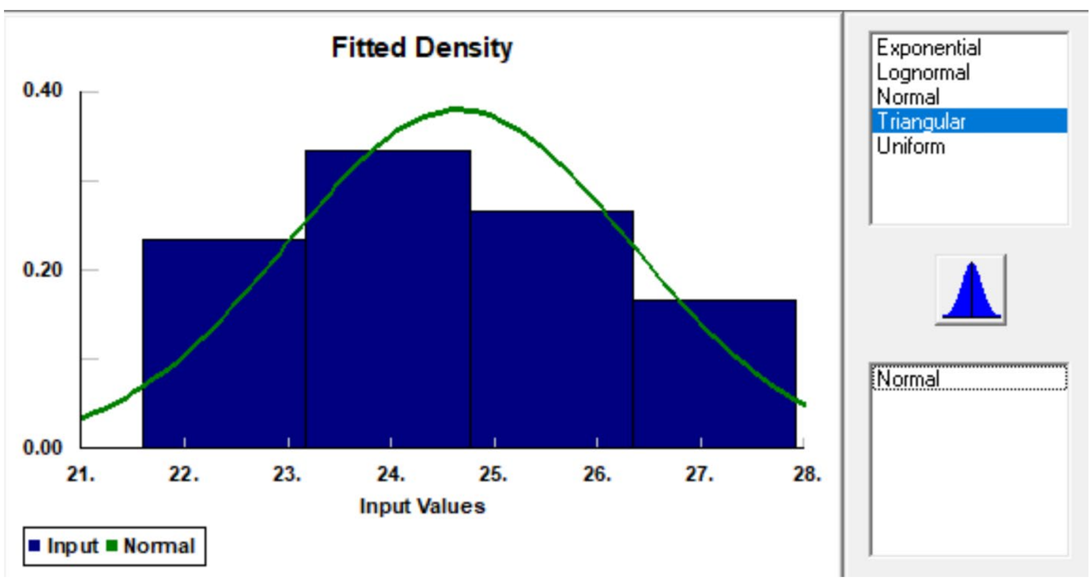


Figure 8. Processing Time in Secs for Quality Inspection Best Fit Distribution

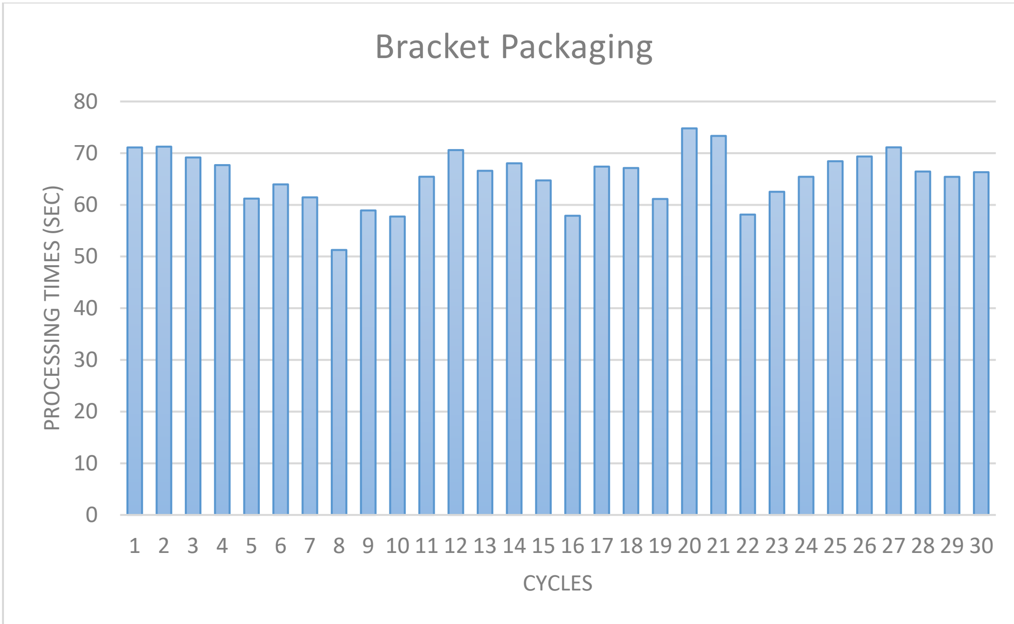


Figure 9. Histogram of Time Study for Steel Bracket Arm Packaging Processing Times in Secs

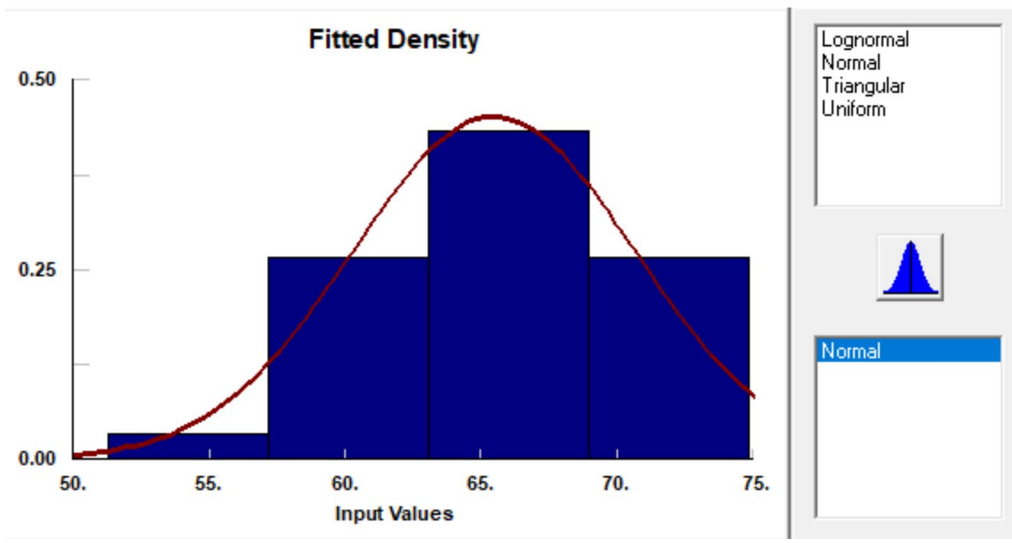


Figure 10. Processing Time in Secs for Packaging Best Fit Distribution

5. Plant Layout Optimization

Developing a plant layout suggests attaining an optimum arrangement of operating equipment, personnel, storage space, material handling equipment, and other services to facilitate the design of the product. Plant layout embraces the physical arrangement of industrial facilities (Patil 2014). A few imperative motives for redesigning plant layouts include continuously fluctuating customer demands and markets, changes in product production or volume, manufacturing, poor space utilization, extensive WIP, high material handling distances, bottlenecks at workstations, and idle time of facilities and workers, etc. (Kovács and Kot 2017). The objective behind applying the SLP method for general layout is to obtain the relationship table of operating units after comprehensively analyzing the relationship between operating units, including the relationship between logistics and non-logistics. The distance between the departments is determined according to the relationship in closeness between the other operating departments (Li et al. 2021). The SLP technique was applied to optimize the current layout. SLP consists of four phases (Figure 11):

Phase I: Determine the location where the facility will be built
Phase II: General overall facility design
Phase III: Determine the design of the facility layout in detail
Phase IV: Preparation and installation of selected layout

During *Phase I* of SLP, the Warren facility was chosen to administer the new plant layout due to the plans to incorporate a Cobot in the Ferndale facility. The Ferndale facility plans to enhance the production and quality of products with the Cobot installation, requiring a fair amount of space to operate smoothly. Therefore, a few of the machining equipment will be transferred to the Warren facility. Analysis of the current layout was necessary to study the conditions of the plant and visualize the available space.

Transitioning into *Phase II* weekly meetings were conducted amongst the engineering team to decide on the general plant layout. The discourse between the meetings established the direction and the main concerns when designing the new layout. Adjacency for the press brakes was a significant change that needed to be implemented to reduce unnecessary motion for operators. Additionally, the relocation of the CS1 inspection tables was a necessary move to smooth operations.

Alongside the four transitional phases, SLP considers input data which are split into five categories:
P (Product): The type of product (goods/service) produced.
Q (Quantity): Volume of each type of goods/ components produced.
R (Route): The order of operation for each product
S (Service): Support service, such as locker rooms, monitoring stations, etc.
T (Timing): In what time the type of component of the product was produced, what machine is used to produce it at that time. (Heragu 2018)

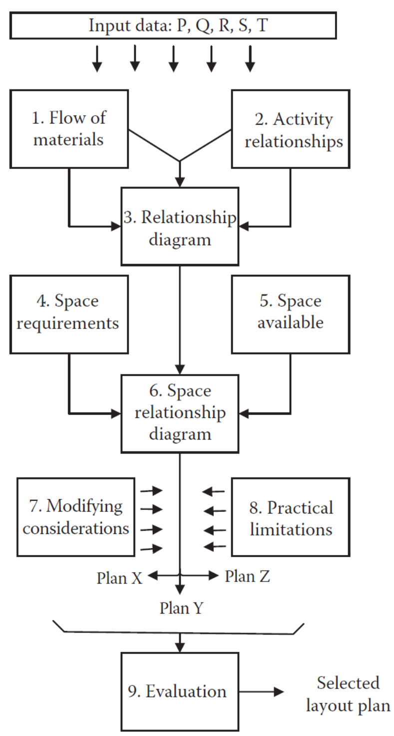


Figure 11. Application of SLP Framework (Heragu 2018)

5.1 Current Layout

The material flow for the products and their relation to the departments are represented in an activity relationship diagram shown in Table 1. The diagram defines the adjacency relationships for each department pair with a specific closeness rating are used and assigned a specific letter code:
A Absolutely necessary
E Especially important
I Important
O Ordinary
U Unimportant
X Undesirable

The closeness ratings indicate the importance of locating department pairs next to each other. (Heragu 2018)

Table 1. Reasons for Closeness (Patil 2014)

Code	Reason
1	Flow of Material
2	Ease of supervision
3	Convenience
4	Production Control
5	Contact

The departments that have the higher ranking in closeness are emphasized in the activity relationship chart in Table 2, emphasizing the importance of augmenting the proximity of machining departments closer to each other to streamline the flow of materials and improve production efficiency. Having the press brakes, milling machines, tooling, and welding departments in a concentrated area can enhance efficiency by creating a work cell. Combining these departments into a work cell minimizes walking distances. Arranging these departments closer can allow for smoother transitions between operations, reducing delays and increasing throughput. The relationship between CS1 Inspection and Shipping & Receiving in production can be improved by locating the departments in closer proximity to one another. This vicinity warrants that inspected parts can be easily transferred for shipping, reducing material handling times and better convivence. Prioritizing these spatial adjustments can significantly improve material handling, reduce waste, and ensure a more efficient plant layout.

Table 2. Activity Relationship Chart

Departments	1	2	3	4	5	6	7	8	9	10
1. Robotic Spot Weld		I-3	A-1	O-3	O-4	E-1	I-3	U-3	I-1	O-4
2. Weld (Focus Factory)	I-9		A-1	I-1	E-4	A-1	I-1	U-3	O-1	O-1
3. Press Brake	E-1	A-1		A-1	E-1	A-1	A-1	O-3	O-2	U-1
4. Milling (CNC)	E-1	I-1	A-1		E-4	I-3	U-5	U-3	O-4	U-4
5. Tooling (Focus Factory)	A-4	E-1	E-4	E-3		I-1	U-3	U-1	E-5	O-4
6. Spot Weld	A-1	I-1	A-1	E-4	I-1		E-3	U-3	O-1	O-4
7. Assembly	O-3	O-1	A-1	A-1	E-3	I-1		I-2	A-1	O-3
8. Heat Shield Assembly	U-3	U-3	I-3	O-4	U-3	U-3	A-1		O-3	E-4
9. CS1 Inspection	O-1	O-3	O-3	U-3	U-1	I-1	E-1	U-5		A-1
10. Shipping & Receiving	O-4	E-4	O-1	O-4	U-1	U-4	E-1	U-1	A-1	

Following the SLP methodology, a space relationship diagram was created to visually understand the flow of material in conjunction with the space available. The spatial requirements are noticeable. Since the Warren facility mainly utilizes assembly, inspection, and shipping/receiving, these relationships are shown the most repeated in the space relationship diagram in Figure 12.

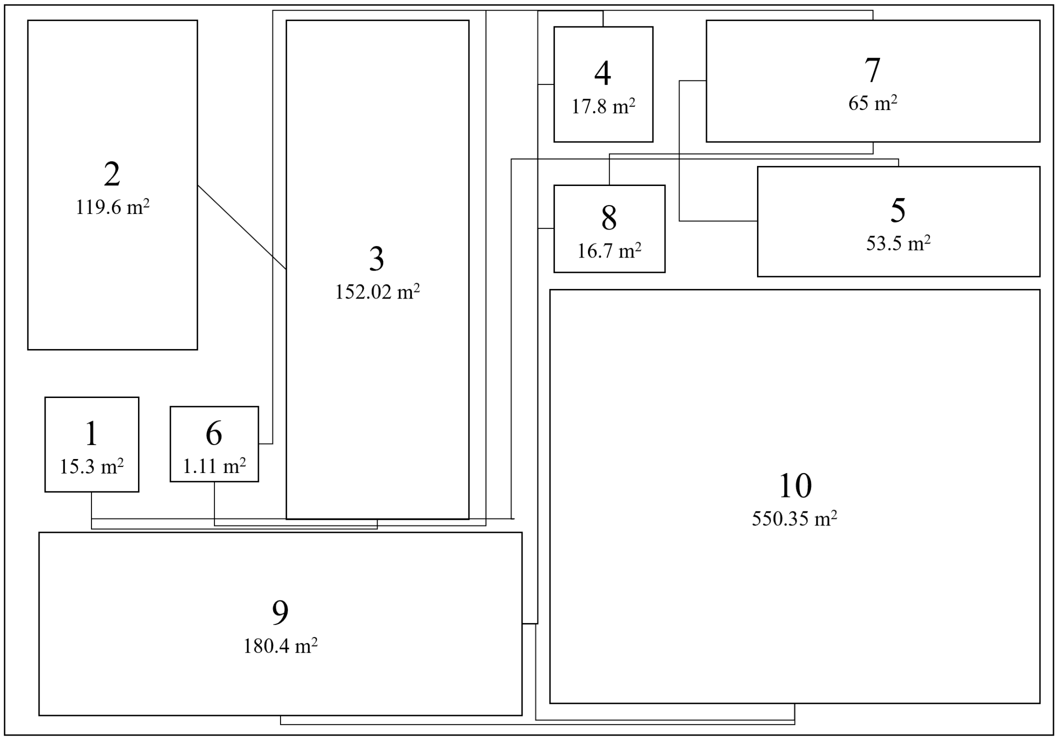


Figure 12. Space Relationship Diagram in Square Meters

To properly visualize the area, including the measurement requirements, a blueprint of the current plant layout needed to be retrieved. Subsequently, AutoCAD software was employed to design the most current existing layout. Drafting a blueprint, shown in Figure 13, of the current layout helped to proportionally draft and generate alternate layouts.

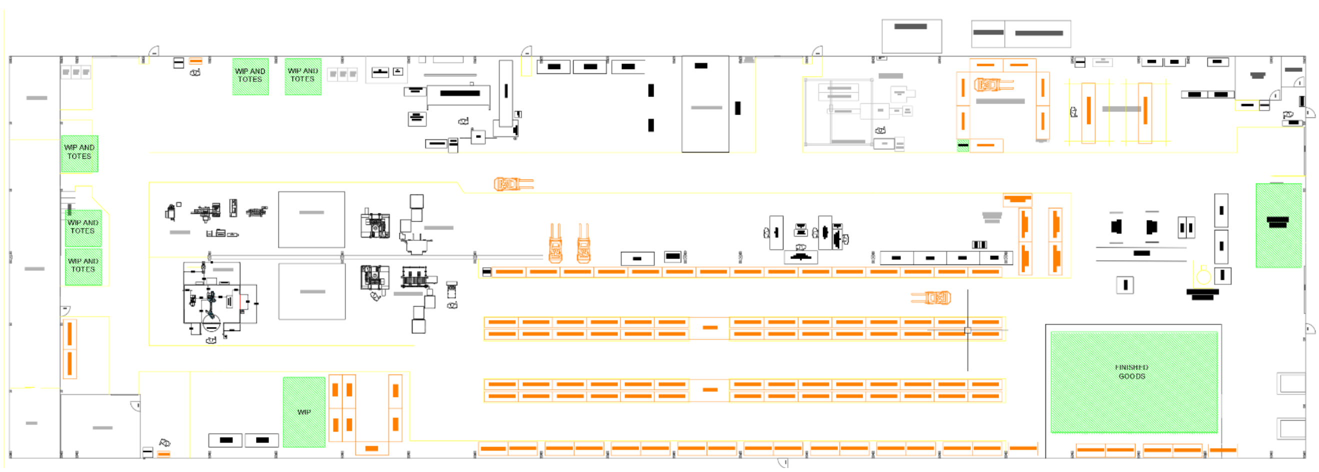


Figure 13**.** Current Plant Layout of Warren Facility

The existing plant layout doesn't consider an efficient arrangement of departments concerning its operational task. Data for the machine measurements and their relationship with the production flow was collected and analyzed according to SLP methodology. The product variety and product production quantity were assessed. The alternate layout designs started as conceptual designs derived from the engineering team sketches. After careful deliberations and discussions, the alternate draft layouts were narrowed down to three alternate designs. Accounting for the constraints and limitations of the designs such as storage areas, enough space between machines for WIP, clear pathways, and planning the layout to the electrical configurations. After careful consideration of the flow of materials, desired adjacency relationships amongst departments, and facilitating a manufacturing cell, *Phase III* is executed to create a more detailed layout plan.

5.2 Optimal Layout

Deciding on the optimal layout design was dependent on the SLP data inputs, the Simio model of the current simulation, and the discussions from the weekly meetings. It was a collective decision to use the opportunity to create a designated work cell area with the additional CNC machining equipment. Assembly has moved closer in proximity to the manufacturing area to enable easier workflow. This layout opened up a better range for operations at the Warren facility. Adding more CNC machines adjusted the layout to be more production-friendly rather than limiting the layout to first-run testing. Having the CS1 inspection tables neighboring the assembly department dramatically improves the flow of movement for workers and bettering efficiency. The saw crane department has been scraped completely as has become obsolete for the company. Therefore, the new layout transitions from idle machinery to better machine utilization. All these changes within the Warren facility are present in the blueprint for the designed optimal layout in Figure 14. The installation of the new layout is still in effect shifting toward the final phase of the SLP Framework.

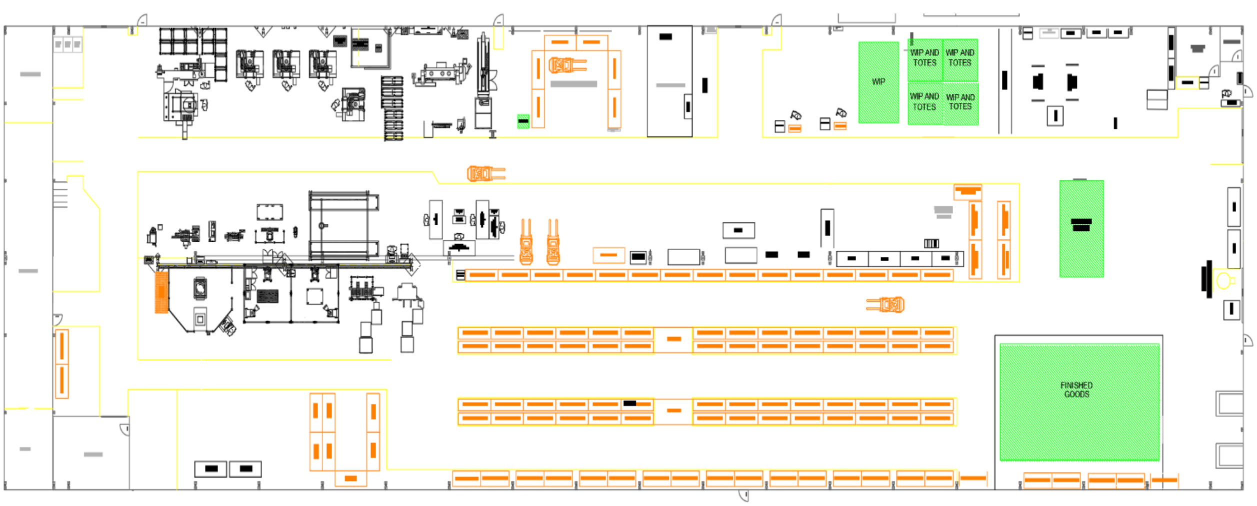


Figure 14. Optimized Plant Layout of Warren Facility

During *Phase IV*, there is more focus on implementing the design, ensuring all adjustments are made to meet safety, efficiency, and operational requirements. Key considerations include verifying OSHA compliance, optimizing equipment placement, and conducting final checks for workflow integration.

6. Statistical Process Control

X-bar and R-chart were applied to the processing time data for bracket production. The X-bar and R charts for machining/form processing times in Figure 15 on the Fadal CNC machine indicate the process remains stable. The X-bar chart shows the sample mean of 145.37, with control limits set at 146.574 (UCL) and 144.166 (LCL). The data point falls well within these limits, suggesting that the process mean is stable and under control. Similarly, the R chart range showcases the variability within the processing times are well within these boundaries revealing that the production for the bracket arm is consistent. These results ensure that the machining process is performing reliably and does not exhibit signs of special cause variation, making it predictable and suitable for continued production without immediate adjustments. The X-bar and R-chart shown in Figure 16 for machining on the Mazak CNC machine were found to reflect similar results, further concluding a stable process.

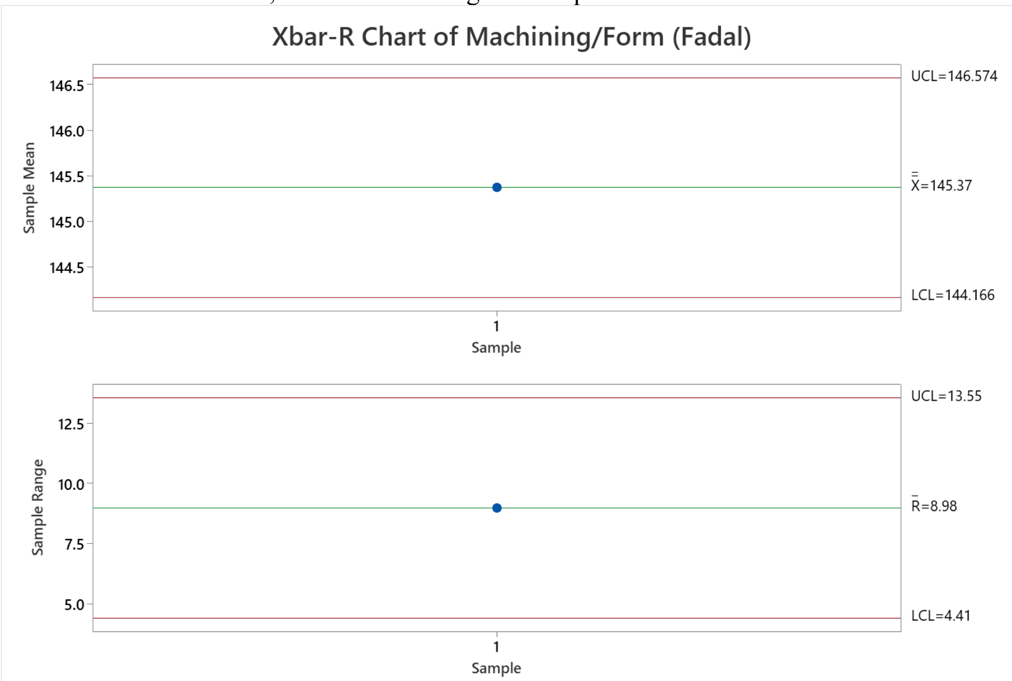


Figure 15. Xbar & Rbar Charts of Steel Bracket Arm Machining/Forming Processing Times in Secs

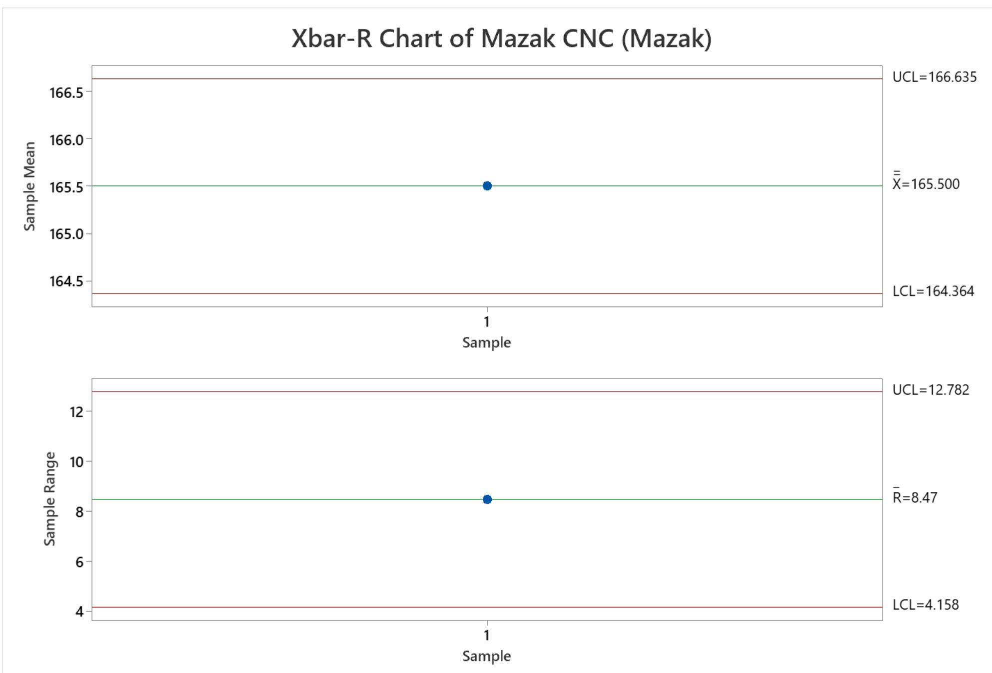


Figure 16. Xbar & Rbar Charts of Steel Bracket Arm Machining Processing Times in Secs

Capability Analysis was applied to determine the repeatability and stability of the current production of metal fixture products. The dimensions for the main areas of quality points were measured on 30 different pieces. The capability analysis reports were computed through Minitab software. The process capability report for machining/ forming in Figure 17 shows that the process has a mean of 145.37, which is slightly above the target of 145 seconds but remains within specification limits of 140 (LSL) and 150 (USL). The process capability conveys that the process is not wellcentered or capable of consistently meeting specifications. The overall process capability (Pp) is 0.65 which misses the benchmark of 1.33 for a capable process. The Cpk value of 0.60 indicates that the process mean is closer to the upper specification limit (USL), suggesting a slight bias in the process. While the process is stable based on the X-bar and R charts, the capability study shows that there is still variability within the processing times and better center the process around the target value. A capability analysis report was performed for the machining operation of the Mazak CNC machine as demonstrated in Figure 18. The analysis also shows that the process has high variability and is inconsistent in performance within specification limits. The processing standard rate is 165 seconds, while the processing times prove that there is still variation within this operation.

Although the machining processes are statistically stable, they are not capable of consistently meeting specifications, potentially leading to several risks for PMMCO's production system. A Cpk below 1.33 indicates a higher possibility of nonconforming parts resulting in an increase in scrap, rework, and customer dissatisfaction. To address these shortcomings, corrective actions should be implemented to further align the process mean closer to the nominal target (145 seconds) and reduce bias, minimizing the variability in cycle times. Standardizing operator practices through developing standard operator procedures, incorporating visual control aids, and poke-yoke fixtures can improve consistency across production. Expanding SPC monitoring across multiple machines and shifts would allow earlier detection of variation, reducing risks of producing out-of-spec parts.

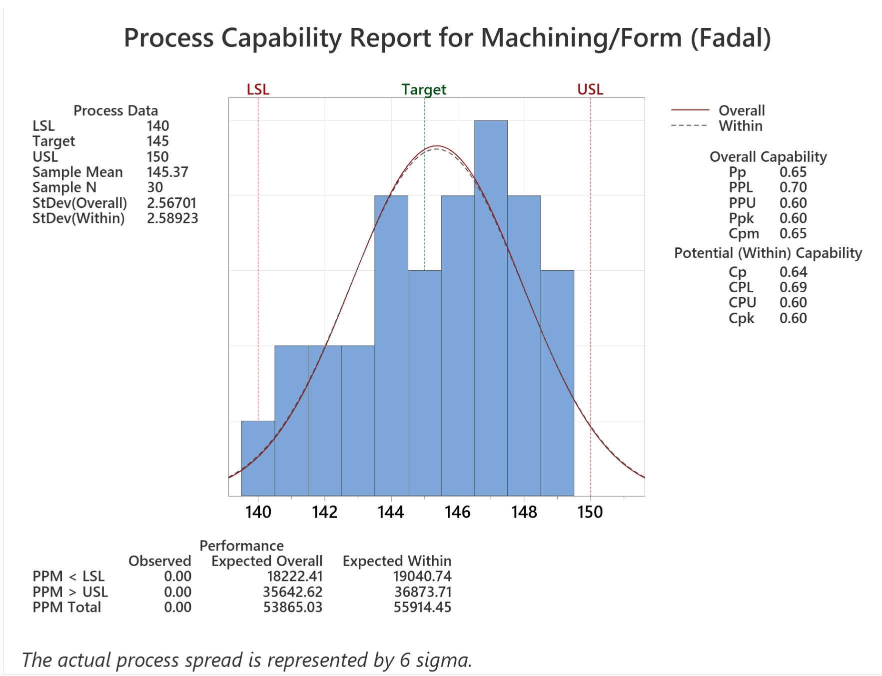


Figure 17. Capability Analysis Report of Steel Bracket Arm Machining/Forming Processing Times in Secs

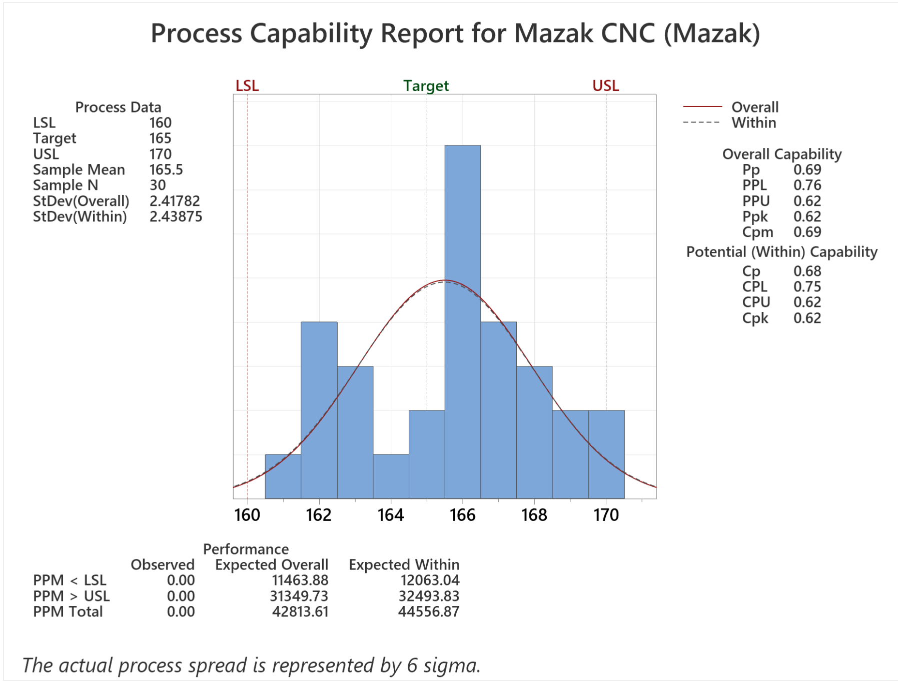


Figure 18. Capability Analysis Report of Steel Bracket Arm Machining Processing Times in Secs

7. Simulation

The simulation approach allows for the opportunity to analyze the performance of facility layout plans without interfering with the current plant. Several researchers employed simulation as a tool to study the performance of the chosen manufacturing system (Naranje and Reddy 2019). Simio software was utilized to design the simulation of the current and alternate plant layout. The simulation model acts as a digital twin for the current manufacturing facility. The layout mimics the internal logic and geometric constraints within the plant. The Simio model contains a library with user-defined components and statistical data. The approach of following an artifact state for the model to optimize via digital resources with different analytical solutions to attain an effective solution that can later be executed in reality (Sadar et al. 2022). Viewing the model visually with analysis of the data will determine the decision to transition towards automation for production.

The simulation considers a product-orientated flow, where the products that run in the model are followed through different departments. This is especially crucial to consider for PMMCO's processes in production, representing a high mix, low volume job shop environment where production is constantly changing according to the thousands of varying parts fabricated. The configuration of the Simio model needs to reflect the flexibility of the machines. Each part manufactured has its defining sequence, processing times, and setup requirements. The model specifies the processing time based on the part type. The current Warren production layout causes many machines to stand idle through production. These machines are not utilized to their full capacity due to the limited quantity of equipment necessary to perform full production. The simulation displays this bottleneck in production and machine utilization in Simio model results. To maximize utilization, the new layout considers transferring three milling machines and one tube bending machine to the

7.1 Simulation Model Logic

Replicating the behavior and pattern of production flow for products produced at PMMCO required inputting accurate data and logic that mirrors the current system. The Simio simulation model utilized different Simio character values to represent the real system and production process for steel bracket arm. This includes the use of entities to symbolize the parts produced in the plant, servers that act as the machinery equipment or the department services, a source, and a sink to replicate the part entering the plant (raw material) and being shipped to the customer.

Outlining the work schedule for the model constructed a time frame for the simulation to run and calculated production metrics appropriately. This was achieved by defining a standard work schedule table for the model to follow. In Figure 19 below, the set workday for PMMCO is divided into a day and night shift. During the day shift more workers are considered in the system and the working hours are 10 hours with allotted lunch and rest breaks.

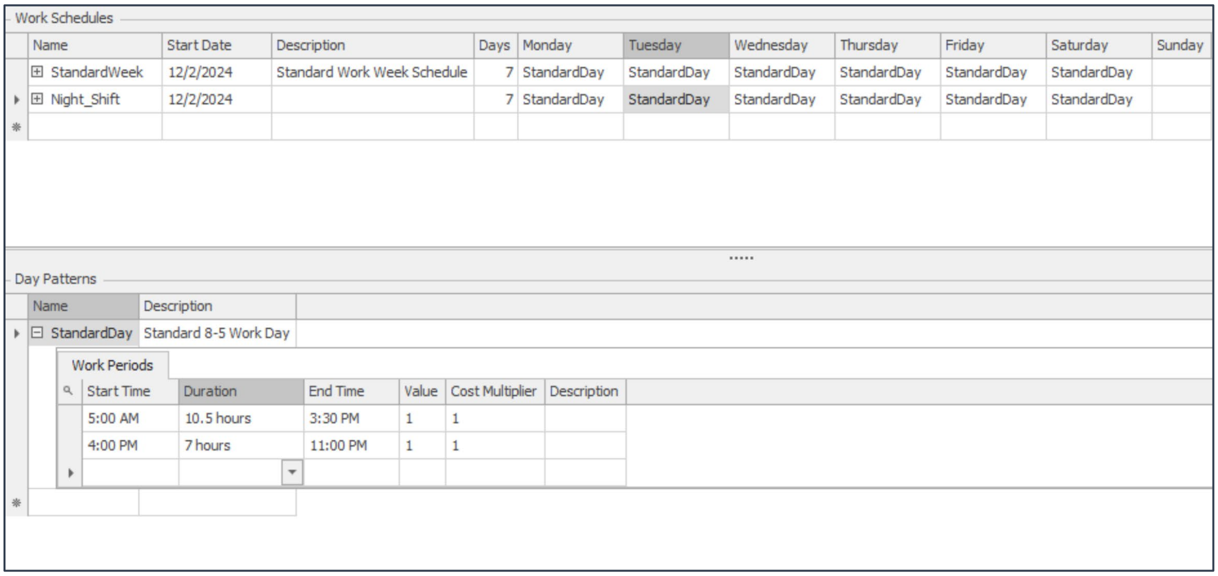


Figure 19. Production Work Schedule Hourly Input Data in Simio Model

The following consideration was the routing for producing the steel bracket arm at PMMCO in the current state. Rather than simply using path connectors to set the flow of production, the model goes a step further by defining the routing for the steel bracket arm as a sequence table. Per the flowchart for the bracket, the routing shown in Figure 20 reveals the sequence table that the model abides by. This table was used as a reference for the entity that represents part the bracket running through the system in the simulation.

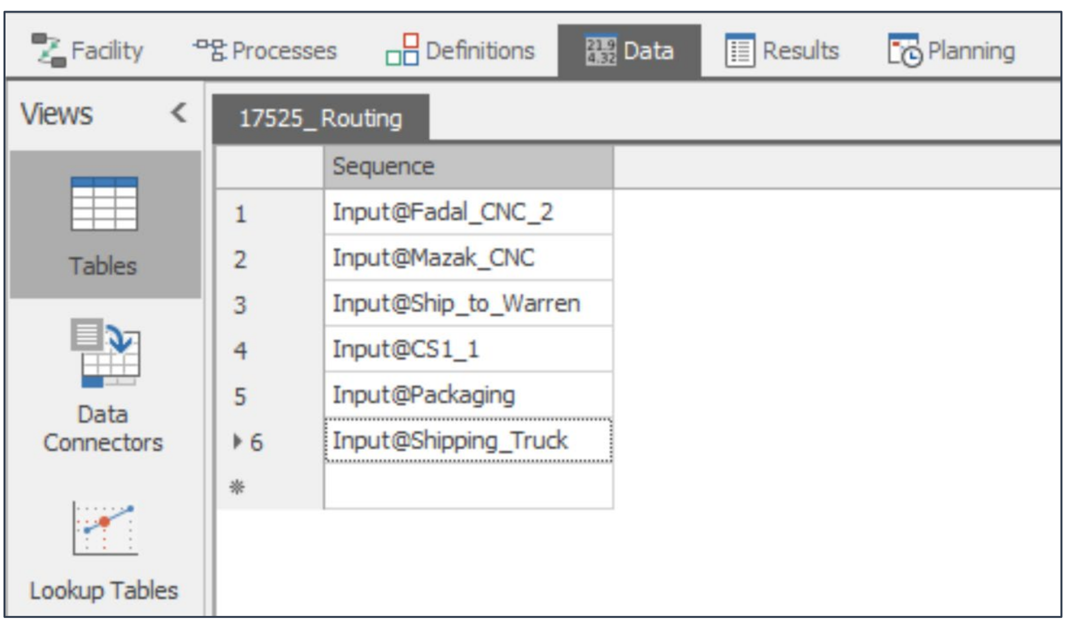


Figure 20. Routing Logic Input Data for Steel Bracket Arm in Simio Model

The Simio model utilizes a changeover matrix which is a matrix that derives their input values on a predefined list. The defined list followed the operational tasks to produce the bracket shown in a sequence string in Figure 21. The changeover matrix displays the sequence defined in the list as a from/to matrix, where each cell has the corresponding changeover time required to change from an entity with the "from" value to an entity with the "to" value (Smith and Sturrock 2024). The list along with its changeover matrix in the model is shown in Figure 22 below. The changeover matrix displays the time between each department in seconds.

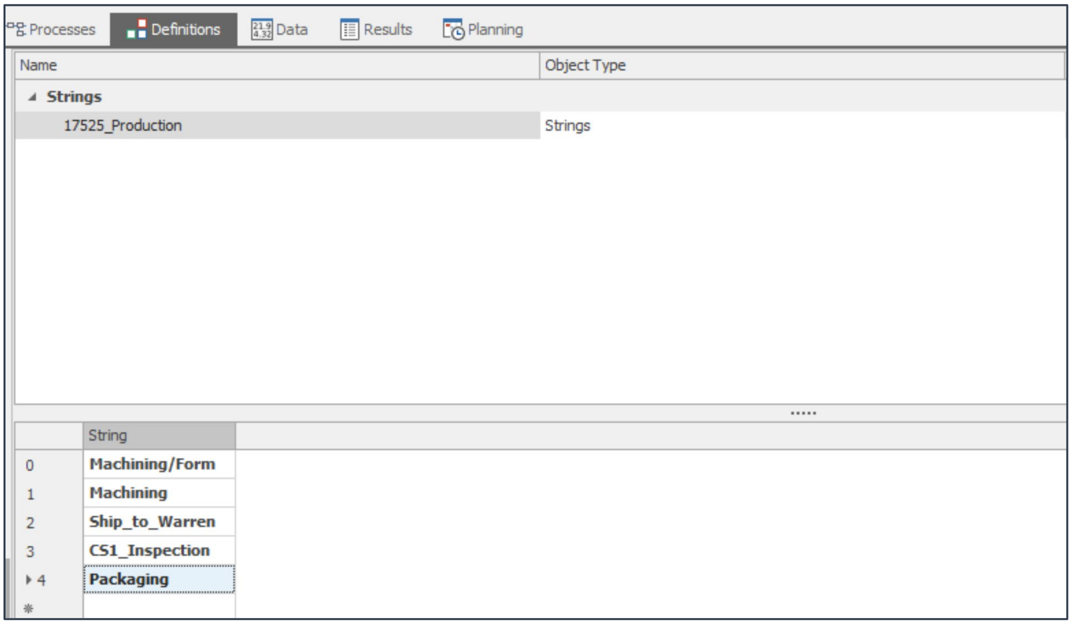
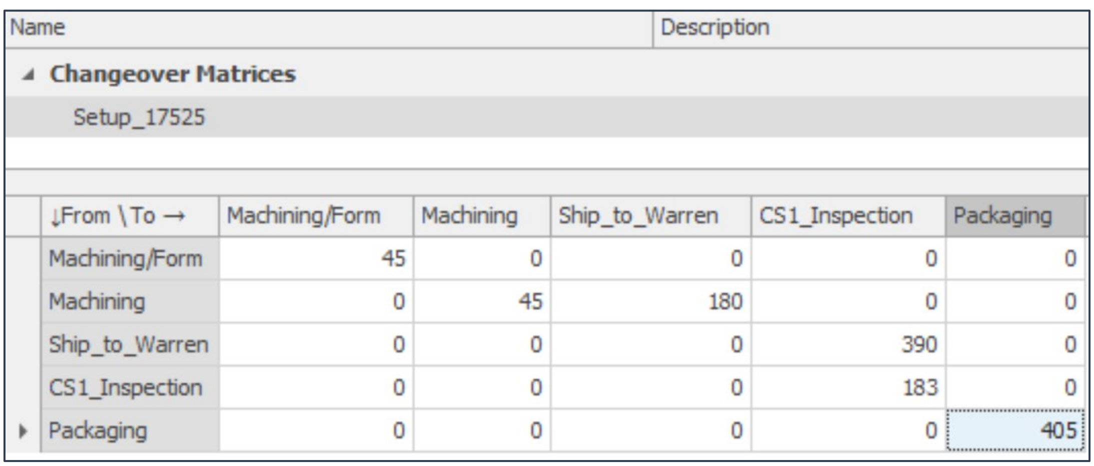


Figure 21. Steel Bracket Arm Department Setup Sequence List Input Data in Simio Model



Name	Description
Changeover Matrices	
Setup_17525	

↓From \ To →	Machining/Form	Machining	Ship_to_Warren	CS1_Inspection	Packaging
Machining/Form	45	0	0	0	0
Machining	0	45	180	0	0
Ship_to_Warren	0	0	0	390	0
CS1_Inspection	0	0	0	183	0
Packaging	0	0	0	0	405

Figure 22. Simio Model Logic for Steel Bracket Arm Setup/Changeover Matrix Time in Secs

Instead of connecting each server with a basic Connector, the model uses Paths, which calculates the travel time based on the entity's speed and the length of the defined path rather than being a zero-time transfer like a Connector. Having production for the bracket run through the servers using paths has allowed the model to simulate the travel times due to its drawn-to-scale property. A Path can be defined as one of two types, Unidirectional and Bidirectional. Unidirectional ensures that the travel route is only from the start node to the end node (Smith and Sturrock 2024). The Simio Model visually replicates the current production flow for the bracket which is currently having to flow through both facilities, Ferndale and Warren plant. A snapshot of the Simio Model design in alternating dimensional views is shown in Figures 23-28 below.

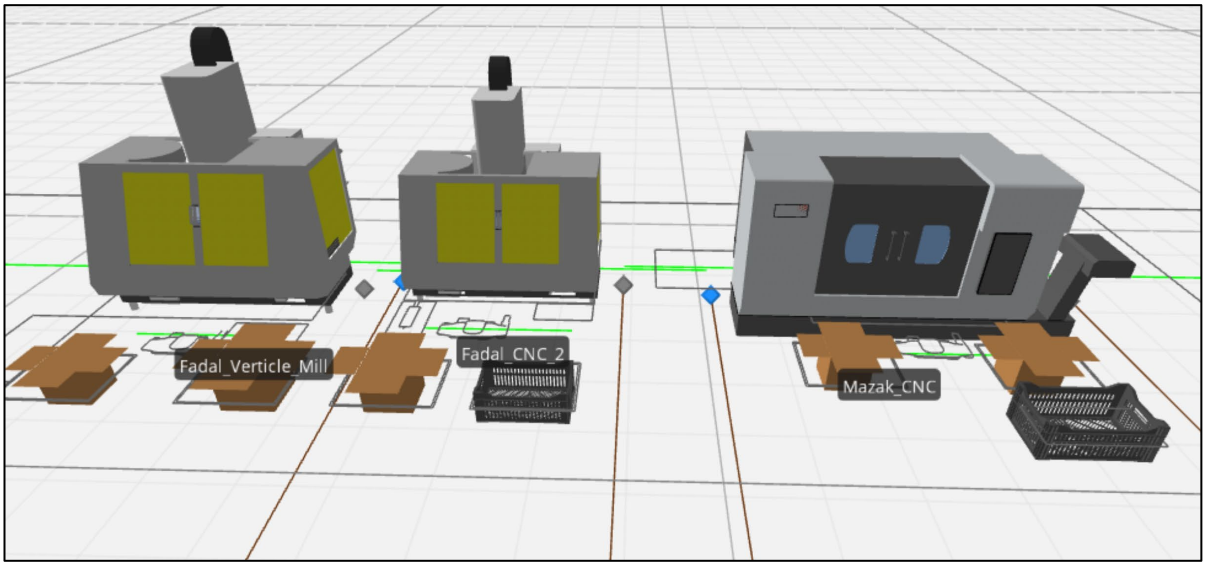


Figure 23. Ferndale Current Steel Bracket Arm Machining 3D View Simio Model

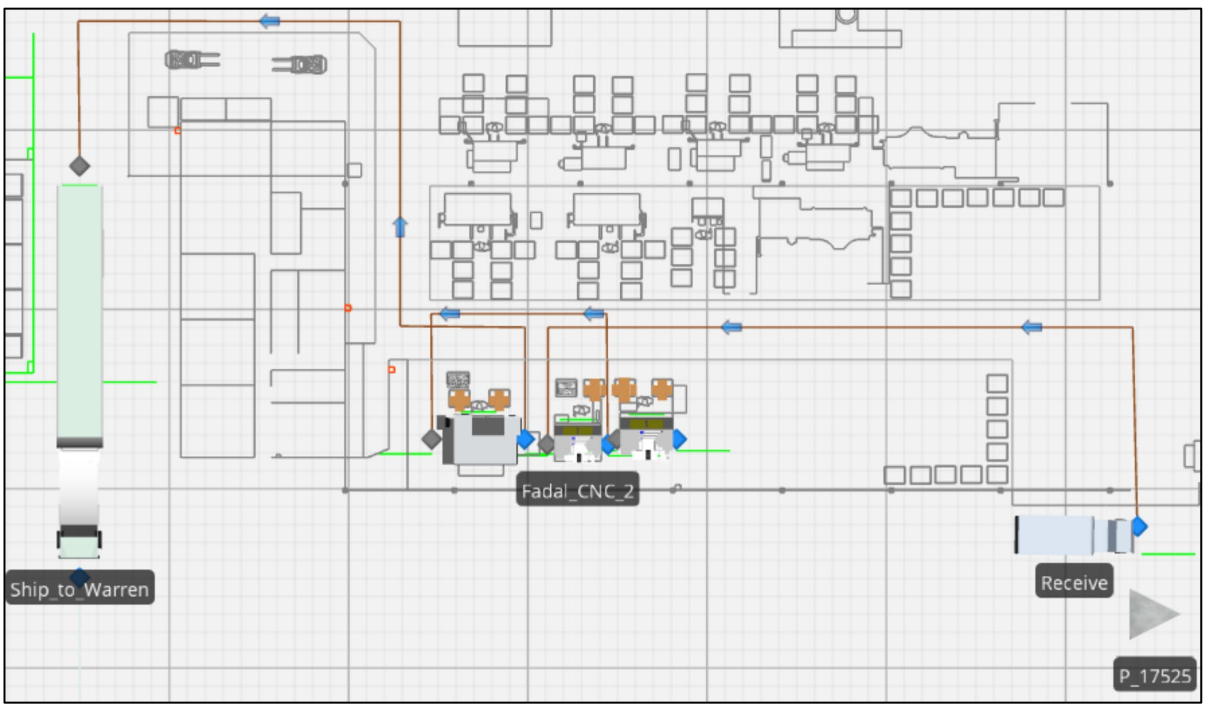


Figure 24. Ferndale Current Steel Bracket Arm Machining 2D View Simio Mode

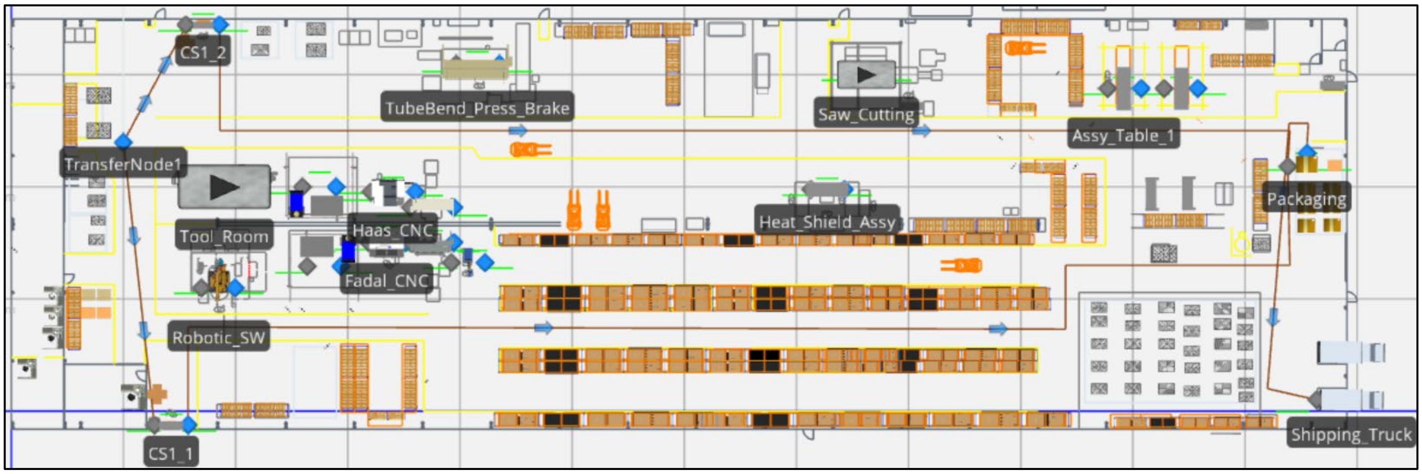


Figure 25. Warren Current Plant Simio 2D Model

Figure 26. Warren Current Plant Simio 3D Model North View

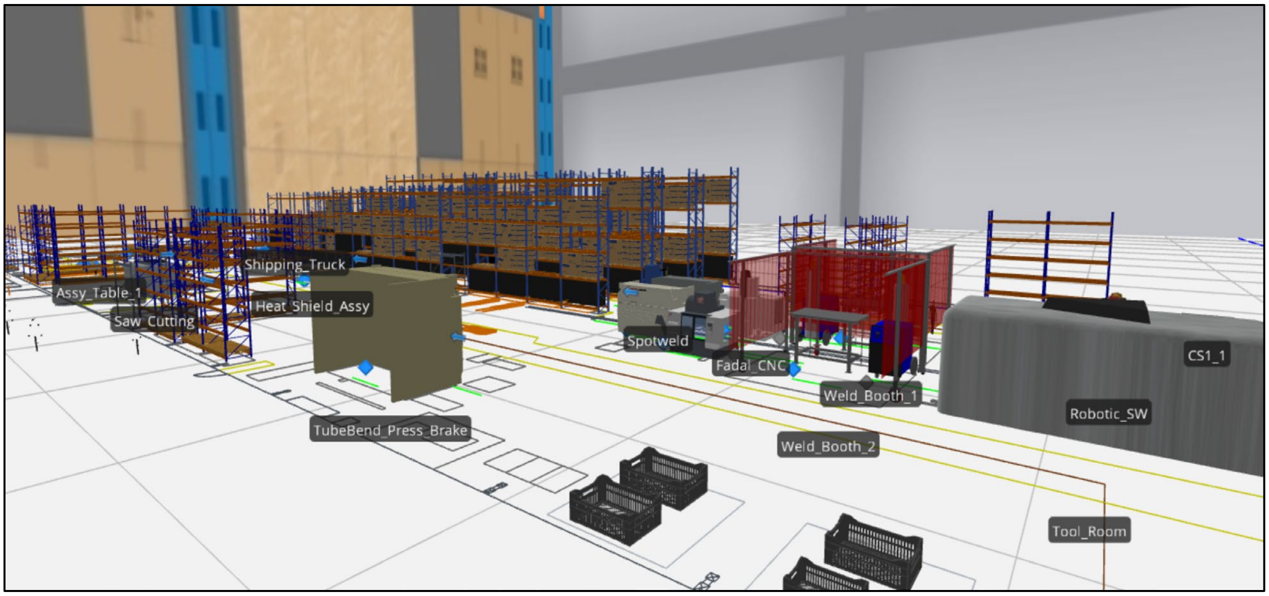


Figure 27. Warren Current Plant Simio 3D Model South View

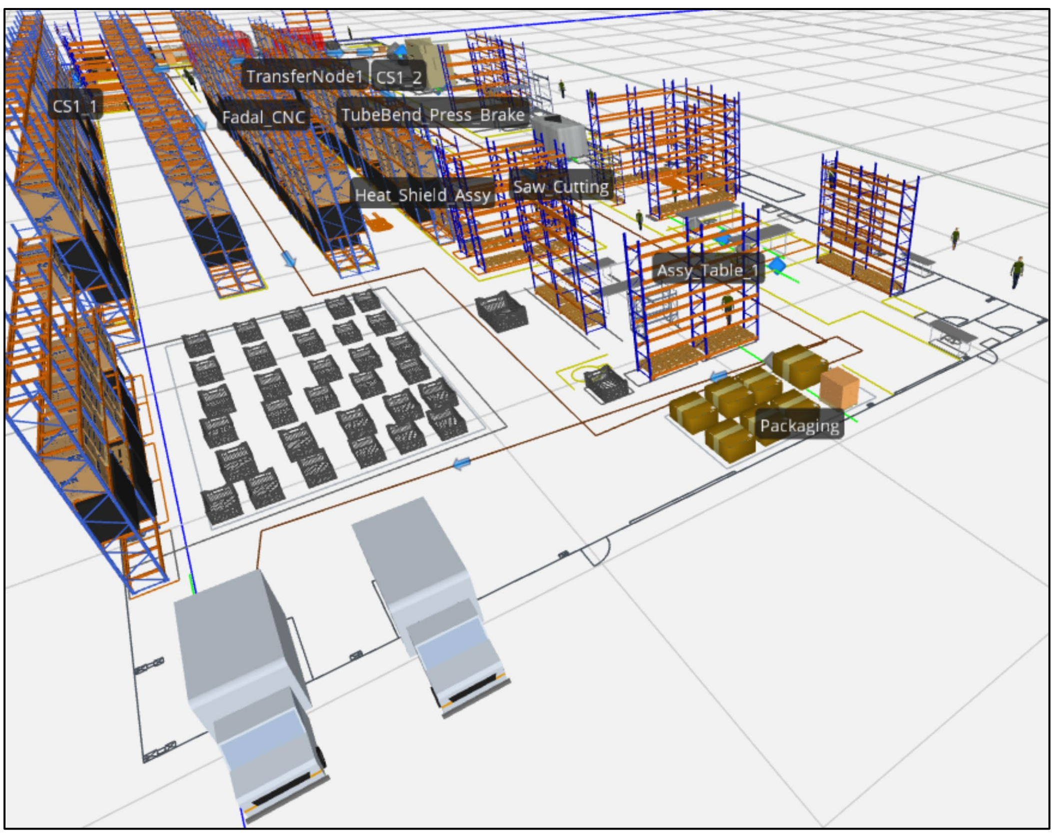


Figure 28. Warren Current Plant Simio 3D Model East View

As mentioned before the model for the bracket must run production in Ferndale, then be shipped to the Warren facility to conclude the following steps for the final product. This routing was modeled with respect to the actual distance between the facilities in Figure 29. The required routing stretches out production time by entailing considerable travel distance. The new optimized layout proposes that the steel bracket arm be produced in one facility cutting down the production time and significantly minimizing distance traveled. Although this model is true for one product, approximately 1800 products follow the same procedure, making this change critical to implement better production flow.

Figure 29. Current Travel Routing Distance for Steel Bracket Arm Simio Model in Square Meters

Running the Simio model under the following work schedule and routing decisions resulted in
The Simio simulation results provide insights into entity flow, system congestion, and resource utilization, which can all contribute to the layout of the plant. The simulation tracks the movement of entities through defined paths (mimicking the actual flow of production). The results from the Simio simulation for the model provided key insights into entity flow, system congestion, and resource utilization, all of which are critical to optimizing the plant layout. One substantial discovery was that the path connecting the Ferndale facility to the Warren facility consistently showed the longest time spent in the system. This delay is a key factor contributing to overall congestion, suggesting inefficiencies in the flow between the two facilities. Additionally, the simulation highlighted that certain servers remain idle for an average of 9.41-time units. These idle resources point to underutilization in the current layout and indicate potential bottlenecks. While some paths, like Path4, experience heavy traffic, others remain underused, which suggests an imbalanced layout that could be contributing to the delays and inefficiencies observed. To address these issues, adjustments in the layout are needed to reduce congestion between the two facilities, improve the utilization of idle machines, and optimize the overall flow of operations. Figure 30 represents the time series plot derived from simulation results.

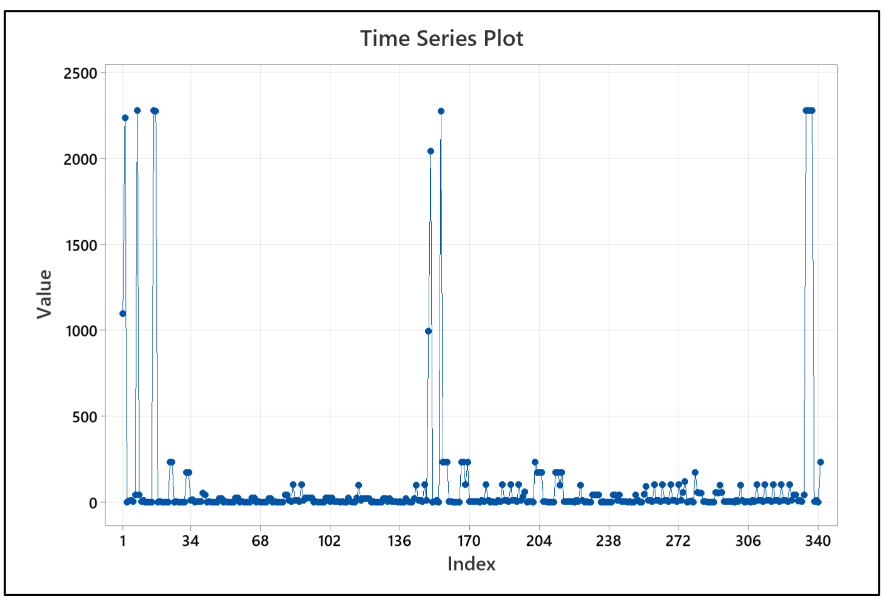


Figure 30. Steel Bracket Arm Time Series Plot in Seconds

8. Muda's 8 Wastes

Plant layout aims to enhance resource utilization and enables the application of lean tools such as 5S, the seven wastes, Kanban, and Just in Time (JIT). These tools are contributing factors in reducing costs and improving product quality (Ali Naqvi et al. 2016). When examining manufacturing systems, it is crucial to consider optimizing material handling technology to decrease cycle times. Time spent on materials handling (WIP) is considered waste during production. The design of the plant layout should facilitate a system that allows for operational tasks to be as functional as possible and is subject to numerous factors, such as the lot size, the number of components, and the distance between warehouses (Centobelli et al. 2016). During the analysis of the current plant layout and overall flow process, four of Muda's eight wastes were identified. The most prevalent waste was motion and transportation. Through the optimization of the plant layout, the concentrated work cells helped to eliminate the extra movement of personnel when performing production. By moving extra milling machines to the facility the need to transport product decreased, targeting a key waste in transportation.

9. 5s Methodology

The 5S methodology was well integrated into the plant layout design, with a particular focus on the shipping department desks. Before the implementation, the shipping desks were located in the middle of the shipping and receiving dock area. This placement often caused traffic congestion and unnecessary movements, hindering workflow efficiency.

By exercising the 5s methodology principles, Sort, Set in Order, Shine, Standardize, and Sustain, the shipping area was reorganized to streamline operations. Non-essential items were removed, and only tools and materials directly required for shipping were kept. The desks were pushed against the perimeter of the area, creating a clear and open pathway for material handling. Visual controls, such as labeling departments and designated pathways, were applied to ensure straightforward identification of storage locations and personnel movement. Regular cleaning schedules and standardized procedures are established to maintain the area's organization and cleanliness, ensuring long-term adherence to 5S principles. This redesign minimized unnecessary travel distances, reduced clutter, and improved safety and efficiency, ultimately creating a time-efficient and inexpensive solution to enhance overall productivity.

10. Improvements

The SLP technique offered the necessary steps and data to consider when designing the overall factory layout with respect to constraints like limitations in size, position, and unit relationship. Improving the plant layout via the SLP method is capable of decreasing the material flow considerably (Elahi 2021). A key improvement was developing a manufacturing work cell with additional CNC machining equipment allowing the Warren facility to attain better machine utilization and minimize distance traveled.

10.1 Limitations

This case study is based on a single product sample of 30 parts per machine, which constrains generalizability. Additionally, the results assume that the variability patterns observed scale consistently across other product families, which may not hold true given the company's nature of a low-volume, high-mix job-shop environment. Future studies should expand the sample size, include different product families, and validate scalability across multiple production runs.

11. Health and Safety (OSHA)

Although the space is limited within the facility, OSHA standards must be considered when designing an optimal plant layout to maintain safety within the work environment. Clear and open walkways must be enforced as well as ensuring the distance between machines isn't close enough to produce hazardous vibration levels. The walkways across the facility averaged between 5-8 ft to allow employees to walk clear pathways that are free from objects and obstructions. Machines should be spaced out to prevent hazardous vibration transfer and facilitate ventilation and noise reduction, aligning with OSHA's machine guarding standards. Electrical safety was a significant consideration, requiring 36-inch clearance in front of electrical panels, compliance with the NEC, secure wiring, and clearly labeled emergency shutoffs (Occupational Safety and Health Administration 2024). Ergonomic workstation design and accessible emergency exits guarantee adherence to OSHA's safety and efficiency guidelines. This reduces risks during inspections and promotes a safe workplace. OSHA standards must be prioritized to maintain a safe work environment.

12. Conclusion

This study effectively integrates discrete event-based simulation with the Systemic Layout Planning (SLP) framework to optimize the facility layout at Progressive Metal Manufacturing Company (PMMCO). The simulation results revealed key issues, including congestion and underutilization of certain machines, which were directly linked to the current layout. The new layout design enhances machine utilization, minimizes idle time, and improves the overall flow of operations, ensuring better alignment with the company's production needs. Specifically, the layout changes facilitate smoother transitions between the Ferndale and Warren facilities, reducing the excessive time spent moving entities between them, and increasing overall throughput. The updated layout expands the operational capacity of the Warren facility by strategically relocating key machines, such as additional CNC equipment and inspection tables, to optimize space and minimize workflow disruptions. The proximity of assembly areas to manufacturing zones has been improved, leading to reduced travel times and more efficient worker movement. By addressing bottlenecks and idle resources the optimal design ensures more balanced resource allocation. These changes collectively streamline operations, allowing PMMCO to achieve higher production efficiency in its high-mix, low-volume job shop environment. Therefore, combining simulation and lean principles to tackle complex layout challenges and deliver a more efficient manufacturing system. The proposed changes not only address current inefficiencies but also position PMMCO to better handle future production demands and maintain a competitive edge in the industry.

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Biographies

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