2. LITERATURE REVIEW

2.1 Lean Manufacturing

Lean manufacturing, often referred to as simply "Lean," has emerged as a prominent operational philosophy and methodology in contemporary manufacturing environments. It is rooted in the relentless pursuit of efficiency and waste reduction while enhancing value for customers (Womack and Jones, 1996). The Lean approach is a systematic method for identifying and eliminating waste or non-value-added activities through continuous improvement. This is achieved by creating a flow of products, including raw materials, work-in-progress, and finished goods, as well as information, using a pull system from both internal and external customers to achieve excellence (Suyanto, D. A. & Noya, S., 2015).

The implementation of Lean Manufacturing aims to achieve the following objectives, as outlined by Waluyo (2007):

1. Reducing Defects and Waste

   This includes minimizing excessive raw material usage as production input, costs associated with reworking defective materials, and unnecessary product features not demanded by customers.

2. Reducing Lead Time and Production Cycle Time

   This involves decreasing waiting times between production stages, such as setup times for production processes.

3. Minimizing Inventory Levels

   Lean aims to minimize inventory at all stages of the primary production process, including work-in-progress (WIP) between production stages.

4. Enhancing Worker Productivity

   Lean practices seek to increase worker productivity by reducing idle time and ensuring efficient task scheduling.

5. Optimizing Equipment and Factory Space

   This is achieved by eliminating bottlenecks, optimizing production levels, and minimizing machine downtime, leading to more effective equipment and factory space utilization.

6. Enhancing Production Flexibility

   Lean Manufacturing allows for greater flexibility in producing products by minimizing changeover costs and reducing changeover times to a minimum.

2.2 Waste

Waste refers to activities that consume resources such as energy, costs, or additional time but do not add any value to the process. For a company to maintain an efficient and effective production flow, it is crucial to minimize waste. In essence, manufacturing companies handle significant quantities of materials, which inevitably result in the generation of waste during the production process (Utama, D. M., 2016). Waste encompasses all activities that do not contribute value, and thus, companies must minimize waste or any obstacles that disrupt the production process to ensure smooth operations.

Various types of waste, as per the Japanese terminology derived from the Toyota Production System: Beyond Large Scale Production, include 'muda' (non-value-adding work), 'mura' (unevenness in work outcomes), and 'muri' (overburdening work). Waste is a symptom, not the root cause of a problem.

1. Overproduction

   This occurs when a company produces more goods or services than the current demand requires. It results in excessive inventory, tying up resources that could be utilized elsewhere and potentially masking underlying process issues.

2. Inventory

   Inventory waste refers to the unnecessary accumulation of raw materials, work-in-progress, or finished products beyond what is immediately needed. Maintaining high inventory levels increases carrying costs and can lead to material obsolescence.

3. Transportation

   This waste pertains to the unnecessary movement of materials or products within a production process. Excessive transportation can result in damage, delays, and increased operational costs.

4. Waiting

   Waiting, or idle time within processes, is a common source of waste. It reduces productivity, extends lead times, and may negatively impact employee morale.

5. Overprocessing

   Overprocessing involves expending more resources or effort than necessary to produce a product or service. Inefficiencies or redundant process steps often lead to overprocessing, which increases costs.

6. Defects

   Defects encompass rework and scrap, representing a significant source of waste. Correcting defects demands extra resources, elevating costs, and diminishing customer satisfaction.

7. Motion

   The waste of motion refers to the movements of workers or machines that do not contribute value to the product. The root causes of this waste can be attributed to inconsistent work methods, poor workplace organization, and inadequately planned layouts.

2.3 Waste Assessment Model

Waste Assessment Model is a developed framework aimed at simplifying the identification and elimination of waste-related issues (Rawabdeh, 2005).

2.3.1 Seven Waste Relationship

Each form of waste is interconnected, with these connections arising from the potential direct or indirect influence of each type of waste.

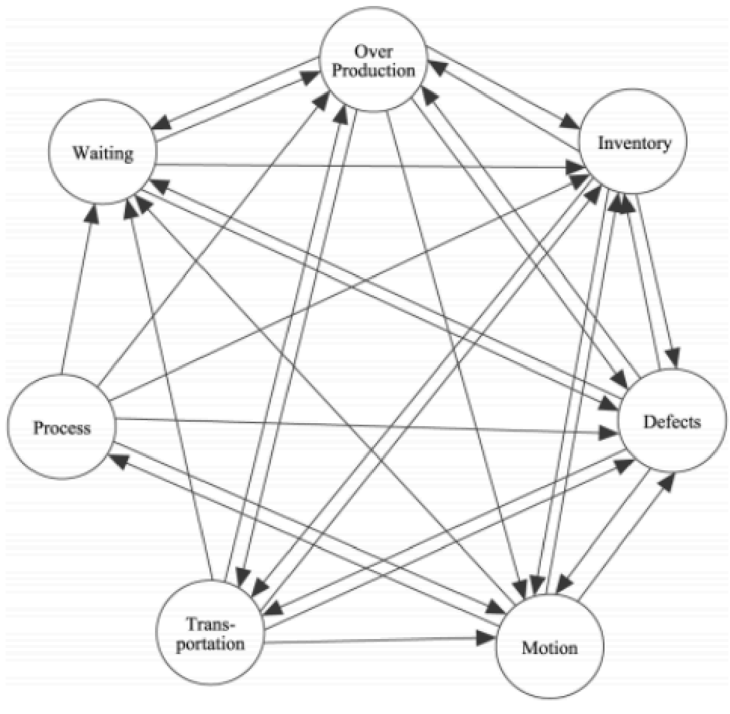

Figure 2.1 Seven Waste Relationship

Source : (Rawabdeh, 2005)

The relationships between different types of waste have varying degrees of significance. Therefore, it is essential to assess the weight or importance of each pattern that occurs among these wastes. To calculate the strength of waste relationships, a measurement is developed using a questionnaire. The relationship between one type of waste and another can be symbolized by using the initial letter of each waste type (Rawabdeh, 2005).

Table 2.1 Criteria for Weighting Waste Relationship Strength

No.	Question	Answer	Score
1	Does *i* result in or generate *j*?	a. Always	4
		b. Sometimes	2
		c. Rare	0
2	What is the type of relationship between *i* and *j*?	a. If *i* increases, *j* increases	4
		b. If *i* increases, *j* remains	2
		b. Uncertain, depends on situation	0
3	The impact of *j* is due to *i*	a. Appears directly & clearly	4
		b. Takes time to become visible	2
		c. Not visible	0
4	Eliminating the effect of *i* on *j* can be achieved by...	a. Engineering method	4
		b. Simple and direct solution	2
		c. Instructional solution	0
5	The impact of *j* due to *i* affects...	a. Product quality	1
		b. Resource productivity	1
		c. Lead time	1
		d. Quality and productivity	2
		e. Quality and lead time	2
		f. Productivity and lead time	2

		g. Quality, productivity, and lead time	4
6	How much does the impact of *i* on *j* increase lead time?	a. Very high	4
		b. Moderate	2
		c. Low	0

Source: (Rawabdeh, 2005).

Based on the question chart, questions were then formulated for each relationship between waste types. There are 31 relationships between waste types defined by Rawabdeh. The total score is obtained from six questions for each relationship between waste types. The total score is then converted into a conversion table as follows:

Table 2.2 Conversion of Range Scores for Waste Relationship

Range	Relationship	Simbol
17-20	Absolutely Necessary	A
13-16	Especially Important	E
9-12	Important	I
5-8	Ordinary Closeness	O
1-4	Unimportant	U

Source : (Rawabdeh, 2005).

2.3.2 Waste Assessment Questionnaire

The Waste Assessment Questionnaire was developed to allocate waste occurring in the production line (Rawabdeh, 2005). This assessment questionnaire consists of 68 distinct questions, aimed at identifying waste. Each questionnaire item represents activities, conditions, or characteristics that contribute to specific types of waste. The questions in the questionnaire are categorized into four groups: man, machine, material, and method. Some questions are marked with "From," signifying that they describe the current types of waste that can trigger the emergence of other types of waste based on the Waste Relationship Model (WRM). Other questions are marked with "To," indicating that they explain how each current type of waste can occur due to the influence of other types of waste. Each question offers three answer choices, and each answer is assigned a weight of 1, 0.5, or 0 (Rawabdeh, 2005). Subsequently, each question is grouped into various types based on the answers to develop a waste assessment questionnaire model.

Table 2.3 WAQ Question Grouping

No	Questions	Total (Ni)
1	From overproduction	3
2	From inventory	6
3	From defect	8
4	From motion	11
5	From transportation	4
6	From process	7
7	From waiting	8
8	To defect	4
9	To motion	9
10	To transportation	3
11	To waiting	5
Total		68

The results of this questionnaire are then processed using an algorithm consisting of several steps developed to assess and rank the waste. The following are the steps for calculating waste scores to achieve the final result, which is a ranking of the waste (Rawabdeh, 2005).
The Waste Assessment Questionnaire (WAQ) involves eight steps for calculating the Waste scores to determine the Waste ranking:

1. Group and count the questionnaire questions based on their types.
2. Perform an initial weighting for each Waste type in each questionnaire question based on the weight values from the Waste Relationship Model (WRM).
3. Normalize the weights in each row by dividing them by the total number of questions in that waste category (Ni) to account for variations in question counts.
4. Calculate the total scores for each waste type, considering the frequency (Fj) of non-zero values in each waste column.

$$Sj = \sum_{K=1}^{K} \frac{(Wj,K)}{Ni}$$

5. Multiply the questionnaire answers (1, 0.5, or 0) with the corresponding weight values in the table.
6. Calculate the total scores for each weight value in the waste column and their frequency (fj), excluding zero values, using the equation:

$$Sj = \sum_{K=1}^{K} Xk \, x \, \frac{(Wj \cdot K)}{Ni}$$

7. Calculate initial indicators for each waste type (Yj), which are numbers that represent how each waste type is influenced by others.

$$Yj = \frac{sj}{Sj} \, x \, \frac{fj}{Fj}$$

8. Calculate the final waste factors (Yj final) by factoring in the probability of influence between waste types (Pj) based on the total "from" and "to" values in the WRM. Express Yjfinal as a percentage to determine the ranking levels of each waste. The formula is:

$$Yjfinal = Yj \, x \, Pj = \left(\frac{sj}{Sj} \, x \, \frac{fj}{Fj} \right) x \, (\%FromJ \, x \, \%Toj)$$

N = Total number of questions (68)
Ni = Number of questions grouped
K = Question number (ranging from 1 to 68)
Xk = Values of each questionnaire question's answer (1, 0.5, or 0)
Sj = Waste score
Sj = Total for Waste weight values
Wj = Weight of the relationship for each Waste type
Fj = Frequency of Waste other than 0 (for Sj)
Fj = Frequency of Waste other than 0 (for sj)
F0 = Frequency of 0 (for Sj)
F0 = Frequency of 0 (for sj)
Yj = Initial indication factor for each Waste type
Pj = Probability of influence between Waste types
Yjfinal = Final factor for each Waste type
%Fromj = Percentage value of From Waste for a specific type
%Toj = Percentage value of To Waste for a specific type

2.4 Value Stream Mapping

The tool utilized in Lean Manufacturing to map the entire flow of production processes, encompassing both information and materials, and to identify waste, is known as Value Stream Mapping (VSM). Value Stream Mapping (VSM) is a concept within lean manufacturing that provides a visual representation of all activities performed by a company (Prayogo, T. & Octavia, T., 2018). It serves as a comprehensive depiction of a company's operations, including material and information flows at each workstation.

Value Stream Mapping is employed to illustrate the production system within a company, allowing for a clear understanding of information flow within the existing system and depicting the lead time required based on the prevailing characteristics. The Value Stream Mapping process consists of two key maps: the Current State Map, which offers an overview of the existing processes within production, involving information and material flow measurements, and the Future State Map, which envisions the desired state of the value chain at a future point after improvements have been implemented (Vinodh, S., Selvaraj, T., Chintha, S. K, & Vimal, K;, 2015). This approach facilitates the identification and reduction of waste, ultimately optimizing the efficiency and effectiveness of the production process.

According to Nash and Poling (2008), both the current state and future state maps in Value Stream Mapping (VSM) consist of three main components:

1. Flow of Production Processes or Material

The flow of processes or material is positioned between information and the timeline. It is represented by a left-to-right depiction. This flow illustrates how the production or material moves through various stages.

2. Flow of Communication/Information

The flow of information in Value Stream Mapping is typically depicted at the top of the map. It allows for a comprehensive view of all types of information and communication, whether formal or informal, that occur within the value stream. This information flow can also identify unnecessary information exchanges that do not add value to the product.

3. Timelines/Distance

At the bottom of the VSM, there is a set of lines containing essential information known as timelines. These timelines serve as a basis for comparing improvements to be implemented. The top line in the timelines is referred to as Production Lead Time (PLT). Production Lead Time represents the time required for a product to go through all processes from raw material to the hands of the customer, typically within a single day. The second line, situated just below the processes, represents the cycle time for all processes in the material flow, with each process's cycle time written above the line directly below it.

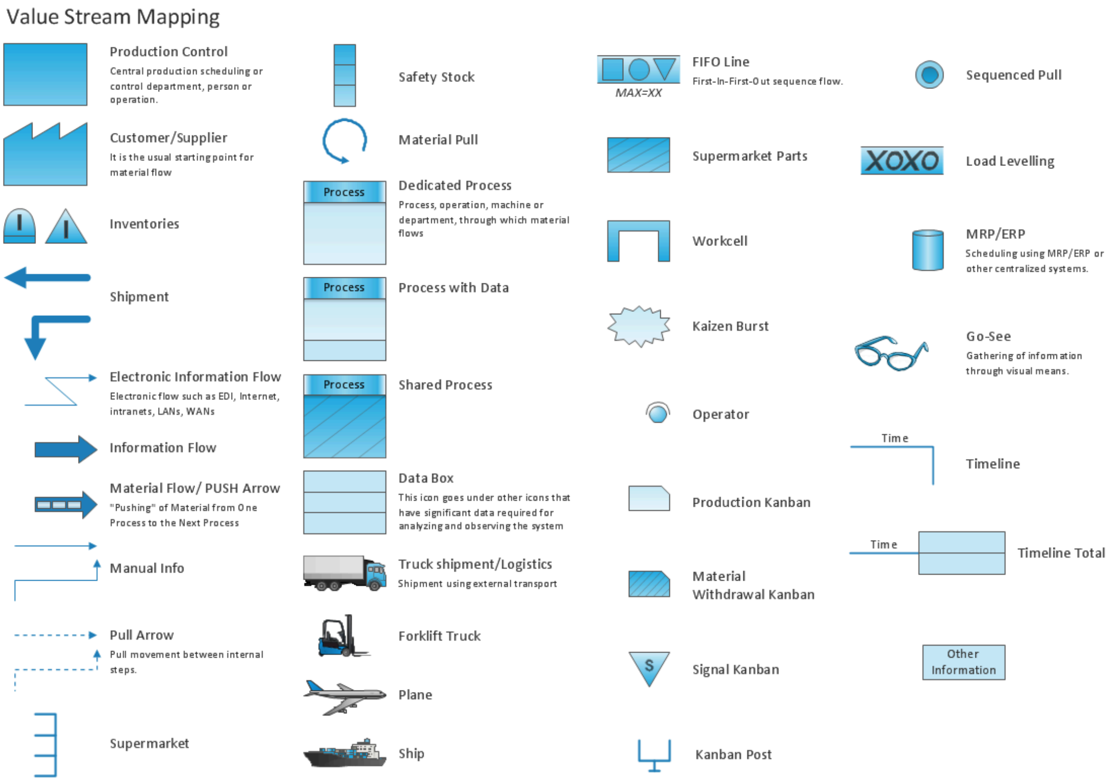

Figure 2.2 Value Stream Mapping Symbols

Source : (ConceptDraw, n.d.)

2.5 Value Stream Analysis Tool (VALSAT)

Value stream analysis tools are used as aids to detail the mapping of the value stream, focusing on the value-adding process. This detailed mapping is utilized to identify the causes of waste that occur within the value stream (Hines & Rich, 1997). VALSAT is a tool developed to facilitate understanding of existing value streams and assist in designing improvements related to the waste present within these streams. There are 7 types of mapping tools that can be used (Hines & Rich, 1997):

1. Process Activity Mapping

Process Activity Mapping is a tool used to record all activities within a process and aims to reduce less important activities, simplifying them to reduce waste. In this tool, activities are classified into several categories: operation, transport, inspection, and storage (Hines & Taylor, 2000). The basic concept involves mapping each activity stage, starting from operations, transportation, inspection, delays, and storage, then categorizing them into types of activities such as value-adding activities (VA), necessary but non-value-adding activities (NNVA), and non-value-adding activities (NVA).

2. Supply Chain Response Matrix

A graph depicting the relationship between inventory and lead time in the distribution channel, thus revealing changes in inventory levels and distribution time in each area of the supply chain. By analyzing this function, management can forecast stock needs associated with shorter lead times. The aim is to improve and maintain service levels in each distribution channel at a low cost.

3. Production Variety Funnel

A visual mapping technique that illustrates the number of product variations at each stage of the manufacturing process (Hines & Taylor, 2000). This tool can identify points where a generic product is processed into specific products (Hines & Taylor, 2000). It can also indicate bottleneck areas in process design and assist in planning inventory policies for raw materials, semi-finished products, and finished products.

4. Quality Filter Mapping

This tool is used to identify the location of quality defects in the existing supply chain (Hines & Rich, 1997). It can depict three different types of quality defects: Product defects, Internal scrap, and Service defects.

5. Demand Amplification Mapping

A map used to visualize demand changes along the supply chain, aiding in analyzing demand variability. This tool helps in decision-making, anticipating demand changes, managing demand fluctuations, and evaluating inventory policies.

6. Decision Point Analysis

Shows various options in different production systems with trade-offs between their respective lead times and the necessary inventory level to cover them during the lead time.

7. Physical Structure Mapping

A tool used to understand the condition of the supply chain on the production floor. This tool is essential to comprehend the industry's operations and to direct attention to areas that may not have received adequate focus for development, thus identifying areas in need of improvement.

The usage of these 7 tools is based on selecting the appropriate tool based on the company's conditions. To simplify this process, a weighting system can be applied, as shown in Table 2.4 below.

- H (High): High correlation and usefulness (Multiplier = 9)
- M (Medium): Medium correlation and usefulness (Multiplier = 3)
- L (Low): Low correlation and usefulness (Multiplier = 1)

This grading system assigns a level to each factor based on its perceived correlation and usefulness to the specific context of applying VALSAT tools within a company. The multipliers assigned (9, 3, and 1) indicate the weight or importance given to each level concerning their impact or relevance.

Table 2.4 The matrix selection for the 7 VALSAT (Hines & Rich, 1997)

Waste / Structure	Process activity mapping	Supply chain response matrix	Production Variety Funnel	Quality Filter Mapping	Demand Amplification Mapping	Decision Point Analysis	Physical Structure (a)Volume (b) Value
Overproduction	L	M		L	M	M	
Inventory	M	H	M		H	M	L
Defects	L			H			
Motion	H	L					
Transportation	H						L
Process	H		M	L		L	
Waiting	H	H	L		M	M	
Overall Structure	L	L	M	L	H	M	H

2.6 Cause and Effect Diagram

The Cause and Effect Diagram, also known as the Fishbone Diagram, is a tool used to determine potential root causes and hypotheses for a problem. Kaoru Ishikawa introduced this diagram in Japan, earning it the alternative name "Ishikawa Diagram." When defects, errors, or issues are identified, it is essential to analyze the potential causes leading to these consequences (Ginting, Rosnani, 2012). In terms of its structure, this diagram is often referred to as a fishbone diagram. At the end of the horizontal line, a problem is written. Each branch pointing to the main spine represents a possible cause, while the branches stemming from these causes contribute to the respective causes. According to Ishikawa, the primary factors contributing to a root problem are human factors, materials, machinery, work methods, and the environment.

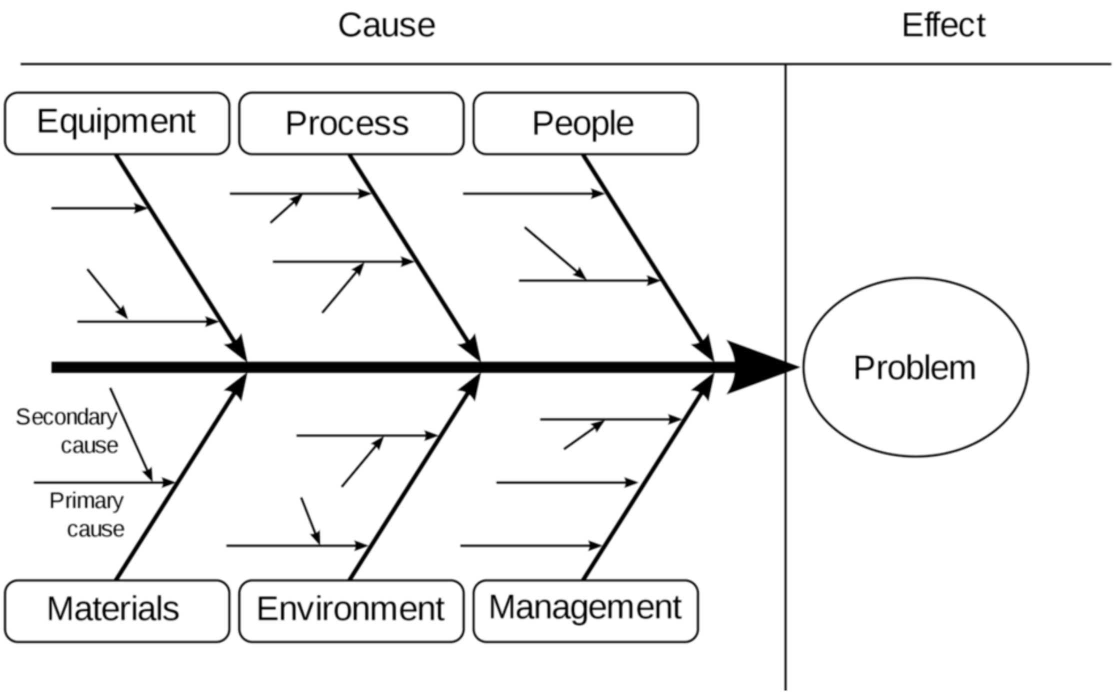

Figure 2.3 Ishikawa Diagram