Sustainable Lean Supply Chain to Minimize Waste in Solar Water Heater Production

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Abstract. [illegible]

1 Introduction

In the contemporary era of rapid development, companies operating in the manufacturing sector are compelled to deliver high-quality products that can endure in the competitive market. This imperative extends to firms specializing in renewable energy products. Concurrent with the evolving landscape, there is a growing awareness of the global ramifications, including the diminishing reservoir of traditional energy sources. Consequently, the emergence of companies dedicated to renewable energy solutions has become pivotal in addressing contemporary global challenges. In this context, the role of Company X is indispensable in its capacity to compete with industry counterparts. Established in 1992, Company X is a prominent player in the renewable energy sector, offering various products. Among these, the Solar Water Heater (SWH) stands out as a flagship product, renowned for its ability to harness solar energy for residential water heating needs. However, Company X frequently needs help with the supply chain management of SWH products. The supply chain flow of SWH products, as depicted in **Fig. 1**, encompasses

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Upstream Activity, Internal Activity, and Downstream Activity. The specific issues identified in the supply chain flow of SWH products are detailed in **Fig. 2**.

The company must meet production targets for customer demand based on the production type of SWH products, precisely, Make to Stock. These production targets serve as a benchmark for the production process, ensuring the ability to fulfil customer and distributor demands. The production target and realization of SWH products are presented in **Fig. 3** and **Table 1**, revealing instances where the production target still needs to be met during various months spanning from June 2021 to January 2022. The failure to achieve these production targets can be attributed to several factors stemming from upstream and internal activities. Notably, issues such as delayed deliveries from suppliers and inefficiencies in the manufacturing process have led to stock shortages in the finished goods warehouse, consequently impeding distributors from meeting customer demand.

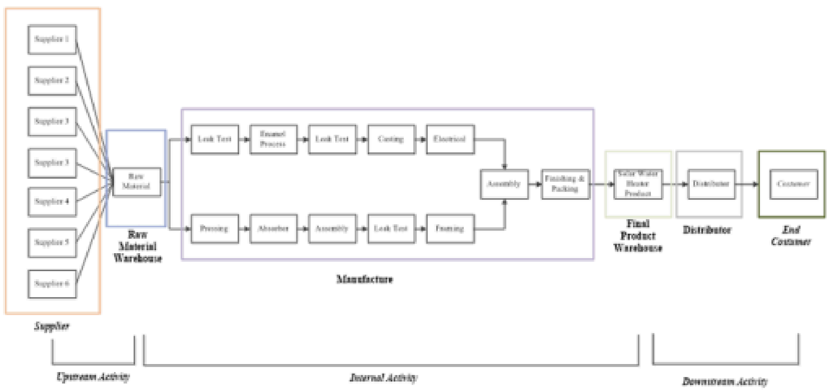

Fig. 1. Supply Chain for Solar Water Heater

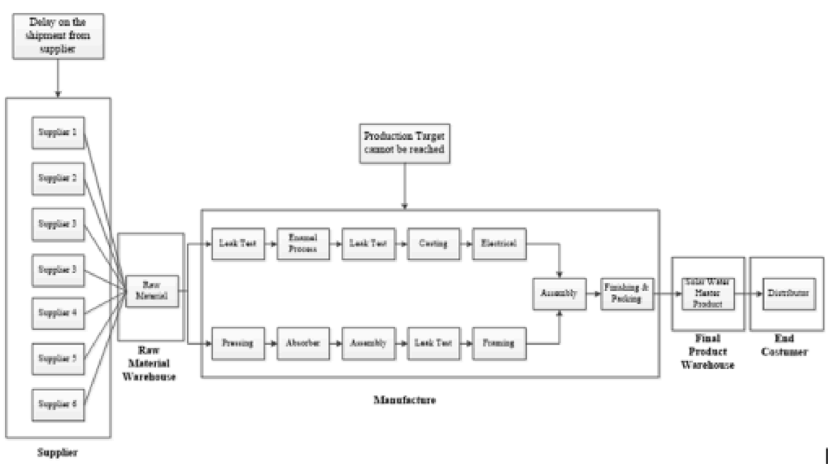

Fig. 2. Problem found in Solar Water Heater Supply Chain

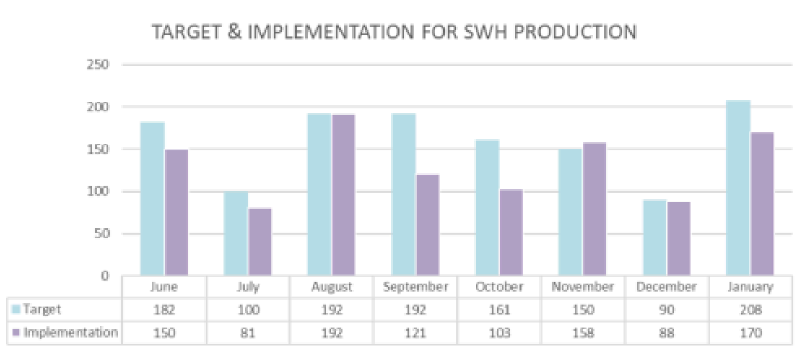

Fig. 3. Chart for Target & Implementation for SWH Production in June 2021 – January 2022

Table 1. Plan and Implementation of Raw Material's Delivery

Material Name	Delivery	Delivery Target Time Difference (Day)	Delay Time (Day)
Thermostat Cable	July	3	2
	September	1	-
	November	4	4
Polyurethane	August	1	3
	October	8	8
	December	4	1
SS Plat	September	-	-
	November	-	-
	January	1	-
SR Tank	August	12	13
	December	8	10
Panel	August	-	2
	November	3	1
Glass	September	-	-
	December	-	1

The issue at hand leads to inefficiencies in various production processes and impedes the sales of SWH products. Therefore, it is imperative to further pinpoint and address waste within the supply chain flow. This is essential for Company X to continue meeting customer demands and enhancing the quality of SWH products. Moreover, Company X strives to bolster its credibility as a sustainable company. Implementing a Sustainable Lean Supply Chain approach holds the potential to mitigate waste by encompassing the three dimensions of sustainability. Given that Company X specializes in renewable energy products, the concept of sustainability aligns with its core offerings. Furthermore, the Lean supply chain concept is closely linked to sustainable supply chain practices, emphasizing waste minimization and process efficiency. The primary objective of this study is to reduce waste in the supply chain through the Sustainable Lean Supply Chain approach. It will involve the following steps:

a. Identifying supply chain flow gaps using the Current State Sustainable Value Stream Mapping tool.
b. Analyze activities in the supply chain flow through value chain analysis.
c. Determining the types of waste using Process Activity Mapping.
d. Constructing an Ishikawa Diagram to ascertain the cause and effect of the identified waste types.

e. Calculating the Sustainability Index value.
f. Proposing suitable enhancements to minimize waste in the supply chain flow.

Sustainable supply chain management (SSCM) involves the coordinated flow of materials and information among supply chain actors, focusing on integrating the three pillars of sustainability: economic, social, and environmental. Adopting Lean concepts can facilitate achieving sustainability goals by enabling companies to analyze these three pillars using tools from Lean principles [1]. Lean methodologies effectively identify and eliminate activities that do not add value, thereby addressing various forms of waste in the production process. These wastes, as categorized by Lean, include overproduction (conducting supply chain activities before they are needed), waiting (time spent in the supply chain flow), transportation (movement of goods between locations), inappropriate processing (engaging in non-value-adding activities), unnecessary inventory (storage of goods that are no longer required), unnecessary motion (repetitive activities that are suboptimal), defects (errors and miscommunication leading to delivery issues), and underutilized employees (worker behaviors that do not contribute value) [2].

In this study, Sustainable Value Stream Mapping (SVSM) tools were utilized to conduct waste mapping within the supply chain flow. The tools above play a crucial role in comprehending the flow of materials and information, thereby aiding in the visualization of a given process [3]. The primary objective of SVSM is to pinpoint areas of waste within a process regarding the three pillars of sustainability: economic, social, and environmental. The study also employed Process Activity Mapping (PAM) to identify further waste, categorizing activities into value-added, necessary, and non-value-added segments. Additionally, the Sustainability Index (SI) was calculated to assess the application of sustainable concepts. This calculation involved an evaluation of the economic (E), social (S), and environmental (N) aspects, which are the three main pillars of sustainability. The indicators selected for calculating the sustainability index were based on the specific conditions of each company.

2 Method

The study was conducted at company X, commencing with a research investigation involving observations on SWH production and interviews with the production division manager and SWH production supervisor. The research was underpinned by a comprehensive literature review encompassing the theory of sustainable lean supply chain, SVSM, value chain analysis, PAM, Ishikawa diagram, and SI. Furthermore, the literature review involved a critical evaluation of prior research. Subsequently, the research progressed to problem identification and establishing research objectives. Data collection was then undertaken, comprising primary data (direct observation and interviews with the Production Division) and secondary data (company-specific information such as history, vision, mission, suppliers, working hours, and standard time in the SWH production process). Data processing involved waste identification, analysis, and proposed improvements. Waste identification was achieved by mapping the supply chain flow using SVSM, analyzing company activities using the value chain, and identifying waste using PAM. Waste analysis was conducted using the Ishikawa diagram and the calculation of the SI (for the calculation refer Sari et al., 2021 [4]), culminating in the proposal of appropriate improvements to minimize waste.

3 Result and discussion

3.1 Current SVSM and SI

The current SVSM mapping reveals that the total standard time is 294454.2 seconds, resulting in a total Supply Chain Lead Time of 540712.3 seconds for the SWH supply chain flow. The Process Cycle Efficiency (PCE) value is calculated at 54%, indicating that waste is still present in each process of the supply chain flow, thereby suggesting that the efficiency of the SWH product supply chain flow has yet to be maximized. Specifically, waste is identified in the primary activities of inbound logistics, operations, and outbound logistics. The current PAM identification highlights 70 activities, with 25 activities classified as value-added, 21 as non-value added, and 24 as necessary but non-value added. The significant percentage of necessary but non-value added and non-value-added activities indicates that numerous activities within the supply chain flow do not contribute added value. Furthermore, the flow mapping identifies 5 out of 8 wastes, including inventory, motion, waiting, overprocessing, defects, and behavior. Waiting is the type of waste with the highest activity percentage, indicating a substantial amount of time spent waiting during the supply chain flow of SWH products.

In calculating the SI, as presented in **Table 2.** with the indicators for SI calculation, the findings indicate that the Economy SI yields a result of 1.491 or 149%. It implies that a 149% effort is required to attain sustainability in the economic aspect. In the social dimension, the Social SI is valued at 1.549, indicating a necessity for 155% effort. The Environment SI is determined to be 0.901, signifying a requirement for 90% sustainable efforts. The SI total value for all three pillars is 143%, indicating that the company needs to exert 143% effort to achieve a sustainable supply chain flow.

3.2 Future SVSM and SI

Based on the proposed improvements aimed at minimizing waste in the SWH supply chain, a Future State SVSM has been developed to estimate the time and value after implementing these improvements. Following the creation of the Future State SVSM, a Future PAM was also established. The Future State SVSM, as depicted in **Fig. 4**, illustrates a decrease in the Supply Chain Lead Time to 475782.19 seconds, leading to an increase in PCE value from 54% to 64%. This improvement can be attributed to adopting various measures such as implementing 5S in the warehouse, evaluating suppliers, implementing Standard Operating Procedures (SOPs) in various activities, and regular training for workers.

Table 2. Indicator Chosen in Sustainable Lean Supply Chain

Sustainability Pillars	***Factor***	**Level**	**Source**	**Explanation**	**Calculation**
Economy (E)	Inventory Turnover (E1)	Supplier	[5]	Inventory that has the longest time of emptying inventory	The highest value of inventory emptying time divided by material demand
	Time (%) (E2)	Supplier - Manufacture – Distributor	[6]	The period between the beginning of the process and the end of the process	(VA/(NVA+VA))*100%
	Defect (%) (E3)	Manufacture – Distributor	[7]	Tolerance of defects found in material or during production	Tolerance of defects set by the company
	Quality of Raw Material (%) (E4)	Supplier	[6]	The quality of the raw material sent by the supplier	Percentage of materials that identify as NG materials

Sustainability Pillars	*Factor*	Level	Source	Explanation	Calculation
	Service Level Quantity (%) (E4)	Distributor	[5]	Information regarding orders delivered is precise in terms of quantity	Percentage of complaints on the number of products shipped from the company
Social (S)	Risk of Safety (%) (S1)	Manufacture	[8]	work safety level of each process	Percentage of employee reports for work accidents from each workstation
	Employee Training (%) (S2)	Manufacture	[9]	Numbers of workers who have done company training	Numbers of workers who have done company training
	Lightning Level (Lux) (S3)	Manufacture	[10]	The lightning intensity at the workstation where the production process	Lightning intensity at PT. XY
Environment (N)	Energy Consumption (kWh) (N1)	Manufacture	[8]	Energy consumption during the production process	Energy consumption during the production process
	Waste Factor (kg) (N2)	Manufacture	[5]	Measurement of the use waste in each production process	The amount of waste that is from the beginning of the process until the product is ready to be shipped

The results obtained from the Future PAM indicate an increase in the percentage of time allocated to value-added activities, rising to 64% from the previous 54%. A decrease in non-value-added and necessary but non-value-added activities accompanies this increase. Before implementing improvements, five types of waste were identified: motion, waiting, overprocessing, defects, and behavior. However, only four types of waste were identified after the improvements were made, as specific processes needing added value were eliminated. The types of waste identified after the improvement are motion, waiting, defects, and behavior.

These findings align with lean management principles and continuous improvement, as they demonstrate reduced waste and increased efficiency within the SWH supply chain. Implementing strategies such as 5S, supplier evaluation, SOP implementation, and worker training has contributed to these positive outcomes. Overall, the proposed improvements have led to tangible enhancements in the SWH supply chain, as evidenced by reduced lead time and increased process efficiency.

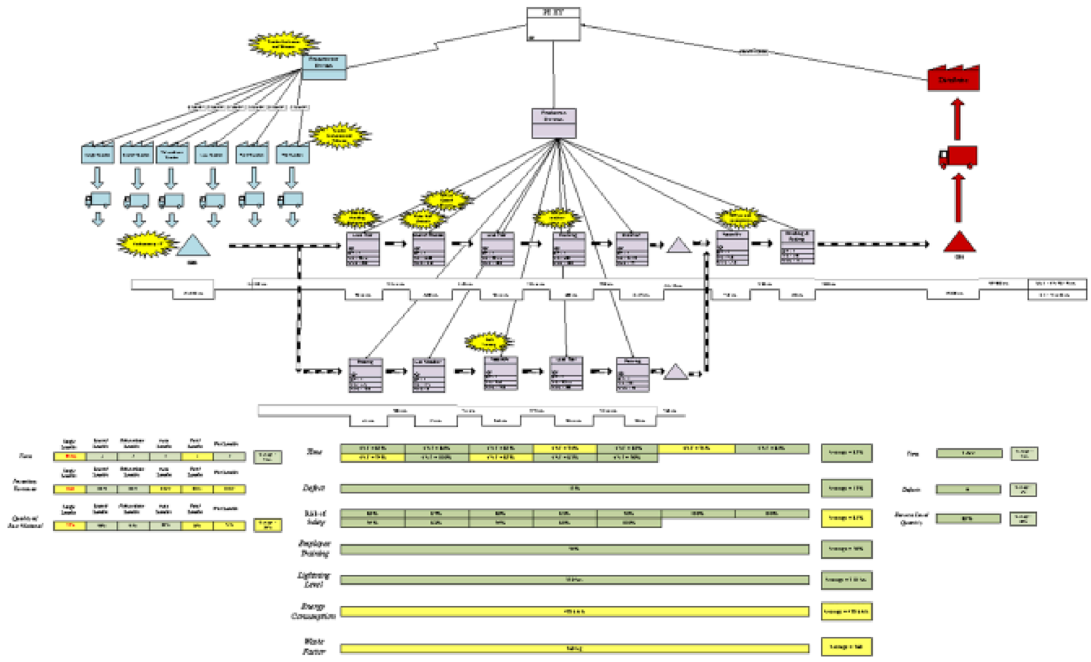

Fig. 4. Future Sustainable Value Stream Mapping

Based on the suggested enhancements for each sustainability indicator, the Future SI can be calculated to assess the impact of these improvements on the overall SI value. This analysis enables the company to gauge the extent of effort required to attain sustainability. As depicted in **Table 3**, there is a reduction in the SI value for both environmental and social aspects. Notably, the calculation of the SI for environmental factors remains unchanged, reflecting the substantial scale of improvements necessary in this domain.

Table 3. Comparison of Current Sustainability Index and Future Sustainability Index

Indicator	Before	After	Improvement
Economic (E)	149%	127%	22%
Social (S)	155%	124%	31%
Environment (N)	90%	90%	0%
Overall	143%	121%	22%

4 Conclusion

Several conclusions can be drawn Based on the research conducted at PT X on Solar SWH products. Firstly, the mapping results on SVSM before improvement indicated a PCE value of 64%, which decreased to 54% after the proposed improvements. An increase in the SWH product supply chain efficiency accompanied this decrease in PCE value. Secondly, the results obtained on PAM after making improvements showed a decrease from 70 activities to 65 activities, with 26 value-added activities, 16 non-value-added activities, and 23 non-value-added activities. Additionally, the type of waste decreased from 8 to 4. Thirdly, the calculation of the SI after making improvements demonstrated a decrease of 22%, with the sustainability index value decreasing from 142% to 121%. Finally, the implementation of Sustainable Lean Supply Chain practices was found to be effective in identifying waste, reducing process time, and increasing the effectiveness of the SWH product supply chain. This approach aids companies in analyzing and reducing the effort required to achieve sustainability goals.

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