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ORIGINAL RESEARCH PAPER

Manufacturing Sustainability Assessment Comprising Physical and Mental Workload: An Integrated Modified SVSM and AHP Approach

Ahmad Mubin[1] · Dana Marsetiya Utama[1] · Reflieks Chandra Nusantara[1]

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Abstract
Sustainable manufacturing is critical today because it incorporates economic, environmental, and social factors into the manufacturing process. This research proposes a new framework for assessing manufacturing sustainability, including physical and mental workloads. The analytical hierarchy process (AHP) method is proposed to determine the weight of the triple bottom line (TBL) indicator. Each TBL indicator is evaluated for efficiency before being integrated into the sustainable value stream mapping (VSM) and traffic light system (TLS). Time, quality, raw materials, energy, water consumption, mental workload, and physical workload are the seven indicators used in this study. The framework proposed is applied to a case study in the plastics industry. The results show that the proposed framework can solve industrial problems. The manufacturing sustainability score in this industry is 75.06%, indicating that the company has moderate performance and needs improvement. In addition, this study includes implications and recommendations.

Keywords Sustainable manufacturing · Lean manufacturing · Value stream mapping (VSM) · Physical workload · Mental workload

Introduction

Manufacturing and logistics have direct environmental and social effects on air and water pollution (Sajan et al. 2017; Utama et al. 2022a, 2020a). This problem encourages the concept of sustainable development of manufacturing organizations to improve the quality of people's lives and impact the environment (Bogue 2014). Therefore, it is essential to evaluate the sustainability of manufacturing production lines and direct the strategy toward long-term growth (Swarnakar et al. 2021). Governments and non-governmental organizations require manufacturing companies to reduce environmental impacts and improve worker safety (Swarnakar et al. 2020). This company's economic, social, and environmental performance can be enhanced by applying sustainable manufacturing principles (Bogue 2014).

✉ Dana Marsetiya Utama
dana@umm.ac.id

1 Jurusan Teknik Industri, Fakultas Teknik, Universitas Muhammadiyah Malang, Jl. Raya Tlogomas No. 246, Malang, Indonesia

Numerous organizations have begun redesigning their existing manufacturing processes to be more environmentally friendly (Mapar et al. 2017). Sustainable manufacturing (SM) is one of the sustainability concepts applied in the manufacturing process to increase the company's effectiveness and efficiency (Machado et al. 2020) (Stock and Seliger 2016). According to Faulkner and Badurdeen (Faulkner and Badurdeen 2014), SM is a manufacturing process that minimizes adverse environmental impacts, is safe for workers, and has a positive long-term economic impact. Determining SM's performance necessitates manufacturers to conduct a manufacturing sustainability assessment (MSA). MSA can be used as a guide for enhancing the sustainability of manufacturing performance in organizations (Zhang and Haapala 2015).

In MSA, most researchers have developed methods for measuring corporate sustainability performance (Searcy 2012) (Feil et al. 2022), and studies proposed that an indicator framework is generally used at the corporate level (Moldavska and Welo 2019). Unfortunately, this framework provides no valuable visual information for internal company decision-makers, particularly those on the shop floor and workstation. Currently, assessing the sustainability performance of manufacturing processes on the shop floor is rarely investigated (Swarnakar et al. 2021) (Patalas-Maliszewska et al. 2022). Hence, the researcher must investigate MSA performance on the shop floor to describe workstation performance. Previous research, in general, proposes a framework that is still conceptual and not practical based on real-world cases (Swarnakar, et al. 2022). Several sustainability assessment frameworks and indicators can be used for MSA at the manufacturer level from an engineering perspective (Theng et al. 2021). As proposed by Lee et al. (Lee et al. 2014), several sustainability assessment frameworks and indicators can be used for MSA at the manufacturer level. Huang and Badurdeen (Huang and Badurdeen 2018) also proposed MSA at the plant and production line levels. Unfortunately, the proposed framework does not present a map of manufacturing sustainability in the production line. In fact, mapping the production line at each workstation aids decision-makers in making sustainable decisions. As a result, the industry necessitates a comprehensive methodology for mapping and measuring manufacturing sustainability performance at the production line level. The triple bottom line (TBL) is a popular sustainable indicator with economic, environmental, and social aspects (Jamil et al. 2020).

Value stream mapping (VSM) is utilized in production lines to map operational relationships to economic aspects (Singh et al. 2011). VSM can map value-added and non-value-added activities, beginning with receiving raw materials and ending with product delivery to customers (Vasconcelos Ferreira Lobo et al., 2020) (Dewi et al. 2021). In conventional VSM, environmental and social aspects are not considered in the mapping (Vinodh et al. 2016). In order to create a comprehensive map, economic, social, and environmental aspects must be incorporated into the mapping process. Brown et al. (Brown et al. 2014) introduced sustainable value stream mapping (SVSM), which was used to map aspects of TBL in the production line. Most researchers have also implemented SVSM in the furniture industry (Hartini et al. 2020) and manufacturing (Mishra et al. 2020) industries. Unfortunately, the SVSM methodology can only map each process stage on the shop floor, and the overall manufacturing sustainability performance score cannot be measured exhaustively. Therefore, Hartini et al. (Hartini et al. 2020) proposed a new MSA scoring framework based on an SVSM performance weighted analytical hierarchy process (AHP) for industrial furniture. To the best of our knowledge, only Hartini et al. (Hartini et al. 2020) research employs SVSM to calculate the MSA score. However, their research did not include ergonomic factors. Dominguez-Alfaro et al. (Dominguez-Alfaro et al. 2021) stated that ergonomic factors could improve productivity and company performance. However, this factor rare investigated by the researcher. In ergonomics, mental and physical workloads are factors that popular investigation. Measuring physical and mental workload is important because it harms workers and company performance (Rathore et al. 2022). The primary cause of employee stress is an excessive workload, and a high workload disrupts employee performance by causing loss of concentration, anxiety, and fatigue. Consequently, the physical and mental workload must be incorporated into the MSA score evaluation to determine the company's overall performance. In addition, industrial plastics have never been the subject of MSA research.

Based on these arguments, we can conclude that MSA research in the plastics industry must consider physical and mental workloads. Therefore, the following are the research goals (RG) discussed in this study:

RG1: Construct a new MSA framework that considers physical and mental workload.
RG2: Evaluate the performance of manufacturing sustainability in the plastics industry.

Based on the RG addressed in this research, indicators of sustainable manufacturing are set based on focus group discussion (FGD), including physical and mental workload. The selected indicators are mapped using SVSM and weighted to determine the level of importance of each indicator. Furthermore, the SVSM mapping results and indicator weights are used to calculate the manufacturing sustainability score index. Finally, a case study on the plastics industry is presented to evaluate MSA's performance. This study contributes significantly to science by providing a new reference for operations managers in assessing the performance of manufacturing sustainability. Furthermore, this study encourages practitioners and researchers to broaden the scope of their research in related fields and investigate the use of VSM sustainability and sustainability indicators for manufacturing sustainability assessment.

This article's structure is as follows: The MSA literature review is presented in "Literature Review". "The Proposed MSA Framework" introduces the proposed MSA framework. Data and case studies from MSA are described in "Data and Case Study". The results and discussion is presented in "Results and Discussion". "Implications and Recommendations" discusses the study's findings and recommendations. Finally, the article concludes with conclusions and recommendations for future research.

Literature Review

Table 1 is a summary of MSA studies. It demonstrates that most researchers include three dimensions of sustainability (economic, environmental, and social), referred to as the

Table 1 Summary of MSA studies

Study	Mapping	Rating score	Indicator selection process	Indicator	Workload	Tools	Applications
Brown et al. (Brown et al. 2014)	V	-	Theoretical	TBL	-	VSM	Electronic
Faulkner and Badurdeen (Faulkner and Badurdeen 2014)	V	-	Theoretical	TBL	V	VSM	Electronic
Helleno et al. (Helleno et al. 2017)	V	-	Theoretical	TBL	-	VSM	Cosmetic
Huang and Badurdeen (Huang and Badurdeen 2018)	-	V	Theoretical	TBL	-	AHP	Electronic
Garza-Reyes et al. (Garza-Reyes et al. 2018)	V	-	Theoretical	TBL	-	VSM	Mining
Soltani et al. (Soltani et al. 2020)	-	V	Theoretical	TBL	-	AHP, VSM, TOPSIS,	Gas bottle
Bait et al. (Bait et al. 2020)	V	-	Theoretical	TBL	-	Simulation, VSM	Manufacturing
Hartini et al. (Hartini et al. 2020)	V	V	Empirical	TBL	-	Delphi, AHP, VSM	Furniture
Swarnakar et al. (Swarnakar et al. 2021)	V	-	Empirical	TBL	-	VSM	Manufacturing
Patalas-Maliszewska et al. (Patalas-Maliszewska et al. 2022)	-	V	Theoretical	TBL	-	Fuzzy AHP, Decision tree	Manufacturing
Castiglione et al. (Castiglione et al. 2022)	-	V	Theoretical	Economic, environmental	-	MEIO	Manufacturing
Bhadu et al. (Bhadu et al. 2022)	-	V	Empirical	Economic	-	AHP	Manufacturing
Utama et al. (Utama et al. 2022b)	V	V	Empirical	TBL	-	Delphi, ANP, VSM	Furniture
This research	V	V	Empirical	TBL	V	AHP, VSM	Plastic industry

triple bottom line (TBL). According to Saavalainen et al. (Saavalainen et al. 2017), selecting appropriate TBL sustainability indicators in MSA is critical. Inappropriate indicators can provide information that is irrelevant to operational managers. Most previous research used theoretical indicators in the selection of indicators. As a result, the indicators used are less relevant to the case study. Furthermore, most researchers advocate for separate production flow mapping and MSA assessment. According to Hartini et al. (Hartini et al. 2020), companies can assess MSA in each process flow by mapping production flows based on TBL indicators. It can calculate the MSA score for the entire production process flow, which helps provide information to operations managers. However, mapping research and manufacturing sustainability assessments are rarely investigated.

Other gaps in previous research include the workload for physical and mental workers in the social aspect that is rarely included in mapping and assessing manufacturing sustainability. Furthermore, applying mapping and assessment of manufacturing sustainability is generally for manufacturing, electronics, and furniture. However, mapping and assessing manufacturing sustainability in the plastics industry has never been investigated. To fill the void, this study measures the performance of manufacturing sustainability based on process flow mapping in the plastics industry, which includes both physical and mental workloads. The mapping results from each process are used to calculate the score for sustainable manufacturing. The TBL indicators in this study were determined using empirical studies.

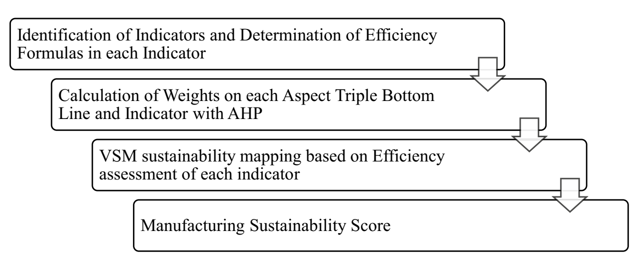


Fig. 1 The proposed MSA framework

The Proposed MSA Framework

This section presents the proposed MSA framework for assessing the manufacturing sustainability score. Figure 1 depicts the proposed MSA framework. Four steps are proposed to assess the manufacturing sustainability score, beginning with identifying TBL indicators and formulating the efficiency indicator formula. The second stage involves calculating indicator weights with AHP. The following stage maps the sustainability of VSM based on the efficiency assessment of each indicator, and the final stage is the manufacturing sustainability score assessment. The following subsection goes over the specifics of each stage.

Table 2 Manufacturing sustainability indicators

Aspects	Indicators	References
Economic	Time	Hartini et al. 2020)
	Quality	Hartini et al. 2020)
Environment	Material	Hartini et al. 2020; Helleno et al. 2017; Vinodh et al. 2014a)
	Energy	Hartini et al. 2020; Helleno et al. 2017; Vinodh et al. 2014a)
	Water consumption	Faulkner and Badurdeen 2014)
Social	Physical load index	Hollmann et al. 1999)
	Mental load index	Hart and Staveland 1988)

Identification of Indicators and Determination of Efficiency Formulas

The first step in MSA is the collection of TBL indicators. Experts use FGD to examine indicators based on a literature review on sustainable manufacturing topics. Identifying indicators from FGD related to TBL encompasses three aspects: economic, social, and environmental. Table 2 shows the indicators proposed in this study. Mental and physical workloads are regarded as indicators of manufacturing sustainability in the social aspects.

Furthermore, an efficiency formula must be developed to assess the performance of each indicator. The efficiency

Table 3 Efficiency Formula for each indicator

No. (i)	Indicators	Input	Formula	References
1	Time (minute)	TE= time efficiency VAT = time in value-added activities TT = total time $NVAT$ = time in non-value-added activities n = process to n	$TE = \frac{VAT}{TT}$ $VAT = \sum_{i=1}^{n} (VATi)$ $NVAT = \sum_{i=1}^{n} (NVATi)$ $TT = VAT + NVAT$	Hartini et al. (Hartini et al. 2020)
2	Quality	QE=quality efficiency ND=number of defects TM=total material	$QE = 1 - (\frac{ND}{TM})$	Hartini et al. (Hartini et al. 2020)
3	Material (kg)	ME= material efficiency VAM = material on activities that have added value TM = total material used $NVAM$ = material on activities that do not have added value n = process to n	$ME = \frac{VAM}{TM}$ $VAM = \sum_{i=1}^{n} (VAMi)$ $NVAM = \sum_{i=1}^{n} (NVAMi)$ $TM = VAM + NVAM$	Hartini et al. (Hartini et al. 2020)
4	Energy (kWh)	EE=energy efficiency VAE=energy in value-added activities $NVAE$=energy in no value-added activities ET=total energy n = process to n	$EE = \frac{VAE}{TE}$ $VAE = \sum_{i=1}^{n} (VAEi)$ $NVAM = \sum_{i=1}^{n} (NVAEi)$ $TE = VAE + NVAE$	Hartini et al. (Hartini et al. 2020)
5	Water consumption	IW= water efficiency AW = amount of water TW = total water	$WE = \frac{AW}{TW}$	Faulkner and Badurdeen (Faulkner and Badurdeen 2014)
6	Mental workload	NASA task load index ($NASA\ TLX$) $MLIE$ = mental load index efficiency	$MLIE = 1 - (\frac{\text{Score NASA TLX}}{56})$	Hart and Staveland (Hart and Staveland 1988)
7	Physic workload	Physical load index (PLI) $PLIE$=physical load index efficiency	$PLIE = 1 - (\frac{\text{Score PLI}}{100})$	Hollmann et al. (Hollmann et al. 1999)

formula for each indicator is determined using the FGDs reviewed in the literature. Table 3 shows the efficiency formula for each proposed indicator. Regarding the social aspect, the physical load index (PLI) is calculated using the PLI value proposed by Hollmann et al. (Hollmann et al. 1999). According to Faulkner and Badurdeen (Faulkner and Badurdeen 2014), the PLI method helps (Searcy 2012), the PLI method helps assess the risk of worker injury. This method monitors the employee's body posture while they work. The PLI method observed 15 body positions, with the PLI score assessment presented in Eq. (1).

$$\begin{aligned}\text{PLI score} = {} & 0.974T_2 + 1.104T_3 + 0.068T_4 \\ & + 0.173T_5 + 0.157A_2 + 0.314A_3 + 0.405L_3 + 0.152L_4 \\ & + 0.152L_5 + 0.549W_{u1} + 1.098W_{u2} + 1.647W_{u3} \\ & + 1.777W_{i1} + 2.416W_{i2} + 3.056W_{i3}\end{aligned} \tag{1}$$

Furthermore, the mental workload was assessed using the NASA task load index (NASA TLX) offered by Hart and Staveland (Hart and Staveland 1988). NASA TLX measures mental workload in several stages, including calculating the comparison of each indicator, event scoring, calculating indicator values, calculating weight workload (WWL), and calculating the average WWL. Furthermore, the TBL indicators chosen from the FGD were weighted to determine their significance. The following section describes the weighting of indicators.

Indicator Weighting with AHP

This section explains how the analytical hierarchy process (AHP) method was used to weight indicators. First, the indicators chosen from the FGD were weighted to determine their importance (Saaty 1990). AHP is a popular weighting decision-making procedure (Baroto et al. 2022; Utama et al. 2020b), which helps determine the weight of the TBL indicator based on the hierarchy (Amrina and Vilsi 2015).

FGDs are used in this section to perform pairwise comparisons of TBL aspects and indicators. The pairwise comparison scale used is a one to nine scale. A scale of 1 indicates that both indicators are equally important. Scales 2 to 9 indicate that the indicator is of low to high importance. a_{ij} denotes pairwise comparisons between indicators i and j. Equation (2) shows the pairwise comparison results using matrix A.

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{21} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} \tag{2}$$

The following step is to construct an A_1 matrix based on matrix A's normalization. The A_1 matrix is shown in Eq. (3), which is based on Eq. (4). It is used to calculate the eigenvalue and eigenvector from Eqs. (5) to (8), where W represents the eigenvector and W_i represents the eigenvalue. The symbol $\lambda_{\max}$ denotes the eigenvalue of the pairwise comparison of indicators. The final stage of the AHP method is to check for consistency. Equations (9) and (10) were used to calculate the consistency index (CI) and consistency ratio (CR). The AHP method considers the CR value of the pairwise comparison matrix to be consistent if it is less than 10%. The AHP method's indicator weight is used as an important score on the manufacturing sustainability score.

$$A_1 = \begin{bmatrix} a'_{11} & a'_{12} & - & a'_{1n} \\ a'_{21} & a'_{21} & - & a'_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a'_{n1} & a'_{n2} & - & a'_{nn} \end{bmatrix} \tag{3}$$

$$a'_{ij} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}} for\ i,j = 1,2,3,\ldots n \tag{4}$$

$$W = \begin{bmatrix} W_1 \\ W_2 \\ \vdots \\ W_n \end{bmatrix} \tag{5}$$

$$W_i = \frac{\sum_{i=1}^{n} a'_{ij}}{n} \tag{6}$$

$$W' = AW = \begin{bmatrix} W'_1 \\ W'_2 \\ \vdots \\ W'_n \end{bmatrix} \tag{7}$$

$$\lambda_{\max} = \frac{1}{n}\left(\frac{W'_1}{W_1} + \frac{W'_2}{W_2} + \cdots + \frac{W'_n}{W_n}\right) \tag{8}$$

$$CI = \frac{\lambda_{\max} - n}{n-1} \tag{9}$$

$$CR = \frac{CI}{\text{Random Index (RI)}} \tag{10}$$

Mapping with SVSM

This study also proposes the sustainability of VSM to map sustainability indicators in the proposed MSA. SVSM described the three aspects of TBLs to map the company's production line performance (Faulkner and Badurdeen 2014). First, each indicator's efficiency

Table 4 Pairwise comparison assessment for each aspect of TBL

	Economic	Environmental	Social
Economic	1	3	2
Environmental	1/3	1	1/2
Social	1/2	2	1

Table 5 Pairwise comparison assessment of each indicator on the economic aspect

	Time	Quality
Time	1	3
Quality	1/3	1

indicators and formulas are identified based on the previous stage. The efficiency value of each indicator is used to map SVSM. Furthermore, each TBL indicator's efficiency value is classified using the traffic light system (TLS) principle. Indicator mapping employs three distinct colors. The red indicates that the indicator score is still less than 60% of the target and needs improvement. Efficiency values ranging from 60 to 90% are highlighted in yellow, indicating that the current indicator needs to be improved. The percentage of indicators greater than 90% indicates that the indicator is on track (indicated in green) (Hartini et al. 2020). The results of each indicator's efficiency calculation are also used to calculate the manufacturing sustainability score (MSS), which is presented in the following subsection.

Manufacturing Sustainability Score (MSS) Assessment

MSS is calculated using the efficiency values and indicator weights generated in the previous subsection. The MSS can be calculated by multiplying the indicator score by the indicator weight (Huang and Badurdeen 2018; Silva et al. 2009). The formula for calculating MSS is shown in Eq. (11), where *Wi* represents the *i*-weight indicator as determined by the AHP method, and *Ei* represents the *i* indicator's efficiency score. *n* represents the number of indicators.

$$MSS = \sum_{i}^{n} Wi.Ei \tag{16}$$

As with efficiency indicators, the TLS principle is used to classify MSS. When the MSS score is less than 60%, the indicator is highlighted in red, indicating that it should be improved. Furthermore, a percentage of 60 to 90% (yellow) indicates that the current production line needs to be upgraded. The MSS score of more than 90% (green) indicates that the production line is running smoothly.

Table 6 Pairwise comparison assessment of each indicator on the environmental aspect

	Energy	Material	Water consumption
Energy	1	3	1
Material	1/3	1	1/3
Water consumption	1	2	1

Table 7 Pairwise comparison assessment of each indicator on social aspects

	Mental workload	Physical workload
Mental workload	1	2
Physical workload	1/2	1

Data and Case Study

The proposed framework is applied to a case study in the plastic industry in Malang, Indonesia. The manufacturing process in this industry includes receiving raw materials, mixing, extrusion, packaging, and storage. Five experts conducted a focus group discussion (FGD) to determine the weight of the indicators based on pairwise comparisons of each TBL aspect and indicator. Table 4 shows the results of pairwise comparisons for each aspect of TBL. Tables 5, 6, and 7 show pairwise comparisons for each indicator in each economic, environmental, and social aspect.

Data from 5 work stations (raw material receipt, mixing, extrusion, packaging, and storage) for each indicator was collected to assess the efficiency of the seven indicators of sustainable manufacturing. Table 3 shows the components of the data collected on the seven indicators used to calculate efficiency and SVSM. Furthermore, the efficiency and SVSM are used to calculate the MSS.

Results and Discussion

Indicator Weight Assessment Results

The results of the weighting of TBL aspects and indicators using the AHP process are presented in this section. Table 8 displays the weighted results of each indicator. In the pairwise comparison of each aspect of TBL, the consistency ratio is 0.009. Furthermore, the consistency of the ratio of indicators on economic, environmental, and social aspects is 0.087, 0.009, and 0.094, respectively. The consistency

Table 8 Weight of each aspect and indicator of TBL

Aspect	Weight aspects	Indicators	Weight indicators	Global weight
Economic	0.54	Time	0.75	0.40
		Quality	0.25	0.13
Environmental	0.16	Energy	0.44	0.07
		Raw material	0.16	0.03
		Water consumption	0.38	0.06
Social	0.30	Mental workload	0.67	0.20
		Physical workload	0.33	0.10

ratio's value is still less than 10%, indicating that the data is consistent.

The time indicator has the highest weighted value of 0.40 based on the indicator weighting. These findings indicate that the time indicator is critical to achieving sustainable manufacturing. Time indicators include cycle time, setup time, and downtime, which can be divided into value-added and non-value-added time (Vinodh et al. 2014b). Idle time, transportation time, and setup time are all non-value-added times (Zhu et al. 2020). If the manufacturing process fails, the time efficiency is very low. However, if the production process goes well, each workstation's time efficiency and efficiency are good (Ebrahimi et al. 2021).

Mental workload comes in second with a weight of 0.20. It demonstrates that workers' mental burden directly impacts productivity, affecting company performance (Sakthi Nagaraj and Jeyapaul 2021). In addition, workloads that are not ideal can reduce morale, affecting the company's performance in the long run. According to Sakthi Nagaraj et al. (Sakthi Nagaraj et al. 2019), one of the causes of poor employee performance is the mental workload in the workplace. As a result, businesses must pay close attention to their employees' mental workload.

The quality indicator is the third most crucial weight. Quality is the most critical indicator in sustainable manufacturing to ensure customer satisfaction. The findings of this study are consistent with those of Hartini et al. (Hartini et al. 2020). According to the findings of Lakatos et al. (Lakatos et al. 2021), product quality can influence customer satisfaction and purchase intent. As a result,

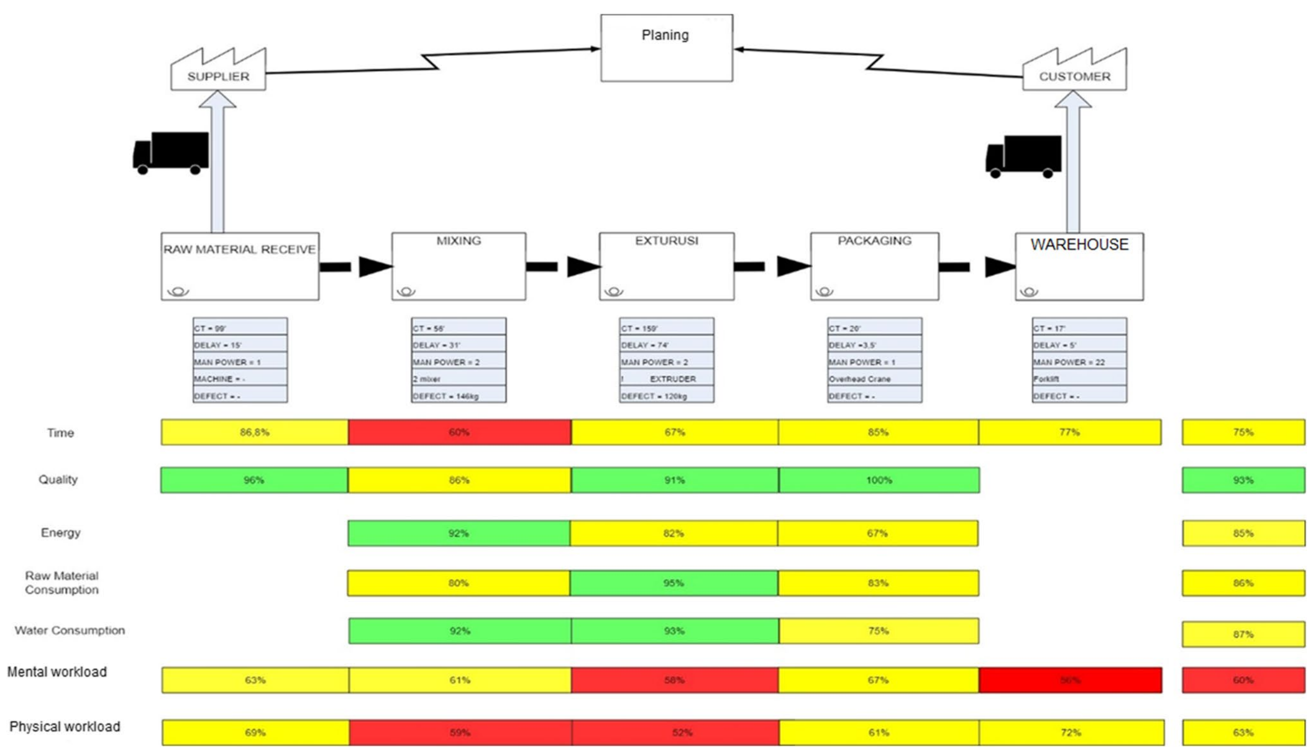


Fig. 2 Mapping results for SVSM

businesses must devise strategies emphasizing product quality as a competitive advantage (Tyagi et al. 2015).

Mapping by SVSM

Figure 2 depicts the results of the efficiency calculation and sustainable value stream mapping. The overall efficiency value on the time indicator is 75%, with a critical value of 60% occurring at the mixing workstation. The packaging workstation's energy efficiency value is 67%, indicating that it needs to be improved. The physical workload efficiency values at the mixing and extrusion workstations are categorized as poor, with values of 59% and 52%, respectively. Extrusion and storage workstations have the lowest efficiency values on the mental workload indicator, with 58% and 56%, respectively.

Manufacturing Sustainability Score Results

This section describes the MSS assessment results from a case study in the plastics industry. Table 9 shows the results of the MSS assessment. According to these findings, the plastics industry's MSS score is 75.06%. It indicates that this industry's MSS score is still in the yellow category, indicating that improvements in the production line are still needed. The assessment results of each indicator show that mental workload, physical workload, and time are three indicators with low-efficiency values. However, these three indicators carry significant weight in the MSS assessment. As a result, to improve MSS performance, decision-makers must focus on these three indicators.

Figure 3 depicts the scores for each aspect of TBL, showing that the economic, environmental, and social index scores are 42.85%, 14.27%, and 18.13%, respectively. The economic aspect contributed the most points to the MSS. These findings are consistent with those of Hartini et al. (Hartini et al. 2020). According to their findings, the indicators of time and quality accounted for the most significant score in the economic aspect.

Implications and Recommendations

This study contains several managerial insights that are both academic and practical. The implications of each point of view are discussed in detail below.

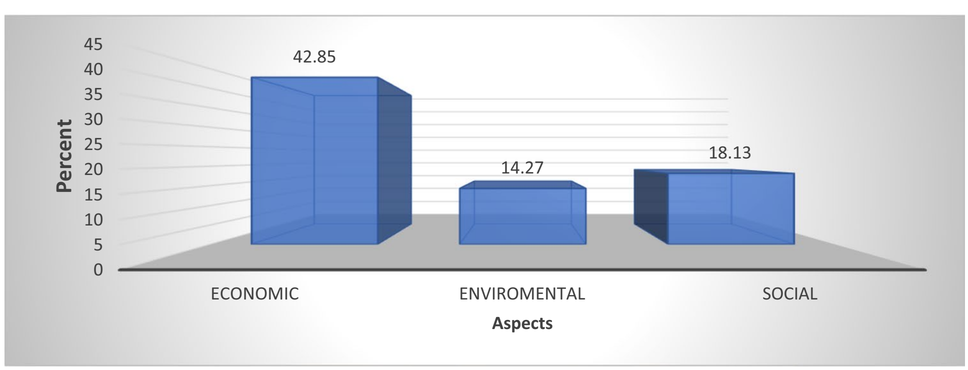
Implications for Academics

The production line is a component of the manufacturing system that contributes to economic, social, and environmental issues. Using this method, manufacturing companies can better assess manufacturing sustainability. The proposed method is intended to fill a gap in previous research that used the TBL concept but did not account for the physical and

Table 9 Manufacturing sustainability score assessment results

Aspect	Indicators	Indicators efficiency (%)	Global weight	Score indicators (%)	MSS
Economic	Time	75	0.40	30.32	75.06
	Quality	93	0.13	12.53	
Environmental	Energy	85	0.07	6.17	
	Raw material	86	0.03	2.39	
	Water consumption	87	0.06	5.71	
Social	Mental workload	60	0.20	11.89	
	Physical workload	63	0.10	6.24	

Fig. 3 The score for each aspect of TBL



mental workload. Decision-makers can measure TBL indicators involving physical and mental workload. Employee performance is affected in the long run by the physical and mental workload of workers on the assembly line. With this knowledge, it is clear that environmental, economic, and social factors all play an essential role in long-term development.

According to the study's findings, inefficient production lines in terms of TBL performance impact scores for sustainable manufacturing. In the plastics industry, social aspects, particularly physical and mental workload, contributed the most points after the weight of the time indicator. As a result of this research, research in other industrial sectors needs to be improved and explored more thoroughly. Previous research on sustainable manufacturing practices has not been thoroughly investigated, but it is a promising start.

Implications for Managers and Recommendations

This research also assists industrial managers interested in sustainable manufacturing practices to increase their chances of implementing sustainable manufacturing. In today's increasingly complex business environment, managers are encouraged to make the best decisions possible in order to increase the value of sustainable manufacturing. The following are some suggestions for improving performance:

a. The physical workload at the extrusion workstation is very low at 52%. The suggestion for workstation improvement is to evaluate and improve ergonomic work methods. According to Jarebrant et al. (Jarebrant et al. 2016), the ergonomic design of workstations can increase worker productivity and reduce stress. This proposal is expected to reduce worker injuries and even work accidents.
b. The extrusion workstation's mental workload indicator contributed 56% (red). Workload analysis is proposed as a way to improve this indicator. It is done in order for the map to have functional elements. According to Bommer and Fendley (Bommer and Fendley 2018), the workload analyses the mental load required to complete the work. The more work elements there are, the more complicated the work becomes. All of these factors contribute to a more significant mental workload.
c. The next indicator is time; the critical value of this indicator is 60% on the mixing workstation. Proposed solutions to this problem include evaluating workers to reduce waiting time and developing standard operating procedures to improve value-added time.
d. Companies must improve their performance on the energy indicator. Companies must incorporate the concept of energy efficiency into their scheduling. With proper scheduling, the company can save energy (Utama and Widodo 2021) (Utama and Primayesti 2022) (Utama et al. 2022c).

Conclusion

The primary goal of this research is to propose a new framework based on AHP and SVSM methods for assessing sustainable manufacturing performance in a production line. This new framework has been successfully proposed to assess the performance of manufacturing sustainability in the production process line. The proposed framework begins by selecting indicators, weighing indicators with AHP, evaluating the efficiency of each indicator, and mapping SVSM and TLS. Then, each indicator's weight and performance determine the manufacturing sustainability score. The case study uses this framework in the Indonesian plastics industry. The case study findings indicate that the manufacturing performance of the plastic industry could be improved. Furthermore, it demonstrates that the proposed method can solve real-world problems.

This study has several limitations, one of which is the lack of a dependency relationship between TBL indicators. Hence, more research is needed to account for the dependency relationship of TBL indicators to measure sustainable manufacturing performance more comprehensively.

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Data Availability All data generated or analyzed during this study are included in this article.

Declarations

Conflict of Interest The authors declare that no competing interests.

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