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Takt Time Reduction of Genset Assembly Line Using Process Optimization and Lean Manufacturing Tools

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Takt Time Reduction of Genset Assembly Line Using Process Optimization and Lean Manufacturing Tools

By

Ninad Joshi

A thesis submitted in partial fulfillment of the

Requirements for the Degree of

Master of Science

In

Manufacturing Engineering Technology

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This thesis has been examined and approved by the following members of the student's committee.

Dr. Kuldeep Agarwal, Advisor

Dr. Pawan Bhandari, Committee Member

Dr. Shaheen Ahmed, Committee Member

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NINAD JOSHI

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE DEGREE OF
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MINNESOTA STATE UNIVERSITY, MANKATO
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ABSTRACT

With rapid developments in the field of AI and data centers, there is a soaring demand for backup power and due to this, genset manufacturers are compelled to increase their throughput and reduce lead times.

This study focuses on incorporating process optimization and lean tools for lowering the overall takt time by reducing the cycle time of the generator assembly process of Line 1 at Rolls Royce Solutions America Inc. The eventual goal is to increase the throughput from 6 generators per day to 7 per day. The paper follows a step-by-step methodology starting from the problem statement and uses statistical analysis to monitor the data. The value chain is identified using the current state value stream map and the standard operating procedures (SOPs). The bottlenecks are singled out and a process improvement action plan is created. The process is monitored again after the changes are made in the assembly process and the results are recorded. A total reduction in process time of 30 minutes is achieved from Cells 2 and 3. The SOPs are adjusted again and an action plan for further scope of research is created.

Introduction

Due to the growing dependence on electricity in today's society and the rise in power outages caused by natural disasters, aging infrastructure, and cyber-attacks, backup power is increasingly important. A backup power setup ensures that vital operations continue in various industries. Providing backup power to healthcare facilities, for instance, ensures the safety and continuity of life support equipment, operation rooms, and other critical medical devices. Data centers and telecommunication networks can also benefit from backup power since it prevents data loss and service disruptions. Power failures can have a range of negative outcomes, ranging from inconvenience to life-threatening situations. Backup power systems help in eliminating these consequences by providing power supply to appliances and systems. It means keeping refrigerators running and maintaining heating and cooling systems to ensure comfort and safety. It also means keeping communication channels open so that emergency services and individuals can reach each other. As environmental calamities and cyber risks grow, backup power solutions boost preparedness and resilience. During crisis situations, they provide both individuals and organizations with a power source for sustaining operations and responding effectively to situations. Further, they contribute to energy security by reducing reliance on the power grid and expanding the range of energy sources available.

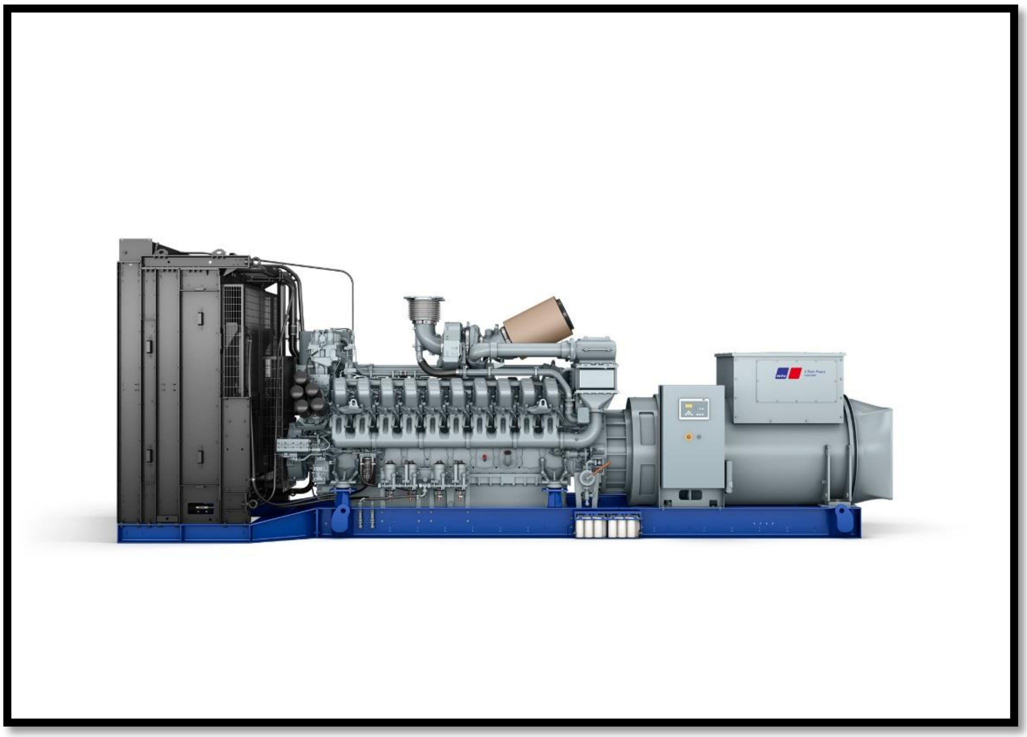


Figure 1. MTU Rolls Royce 4000 Series Genset

The Mankato division of Rolls Royce Power Systems is responsible for producing low and high-power range generators. This research focuses on Line 1, which is a mixed-model assembly line consisting of six workstations in total. Each workstation has different steps and process times, and the number of assemblers working on it.

Problem Statement

The company is trying to increase production from 6 units/day to 7 units/day by the end of 2024. This requires a time study to analyze the trends in current process times and to improve procedures that are currently causing variations and acting as bottlenecks. Streamlining processes keeping worker safety and ergonomics into consideration is one of the key objectives. The final goal is to make incremental improvements and achieve a considerable reduction in maximum process times to stay under the target takt time.

Literature Review

1. Introduction to Lean Manufacturing

1.1 Lean Manufacturing

There has been an ascending trend since the 1980s to adapt the concept of continuous improvement to enhance production efficiency. Several companies throughout the globe have faced challenges in maintaining product quality standards and growth. A new approach was developed by the Toyota Production System from Japan that established key manufacturing techniques, which is now known as Lean manufacturing. It has been consistently proven that implementing these techniques effectively can result in enhancements in processes (Womack et. al, 1990).

Many companies within the manufacturing sector still struggle to meet customer expectations. This is mainly due to extended lead times and late deliveries, causing issues for small businesses too. Despite investing in cutting-edge technologies and market strategies, these companies often fail to achieve growth or competitive advantage (Khadse et. al, 2003) (Rogstad, n.d.). One key contributing factor is the absence of a culture focused on improvement within organizations – a failure to instill the principles of lean thinking, among their workforce. However, only a small fraction of companies succeed in maintaining process improvement initiatives and fostering a culture of continuous training in their workplace. The core concept of improvement involves identifying value-added activities and transforming them into value-added ones. A lean process typically involves examining the operation of a plant initiating from materials to final delivery. A comprehensive understanding of value from suppliers to downstream customers is needed to implement lean principles.

Here are some core principles of lean manufacturing:

1. Customer Value: To clearly define what constitutes value from a customer's standpoint.

2. Smooth Flow: To ensure that all the value-adding processes are tightly interconnected to help assist in a seamless product flow towards the consumers.
3. Streamlining Value Flow: To map out the entire value stream and to get rid of any steps that do not contribute to value creation.
4. Just in Time (JIT) Production: To ensure goods are only produced as per the requirements of customers to avoid overproduction.
5. Continuous Improvement: To strive for perfection by refining the existing processes in small incremental steps, also referred to as ‘kaizen’.

1.2 7 Types of Waste

In a manufacturing environment, waste refers to any task or activity that does not bring any value to the producer or the customer (Womack, 2010). Various strategies and methods in management aim to remove these activities. It is estimated that almost 90% of actions in a production process are often regarded as wasteful. The fundamental principle of lean philosophy is to identify and eliminate waste as much as possible. Issues related to quality and management can also surface out while trying to target waste, which is very essential for a company. Following the Toyota Production System, seven types of waste are identified (El-Namrouty, 2012):

1. Overproduction: When operations continue past set periods, it leads to products being premature and increased inventory levels.
2. Transportation: This includes the movement of materials like work in progress (WIP) between two stages of operation. Minimizing transportation helps reduce process time and also prevents handling damage.
3. Waiting: Also known as queuing, this occurs when downstream processes experience downtime due to delays in activities.

4. Over Processing: This refers to activities operations like rework, handling, reprocessing, or storage that may arise due to overproduction, excess inventory, or defects.
5. Motion: This involves unnecessary movements by employees and equipment and consumes time without adding any value to the product or service.
6. Inventory: Inventory includes all the stock that is not immediately needed for customer orders including finished goods, work in progress, or raw materials. Managing inventories requires additional effort and space.
7. Defects: These are products or services that do not meet the required specifications or customer expectations, resulting in customer dissatisfaction.

All seven types of waste, also known as 'muda', are also identified as TIMWOOD, making them quickly memorable.

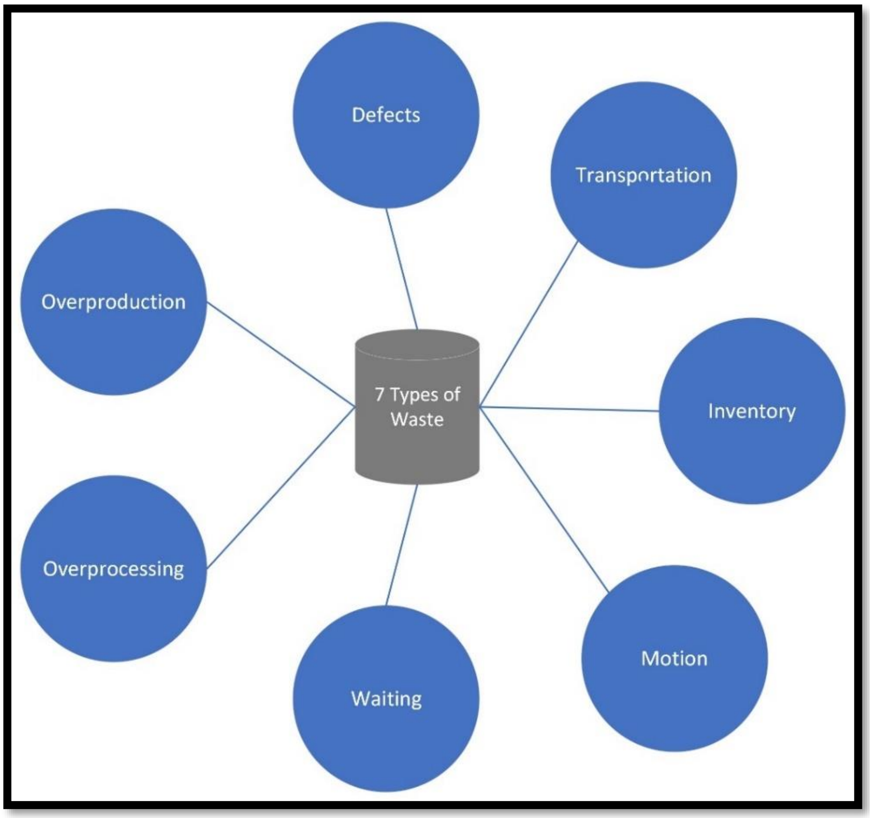


Figure 2. 7 Types of Waste

2. Key Concepts

2.1 Takt Time

The word takt dates back to the 1930s and is a German term for pulse or beat. It was initially used for airplane manufacturing and later adopted by other industries. Takt time refers to the rate at which a product must be produced to meet customer demand. It is a crucial factor in reducing waste and improving efficiency in production processes. Takt time is calculated using the following formula.

$$Takt\ Time = \frac{Available\ Production\ Time}{Customer\ Demand} \qquad \textit{(Wilson, 2009)}$$

Takt time is a guiding hand to lean manufacturing and Six Sigma methodologies since it assists in process improvement efforts and aligning production with actual customer demand. By making sure that only the right amount of value is delivered to the end consumer, takt time also helps in eliminating waste and overproduction. Various other factors like wait times, inefficiencies, and bottlenecks can also be reduced by aligning the production rates with customer demand. In addition to these benefits, it also helps in reducing storage costs by eliminating excess inventory of raw materials. Lastly, it provides a clear picture for identifying areas for continuous improvement. Companies can constantly evaluate and update their value creation process, thereby improving customer satisfaction and cost savings (Nagaraj et. al, 2015). Takt time can also serve as a standard reference in the identification of bottlenecks in an assembly process and should always be greater than cycle time which is defined below.

2.2 Cycle Time

Cycle time is one of the most important metrics that is used to measure the time required to complete a single task or process from start to finish. In an assembly line setting, cycle time would involve the actual working stage – from the time the product is at the initial workstation till it is ready for delivery. Since the term can be often misinterpreted, cycle time is generally classified as Production Cycle time and Process Cycle Time. Production Cycle time is the period between two consecutive production units at the end of the production process, whereas process cycle time is the total time the unit is being worked on at a given point in production (Wilson, 2009). Cycle time is calculated using the formula below:

$$Cycle\ Time = \frac{Net\ Production\ Time}{Total\ Number\ of\ Units\ Produced} \quad \text{(Wilson, 2009)}$$

It is important to understand that cycle time also includes any downtime and wait times associated with the production process. Downtime is referred to as the time during a production process in which the machine/equipment is not functioning and nothing is being produced, while wait time is the interval during production when the operator/machine is waiting for materials/changeover. By calculating the cycle time, an organization can reap numerous benefits. It can help improve resource allocation more effectively and ensure that sufficient resources are allotted to individual projects. It also results in better scheduling and planning which can aid organizations to meet the deadlines and boost the overall efficiency (Seth & Gupta, 2005). By monitoring cycle time, organizations can also pinpoint defects in the process, thereby achieving higher quality outputs. Overall, improvement in delivery times can be achieved by reducing cycle times resulting in better customer satisfaction.

2.3 Lead Time

Lead time refers to the total time starting from a customer placing an order to the product being delivered. It confines various stages including manufacturing, transportation, order processing, and delivery. It is affected by many factors such as production time, downtime, transportation time, and wait times (Sellitto, 2018). Lead time is a key component in evaluating the effectiveness of a supply chain.

2.4 Supply Chain

The supply chain involves all the key stakeholders starting from the suppliers, manufacturers, logistic companies, and distributors who play a crucial role in fulfilling a customer order from start to finish. In order to manufacture a tangible product, an effective use of the supply chain is very essential. From the procurement of raw materials to the delivery of the finished goods, every person plays a key role in ensuring that all issues within the supply chain are addressed and resolved within an appropriate timeframe. The end goal of any kind of supply chain is a satisfied customer.

Figure 3. A typical supply chain in manufacturing

2.5 OEE – Overall Equipment Effectiveness

Overall Equipment Effectiveness is a key performance indicator used to showcase how effectively a manufacturing process is operating. OEE value of 100 % indicates that only good parts are being produced, with no downtime. This is not practically feasible in a real manufacturing setting since the line needs to be stopped to perform critical functions such as changeovers, preventive maintenance, and sanitation. Generally, an OEE value of 85% is considered top-class. OEE is calculated using the following formula:

$$OEE = Availability \text{ x } Perfomance \text{ x } Quality$$

Availability is the ratio of the time that the assembly line ran to the time it could have run.

$$Availability = \frac{Run\ Time}{Available\ Run\ Time}$$

Performance is the ratio of the actual cycle time to the ideal cycle time. Ideal cycle time refers to the fastest cycle time a process can achieve.

$$Performace = \frac{Actual\ Cycle\ Time}{Ideal\ Cycle\ Time}$$

Quality refers to the ratio of good units produced to the total count of units produced.

$$Quality = \frac{Good\ Count}{Total\ Count}$$

The following formulas were retrieved from the research done by (Muchiri & Pintelon, 2008). It is crucial to consider these individual components while looking at OEE. They can be well utilized to provide insights into the root causes of lost productivity and decreased efficiency.

3. Lean Tools & Techniques

Various tools can be utilized to implement continuous improvement and lean manufacturing. Some of these tools are:

1. 5S: This tool guides in organizing a workplace to enhance efficiency and effectiveness. The five steps involved are Sort, Set in order, Shine, Standardize, and Sustain. Implementing this tool will always result in a well-organized and productive workplace.
2. Kaizen: In its application as a tool, kaizen involves events or activities that emphasize improvement (Kumar et al., 2010). Kaizen events typically involve term projects where a team collaborates intensively to enhance specific areas (Dana, 2014).
3. Kanban: This tool aids in efficiently managing action items by representing them using cards that indicate when these parts need to be moved through the production process. Kanban is essential in minimizing bottlenecks and has proven to enhance efficiency.
4. Value Stream Mapping (VSM): VSM as a tool illustrates the flow of materials and information as a product or service through the value stream. It helps in identifying areas of waste and opportunities for enhancement.
5. Just in Time: JIT strategy in production aims to minimize in-process inventory and associated carrying costs by producing only what is necessary, by when it is needed, and in the required quantity (Singh & Ahuja, 2012).
6. Poka Yoke: It is a mistake-proofing technique that works in a way that avoids the possibility of errors on an operator’s end. Poka Yoke devices and techniques assist in detecting and rectifying errors promptly.

7. Six Sigma: This is a vast field that focuses on reducing variability and enhancing quality standards using the DMAIC approach. The term stands for Define, Measure, Analyze, Improve, and Control and follows the same sequence to identify trends in data and analyze the root cause of the variability seen in the data. This approach also assists in improving and monitoring the new process to ensure stability.
8. Total Preventive Maintenance (TPM) : This tool strives to enhance production efficiency and minimizing downtime by maintaining equipments at regular intervals and making sure defects are getting repaired ahead of time.

3.1 Value Stream Mapping

Value Stream Maps play a key role in process streamlining and continuous improvement initiatives. It visually illustrates how materials and information flow through the value stream during the production or service delivery process (Kumar et al., 2022). This method plays a pivotal role in identifying inefficiencies resulting in delays and boosting equipment effectiveness (Miles, 2015). Given below are some of the advantages of using value stream maps:

1. Waste Identification: VSM helps in recognizing types of waste such as waiting times, unnecessary transport, extra processing steps, unnecessary motion, overproduction, and defects. This enables organizations to individually and strategically target these zones and help eliminate these inefficiencies.
2. Enhancing Efficiency: By identifying and removing waste, VSM aids in streamlining processes by reducing lead times and improving efficiency. This also results in cost savings and higher productivity.
3. Improving Communication: VSM fosters alignment and understanding by clearly communicating how processes function and where the improvements can be implemented.

4. Facilitating Continuous Improvement: VSM as a tool supports and advocates for enhancement of processes that are in line with the core principles of lean methodologies.
5. Improving Quality: Value stream maps also aid in pinpointing process bottlenecks and defects, and lays down areas prone to quality issues. This allows for flexibility in intervening to improve service quality and boost customer satisfaction.

The beauty of using VSM in organizations is that it depicts both their current and future conditions, thereby assisting in the implementation of small incremental improvements and tracking their effects. This also helps foster an environment that promotes progress and excellence in the long run.

3.1.1 Current State Value Stream Map

.

The current state map represents the current flow of material and information in an organization. It provides instant clarity about which workstation/stakeholder is the bottleneck and helps identify other key areas of improvement. By looking at a current state VSM, the reader can clearly understand what time each process takes and which time is nonvalue added. The forecast and information flow can also be easily comprehended. The map, however, cannot be used to include kaizen bursts and opportunities.

3.1.2 Future State Value Stream Map

While the current state VSM focuses on the present conditions, the future state map illustrates how a process will transform after implementing the desired improvements. It may involve the joining of two workstations, also known as cellular manufacturing, adjustment of inventory, and improved information flow to achieve the desired targets. A future state VSM helps companies focus on the changes and sets a standard for the employees to achieve.

3.2 Yamazumi Chart

The Japanese word Yamazumi means to stack up. It is basically a stacked bar chart that illustrates the process time workloads between various operating crew in a production floor or assembly line. The chart can either depict a single product time cycle or a multi-product line. The main objective of these charts is to present the work content of a series of tasks and facilitate work balancing and the isolation and elimination of non-value-added work content (Waghmare, 2016). The main benefit of implementing these charts is that the management can visualize the performance of the workforce and can also provide an assessment of what tasks are causing the most variation and taking up too much time. The bar graph consists of an X and Y axis. Each block represents the different steps, The X-axis represents different workstations or operators and the Y-axis represents the cycle time/time required to complete the particular tasks. These charts can also be color-coded for ease in understanding and analyzing the data. It makes achieving goals much easier by allowing readers to view and identify the areas of the process flow and the workstations that require optimizations. While creating a Yamazumi chart, one must be aware of the processes involved and the different teams of operators handling the job. It is always a benefit to have a target time that acts as a reference for comparison of data ("What is a Yamazumi chart and how it works," 2024).

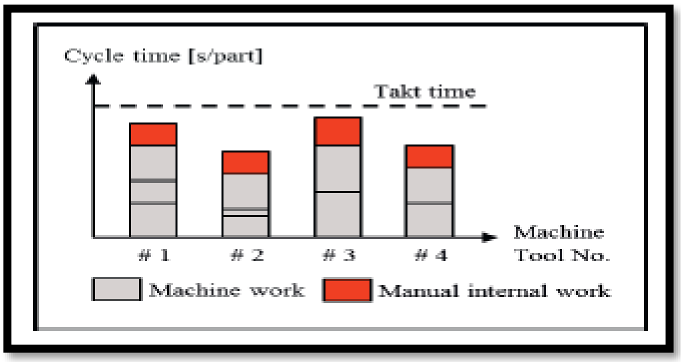


Figure 4. Example of Yamazumi Chart (Nagaraj et al., 2015)

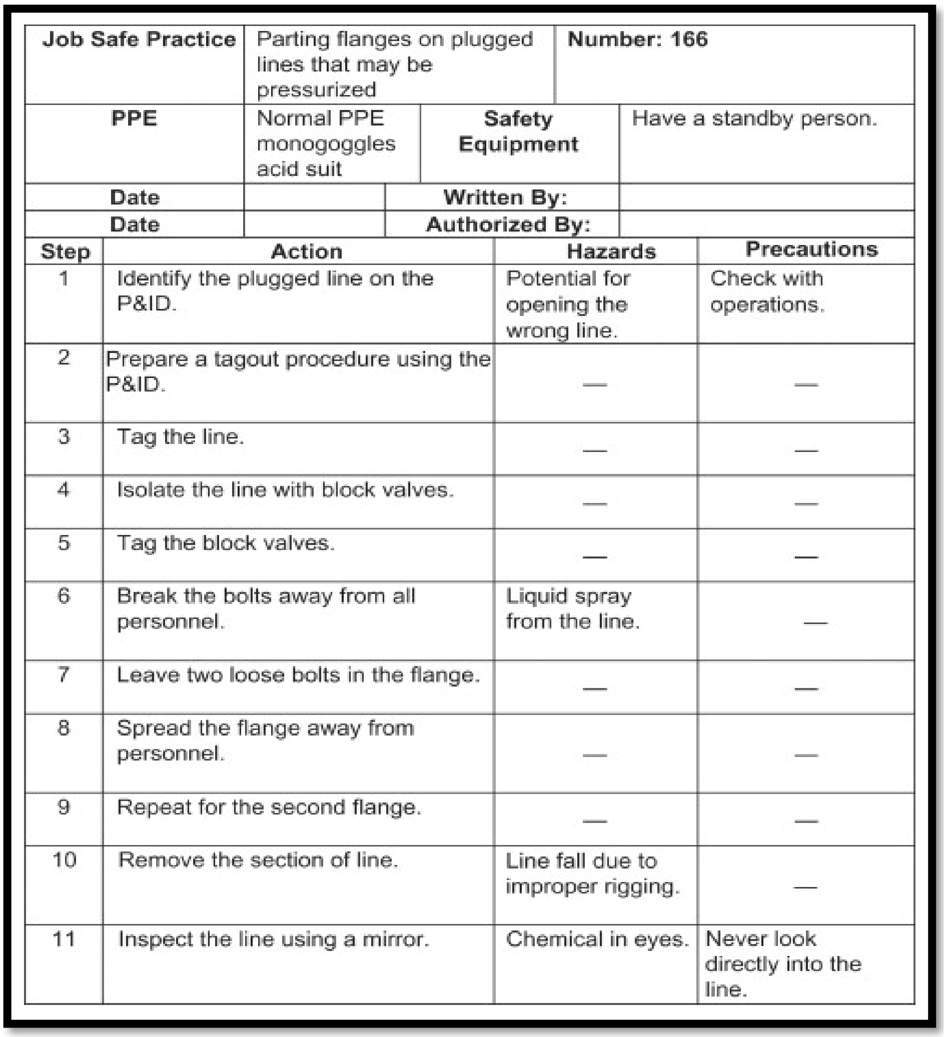
3.3 Statistical Process Control (SPC)

Statistical process control is a statistical method to evaluate and monitor the performance of a process by utilizing control charts to keep the process under control. It can also be used to differentiate between two types of variations, namely special cause variation and common cause variation. Common cause variation is the natural variation in any process that cannot be controlled or eliminated, whereas special cause variation is the unnatural variation that causes defects and process instability. It signals a positive or negative unanticipated change in the process. SPC is a large collection of problem-solving tools that help in reducing variability and help in achieving the target stability and capability. The seven major tools of SPC are the Pareto chart, histogram, cause-and-effect diagram, scatter plot, control charts, defect concentration diagram, and check sheets (Montgomery, 2020). For this research, we are going to use control charts that will help us identify the variations in the assembly process.

Control charts are graphical tools to present the performance of the process in statistical process control. They can help detect special cause variation and determine whether the process is in statistical control. There are various types of control charts, namely Xbar R chart, U chart, Np chart, etc. The Xbar chart monitors the process mean while the R chart monitors the variation within the subgroups. The Xbar chart is only valid as long as the R chart is in control. These control charts are very popular and in use in most U.S. industries since they are proven to improve productivity, are effective in defect prevention, and eliminate the need for unnecessary process adjustment. These charts can also help in the identification of patterns, which must be carefully assessed while monitoring a process. The pattern should not violate any of the rules for control charts.

3.4 Standard Operating Procedure (SOP)

SOPs are a set of work instructions used to train employees to perform a particular task from start to finish. It contains clear step-by-step instructions along with pictures to make sure there is no scope for error while completing the task. It helps workers carry out complex day-to-day operations with ease. SOPs aim to achieve efficiency and improve quality output by reducing miscommunication and lowering the risk of failure to comply with industry regulations. SOPs also help in fair performance assessments of every individual since everyone follows the same processes (Breaks & Duty, 2008) (Manghani, 2011).



Job Safe Practice	Parting flanges on plugged lines that may be pressurized	**Number: 166**	
PPE	Normal PPE monogoggles acid suit	**Safety Equipment**	Have a standby person.
Date		**Written By:**	
Date		**Authorized By:**	

Step	Action	Hazards	Precautions
1	Identify the plugged line on the P&ID.	Potential for opening the wrong line.	Check with operations.
2	Prepare a tagout procedure using the P&ID.	—	—
3	Tag the line.	—	—
4	Isolate the line with block valves.	—	—
5	Tag the block valves.	—	—
6	Break the bolts away from all personnel.	Liquid spray from the line.	—
7	Leave two loose bolts in the flange.	—	—
8	Spread the flange away from personnel.	—	—
9	Repeat for the second flange.	—	—
10	Remove the section of line.	Line fall due to improper rigging.	—
11	Inspect the line using a mirror.	Chemical in eyes.	Never look directly into the line.

Figure 5. Example of a SOP (Christiansen, 2024)

3.5 Continuous Improvement

In the manufacturing sector, production systems are facing the ongoing challenge of devising a process to boost output. To address this crisis, companies need a large chunk of workforce and resources to uphold growth and deliver top-notch products to their clients. By setting up a series of value-adding activities with the application of lean methodologies, an efficient process can be crafted. Several tools including motion analysis, value stream analysis, 5S methodology, design optimization, and bottleneck analysis can be utilized (Rother & Shook, 2003).

In today's competitive environment, industries must continually enhance their operations to stay relevant. Organizations can boost productivity and save costs by optimizing resources and reducing waste. Continuous improvement also gives manufacturers the freedom to adapt swiftly to changing customer needs, market trends, and industry standards to help them stay competitive. Six Sigma and Lean manufacturing are key methods that focus on boosting product quality by minimizing defects and reducing variations, thereby achieving higher customer satisfaction. Promoting a culture of improvement within an organization always encourages teamwork, dedication, and problem-solving abilities. By adopting this approach, companies can respond effectively to advancements, market variations, and regulatory changes for long-term stability. Lastly, by optimizing processes and boosting quality metrics, manufacturing firms can drastically improve profitability and achieve a higher return on investment (Magar & Shinde, 2014).

3.6 Assembly Lines

Assembly lines are essentially a series or group of workstations that are used in the production of a part. In manufacturing settings, different types of assembly lines cater to production needs and product characteristics. The selection of the type of assembly line is influenced by factors such as volume, the overall manufacturing strategy of the company, and the customization level required (Kumbhar et al., 2014). Mentioned below are a few of the varieties:

1. Traditional Assembly Line: This setup is best suited for mass production with minimal variations. This follows a setup where workers/machines perform the required tasks in a line before passing the product to the next station.
2. U Shaped Assembly Line: This setup contains workstations that are arranged in a U layout. The idea is to make it easier for workers to share tasks and facilitate collaboration.
3. Automated Assembly Line: These lines involve robots and automated machines that ensure precise, consistent, and swift production processes.
4. Mixed Model Assembly Line: This kind of assembly lines allows the production of distinct models and are assembled sequentially on the same line in an intermixed sequence.
5. Parallel Assembly Line: During scenarios where production levels are very high, parallel assembly lines can use several lines running at the same time.
6. Customizable Assembly Line: This allows products to be customized as they run along the line while using computerized control systems for flexibility. It is best suited for industries that run on product variety, like the electronics sector.
7. Lean Assembly Line: This line follows lean manufacturing principles that aim at creating an efficient workflow by simplifying the process and by reducing waste.
8. Progressive Assembly Line: The products in this type of assembly line move through stations with each station handling a task. The changeover of product from one station to another happens automatically and offers flexibility compared to other setups.

Methodology

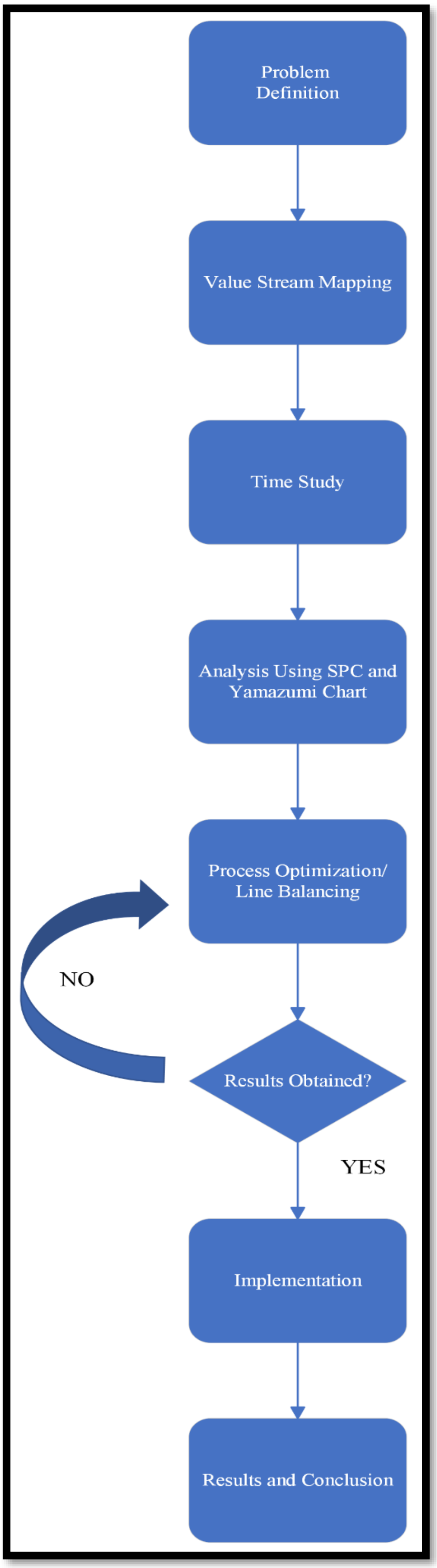


Figure 6. Thesis methodology

A step-by-step research methodology is followed for this study. The problem is first clearly defined and objectives are laid out. A precise current state value stream map is drafted to understand the process and information flow. This includes the necessary cycle time and lead time information along with the different forecasts both from the supplier and the customer side. A time study is then conducted on Line 1 for 10 consecutive days for the same type of unit to analyze the trends. This is done using a stopwatch for each assembler and the total process time at each workstation is taken into consideration. The total process cycle time is calculated by adding the time taken by each assembler to complete a task at each workstation. After conducting the time study, the data is then processed using both Minitab and Excel statistical software in order to understand the current trends and variations in the process times. Box plots and time plots are created along with the Yamazumi chart to identify which process times and workstations are posing as bottlenecks. After the identification of the constraints, an action plan is laid out to streamline the processes and achieve a considerable reduction in the process times. A time study is conducted again to see if there are any changes. If the process times are not reduced, the step of line balancing or process optimization is conducted until considerable reductions are achieved. The results are clearly mentioned along with the future plan of action to achieve the target reductions in other workstations as well. The research finally ends with a brief conclusion of what was achieved and how the efficiency of the line was increased with the help of all the lean manufacturing tools used.

Analyzing the Current Value Stream

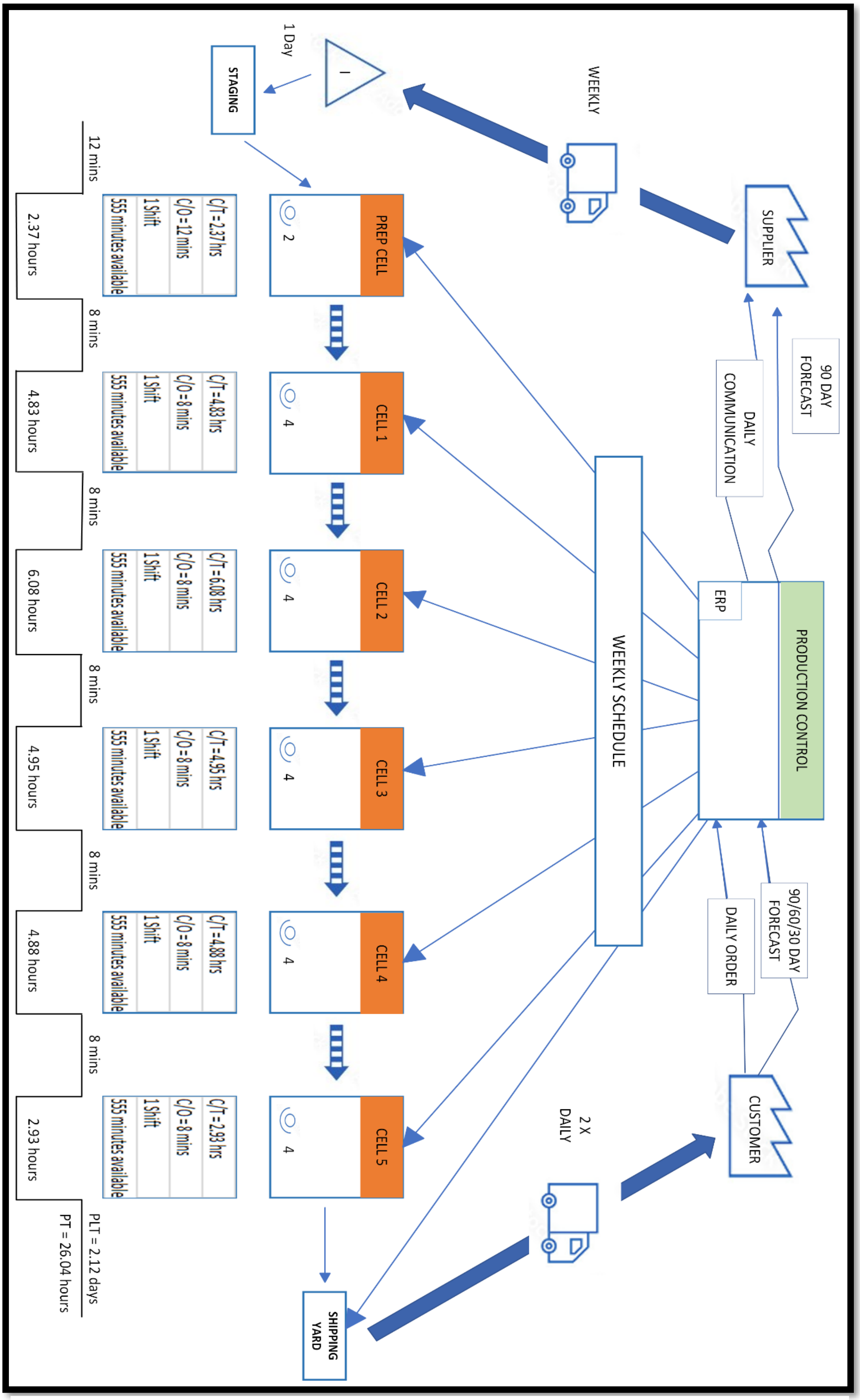


Figure 7. Current State VSM

The process starts from the prep cell and ends at Cell 5 after which is sent out for testing and shipping.

Data Collection and Analysis

Time Study to Analyze Trends in Process Times

Table 1. Time Study of Process Cycle Time

Days	Prep Cell	Cell 1	Cell 2	Cell 3	Cell 4	Cell 5
Day 1	140	340	339	355	325	215
Day 2	132	362	365	373	354	202
Day 3	187	391	386	352	374	244
Day 4	121	344	348	359	436	180
Day 5	191	379	369	379	387	208
Day 6	147	347	405	353	384	201
Day 7	182	334	388	351	381	196
Day 8	184	346	362	364	379	210
Day 9	146	372	359	370	422	211
Day 10	154	346	357	359	351	205

The data was recorded for 10 consecutive days (2 weeks) and the time shown above is in minutes.

Target Takt time calculation for Increasing Throughput

$$Takt\ Time = \frac{Available\ Production\ Time}{Customer\ Demand}$$

The shift runs for 10 hours and there is a total break of 45 minutes throughout the shift. This brings the available production time to 555 minutes a day. We are trying to target 7 units a day, so this is our customer demand for target takt time.

$$Tkt = \frac{555}{7}$$

$$Target\ Takt\ time = 79\ minutes$$

Yamazumi Chart before Improvement

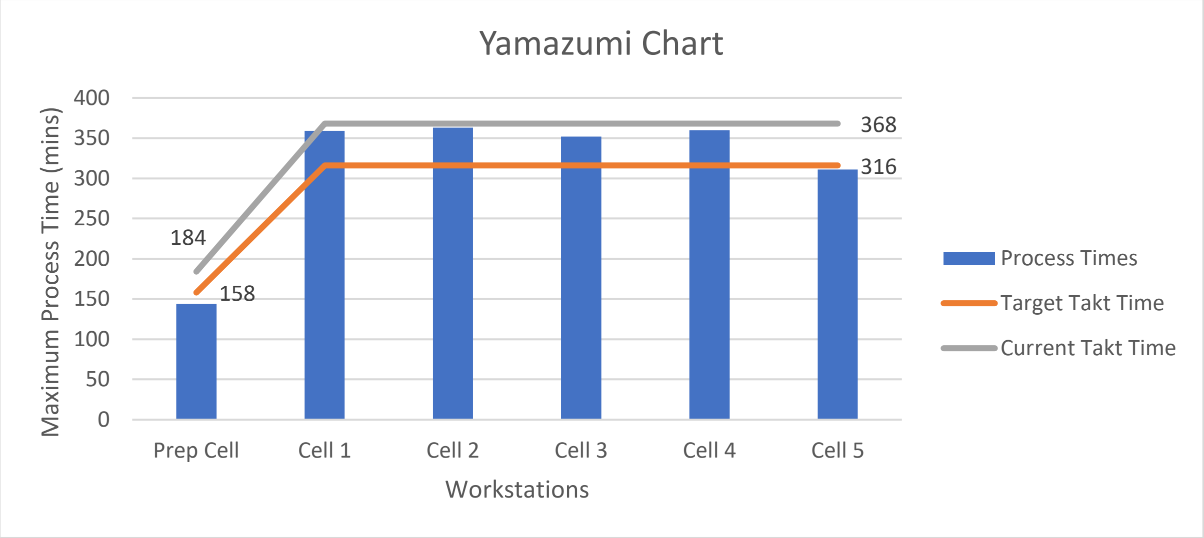


Figure 8. Yamazumi Chart before process optimization

The chart shows Cell 1,2,3 and 4 have process times that are way above the target takt times and need to be worked upon. Prep cell and Cell 5 are still very much under control and should be workstations to not focus on for the purpose of this study. It is also important to note that all the workstations are still under the current takt time level, which shows the process is stable and working efficiently.

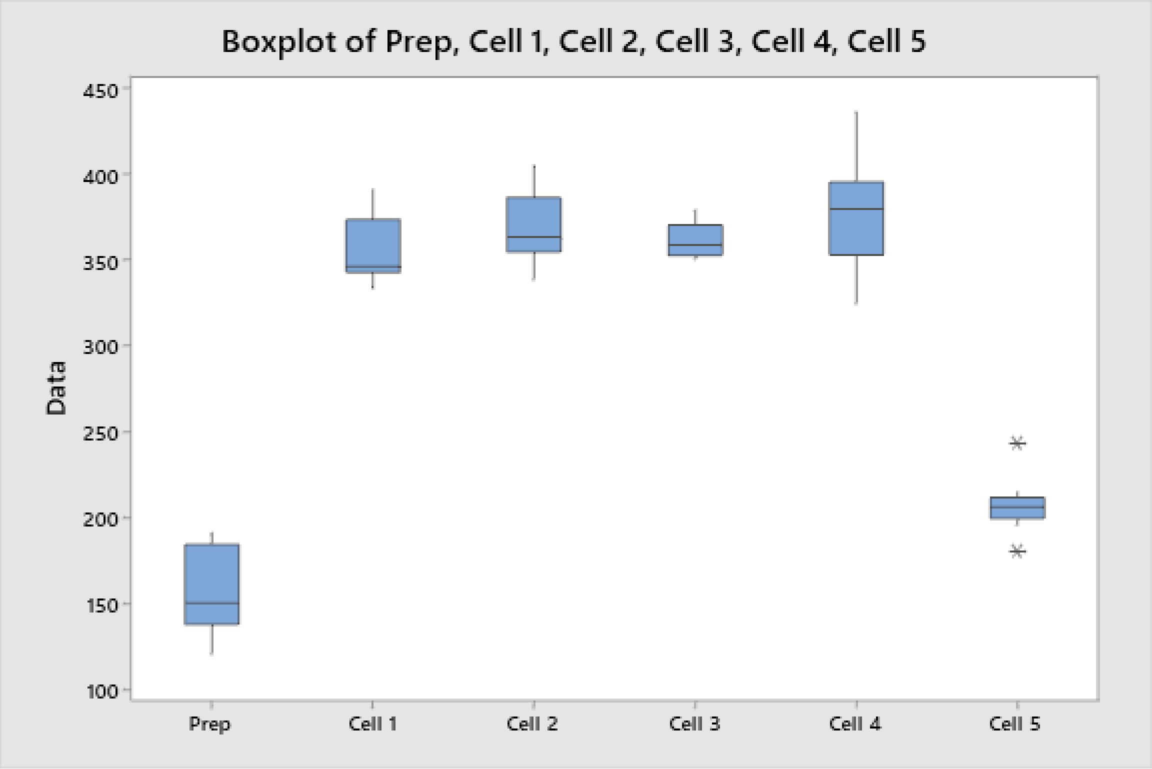


Figure 9. Box Plot of Time Study Data

Though there is some variation in cycle times, none of the data points lie outside the control limits, indicating that the process is stable.

The variations can arise due to:

1. Worker Speed
2. Fatigue
3. Training
4. Man dependent process

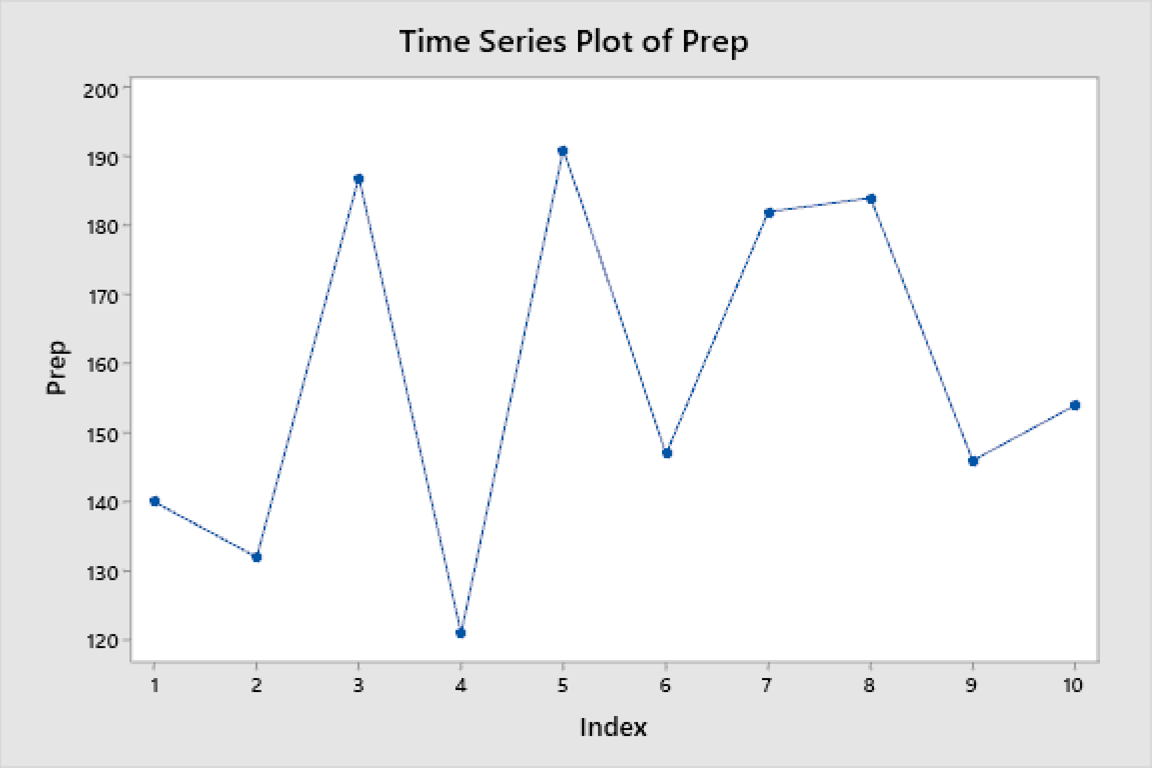


Figure 10. Time Series Plot of Prep Cell

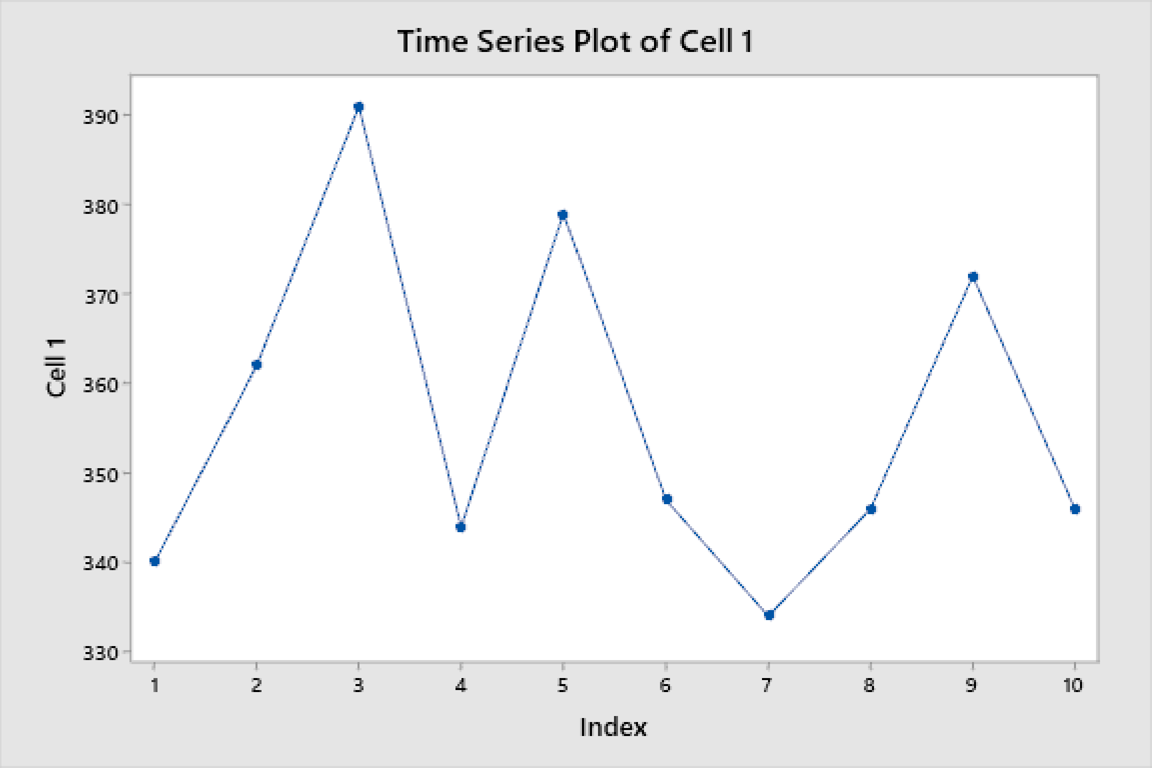


Figure 11. Time Series Plot of Cell 1

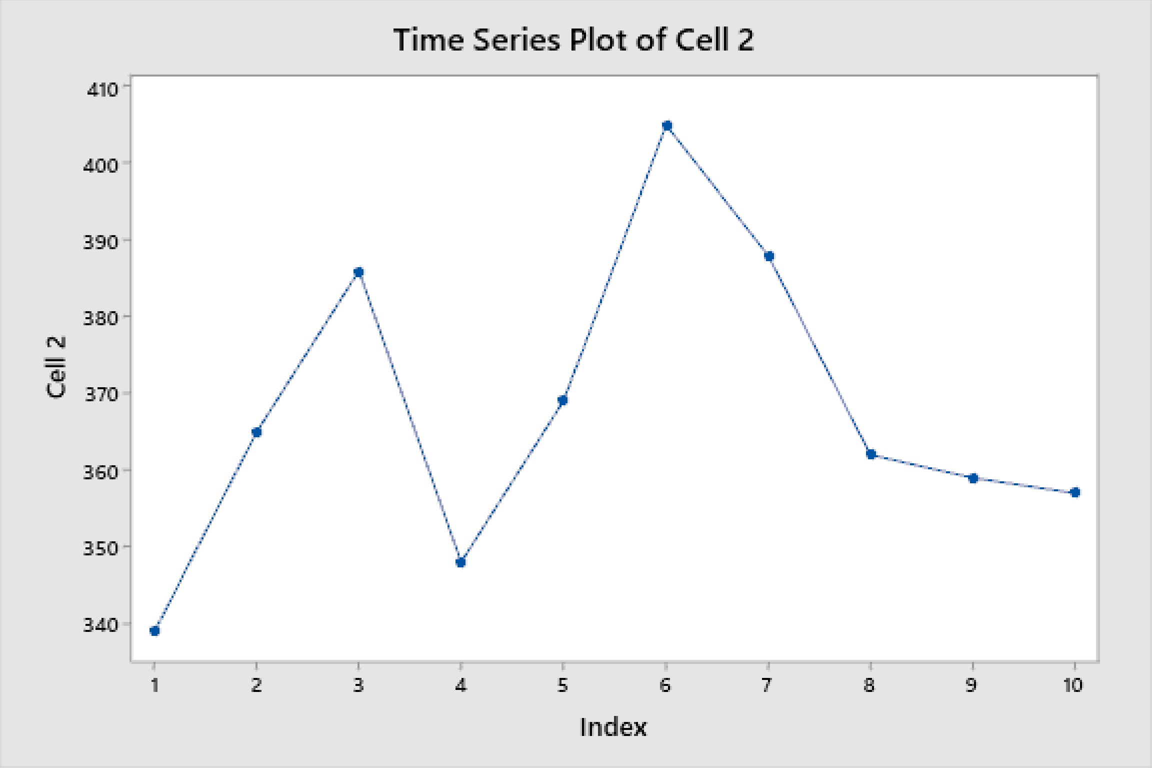


Figure 12.Time Series Plot of Cell 2

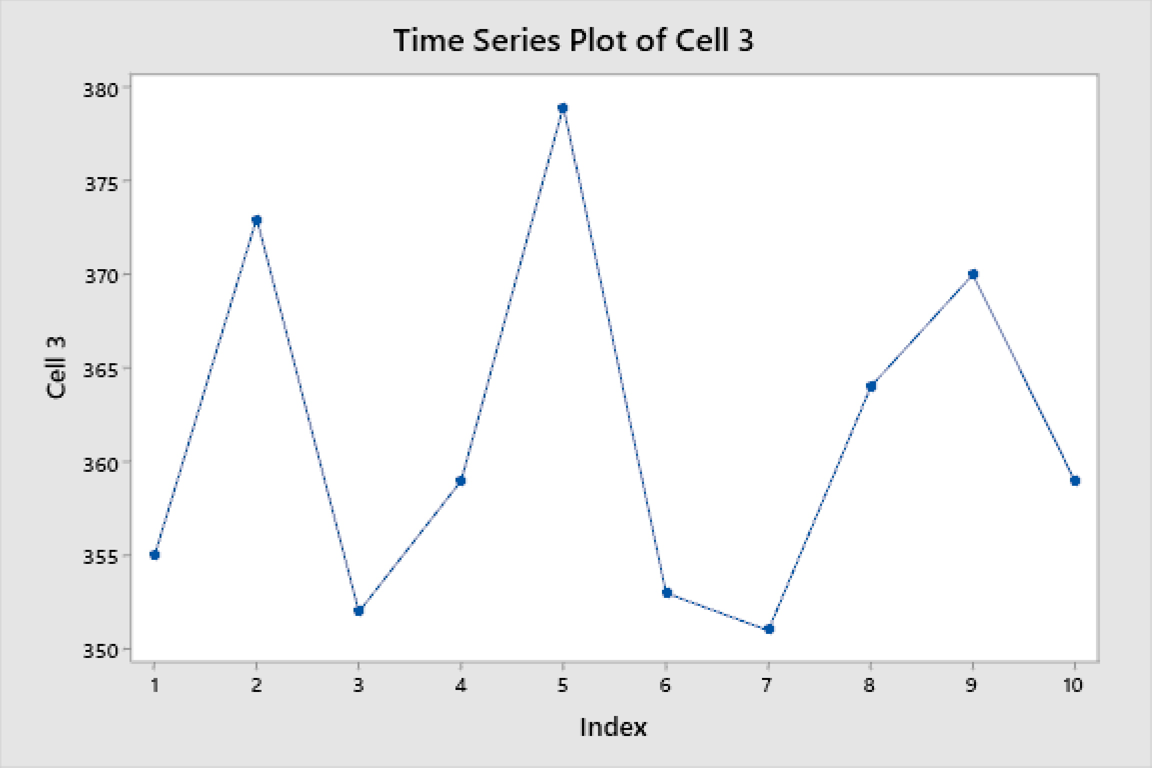


Figure 13. Time Series Plot of Cell 3

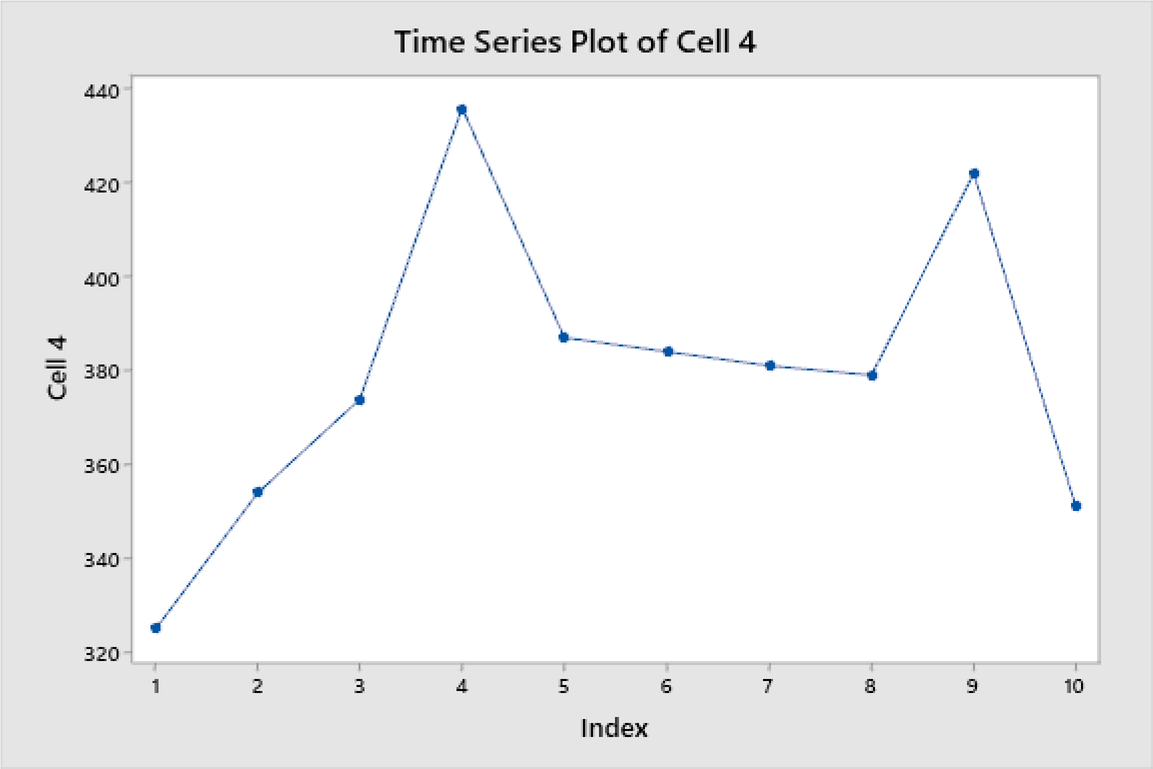


Figure 14. Time Series Plot of Cell 4

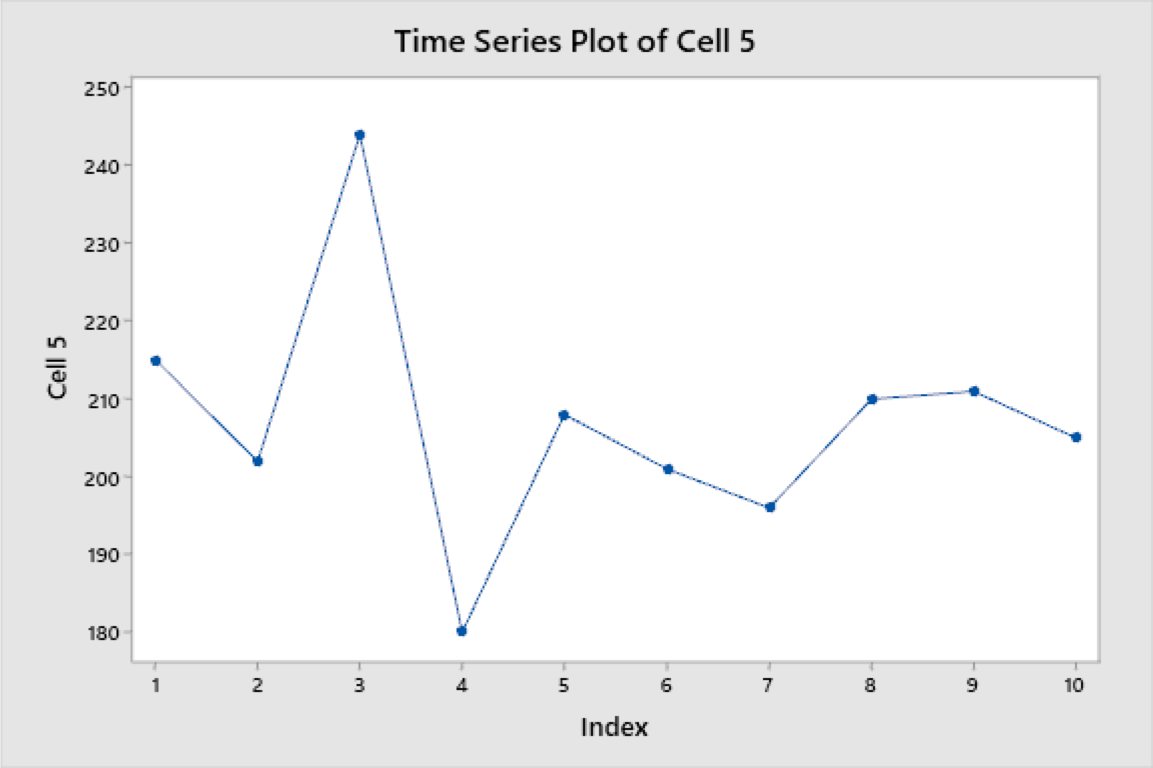


Figure 15. Time Series Plot of Cell 5

VSM Showing Opportunities

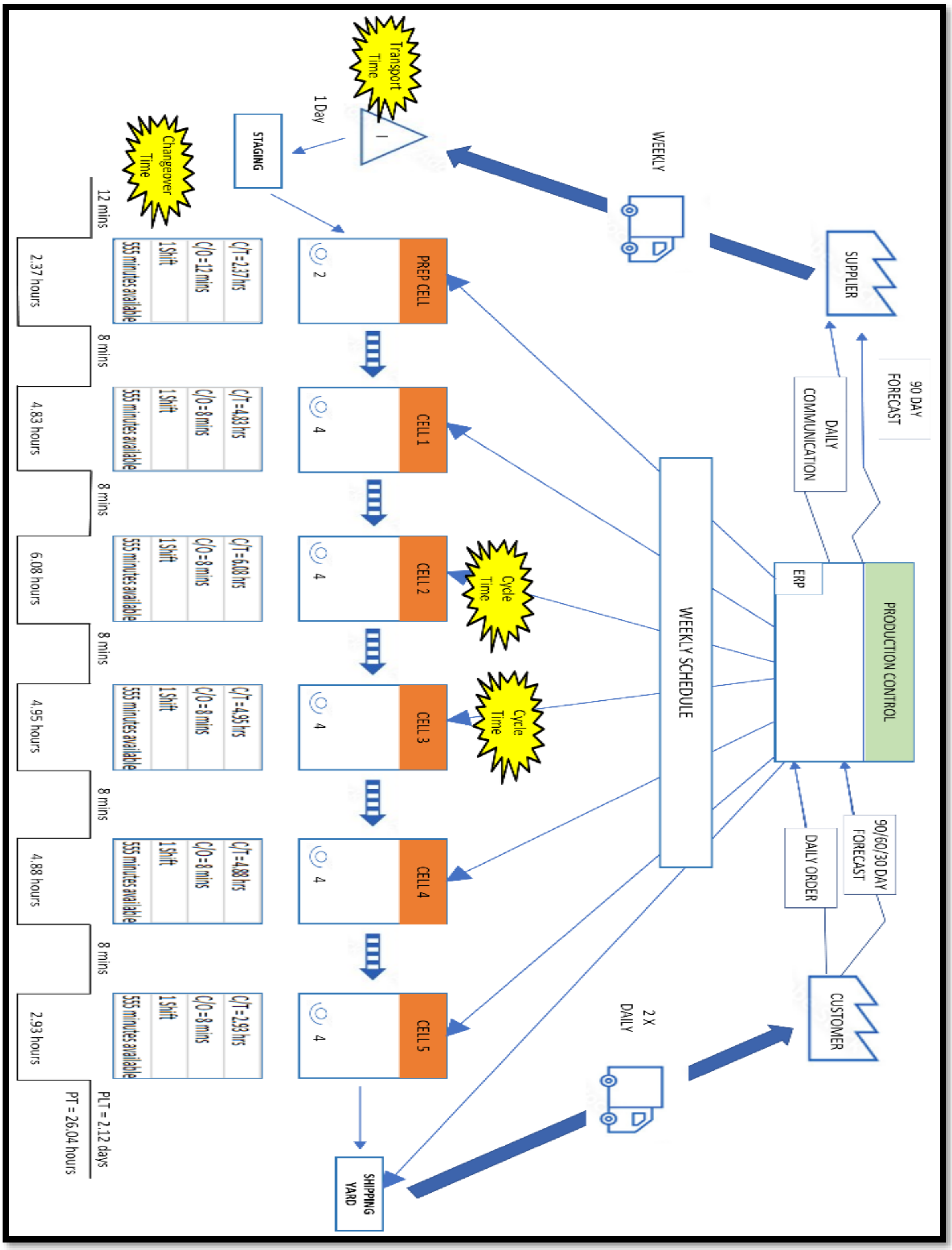


Figure 16. VSM showing opportunities

Action Plan

Table 2. Action Plan to streamline processes

S No.	Actions	Cell No.
1	Pre-wire Oil-Drain oil leveler sub-assemblies	Cell 3
2	Pre-cut blue silicone, green-stripe hose	Cell 2
3	Install edging on panels & brackets for disconnect switch in MSA (breaker)	Cell 3

After analyzing the work procedures of all the workstations, it was identified that around 30 % of the time was utilized in installing wiring and hoses on Cell 2 and Cell 3. A considerable amount of time was also used to install the circuit breaker in Cell 3. The above action plan was created to address these issues. It was anticipated that after implementing action item 1, 6-7 minutes would be saved in Cell 3. Similarly, implementation of action item 2 would result in a reduction of 5-6 minutes in Cell 2 and the anticipated time savings after implementation would be 8-10 minutes.

Results

Table 3. Process cycle time data after implementing action items

Workstation	Avg Time (mins)
Prep Cell	144
Cell 1	359
Cell 2	353
Cell 3	332
Cell 4	360
Cell 5	311

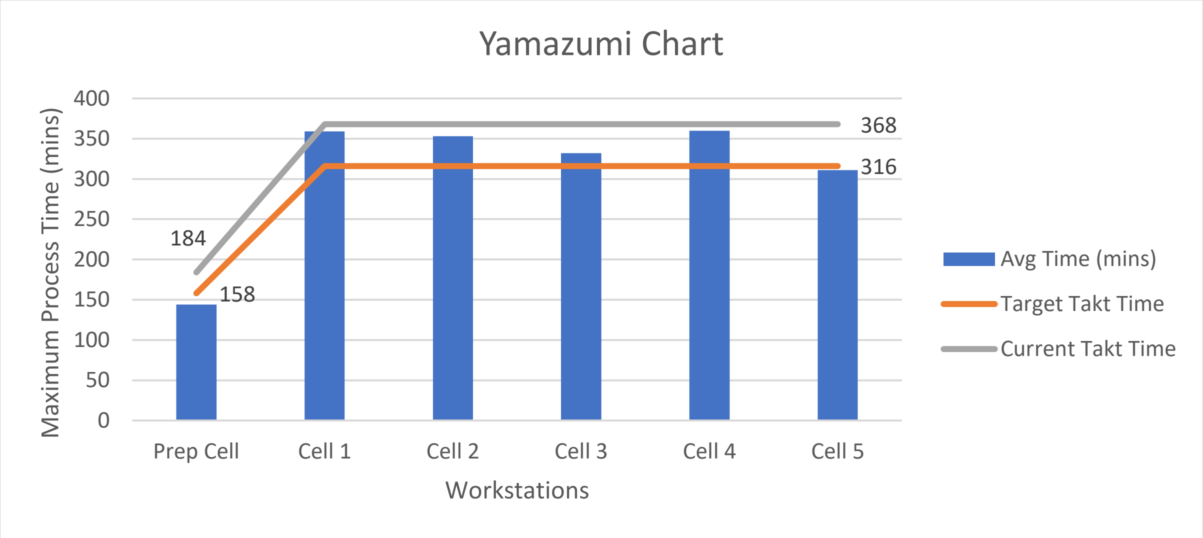


Figure 17. Yamazumi Chart After Process Optimization

Cycle time reductions were achieved in two cells. Cell 3 saw a 20-minute reduction. Cell 2 experienced a 10-minute reduction. In total, these improvements resulted in an overall cycle time decrease of 30 minutes across the manufacturing process. The targeted efficiency gains were achieved through systematic analysis and implementation of lean methodologies.

Further Scope of Research

An action plan is developed for reducing process times further and would be a part of future research. The anticipated reduction would be a total of 190 minutes across all workstations.

Table 4. Future Action Plan

S No.	**ME Actions:**	**Time saved on HPR Line(each)**	**Cell where time is reduced**	**Status**
1	Assembler to mount load-bank & glove plates on the radiator	45	Cell 1 & Cell 4	Started
2	Install support bracket under load-bank at FINAL	20	Cell 2?	Started
3	Assembler to pre-plumb S2000 radiators	20	Cell 1	NOT STARTED

4	Pre-assemble fuel-water separator assembly on mounting bracket	35	Cell 4	Started
5	Add hoses and wiring to fuel-water separator sub-assembly	20	Cell 4	Pending completion of above
6	Pre-assemble fuel monitoring sub-assemblies	15	Cell 4	Started
7	Pre-wire battery chargers	10	Cell 3	Pending completion of above
8	Pre-wire water heater DC harnesses	10	Cell 3	Pending completion of above
9	Pre-wire S4000 voltage regulators	15	Cell 4	Pending completion of above

Conclusion

The research focused on optimizing cycle times across the Line 1 High Power Range Assembly line across six manufacturing cells. After performing detailed time studies and implementation of lean principles, considerable improvements were achieved in two cells, where the overall cycle time was reduced by 30 minutes in Cell 2 and Cell 3 effectively, showcasing efficiency gains of 2.75% and 5.68% respectively. The significant gains were achieved by eliminating non-value-added activities and optimizing work processes. The focus was to reduce setup times and streamline the overall material handling process. Further scope of research would help in addressing constraints and opportunities of the other workstations.

Overall, process optimization along with the use of lean manufacturing tools demonstrated how productivity can be increased and processes can be streamlined in various manufacturing settings.

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Appendix

Table 5. Prep Cell SOP

		Assigned To	**Assigned To**	**Assigned To**
Seq. #	**Work Content Description**	**ASM 1**	**ASM 2**	**ASM 3**
1	Move Base into work Cell			
2	Move Engine into work Cell			
3	Move Generator into work Cell			
4	Base Prep	**30**	**30**	
5	Verify Correct Engine	**1**		
6	Engine-Verify Nameplate when Job Requires System to be UL	**1**		
7	Leave Engine Flywheel Covers in the box for Final Line 1 to install	**1**		

8	Engine-Jacket Water & After Cooler Flange Surfaces Prep		**16**	
9	Engine-Remove bolts from engine feet attached to skid		**4**	
10	Engine Flywheel Prep & Engine Lock Removal	**8**		
11	Engine-Torque & Mark Outer Ring Gear Coupler	**6**		
12	Engine-Install Oil Drain	**2**		
13	Engine-Install Oil Leveler Plumbing	**2**		
14	Engine-Install Oil Drain Hose to Engine	**2**		
15	Verify Correct Generator	**1**		
16	Remove Generator Screen & Save Hardware	**2**		
17	Generator Face Prep	**5**		
18	Generator-Torque & Mark Inner Gear Coupler	**13**		
19	Generator-Remove Generator bolts attached to skid	**2**		
20	Generator-Prepare Pusher Brackets and Hardware	**8**		
21	Torque and QATS Marks Applied and Verified	**1**	**1**	
22	Fill out Checklist and Documentation	**1**	**1**	
23	Cleanup (Dirt & Debris)	**2**	**2**	
24	Complete & Close Operation	**1**	**1**	
	Max Process Time =	**89**	**55**	**0**

	ASM-1	ASM-2	Total
Current	89	55	144
Goal	79	79	158

Table 6. Cell 1 SOP

		Assigned To	**Assigned To**	**Assigned To**	**Assigned To**	**Assigned To**
						-
Seq. #	**Work Content Description**	**ASM 1**	**ASM 2**	**ASM 3**	**ASM 4**	**MH 1**
1	Move A-Frame Assy into work Cell					**4**
2	Move Radiator into work Cell					**4**
3	Move Base into work cell	**8**				
4	Move and Install Engine to Base		**7**	**7**		
5	Level & Center Engine to Base		**6**	**6**		
6	Torque Engine to Base		**12**	**12**		
7	Remove Hoist from Engine		**3**	**3**		
8	Move Generator to Base		**5**	**5**		
9	Remove Generator Scrap from the Prep Cell					**4**
10	Remove Engine Scrap from the Prep Cell					**4**

11	Check the G-Dimension	**2**				
12	Couple Generator to Engine		**23**	**23**		
13	Verify Flex Plate Seating	**2**				
14	Install AC Lower Left Pipe	**10**				
15	Generator-Install Adjustable Chocks, Torque & Mark Generator Feet	**16**				
16	Generator-For 2 Bearing Generators - Run Out Sheet & Engine Drive Hub	**4**				
17	Generator-Torque & Mark Flex Plate	**10**				
18	Generator-Torque & Mark Bell Housing Hardware	**6**				
19	Remove Hoist and Clevis from Generator	**4**				
20	Generator-Install Generator Screen	**4**				
21	Generator-Install Pusher Brackets	**5**				
22	Install Pre-Lube Pump Fittings in Block				**25**	
23	Install & Plumb Oil Pre-Lube Pump				**30**	
24	Verify Correct A-Frame Fan Assy		**1**			
25	Verify Correct Radiator		**1**			
26	Install and Align A-Frame Fan Assy and Torque		**7**	**7**		
27	A-Frame Fan Assy-Record Hertz Reading of Belt		**4**			

28	Radiator-Remove Plugs from Fill and Vent Lines	**5**				
29	Radiator-Remove Radiator bolts attached to skid			**2**		
30	Install Radiator & Torque		**18**	**18**		
31	Install Aeroquip Coolant Drain Hose				**12**	
32	Install Upper Radiator Screen				**19**	
33	Check and Record the Axial Measurement				**2**	
34	Remove Radiator Scrap from Cell 1					**4**
35	Remove A-Frame Assy Scrap from Cell 1					**4**
36	Radiator S/N Entered into M-Serializer	**3**				
37	Torque and QATS Marks Applied and Verified	**1**	**1**	**1**	**1**	
38	Complete Coupling Sheet, Record Serial Numbers & Give to Line Lead			**2**		
39	Fill out Checklist and Documentation	**1**	**1**	**1**	**1**	
40	Cleanup (Dirt & Debris)	**2**	**2**	**2**	**2**	
41	Complete & Close Operation	**1**	**1**	**1**	**1**	
	Max Process Time =	**84**	**92**	**90**	**93**	**24**

	ASM-1	**ASM-2**	**ASM-3**	**ASM-4**	**Total**

Current	84	92	90	93	359
Goal	79	79	79	79	316

Table 7. Cell 2 SOP

		Assigned To	**Assigned To**	**Assigned To**	**Assigned To**	**Assigned To**
						-
Seq. #	**Work Content Description**	**ASM 1**	**ASM 2**	**ASM 3**	**ASM 4**	**MH 1**
1	Move Genset into work cell	**8**				
2	Install Water Heater Harness			**5**		
3	Prep and Install DECS, Brackets and Hardware				**5**	
4	Install CSA Lugs (Generator Foot)				**3**	
5	Tighten Upper and Lower Radiator Screens	**5**			**10**	
6	Install Fan Screen Bracket	**4**			**4**	
7	Install All Fill & Vent Lines	**15**	**45**			
8	Install Radiator Brackets & Tubes, Torque / Install Remote Cooling System Tubes & Pipes, Torque (20 min.)	**40**	**35**			

9	Install LWL Cable & Run to Top of Radiator, Torque/QATS LWL Probe(s) & Connect Cable(s)	**15**	**5**			
10	Install zip ties for wire harness			**4**		
11	Install 8 mm Studs			**4**		
12	Install 10mm Ground Stud			**4**		
13	Install Main Eng. Harness			**27**		
14	Install Alternator Harness			**10**		
15	Install Main ADEC Harness				**10**	
16	Install Generator Harness				**5**	
17	Install RTD Harness				**5**	
18	Install Oil Leveler			**5**		
19	Install battery terminal bracket			**10**		
20	Install Starter Neg. & Pos. Cables			**20**		
21	Install Solenoid Bracket(s) & Solenoid			**4**		
22	Install drain fittings				**22**	
23	Install drain hoses				**24**	
24	Torque and QATS marks applied and verified	**1**	**1**	**1**	**1**	
25	Fill out checklist and documentation	**1**	**1**	**1**	**1**	
26	Cleanup (Dirt & Debris)	**2**	**2**	**2**	**2**	
27	Complete & Close operation	**1**	**1**	**1**	**1**	
	Max Process Time =	**92**	**90**	**98**	**93**	**0**

	ASM-1	**ASM-2**	**ASM-3**	**ASM-4**	**Total**
Current	92	90	98	93	373
Goal	79	79	79	79	316

Table 8. Cell 3 SOP

Seq. #	**Work Content Description**	**ASM 1**	**ASM 2**	**ASM 3**	**ASM 4**	**MH 1**
1	Move Genset into work cell	**8**				
2	Install Thermo Couplers w/Heat Sleeve			**14**		
3	Install turnbuckle			**14**		
4	Verify Control Panel per Job		**2**			
5	Verify Charger per Job		**2**			
6	Install Control Panel / Charger Bracket(s)		**23**			
7	Plug in Harness to Control Panel		**5**			
8	Install Battery Disconnect Wire Harness			**5**		
9	Wire Battery Disconnect Switch(s)			**10**		
10	Install differential Fuel Gauge	**9**				
11	Prep Battery Disconnect Switch(s)	**5**				
12	Mount Battery Disconnect Switch(s)	**2**				
13	Install Dry Contact Box/Junction Box & cover		**24**			
14	Starter & Start Solenoids			**30**		

15	Mount Breaker Bracket				**15**	
16	Mount Breaker Enclosure(s) Assembly				**15**	
17	Route and Wire Breaker Accessories				**18**	
18	Wire Alternator			**3**		
19	Install Oil Leveler Harness				**5**	
20	Plumb Oil Leveler				**10**	
21	Install, Plumb & Wire Fuel Priming Booster Pump			**11**		
22	Install Fuel Water Separator & Bracket		**34**			
23	Install Fuel Bypass Valve Brackets and Hoses				**5**	
24	Verify Water Heater / Voltage	**2**				
25	Install Water Heater(s), Bracket(s)	**15**				
26	Install Water Heater Plumbing & Hose / Install Valves, Hardware & Plumb 'No Water Heater' option (10 min.)	**26**				
27	Install and Wire Recepticles	**20**				
28	Torque and QATS marks applied and verified	**1**	**1**	**1**	**1**	
29	Fill out checklist and documentation	**1**	**1**	**1**	**1**	
30	Cleanup (Dirt & Debris)	**2**	**2**	**2**	**2**	
31	Complete & Close operation	**1**	**1**	**1**	**1**	
	Max Process Time =	**92**	**95**	**92**	**73**	**0**

	ASM-1	**ASM-2**	**ASM-3**	**ASM-4**	**Total**
Current	92	95	92	73	352

Goal	79	79	79	79	316

Table 9. Cell 4 SOP

		Assigned To	**Assigned To**	**Assigned To**	**Assigned To**	**Assigned To**
						-
Seq. #	**Work Content Description**	**ASM 1**	**ASM 2**	**ASM 3**	**ASM 4**	**MH 1**
1	Move Genset into work cell		**8**			
2	Install Restrictors			**16**		
3	Install Duct Flange			**22**		
4	Verify Breaker Amps	**1**				
5	Verify Wire Size	**2**				
6	Wire Fuel Water Separator Handy Box	**30**				
7	Install Breaker Leads in Breaker and Number of Wires				**85**	
8	Install DECS controller wiring	**25**				
9	Wire Water Heater	**9**				
10	Install and Wire Battery Charger	**15**				
11	Install Pre-Lube Pump Wire Harness	**5**				

12	Install Fuel System Lines		**25**			
13	Plumb Fuel Water Separator / Fuel Cooler		**20**			
14	Install Fuel Bulkhead Fittings		**12**			
15	Plumb Fuel Differential Gauge		**15**			
16	Install Oil Sampling Port			**20**		
17	Plumb Oil Differential Gauge			**30**		
18	Torque and QATS marks applied and verified	**1**	**1**	**1**	**1**	
19	Fill out checklist and documentation	**1**	**1**	**1**	**1**	
20	Cleanup (Dirt & Debris)	**2**	**2**	**2**	**2**	
21	Complete & Close operation	**1**	**1**	**1**	**1**	
	Max Process Time =	**92**	**85**	**93**	**90**	**0**

	ASM-1	ASM-2	ASM-3	ASM-4	Total
Current	92	85	93	90	360
Goal	79	79	79	79	316

Table 10. Cell 5 SOP

		Assigned To	**Assigned To**	**Assigned To**	**Assigned To**	**Assigned To**
						-
Seq. #	**Work Content Description**	**ASM 1**	**ASM 2**	**ASM 3**	**ASM 4**	**FLTR 1**
1	Move Genset into work cell	**8**				
2	Install Auxiliary Oil Tank and Hardware			**30**		
3	Install Oil Valve Solenoid, Hardware and Wire			**30**		
4	Route Auxiliary Oil Tank and Solenoid Hoses and Clamp			**30**		
5	Install Fuel Flo Scan				**45**	
6	Install Breaker Leads in Breaker and Number of Wires	**70**	**70**			
7	Install Exhaust Pyrometer Thermocouples					**90**
8	Torque and QATS marks applied and verified	**1**	**1**	**1**	**1**	**1**
9	Fill out checklist and documentation	**1**	**1**	**1**	**1**	**1**
10	Move Genset to next cell		**8**			
11	Cleanup (Dirt & Debris)	**2**	**2**	**2**	**2**	**2**

12	Complete & Close operation	**1**	**1**	**1**	**1**	**1**
	Max Process Time =	**83**	**83**	**95**	**50**	**95**

	ASM-1	**ASM-2**	**ASM-3**	**ASM-4**	**Total**
Current	83	83	95	50	311
Goal	79	79	79	79	316