

A LEAN APPROACH TO IMPROVING THE LABORATORY VERIFICATION PROCESS IN THE ELECTRONICS INDUSTRY

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This study investigates the use of lean thinking to improve process efficiency in the mechanical stress test laboratory of Company I, a semiconductor verification firm in Taiwan. It addresses a practical problem in which, despite relatively stable project volumes, project working hours increased due to greater case complexity, inefficient project handovers, and operational waste in laboratory workflows. The study introduces a modified 6Ws framework, replacing the conventional “how” dimension with “whom” to strengthen problem definition in a service-intensive laboratory context. This framework was combined with a suppliers, inputs, processes, outputs, and customers (SIPOC) analysis and value stream mapping (VSM) to identify non-value-added activities, redesign project intake and handover procedures, improve scheduling visibility, and optimize workspace and tool arrangements. The results show that the controllable labor component was reduced from 160 minutes to 58 minutes, representing a 63.75% reduction in labor time. The 102-minute improvement is a substantial reduction in human effort across the 50 hours of the total end-to-end cycle, which is dominated by machine operation and testing. Overall, the findings demonstrate that lean thinking can significantly reduce avoidable labor waste in laboratory operations and provide a practical improvement model for similar technical service environments.

Keywords: Lean Production; Lean Thinking; Value Stream Mapping; SIPOC; 6Ws Analysis.

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1. INTRODUCTION

Originating from the Toyota Production System (TPS) in Japan (Ohno, 1988), lean production (Krafick, 1988) revolves around the core principle of creating value with minimal effort (Hegedic *et al.*, 2024; Popov, 2023; Pozzi *et al.*, 2024; Zaidi *et al.*, 2021). It aims 1) to eliminate wasteful practices in the production process, 2) to establish streamlined and versatile production procedures, and 3) to continually pursue improved process efficiency and service quality (Womack and Jones, 1994). “Lean” does not entail arbitrary cost-cutting or exploitation of workers and suppliers, because this can compromise relationships. Instead, as Ker *et al.* (2014) emphasized, “lean” refers to a methodology focused on enhancing quality, reducing time, and lowering costs by eliminating various inefficiencies in the process.

Unlike traditional mass production, lean production seeks to eliminate waste by minimizing the time from receiving an order until the order is filled (Gherghea *et al.*, 2020). This approach minimizes inventory accumulation, utilizes fewer resources, reduces space and capital requirements, and enhances the operations’ value-added activities. It caters to the demand for diverse, customer-centric products while eliminating the need for warehousing excessive inventory (Prasetyawan and Ibrahim, 2020). Instead, it strives to prepare materials and products swiftly based on the orders customers submit in order to ensure efficiency and responsiveness. Such lean principles have become a cornerstone of modern industry and service management (Hamzeh *et al.*, 2021; Hegedic *et al.*, 2024; Popov, 2023). On the other hand, the relentless pace of technological advancement has shortened products’ lifecycles and increased the demand for customization. Lean thinking and continuous

improvement practices have enabled streamlined production processes, cost reduction through automation, and the production of high-efficiency, cost-effective, and top-quality products (Antunes and Poshdar, 2018; Asnaashari and Khodabandehlou, 2024; Kassem *et al.*, 2023).

In the electronics industry, reliability verification remains indispensable to new product development and supply chain qualification. Before products can be commercialized, they must undergo rigorous testing to confirm their safety, durability, and functional reliability (Farhadi *et al.*, 2018). However, product lifecycles in the electronics sector have become increasingly short, while product architectures and customer requirements have become more complex. As a result, verification laboratories face rising pressure to process diverse and customized projects quickly, even though laboratory work frequently involves multiple handovers, specialized preparation, manual data handling, and formal reporting requirements (Eli *et al.*, 2023; Hernandez, 2023; Pozzi *et al.*, 2024).

Various products typically comprise thousands of different components, and a malfunction in any one of them during usage can lead to unforeseen adverse consequences. Therefore, comprehensive environmental tests are indispensable to ensure the required performance of electronic products in diverse conditions. Equally important after mass production is the reliable and safe delivery of electronic products to customers. Although careful thinking has been widely applied in production processes throughout diverse industries (Lyons *et al.*, 2013; Wang *et al.*, 2023; Zaidi *et al.*, 2021), few studies have focused on the use of lean thinking to reduce the labor time required to analyze and verify the viability of laboratories in the electronics industry. Therefore, the use of lean thinking principles represents a significant transformation within laboratory settings, which motivated this study.

The semiconductor verification company acts as a diagnostic entity in the supply chain, assessing electronic products across the semiconductor industry's upstream, midstream, and downstream sectors (Lam, 2005). It employs testing and analysis instruments to scrutinize component materials and structures, and it conducts failure analyses to identify issues that could stem from the designs of integrated circuits (ICs), manufacturing, packaging, and downstream assembly. The laboratory provides customers with valuable test results and process recommendations, ultimately contributing to the quality of electronic products and yields, thereby making the inspection of semiconductors an indispensable link in the semiconductor supply chain.

This study focuses on Company I in Taiwan—specifically, its mechanical stress test laboratory (MSTL), which serves as an independent third-party quality verification laboratory for the electronics and semiconductor industries. Although the number of cases handled by the MSTL has not increased substantially, the working hours required to complete projects have risen noticeably. This pattern suggests the presence of hidden inefficiencies in project intake, handovers, scheduling, workspace layout, and test preparation. For a laboratory that operates in a market-oriented and customer-centric environment, such inefficiencies can lengthen turnaround time, increase labor cost, and weaken service performance.

Although lean thinking has been widely applied in manufacturing and production-oriented settings, the current state of the industry remains centered largely on production efficiency, material flow optimization, and waste reduction in shop-floor environments. Existing studies have demonstrated the usefulness of lean tools such as suppliers, inputs, processes, outputs, and customers (SIPOC) and value stream mapping (VSM) in manufacturing, semiconductor production, procurement, and sustainability-related applications. However, much less attention has focused on laboratory-based verification environments in the electronics industry. Such environments differ from conventional production settings because their workflows are project-based and depend heavily on handovers, cross-functional coordination, test preparation, scheduling visibility, data processing, and report generation. As a result, the literature still provides limited insights into how lean thinking can be adapted to reduce labor time and improve process efficiency. This study addresses that gap by examining the application of lean thinking in the mechanical stress test laboratory of a semiconductor verification company.

This study aims to examine how lean thinking can be used to improve the verification process in Company I's MSTL and reduce non-value-adding labor time while maintaining service quality. The study also seeks to extend the application of lean thinking from production settings to laboratory-based verification services in the electronics industry. The study pursues the following objectives:

1. Identify the causes of increased project working hours despite stable project numbers.
2. Review the project acquisition process within the MSTL and streamline it by eliminating unnecessary steps.
3. Develop the current and future ideal VSM to reduce the cycle time.
4. Assess the improvement outcomes, ensure feasibility, and use the outcomes as initiatives for future improvement.

This paper is organized into five sections. Following the introduction, Section 2 reviews existing research on lean thinking, lean tools, and lean applications. Section 3 presents the case background and research methodology and explains the study design using Saunders' research onion. Section 4 analyzes the outcomes achieved by implementing lean project improvements at Company I; discussions, comparisons, and illustrative examples are provided to elucidate the impact of these changes. Section 5 concludes the paper with managerial implications, limitations, and suggestions for future research.

2. LITERATURE REVIEW

2.1. Lean Thinking

The authors of *Lean Thinking* (Womack and Jones, 1996) defined lean as follows: “Lean is about providing a more efficient way of doing things, giving customers what they need with less manpower, less equipment, less time and less space.” In short, “lean production” involves eliminating all kinds of waste, promoting efficiency, pursuing quality, shortening the lead time, improving production yield, lowering costs, achieving a small number of diverse products, reducing the overall inventory of the enterprise, and meeting the needs of customers (Borgave and Sapkal, 2020; Lyu *et al.*, 2021; Momenitabar *et al.*, 2020; Quispe Córdova *et al.*, 2023; Rahman *et al.*, 2023).

Womack and Jones (1996) believed that the key to enterprise transformation is providing a new way of thinking to change people’s organizational activities. In other words, the key to introducing lean in enterprises is not the technology, operation mode, or management mode of lean production but the methodology to produce changes from the fundamental thinking, which is the difficulty of introducing lean (Gupta and Jain, 2013). As this is an issue at the level of thinking, Womack and Jones (1996) proposed a set of arguments. They believed that by implementing five critical steps of practical training and learning over and over again, project leaders and their members could successfully convert system processes into lean systems. These five essential steps have been applied successfully in many practical projects (Locatelli *et al.*, 2013; Marques *et al.*, 2022; Sony, 2018).

The five critical steps in the lean methodology are as follows:

(1) Value

The initial step in lean thinking centers on identifying value. Value is generated by the producer, but it is defined by the ultimate customer (or the end-user); it is the *raison d'être* for the producer’s existence. This means that a product or service is offered to the customer at a specific price, at a particular time, and with great satisfaction.

(2) Value Stream

This step pertains to all activities throughout the process, from raw materials to the final product or service, which contribute value to the end customer (the value stream). It encompasses the complete journey, including procuring raw materials from suppliers, processing them into finished products within the company, and then distributing them to customers through various channels. Beyond the physical flow of converting raw materials into finished goods, the information flow within the company and between suppliers and customers is also part of the value stream. Activities within the value stream can be categorized as either value-added (VA) or non-value-added (NVA). Project managers can identify and eliminate wasteful components that do not add value by understanding the production steps and mapping the value stream.

(3) Flow

Flow involves the creation of a seamless production process. To ensure efficient operations of the value stream and reduce lead times, waste must be eliminated, especially the seven significant areas of waste: inventory, waiting, defects, overproduction, unnecessary motion, transportation, and excess processing (Khairunnisa *et al.*, 2019; Mayatra *et al.*, 2015). The objective of a smooth flow is to eliminate these wasteful elements, enabling valuable steps to be executed efficiently. Furthermore, both incoming and retained processes should contribute value, resembling a stream that allows products to reach the customer without undue effort.

(4) Pull

Pull refers to the implementation of a pull production system. Unlike traditional push production, pull production adapts input and output to the customer’s practices, demands, timing, and location (Araújo *et al.*, 2024). In essence, it employs market demand data to initiate the entire production and assembly processes and then pulls the need for components and processing through the assembly of products. Each process in the production line is initiated by the preceding step, ensuring that actions are taken only when necessary and are executed promptly and effectively. This approach minimizes premature and excessive inputs, thereby reducing inventory waste.

(5) Perfection

Project managers aim for perfection by applying the preceding four lean steps—namely, correctly defining value, delineating the value stream, establishing a continuous and seamless flow, and instituting the pull production system—thereby creating an ongoing process of continuous improvement. Once a round of improvements is completed, the processes of lean thinking restart by returning to the first step (i.e., defining value). Improvement is a perpetual journey, much like the iterative cycle of plan–do–check–act (PDCA) (Ghatorha *et al.*, 2022; Pozzi *et al.*, 2024). In the relentless pursuit of perfection, project managers repeatedly reassess and eliminate waste, forming a virtuous cycle of continuous enhancement.

2.2. Lean Tools and Applications

The SIPOC is a Lean and Six Sigma tool that considers suppliers, inputs, processes, outputs, and customers for mapping and analyzing business processes and identifying improvement opportunities. Nshirim and Nwagwu (2018) studied the integration of value engineering and lean methodology with SIPOC and VSM diagrams and created a comprehensive framework for continuous process improvement and waste reduction. Brown (2019) concluded that SIPOC can accomplish the business's continuity imperatives while adding value to the organization when resources are short. Furthermore, Zhang *et al.* (2022) used a deep learning algorithm and SIPOC to conduct an in-depth analysis and research on the procurement management process in e-commerce environments. Assis de Souza *et al.* (2023) used SIPOC-OI (open innovation) to support the management of knowledge sources present in the supply chain, promoting the company's efficiency and improving its innovative capacity. Chen *et al.* (2023) integrated the Six Sigma DMAIC method with SIPOC to reduce the management reserve cost of the case company's outsourcing projects.

VSM, a visual tool that displays all critical steps with corresponding time and volume in a specific process, shows the flow of materials and information as they progress (Rother and Shook, 1999). McManus and Millard (2002) explored the concept of VSM as applied to product development (PD) efforts in nine major U.S. aerospace organizations. Meanwhile, Seth and Gupta (2005) used VSM to enhance productivity at a supplier's end in the auto industry. The results showed improved production output per person and reduced both the work-in-process (WIP) and the finished goods inventory, positively impacting productivity. Ng *et al.*'s (2013) study implemented a new production process flow in a semiconductor manufacturing company based on the future state of VSM. NVA activities were reduced or removed by assigning butterfly operators to perform these tasks, improving personnel efficiency and optimizing the headcount of the production lines. A two-phase planning model based on a lean-pull strategy was proposed and applied in a semiconductor wafer ingot-pulling manufacturing company. Phase one used the lean-pull logic to select appropriate orders from the central queue and accumulate them to form a production Kanban for an available machine. Phase two minimized the total shipping costs of the fulfilled orders using a linear programming formulation (Wang *et al.*, 2018). Taguchi's two-step procedure and simulation optimization were used to determine the optimal parameter values for a robust system (Yang *et al.*, 2020).

Lyu *et al.* (2021) used VSM of lean production (by removing the NVA activities) and automation to improve the case company's wafer outgoing quality assurance (OQA) processes. Four control factors, including the pulling strategy, machine limitations, dispatching rules, and batch-size control, were identified to generate the future state of VSM in a lean production system design for a semiconductor crystal-ingot pulling manufacturing firm. VSM was applied to the production of steel pipe in a case study involving data analysis, initial process mapping, waste identification, and future process planning. The implementation improved processes and achieved financial savings (Salwin *et al.*, 2021). Wang *et al.* (2023) discussed a case study of the application of VSM in a furniture company to improve productivity by reducing lead time and inventory time and enhancing the process cycle efficiency (PCE) ratio.

Lean production has been applied to sustainability and environmental responsibility. In their case study using lean implementation with green VSM, Belhadi *et al.* (2018) showed a strong correlation between operational and green metrics improvement. Gaikwad and Sunnapwar (2020) investigated how lean and green practices and tools are used to improve social, economic, and environmental performance that directly affect overall business performance by adopting best practices and the generation of waste in manufacturing processes. A case study was conducted in an Indonesian plastic molding company implementing sustainable value stream mapping (SVSM) and a sustainability index (SI) (Sari *et al.*, 2022). Hegedic *et al.*'s (2024) survey identified critical economic and environmental performance indicators and investigated how lean tools influence these indicators. They developed a decision-making model facilitating lean tool implementation based on a company's financial and environmental performance priorities. The methodology involves a literature review complemented by questionnaires and interviews with experts from academia and the industry sector. Hegedic *et al.* (2024) concluded that VSM enhanced with an environmental component is most frequently used for implementing lean and green practices.

More recent works show that lean applications are evolving to meet the challenges of modern manufacturing. Rahmatillah and Rusindiyanto (2025) illustrated the application of Lean Six Sigma in defect reduction. Kashyap *et al.* (2025) developed interactive VSM approaches to minimize inefficiencies. Chivukula and Pattanaik (2023) analyzed the integration

of lean tools with Industry 4.0 technologies to prioritize tool groups based on their compatibility and effectiveness. Gomaa (2025) proposed Lean 4.0 frameworks to align lean with digital transformation. These studies emphasize the continued significance of lean and its capacity to evolve in response to modern challenges. Table 1 summarizes that the current field is dominated by applications of SIPOC and VSM in manufacturing, supply chain, procurement, and production-related environments.

Table 1. Characteristics of lean improvement cases.

Authors	Context	Tools Used	Outcome Metrics	Industry
Seth and Gupta (2005)	Supplier-end productivity improvement	VSM	Improved output per person; reduced WIP and finished goods inventory	Automotive manufacturing
Ng <i>et al.</i> (2013)	New production process flow design	VSM	Reduced or removed non-value-added activities; improved cost productivity	Semiconductor manufacturing
Belhadi <i>et al.</i> (2018)	Operational and environmental performance improvement	Green VSM / lean implementation	Improved operational and green metrics	Manufacturing SMEs
Nshirim and Nwagwu (2018)	Continuous process improvement and waste reduction	SIPOC + VSM + value engineering	Process improvement and waste reduction	General process / industrial improvement
Brown (2019)	Process continuity and value creation under constrained resources	SIPOC	Clarified process structure and improved business continuity decision-making	Business continuity / service setting
Lyu <i>et al.</i> (2021)	Outgoing quality assurance process improvement	VSM + lean production + automation	Improved personnel efficiency and optimized headcount	Semiconductor foundry
Salwin <i>et al.</i> (2021)	Waste elimination in process flow	VSM	Process improvement and financial savings	Steel pipe manufacturing
Chen <i>et al.</i> (2023)	Procurement improvement in outsourcing projects	DMAIC + SIPOC	Reduced management reserve cost	Project procurement / outsourcing
Wang <i>et al.</i> (2023)	Productivity improvement	VSM	Reduced lead time and inventory time; improved process cycle efficiency	Furniture manufacturing
Hegedic <i>et al.</i> (2024)	Lean and green performance alignment	Lean tools with environmental components	Identified economic and environmental performance indicators; highlighted VSM with environmental extension	Lean-green manufacturing
The current study	Context / Problem focus	Main tool(s) used	Outcome metrics / main results	Industry / Setting

2.3. Summary

Based on this literature review, lean thinking centers can efficiently deliver precisely what customers need while using fewer resources. Lean production is a system that aims to eradicate waste, thereby enhancing quality, reducing lead times, cutting costs, and meeting customers' needs effectively. Therefore, lean thinking has been applied extensively in production processes and production lines (Lyons *et al.*, 2013; Lyu *et al.*, 2021; Wang *et al.*, 2023; Zaidi *et al.*, 2021).

Furthermore, as new electronic products and technologies are developed, the verification and analysis of laboratory work in the electronics industry have become increasingly essential. A mechanical stress test laboratory differs from semiconductor manufacturing and service industries in several ways that affect lean implementation. Processes used in semiconductor manufacturing are usually highly repeatable, high-volume, and tightly regulated. In the service industry, where machines or specialized equipment are often not involved, lean thinking often focuses on reducing cycle time, simplifying processes, and eliminating misunderstandings. On the other hand, testing methods at a mechanical stress test laboratory are frequently more unique, varied, and non-repeatable. One of the main constraints is equipment availability, as environmental

chambers, fixtures, and testing machines may have limited capacity or lengthy running cycles. In addition, poor test design can quickly lead to delays, idle time, and reduced equipment usage. Examples of this include inadequate scheduling or an improper test sequence. Lean implementation in a mechanical stress test laboratory should therefore consider equipment utilization, test scheduling, setup reduction, and data flow management, in addition to process standardization. However, few studies have focused on using lean thinking to reduce the labor time required for verification and analysis in the electronics industry. The use of lean thinking principles represents a significant transformation within laboratory settings. Hence, this study fills the gap by exploring the application of lean thinking to reduce the labor time in the electronics industry's mechanical stress test laboratories.

3. CASE BACKGROUND AND RESEARCH METHODOLOGY

3.1. Company I Profile

Company I's mechanical stress test laboratory facilitates reliability-related testing for its clientele. Beyond conforming to top-tier manufacturers' specifications, it can accommodate customized testing requirements tailored to specific project needs. Established in 1994, Company I, a key player in the semiconductor industry's verification testing sector, underwent Taiwan's over-the-counter (OTC) stock market listing in 2004. It specializes in delivering verification services for electronic components, semiconductor ICs, and system templates, earning its status as a leading player in the domestic electronics industry. The company offers a range of invaluable services, acting as a third-party, impartial laboratory, assisting customers in maintaining product quality standards, and serving as a strategic R&D partner to expedite the market introduction of their products. It also aids in obtaining the qualifications necessary for supply chain verification from renowned top-tier brands. Its comprehensive service portfolio encompasses analysis and verification services, including IC repair, fault analysis, reliability verification, material analysis, signal testing, and chemical analysis. Company I is a capable provider of testing, verification, and analysis services spanning the entire supply chain of the global semiconductor industry, optoelectronics industry, IT industry, and automobile electronics industry, as well as throughout various product life cycle phases. Company I operates within the service sector of the semiconductor technology industry chain. In addition to supporting customers in implementing lead-free and halogen-free process enhancements, it exhibits a deep understanding of various environmental protection regulations set forth by top international manufacturers and the European Union (EU). This expertise enables major enterprises to maintain a sustainable and beautiful planet with green manufacturing processes. The board-level reliability (BLR) engineering section in

Figure 1. Figure 1 comprises three laboratories: the temperature cycling test and temperature/humidity storage test laboratory (TCT & THSTL), the shock test laboratory (STL), and the MSTL. This study focused on the MSTL, which adopted lean thinking practices. This laboratory specializes in simulating external stresses to evaluate the robustness of integrated components and the impact of repeated usage on product life. Its primary objective is to assess whether solder joints are susceptible to damage, potentially compromising a product's service life due to deformation when the printed circuit board (PCB) undergoes severe dynamic deformations during packaging, transportation, and regular usage following IC packaging. As of March 2021, the MSTL at Company I employed a team of 11 individuals, including one section chief, one project manager (PM), three engineers, and six technicians.

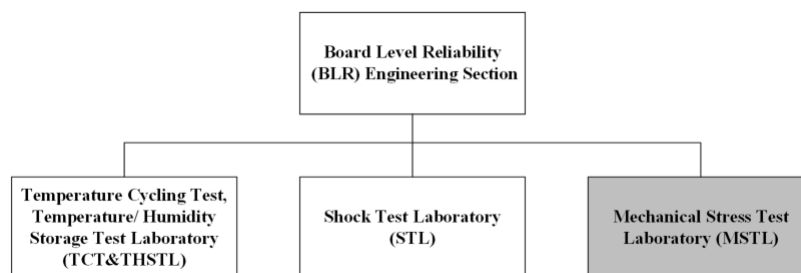


Figure 1. Organizational structure of the Board Level Reliability (BLR) Engineering Section at Company I

The project initiation process at Company I comprises nine essential steps, each of which contributes to the seamless execution of testing projects:

- (1) Project Commissioning: Customers initiate projects and engage in test consultations with the company's employees via phone or email. The PM assesses the scope of the project, gathers pertinent project information, delineates test

requirements, specifies sample details, and discusses test conditions and delivery timelines (lead times) with the customer.

- (2) **Sample Collection:** Upon confirmation of the project, the PM arranges for couriers to collect samples from the customer for testing. Alternatively, customers can send their samples directly to Company I's MSTL.
- (3) **Project Acceptance:** Upon receipt of the sample, the PM verifies the specifications of the sample, refines the test conditions, evaluates the required workforce and equipment load, and prepares a run-card. The run-card details test conditions, sample quantities, test delivery dates, and any necessary precautions.
- (4) **Project Summary and Handover:** At the end of each workday, the PM transfers all received projects, along with their respective run-cards and samples, to the engineers designated to oversee the subsequent phases of the project.
- (5) **Engineer and Technician Assignment:** Engineers coordinate the assigned projects and delegate specific tests to technicians based on the test conditions and the delivery dates outlined in the run-card.
- (6) **Pre-test Preparations:** Before conducting tests, essential preparatory work includes acquiring necessary test tools, soldering wires, and completing sample grinding and adhesion. After adhering the strain gauge, a 24-hour waiting period is required before testing begins.
- (7) **Test Execution:** Using bending tests as an example, the strain gauge is connected to the testing machine, and strain data and resistance values are monitored while pressure is applied with the mechanical stress test machine.
- (8) **Data Collection:** After the test, test data and information are organized and collated, and this information is handed over to assistants for further processing.
- (9) **Formal Report Production:** Assistants compile project-specific sample information, test data, and other relevant details into a formal report, typical of third-party impartial laboratories. This comprehensive report is then provided to the customer.
- (10) The PM within Company I's MSTL is the crucial link between customers and engineers and is primarily responsible for communication with the customer and coordination with those involved. To assess whether a project can be undertaken, the PM must understand customers' product packaging, test requirements, schedule, and budget. The PM assumes the role of project acquisition and scheduling planning. All projects received on a given day are distributed to the three engineers during the handover phase after the PM has assessed and organized them. The three engineers subsequently strategize the allocation of the projects to technicians based on the complexity and difficulty of the tests involved, with a typical project being assigned to one or two technicians (as depicted in Figure 2).
- (11) In this study, the complete service process, encompassing customer consultations, project commission, handovers by the PM and engineers, tests conducted by technicians, and the creation of formal reports, is collectively referred to as a "project" and is subject to discussion within the context of project management.

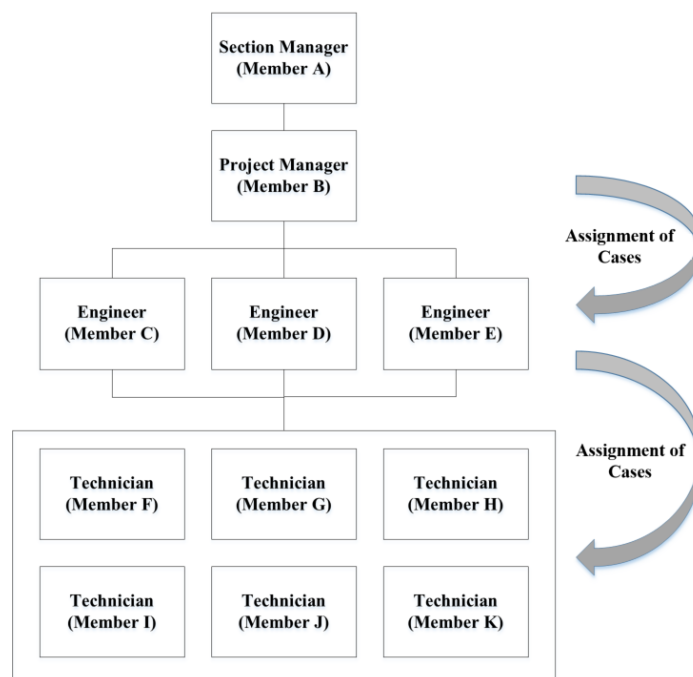


Figure 2. Staff allocation of Company I's MSTL

3.2. The Case Context and Analysis

The case study delves into the challenges faced by Company I's MSTL. The lab's operations have become increasingly complex due to the demand for small-scale, diverse, customized tests. Interestingly, although the quantity of projects has not significantly increased, there has been a notable increase in the laboratory personnel's working hours. This study seeks to understand the underlying reasons, evaluate processes and scheduling, and identify and mitigate potential sources of waste in personnel activities. Key observations and identified issues are:

- (1) **Project Complexity:** The increasing complexity of projects, characterized by their small scale, diversity, and customization, has led to higher workloads for laboratory personnel despite the relatively stable project quantity.
- (2) **Project Manager Limitation:** A significant issue is the presence of only one PM, who can be engaged in only one of the commissioned projects at a time. This necessitated the assistance of two engineers to manage multiple projects concurrently, implying the workload needed to be more substantial for a single individual to manage effectively.
- (3) **Personnel Efficiency:** Although the total working hours reflected high productivity, the study uncovered repetitive inefficiencies in personnel operations, resulting in longer working hours.
- (4) **Inefficient Handover Process:** The original scheduling arrangement relies on a single PM responsible for project handovers. The PM transfers projects to three engineers, who then allocate them to technicians for testing. With a limited window for project initiation and multiple engineers involved, this process leads to wasted free time and the need to wait for engineers. In addition, the frequent coordination and confirmation of work assignments are time-consuming.
- (5) **Waste in Laboratory Operations:** Waste exists in various forms within the laboratory, including technicians traveling long distances to access tools or materials, waiting periods during machine operations, and engagement in tasks unrelated to the ongoing tests. Unscheduled work disrupts test processes, reduces efficiency, and derails established schedules, providing no value to the tests for customers and Company I.
- (6) **Variability in Technician Efficiency:** Differences in production efficiency among technicians performing the same project impact overall productivity and can result in increased overtime. Furthermore, the inability to monitor technicians' working conditions in real-time can lead to idle personnel and resource wastage.

3.3. Saunders' Research Onion

This study uses Saunders *et al.*'s (2019) research onion as a framework to clarify the methodological choices underpinning the research design. The research onion helps align the study's philosophy, approach, methodological choice, strategy, time horizon, and data collection and analysis procedures coherently.

- **Research Philosophy:** The study adopts a pragmatic philosophy because it is driven by a practical operational problem in Company I's MSTL and seeks solutions that are both analytically rigorous and managerially useful. Accordingly, the study values both contextual understanding and measurable process improvement outcomes.
- **Approach to Theory Development:** The study follows an abductive approach. Existing lean thinking concepts from the literature were used to guide problem diagnosis and process redesign, while empirical observations from the case were used to refine understanding of waste sources and improvement actions.
- **Methodological Choice:** The study employs a mixed-method design.
 - Qualitative evidence was obtained through process reviews, on-site observation, and cross-functional discussions with project personnel.
 - Quantitative evidence was derived from labor-time records, handover times, and value stream mapping data used to compare the process before and after improvement.
- **Research Strategy:** The research strategy is a single case study focused on Company I's MSTL. This is appropriate because the study investigates a bounded organizational setting in depth and examines how lean thinking can be applied to an actual verification process in the electronic industry.
- **Time Horizon:** The study adopts a longitudinal time horizon because it covers both a preliminary evaluation period and a subsequent improvement period rather than a single point in time. Specifically, the study follows diagnosis and reform activities conducted during 2020 and evaluates change by comparing the current and future process states.
- **Techniques and Procedures:** The study combines several diagnostic and process-improvement tools, including the modified 6Ws framework, SIPOC, process review, personnel time analysis, and VSM. These tools were used to identify waste, design corrective actions, and evaluate improvement outcomes.

3.4. Research Structure

This study examines lean thinking implementation challenges in the MSTL of a semiconductor testing plant. We prioritize problem identification as the foundation for improvement. The methodology highlights are:

- (1) **6Ws Analysis:** We utilized the 6Ws method to assess all potential problems, which involved asking questions about why the problems exist, what actions are needed, when they should occur, where they should be executed, how to solve the identified problem, who is responsible, and who benefits. This analysis generally uncovers critical organizational challenges.
- (2) **SIPOC Diagram Definition:** To gain a holistic understanding of the process and validate the scope of the project, we introduced a SIPOC diagram (Assis de Souza *et al.*, 2023; Brown, 2019; Chen *et al.*, 2023; Zhang *et al.*, 2022). This diagram provided insights into the end-to-end process, from project initiation to the generation of the formal report.
- (3) **Process Review and Time Analysis:** We conducted an in-depth review of the laboratory process while tracking personnel's time allocation. This detailed analysis enabled us to identify and classify the laboratory's primary challenges.
- (4) **Value Streamlining:** As a crucial step towards process enhancement, we diligently eliminated NVA activities wherever possible, ensuring a focused and impactful improvement process based on VSM.

Figure 3 illustrates the study's framework, outlining our methodology, analysis, and improvement process.

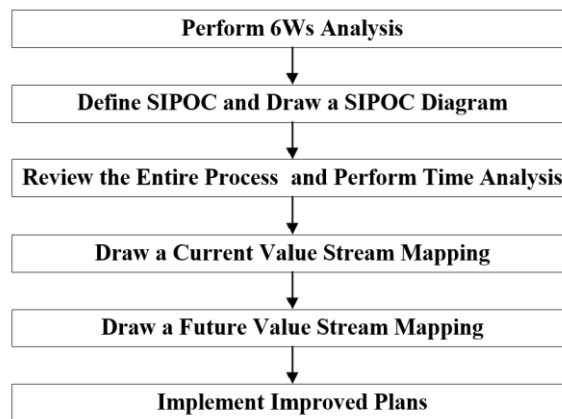


Figure 3. Research framework

3.5. Lean Analytical Tools

3.5.1. Modified 6Ws

In *The Elephant's Child*, published in 1902 by Nobel Prize-winning English writer Rudyard Kipling, the modern 6Ws first appeared in his poems: "I keep six honest serving-men (They taught me all I knew): Their names are What, Where, When, How, Why and Who." The 6Ws method comes from English question words, also known as the questioning strategy of 6Ws or 5WIH. As the questions comprising these six English question words are not valid or false but need specific answers, the 6Ws method is often used to analyze problems.

Because the execution technique in the mechanical stress-testing sector is rigidly regulated by standardized codes, calibrated apparatuses, and physics, the "how" part is often left out of the basic planning and scoping phases (the 6Ws framework). Instead of being an open variable to be brainstormed, "how" is viewed in this area as a definite technical constraint.

First, engineers have no control over how force is applied, data are collected, or a specimen is shaped during mechanical testing. International standards groups like the International Organization for Standardization (ISO), Deutsches Institut für Normung (DIN), and American Society for Testing and Materials (ASTM) strictly regulate these areas. Second, highly specialized, calibrated hardware, such as hydraulic actuators, environmental chambers, and universal testing machines, is necessary for mechanical stress testing. Third, by separating the method from the investigation findings, removing "how" allows the team to focus on the problem domain rather than the solution domain. In this study, the technique of 5Ws was used to analyze Company I, and the additional "whom" was added to become the modified 6Ws method to identify the main problems of the organization.

- a. **Why:** The purpose or rationale behind the action.
- b. **What:** The specific tasks or actions required to address the problem.
- c. **When:** The timeline or deadline for completing the task.

- d. Where: The location or place where the task should take place.
- e. Who: The individual or group responsible for implementing the solution.
- f. Whom: The intended beneficiaries or recipients of the action.

3.5.2. SIPOC

To understand the process comprehensively and determine the scope of the project, we utilized a straightforward diagram outlining the entire workflow from the initiation of the project to the generation of the final report. The SIPOC diagram is a system organization model initially proposed by Dr. Deming, a renowned American quality management scientist (Deming, 2018). It is commonly used in process management and technical improvement and comprises the following five key components:

1. Supplier: The component providing essential information, resources, organizations, processes, or individuals crucial for the core processes of the case.
2. Input: The supplier's resources, typically data or materials.
3. Process: A sequence of activities that enhance the value of input resources.
4. Output: Products, services, or related information generated in the process.
5. Customer: The end recipient of the output; this can be an external customer or an internal customer within the organization.

3.5.3. Value Stream

The value stream encompasses all activities associated with a product, from the initial raw materials to the production process, culminating in the finished product delivered to the customer. VSM serves as a visual management tool used in lean thinking/lean production to depict the flow of both materials and information (Rother and Shook, 1999).

The primary purpose of VSM is to identify areas of waste within the process that do not contribute value, seek opportunities for improvement, or create a future value stream map (Belhadi *et al.*, 2018; Kiran, 2021; Wang *et al.*, 2023). The value stream diagram can be categorized into NVA, necessary but non-value-added (NNVA), and VA processes by scrutinizing material and information flows. VA is defined as an operation that immediately transforms the good or service into what the customer wants and is willing to pay for. NNVA is defined as an activity that does not directly benefit the client but has become necessary due to laws, quality control, safety, traceability, customer requirements, or business process needs. NVA is defined as an action that neither creates value for the customer nor is necessary. As it is waste, it needs to be reduced or eliminated (Hines and Rich, 1997). For instance, "The technician's preparation of materials for sample grinding and adhesion required" is considered VA, as the sample cannot proceed to the necessary testing or evaluation stage without this preparation. As a result, the activity contributes directly to the sample's transformation and completion in compliance with the process specifications. However, although it supports the experiment and does not directly alter the product, sample, or test result, "PM organizing experimental conditions" is usually regarded as NNVA. It fosters value-added work, but it does not, by itself, change the product or service from the client's perspective.

4. ANALYSIS OF RESEARCH RESULTS

The case examined in this study represents a key customer for Company I, characterized by a substantial quantity and value of projects commissioned. Consequently, Company I places great importance on projects from this client. In May 2020, a lean reform was initiated in the MSTL of Company I. The primary goals were to enhance project processing timelines among laboratory staff members and reduce personnel waiting times. Under professional guidance, the reform process commenced with a two-month preliminary evaluation program and identified the following specific issues:

1. The PM's responsibilities included communicating with the clients, responding to emails, and conducting projects. However, two engineers were also involved, and they assisted in doing these tasks outside of their normal duties.
2. Project assignment followed multiple levels, with projects passing from the PM to engineers and technicians, leading to redundant work.
3. Waiting and handover time for the PM, engineers, and technicians resulted in inefficiencies.
4. There were instances of personnel engaging in excessive, unproductive actions during their work (such as unnecessary movement, transportation, and waiting).
5. The timeline for conducting tests had to be clarified after the handover of a case.

Based on the analysis of these findings, a reform plan for the next six months was devised.

4.1. Introduction of the Lean Reform Project in Company I

4.1.1. Process of Introducing the Lean Reform Project in Company I

The timeline and steps for the Lean Reform Project implementation are as follows:

1. August 2020: The integrated project intake and management window was introduced and exclusively managed by dedicated personnel to enhance operational efficiency.
2. September 2020: Project categorization and planning were established, making it easier to clarify the roles and responsibilities of various members of the team. Project arrangement became more efficiency with the introduction of systematic scheduling. This allowed for the direct input of estimated project working hours into the system, providing a visual interface for tracking ongoing projects. A specialized computer program was also developed to automate textual and graphical data arrangement, which increased personnel efficiency.
3. October 2020: Equipment integrations were redesigned, which increased the equipment's uptime and productivity. Jigs and tools were efficiently organized and strategically placed near the respective equipment, reducing the time wasted in retrieving tools.
4. December 2020: Efforts were made to enhance personnel training and standardize working hours in order to improve overall quality and efficiency.

4.1.2. Establishment of the Lean Reform Project Team

The first step in introducing the lean reform project at Company I was forming a cross-departmental and cross-organizational team. This team shared information across departments, enhanced its capabilities, and effectively involved all staff in the improvement efforts. The key members of this team are as follows:

a. Results review group

This group comprised the top management of Company I, and the group is primarily responsible for reviewing the program's outcomes. The company's top management has been actively engaged in the lean reform project since its inception, reviewing program content and maintaining close communication with the project leader. Their active involvement demonstrated their strong commitment to the program. This high-level attention reinforced the program's significance and resulted in employees taking the improvement measures more seriously.

b. Advisory group

- **Professional advisor:**

Company I hired experts from the Quality Management Association (QMA) as external consultants. Their primary responsibilities included providing technical guidance for the lean reform project, assisting in its specific implementation and execution methods, confirming plans, and monitoring process improvements.

- **Sharing of project experience by experienced personnel:**

Team leaders within Company I who had undergone project training shared their project experiences. They served as internal consultants for the company. They were dedicated to closely tracking project plans, gaining in-depth knowledge of various departmental processes, sharing insights from reform projects in other departments, and offering professional advice and suggestions.

- **E-system information personnel:**

These system information developers from the case company collaborated with users, management, and professional consultants. They assessed computer and system requirements, aided in introducing and enhancing internal systems, checked relevant specifications and processes, planned applications, and addressed processes and functions that required repetitive execution.

c. Implementation group

- **Project leader:**

The role of project leader was assumed by a departmental supervisor at the section level within the MSTL of Company I. Program leaders were wholly dedicated to overseeing the program and facilitating cross-departmental coordination. They had primary responsibility for front-line execution, leading project team members, and utilizing principles and tools of lean thinking to implement process improvements and ensure that the program was executed accurately and smoothly.

- **Project implementer:**

Project team members selected from the MSTL of Company I were project implementers. They played a crucial role as front-line executors, identifying real-world issues encountered in the laboratory, participating in discussions of the implementation plan, completing assigned tasks, and assisting the section-level supervisor in fulfilling higher-level instructions.

4.2. Analysis Using the Modified 6Ws Method

To identify and address the main problems within Company I, this study used the modified 6Ws method. The following analyses were conducted:

- Why:** The motivation behind the analysis. The laboratory has been experiencing a continuous increase in working hours due to more complex projects, despite the fact that the overall quantity was not increasing significantly.
- What:** The steps to address the problem. The approach involved reviewing processes and handover methods and designing scheduling management methods to reduce the potential for wasting time.
- When:** The timeline for completion. The initiative was set to span six months, starting on June 10, 2020. Group meetings were scheduled every Wednesday, and expert guidance sessions for the lean reform project were planned monthly.
- Where:** The location for the implementation was the MSTL within Company I.
- Who:** The individuals responsible for implementation. The PM and engineers working in the MSTL were tasked with executing the necessary changes.
- Whom:** The beneficiaries of these efforts. The improvements ameliorated the board-level reliability engineering section's MSTL within Company I.

4.3. Existing Process Analysis

4.3.1. SIPOC

To understand the project's scope and process comprehensively, this study used a straightforward SIPOC diagram to visualize the workflow from the initiation of a project to the generation of the formal report. The diagram in Figure 4 illustrates the five essential components of each task (i.e., suppliers, inputs, processes, outputs, and customers), along with their corresponding elements in each segment.

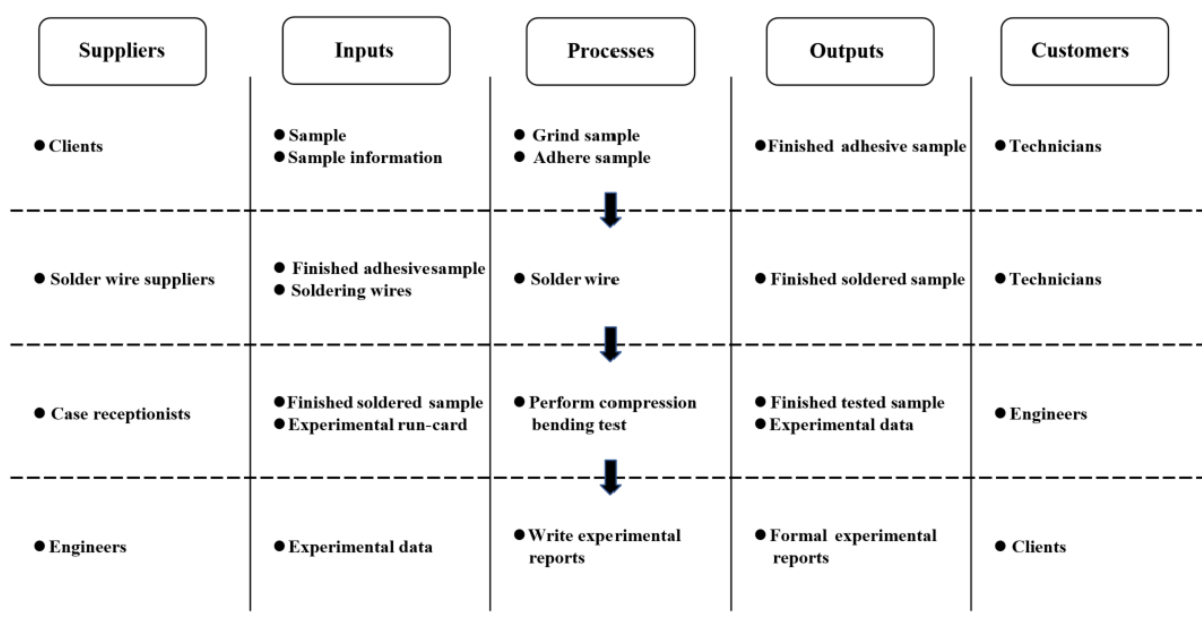


Figure 4. SIPOC diagram of MSTL projects

4.3.2. Project Management

The current project management consists of two primary process stages: the project intake process and the operational process. These stages were analyzed as follows.

Regarding the project intake process, transferring project information from customer commissioning to actual testing implementation involved multiple handoffs among the PM, engineers, and technicians. Unfortunately, this process was not seamless, and it resulted in a significant delay of approximately 90 minutes. In addition, engineers had a variety of tasks categorized into three types: established tasks, routine tasks, and temporary tasks. Established tasks, such as meetings, training, and business trips, had predefined timeframes. Routine tasks, including most tests, could be completed within the set timeframes. Temporary tasks had to be dealt with immediately, disrupting ongoing work. Managing these tasks simultaneously was challenging for the PM and engineers, which made it difficult to track progress and project assignments.

Regarding the operational process, the existing bulletin board system displayed project delivery dates, but it needed features to effectively prioritize projects and to assess the workloads of the technicians. Engineers faced challenges in project coordination, mainly when urgent or ad-hoc projects arose, requiring manual progress checks and personnel reallocations. In addition, the lack of a transparent information system hindered engineers' ability to monitor technicians' work progress and task locations. This opacity resulted in perceived workload imbalances among technicians, impacting their efficiency and overall productivity.

Recognizing these issues, Company I sought to implement lean thinking principles to address root causes within the project intake and operational processes, aiming to enhance overall quality and efficiency.

4.3.3. Current VSM

Following a comprehensive review of the existing processes and collecting information from various sites, the current processes were segmented into nine key stages. These stages encompassed the entire workflow, from project commissioning by the customer (customer commission) to the production of the formal report (project documentation), with pivotal points such as sample retrieval, PM's acceptance, PM handover, engineer handover, preliminary preparation, test execution, and data collection. The current project processes were integrated into the current VSM (Figure 5).

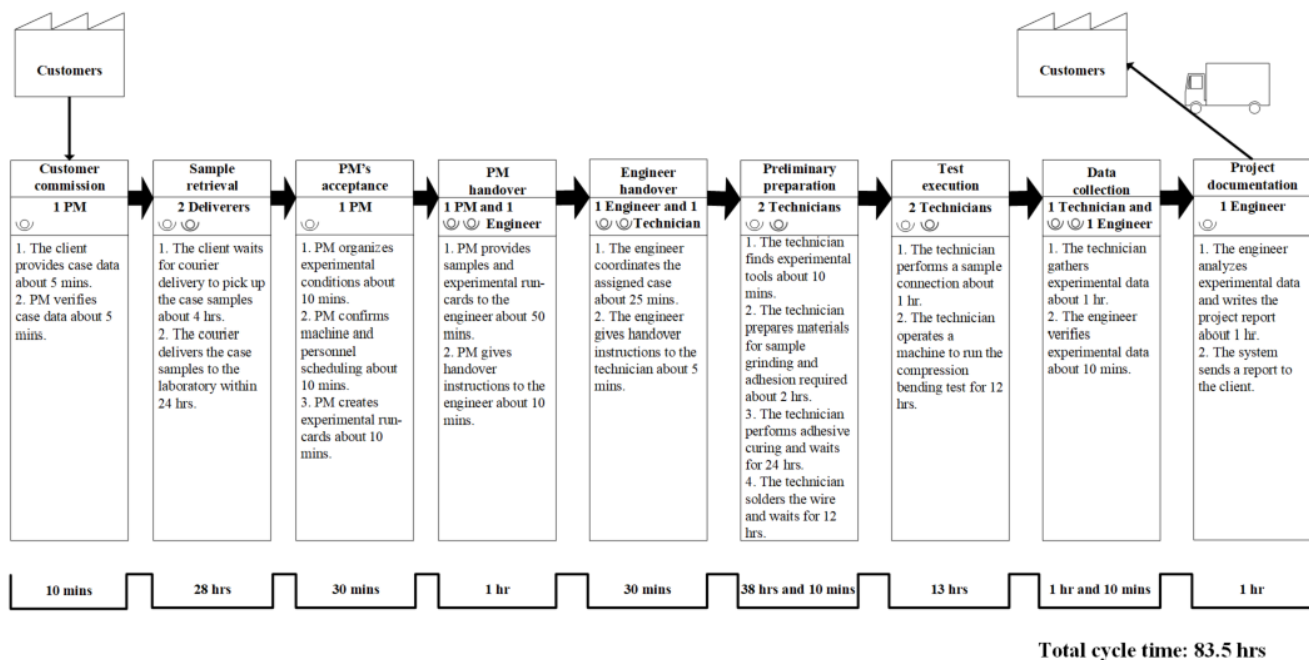


Figure 5. The current VSM

This study primarily targeted the improvement of four specific stages (Table 2): PM handover, engineer handover, preliminary preparation, and test execution. These stages were analyzed based on their distinct characteristics, and their activities were categorized into two primary groups: labor time and test time. Labor time encompasses the activities conducted

by personnel, including communication, coordination, movement, and the retrieval of tools. Conversely, test time refers to the duration associated with the actual testing process and covers both preliminary work time and machine test time. The study's focus for improvement concentrated primarily on reducing labor time.

The total labor time was 160 minutes, and this time was distributed as follows:

1. 50 minutes were allocated to the PM for sample and run-card provision to the engineer. 10 minutes were dedicated to verbal precautions provided by the PM to the engineer.
2. The engineer spent 25 minutes coordinating and assigning projects to the technicians. The engineer utilized 5 minutes for verbal precaution handover to the technicians.
3. An additional 10 minutes were spent by the technicians searching for test tools and fixtures.
4. The technicians spent 60 minutes during the sample connection phase.

The total test time was 50 hours, which consisted of the following stages:

1. Sample grinding and adhesion required 2 hours. An additional 24 hours were allocated for adhesive curing. Soldering the wire took 12 hours.
2. The machine performed the compression bending test over 12 hours.

Table 2. VA, NVA, and NNVA are among the nine stages of the current process

VSM	Customer commission	Sample retrieval	PM's acceptance	PM handover	Engineer handover	Preliminary preparation	Test execution	Data collection	Project documentation
VA						2. The technician prepares materials for sample grinding and adhesion as required.	1. The technician performs a sample connection.	1. The technician gathers experimental data.	1. The engineer analyzes experimental data and writes the project report.
						3. The technician performs adhesive curing.	2. The technician operates a machine to run the compression bending test.	2. The engineer verifies experimental data.	2. The system sends a report to the client.
						4. The technician solders the wire.			
NVA	N/A								
NNVA	1. The client provides case data.	1. The client waits for the courier delivery to pick up the case samples.	1. PM organizes experimental conditions.	1. PM provides samples and experimental run cards to the engineer.	1. The engineer coordinates the assigned case.	1. The technician finds experimental tools.	N/A	N/A	N/A
	2. PM verifies case data.	2. The courier delivers the case samples to the laboratory.	2. PM confirms machine and personnel scheduling. 3. PM creates experimental run-cards.	2. PM gives handover instructions to the engineer.	2. The engineer gives handover instructions to the technician.				

4.4. Improvement Implementation and Comparison

4.4.1. Project Intake Process Reorganization

The roles and responsibilities of personnel involved in project intake and testing were redefined. After reviewing the intake process, it became evident that more than one PM was needed to meet the demand for accepting projects. As a result, the configuration was modified to include two full-time PMs, with engineers assuming these roles (Figure 6). The labor time was reduced by 30 minutes by removing the engineer's handover step. This streamlined process and software enhancements allowed for most projects to be handed over directly to technicians, significantly improving process efficiency and flow.

Company I's IT department designed and implemented systematic scheduling software, making the handover process more efficient. The software system provided access to test schedules, conditions, quantities, and assigned engineers, all previously recorded on paper run-cards. Consequently, approximately 70% of projects could be handed over directly to technicians through the system, which takes only 5 minutes. The remaining 30% of more complex projects require two PMs to provide sample and experimental run-cards to a technician, which takes about $70\% \times 5 + 30\% \times 15 = 8$ minutes. For both cases, an extra 2 minutes for time allowance is needed. Next, one of the PMs gives handover instructions to the technician,

which takes about 5 minutes. Therefore, the process took only about $10 + 5 = 15$ minutes to reach the implementer (Figure 6). This reduced the handover time from the original 90 minutes to 15 minutes, resulting in a 75-minute reduction overall.

Engineers could input their project's estimated working hours into the system, which visually displayed all existing and historical project schedules. Implementers were required to record the actual machine operation time at the beginning and end of each task, providing a clear overview of machine operation time. The system also allowed for monitoring personnel's productivity for the current and previous days and identifying idle personnel, which could assist the PM in project and workforce allocation decisions.

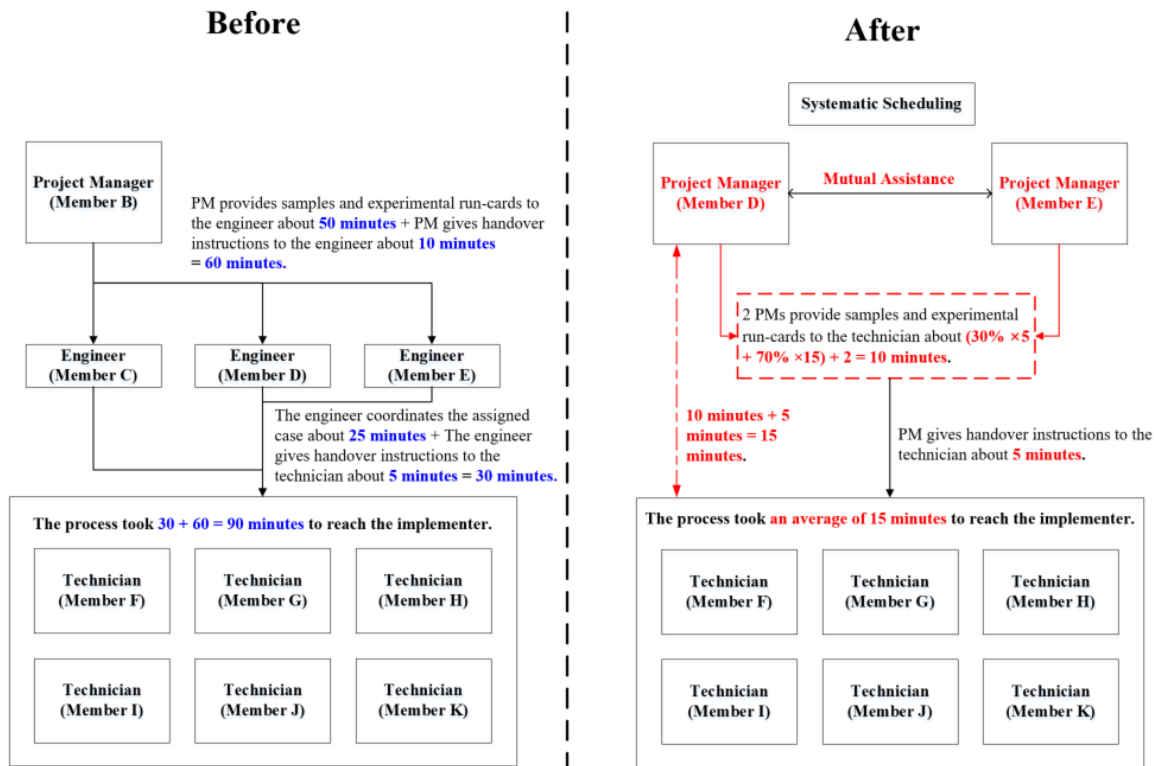


Figure 6. Before and after the project intake process reorganization

4.4.2. Operational Process Improvement

(1) Laboratory configuration

In the configuration of the existing test area, the machines had limited workspace, making it inconvenient to access them. There was also a shortage of jigs and tools; although they were stored together in a toolbox (Figure 7a), they were not located conveniently along the traffic flow, causing personnel to waste time moving around and searching for the necessary tools before operating the machines. Therefore, the layout of the toolbox was modified by acquiring new jigs and tools (Figure 7b). The tools required by each piece of equipment were positioned in front of the equipment, significantly reducing the time wasted in trying to locate the tools.

Following the reorganization of the workspace, the industrial computer was relocated under the desk, which cleared space on the desk (Figure 7c) and expanded the available work area. This facilitated the placement of project samples for testing and improved overall operational convenience.

(2) Redesigning the processes

The original equipment arrangement and setup resulted in time-consuming preliminary tasks and inadequate stability in the machine connection. The changes made in the test area involved installing fixtures and eliminating the need for tool retrieval actions. The strength of the connection was also enhanced (Figure 7d).

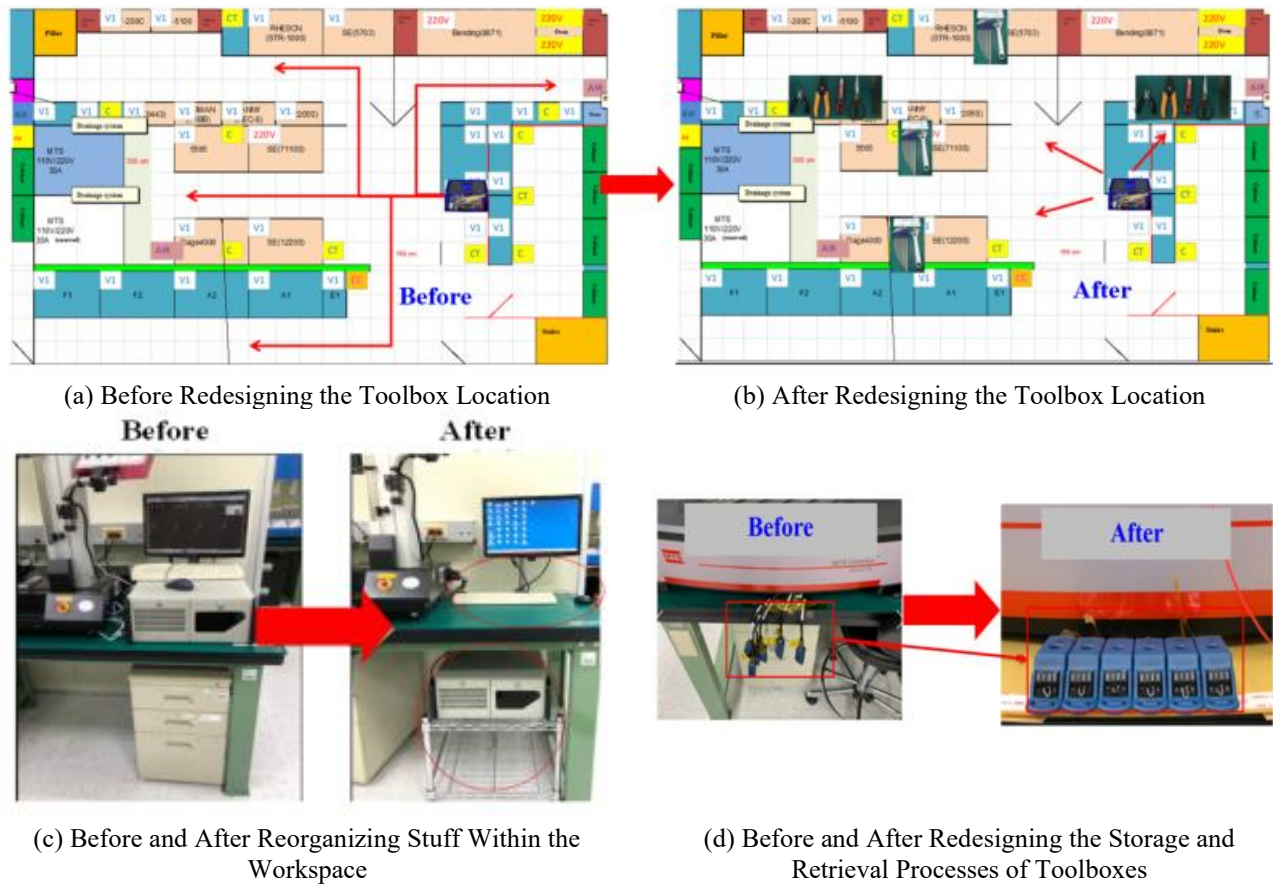


Figure 7. Before and after redesigning the toolbox location, reorganizing stuff within the workspace, and redesigning the processes of toolboxes' storage and retrieval

4.4.3. Future VSM

After the project members identified waste in the workflows of the current VSM (Figure 5), the project leader held regular brainstorming meetings and encouraged team members to propose potential countermeasures to reduce waste. The countermeasures described in Sections 4.4.1 and 4.4.2 are summarized in Table 3. Each waste-countermeasure pair can be viewed as valuable knowledge for the case company to perform knowledge management.

In the 6-month lean reform project, the improved benefits related to labor time were evaluated through the future VSM (Figure 8). The numerical results of workflow improvement are depicted in Figure 9. The key points of workflow improvement are as follows.

- A. **PM Handover Workflow:** The elimination of repeated handover processes led to a reduction in waiting time. Before the improvement, the project was handed over from the PM to the engineer and the technician. After the improvement, the PM directly handed the project over to the technician, reducing the handover time from 90 (= 60 + 30) minutes to 15 (= 10 + 5) minutes. Scheduling software systematically replaced the paper run-card handover method. Two stages (i.e., PM handover and engineer handover) were merged into one stage (PM handover).
- B. **Preliminary Preparation Workflow:** By acquiring additional jigs and improving the organization of tools, the time wasted on tool movement and retrieval was eliminated, reducing it from 10 minutes to 5 minutes—about a 50% improvement.
- C. **Test Execution Workflow:** For customer testing cases, the average number of test samples is about 200. After redesigning the test area and processes, the technician could connect 200 samples in about 38 minutes, based on Company I's historical data. Therefore, the total processing time for a testing case could be reduced from 60 minutes to 38 minutes, resulting in a 22-minute savings—about a 36.67% improvement.
- D. **Overall,** the total labor time decreased significantly from 160 minutes (= 90 + 10 + 60) to just 58 minutes (= 15 + 5 + 38), saving 63.75% (= (160 – 58) / 160 × 100%) of the total labor time.

Table 3. Identified waste and related countermeasures.

Identified Waste	Countermeasures
Project Complexity	By reducing the variability brought on by technicians' inconsistent efficiency and lengthy processes, the implementation of streamlined processes and scheduling software for personnel efficiency monitoring helps lower project complexity.
Project Manager Limitation	A policy was implemented to employ two full-time project managers to concurrently supervise various projects.
Personnel Efficiency	IT department designed and implemented systematic scheduling software, which provided access to test schedules, conditions, quantities, and assigned engineers.
Inefficient Handover Process	The engineer's handover step was removed.
Waste in Laboratory Operations	The industrial computer was moved to the area beneath the workstation to free up desk space and expand the workspace.
Variability in Technician Efficiency	The company's scheduling software, which offers a clear overview of machine operation time and allows for the monitoring of personnel productivity for the current and previous days as well as the identification of idle personnel, required employees to record the actual machine operation time at the start and end of each task.

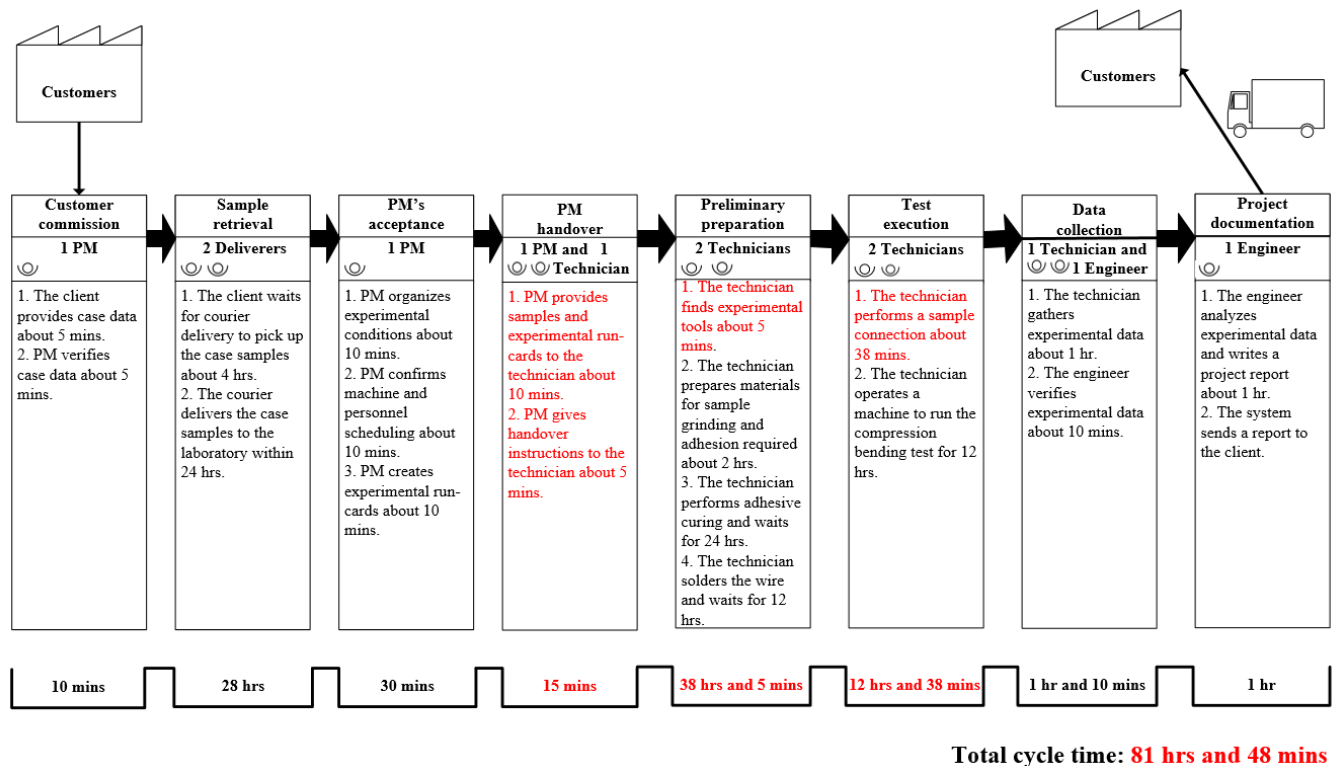


Figure 8. The future VSM

4.5. Managerial Implications

This study focused on the MSTL, but its methodology and approach can be applied to other laboratories and related projects within Company I. Although each laboratory may have unique processes, they can still follow the steps outlined in this study to introduce lean thinking and implement lean reform plans.

The process begins with identifying the primary issues within each laboratory using the modified 6Ws method. The SIPOC diagram can then be used to understand the overall process by reviewing the entire process, collecting data related to each step (such as VA, NVA, and NNVA), and creating a current VSM based on the gathered data.

Once identified, wasteful elements throughout the process can be pinpointed using the VSM, distinguishing among VA, NVA, and NNVA activities. After recognizing potential areas of waste, a reform plan can be developed to reduce inefficiencies, decrease the overall cycle time, and create a future VSM to evaluate the effectiveness of the reform plan.

The company's efficiency can be improved by eliminating waste, resulting in increased economic benefits for the organization. This approach provides a structured and systematic method for continuous improvement in various laboratory settings.

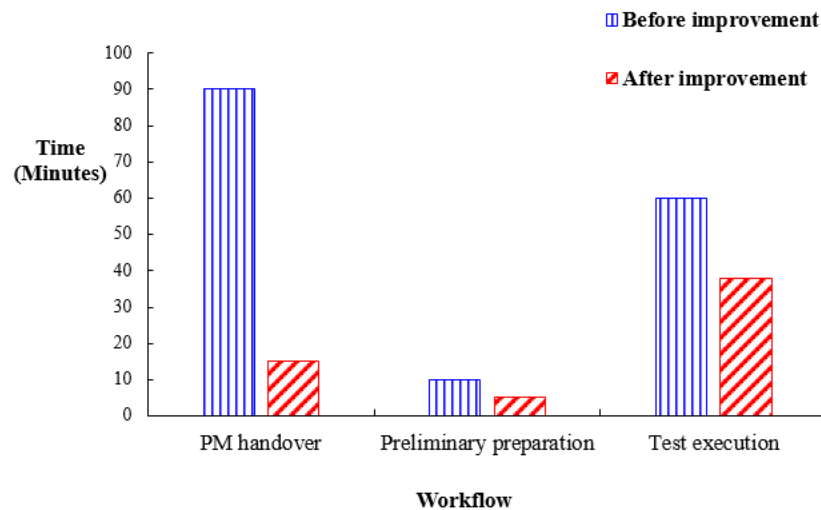


Figure 9. Comparison of three redesigned workflows between the current VSM and future VSM

5. CONCLUSION AND SUGGESTIONS

5.1. Conclusion

This paper presents a case study focused on Company I, using lean thinking as the foundational framework to identify and rectify unnecessary waste across the entire testing process, encompassing customer demand and producing formal reports. The primary subject of this case study is a crucial customer of Company I, a prominent international manufacturer with a substantial volume of commissioned projects. Redesigning this process has the potential to significantly reduce the waste of time.

Throughout this study, it became apparent that personnel experienced extended waiting periods during project handovers, and various forms of waste were prevalent throughout the process. It became evident that this process could be improved. Consequently, this study applied the principles of lean thinking to offer a systematic approach to enhance efficiency within the case company.

The study effectively leveraged lean thinking, conducting comprehensive analyses and in-depth discussions within the project team. As a result, improvements were implemented in three critical areas: project intake, operations, and workforce management. The summarized conclusions and implementation guidelines are provided below:

1. The study successfully reduced unnecessary steps in the processes by applying the principles of lean thinking and proposing countermeasures. For instance, the original workflow involved the PM passing the project to technicians via the engineer, resulting in a time-consuming process. With the introduction of the new software, the need for engineers to be the intermediary in the project handover was eliminated. This optimization reduced the project handover time dramatically (i.e., from 90 minutes to 15 minutes).
2. The new setup designated two engineers as PMs specifically responsible for project intake tasks to address workforce allocation and disruptions in machine operations caused by engineers taking on dual roles as PMs. This dedicated team substantially enhanced overall execution efficiency.
3. The study implemented a software system for estimating the required project hours and directly managing scheduling, providing a visual display of all ongoing projects.

4. Improvements were made in organizing the necessary jigs and tools for testing, with dedicated tools being placed in front of each piece of equipment.
5. Measuring equipment and connectors were improved.
6. The textual and graphical data underwent programmed sorting by the software.
7. Standardized working hours were introduced to enhance the quality and efficiency of personnel.

5.2. Research Limitations and Suggestions for Future Studies

This study only makes inferences for projects of the MSTL of Company I, and its analysis method is based on the principles of lean thinking. Although the study could not represent other industries, it could provide specific reference value through the analysis of relevant literature (Borgave and Sapkal, 2020; Gherghea *et al.*, 2020; Momenitabar *et al.*, 2020; Quispe Córdova *et al.*, 2023) and the case discussion of Company I. For subsequent relevant research, the following points are proposed as references for future research.

The analysis and implementation of the principles of lean thinking in this study, aimed at improving the testing process within Company I's MSTL, may only be applicable to some industries. However, it does provide valuable insights through its examination of relevant literature and the specific case of Company I. The following recommendations are proposed for future research in this field:

1. The collection of data and the statistical work in this study were time-consuming. Well-collected and organized data not only aid in process reviews but also facilitate workforce allocation and other purposes (Obeysekare *et al.*, 2016). Despite the assistance provided by Company I's computer system, manual calculations and data recording were still necessary for tracking working hours. Hence, additional improvements and upgrades to the system and software are needed (Pozzi *et al.*, 2024).
2. This study focused primarily on the first round of improvements related to labor time. Future research is suggested to extend its analysis and discussion and improve the hardware's operation time.
3. The improved processes should undergo regular reviews, analyses, and discussions to ensure ongoing enhancements and the reduction of waste, aligning with the modern trend of constant change (Knol *et al.*, 2019).
4. Before the introduction of lean thinking, it is advisable for companies to foster active employee engagement through continuous improvement plans promoted by supervisors as well as education and training. This approach can help break conservative conformity and instill a culture of continuous improvement.

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