Value Stream Mapping in Long-Lasting Insecticidal Net Production Improvement of Small and Medium Enterprise for Sustainable Manufacturing in Thailand

Oranicha Buthphorm*

Faculty of Science and Social Sciences, Burapha University, Watananakorn, Sakaew, 27160
E-mail: oranicha@buu.ac.th*

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บทคัดย่อ

งานวิจัยนี้มุ่งศึกษาการประยุกต์ใช้แนวคิดการผลิตแบบลีน (Lean Manufacturing) เพื่อแก้ปัญหาการสูญเปล่าที่เกิดขึ้นในกระบวนการผลิตมุ้งฆ่าแมลงแบบออกฤทธิ์นาน (Long-Lasting Insecticidal Net: LLIN) สำหรับอุตสาหกรรมขนาดกลางและขนาดย่อมในประเทศไทย โดยใช้ทั้งวิธีวิจัยเชิงคุณภาพและเชิงปริมาณ ซึ่งรวมถึงการสังเกตการณ์ การสัมภาษณ์เชิงลึกกับพนักงานจำนวน 22 คน และการเก็บข้อมูลผ่านแบบสอบถาม เครื่องมือที่ใช้ในการวิเคราะห์กระบวนการ ได้แก่ แผนที่สายธารแห่งคุณค่า (Value Stream Mapping: VSM) เพื่อแยกกิจกรรมที่เพิ่มมูลค่า (Value-Added: VA) ออกจากกิจกรรมที่ไม่เพิ่มมูลค่า (Non-Value-Added: NVA) และการวิเคราะห์ข้อบกพร่องโดยแผนภูมิต้นไม้ (Fault Tree Analysis: FTA) เพื่อหาสาเหตุรากเหง้าของปัญหา ผลการศึกษาพบว่าการปรับปรุงกระบวนการตามแนวคิดลีนช่วยลดเวลาในการผลิตทั้งหมดลง 23.08% ลดขั้นตอนในกระบวนการลง 31.03% และเพิ่มประสิทธิภาพการผลิตต่อชั่วโมงขึ้น 9.39% นอกจากนี้ยังช่วยลดสินค้าคงคลังระหว่างผลิต (Work-In-Process Inventory) ลง 7.46% และลดกิจกรรมที่ไม่เพิ่มมูลค่าลง 6.38% งานวิจัยนี้มีความสำคัญในเชิงปฏิบัติสำหรับผู้จัดการฝ่ายผลิตและองค์กรที่ต้องการพัฒนาการผลิตอย่างยั่งยืน และสนับสนุนการบรรลุเป้าหมายการพัฒนาที่ยั่งยืน (Sustainable Development Goals: SDGs)

คำสำคัญ: แผนที่สายธารแห่งคุณค่า กิจกรรมที่ไม่เพิ่มมูลค่า การผลิตอย่างยั่งยืน มุ้งฆ่าแมลงแบบออกฤทธิ์นาน การวิเคราะห์ข้อบกพร่องโดยแผนภูมิต้นไม้

Abstract

The aim of this study is to examine how to implement lean manufacturing solutions to reduce production waste in long-lasting insecticidal net (LLIN) production. Data was collected using a mix of literature-based qualitative and quantitative methodologies. The qualitative methodologies include observational and in-depth semi-structured interviews with 22 employees, whereas the quantitative methodologies include a questionnaire. The qualitative methodologies start with a study of the current process as well as customer demand. Value Stream Mapping (VSM) will serve as a tool for the identification of waste by separating value-added activities from non-value activities in the LLIN process. As part of the improvement process, fault tree analysis (FTA) techniques are used to determine the causes, along with the type of lean tools used. The results revealed that, after the proposed improvement, the total lead time decreased by 23.08% and the process step was shortened by 31.03%, which was quite an exceptional outcome. In addition, productivity was able to improve by 9.39%, work-in-process inventory was reduced by 7.46%, production time was reduced by 8.14%, and NVA was lowered by 6.38%. The findings of this study could provide some guidelines for the production manager and the manufacturing organization to deliver successful Sustainable Development Goals and achieve sustainable manufacturing.

Keywords: Value Stream Mapping, Non-Value Added, Sustainable Manufacturing, Long-Lasting Insecticidal Nets, Fault Tree Analysis

1. Introduction

The industrial manufacture of long-lasting insecticidal nets (LLINs) serves as essential for the global malaria prevention strategy. During COVID-19, 625,000 people worldwide will die from malaria in 2021, up from 619,000 in 2020. Malaria has increased the number of deaths in the world [1]. Malaria continues the primary risk to public health amid years of efforts to control it. This miserable disease damages the economies and profitability of infected areas [2]. The most sustainable and efficient malaria prevention measure currently available is LLINs [3]. According to UNICEF's annual prediction exercise in 2022, 60 million LLINs would be required between 2022 and 2023. It demands the purchase of 60 million LLINs for large-scale operation in Afghanistan, Burundi, Chad, Côte d'Ivoire, South Sudan, and Sudan in 2022–2023. In 2022 and 2023, respectively, UNICEF plans to purchase 28 million and 32 million mosquito nets [4].

As a result, there has grown an urgent need for LLINs use in order to prevent malaria globally. In order to safeguard themselves against malaria-carrying mosquitoes, companies that manufacture LLINs must continuously innovate and enhance their production procedures, as well as their sustainable production procedures and sustainable management of client demand. A total of 13 manufacturers, including those from Tanzania, China, Thailand, Vietnam, Rwanda, Pakistan, India, and Uganda, have 23 prequalified LLINs products on the World Health Organization (WHO)'s current list of approved products [4].

Manufacturers worldwide deliver between 240–270 million nets annually from a production capacity of 480 million nets, according to UNICEF estimates for the LLINs sector [4]. However, there are many current and upcoming difficulties that LLINs producers must overcome in order to operate and produce their products. These difficulties include rising costs for raw materials, technology, machinery, and processes for resource optimization, environmental sustainability, innovation, and the dynamic marketplace for LLINs suppliers. In addition, many LLINs businesses in developing countries like Thailand face considerable difficulties in adjusting their operational status to Industry 4.0 due to resource constraints and circumstances. Because of this, enterprises need to figure out how to manage production more effectively, pinpoint the root causes of issues, and develop workable solutions. Lean management is one of the methods that could potentially use to manage the manufacturing process to be more efficient, according to numerous pieces of relating studies.

In this study, we take a small and medium enterprise (SME) in a small town in Thailand as a case study. With a 15-year of experience in the textile business, the study company has been selected to manufacture the LLINs. The annual production capacity is roughly 12 million units. Customers' strategic plan, which calls for more products at the same or cheaper costs, has been accountable for this. In order to fulfill client demand, the company is forced to develop techniques to boost manufacturing capacity. As a result, the company is working on a project to increase production capacity to 17 million units annually. This is due to the company's output of the LLINs repellent falling short of the goal of 5 million nets annually, or 416,667 nets per month. As a consequence of this, the company fails to have the chance to raise its revenue and the potential to expand itself so that it can compete with new competitors who will enter the LLINs and win over existing clients. The firm concurs with the vitality of exploring methods and techniques to enhance operational processes, increase productivity, analyze the causes and variables that are causing lower-than-target productivity, and develop both short- and long-term solutions. In order to satisfy consumer demand, increase production efficiency, and get rid of waste, this study examine how to implement lean manufacturing solutions to reduce production waste, maintain customers, and gain a significant competitive edge in the sustainable market for LLINs.

2. Objective

To suggest the implementation lean manufacturing to reduce waste in the production of LLIN.

3. Literature review

3.1 Sustainable Development Goals (SDGs) and Long-lasting insecticide-treated nets (LLINs)

The Sustainable Development Goals (SDGs) 2030 are a global action plan for economic growth, the environment, and society [5]. Work on one issue may promote or impede progress on others, frequently through extensive systemic connections [6]. The SDGs are inspired by UN goals have a positive influence across all industries and attempt to address the entirety of people, prosperity, planet, peace, and partnership. The SDGs were established by the UN and were ratified by 193 of its member nations in 2015. The comprehensive 2030 Agenda for Sustainable Development, which outlines 17 Goals and 169 objectives, unifies the economic, social, and environmental aspects of sustainable development [7]. The circular economy is a sustainable paradigm for the majority of industries, according to UNICEF. In order to promote the SDGs involves LLIN production: Goals 12 and 13 deal with responsible production and consumption, while Goals 14 and 15 are concerned with life on land and under the sea, respectively. In order to assist in minimizing waste and promoting recycling, UNICEF actively promotes programs, ideas, and goods like LLINs [4].

Target Goal 3, at the same time, focuses on ensuring that people live healthy lives and encouraging well-being for all individuals regardless of age. The key welfare concerns addressed by Target 3.3 are the eradication of hepatitis, illnesses transmitted through water, and other infectious diseases by 2030, as well as the eradication of AIDS, TB, malaria, and neglected tropical diseases. With over 200 million cases annually, malaria accounts for a sizable share of the worldwide illness burden and is a significant public health concern in Africa [3]. Long-lasting insecticidal nets (LLINs) have been used as an effective replacement for conventional insecticide-treated nets (ITNs) for more than 10 years [8]. In regions where malaria is a major cause of mortality, long-lasting insecticide-treated nets (LLINs) are frequently supplied, especially to children under the age of five [6]. Additionally, as noted by [8] in the 1990s, a number of cluster-randomized trials showed that treated mosquito nets for children under the age of five significantly improved their chances of survival. LLINs have prevented more than 663 million scenarios of malaria since the year 2000, or 68% of all cases that have been prevented by all malaria prevention programs [9]. With respect to broadening distribution, 46% of sub-Saharan Africans who were at risk for malaria slept under a treated net in 2019. As a result, malaria mortality consistently reduced from 736,000 cases in 2000 to 409,000 cases in 2019 [10]. The objective internationally is for 80% of people who live in malaria-endemic regions to have access to and use an LLIN [11]. The SDG Goal Nine, on the other hand, focuses on encouraging equitable and sustainable industrial development as well as fostering innovation. The promotion of comprehensive and sustainable industrial growth is a goal under Goal 9. By employing cleaner, more environmentally friendly technology and industrial processes, we can boost the economy and attain sustainability.

The SDGs are global objectives, but it is crucial to localize them to fit the particulars of each country (a process called SDG localization). As a result, each nation operates in accordance with its unique resources [7].

3.2 Sustainability Manufacturing

The incorporation of systems and processes that can produce excellent products and services while using fewer and more sustainable resources (such as power and resources), while also being safer for employees, clients, and the communities it serves, and able to minimize adverse effects on the environment and society over the course of its entire lifespan [12], is known as sustainable manufacturing. In order to produce merchandise that is used in regular life while maintaining the planet's health, sustainable manufacturing primarily focuses on enhancing processes for manufacturing, materials, reusing and recycling methods, waste management approaches, computer programs, preventive pollution techniques efficient operations, and business growth [13]. The foremost objective of sustainable manufacturing, also known as green manufacturing, is to establish a production process that produces less waste and pollution [14]. The OECD defines the scope of sustainable manufacturing in seven areas, each with corresponding objects and applied disciplines. These areas are: mapping your impact and setting priorities; choosing useful performance indicators; measuring the inputs used in production; assessing the facility's operation; evaluating your products; understanding measured results; and performing to improve performance [15]. Whereas, Bonvoisin et al. [16] identifies sustainable manufacturing from four perspectives; technologies, product life cycles, value creation network, and global manufacturing impact.

3.3 Sustainability Manufacturing in the Clothing/Textile Sector

Recently, Millward-Hopkins [17] created scenarios looking at how the UK apparel industry could, over the next two decades, accomplish the ambitious environmental impact reductions required to bring humanity's influence back within planetary limitations. In order to foresee whether the garment business will be successful in reducing its environmental impact over the next 20 years, researchers in England undertook a study. The researchers conducted a study on the impacts of production- and consumption-focused adjustments using a model that employs material flow analysis to create an assessment of energy consumption, carbon emissions, water consumption, and land usage. By 2040, footprints might be reduced by 60–70% through cleaner production and recycling on its own, which would have enormous beneficial effects on land and water use. Similarity with the McKinsey report published in 2020, mentioned that the consumers will consider sustainability very carefully while making mass-market garment purchases in 2025 [18]. When linked to the SDGs (defend terrestrial life), sustainability innovation, particularly in the form of cleaner production, supports SDGs 9 (industry, innovation, and infrastructure), 12 (sustainable production and consumption), and 15 (climate action). The global textile industry must change from its destructive, traditional education, and growth-focused structure if it is to become environmentally sustainable [19]. However, fundamental adjustments will be needed throughout supply chains at customer and post-consumer phases in order to significantly decrease energy use [17].

3.4 Lean Tools

There have been several research on manufacturing and lean. Five fundamental lean manufacturing techniques—just-in-time (JIT), autonomy, kaizen/continuous improvement, total productive maintenance (TPM), and value stream mapping (VSM)—were the subject of research by [20] that looked at how they affected resource use, energy use, non-product output, and pollutant emissions. According to this study, which polled 250 manufacturing organizations throughout the globe, TPM and JIT have the most significant links with environmental performance, but kaizen is only pertinent to material use and pollutant emissions [20]. The key outcomes were a decrease in the frequency of machine interruptions waste, repeated actions, enhanced quality, and, most importantly, the adoption of sustainable business practices [21][22][23]. Numerous research teams have looked into alternative strategies to increase manufacturing effectiveness. Use the MTM2 approach to demonstrate how to indicate standard time in working units [24]. In addition, shorter lead times and improved production times are produced when fuzzy algorithms are used combined with VSM to detect process variation [25].

3.4.1 VSM in the Net Manufacturing

By contributing to the identification of value-adding activities and the elimination of non-value-adding waste, VSM, a visual tool, supports the process of lean production. According to, Seth & Gupta [26] stated that VSM gives the production process a visual representation and an agreed-upon language, enabling more thoughtful choices to enhance procedures. There are numerous examples of applications in the literature. For example, Vesely et al. [27] applied VSM to establish lean production in a fishing net manufacturing company. Without facing any budgetary constraints, the scenario company may place the future state map into practice to achieve lean manufacturing.

3.4.2 Fault Tree Analysis (FTA)

FTA is an analytical technique that involves first defining an undesirable event (typically a system or subsystem failure) and then examining the system in the context of its surroundings and functioning to find all potential combinations of fundamental events that will cause the undesirable event [28]. An effective instrument for assessing the dependability and safety of complicated structures is FTA [29]. FTA is portrayed as a conceptual flowchart that moves from top to bottom and is "single event-oriented". It illustrates that risky events and their underlying causes are related and dependent on one another. The word "basic events" refers to the underlying causes, which might include human mistakes, defective parts, as well as operational and environmental variables [30]. Thus, a fault tree offers a visual illustration of the reasoning links between the undesirable occurrence and the fundamental problem event [31].

With a particular focus on the small-to-medium textile firm sector, this study extends on previous studies that used lean manufacturing to reduce production waste. In order to detect waste, improve productivity, and accomplish sustainable manufacturing goals, this study goes deeper into the case of LLINs production than previous works that examined the general application of lean techniques like VSM in manufacturing. Furthermore, the study uses FTA, which has not been thoroughly studied in previous studies, to identify the underlying reasons of inefficiency.

4. Methodology

The lean production method can be used in businesses to minimize and remove waste in order to enhance the manufacturing process, save costs, and increase profits, according to a study of numerous documents and research articles. Finding lean wastes in the processes and determining their main causes are crucial for achieving effective and sustainable manufacturing. Studying pertinent theories and research publications, as well as primary data from the case study factory, is the first step in this research methodology. The key pieces of information included each process's cycle duration, change over time, lead time, and process flow from yarn to LLIN. Additionally, secondary statistics are gathered, including annual demand, labor shifts, and machinery.

Some secondary data was obtained from insight brainstorming from the 1 from each as managing director, general manager, factory manager, subcontractor manager, 6 production supervisors from each department from Rayong and Nakhon Pathom, 1 from each Customer service and quality control, the 3 from warehouse, and 3 from logistics department, in a total of 22 people. The period of data collecting was February 2023–March 2023. To guarantee dependability, observations and timing studies were conducted over a period of four weeks, with 26 samples taken at each stage of manufacture. We observed the factory to determine the process flow and shift count. Data on cycle times were gathered by measuring the factory's production process cycle time. Taking into account the production layout, waste, value- adding and non-value-adding operations, and time study, data are gathered throughout the entire production process. A stopwatch measuring device was used to show averaged data for up to 26 samples over a period of 4 weeks. Through performing a time analysis across multiple production steps within the LLIN manufacturing workflow, the standard time was established. Cycle times for each task were recorded using a stopwatch. 26 samples were collected for each phase over the four weeks of observations. To ensure precision and consistency in the measurements, these data were averaged to reflect the standard time.

In addition, we employed questionnaires to identifying the VA and NVA and drawing conclusions about the variables that affect waste, the results are utilized to optimize the production process using lean and industrial technologies. While the evaluation that results call for continuous enhancement.

5. Results

5.1 Overview of the Case Company

The case company made the decision to start this project as a result of the aforementioned factors in order to look for methods to improve its environmental performance, increase operational efficiency, and diminish the total environmental effect of its clients. This gave the authors the chance to conduct a thorough case study of the business in order to identify lean and waste across the process and to establish frameworks and strategies for continuous improvement in the operational performance of the organization.

5.2 The Process Activities Mapping (PAM)

Process mapping tasks in the LLIN manufacturing process provide the first step of the methodology. Process mapping, according to [32], is a task to visualize the primary choices and steps in a typical workflow. It keeps track of how information, resources, and documents move through the process and clarifies the tasks, decisions, and actions required at specific times. The current state of the LLIN production process (Figure 1) includes the process from incoming material, warping, knitting, heat setting, impregnation, cutting/sewing/packing to shipping of finished goods to customer (Table 1). The process maps all important activities of the LLIN process, including their flow and sequence, and different types of waste such as overproduction, waiting, transportation, unnecessary inventory, non-effective process, motion, and defect/rework. The next step of our methodology involved analyzing the causes of wastes by doing root cause analysis (RCA) by FTA.

5.3 Root cause analysis (RCA) of the wastes

When products and services fail short of the standards set by customers and other end users, production managers at manufacturing and service businesses are frequently forced to come up with a solution [33]. RCA is a solid method for achieving long-term business gains. It offers a range of techniques that enable teams to pinpoint the key causes of failure. Through process testing and data analysis, fundamental problems can be effectively addressed.

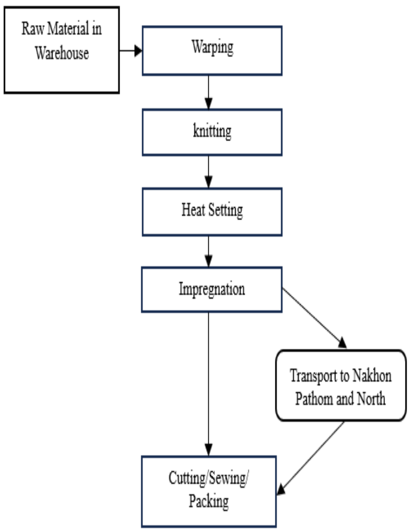

Figure 1 The LLIN production process

Root cause analysis was made more widely known as a method of problem-solving by the Toyota production system and the lean manufacturing methodology, which assist manufacturing companies in their processes of continuous improvement in areas such as production cost, productivity, quality, and maintenance [34,35]. Its goal is to identify the underlying reasons and carry out the appropriate solutions [36]. RCA can also be carried out in many ways and via various phases. Groups may employ one or more tools and techniques to identify the root causes when conducting root cause analysis [36]. The five whys, fishbone diagrams, cause and effect analysis, FTA, and Six Sigma are some of the tools and techniques that are used the most frequently [37,38]. FTA has been adopted given that it is a successful technique for systematically identifying and investigating the root causes of issues or inefficiencies in a manufacturing system. Its rational, top-down approach provides a comprehensive understanding of how various factors, including process flaws, equipment failures, and human error, lead to undesirable outcomes. Because it clearly illustrates the connections between likely failures and their underlying causes—a critical component of LLIN production, where quality and consistency are paramount—FTA is an effective instrument for this study.

Owing to the above reasoning, the next step of our methodology involves analyzing the causes of waste by doing FTA.

5.4 The current VSM

The analysis of all the current operations of VSM (Figure 2) showed that the performance of the workers in the LLIN process with the retrieval of raw materials needs to be improved. The analysis of the current 8 subordinate activities showed that 2,064 hours are spent in the current production process, of which 1,742 hours result in VA and 322 hours in NVA, or84.17 percent and 15.83 percent, respectively (Table 2).

Table 2 Activities analysis of the process

Process	Time (Hr.)	Percentage
VA (hr.)	1,742	84.17
NVA (hr.)	322	15.83
Total	2,064	100

Table 1 The PAM results

Process	Activity	Type of Activity	Value Analysis
Warping	- Put the yarn to spin in the bobbin - Move the spin to the weaving department	Operation Transport	VA NVA
Knitting	- Move the spin to the weaving loom - Check the quality of the fabric - Move the fabric to be woven into the plan and stretch the face	Operation Inspection Transport	VA NVA NVA

Process	Activity	Type of Activity	Value Analysis
Heat Set	- Fabric waiting to wash and stretch	Delay	NVA
	- Wash and stretch the face	Operation	VA
	- Collect samples of woven fabrics to send to inspection	Inspection	NVA
	- Transport woven fabric to dying and impregnated	Transport	NVA
Impregnated	- Waiting for dying and impregnation	Delay	NVA
	- Dying and impregnation	Operation	VA
	- Collect samples of impregnated woven fabric to inspection	Inspection	NVA
	- Waiting for the result	Delay	NVA
Transport	- Woven fabric weighting	Inspection	NVA
	- Waiting for transport to Nakhon Pathom	Delay	NVA
	- Loading to vehicle	Operation	NVA
	- Transport to Nakhon Pathom	Transport	NVA
Cutting	- Nakhon Pathom receiving and inspection	Inspection	NVA
	- Store the impregnated woven fabric by purchase order	Storage	NVA
	- Cutting and distribution to sewing and subcontractor	Operation	VA
Sewing	- Receiving and inspection of impregnated woven fabric from subcontractor	Inspection	NVA
	- Sewing-impregnated woven fabric	Operation	VA
	- Inspection impregnated woven fabric	Inspection	NVA
	- Transport to packing section	Transport	NVA
Packing	- Packing	Operation	VA
	- Sealing	Operation	VA
	- Pack in the sack	Operation	VA
	- Transport to store in front of the machine room	Transport	NVA
	- Sorting sacks according to order for inspection	Storage	NVA

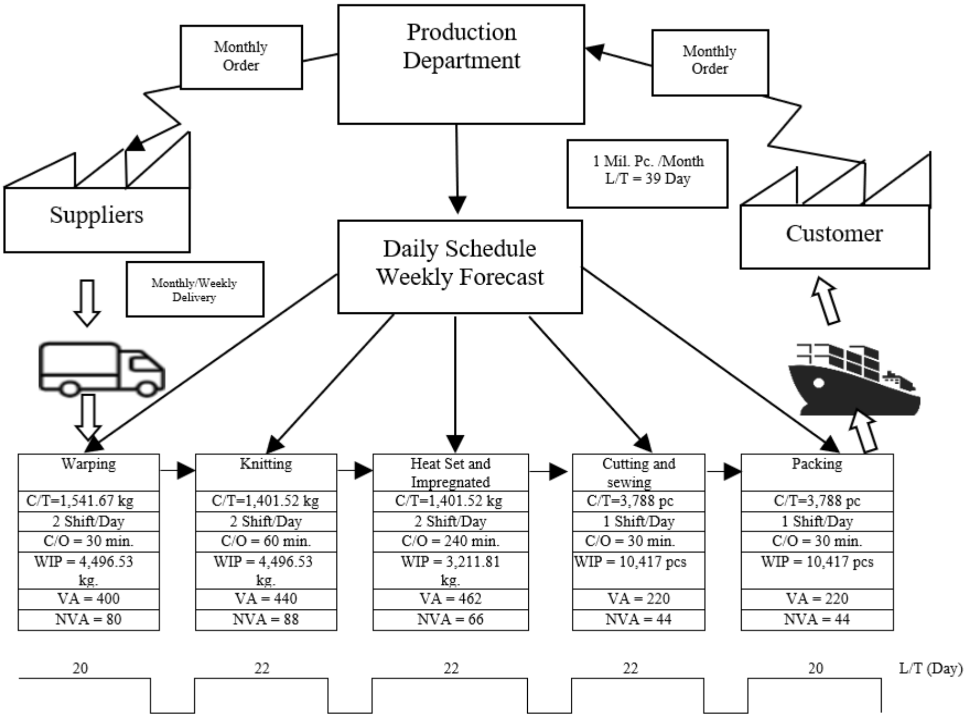

Figure 2 Current VSM

The following list of immediate and long-term adjustments addresses problems with the manufacturing process and the current status of the value stream diagram. These corrections were discovered and are considered production waste that added no value.

Waiting, excessive work during manufacturing, sunk costs, and unnoticed costs are examples of waste that results from overproduction or an imbalanced quantity of work. The issue can be resolved in the immediate future by using technology and information to plan production so that it is balanced and to maximize the usage of workers and equipment, such as MRPI and MRPII, to decrease work during production and decrease waiting. Investigating the feasibility of organizing new production would be a long-term solution. To lower the cost of wear and tear on handling equipment, various machines should be better laid up, the ERP system should be studied, and Just in Time (JIT) manufacturing should be utilized to reduce fabric moves.

Eliminating the waste of tiny stops in the machine can fix or prevent three issues: putting into practice TPM, a strategy for maintaining machinery and equipment in which everyone participates, and strictly using high-quality parts, equipment, and spares in accordance with the instructions specified in the machine manual. Establishing a comprehensive training program for machine operators and educating staff members on their responsibility in preventing production damage and reducing errors.

Application of the five S principles, use of an efficient inventory management system, efficient purchase planning, and JIT delivery and production techniques are all recommendations for decreasing inventory waste.

Waste from monitoring the woven fabric's quality during production and from the finished product (a mosquito net made of fabric). The following are some recommendations for solving the issues: implement TPM in order to get maximum use of the machinery. In order to bring out the product according to the target and ensure the quality satisfies client needs, it is also vital to retain valued people with excellent work skills. These methods increase quality assurance while lowering manufacturing process defects and requiring rework.

Transportation waste from Rayong to Nakhon Pathom and the northern area for sewing and packing, with the following long-term solutions: putting in place a strict and comprehensive sewing training and education program at the Rayong facility in order to cut the transportation correlate to Nakhon Pathom and the North. In order to reach the customer's objectives in the key areas of contract compliance and volume expansion.

5.5 Proposed Improvement by Lean Techniques

The entire range from guidelines for improving the production process and flow to new phases of manufacturing including new production planning, cutting waste with lean tools, total production time, and work-in-process inventory. Organizations can cut costs and enhance product quality by reducing total production lead time and work-in-process inventory. The FTA that follows demonstrates lean methods and recommendations for cutting waste during the manufacture of LLIN (Figure 3).

A combination of observations, time studies, interviews, and questionnaires were used to gather the data for Figure 4. A stopwatch was used to measure the cycle times for each production stage, and 26 samples were collected over a period of four weeks. Qualitative insights about inefficiencies were obtained through semi-structured interviews and observations with 22 employees. Additionally, elements that contribute to waste were identified through the use of surveys. Accurate data was guaranteed for the value stream map and lean improvement proposals attributable to these coupled techniques. A tool that's beneficial in increasing process efficiency is the application of lean manufacturing techniques to the example company's future value stream diagram and continuous enhancement in each process. A lean manufacturing system might reduce the time it takes to change machinery and decrease the number of steps in the production process from 29 to 20 or 31.03 percent, and the overall production time from 39 to 30, or 23.07 percent. Lead times, and NVA can all be decreased by lowering work-in-process inventory, as shown in Figure 4. A variety of tools were used to collect the data shown in Table 3, including process mapping techniques to document workflow and identify bottlenecks, questionnaires to identify VA and NVA activities, and stopwatches to quantify cycle time across processes. Together, these resources made it easier to conduct a thorough examination of both existing and enhanced production situations. Together, these tools made it more accessible to conduct a thorough examination of both existing and enhanced production circumstances.

6. Discussion and Conclusion

Findings of this study indicate how effectively lean manufacturing approaches may be applied to increase LLIN production efficiency. The notable decreases in NVA (6.38%), production steps (31.03%), and overall lead time (24.08%) are consistent with the findings of other studies on lean tools in the textile industry. As an illustration, [26] pointed out that VSM efficiently decreases cycle times and identifies waste in production processes, which is in line with our findings that demonstrate notable gains following lean deployment. The study's 9.39% productivity improvement supports findings by [22], who found that integrating lean techniques like TPM and JIT into production processes increased manufacturing output. Furthermore, the decrease in work-in-process inventory (7.46%) is consistent with [19], who highlighted the importance of lean in SMEs for maximizing resource utilization and reducing waste. The inclusion of FTA in the RCA process makes it possible to identify and eliminate significant inefficiencies. This supports the findings of [29], who noted that FTA provides a systematic framework for determining the underlying causes of complex systems. By employing FTA to identify waste sources and recommend targeted lean activities, this study contributed to the broader understanding of RCA applications in sustainable production.

This experiment's findings can be used to establish a work standard that, when put into practice, will increase revenue for the company and improve customer service. Overall, this study contributes to the growing body of research on lean manufacturing in SMEs by providing insightful information about how lean tools might support sustainability and efficiency in LLIN production. These findings demonstrate how essential it is to integrate qualitative methods (such as surveys and interviews) with quantitative tools (such as time studies and VSM) in order to achieve comprehensive improvements. Future research should look at how similar lean methodologies might be applied in different industries in order to successfully accomplish the more general sustainable development goals (SDGs).

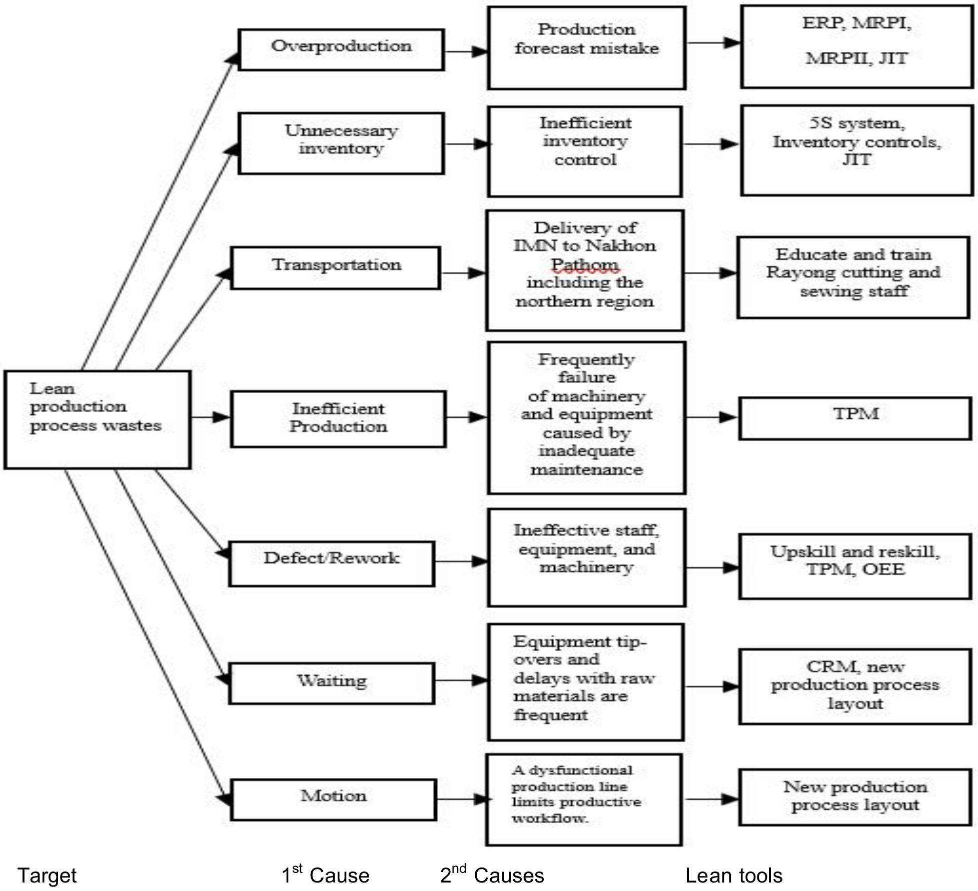

Figure 3 Fault Tree Analysis Diagram

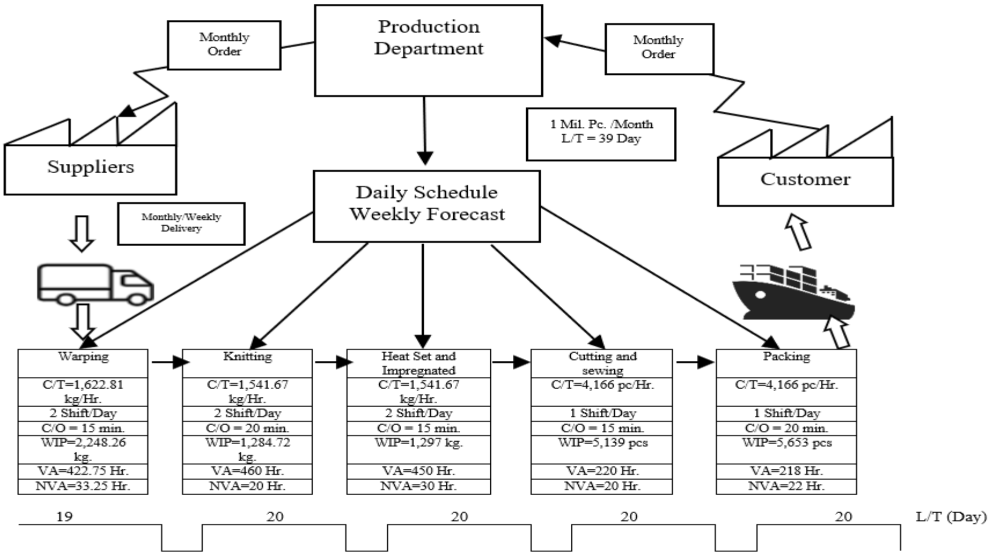

Figure 4 Future VSM

Table 3 Comparison of the current and future VSM

Measurement	Current	Future	Performance		Measure Unit
			Decrease	Increase	
Total lead time	39	30	9		Day
Process	29	20	9		process
NVA	12.98	6.61	6.38		%
Production time	2,064	1,896	168		Hour
WIP Inventory	16.18	8.72	7.46		%
Productivity/hr.	11,920.45	13,039.47		9.39	%

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