

Development Value Stream Mapping to Identify 8 Types of Waste

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Abstract—This study proposes an **Extended Value Stream Mapping (Extended VSM) framework to address the limitations of traditional VSM in identifying all eight types of waste (Muda), particularly those associated with human factors, environmental conditions, and material movement. While conventional VSM effectively maps value-added and non-value-added activities, it often fails to detect motion waste, transportation inefficiencies, and underutilized human potential. The proposed framework integrates time measurement using Stopwatch Time Study (STS), workflow analysis through the Operation Process Chart (OPC), ergonomic risk evaluation with the Rapid Entire Body Assessment (REBA), mental workload assessment via NASA Task Load Index (NASA-TLX), and environmental condition indicators such as lighting, temperature, and noise. Designed for labor-intensive production systems, EVSM offers a multidimensional mapping tool capable of supporting continuous improvement initiatives. Although this research does not include a real-case implementation, the framework is designed to be practically applicable and empirically validated in future studies.**

Index Terms—About; Eight Waste; Lean Manufacturing; Muda Waste; Value Stream Mapping.

I. INTRODUCTION

Value Stream Mapping (VSM) is one of the main tools in the implementation of lean manufacturing, which serves to map, analyze, and improve the flow of production processes with a focus on value-added activities and the identification of waste (non-value-added) activities. (Rother & Shook, 1999). However, in

practice, traditional VSM generally only identifies some types of waste, such as waiting time, overprocessing, and inventory (Roosen & Pons, 2013; Suhardi, Hermas Putri K.S, & Jauhari, 2020). Other wastes such as transportation, motion, and defects, especially those related to operator activities and material movement, are often overlooked because VSM is not designed to capture these aspects in depth. (Carrim & Gupta, 2024; Fatma, Ponda, & Sutisna, 2022) In fact, the eight types of waste known as Muda Waste, namely overproduction, waiting, transportation, overprocessing, inventory, motion, defect, and non-utilized talent, are all interconnected and significantly contribute to the inefficiency of the production system (Liker & Hoseus, 2008; Ohno & Bodek, 1988). Therefore, there is a need to expand the scope of VSM to be able to comprehensively identify all of these types of waste.

In response to these limitations, various developments of VSM have been carried out, such as Ergonomic VSM (Ergo-VSM), which integrates aspects of work posture, physical load, and mental workload into the value stream. (Domínguez, Mendoza, Montoya, Vargas-Bernal, & Jacobo-Galicia, 2023; Jarebrant, Winkel, Johansson Hanse, Mathiassen, & Öjmertz, 2016), as well as Environmental VSM (Environment-VSM), which adds sustainability indicators such as energy consumption and the quality of the work environment (Garza-Reyes, Torres Romero, Govindan, Cherrafi, & Ramanathan, 2018). Nevertheless, both approaches still have limitations, such as Ergo-VSM being qualitative and not fully integrated with work time measurement (Suryoputro, Sari, Burhanudin, & Sugarindra, 2017), while Environment-VSM emphasizes environmental impacts more than pure operational efficiency aspects (Garza-Reyes et al., 2018)

To address these various limitations, several supporting tools can be used to enhance the

effectiveness of waste mapping. Tools like the Rapid Entire Body Assessment (REBA) are used to assess the risk of work posture quantitatively (Hignett & McAtamney, 2000), the NASA Task Load Index (NASA-TLX) to measure mental workload (Hart & Staveland, 1988), and Stopwatch Time Study (STS) to objectively identify time wastage and overprocessing (Hadad, Keren, & Hanani, 2014). Environmental allowances based on ILO (International Labour Organization) standards are used as a reference in assessing additional working time due to non-ideal working conditions, thus providing a more accurate picture of non-productive activities that arise due to environmental factors (Lukodono & Ulfa, 2018). Considering the limitations of traditional VSM as well as the potential for integration with other methods, the development of an Extended VSM is necessary. The Extended VSM is expected to not only map value streams and waste from an operational perspective but also to integrate aspects of ergonomics, human factors, the work environment, and material movement as important elements in the production system.

II. METHODS

This research method is structured in several stages for developing Extended VSM, which aims to identify the eight types of waste (Muda). The stages begin with a literature study to examine the limitations of traditional VSM, followed by the identification of relevant additional aspects, the selection of appropriate measurement tools, and the design of a visual structure for the Extended VSM based on the integration of operational, ergonomic, and working environment aspects.

A. Determining the Identification of Waste in Extended VSM

Extended VSM was developed with the aim of being able to identify the eight types of waste (Muda) more comprehensively, namely: overproduction, waiting, transportation, overprocessing, inventory, motion, defects, and non-utilized talent. Each waste is indicated by a specific indicator and measurements, thus facilitating the mapping and analysis process. The determination of the type of waste to be mapped is done by referring to the limitations of traditional VSM and the need for cross-aspect integration in the production system (Liker & Hoseus, 2008; Ohno & Bodek, 1988).

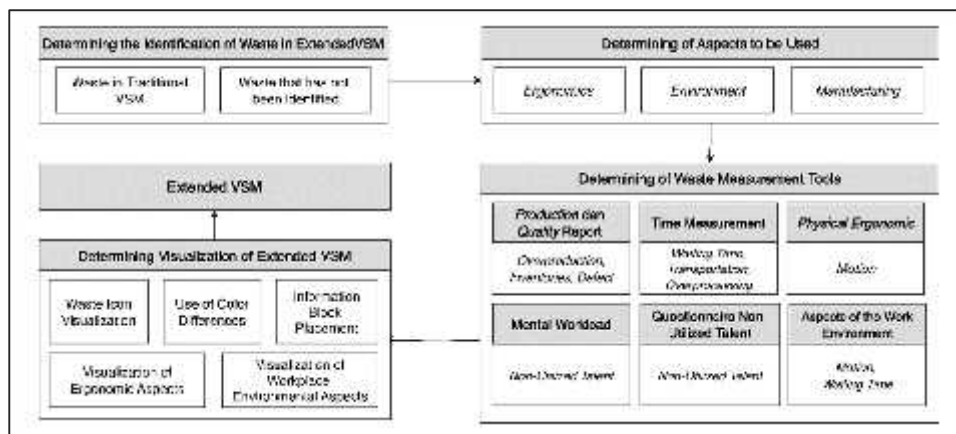


Figure 1: Flowchart of Methodology

B. Determining the Aspect

The aspects involved in the design of Extended VSM include manufacturing aspects adapted from traditional VSM, ergonomic aspects adapted from Ergo-VSM, and environmental aspects adapted from Environment-VSM. These three types of VSM serve as the foundation for determining waste measurement tools, which are derived from

the production and quality reports of an industry, observations, and questionnaires. The eight types of waste measured in the development of Extended-VSM include:

1. Manufacturing system metrics derived from production and quality reports are indicators of the existence of waste, such as overproduction, inventories, and defects. Additionally, work time measurements serve

as indicators of waste from waiting time, transportation, and overprocessing.

2. Ergonomic aspects, consisting of physical ergonomics, mental workload, and non-utilized talent questionnaires, as indicators of waste from motion and non-utilized talent.

Environmental aspects, including noise, temperature, and lighting, are used as considerations.

C. Determining Visualization of Extended VSM

Visualization in the development of Extended VSM is designed to enrich the value stream map display with more comprehensive information. This visualization includes several additional elements, such as waste icons to directly represent types of waste at each activity, as well as the use of symbols and colors to distinguish between categories of activities and their risk levels.

First, special icons are used to represent each of the eight types of Muda Waste, such as symbols for waiting, overprocessing, or motion, which are placed directly on the relevant process flow. This adopts the visual concept of Service-VSM that uses thematic icons to clarify the types of waste (Bonaccorsi, Carmignani, & Zammori, 2011).

Second, visualization is enhanced through the use of colors and symbols that distinguish between value-added activities, non-value-added activities, and activities with high risks. This principle refers to the design of Cost-Based VSM, where variations in the color of lines or arrows illustrate differences in the intensity of activities or cost risks (Gunduz & Fahmi Naser, 2017). Colors are also used to mark processes with high ergonomic risks, exposure to extreme environments, or excessive mental workloads.

Third, ergonomic data is presented in a structured manner within each process block. The physical ergonomic score results will be visualized in the form of work posture risk values, while mental demand will be shown through total mental workload scores. This integration follows the visual structure of Ergo-VSM, which places ergonomic indicators under cycle time information (Jarebrant et al., 2016).

Fourth, the work environment aspects are visualized based on parameters such as temperature, lighting, and noise. These values will be compared with the recommended work allowances by the ILO to indicate whether the conditions may lead to wasted motion due to

disruptions in work comfort (Garza-Reyes et al., 2018). Finally, all process data, such as cycle times and activity categories, will be summarized in one information panel for each work process. With this integrated visualization, Extended VSM is expected to provide a comprehensive overview of waste from the perspectives of operations, ergonomics, and the work environment.

III. RESULT AND DISCUSSION

The proposed framework of Extended Value Stream Mapping (EVSM) aims to expand the analytical capability of traditional VSM by integrating human factors and ergonomic assessments into the value stream analysis. The following sections outline the design strategy, implementation steps, and visualization components of the proposed framework.

A. Extended Value Stream Mapping Strategy

In the development of Extended Value Stream Mapping (Extended VSM), the design strategy begins with identifying the limitations of conventional Value Stream Mapping (VSM) methods, particularly in detecting non-operational waste such as non-ergonomic work postures, mental workload, and low labor utilization. Extended VSM is designed to address the need for a more comprehensive value stream mapping by integrating measurement elements from physical ergonomics (through REBA), mental workload (through NASA-TLX), and cycle time data (with Stopwatch Time Study). The addition of these aspects allows Extended VSM to not only identify non-value-added activities but also to explain the root causes of waste based on objective data. This strategy aligns with a human-centered lean approach, where the improvement process is not only focused on material and time efficiency but also considers the well-being of workers in the system.

Waste related to defects and overproduction is identified through analysis of production quality reports and output data. Defect waste is quantified by calculating the number and types of rejected, reworked, or failed products recorded over a given period. These quality records are used to trace back defective outputs to specific processes, operators, or environmental conditions. On the other hand, overproduction waste is detected by comparing actual production volumes against customer demand or takt time targets, highlighting

areas where excessive production occurs due to poor scheduling, large batch sizes, or misaligned production planning. Additionally, inventory waste is identified through process observation and material flow documentation, especially when raw materials, work-in-progress (WIP), or finished goods accumulate without corresponding throughput.

B. Integration of Time Measurement with Stopwatch Time Study (STS)

The initial step begins with the preparation of a value stream map using the traditional VSM approach. At this stage, the flow of materials and information from the beginning to the end of the production process is mapped using standard VSM symbols (Rother & Shook, 1999). The purpose of this mapping is to identify value-added activities (Value Added / VA) and non-value-added activities (Non-Value Added / NVA). The information collected includes cycle time, waiting time, the number of workers, stock quantities, and information flow such as production schedules (Rother & Shook, 1999). Meanwhile, environmental factors contributing to indirect waste, such as high temperature, poor lighting, and excessive noise, are monitored using direct workplace measurements and compared with standard thresholds set by the International Labour Organization (ILO) to evaluate ergonomic environmental conditions.

C. Mapping of Traditional Value Streams

The second stage involves collecting work time data using the Stopwatch Time Study method to accurately determine cycle time, process time, and wait time. The results of this STS are used to measure process efficiency and identify waste types such as waiting, overprocessing, and transportation. STS is considered more accurate compared to subjective estimates because it is based on the actual amount of work activity in the field, including adjustments for allowance factors [23].

To further improve the identification of transportation waste, this research also incorporates the Flow Process Chart (FPC). FPC is used to visually document each step in the workflow, including movements and inspections, enabling the detection of non-value-added transport activities between operations. When used in conjunction with STS, FPC helps pinpoint excessive or unnecessary material and operator

movements that contribute to inefficiencies in the production system (Wignjosoebroto, 2008). This integration of STS and FPC strengthens the diagnostic capability of Extended VSM in capturing time-based and movement-related waste more comprehensively.

D. Physical Ergonomic Evaluation with Rapid Entire Body Assessment

To capture the dimensions of waste from the aspect of motion waste and the potential for musculoskeletal disorders, an assessment of work posture was conducted using the Rapid Entire Body Assessment (REBA) method. REBA allows for a quantitative assessment of body positions while working (neck, back, arms, legs) and assigns risk scores to each activity (Hignett & McAtamney, 2000). The integration of REBA in the value stream map provides an overview of which activities pose high risks and have the potential to reduce productivity and increase physical workload (Suryoputro et al., 2017).

E. Measurement of Mental Workload and Workforce Engagement (Non-Utilized Talent)

The measurement of cognitive aspects is carried out using the NASA Task Load Index (NASA-TLX), which assesses six dimensions of mental load, namely mental demand, physical demand, temporal demand, performance, effort, and frustration (Hart & Staveland, 1988). These dimensions describe the extent of the subjective load felt by operators in carrying out their tasks. In addition, a measurement of potential non-utilized talent wastage is conducted through a questionnaire designed to identify whether the ideas, skills, or potential of operators have been utilized optimally.

F. Measurement Extended Value Stream Mapping Visualization Design

The design of Extended Value Stream Mapping (Extended VSM) visualization is an important stage in ensuring readability and effective communication between functions in the production system. A good Extended VSM design must be able to integrate information from various dimensions, including material flow, information flow, processing time, as well as ergonomic and cognitive data, into a single map that is easy to understand and used as a decision-making tool.

Green	Corrective action is not required.
Yellow	Requires further evaluation.
Red	The evaluation must be conducted immediately.

Figure 2: Visualization of Action Levels with Color



Figure 3: Visualization of Information Block and Material Flow

1. Integration of VSM Standards Symbols with Additional Indicators and Color

Essentially, the main structure of Extended VSM still refers to the standard symbol format of traditional VSM as proposed by Rother & Shook (1999), such as process box, data box, information arrows, and inventory symbols. This aims to maintain readability and visual consistency for lean practitioners who are familiar with conventional value stream maps. The Extended VSM framework leverages color-coded indicators to provide a comprehensive yet accessible map of production processes. However, to reflect the broader dimension of wastefulness, these symbols are enhanced with additional indicators in the form of:

- The REBA score (Rapid Entire Body

Assessment) is displayed in the form of numerical labels under each work activity. This score indicates the level of ergonomic risk from the operator's working posture and is color-coded: green (low risk), yellow (medium), red (high) (Hignett & McAtamney, 2000).

- The NASA-TLX index is displayed as a mini bar graph below the process information path, reflecting the operator's perception of mental workload (Hart & Staveland, 1988).
- Special symbols for Non-Utilized Talent, such as a yellow silhouette icon of a person, to indicate work areas with workers' cognitive potential that is not utilized.

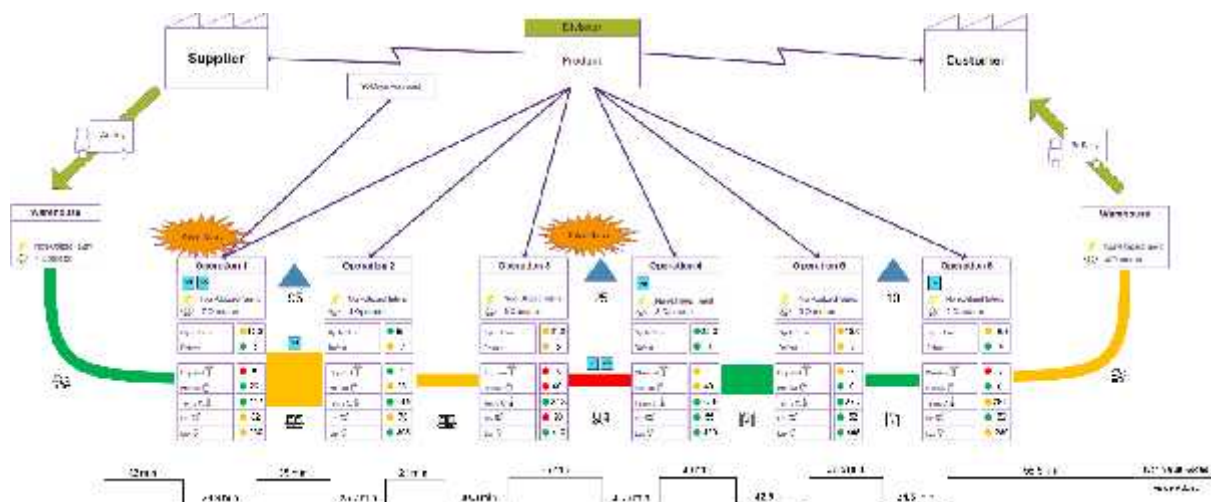


Figure 4: Extended-Value Stream Mapping

The internal reference to this structure refers to the visualization approach developed by Ergo-VSM (Jarebrant et al., 2016), which adds an ergonomics column below the process data box, as well as E-VSM (Garza-Reyes et al., 2018), which adds a workplace environment layer into the production symbol.

2. *Multilayer Design: Time Flow, Material Flow, and Ergonomic Flow*

Extended VSM is designed in a multilayer structure as shown by the Sankey-VSM approach (Nuss, Blengini, & Mayer, 2017), where material flow is depicted using thick arrows that indicate the intensity or frequency of movement. Meanwhile, workload and ergonomics data are added as a layer beneath the process box.

- The flow of time is depicted with a horizontal timeline, maintaining the format of lead time and cycle time.
- The flow of material is visualized through arrow paths that vary in thickness, indicating the amount or frequency of material movement.

3. *New Symbols and Icons for Human Factor and Environmental Aspects*

In order to expand the scope of analysis regarding waste in the production system, the Extended VSM visualization design developed in this research integrates additional symbols and icons to represent aspects of human factors and the work environment. To mark activities that have a high level of ergonomic risk based on assessment results using the REBA method, human body posture icons in red or orange are used as visual indicators. This symbol provides early warnings about activities that may lead to musculoskeletal disorders, as well as facilitating the process of identifying work areas that require ergonomic interventions. In addition, a brain-shaped icon or cognition symbol is inserted into the workflow processes that have high scores based on the NASA Task Load Index (NASA-TLX), to indicate excessive mental workload that can disrupt concentration, trigger stress, and reduce operator performance (Hart & Staveland, 1988). The placement of this icon not only provides quantitative information from the

psychosocial aspects of work but also encourages data-driven decision-making regarding training needs, job rotation, or task load adjustments. In order to encompass ergonomic aspects of the environment, Extended VSM also includes specific icons such as a sound symbol (for noise), a thermometer (for working temperature), and a light bulb (for lighting), which refer to physical factors in the work environment that can affect operator comfort and productivity (Garza-Reyes et al., 2018).

IV. CONCLUSION

This study proposed an Extended Value Stream Mapping (Extended VSM) framework that enhances conventional VSM by integrating ergonomic and cognitive assessments, enabling a more comprehensive identification of the eight types of waste in lean manufacturing. Through the incorporation of Stopwatch Time Study (STS), Rapid Entire Body Assessment (REBA), and NASA-TLX, the Extended VSM effectively maps not only operational wastes such as overproduction, waiting, transportation, overprocessing, and inventory, but also human-centered wastes including motion, defects, and non-utilized talent. The visual representation of Extended VSM integrates standard VSM symbols with ergonomic risk scores, mental workload indicators, and intuitive icons, providing a multidimensional diagnostic tool. This approach supports both efficiency improvement and worker well-being, offering significant value for labor-intensive manufacturing environments aiming for sustainable lean transformation.

V. RECOMMENDATION

Although the proposed Extended Value Stream Mapping (EVSM) framework successfully integrates time analysis, ergonomic assessments, mental workload evaluation, and environmental condition monitoring to comprehensively identify the eight types of waste, further research and development are recommended to enhance its applicability and effectiveness in industrial settings.

First, the integration of digital tools such as motion tracking sensors, wearable devices, and real-time data acquisition systems could significantly improve the objectivity and

automation of data collection. Combining Extended VSM with Industry 4.0 technologies may lead to the development of smart VSM systems that allow for continuous monitoring and instant feedback for waste elimination. Second, while this study incorporated human factors and environmental ergonomics, future improvements could include psychosocial aspects of labor, such as motivation, stress levels, and team dynamics,

which also influence performance and potential waste. Lastly, it is advisable to develop standardized visual notations for displaying ergonomic and environmental indicators within VSM to support consistency, comprehension, and cross-functional communication across different departments and stakeholders.

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