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Optimizing Electronic Manufacturing Processes Using Value Stream Mapping: A Case Study

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Abstract

In today's competitive manufacturing landscape, improving efficiency and reducing waste are critical for maintaining product quality and customer satisfaction. This study investigates the application of Value Stream Mapping (VSM) as a lean manufacturing tool to enhance the testing phase of the product line at a Vietnamese electronics company. Testing, though essential for quality assurance, was found to be a major bottleneck due to manual operations, inconsistent inspection times, and defect-prone procedures. Through a structured VSM approach, the current-state process was mapped, inefficiencies were identified, and a future-state map was designed incorporating automation at key testing stations. The implementation resulted in a 14.3% reduction in cycle time, a 35% decrease in cosmetic defects, and an overall improvement in process cycle efficiency from 11.4% to 16.1%. The case study demonstrates that even in resource-constrained environments, VSM can serve as a powerful standalone strategy to guide operational improvements, reduce production waste, and elevate product quality.

Keywords
Lean Manufacturing, Value Stream Mapping, Electronics Manufacturing, Process Optimization

1. Introduction
The electronics manufacturing industry has witnessed explosive growth over the last two decades, becoming a critical sector in developed and emerging economies (Tuuri and Koskela 2020, Legner et al. 2017). The industry has been a cornerstone for industrialisation in countries like Vietnam, contributing significantly to GDP growth and export turnover. With increasing integration into global supply chains, Vietnamese manufacturers face pressure to deliver high-quality products rapidly and cost-effectively. However, many small-to-medium-sized enterprises (SMEs) within this sector still rely heavily on manual processes, particularly in quality control and testing stages, which are prone to inefficiencies and high variability (Oztemel and Gursev 2020).

Testing is crucial in electronics manufacturing, ensuring that products meet technical specifications and performance standards before reaching customers (Chang and Chen 2019). However, this phase is often characterised by prolonged inspection times, redundant handling, inconsistent operator performance, factors contributing to defects, rework, and delivery delays. These issues are especially problematic in high-volume production environments where even minor delays or inconsistencies can have amplified impacts on throughput and customer satisfaction.

Lean Manufacturing (LM), particularly Value Stream Mapping (VSM), has emerged as a proven approach for visualising and improving production processes (Wang et al. 2023). VSM allows organisations to analyse the flow of materials and information, identify non-value-adding (NVA) activities, and design a more efficient future state. While the utility of VSM has been well documented in literature, its application has predominantly been within large corporations in developed countries, focusing on core assembly lines or logistics functions. By contrast, few empirical studies have examined the use of VSM in the context of SMEs in emerging economies like Vietnam, where operational constraints and resource limitations present unique challenges (Wang et al. 2024, Nguyen et al. 2023).

More specifically, there is a notable research gap in applying VSM to optimise testing and inspection processes, a critical yet understudied segment of electronics production. Most existing studies emphasise process improvement in assembly or warehousing, while the testing phase, which directly impacts product quality, remains overlooked. Furthermore, limited research has explored the integration of VSM with automation strategies to improve testing reliability, reduce labour dependency, and streamline quality assurance workflows (Nguyen and Do 2016, Wang et al. 2023, Vo and Nguyen 2019, Nguyen et al. 2023, Chau and Tien 2018).

This study addresses these gaps by applying a VSM-based improvement strategy to the product line at Company Y, a Vietnamese electronics SME. The testing stage for this product was identified as a major operational bottleneck due to excessive manual handling and variable process times. Through detailed mapping of the current process, identification of inefficiencies, and implementation of a redesigned future-state map incorporating automation, this study aims to demonstrate how VSM can be leveraged as a practical and low-cost method for enhancing testing efficiency, even in resource-constrained settings.

This research advances the lean manufacturing literature by offering empirical evidence from a developing market and addressing the often-overlooked phase of product testing in electronics manufacturing. Focusing on a resource-constrained SME context, the study provides practical guidance for enhancing quality control through structured VSM and low-cost Lean interventions. The paper is structured into six sections. Section 1 introduces the background, objectives, and significance of addressing inefficiencies in the testing stage. Section 2 reviews relevant literature on Lean Manufacturing and the application of VSM in electronics production. Section 3 outlines the research methodology, detailing the five-step VSM-based approach in the case study. Section 4 presents the case of Company Y, including data collection, current-state diagnosis, improvement strategies, and future-state mapping. Section 5 discusses the results and their practical, economic, and environmental implications. Finally, Section 6 concludes the paper with key takeaways and recommendations for future research and industrial practice.

2. Literature Review

This section reviews relevant literature on the role of testing in electronics manufacturing and the application of VSM as a lean improvement tool. It highlights the existing research gaps that this study seeks to address.

2.1. The Critical Role of Testing in Electronics Manufacturing

In electronics manufacturing, the testing and inspection phase is the final product quality gatekeeper (Grochowski et al. 2002). It ensures that devices meet performance, functionality, and safety standards before reaching customers (Vo and Nguyen 2019). As products become more complex and miniaturised, the precision required in testing has increased significantly. It is estimated that more than 30% of quality-related rejections in electronics result from shortcomings in final testing and inspection (Chang and Chen 2019). Delays or inefficiencies in this phase can disrupt production schedules, increase rework, and lead to defective units escaping to the customer, damaging brand reputation and incurring warranty costs (Cai et al. 2015).

Despite its importance, testing is often conducted manually, especially in SMEs in emerging markets. Manual operations are inherently variable, depending heavily on operator skills, attentiveness, and consistency. Manual testing environments suffer from fluctuating cycle times and are prone to human-induced defects such as improper connections, missed steps, or incomplete checks (Vo and Nguyen 2019). These problems are exacerbated when production volumes increase without proportional investment in automation or process standardisation.

2.2. VSM in Lean Manufacturing

VSM is one of the foundational tools in LM, and it was initially popularized by (Rother and Shook 2003). It visually represents material and information flows throughout a production process and is used to identify waste, such as delays, excess inventory, and unnecessary motion. VSM supports the design of a streamlined future-state process that eliminates NVA steps, synchronizes operations with takt time, and promotes flow and pull-based production (Abdulmalek and Rajgopal 2007, Rahani and Al-Ashraf 2012).

Numerous case studies confirm the effectiveness of VSM across industries. VSM implementation in process industries has yielded 10–25% cycle time improvements along with significant labour savings (Rohani and Zahraee 2015, Seth et al. 2017). In the electronics sector, its application to printed circuit board assembly lines has led to lead time reductions exceeding 30% (Vo and Nguyen 2019). However, such implementations typically occur in structured environments with established lean maturity, centralised planning, and data-driven operations, conditions that are seldom found in SMEs (Rosenbaum et al. 2014).

Moreover, most VSM studies have focused on physical assembly or logistics flows, where material handling and production sequences are easy to observe and measure. By contrast, quality control and testing stages, often seen as service processes with indirect value, are underrepresented in Lean literature, even though they directly impact customer satisfaction and product performance.

2.3. Identified Research Gaps

Although integrating LM tools, particularly VSM with Six Sigma, automation, and digital technologies, has seen significant growth in the literature, several notable research gaps remain unaddressed (Haque et al. 2012, Seth et al. 2017, Wang et al. 2024).

Firstly, there is an apparent underrepresentation of testing and inspection processes within the scope of most VSM applications. Existing studies primarily concentrate on optimising physical assembly lines, material flows, and inventory management, while treating testing as either a peripheral step or omitting it entirely. However, in electronics manufacturing, testing is essential for quality assurance and represents a significant source of process delays, rework, and variability, primarily when performed manually. Overlooking this stage in VSM compromises the comprehensiveness of improvement strategies and leaves untapped opportunities for performance gains in both time and quality (Patel et al. 2021).

Secondly, the current body of literature has a geographical and organisational imbalance. Most empirical studies involving Lean tools and VSM are concentrated in large, well-resourced manufacturers based in developed countries such as Japan, Germany, or the United States. In contrast, a dearth of research focuses on SMEs operating in emerging markets like Vietnam. These firms often encounter challenges such as constrained capital, labour-intensive workflows, low automation maturity, and inconsistent process control. Ironically, they stand to gain the most from practical Lean tools like VSM due to their affordability and visual clarity. Still, little scholarly guidance exists to inform their real-world application in such settings.

Thirdly, while Lean and automation are frequently studied in parallel, there is limited exploration of their integrated application within the testing phase, particularly guided by VSM logic. Few studies address how SMEs can use VSM to visualise current bottlenecks and strategically identify where targeted automation can deliver the greatest return on investment, such as reducing manual inspection steps, eliminating rework loops, or enhancing data traceability. The absence of detailed frameworks for this integration limits the practical utility of VSM in environments where digital transformation is incremental rather than holistic.

In response to these gaps, this research conducts a real-world case study at a Vietnamese electronics SME, focusing specifically on the testing stage of the product line. Unlike last works emphasising system-wide production or macro-level logistics flows, this study narrows its scope to a highly labour-dependent and error-prone micro-process. By applying VSM with digital inspection tools and partial automation, the study seeks to demonstrate how visual Lean tools can be deployed effectively in resource-constrained contexts to achieve quantifiable gains in cycle time, defect rate, and process efficiency.

3. Methodology

This study followed a structured five-step methodology to improve the testing process of the product line at Company Y, applying VSM as the core tool, supported by complementary LM techniques. The methodology is visually outlined in Figure 1, and each step is described in detail below.

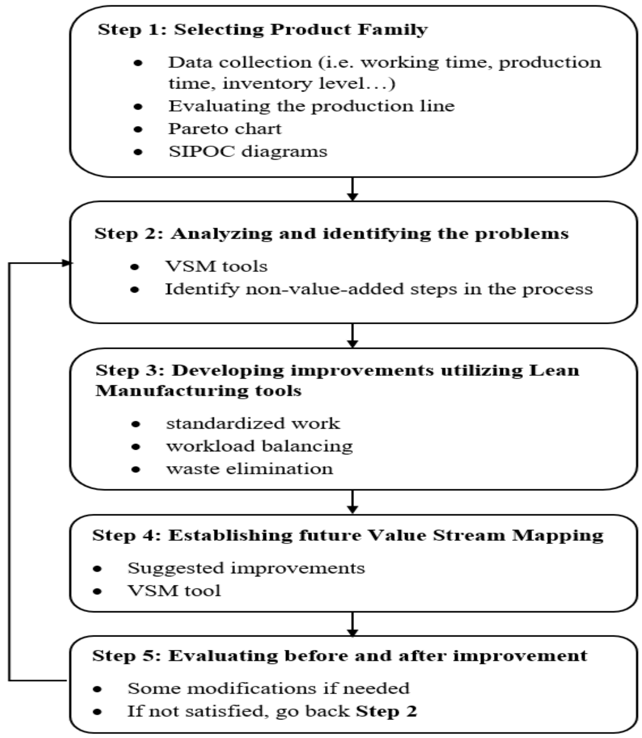

Figure 1. Methodology of implementation research

The first step involved selecting the appropriate product family for analysis. The product line was chosen due to its high production volume, strategic importance, and consistent customer demand. To understand the current state of operations, data were collected on working hours, cycle time, and inventory levels. Additionally, Pareto charts were employed to identify the most frequent issues in the testing process. In contrast, a SIPOC (Supplier–Input–Process–Output–Customer) diagram was developed to define the system boundaries and clarify stakeholder relationships.

The current testing workflow was analysed in the second step to identify bottlenecks and inefficiencies. A detailed VSM was created based on direct observations and time studies conducted at each testing station. The analysis focused on locating NVA activities such as excessive manual handling, prolonged waiting times, and process redundancies. Particular attention was given to the Functional Test (FT) and Rework Confirmation (RC) stations, which exhibited significant delays and rework frequency.

The third step focused on developing targeted improvement strategies by applying key LM tools. Standardised work procedures were proposed by introducing digital inspection checklists to reduce variation and inconsistency. Workload balancing was performed by redistributing tasks across stations to eliminate bottlenecks. In addition, various types of waste, such as manual data entry, idle time, and unnecessary operator movement, were identified and targeted for elimination.

Based on the findings, the fourth step involved constructing a future VSM. This redesigned map incorporated the proposed improvements, including the partial automation of test steps at the FT and RC stations, barcode-based product tracking, and a real-time feedback mechanism between testing and assembly. The new design aimed to ensure a smoother flow, better takt time alignment, and enhanced visibility of production performance.

In the final step, an evaluation framework was developed to compare performance indicators before and after implementation. Metrics such as cycle time, defect rate, and process cycle efficiency were selected to quantify improvements. If the expected outcomes are not achieved, the methodology allows for a feedback loop to revisit earlier steps, especially problem analysis, for iterative enhancement.

4. Case Study

4.1. Selecting the Product Family

Company Y is a Vietnamese SME specializing in manufacturing innovative electronic modules, serving domestic and export markets. Among its products, the U12x model is a high-demand control module featuring programmable microcontrollers used in industrial and consumer applications specifically the producing line of long sleeve shirt, one of family products (Figure 2).

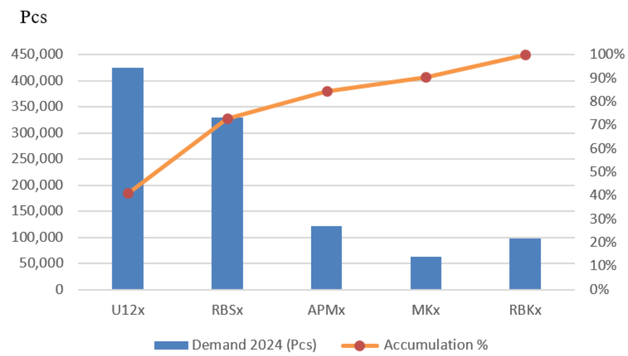

Figure 2. The Pareto chart shows production demand in 2024

The overall process is presented by SIPOC (Table 1). Due to rising order volumes and customer quality expectations, the company identified persistent inefficiencies in the product's testing phase.

Table 1. SIPOC U12x production process diagram

Suppliers	Inputs	Process	Outputs	Customers
Raw material manufacturer	Materials: - PCB - Electronic components - Product shell - Worker - Machines	Production Processing SMT ↓ PTH ↓ ASSEMBLY ↓ TEST ↓ PACKING ↓ WAREHOUSE ↓ SHIPPING	Device U12x	Singapore customers

Each shift lasts eight hours, including a one-hour lunch break from 8:00 AM to 5:00 PM. To obtain a holistic view of the production line, detailed data were collected from six primary stations: Surface Mount Technology (SMT), Pin-Through-Hole (PTH), Testing, Assembly, Packing, and Warehouse. The parameters include Cycle Time (CT), Changeover Time (CO), Uptime (UT), number of operators (OP), inventory quantity, and inventory time. This data is summarised in Table 2.

Table 2. Data collected on the current status of the production station according to general procedures

Station	Measurement parameters						Inventory (products)	Inventory time (hour)
	CT (sec)	CO (min)	APT (sec)	AOP (sec)	UT (%)	OP (person)		
SMT	539	20	28800	27600	95.83	10	43	1.5
PTH	475	15	28800	27900	96.88	8	116	4
TEST	564	25	28800	27300	94.79	8	0	0
ASSEMBLY	336	10	28800	28200	97.92	6	0	0
PACKING	302	15	28800	27900	96.88	5	0	0
WAREHOUSE	347	5	28800	28500	98.96	6	0	0

Data analysis identified two major inventory accumulation points in the production flow. The first occurs between the SMT and PTH stations, with a delay of approximately 1.5 hours, mainly caused by the physical separation of work areas, where SMT is located on the first floor and PTH/Testing on the third. Transport time and intermediate quality checks further contribute to the delay. A second, more significant, delay of 4 hours was found between the PTH and TEST stages, resulting from inefficient layout design, redundant inspections, and inconsistent task pacing across shifts. These issues underscore the need to streamline material flow, reduce inventory buildup, and balance workloads more effectively. They form the basis for the subsequent VSM and LM improvements discussed in the following sections.

4.2. Analysing and Identifying Problems

To assess the current performance of the U12x testing process, all relevant data were consolidated into a CSVSM. This map was a diagnostic tool to visualise the end-to-end testing workflow, allowing the research team to identify inefficiencies, delays, and imbalances (Figure 3). Key performance indicators (KPIs) were thoroughly analysed, such as average cycle time per station, actual throughput versus takt time, work-in-progress (WIP) accumulation, and rework percentages.

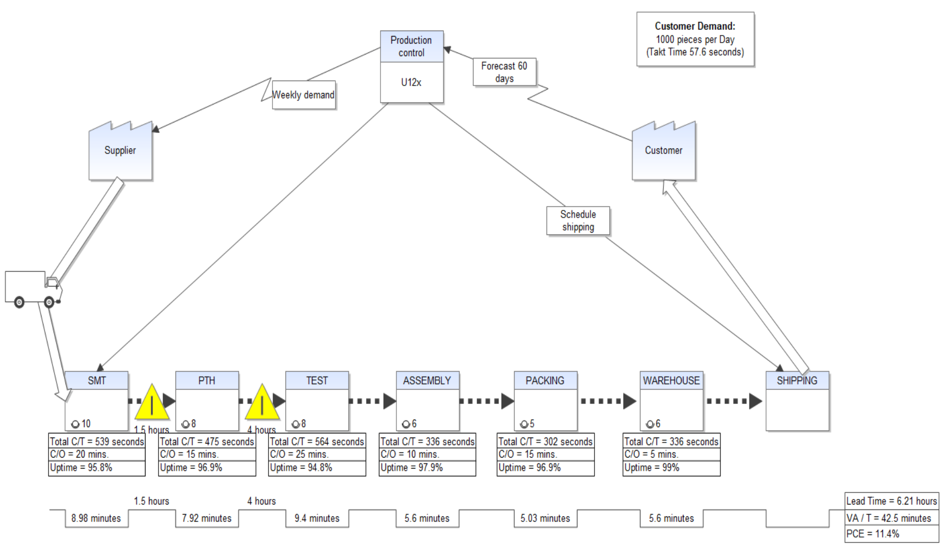

Figure 3. CSVSM of the U12x Testing Process

The CSVSM of the U12x product line (Figure 3) reveals several critical inefficiencies that hinder overall process performance. Two major inventory buildups, 1.5 hours between SMT and PTH, and 4 hours between PTH and TEST, are caused by layout separation across floors and delays in intermediate inspections.

The TEST station emerges as a key bottleneck with a total cycle time of 564 seconds, nearly ten times longer than the takt time of 57.6 seconds required to meet daily customer demand (1,000 units/day). This mismatch significantly disrupts flow and contributes to excessive WIP. Additionally, the TEST station's uptime is only 94.8%, the lowest across all stations, further reducing throughput.

Overall process performance is suboptimal, with a total lead time of 6.21 hours and only 42.5 minutes of value-added time. This results in a critically low Process Cycle Efficiency (PCE) of 11.4%, indicating that most production time is spent on non-value-added activities such as waiting and re-inspection.

A set of focused LM countermeasures was developed to address these issues, targeting the three most prevalent waste types: excessive waiting, inventory buildup, and defect-related rework, mainly concentrated at the FT and RC stations. The proposed solutions leverage foundational Lean tools such as standardised work instructions, workload redistribution, visual control systems, and digital inspection aids. These interventions aim to streamline the testing process, improve flow efficiency, and enhance product quality.

A structured summary of the waste types, their root causes, and corresponding Lean strategies is presented in Table 3.

Table 3. Identified Waste Types in the U12x Testing Line and Their Root Causes

Type of Waste	**Description**	**Causes**	**Impact**	**Proposed Lean Solutions**
Waiting	Idle time occurred frequently between FT and RC.	- Lack of real-time task updates - No digital coordination system - Imbalanced workloads between FT and RC	- Delays in processing - Operator underutilization - Slower throughput	- Real-time dashboards for task visibility - Andon visual signalling system - Task reallocation for workload balance
Inventory (WIP)	Excessive WIP, especially in front of the RC station, with no defined pacing or limits.	- FT output exceeds RC capacity - No inventory control or pull mechanism	- Space congestion - Slower feedback on defects - Masked process inefficiencies	- Kanban system to limit WIP - Takt time alignment across stations - One-piece flow adoption
Defects	High rate of cosmetic and minor functional defects with inconsistent tracking.	- Manual, paper-based inspection logs - No standardised checklists - Shift-based operator skill variation	- Increased rework - Quality inconsistency - Inefficient use of labour	- Digital checklists with error-prevention logic - Visual defect classification guide - Operator training and barcode traceability

4.3. Developing Improvements Utilising Lean Manufacturing Tools

To address the critical inefficiencies in the U12x testing process, a suite of LM interventions was developed to minimise idle time, control inventory buildup, and reduce defects. These solutions were carefully designed to align with the resource limitations and operational characteristics of SMEs in Vietnam.

As visualised in Figure 4, a comprehensive Lean–FMEA–Automation integration approach was adopted to streamline operations between the FT and RC stages. Each subfigure corresponds to a targeted intervention strategy detailed below:

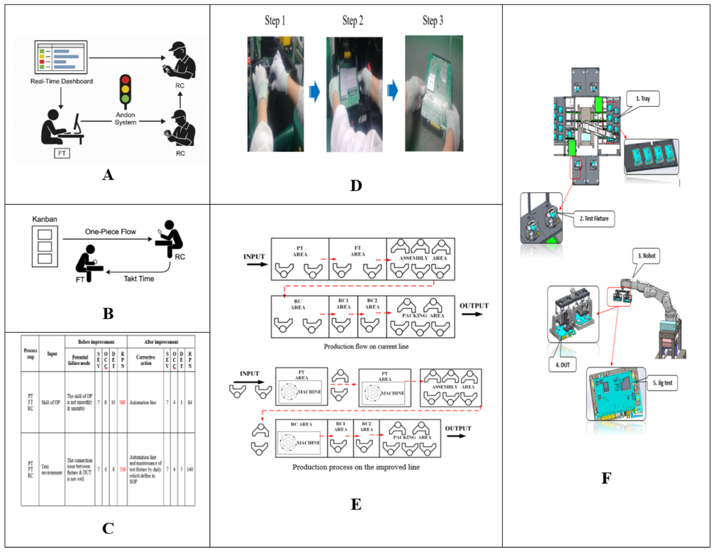

Figure 4. Integrated Lean Solutions for FT–RC Testing Line Optimization: (A) Dashboard & Andon Communication, (B) Kanban & One-Piece Flow Design, (C) FMEA Analysis of FT–RC Bottlenecks, (D) Standardised Testing Procedure (Manual Steps), (E) Line Layout Before vs. After Lean Improvements and (F) Robotic Jig Inspection Workflow

4.3.1. Minimising Waiting Time

A synchronised workflow incorporating digital tools and real-time alerts was introduced to tackle idle time between FT and RC (Figure 4A). A dashboard system enabled operators to track inspection status instantly, while a colour-coded Andon board signalled the need for RC interventions, accelerating response to abnormalities. Additionally, RC personnel were cross-trained to assist at FT during low-demand periods, improving labour efficiency. Standardised work instructions (Figure 4D) further ensured consistent pacing and eliminated ambiguity in task execution. Collectively, these measures turned idle time into value-added activity, reducing overall cycle time and enhancing PCE.

4.3.2. Controlling Inventory and Enhancing Process Flow

Visual inventory control via Kanban and one-piece flow principles was introduced to prevent excess WIP between FT and RC (Figure 4B). Takt time was recalibrated to match customer demand, ensuring smoother station synchronisation. This allowed each unit to move sequentially through the process with minimal delay, supporting faster defect detection and reduced lead times. Layout redesigns (Figure 4E) separated RC zones for rework and final confirmation, facilitating continuous movement and improving flow clarity.

4.3.3. Reducing Defects through Standardisation and Digitalisation

Inspection quality was improved through a combination of digital and training-based initiatives. Digital checklists replaced paper logs, reducing errors and improving data accuracy. Visual guides standardised cosmetic defect classification across shifts. Operator training reinforced correct procedures, while barcode tracking enhanced traceability and targeted rework. Together, these initiatives (supported by Figure 4C and Figure 4F) reduced subjectivity, minimised defect rates, and increased first-pass yield.

4.4. Establishing Future-State Value Stream Mapping (FSVSM)

Building upon the LM interventions implemented, a future-state workflow was designed to eliminate the root causes of inefficiencies identified in the current-state analysis of the U12x testing line. The redesigned process consolidates the most effective elements of digitalisation, task balancing, and low-cost automation, each tested and validated in earlier improvements, to form a streamlined, synchronised, and scalable production model tailored to SME capabilities in Vietnam.

Key interventions, such as the Andon-based coordination system, real-time dashboards, Kanban-controlled flow, and standardised digital inspection protocols, were fully integrated into the new value stream configuration.

Microcontroller-based test rigs were installed at FT and RC to ensure stable inspection performance, while barcode tracking was applied to each unit to enhance traceability and enable faster feedback loops to upstream assembly. Digital inspection forms, deployed on tablets, replaced error-prone paper logs and accelerated reporting, and task redistribution between PT and FT helped balance workloads and reduce bottlenecks.

Real-time feedback mechanisms were also implemented, allowing upstream processes to respond quickly to quality issues detected at FT or RC. As a result, rework loops were shortened and defect recurrence was reduced.

Table 4 summarises the updated performance metrics. Notably, the TEST station's changeover time was reduced from 25 to 20 minutes, and UT improved to 95.83%, even with one fewer operator. Inventory buildup between SMT–PTH and PTH–TEST was significantly reduced, decreasing total holding time from 5.5 to 3.5 hours. These systemic upgrades were visualised as an FSVSM (Figure 5), illustrating smoother material flow, reduced inventories, and optimised cycle time across the entire production line.

These enhancements resulted in a drop-in total production time from 6.21 to 4.17 hours, while PCE increased from 11.4% to 16.1%, confirming the effectiveness of the implemented Lean interventions (Figure 5).

Together, these changes represent a transition from a reactive, manually intensive system to a synchronised, transparent, and responsive production line, demonstrating the tangible impact of structured Lean practices when adapted thoughtfully to the realities of SME manufacturing environments.

Table 4. Data collected on the future status of the production station according to general procedures

Station	**Measurement parameters**							
	CT (sec)	**CO (min)**	**APT (sec)**	**AOP (sec)**	**UT (%)**	**OP (person)**	**Inventory (pcs)**	**Inventory time (hour)**
SMT	539	20	28800	27600	95.83	10	26	1.5
PTH	475	15	28800	27900	96.88	8	58	2
TEST	423	20	28800	27600	95.83	7	0	0
ASSEMBLY	336	10	28800	28200	97.92	6	0	0
PACKING	302	15	28800	27900	96.88	5	0	0
WAREHOUSE	347	5	28800	28500	98.96	6	0	0

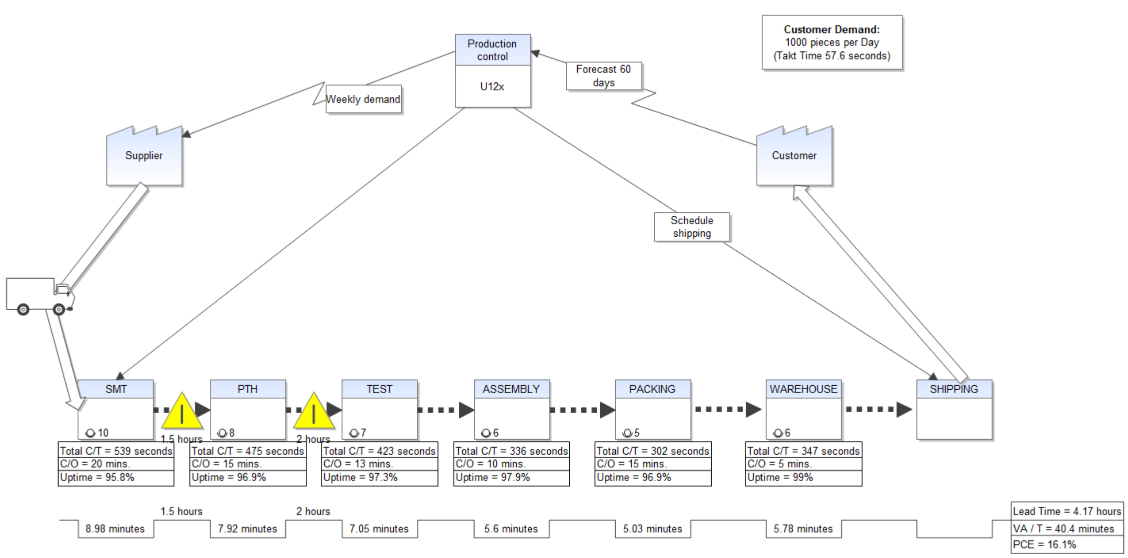

Figure 5. Future VSM

5. Results and Discussion

5.1 Operational Results Overview

Implementing LM solutions, as developed and deployed in the U12x testing line, yielded various measurable benefits across operational, quality, and sustainability dimensions. The structured application of VSM, even without reliance on advanced automation, proved effective in identifying and resolving key inefficiencies that constrained throughput, quality, and cost performance (Table 5).

Table *5*. Summary of Quantitative Results Following Lean Improvements in U12x Testing Line

Category	Metric	Before	After	Change (%)
Operational	Average Cycle Time (hours)	6.21	4.17	↓ 33%
	Process Cycle Efficiency (PCE, %)	11.4	16.1	↑ 41%
	Inventory Time (FT–RC, hours)	5.5	3.5	↓ 36%
	Changeover Time at TEST (minutes)	25	20	↓ 20%
	Operator Utilisation at TEST (%)	90.6	95.83	↑ 5.2%
	No. of Operators at TEST	8	7	↓ 1 Operator
Quality	Cosmetic Defect Rate (%)	4.2	2.6	↓ 38%
	Functional Defect Rate (%)	3.8	2.6	↓ 31%
	Total Defect Rate (%)	8.0	5.2	↓ 35%
Economic & Environmental	Estimated Annual Cost Savings (USD)	–	357,011	–
	CO_2 Reduction (kg/year)	–	3,430	–

From an academic perspective, this case study contributes new insights to the LM literature by focusing on the often-overlooked testing and inspection stages. While most previous studies emphasised assembly and logistics, this research introduces a replicable methodology to diagnose micro-level inefficiencies and implement low-cost digital tools in predominantly manual environments. It also enriches empirical knowledge on Lean practices among SMEs in emerging markets, particularly in Vietnam, where capital and technological constraints are prominent.

From a practical perspective, the implemented interventions demonstrate that substantial improvements in production performance can be achieved without significant infrastructure investments. By applying a combination of standardised work instructions, task reallocation, digital inspection checklists, barcode-based traceability, and low-cost targeted automation, the project successfully enhanced throughput, reduced defect rates, and optimised resource utilisation across the U12x testing process.

Notably, the average cycle time was reduced from 6.21 to 4.17 hours per batch, representing a 33% increase in processing speed. In parallel, the combined cosmetic and functional defect rate dropped significantly, from 8.0 to 5.2%, equivalent to a 35% improvement in product quality. Furthermore, the PCE improved from 11.4 to 16.1%, indicating a substantial reduction in non-value-added activities and a more streamlined, responsive workflow.

Importantly, these gains were achieved while maintaining uninterrupted production. This underscores that when appropriately adapted, Lean enhancements can be both impactful and non-disruptive, particularly relevant for SMEs where production downtime is often unaffordable.

Beyond operational gains, the intervention also produced notable economic and environmental benefits. It is estimated that annual cost savings reached approximately $357,011, primarily attributed to decreased rework, reduced labour consumption, and improved first-pass yield. Environmentally, the improvements contributed to an annual reduction of 3,430 kilograms of CO_2 emissions, thanks to lower energy use and minimised material waste during inspection and rework activities. These outcomes align with the company's broader sustainability objectives and demonstrate the dual potential of Lean practices to drive both economic efficiency and environmental responsibility.

The case reinforces the strategic value of Lean thinking when targeted at inspection-intensive, error-prone production segments. It presents a scalable and transferable model for SMEs throughout Southeast Asia and similar developing regions, showcasing how Lean principles, when adapted thoughtfully, can unlock significant gains in efficiency, quality, and sustainability with minimal resources.

5.2 Critical Discussion and Theoretical Implications

While the quantitative results validate the effectiveness of Lean Manufacturing interventions, a more profound reflection reveals important managerial and theoretical implications.

A key observation is the persistent misconception of productivity as output, rather than process efficiency. Supervisors focus primarily on increasing throughput during the early stages without fully understanding metrics such as PCE or first-pass yield. This reflects a fundamental gap in managerial knowledge, which often leads to a narrow focus on short-term production targets. Rother and Shook (2003) suggest that Lean success depends on shifting from output-based thinking to flow-oriented process control.

Additionally, many inefficiencies identified, such as excessive waiting, redundant inspections, and inventory accumulation, stemmed not just from layout or technology but also from limited Lean literacy among operators. The lack of standardised procedures, real-time feedback, and visual control systems amplified these issues. Such findings echo the conclusions of Rosenbaum et al. (2014), who highlight that cognitive and cultural barriers, rather than financial constraints, often hinder Lean adoption in SMEs.

The interventions applied in this study, particularly low-cost digitalisation (e.g., barcode tracking, dashboards, digital checklists), demonstrate how Lean can be adapted through context-appropriate technologies. Instead of investing in full-scale automation, the project introduced targeted improvements that align with the "frugal innovation" approach (Wang et al., 2024), suitable for emerging market SMEs.

One notable outcome is the strategic repositioning of the testing stage. Traditionally viewed as a downstream quality control gate, testing here was restructured into a proactive driver of feedback, standardisation, and real-time process correction. This supports the theoretical assertion that when integrated with Lean principles, inspection can enhance system-wide responsiveness and continuous improvement (Abdulmalek & Rajgopal, 2007).

Lastly, this case contributes to Lean literature by extending VSM applications to underexplored production stages (i.e., testing) and offering a practical model for SMEs with constrained resources. The results support the view that Lean tools can deliver operational and strategic benefits when embedded in socio-technical systems, even in environments with limited automation maturity.

6. Conclusion

This study explored the application of VSM as a strategic tool to improve the testing process in electronics manufacturing, using Company Y, a Vietnamese SME, as a case study. Focusing on the U12x product line, the research addressed a critical yet often neglected stage in the production process: product testing. The current-state analysis revealed multiple inefficiencies, including unbalanced workloads, excessive manual handling, and a lack of standardised inspection procedures, all of which contributed to increased cycle times and elevated defect rates.
The future-state map proposed a series of low-cost, practical interventions, including partial automation, barcode tracking, digital inspection checklists, and real-time communication with upstream stations. Although full implementation and validation of these improvements are planned for future production cycles, the study presents a replicable framework for how SMEs in emerging markets can apply lean tools such as VSM even in constrained settings.

This research contributes to the literature in several key ways. First, it expands the scope of VSM applications beyond traditional assembly and logistics processes to include testing and quality control, an underrepresented area. Second, it provides context-specific insights for lean implementation within SMEs in developing countries, where resources and infrastructure may limit adopting more capital-intensive improvement strategies. Finally, it highlights the value of integrating lean thinking with digital tools and targeted automation to enhance operational efficiency and long-term competitiveness.

For practitioners, the study offers actionable guidance on approaching process improvement in stages that are traditionally resistant to change. VSM can identify waste, facilitate cross-functional dialogue, prioritise interventions, and align improvement goals with broader strategic objectives.

In subsequent research phases, collecting and analysing post-implementation data to quantify improvements in performance metrics such as cycle time, defect rate, process efficiency, and cost savings is essential. In addition, exploring employee feedback, training challenges, and system integration issues will provide a more holistic evaluation of implementation success. Further studies may also investigate the scalability of such lean interventions across multiple production lines or product families within the same organisation.

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