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Optimising Efficiency in Manufacturing Processes Through Lean Approaches

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Abstract

Manufacturing companies in Singapore face increasing operational challenges due to limited space, manpower constraints, and demand variability, often resulting in production delays and inefficient material flow. This study examines how inventory management systems, production layout orientation, and lean principles can be applied to improve operational efficiency within an assembly line. Using a case study approach, the research focuses on a Singapore-based life sciences manufacturing facility, referred to as Company T. The study adopts the Lean Six Sigma Define, Measure, Analyse, Improve, and Control (DMAIC) framework to structure the improvement process. Data was collected through time studies, process observations, and Value Stream Mapping (VSM) to establish the current operational state. Root cause analysis was conducted using a Fishbone Diagram to identify contributors to inefficiencies, including inventory shortages, layout constraints, and inconsistent task execution. Improvement initiatives, such as a U-shaped layout redesign, supermarket shelving systems, dual racks at workstations, and line balancing based on takt time were proposed and evaluated. The findings indicate improved material accessibility, smoother production flow, and increased technician efficiency. The proposed solutions achieved an estimated 18.3% reduction in cycle time, annual time savings of approximately 1.5 hours per 600 units, and hard cost savings of USD 60,000x. These improvements were reinforced through control measures including standardised work, 5S (Sort, Set in Order, Shine, Standardise and Sustain) housekeeping practices, and performance monitoring.

Keywords
Lean Six Sigma, Manufacturing Operations Improvement, Assembly Line Optimisation, Facility Layout and Material Flow, Operations Excellence

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1. Introduction

Manufacturing is one of the main drivers of Singapore's economy, contributing 22% to Singapore's Gross Domestic Product (GDP) and around 13% of total employment (Ministry of Trade and Industry Singapore 2023). The sector includes key production areas such as electronics, biomedical, precision engineering, and general food products (Singapore Economic Development Board, 2021). Despite being a global trade hub, Singapore faces constraints due to limited land and resources (Goh 2024). Following the global pandemic, worldwide competition has intensified, placing pressure on manufacturing companies to improve operational efficiency, minimise waste, and respond to fluctuating demand (Shih, 2020). Lean principles are widely recommended to streamline production processes and optimise resource utilisation, leading to improvements in productivity and profitability (Handoyo et al. 2023). However, reducing production delays, particularly cycle time, remains a major challenge in manufacturing operations, often influenced by ineffective inventory management and disrupted material flow (Taifa and Vhora 2019). Inventory management involves controlling raw materials, work-in-progress (WIP), and finished goods while preventing stockouts and minimising holding costs (Truong 2023; Panigrahi et al. 2021). Inefficient material flow within facilities can further increase downtime and reduce operational efficiency, especially in space-constrained environments such as Singapore (Karagoz and Karagoz 2025). Therefore, this study examines how improvements in inventory management and material flow can help manufacturing companies reduce production delays and improve operational efficiency through a case study of a Singapore-based life sciences manufacturing facility, referred to as Company T.

1.1 Objectives of this Study

The objective of this study is to analyse the production process that focuses on efficiency in production with the aid of production efficiency techniques, such as lean approaches. The following three research questions (RQ) have been created to address and guide the study.

1. **How can inventory management systems improve material flow and reduce production delays in manufacturing?** The first objective question seeks to establish the importance of inventory management in the production process, in relation to material availability without delay.
2. **How does layout orientation affect the cycle time and worker efficiency?** The second objective question aims to identify how an assembly line layout affects task distribution, material flow, and overall cycle time.
3. **What lean measures can companies take into account to improve operational efficiency?** The third objective question aims to determine which lean principles and tools can help reduce waste and optimise processes in manufacturing companies.

2. Literature Review

2.1 The Role of Inventory Management in Reducing Production Delays

Effective inventory management plays an essential role in ensuring smooth material flow and uninterrupted manufacturing production processes. This article highlights the importance of proper inventory handling to help prevent stockouts and reduce excessive inventory. There are many practices adopted by companies in this industry, which include using just-in-time (JIT) inventory systems, material requirement planning (MRP), and vendor-managed inventory (VMI). In Singapore, where space and resources are limited, manufacturing companies can consider implementing systems, such as JIT and MRP, to reduce bottlenecks and meet production targets.

Additionally, this can assist companies in ensuring operational efficiency as there will be smoother processes and workflows, enabling the company to reduce cycle time and meet the customers' demands on time. Hence, this can improve overall customer satisfaction, minimise workers' idle time, reduce production delays, and operational costs (Al Shukaili, Jamaluddin and Zulkifli 2023). However, this study focuses on strategic inventory management practices without considering how layout design, such as incorporating storage areas for systematic shelving, can further help improve operational efficiency and reduce delays.

2.2 Impact of U-shaped Assembly Line Layout in Production

The orientation of the production layout influences the material flow, operator efficiency, and overall cycle time. As seen from Figure 1, assembly lines used either a straight-line cell production layout (a) or a U-shaped layout (b). It has been highlighted in this article that the U-shaped assembly line outperforms the traditional straight-line layout by producing more finished goods, providing greater flexibility, improved communication between operators, and reduced movement distances (Pujo et al. 2015). Experimental results showed that the switch from traditional straight

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line to U-shaped layouts can achieve cycle time improvements exceeding 10%, with approximately 95% of trials demonstrating better performance.

It was also mentioned that the U-shaped layout design allows the management to align the workforce distribution, allocate their operators for better productivity, and to adapt to fluctuating demand changes more easily based on takt time. Additionally, the change of layout can help manufacturers with adaptability, making it suitable for lean environments that are focused on continuous improvement. Hence, the U-shaped layout can help companies gain better efficiency and operator flexibility. As Singapore is a country where most companies struggle with constrained space, manufacturing companies can consider switching from a straight-line to a U-shaped layout for better space utilisation, productivity, and cost savings (Figure 1).

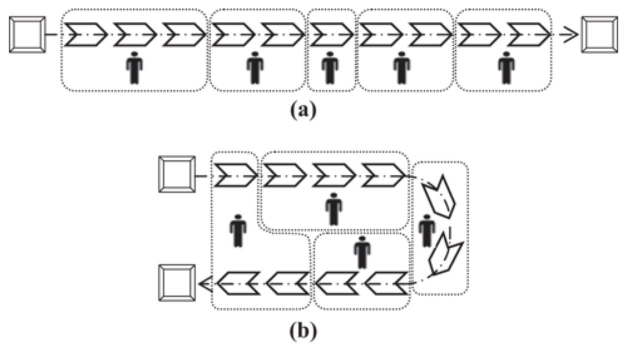

Figure 1. Layouts in Assembly Line Production Cells (Pujo et al. 2015).

2.3 Sustaining Lean through Continuous Improvement

As lean manufacturing practices are widely implemented, sustaining the practices for continuous improvement over time remains a challenge. It was highlighted in the article that lean is not just a collection of tools that can be used to optimise the process, but also a transformation that requires stability, problem-solving skills, and enforcement from the workforce (Protzman et al. 2022). It is recommended to practice the Plan-Do-Check-Act (PDCA) cycle to adopt continuous improvement in an organisation and to treat failures as an open opportunity for learning.

Through the implementation of lean manufacturing practices, this can help ensure flexibility, especially when demand fluctuations or manpower shortages occur. For manufacturing companies to sustain the improvements, they must focus on developing standardised work processes, clear and direct job instructions, and workforce engagement to maintain adaptability and stability. It is essential for companies to cross-train employees, so that they can perform multiple roles to enhance operational flexibility and productivity during manpower shortages. Therefore, sustaining lean practices requires commitment from the relevant stakeholders of the companies to ensure a long run of continuous improvements.

3. Methodology

As mentioned, Company T was chosen as the case study research due to its complex assembly line processes and operational challenges observed during the researcher's internship. The case study approach allows an in-depth evaluation of real-world practices related to inventory management, material flow, and lean implementation.

4. Data Collection

To ensure that the solutions to the process are systematic, the application of the **DMAIC** (*Define, Measure, Analyse, Improve, and Control*) framework from Lean Six Sigma will be utilised.

Define

The project will establish a foundation in a project charter to ensure that the objectives and goals are clearly articulated to provide transparency in the study's direction (Tay 2025).

Measure

Time studies measured each assembly task four times using a stopwatch and video to determine the average standard time (Hartani 2016). Takt time was calculated based on a demand of four units per day, and an AS-IS Value Stream Map (VSM) was created to visualise process flow (Tay 2025).

Analyse
Collected data, cycle time, and takt time were analysed using the AS-IS VSM to identify bottlenecks and non-value added (NVA) activities, while Fishbone Diagram determined root causes of inefficiencies (Tay 2025).

Improve
Improvement solutions were proposed to optimise material flow and assembly line layout, supported by a TO-BE VSM to visualise the improved process (Tay 2025).

Control
Control measures such as KPI monitoring, updated work instructions, and continuous improvement practices (PDCA) were implemented to sustain the improvements (Tay 2025).

4.1 Analysis
Quantitative Data
Time Study Analysis
The collected time study data will be calculated to find the average value for each process to represent the standard time and the total cycle time for the whole assembly line process. Afterwards, the calculation to identify the takt time is used to determine the time needed to produce a unit for a specific quantity of demand during the available working hours (Fekete and Hulvej 2013). The takt time will then be compared to the cycle time to reveal whether the current assembly line is balanced or if certain workstations are facing difficulties that may contribute to the production delays. This analysis addresses RQ2, which evaluates the relationship between layout orientation, cycle time, and worker efficiency.

VSM
An AS-IS VSM will be established using data from the time study and process observations, where the key metrics such as cycle time, lead time, waiting time, and material movement across the assembly line (Tay 2025). The VSM will help to visualise and identify NVA, bottlenecks, and waste. After implementing the suggestions to streamline operational efficiency, a TO-BE VSM will be established to visualise the improvements. The insights gained addresses RQ1, which evaluates how inventory management systems improve material flow and reduce production delays.

Qualitative Data
Fishbone Diagram
A Fishbone Diagram will be developed to categorise the different root causes of inefficiencies under the six common classifications: Manpower, Material, Method, Machinery, Measurement and Environment (Tay 2025). The visualisation will assist in identifying the underlying factors that contribute to the challenges, such as inventory delays, layout constraints, and process inefficiencies, and focus more on how to improve the inefficiencies. This evaluation addresses RQ3, which explores lean measures that can be implemented to enhance operational efficiency.

5. Results and Discussion
5.1 Define and Measure
Define
The project began with the development of a Project Charter (Figure 2), where the company established a clear foundation, goals, and direction for the study.

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Company T's DMAIC Project Charter			
Project Title:	Optimising Inventory Management and Material Flow through Lean Approaches		
Project Leader:	Process Improvement Leader		
Project Champion:	Operations Manager, Company T		
Team Members:	Production Supervisor, Manufacturing Engineer, Warehouse Coordinator, Quality		
Business Case:	Company T's manufacturing line produces high-precision scientific instruments, where efficient material flow and inventory management are crucial to meet production targets. However, inefficiencies such as missing components, disorganised workstations, and inconsistent manpower planning have caused production delays, idle time, and increased operational costs. These challenges disrupt workflow continuity and reduce productivity. By applying Lean principles and the DMAIC methodology, this project aims to streamline inventory processes, enhance layout efficiency, and minimise waste, aligning with Company T's goal of operational excellence and timely order fulfilment.		
Problem Statement:	Frequent production delays occur due to missing inventory, poor layout design, and inconsistent manpower allocation, leading to longer process times, technician idle periods, and reduced efficiency.	**Goal Statement:**	Improve inventory accessibility and optimise material flow to reduce production delays by 30%, standardise workstation layouts for smoother operations, and ensure consistent manpower planning within six months of implementation.
Project Scope:	Project Start / Stop Point: Beginning of the component picking process. / Completion of final assembly and product handover to quality inspection.		
Projected Benefits:	Reduction in material handling time and technician idle time, improved inventory accuracy and accessibility, enhanced production line efficiency through optimised layout and manpower allocation, strengthened lean culture and continuous improvement mindset among operators.		
Preliminary Project Plan:			
Phase	*Target Date*	*Actual Date*	
Define	Jun-25	Jun-25	
Measure	Jul-25	Jul-25	
Analyse	Aug-25	Aug-25	
Improve	Sep-25	Sep-25	
Control	Oct-25	Oct-25	

Figure 2. Company T's DMAIC Project Charter.

The charter assisted in identifying the main business problem, which was the occurrence of production delays and inefficiencies within the assembly line due to poor inventory accessibility, unstructured workstation layouts, and poor lean measures. These challenges eventually led to longer processing times, idle technicians, and reduced productivity. Additionally, these problems are linked to the three research objectives.

The goal of the project was to amplify material flow, minimise production delays, and improve optimisation of technician efficiency through the implementation of lean approaches. Hence, by establishing clear project boundaries and measurable goals, the *Define* stage ensured the alignment between the problem, objectives, and business impact.

Measure

A time study was conducted across the assembly processes from start to finish. Each process was observed five times at a normal working pace to determine the average cycle time and the standard time for analysis. The takt time was then calculated to determine the production rate required to meet daily demand. Afterwards, an AS-IS VSM (Figure 3) was developed using the collected data to visualise the existing process flow, which includes waiting time, lead time, and material movement between workstations. It has also been noted that the technicians in Company T are working a regular shift of 7 hours per day, excluding an hour of lunch break.

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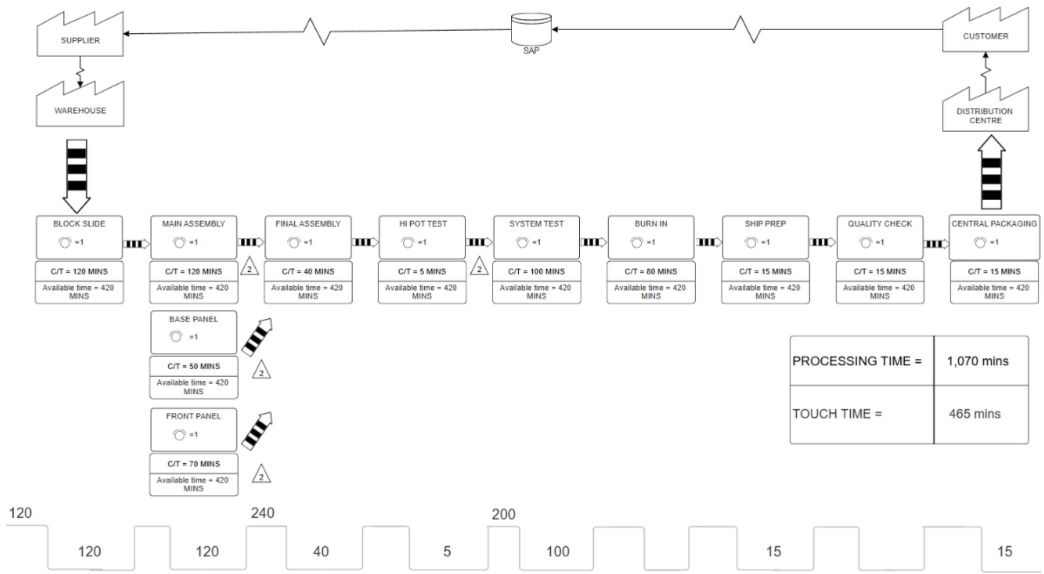

Figure 3. AS-IS VSM.

As seen from the VSM, the total time taken for the entire process was 1,070 minutes (17.8 hours), and the total time taken where the technicians needed to attend to the instruments, also known as ‘Touch Time’, was 465 minutes (7.75 hours). Since the ‘Touch Time’ exceeds regular working time of 420 minutes (7 hours), the technicians would need to work overtime to ensure the demand for the day is met. Additionally, a simplified version of the initial assembly line layout (Figure 4) is developed to aid with the visualisation and understanding of the VSM.

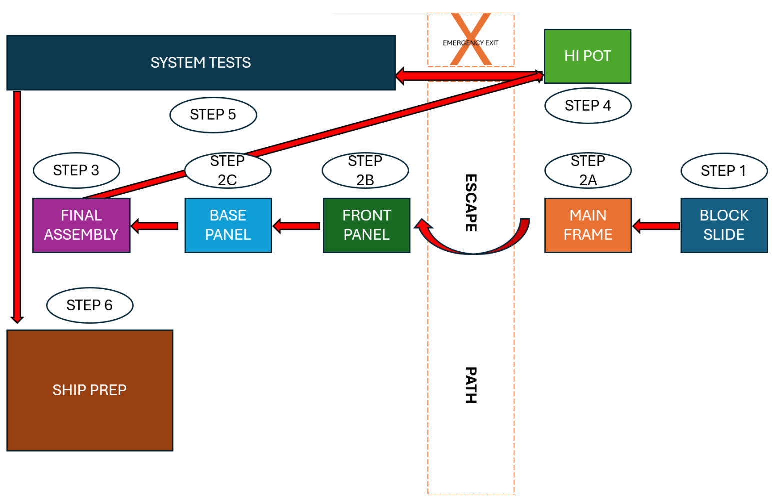

Figure 4. Initial Assembly Line Layout.

As seen from the layout, it showed an unstructured straight-line configuration, which resulted in long walking distances around the assembly line and excessive motion waste whenever the technicians needed to retrieve missing items or materials from the warehouse that is located on a different floor. There were also other findings observed during the time study, especially how missing inventories caused interruptions in the workflow. This includes the unbalanced workloads and idle time across technicians, where technicians often needed to walk over to other assembly lines to borrow missing items. As the movements of the technicians can be seen as complicated due to space constraints, there was potential transportation waste, such as the unnecessary movement of materials, due to poor material accessibility.

5.2 Analyse

Analyse stage was aimed at determining the root causes of the identified inefficiencies. Alongside the collected time study data and AS-IS VSM metrics, they were compared against the takt time, to assess whether the assembly line was balanced. The results indicated that several processes exceeded the takt time of 120 minutes per process, as seen from the calculations in Table 1. It is also important to note that a time allowance of 6% is given to consider breaks taken by the technicians, such as toilet breaks or meetings with their supervisors. Additionally, notes were taken based on the observations from the time study, where the recorded video showed several issues that also contributed to delays and operator idleness.

Table 1. Takt Time Calculations for Output Demand of 4 units per day.

Output Demand per day	4
Takt Time	$\frac{Total\ Available\ Time}{Output\ demand} = \frac{8 \times 60}{4} = \mathbf{120\ mins}$
Total Cycle Time	$\mathbf{380\ mins}$
Technicians to Takt [With 6% time allowance]	$\frac{Total\ Cycle\ Time\ \times 1.06}{Takt\ Time} = \frac{380\ \times 1.06}{120}$ $\approx \mathbf{4\ technicians}$

According to the compiled notes of the observations, a Fishbone Diagram (Figure 5) based on the main issue, 'Operational Inefficiency in Assembly Line Processes', was developed.

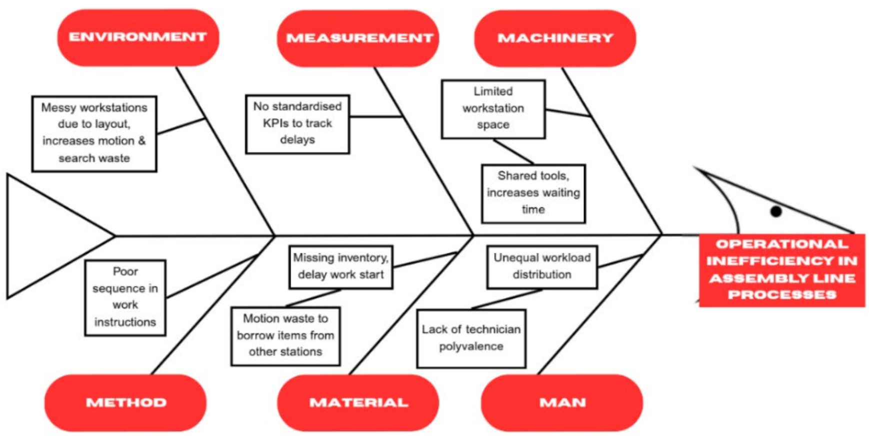

Figure 5. Fishbone Diagram.

- Manpower: Technicians were not fully cross-trained, leading to hesitation when covering absent workers. There was also unequal workload distribution across the assembly line.
- Material: Missing or misplaced inventory increased search and retrieval time, taking an estimated three days for inventory to arrive at the warehouse upon ordering, causing additional motion waste.
- Method: Lack of standardised work procedures caused inconsistency in task execution.
- Machinery: Shared tools affected waiting time and technician efficiency.
- Measurement: Lack of real-time tracking for delays in inventory and updates on KPIs.
- Environment: Unstructured straight-line layout caused congestion and disorganisation.

As a result of the Fishbone Diagram, it was evident that inefficient material flow, missing inventories and poor workstation layouts were the main contributors towards the delays, which relates to both RQ 1 and 2. Hence, addressing these through proper layout optimisation, lean tools, and improved standardisation would help streamline the efficiency of the operations and align with the project objectives.

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5.3 Improve

In this stage, the company aimed to develop feasible and sustainable solutions to address the root causes identified in the Analyse stage. To address the challenges, the first proposed improvement involves redesigning the existing layout into a U-shaped assembly layout, as shown in Figure 6.

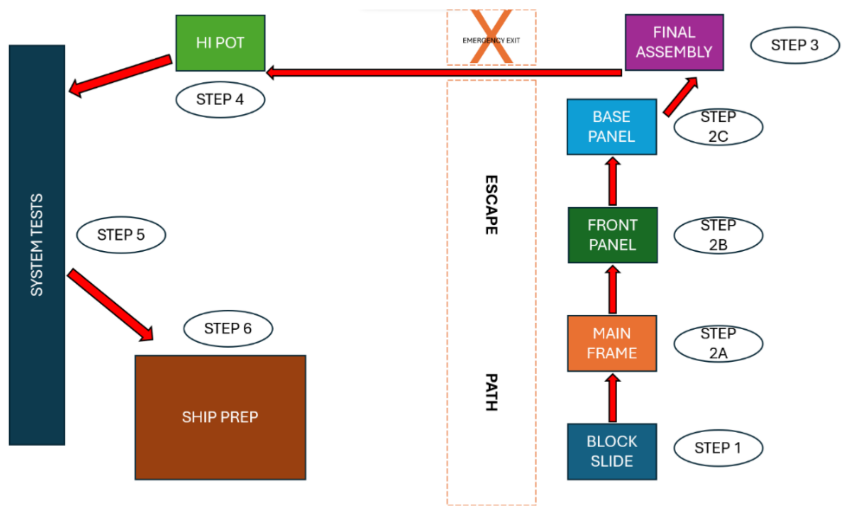

Figure 6. New layout using U-shaped layout.

This layout enhanced space utilisation, streamlined communication between technicians, and reduced unnecessary movement during operations. With Singapore's manufacturing context of spatial constraints, the U-shaped arrangement efficiently used floor space. It also supported a continuous one-piece flow, a fundamental lean concept that aids in reducing lead time and increasing productivity (Soliman 2022). This allowed greater flexibility for operators to perform multiple tasks within a smaller area and for supervisors to easily oversee the entire assembly line. This directly relates to RQ2, which examined how layout orientation affected cycle time and worker efficiency. Furthermore, the change of layout aligned with RQ3, as it applied lean principles, such as motion reduction, continuous flow, and improved standardisation, which contributed to overall operational efficiency.

The second proposed improvement introduced two concepts: the supermarket rack situated near the assembly line and dual racks near each workstation, as seen in Figures 7 and 8 below. Previously, technicians had to walk to retrieve materials from other workstations or the central warehouse, located on a different floor from the assembly line, which resulted in increased waiting time and process interruptions. In addition, the tools and raw materials were found disorganised at workstations, which increased motion waste searching for missing parts. Hence, by implementing decentralised inventory storage through the supermarket and dual racks approach, technicians could access frequently used components in smaller batches at the point of use. This set-up aligned with JIT inventory principles aimed at reducing stockouts and excess inventory, while maintaining a steady flow of materials.

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Figure 7. Sketch of Supermarket Racks. Adapted from prompt to Gemini (Google), (21 October 2025).

Figure 8. Sketch of Dual Rack. Adapted from prompt to Gemini (Google), (21 October 2025).

This improvement directly supported RQ1, which focused on how inventory management systems could improve material flow and reduce production delays. By reducing technicians' movements and ensuring materials and inventories are readily available, the supermarket and dual rack systems enhanced workflow productivity and minimised waste. It also supported RQ3 by integrating lean principles to eliminate unnecessary activities and strengthen overall operational performance. Overall, these improvements created a leaner, more balanced assembly line that helped with the objective of this study, which was to strengthen material flow, technician productivity, and overall efficiency.

5.4 Control Stage

The project ended with a Control stage focused on sustaining the improvements achieved and ensuring that operational efficiency continued in the long run. A Line Balanced Chart (Figure 9) was developed to evenly distribute workloads according to the calculated takt time and load chart, and to ensure that all stations operated at a balanced production flow, where the colours and stations are coded based on the activities of the responsible technicians. Additionally, a TO-BE VSM (Figure 10) was developed to visualise the positive outcomes in the post-improvement state, showing reduced cycle times, smoother material flow, and improved process flow.

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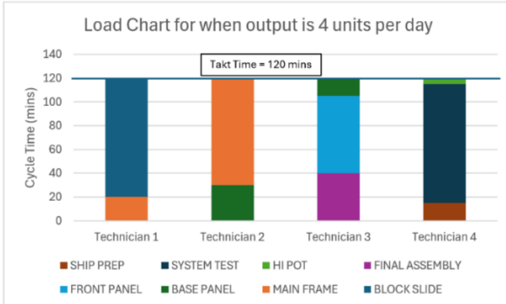

Output demand per day	4
Takt Time	$\frac{Total\ Available\ Time}{Output\ demand} = \frac{8 \times 60}{4} = 120\ mins$
Total Cycle Time	380 mins
Technicians to Takt [With 6% time allowance]	$\frac{Total\ Cycle\ Time\ \times 1.06}{Takt\ Time} = \frac{380\ \times 1.06}{120} \approx 4\ technicians$

Technician	Activity Summary	Duration (mins)
1	Perform Block Slide Assembly (All steps) Perform Main Frame Assembly (Steps 1 to 6)	120
2	Perform Main Frame Assembly (Steps 6 to 20) Perform Base Panel Assembly (Steps 1 to 12)	120
3	Perform Base Panel Assembly (Steps 12 to 20) Perform Front Panel Assembly (All steps) Perform Final Assembly (All steps)	120
4	Perform Hi Pot Test (All steps) Perform System Test (All steps) Perform Ship Prep (All steps)	120

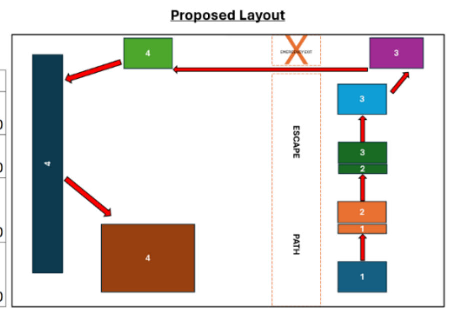

Figure 9. Line Balancing Chart Sample for Demand of 4 units per day.

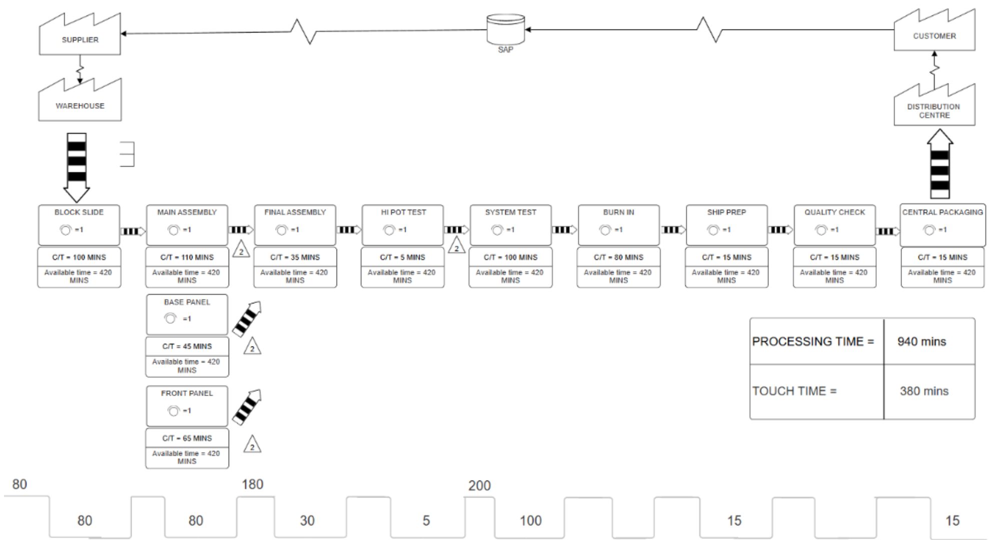

Figure 10. TO-BE VSM.

To maintain these outcomes, three measures based on lean principles were proposed. Firstly, the introduction of Standard Work practices complemented these improvements by ensuring process consistency and clear guidance for technicians. The updated documentation of work instructions and specified task sequences could improve cross-training efforts and support a stable operational environment. Secondly, the implementation of 5S (Sort, Set in Order, Shine, Standardise and Sustain) housekeeping practices to sustain workstation organisation and safety. By introducing the 5S practices into the workstations, the flow of production and productivity could be effectively enhanced (Ahire et al. 2021). Lastly, the company must regularly monitor the KPIs by conducting weekly tier meetings of the assembly line. In this way, they could track ongoing efficiency, such as cycle time, technician utilisation, and material retrieval time, and discuss necessary interventions for improvement to ease production flow to track ongoing efficiency.

Based on these control measures, measurable results were achieved. These improvements led to an estimated hard savings of approximately $60,000x, a total reduction of 1.5 hours based on an annual output of 500 units, and an 18.3% reduction in overall cycle time. These results demonstrated the effectiveness of the implemented lean measures in producing notable improvements. Overall, these initiatives have addressed RQ3 on improving operational efficiency through lean practices. By applying these lean principles, such as Standard Work, takt time monitoring, and 5S practices, Company T sustained its improvements and adopted a brand new culture of continuous improvement in the long run.

6. Conclusion and Recommendations

6.2 Key Findings

Under RQ1 on the role of inventory management, the time study and AS-IS VSM divulged inefficiencies caused by missing inventory and unstructured material flow, as part of the Measure stage. According to the Fishbone Diagram under the Analyse stage, the technicians had to frequently walk between other assembly lines or the warehouse to retrieve necessary materials, which increases motion waste. For the Improvement stage, the implementation of supermarket shelving systems and dual racks near the technicians' workstations improved accessibility and reduced cycle time. Hence, these changes enhanced the continuous workflow and aligned with lean practices of reducing both motion and waiting waste.

For RQ2 on the layout orientation that affects cycle time and worker efficiency, the existing straight-line layout found in Company T's assembly line caused congestion and restriction on the technicians' movements. Under the Improvement stage, the shift to a U-shaped layout enhanced space utilisation and communication among the team, which includes the technicians and the supervisor. With the line balanced based on takt time, this ensured fair workload distribution among the technicians, improved work efficiency and maintained expected demand to be met. Thus, this results in an 18.3% reduction in cycle time and smoother production flow across the station.

Under RQ3 on the lean principles that can be adopted to improve operational efficiency, for the Control stage, the key lean tools applied in this study include standard work, 5S, and line balancing, which helped structure processes and sustain improvements. By updating the work instructions, it enhanced consistency and reduced human and quality errors. Additionally, the routine of regular monitoring of KPIs of the assembly line through weekly tier meetings ensured performance tracking was maintained and persistent. Therefore, this results in a fostered culture of continuous improvement, with hard savings of approximately $60,000x and a reduction of 1.5 hours based on the annual output of 500 units.

6.3 Key Recommendations and Next Steps

Key Recommendations

Aside from the Improvements made in the case study, the following are three key recommendations that could be adopted to achieve better results:

1. Develop a real-time tracking dashboard to track on-site inventory levels across assembly lines. This helps warehouse staff monitor stock availability, forecast demand, and improve inventory management and operational efficiency (Yerra 2025).
2. Adopt periodic line balancing instead of the takt time balancing. Regular reviews, periodically and continuously, allow management to adjust task allocation based on demand and process flow, reducing task interruptions and inefficiencies (Li et al. 2022).
3. Implement skill-based manpower planning with technician rotation across multiple workstations. This enhances workforce flexibility, builds competency and improves task allocation based on technician skills and experience (Gräßler et al. 2021).

Next Steps

These are three suggestions for the next steps after the completion of the study:

- Expand the improvements to other assembly lines while incorporating the new recommended solutions.
- Monitor the effectiveness of the implemented solutions, monthly or quarterly, to ensure continuous improvement.
- Ensure standardisation by developing detailed and updated Standard Operating Procedures (SOPs) to maintain and sustain consistency across all assembly lines.

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