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AN INITIAL LEAN WASTE ASSESSMENT AT A MANUFACTURING PLANT: AN ATTEMPT TO PRIORITISE WASTE ELIMINATION

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ABSTRACT
Lean is a management philosophy aimed at improving efficiency by eliminating all forms of Lean waste in the workplace. While lean practices are well-established in manufacturing, their application in sectors like printing remains significant. This study focuses on identifying and prioritizing critical Lean waste in a flexographic printing plant, a key area for operational improvement. Using a three-step approach, Waste Identification, Waste Assessment, and Root Cause Analysis, the study identifies defects and inventory as the most Critical lean waste types in the printing plant. Data was collected through Gemba walks, walkthrough surveys, interviews, and company records. The Waste Assessment Questionnaire (WAQ) and Waste Relationship Matrix (WRM) were used to prioritize lean wastes and analyze their interdependencies. Cause and Effect diagrams were used to uncover the root causes of defects, and a 5-Whys analysis was used to uncover the root causes of inventory. The findings provide actionable insights for reducing waste in the flexographic printing Plant, offering broader implications for cost reduction and efficiency in related sectors.

Keywords: Lean Waste Assessment, Flexographic Printing, Waste Relationship Matrix, Waste Assessment Questionnaire, Root Cause Analysis

1. Introduction
When considering the printing production market, it can be seen that there is a tendency to use flexographic printing techniques. This relates to significant developments in the packaging industry, such as introducing innovative technologies and reducing production costs (Havenko, Ohirko, Ryvak, & Kotmalova, 2020). Flexography printing

facilitates products with high aesthetic value, quality, and uniqueness. Flexography's ability to perform inline finishing processes such as cutting, lacquering, laminating, and stamping directly after printing further enhances its attractiveness. This improves efficiency and opens the path to high-quality and specialized printings, including spot colors and labels printed on the glue side of self-adhesive materials, doubling the labels' information capacity. Flexographic printing offers a unique set of advantages to the printing industry, with the ability to print on absorbent (paper) and nonabsorbent (plastic films) substrates. This feature makes it possible to print alternatively on various bases—including elastic bases with variable thicknesses—all on the same assembly line without requiring any changes. In addition, quick ink drying time enables the usage of high-speed machinery, and low-cost printing plates make an economical choice compared to the other printing techniques (Izdebska J. E., 2015).

Despite these advantages, the flexographic printing industry still faces significant challenges related to waste and inefficiency. Though successful in manufacturing, Lean production principles are still evolving in the printing sector. Lean Manufacturing, often called "Lean," is a management philosophy and approach focused on maximizing customer value while minimizing lean waste (Rimawan, Molle, & Putra, 2018). Originating from the Toyota Production System (TPS) and popularised by the seminal work "The Machine That Changed the World" by Womack et al. in 1990, Lean has become a widely adopted methodology in various industries worldwide. Production costs are reduced by identifying and eliminating or reducing seven types of waste. This approach is very important for companies competing globally, prompting organizations to explore and adopt lean philosophy and its tools (Chivatxaranuku, 2019).

The main objective of this research is to conduct an initial lean waste assessment at the flexography plant to identify the critical lean waste within the production process and find the root causes of major lean waste. This study is significant as it addresses a crucial challenge faced by a major label printing company in Sri Lanka by directly tackling the urgent need for operational efficiency and cost reduction. While lean production principles have been successful in manufacturing, their application in specific industries like printing is still evolving. This research contributes to the field by demonstrating how lean practices can be adapted in the printing sector, enhancing operational efficiency and competitiveness.

2. Literature Review

In today's competitive business landscape, success is not dependent on a single category of consideration (Gaspersz, 2007). It is a broad term with no proper definition of being a successful business worldwide. All the businesses worldwide are competitively looking for the operational excellence of their respective industries. There are many powerful approaches to achieving operational excellence, and one of the most significant aspects is the Lean concept.

Lean concepts focus on eliminating waste by assessing the value-adding and non-value-adding activities and maximizing the value addition throughout the process. To do that, various lean tools can be used to explore the impact on the business processes.

Lean waste, as identified by Toyota, encompasses seven types that do not add value to the Customers. "Transportation waste" refers to the unnecessary movement of items, leading to time, space, and equipment costs due to poor organization and layout (Arunagiri & Gnanavelbabu, 2014). "Inventory waste" involves the costs of holding excess stock, including storage and obsolescence (Liker, 2003). "Motion waste" results from inefficient workplace design, causing excessive employee movement and fatigue (Arunagiri & Gnanavelbabu, 2014). "Waiting waste" is the idle time of the employees or machines within the production process (Arunagiri & Gnanavelbabu, 2014). "Overproduction waste" arises when production exceeds demand, leading to excess inventory and additional costs (Mekong Capital, 2004). "Over-processing waste" involves adding unnecessary features that do not enhance customer value (Mekong Capital, 2004). Lastly, "defect waste" produces faulty goods, requiring rework or disposal and reducing customer satisfaction (Mekong Capital, 2004). Together, these wastes highlight inefficiencies that detract from the overall value generated to the customer.

Comparison of Lean Principles: Traditional Manufacturing vs. Flexographic Printing

The primary objectives of lean principles in conventional manufacturing are to optimize assembly lines, decrease cycle times, and reduce excess inventory. Transportation, waiting, and defects involving waste in repetitive processes, such as automotive assembly, are prominent targets for improvement (Rimawan, Molle, & Putra, Lean Production Design with Waste and Method Analysis of VALSAT for Assembly Process of Four Wheel Vehicle Components, 2018). To mitigate production constraints, inventory management and machine configuration are implemented to rationalize material flows.

Flexographic printing is a specialized industry with unique processes, including inline finishing, cutting, laminating, stamping, and printing on absorbent and nonabsorbent substrates (Izdebska J. , Flexographic Printing, 2015). Specialized processes like these can bring about specific types of waste and inefficiencies not seen in traditional manufacturing.

In flexographic printing, process challenges include the management of ink waste and minimizing the changeover times of machinery, but not limited to this. Key areas of development include reducing defects and increasing setup speed due to the diversities of materials involved and inline finishing processes. Furthermore, frequently adjusting printing plates, ink levels, and machine velocities introduce waste associated with motion and delay. Although Lean's objective of eliminating waste remains the same, these focal areas alter flexographic printing and need further emphasis on quick setups and strict defect control for quality maintenance.

Lean Waste Assessment Tools

The researchers use different tools to identify the seven types of lean waste. These tools served as a framework to identify and categorize the wastes within a process in a systematic way (Akrami, Mirghaderi , & Naghi, 2021). Below, we identified several tools that were used in previous studies (Bizuneh & Omer, 2024), (Rindi Kusumawardani, 2024), (Mulyana, Hartanti, Herdianto, & Gunawan, 2022) and these tools not only give a comprehensive understanding of the waste but also contribute to the development of strategies for waste reduction and process optimization (Psomas, 2021).

Waste Assessment Model

The Waste Assessment Model (WAM), introduced by Rawabdeh (Rawabdeh I. , 2005), aims to identify crucial lean waste issues for effective elimination strategies. WAM consists of two instruments: the waste relationship matrix (WRM) and the waste assessment questionnaire (WAQ).

Waste Relationship Matrix

The Waste Relationship Matrix (WRM) is a tool employed to assess the relationship between different types of lean waste. Each row displays the impact of one waste on six others, while columns indicate the impact received. The diagonal showcases the highest relationship value, signifying a solid connection with itself. This matrix aids in understanding and gives weight to the relationship between each waste for effective lean waste management strategies (Rimawan, Molle, & Putra, 2018).

Waste Assessment Questionnaire

The Waste Assessment Questionnaire (WAQ) is a lean tool for prioritizing waste within the production line (Rawabdeh I. , 2005). It is built on the questioner and weights of the relationships between wastes given by WRM. Each question on the WAQ addresses a specific condition, activity, or behavior that may lead to waste generation. Some questions are marked "from," indicating that they reveal a type of waste capable of triggering others, while those marked "To" explain the potential emergence of different waste types due to specific conditions. The WAQ provides a structured approach for comprehensively understanding and prioritizing waste in the production process (Rimawan, Molle, & Putra, 2018).

Value Stream Mapping (VSM)

Value Stream Mapping (VSM) originated from the Toyota production system as "material and information flow mapping." Described by Russell and Shook (1999) as a potent tool, VSM not only defines processes but also guides improvement initiatives. According to (Womack & Jones, 2003), VSM visually maps information and material flow to enhance methods and performance in future state proposals. This tool provides valuable insights into system information and physical flow, facilitating informed decision-making (Rother, 1999).

Root Cause Analysis

One of the most crucial lean management techniques is root cause analysis, which assists in identifying the underlying causes of process inefficiencies or problems. The Fishbone Diagram (the Ishikawa or Cause-and-Effect Diagram) and the Five Why Analysis are the two most widely used RCA methodologies.

The Fishbone Diagram categorizes potential causes of a problem into significant groups such as man, method, machine, and material, visually mapping out the relationships between various factors and the problem at hand. This helps in systematically identifying contributing factors that may not be immediately obvious.

The 5 Why Analysis is a simple yet powerful tool that asks "why" five times (or more) to drill down to the root cause of a problem. Each answer leads to a deeper exploration of the issue, helping to uncover the fundamental cause behind surface-level symptoms.

Both tools are essential in lean practices, as they provide structured, precise methods to identify and address the root causes of waste in any process.

3. Methodology

This study was conducted at a flexography printing department of a famous label printing company in Sri Lanka, and the total process was initially divided into three steps as below.

Table 1: Steps in this study.

	Phase	Techniques used in each step
1.	Waste Identification	walkthrough surveys, interviews, Gemba, and referring to records

2.	Waste Assessment	Waste Relationship Matrix (WRM), Waste Assessment Questionnaire (WAQ).
3.	Root Cause Analysis	Cause and effect diagram, 5-Why's

In the first stage, the data collection process to identify the seven types of lean waste in the flexography printing plant was done using walkthrough surveys, interviews, Gemba walks, and referring to records (Micieta, Howaniec, Binasova, & Kasajova, 2021). Walkthrough surveys were conducted across different production shifts (Day shift and night shift), allowing detailed observation of material flow, machine operations, and employee movements. Interviews with supervisors and operators gave insight into recurring issues such as machine breakdowns and bottlenecks.

The Gemba walks provided firsthand observations of the production process, focusing on waste like motion, waiting, and defects. These walks were conducted over 4 weeks to capture varying operational conditions. Observations were systematically structured to identify inefficiencies based on lean waste categories.

Furthermore, existing production records were reviewed to analyze historical data on inventory levels, machine downtime, and defect rates. This multi-method approach ensured comprehensive data collection, providing a holistic view of the plant's operations and helping prioritize critical areas for waste elimination.

Then, the result of the initial waste identification process was used to design the questionnaire for the Waste Relationship Matrix (WRM) and distributed to 5 company supervisors of the Flexography plant for their response. We get answers from only supervisors because when we refer to previous research (Rindi Kusumawardani, 2024), (Febianti, Irman, & Juliana, 2020), researchers used only experienced and knowledgeable employees about the process to get responses. Those responses help to develop the Waste Relation Matrix (WRM). WRM outlines the strength of the direct relationship between seven lean wastes. Then, another questionnaire was developed for the waste assessment questionnaire. Responses to the second questionnaire and the relationship weights obtained from WRM were then used as input for WAQ, as advised by Rawabdeh (Rawabdeh I. , 2005). A waste assessment questionnaire is used to prioritize the wastes that occur within the production line, and this helps identify the critical wastes that should be addressed immediately. The seven different categories of lean waste in the flexographic printing plant were ranked in order of importance using the WAQ. The WAQ's total score portion, which has the most significant percentage value, can be used to identify which important waste has to be eliminated first. Then, a cause-and-effect diagram and a 5-Why analysis are used in root cause analysis to identify the root causes of two major lean wastes identified in WAQ.

4. Results/Analysis and Discussion

This research study was conducted at the Flexography printing plant in Sri Lanka, where the company produces diversified printing and packaging solutions for its customers. The production process of the Flexography printing plant is shown in Figure 1.

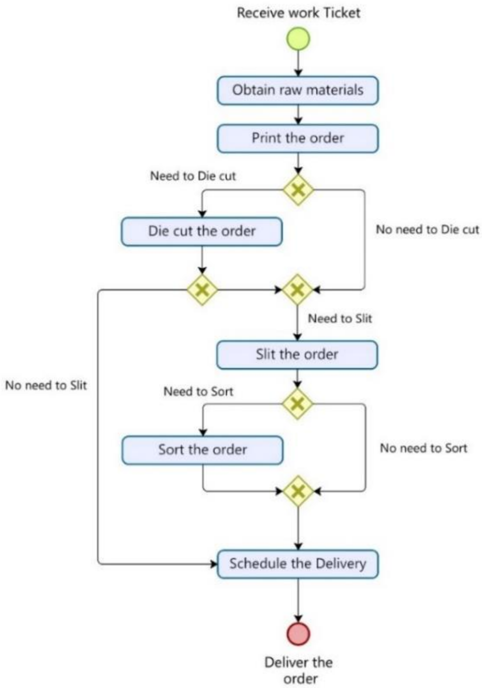

Figure 1: Printing Process of the Flexography Printing Plant.

4.1. Lean Waste Identification

Lean Waste Identification was conducted using walkthrough surveys, interviews, Gemba, and referring to records. Table 2 shows the seven types of wastes initially identified in the flexography printing plant.

Table 2: Identified Lean Wastage in the Manufacturing Plant.

Waste Category	
Transportation	• Complex layout with inefficient pathways between machines and departments. • Occur of unnecessary employee movement due to inventory blocking paths. • Employees move items many times among processes due to defects.

Inventory	• Products are awaiting orders due to overproduction of some products and defects. • Work-in-progress (WIP) inventory occurs due to bottlenecks in slitting and sorting. • Increase raw material inventory due to frequent changes in the daily production schedule. • Finished goods are stacked in different locations of the Flexography printing plant due to not having a specific warehouse for finished goods.
Motion	• Occur of inefficient employee movement due to stacked inventory on the pathways. • Unnecessary motion occurs when handling old machines that need constant inspection. • Employees who do not follow the Standard Operating Procedure (SOP) leads to unnecessary motion. • Excess motion occurs while finding relevant tools for printing.
Defects	• Occurrence of Colour variations, white spots, and dust on the printed labels. • Labels are getting damaged due to improper handling or processing. • Reels are misaligned when connecting reels to the machines. • Frequent reworks and manual sorting take longer since employees do not follow the SOP.
Overproduction	They produce large quantities for smaller orders to cut costs.
Overprocessing	Overprocessing non-defective labels due to defects. (Because if the defect happens, the whole printed reel goes to sorting to remove defect labels.)
Waiting	• Employees are waiting because of machine breakdowns. • Employees wait until the weekly/ monthly machine services are done. • Delays while awaiting sample print approval from Quality Assurance (QA). • Employees in the delivery department need to wait until WIP is converted to Finished goods due to WIP going for rewinding/ reworks. • Production employees wait if defects to be identified in the raw materials of ongoing production. • Production employees wait until raw materials are brought from the inventory department when the reworks need to go.

4.2. Waste Assessment Model (WAM)

The Waste Assessment Model aims to identify critical lean waste and prioritize those wastes based on their impact. WAM consists of two instruments: the waste relationship matrix (WRM) and the waste assessment questionnaire (WAQ). The Waste Relation Matrix (WRM) outlines the strength of the direct relationship between various lean wastes and WAQ, which is used to prioritize the seven types of waste (Rawabdeh I. , 2005).

4.2.1. Waste Relationship Matrix

The relationships among different types of waste are intricate due to their interdependent effects (Rawabdeh I. , 2005). Finding this relationship will be difficult because the influence of one waste from another six types of waste can happen directly or indirectly. WRM is used to capture the relationship between seven types of waste and find the strength of the relationship between each type of waste (Rawabdeh I. , 2005). In WRM, each row represents how a specific type of waste impacts the other six types, while each column indicates the degree to which a particular type of waste is affected by the others (Rawabdeh I. , 2005). These relationships are indicated using a questionnaire developed based on the observations in the waste identification step. The questionnaire consists of 37 questions, each with three answers: agree, neutral, and disagree. If the respondent's answer agrees, it receives five marks; if it is neutral, it receives 3; and if it disagrees, it is 0 (Rawabdeh I. , 2005). Based on the answers obtained from the above questionnaire, the weight was calculated for the relationship between each type of waste and the assigned symbol for each relationship (Table 4) based on the average score using Table 3 (Rawabdeh I. A., 2005). The type of relationship in Table 3 determines the average score of a question. For example, if a question received answers from 5 responders 5,3,5,5,3, the average score is 4.2, and it receives a symbol as “A”, meaning necessary (Rawabdeh I. , 2005).

Table 3: Strength of Direct Relationship of Waste.

Range	Type of relationship	Symbol
4 to 5	Necessary	A
3 to 4	Especially important	E
2 to 3	Important	I
1 to 2	Ordinary closeness	O
0 to 1	Unimportant	U

Table 4: Conversion of Values to the Waste Relationship Table.

F/T	T	I	M	W	O	P	D
T	A	A	O	E	X	E	A

I	A	A	E	I	I	X	O
M	E	A	A	A	X	A	A
W	X	A	X	A	I	E	A
O	A	E	X	O	A	A	A
P	E	A	A	E	X	A	O
D	A	A	A	A	A	A	A

Table 5 shows the numeric weight values obtained by each relationship. The defects have the highest (18.43%) influence on the other six types of waste, and the inventory has the influence (17.35%) on the other six types of waste.

Table 5: Waste Relationship Matrix.

F/T	T	I	M	W	O	P	D	Score	%
T	5	5	1.2	3.6	0	3.6	3.6	22	11.85
I	5	5	4	3.6	5	4	3	29.6	15.95
M	4	4.6	5	4.6	0	5	5	28.2	15.19
W	0	5	0	5	2.2	3.2	4.2	19.6	10.56
O	4.2	3.8	0	1.6	5	5	5	24.6	13.25
P	4.6	4.2	4	4	2	5	3.6	27.4	14.76
D	5	4.6	5	5	4.6	5	5	34.2	18.43
Score	27.8	32.2	19.2	27.4	18.8	30.8	29.4	185.6	100
%	14.9	17.35	10.34	14.7	10.1	16.5	15.8	100	

4.2.2. Waste Assessment Questionnaire

A waste assessment questionnaire is used to prioritize the wastes that occur within the production line, and this helps identify the critical wastes that should be addressed immediately. The waste assessment questionnaire consists of 50 questions, and these questions are associated with the activities, conditions, or behavior of the employees that lead to a specific type of waste. These questions can have three types of answers, and based on the answer, the question weighs 1, 0.5, and 0 (Rawabdeh I. , 2005). For example, If the waste implied in the question is there on the production floor value for the question given as 1, if it can be there, sometimes the value given is 0.5 and not there, then the value given is 0. Then, all the questions were grouped into four categories: man, method, material, and machine (Rawabdeh I. , 2005).

Table 6 is calculated by the weights of each question in the questionnaire and the weight of each relationship in the waste relationship matrix. This calculation has been done following the steps in (Rawabdeh I., 2005); then Table 6 can be obtained. Those values in Table 6 help rank the seven types of wastes within the production line.

Table 6: Final Results of the Waste Assessment Model.

	T	I	M	W	O	P	D
Score (Yj)	0.125	0.165	0.123	0.137	0.073	0.106	0.128
Pj Factor	0.020	0.021	0.019	0.018	0.012	0.021	0.032
Final result (Yjfinal)	0.002	0.004	0.002	0.002	0.001	0.002	0.004
Final result (%)	14.01	19.67	12.95	13.46	4.78	12.35	22.79
Rank	3	2	6	4	7	5	1

The final result of the waste assessment calculation is indicated in Table 6. It can be seen that the first rank is Defects at 22.79%, the second rank is Inventory at 19.67%, and the third one is Transportation at 14.01%.

4.3. Root Cause Analysis of the Main Wastage

Based on the waste assessment results, it was found that defect and inventory were the two Main wastes that resulted in the printing process. Root cause waste analysis is conducted to determine the root causes of those two wastes. The Fishbone diagram is used to identify all potential causes of a problem (Elita Amrina, 2017). A series of discussions were conducted with machine supervisors, Forman, and company staff to develop the Fishbone diagram. The fishbone diagram of the Defects is shown below.

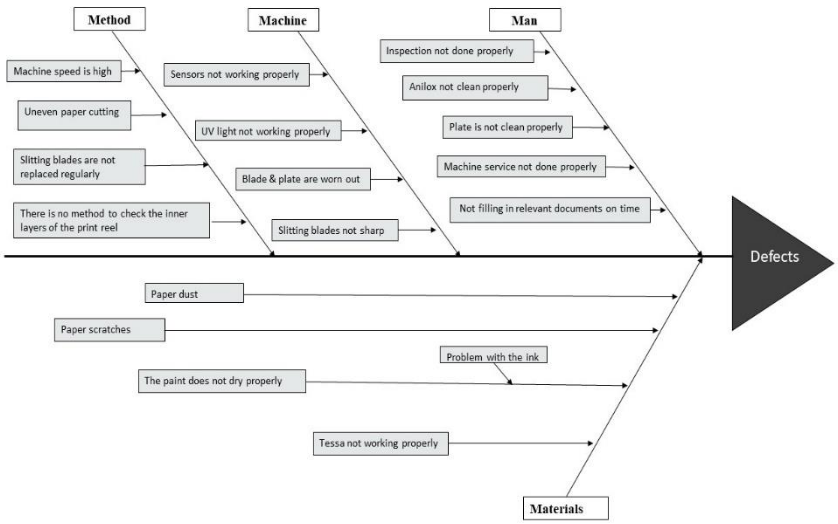

Figure 2: Fishbone Diagram Presenting the Root Cause Analysis Results for Defects.

Based on the fishbone diagram, Under Method, high machine speed, uneven paper cutting, and slitting blades are not replaced regularly, and no method to check the inner layers of the paper reel is highlighted as critical causes. Machine-related causes include malfunctioning components like UV lights, faulty sensors, and worn-out blades and plates. Man-related causes involve improper inspection and delayed documentation, anilox and plates not cleaning properly, and machine service not being done correctly. In the Materials category, the leading causes are paper dust, paper scratches, Tessa not working properly, and the paint not drying correctly.

Furthermore, to find out the root causes of the Inventory (the second highest waste), an analysis was carried out using the 5 Why's method based on brainstorming with machine supervisors, Forman. Following Table 7 is a 5-why table that has been formed from the results of the supervisor's brainstorming. It shows the root cause of the inventory at each production level.

Table 7: 5-Why Analysis for Inventory Waste.

Inventory	Why 1	Why 2	Why 3	Why 4	Why 5
Raw materials	Because there are so many reels on the production floor	Because there are so many process delays in the printing process	Because Employees do not meet the production plan	Because there are so many reworks that happen	Because there are so many defects that happen
				Because The planner changes the production plan frequently	Because Customers change their requirements
Slitting	Because there are so many WIP reels on the production floor	Because there is not enough machine capacity	Because There is so much rewinding happens	Because there are so many defects that happen	Because Employee errors and material errors occur
Sorting	Because there are so many reels to sort on the production floor	Because there is not enough manpower	Because the allocated manpower for the sorting department is limited	Because The company has signed a contract for a limited manpower	Because Financial expenses for manpower contracts are high
		Because some printed reels need to be checked for defects manually	Because there are so many defects in the printing process	Because Employee errors and material errors occur	Because Employees do not follow the standard methods and do not fill in the

					relevant documents
Finished goods	Because there are so many finished goods stored on the productio n floor	Because the rewinding process for finished goods takes more time.	Because there is not enough machine capacity.	Because there are so many defects that happen	
		Because Some customers obtain finished goods in small amounts, not in bulk.	Because They use companies' storage capacity as their outsourced warehouse	Because it is a financial saving for customers rather than having a separate warehouse	

In the raw materials stage, excess reels and process delays stem from frequent changes in customer requirements and production plans, highlighting a need for better alignment and communication. The slitting process suffers from insufficient machine capacity and high defect rates, leading to significant rewinding and material errors, indicating a need for improved machine maintenance and quality control. In the sorting stage, the primary issue is a shortage of manpower, exacerbated by financial constraints and limited manpower contracts, suggesting that resource allocation and budget management need to be addressed. The finished goods stage is burdened by extended rewinding processes and customer reliance on company storage capacity for cost savings, pointing to inefficiencies in processing and storage strategies. Common causes such as frequent changes, high defect rates, machine capacity limitations, and manpower issues underline the need for systemic improvements in planning, resource management, and quality control to reduce inventory waste effectively.

A limitation of this study is the data collected from only five supervisors. While we focused on experienced and knowledgeable employees similar to other studies such as those by (Rindi Kusumawardani, 2024) and (Febianti, Irman, & Juliana, 2020) the small sample size may limit the generalizability of the findings. The insights gained from these supervisors, although valuable, might not fully represent the entire workforce's perspective or capture all potential sources of waste. Future research could benefit from a larger sample size, including a broader range of employees, to enhance the robustness and applicability of the results across different contexts and sectors.

The findings of this study, while focused on lean waste assessment in a flexographic printing plant, have broader implications that extend beyond this specific sector. The waste types identified, particularly defects, inventory, and transportation, are common across various manufacturing industries, including packaging, automotive, and general manufacturing. In these sectors, lean principles can be applied similarly to reduce inefficiencies and improve operational performance.

For example, the root causes of defects in flexographic printing, such as improper machine maintenance and poor employee training, can inform other industries facing similar challenges. Implementing lean tools like 5-Why analysis and Cause-and-Effect diagrams to address defect issues in packaging or automotive assembly lines could significantly improve quality and efficiency.

Furthermore, the prioritization of waste using tools like the Waste Assessment Model (WAM) can be adapted to other sectors where complex, interrelated processes exist. The methods outlined in this study offer a structured approach to identifying, prioritizing, and addressing waste, making them applicable to diverse manufacturing contexts.

5. Conclusion and Implications

This paper has applied lean manufacturing to assess wastes in the flexography printing plant. Lean Waste Identification was conducted using walkthrough surveys, interviews, Gemba, and referring to records. The Waste Assessment Questionnaire (WAQ) has been used to prioritize the waste that occurs within the production line. According to the Waste Assessment Matrix, three types of waste are most critical and should be eliminated first, namely waste with defects, Inventory, and transportation, which can highly influence the appearance of other types of waste, respectively 22.79%, 19.67%, and 14.01%. Furthermore, a root cause analysis was conducted to determine the root causes of defects and a five-why analysis was conducted for inventory. Addressing the root cause helps with discussing targeted improvements in Man, Method, Machine, and Materials, and it can be a significant milestone for efficiency enhancement.

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