From Waste to Value: A Practical Framework for Waste Identification and Mitigation Using Lean Management Principles

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In the complex and fast-changing marketing environment, there is a constant need to reduce costs and enhance the performance of production systems. The cost-cutting strategies need to consider the long-term effect on the company. For example, the layoff may reduce the cost in the short term, but in the long term, it may significantly affect employees' psychological safety and increase human error. Hence, any changes in the company must be based on a clear management philosophy. Lean management focuses on continuously improving processes by eliminating non-value-adding activities. It tries to create more value for customers with fewer resources, increasing efficiency, quality, and customer satisfaction. Lean philosophy considers these non-value activities in three general categories: overburden, unevenness, and waste, and tries to remove them from the value production cycle through the continuous development process. Although the lean management style is a well-known approach style, there is much difficulty in implementing this approach. One of the main reasons is the organization's culture and habits, daily routine, and approach, which may not be aligned with lean thinking. Furthermore, for lean thinking to be effectively applied throughout the organization, it must be comprehensible and straightforward. In some cases, the Lean tools need to modify based on the already well-developed approach of the company. The main goal of this paper is to present a practical approach for implementing Lean thinking in identifying and prioritizing non-value activities for the industry. Here, "Waste walking" and "Value-stream mapping" lean tools and the FMECA principle are used to develop "waste ranking criteria" for the identification and prioritization of non-value activities.

Keywords: Value-stream mapping, Waste identification, Lean management, Rapid improvement, VUCA

1. Introduction

Nowadays, the working environment is categorized by high volatility, uncertainty, complexity, and ambiguity (VUCA), where volatility refers to the nature and speed of change, where unexpected and sudden shifts can occur, making it difficult to anticipate future outcomes. Uncertainty is the lack of predictability and the presence of unknowns. It involves dealing with incomplete or insufficient information, making it challenging to make confident decisions. Complexity represents the intricate and interconnected nature of problems and situations. It involves multiple factors and relationships, making it harder to understand and address the underlying dynamics, and ambiguity refers to multiple interpretations or possible meanings. It involves dealing with unclear or contradictory information, which can lead to confusion and difficulties in decision-making. VUCA simultaneously provides threats and opportunities where companies are under the dynamic external forces to change; hence, they need to react fast, logically, and continuously to the changes to avoid losing opportunities and responding to the threats. Such changes need to enhance the decision-making capability of all employees to make the right decision at the right time. The company needs a clear understating and the agility capacity to adapt, be agile, and develop strategies to navigate and thrive in such dynamic and unpredictable conditions.

In these terms, traditional management approaches, where top and middle managers make the most decisions, cannot effectively control and mitigate the company's challenges and opportunities. The COVID-19 pandemic was an example of a VUCA condition (Bennett and Lemoine 2014; Mack et al. 2015). Studies showed that only companies that were able to rapidly be evolved and applied to adapt to organizational objectives to reduce activity time, reduce expenditures, predict, and adapt products to customers' changing needs were able to survive and even grow.

Figure 1 shows the internal and external factors affecting the organization. Lean thinking can help the organization to adapt itself to VUCA conditions. Lean thinking is based on continuous improvement. It is a way of comprehending problems, identifying the causes of difficulties, and an attitude to using scientific methods to define the system values and concentrate on improving and creating value-generating flows in production (Buckley et al. 2017).

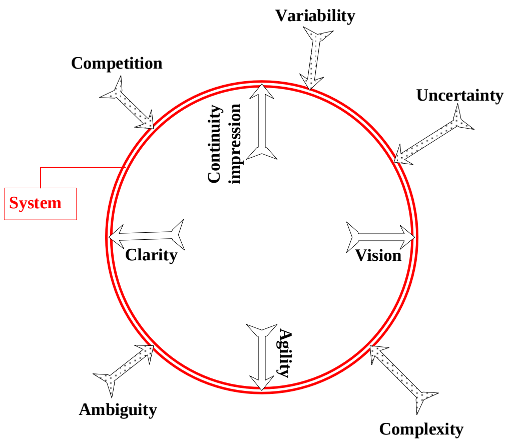

Figure 1- Internal and external factors affecting the organization

It fosters a culture of efficiency, problem-solving, and learning to achieve sustained improvements. Lean production is not a tactic or a mere tool to reduce costs but a method of thinking and a complete system for managing an organization however, over the years, some tools have been developed which can be used in the implementation of lean thinking, such as value stream mapping, 5S, Kanban, standardized work, and continuous improvement cycles (such as the Plan-Do-Check-Act or PDCA cycle) to drive operational excellence and optimize processes (Isniah, Purba, and Debora 2020).

In recent decades, lean management has been used in various fields such as industry, service, and Healthcare sectors (Institute 2003; King 2009; Womack and Jones 1997). The lean management approach, along with the traditional management methods through waste elimination, has improved the production system's agility for VUCA environments. However, research has indicated that over 70% of companies attempting to implement lean practices have struggled with successful implementation. One of the main reasons can be the low commitment of top management and middle manager to the philosophy of thinking, which need to change the whole decision-making of the organization. They mostly see lean as a set of tools that can be used to reduce costs or the workforce. Other reasons can be inadequate employee involvement, insufficient training, and education, failure to address cultural barriers, unrealistic expectations, and a lack of a continuous improvement mindset. It should be considered that lean implementation is a culturally changing process. To have a useful transition to a lean organization, a deep understanding of the current culture and tools which the company is using are required (Leite and Vieira 2015; Grant and Parker 2009; Spreitzer et al. 2005).

Systems with heavy equipment, such as steel industries, oil and gas industries, mines, etc., are associated with a long-life cycle due to their system structure and deployment. On the other hand, applying rapid changes in their production technology is costly due to the fixed cost of high investment for implementing such industries. Moreover, due to the poor maintenance and inefficiency of information flow, these systems will sometimes face increased waste caused by equipment aging (Abdulmalek, Rajgopal, and Needy 2006; Rossi et al. 2022; Rachman and Ratnayake 2016). In these companies developing a systematic and comprehensive process for waste identification is one of the first steps to be implemented. Such a process needs to be developed based on the current practice that the company is developing. As a key motivation of this paper, a practical and comprehensive approach was introduced to identify and prioritize sources of waste in production facilities. This approach utilized various lean management tools to effectively address and mitigate waste, including waste walking, value stream mapping, etc. In this context, we employed a similar line of thinking as FMECA (failure modes, effects, and criticality analysis) as a foundation. However, rather than focusing on identifying and ranking failures, our objective was to rank waste for future rapid improvement purposes. In this regard, the research structure has been presented as follows:

In the first part, the leading theory and philosophy of the subject are discussed. Then, the proposed methodology has been described in four general sections, including "system review and recognition," "value identification," "waste identification," and how to prioritize the origins of waste to take appropriate measures. Finally, the application of the methodology is shown by a case study.

2- Research theory and methodology

As mentioned, the overall goal of the lean management approach is to eliminate system waste to make the system as adaptable as possible. Waste refers to any activity for which the customer refuses to pay, and eliminating all these processes would not negatively impact the company's products.

Figure 2 depicts the Lean production system (Institute 2003).

Figure 2- Lean management approach (Martin and Osterling 2017)

It highlights the foundational role of value stream mapping and waste identification in constructing a lean organization. By first identifying value from the customer's perspective, these practices serve as building blocks for lean management. Waste identification and elimination must be based on the scientific approach, where the target condition must be identified at the first stage. The current condition needs to be evaluated; wastes can be found based on these two important information processes. Furthermore, finally using the PDCA loop, the waste should be eliminated (Figure 3).

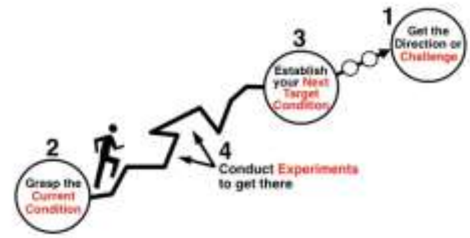

Figure 3- Waste elimination process By Toyota Kata (Rother 2009)

This scientific approach creates a common language where value recognition in the organization, continuous production flow, information circulation, increasing quality, and production speed is considered the basic principle and working philosophies. Over the years, lean management has evolved and introduced various tools such as 5S, A3, VSM, and more. However, for production facilities to achieve the desired outcomes, it is essential to employ these tools effectively within a well-developed managerial infrastructure. These tools should encourage maximum participation from all levels of the organization and aid in identifying potential errors before they disrupt the system. Consequently, they enable managers to implement appropriate preventive solutions (Gapp, Fisher, and Kobayashi 2008; Alnajem 2020; Sawhney et al. 2010; Priya, Jayakumar, and Kumar 2020; Seth, Seth, and Dhariwal 2017).

Here considering this principle, a step-by-step guideline for team building and waste identification is presented in Figure 4 and is briefly carried out through the following steps:

- Team building, training commitment, and consensus building.
- Process review and recognition
- value identification
- wastes identification
- waste prioritization
- Develop rapid improvement and starting experience (PDCA)

This approach suggests that system analysis should be done first to fully understand the production system and a team with authority should be selected to carry out the job, and a well-trained person must be appointed to facilitate the implementation process.

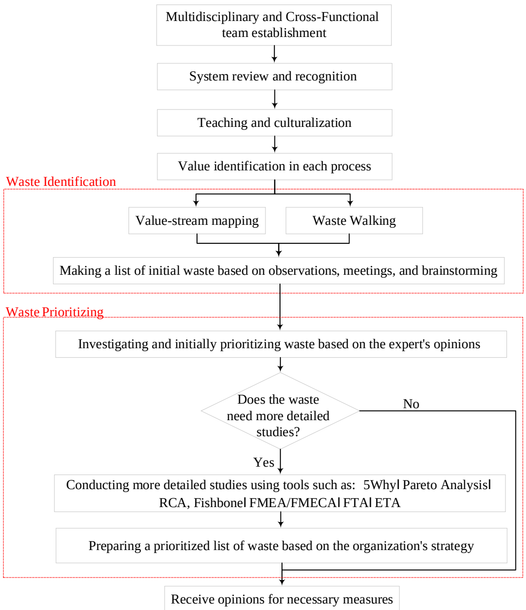

Figure 4- The process of waste identification in industrial systems (WIP)

The selected team must have the required knowledge about the process, and the team working environment should be inclusive. Facilitators should be able to take care of the team's psychological safety. Ensuring agreement among all team members regarding a solution might not always be feasible in certain situations. However, it is essential to foster commitment within the team. If necessary, the facilitator can employ a role change approach, whereby the dissenting individual assumes a supportive role, and the supportive person takes on the opposing role.

After the team building, the value should be defined based on the customer's perspective; waste identification can be carried out through Waste walking and Value Stream Mapping. A customer can be defined as an internal or external customer. Internal customers refer to individuals or departments within an organization who rely on the outputs or services of another department or team. They are recipients of value-added processes and outputs further down the value stream. Recognizing and meeting the needs of internal customers is vital for achieving smooth workflow, collaboration, and efficient resource allocation. On the other hand, external customers are the end-users or clients who directly benefit from the organization's products or services.

Once the initial list of waste is identified, it is crucial to prioritize it using predefined criteria. These criteria should be developed collaboratively by the team and approved by the responsible process manager. Once the ranking is analyzed, waste items are categorized based on type. Some waste will be targeted for immediate elimination, while others will undergo future root cause analysis to establish a proactive rapid improvement approach. This systematic approach ensures that resources are allocated efficiently and that immediate and long-term waste reduction strategies are implemented effectively.

2.1. Team building and culturalization

This fact has always been considered that presenting any new idea or change always faces human force resistance. Resistance against the behavior change observed in individuals can be a positive factor providing the required space for preparing and accepting the change. Since waste identification and elimination requires workforce commitment and engagement, and the responsibilities are ultimately on the team and the workforce, the senior and middle management need deep soft skills such as communication skill, conflict resolution, and other human skills (Green, Ashton, and Felstead 2001; Nowrouzian and Farewell 2013). Having a clear understanding of the concept of lean and its purpose is instrumental in building organizational commitment and engagement. When employees comprehend the principles and goals of lean management, they can align their efforts toward achieving the desired outcomes. By grasping the importance of waste reduction, continuous improvement, and customer value, individuals become more motivated and committed to implementing lean practices. They understand how their work directly contributes to the organization's success and customer satisfaction. This knowledge fosters a sense of ownership, empowerment, and engagement among employees as they actively seek opportunities for improvement and willingly participate in lean initiatives. Clear comprehension of lean principles builds a collective commitment to excellence and a culture of continuous improvement throughout the organization. Hence, the purpose of teaching the concept of lean to a team is to instill a deep understanding of the philosophy behind it, with a specific focus on waste identification. Through comprehensive instruction and interactive sessions, the team is equipped with the knowledge and tools to recognize and eliminate various forms of waste within their processes (Clark, Silvester, and Knowles 2013).

Creating a safe and open learning environment that encourages active participation and collaboration is essential when teaching lean principles and waste identification. Tailoring the teaching approach to the team's needs, utilizing visual aids and hands-on activities, and incorporating practical exercises and simulations can enhance understanding and application. Emphasizing continuous learning and improvement ensures the team develops the knowledge, skills, and mindset necessary for driving waste reduction and continuous improvement within the organization (Bertagnolli 2018).

Small teams of up to six individuals are recommended, with one designated as the facilitator within each group. These teams receive support from downstream teams and workers, who impart additional skills such as equipment repair, quality control, cleaning, and materials management.

2.2. Process review and recognition

Implementing any approach and applying changes in a production facility depends on the system's accurate recognition. All most recent changes and system knowledge should be obtained during the on-site visits and meetings with experts. This step aims to gain a more accurate recognition of the production systems. The way of the information circulation process, the implementation of maintenance and repair activities, comprehension of the production process and the influential factors, making daily, mid-term, and long-term decisions, criteria, and the way of making decisions, comprehending the way of optimizing the process, the behavior and reactions of management and human force regarding the events, are among the identified cases. The site visit will follow the "Gemba or Waste walking" principle, aiming to see the actual thing happening and get first-hand information from the people dealing with the production. Moreover, this walk will show that their contribution is important and can enhance the worker's engagement in waste identification and elimination. Cultural factors can also influence the Gemba approach. For example, in authoritarian company settings, where authority figures hold significant power and control, team members may have concerns about the potential for waste and failures to be hidden. In this authoritarian culture, employees may hesitate to report failures or problems during Gemba walks, fearing potential consequences or repercussions (Dana 2015).

To address this issue, the team needs to be aware of the potential challenges within an authoritarian company and be proactive in fostering a culture of trust and transparency. This can be achieved through open communication channels, where employees feel safe to share their observations and concerns without fear of retribution. Leadership is crucial in creating an environment that encourages open dialogue and learning from failures. By setting an example of admitting mistakes and valuing continuous improvement, leaders can promote a culture where employees are more likely to report failures during Gemba walks rather than concealing them (Dalton 2019).

Moreover, implementing feedback mechanisms, such as regular team discussions or improvement forums, can allow employees to discuss and address issues identified during Gemba walks openly. This creates a supportive environment that encourages collaboration and problem-solving. Gemba walks can become effective tools for identifying failures, waste, and areas for improvement by fostering a culture of trust, transparency, and collective responsibility within an authoritarian company. This culture shift allows the team to openly address issues, drive continuous improvement, and enhance the organization's overall performance (Luckett and Eggleton 1991; Agrawala and Josephb 2023).

2.3. Process value identification

Lean thinking is a customer-centric approach to manufacturing that defines value based on the end user's needs. Value is at the heart of lean management, driving organizations to continuously improve and deliver superior products and services that meet or exceed customer expectations. Value is products, services, and features that customers perceive as valuable. The process of creating this value is known as the value stream, and the activities that make up a value stream can typically be classified into the following categories (Makwana and Patange 2021; Andreadis, Garza-Reyes, and Kumar 2017; Chen and Meng 2010):

- Value-Adding Activities: These are the activities that directly contribute to transforming inputs into outputs that are valuable to the customer. Value-adding activities enhance the product or service's form, function, or utility. Examples include assembling components, designing features customers value, and conducting quality inspections.
- Non-Value-Adding Activities: Non-value-adding activities do not contribute to the final product or service from the customer's perspective. These activities add no value and are considered waste. Examples include waiting time, excessive inventory, unnecessary movement, and rework.
- Necessary Non-Value-Adding Activities: These activities are essential but do not directly add value to the product or service. They must support value-adding activities or ensure compliance with regulations, safety standards, or quality requirements. Examples include maintenance, compliance checks, and documentation.

2.4. Waste identification in processes

According to Figure 5, non-value activities can be divided into Muri, Mura, and Muda (3Mu.). Muri (overburdened) is defined as excessive use of resources and puts huge pressure on resources (Such as humans or machines) (Pieńkowski 2014; Buckley et al. 2017). For instance, if a production line has a maximum capacity of 1,000 units under optimal conditions, expecting to produce 1,200 units may lead to overworking the machinery or employees, resulting in reduced efficiency, increased downtime, and potential quality issues. Mura (variation in production) means improper usage of an organization's resources (Pieńkowski 2014; Buckley et al. 2017). For example, improper work allocation within a common department can lead to one employee being fully occupied while the other is 50% more productive but underutilized. Muda (Waste) is activities where part of the resource capacity is wasted.

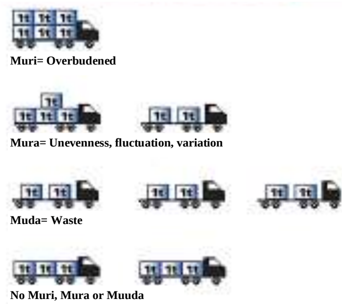

Figure 5- Types of waste in the system (Club and Delhi 2018)

Muda is divided into the following eight types (King 2009; Womack and Jones 1997; Hines and Rich 1997; Jasti and Sharma 2014):

1. **Overproduction:** This Waste appears when the production speed of the upstream unit is higher than the downstream unit
2. **Inventory:** the stock includes end products, semi-raw material, spare pieces, or information overload.
3. **Production defective:** Equipment failure and lack of effective implementation of the production process will reduce the efficiency and mineral recovery and the waste of human force and raw materials.
4. **Motion:** Any excess motion of human force that does not directly create value added to the customer.
5. **Transportation:** It is caused by disproportionate transportation and unnecessary transfers of raw materials, tools, and information at the complex level.
6. **Waiting:** It is one of the most common types of waste in production processes and is caused by waiting for human force, equipment, information, and materials.
7. **Extra processing:** This Waste is caused by processes that do not add any value to the product from the point of view of internal and external customers.
8. **Non-Utilized Talent of the Workforce:** This type of waste will bring dissatisfaction in the human force and loss of suitable opportunities to improve the organization's performance.

2.4.1. Waste walking (WW)

To eliminate waste, the company should start by closely evaluating and improving the core activities associated with its main product or service, streamlining operations, and enhancing customer value. This process should be evaluated by Waste walking (Gemba). Waste walking is where the team can closely examine problems and opportunities for improvement by collecting field information from operators, technicians, and engineers. Effective WW provides first-hand knowledge of the production system and the workforce. Following the WW method, a more structured method capable of classifying and grouping the causes can be used to identify the causes of an event. Fishbone Diagram (Ishikawa diagram), Fault tree analysis (FTA), or Cause and Effect diagram are someone of some highly beneficial tools in this way (Institute 2003; Jannah and Siswanti 2017; Simon and Canacari 2012). The fishbone diagram's first step is determining the factors contributing to process variations. The contributing factors include *man, machine, method, material, measurement, and Mother Nature* (operational condition), known as 6M. These 6 Ms influence variations in all processes and serve as the first six main “bones” of your fishbone. The fishbone diagram should be developed based on unit engineers' and their managers' collective wisdom (Brainstorming). After finding the involved factors in the event, they must be reconfirmed or signed off, which must be related to the event under investigation. Otherwise, ineffective strategies will eventually be developed (Bicheno 2006; Radwan et al. 2020).

2.4.2. Value-stream mapping

WW is a useful method for identifying waste, but it is insufficient for preparing a road map and future measures. Value Stream Mapping (VSM) is a critical tool proposed to solve this shortcoming. VSM helps to illustrate all production processes, material streams, and information using a set of predefined and standard icons. The inflection point of VSM implementation is working on the company's big picture rather than individual processes, and it can illustrate information and material streams simultaneously, making it superior to other mapping tools. The steps of VSM can be summarized as follows (Martin and Osterling 2017; Rother et al. 1999):

- **Value stream selection:** The customer usually determines the target value stream. Otherwise, "quantitative product analysis" or "product path analysis" are replaced.
- **Illustrate the current map:** A visual illustration of the materials stream and current information is presented, which leads to a more accurate comprehension and identification of waste resources in the value stream.
- **Selection and measurement of performance criteria:** Selecting criteria depends on the type of the system under study. However, criteria should be selected that are easy to understand. One of the widely used criteria in this sector is the Overall equipment effectiveness.
- **Illustrate the Future map:** The future map of the value stream is based on the findings of the administration of the value stream management model, depending on the three stages of demand satisfaction, stream creation, and production smoothing. The purpose of illustrating the future map of the value stream is to eliminate waste resources that have been identified by illustrating the current map.
- **Planning to deal with Waste:** At this stage, the necessary arrangements and measurements are planned based on the effectiveness of each item to deal with the existing waste.
- **Program administration:** The final plan for administration is announced, and the cycle is repeated.

Regarding applying the WW or VSM method for waste identification, it should be noted that these two methods are complementary. Depending on the sensitivity of the work, one could be selected among these two methods (or both methods could be selected).

2.5. Waste Prioritization

Based on the output of WW or VSM, the team prepares a list of wastes. The prepared list is presented to upstream managers for the initial investigation to prepare an initial prioritization of waste for further measures through receiving opinions.

The main idea is to develop a continuous improvement culture to eliminate the identified wastes. Continuous improvement needs to establish to eliminate identified wastes. One of the challenges of continuous improvement is the duration of its effects on the system, which may not be compatible with the short-term management spirit. Sometimes managers implement projects for their portfolios and look for short-term results apart from long-term effects. Therefore, the Kaizen events or rapid improvements such as accelerated improvement workshops or Kaizen blitz are suggested, similar to Kaizen in philosophy and slightly different in implementation (Glover, Farris, and Van Aken 2014; Manos 2007; Farris et al. 2008). Rapid improvement has been an effective tool for moving forward, relates improvements to a larger strategy, and includes all critical perspectives to create relevant, measurable, and sustainable developments. Rapid improvement is a two- to five-day focused improvement activity during which a discrete, multidisciplinary team (of different expertise) designs and fully implements improvements in a specific process or work area. A Kaizen event is a focused, structured development project by a Cross-functional team to quickly improve the work environment with specific objectives (Glover, Farris, and Van Aken 2014). Here, to implement improvement, the importance of each waste needs to be identified. Figure 6 shows a step-by-step guideline to rank the identified waste. The waste raking is carried out by identifying the severity, rate of occurrence, and detectability.

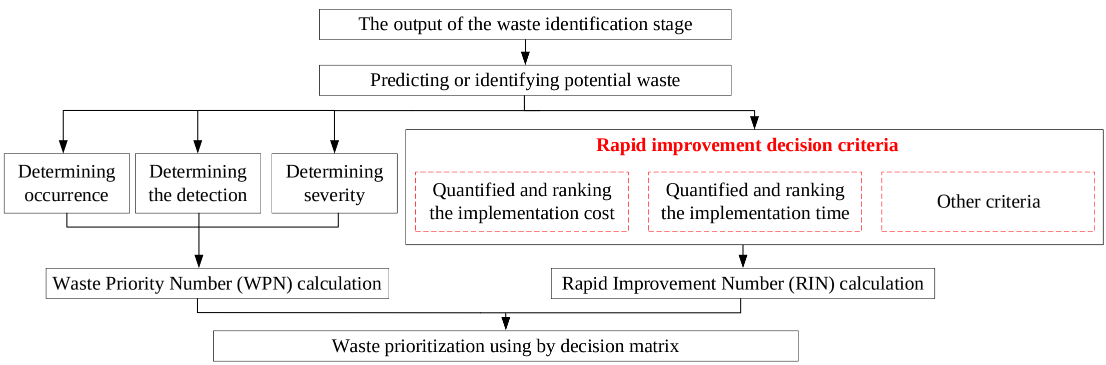

Figure 6- Prioritization algorithm with two decision criteria, including time and implementation cost

The severity of waste refers to the extent of its negative impact across different criteria.

The table in the final column presents an illustrative instance of a defect considered waste in a geho pump within an aluminum production company in an underdeveloped country. In this case, the weight assigned to safety is 10, indicating its significance within the company's context. However, the defect level for safety is identified as 2, resulting in a weighted severity of 20.

The criteria mentioned in this table encompass various aspects crucial for the success of a production facility and maximizing its value. For example, safety ensures the well-being of employees, customers, and stakeholders by addressing potential hazards and unsafe practices. The financial impact is essential for maintaining profitability and sustainability, focusing on mitigating excessive costs and improving resource utilization. Transparency and accountability foster trust and ethical governance, while strategic alignment ensures organizational initiatives are aligned with long-term goals. Talent and workforce management enhance productivity and employee engagement, while service delivery directly impacts stakeholder satisfaction.

The relative importance of the criteria mentioned above can vary based on the unique characteristics of a production facility, the prevailing culture, and the operational conditions within an organization. Due to inherent challenges or criticality, specific criteria may carry more weight in certain contexts. For example, the safety criterion may take precedence over others in a production facility with high safety risks, or the operational environment poses potential hazards.

Table 1 shows a sample of criteria for the severity identification of the waste. It considers the consequences and implications associated with the waste in question.

Table 1- An example of waste severity ranking

Identified Waste		**Defect no 1: Geo pump leakage**	
Criteria	**Explanation**	**Severity**	
		level	**Weight**
Safety	The highest priority is addressing hazards, unsafe practices, and potential accidents for a safe environment	**2**	**10**
Financial Impact	Crucial for profitability and sustainability, addressing excessive costs, financial losses, and inefficient resource utilization.	**8**	**8**
Customer Satisfaction	Vital for success, addressing defects, delays, poor communication, and failure to meet exceptions to enhance customer experience.	**2**	**5**
Process Efficiency	It affects productivity, addressing unnecessary steps, waiting times, transportation inefficiencies, and underutilization of resources.	**8**	**10**
Compliance and Regulatory	Essential for legal and ethical reasons, addressing non-compliance, violations, fines, and failure to meet required standards.	**1**	**5**
Transparency and Accountability	Crucial for trust and ethical governance, addressing fraud, corruption, lack of documentation, and improper resource use.	**0**	**5**
strategic Alignment	Ensures initiatives align with strategic goals, addressing misallocation of resources, lack of goal clarity, and ineffective planning	**5**	**7**
Talent and Workforce	vital for productivity and engagement, addressing skill gaps, low morale, inadequate training, and inefficient utilization.	0	5
Service Delivery	Essential for meeting stakeholder needs, addressing delays, inefficient channels, lack of accessibility, and poor service.	1	5
Stakeholder Engagement	Important for communication and collaboration, addressing limited feedback, lack of transparency, and inadequate collaboration.	2	2

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Similarly, in a culture that strongly emphasizes compliance and regulations, ensuring adherence to legal requirements and ethical standards may be of utmost importance. Furthermore, in an underdeveloped country with limited financial resources, the financial impact criterion could carry significant weight in decision-making processes. It is essential to assess and understand the specific circumstances, challenges, and priorities within each organization and align the criteria accordingly to optimize the overall performance and success of the production facility.

When a waste affects multiple criteria, its severity increases as the repercussions are more widespread and significant. For instance, if a waste poses a safety risk and leads to substantial financial losses, its severity is considered higher than a waste that only impacts one criterion. The severity of waste helps assess its impact and determine the level of attention and resources required for its resolution. Since waste can have diverse impacts across different criteria, it is essential to utilize a systematic approach that considers the relative importance of each criterion. For example, by using multi-criteria decision-making methods, the team can objectively evaluate the significance of each waste based on its impact on various criteria. This approach involves assigning weights to different criteria and considering the severity of the waste in each category. By combining and analyzing these weights, decision-makers can arrive at a comprehensive assessment of the overall severity of the waste. Ultimately, using multi-criteria decision-making facilitates a well-informed and systematic approach to addressing waste in a balanced and efficient manner.

After identification of the severity(S), the rate of occurrences (ROC) of waste needs to be identified. Here, the waste occurrence rate refers to the frequency at which a particular waste is observed within a production process, measured concerning the production units. It quantitatively measures how often a specific waste event happens while producing goods or services. For instance, let us consider a car production system. Suppose there is a waste of defects in the manufacturing process. If it is found that, on average, three defects are identified for every car produced, the waste occurrence rate for defects would be three per production unit. This means that, statistically, there are three defects per car manufactured.

To determine the ROC, the first step involves collecting data related to the occurrence of each waste. This data collection can be accomplished through various methods, including process observation, time studies, value stream mapping techniques, or data analysis. Once the data is gathered, the occurrence of each waste needs to be assessed based on the collected information. During this analysis, it is crucial to identify patterns, trends, or areas where wastes occur most frequently or significantly impact overall process performance.

Table 2 provides a simplified representation of waste ROC per unit of production.

Table 2- Waste occurrence for the unit of production

Description	Criteria	Level
Extremely rare occurrence per unit of production	less than 0.001	**1**
Very rare occurrence per unit of production	0.001 to 0.01	**2**
Rare occurrence per unit of production	0.01 to 0.1	**3**
Occasional occurrence per unit of production	0.1 to 1	**4**
Frequent occurrence per unit of production	1 or more times	**5**

The levels in the table indicate the frequency of waste events within a production process. Level 1 signifies an extremely rare occurrence, with less than 0.001 instances per production unit. As we move up the levels, the occurrence becomes more frequent, ranging from very rare to rare, occasional, and eventually frequent, denoting one or more times per production unit. Detectability(D) of waste is another decision criterion that needs to be quantified. As systems become increasingly complex over time, waste identification becomes progressively challenging. Waste detectability refers to the level of expertise or skill required to identify waste within a system or process.

It represents the proficiency or knowledge necessary to recognize and pinpoint wasteful activities or resources that do not contribute value. The higher the level of detectability, the more advanced the expertise required to identify and classify different types of waste accurately. An expert in waste detectability deeply understands lean principles, process optimization, and the specific domain or industry in which waste is being examined. The goal of improving waste detectability is to enhance the ability of individuals, whether they are managers, team members, or specialized experts, to identify waste efficiently. By developing expertise in waste detectability, organizations can more effectively target and eliminate non-value-added activities, leading to increased efficiency, cost reduction, and improved overall performance. Table 3 shows an example of detectability.

Table 3- Detectability ranking scale

Explanation	Level
Waste at this level is easily recognizable without in-depth knowledge of production systems, costs, quality, or organizational effects. It may include visible sources of waste.	**1**
At this level, there is a basic understanding of different waste types but minimal awareness of production systems, costs, quality, or organizational effects. It involves identifying waste that may be more subtle or hidden	**2**
Waste at this level is relatively straightforward to identify with a moderate understanding of production systems, costs, quality, and organizational effects. It may involve common sources of waste that are efficiency and performance.	**3**
This level of waste requires a deeper understanding of the production system, costs, quality, and organizational effects. It involves identifying waste that may be interconnected and have a significant impact on overall operational performance.	**4**
At this level, there is moderate complexity in identifying various types of waste. It requires considering production systems, costs, quality, and organizational effects to pinpoint waste that may be multifaceted and affect multiple areas.	**5**

The criteria considered in the table include factors that help determine the detectability of waste. These factors include knowledge of production systems, understanding the cost of production, considering the quality of processes and products, assessing the production rate, evaluating HSE risks, and considering the short and long-term effects on the organization. For example, knowledge of production systems is essential as it provides a deep understanding of the processes involved, enabling effective waste identification and elimination.

Analyzing the cost of production helps prioritize waste detection efforts by focusing on areas with a significant financial impact and optimizing resource allocation. Considering the quality of processes and products ensures that waste affecting quality is promptly identified and addressed, preventing customer dissatisfaction and the need for rework.

Monitoring the production rate helps identify waste that hampers output efficiency, allowing for targeted improvements to enhance productivity and reduce resource consumption. Evaluating HSE (Health, Safety, and Environmental) risks is crucial to identify waste that poses potential hazards to health, safety, or the environment. Lastly, considering the short and long-term effects on the organization helps assess the overall impact of waste and make informed decisions to drive continuous improvement. By considering these criteria, organizations can enhance waste detection efforts, optimize resource utilization, and improve operational performance.

In the next step, after obtaining the ROC, S, and D values, the WPN (Waste Priority Number) is calculated by the following:

$$WPN = O.ROC.D \tag{1}$$

The WPN provides a base for ranking the identified waste. When it comes to selecting waste elimination approaches, several factors need to be considered. This is because each organization and system is unique, and a one-size-fits-all approach may not be effective. Factors such as the cost of rapid improvement, implementation time, effectiveness, feasibility, scalability, sustainability, compatibility, and stakeholder engagement play crucial roles in the decision-making process. Table 4 shows some decision criteria for finalizing the rapid improvement approach to identified waste.

Table 4- Decision criteria for rapid improvement approach of identified waste.

Criteria	Explanation	wight
Cost of implementation	Financial implications of implementing the waste elimination approach. Considers expenses and potential long-term cost savings.	1
Implementation Time	Duration required to implement the waste elimination approach successfully. Considers planning, repetition, and the timeline for results.	1
Effectiveness	The degree to which the approach reduces identified waste and improves operational efficiency.	1
Feasibility	Practicality and viability of implementing the approach within available resources and capabilities.	1
Scalability	Potential to apply the approach on a broader scale across various areas or processes	1
Sustainability	Long-term viability and maintainability of the approach. Ensures prevention of waste recurrence.	1
Compatibility	Alignment with the organization's values, goals, and systems. Considers integration and support for overall objectives	1
Stakeholder Engagement	Involvement and collaboration of relevant stakeholders. Considers input, perspectives, and support of employees, managers, and customers.	1
Employee well-being	Impact on employee safety, satisfaction, and work conditions.	1
Organizational Culture	Compatibility with the organization's values, beliefs, and employee mindset.	1

Again, these criteria may have different weights based on the organization setting. Here as an example, the two criteria of Cost of Rapid improvement (C) and Implementation Time (T) of implementation are considered with the same weight (=1) for RPN calculation. In general, the value of the rapid improvement number (RIN) can be calculated in the simplest form as the following equation:

$$RIN = \sum_{i=1}^{n} W_i Criteria_i \tag{2}$$

In this relationship, W_i represents the weight of the criteria and $Criteria_i$ represents the impact of the criterion.

In other words imagen, a company that only these two criteria need to be considered. Table 5 provides a simplified overview of the implementation time and cost of rapid improvement, two important criteria for evaluating waste elimination approaches.

For example, rapid improvement with a scale of 1 on the implementation time can be implemented within hours, allowing for immediate action and quick results, while those with a scale of 5 may require years, indicating a longer-term commitment. Conversely, rapid improvement with a cost scale of 1 entails very low costs or minimal expenditures, making them financially feasible even for organizations with limited resources. In contrast, approaches with a scale of 5 involve very high costs, requiring significant financial resources or long-term investments.

Table 5- An example of a defined level for implementation time and cost of rapid improvement

Implementation Time	Cost of rapid improvement	Level
Hours	Very low cost or minimal	1
Days	Low cost	2
Weeks	Moderate cost	3
Months	High cost	4
Years	Very high cost	5

It is vital to note that the cost range associated with each level may vary significantly depending on the specific context, industry, and project scope. The scale should be tailored and adjusted based on the organization's budget and cost considerations for accurate planning and decision-making. With the RIN and WPN in hand, task prioritization becomes possible. In Figure 7, a practical example illustrates how appropriate tasks can be selected. In this case, the priority tasks possess the highest WPN and the lowest RIN. This indicates that they offer the greatest anticipated benefit and are relatively easy to implement, with a focus on addressing the most severe waste. It is advisable to begin by implementing these priority tasks first. After completing the priority tasks, the Action tasks, which offer slightly lower benefits but are still relatively easy to implement, should be addressed. The tasks labeled as considered can be evaluated after the priority and action rapid improvement measures have been taken. Finally, eliminating tasks should be removed from consideration as their low benefit does not justify the high cost and effort required. The definition of boundaries for each action needs to be defined by the company.

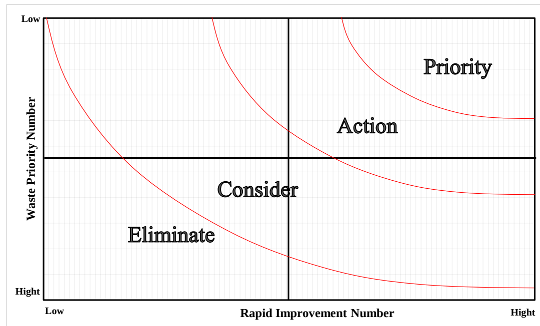

Figure 7- A sample of the decision matrix for prioritizing identified motivation

3. Illustrative case study: Maintenance challenges in an industrial unit

To better understand the methodology presented in Figure 4, this section provides an illustrative example of the challenges that may arise during the industrial maintenance of a gheo pump in an alumina company. Here, the waste is identified by brainstorming (and WW) and visualized using a fishbone diagram, as shown in Figure 8.

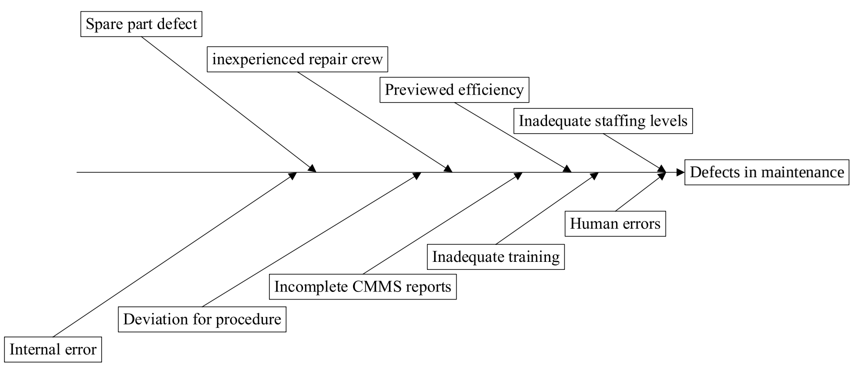

Figure 8- Fishbone of maintenance defects in an industrial unit

This diagram highlights nine significant sources of waste, such as lack of attention to maintenance procedures, defects in spare parts, understaffing, Insufficient expertise, and inadequate training.

The developed approach is utilized to prioritize these various sources of waste. This involves assessing the severity, occurrence, and detectability values for each of the nine sources of waste based on Table 1, Table 2, and Table 3. The resulting values are multiplied and used to calculate the WPN, as shown in Table 6.

Table 6- The calculation of the maintenance challenges priority number

Waste Numer	Wastes	Severity	Probability	Detectability	WPN	Cost	Time	RIN
1	Internal error	4.00	6.00	4.00	96.00	7.00	7.00	49.00
2	Deviation for procedure	3.00	4.00	2.00	24.00	6.00	6.00	36.00
3	Previewed efficiency	8.00	8.00	7.00	448.00	5.00	6.00	30.00
4	Spare part defects (Incorrect, poor quality, and inventory management)	7.00	8.00	7.00	392.00	4.00	5.00	20.00
5	Inadequate staffing levels	5.00	4.00	4.00	80.00	6.00	7.00	42.00
6	Insufficient expertise	2.00	2.00	2.00	8.00	6.00	6.00	36.00
7	Inadequate training	4.00	3.00	2.00	24.00	6.00	6.00	36.00
8	Human error	5.00	4.00	3.00	60.00	6.00	6.00	36.00
9	Incomplete CMMS reports	4.00	4.00	3.00	48.00	7.00	7.00	49.00

Next, based on Table 4, two criteria, cost and time, are used for prioritizing waste sources for corrective action. This information can be added in the sixth and seventh columns of Table 6, using Table 5 as a guide. The resulting values are then multiplied and used to calculate the RIN, as shown in the eighth column of Table 6.

The weight of importance for cost and in Eq.(2) is equal to 1. It is important to note that these values may be obtained through expert opinions gathered via a questionnaire in real scenarios.

The prioritization of waste can be achieved by referring to Figure 2 and calculating WPN and RIN. Figure 9 shows that the two major wastes, waste number 3 (Previewed efficiency) and number 4 (Spare part defect), are the top priority for action, while waste number 6 (Insufficient expertise) is considered the least important waste.

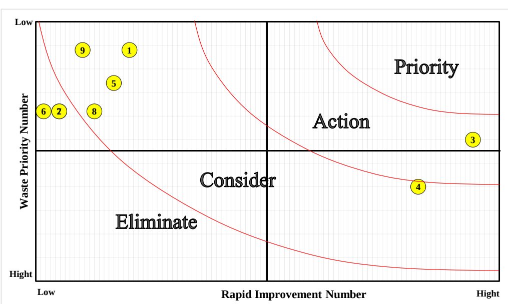

Figure 9- Decision matrix for maintenance wastes prioritizing

4. Conclusion

Companies must adopt a lean thinking approach to thrive in the volatility, uncertainty, complexity, and ambiguity (VUCA) environment and achieve sustained improvements. It is essential to understand that lean implementation is a culturally changing process that requires a deep understanding of the current culture and tools which the company is using. The commitment of top management and middle managers is critical to the success of lean implementation, and employee involvement, training and education, cultural barriers, unrealistic expectations, and a continuous improvement mindset are essential factors to consider.

As a key motivation of this paper, a practical and comprehensive approach was introduced to identify and prioritize sources of waste in production facilities. This approach utilized various lean management tools to identify waste effectively, including waste walking, value stream mapping, etc. Then to implement improvement, the importance of each waste needs to be identified. The waste raking (WPN) is carried out by identifying the severity (the extent of its negative impact across different criteria), rate of occurrence (frequency at which a particular waste is observed within a unit production process), and detectability (the level of expertise or skill required to identify waste within a system or process. When selecting waste elimination approaches, organizations must consider cost, implementation time, effectiveness, feasibility, capability, sustainability, compatibility, stakeholder engagement, and their weights in RIN calculation. Finally, the rapid improvement action priority is defined based on the decision matrix. The scale and weight in different steps should be tailored based on the organization's criteria for accurate planning and decision-making.

Implementation of the proposed approach in an illustrative case study of maintenance defects in an industrial unit showed that utilizing the proposed method in organizations can optimize their processes, reduce costs, improve quality, increase productivity, achieve a sustained competitive advantage, and become more resilient to changes in the market, allowing them to adapt quickly to new challenges and opportunities. By implementing it, organizations can create a culture of continuous improvement, resulting in increased innovation, employee engagement, and customer satisfaction.

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