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Integrating Lean Six Sigma into waste management evaluation to enhance supply chain productivity: A case study

Pramudi Arsiwi[1*], Tita Talitha[2], Safarudin Ramdhani[3], Sahana Pramukti[4], Hanifah Septiani Wulandari[5], Elsa Diah Saputri[6], Fitri Indah Rahayu[7]
[1-7] Industrial Engineering Department, Engineering Faculty, Universitas Dian Nuswantoro, Indonesia

*Corresponding author E-mail: pramudi.arsiwi@dsn.dinus.ac.id

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Abstract

This study investigates how waste management performance at community-based 3R waste management facilities (CWMFs) can be improved to enhance environmental sustainability and supply chain productivity. As urban waste continues to increase, effective community-based systems are critical to reducing landfill dependency. The research, conducted at TPS3R DR Indonesia, employed Lean Six Sigma tools such as SIPOC (Supplier-Input-Process-Output-Customer), process flow mapping, and fishbone analysis, to identify inefficiencies and their root causes. The analysis revealed that waste management efficiency reached only 60%, leaving approximately 2,400 kg of waste unprocessed daily. Key bottlenecks were found in equipment maintenance, work methods, staff awareness, and monitoring systems. Implementing structured improvement approaches such as 5S, 5W1H, and standardized operating procedures (SOPs) could enhance recovery efficiency by up to 20%. These interventions not only reduce residual waste but also improve workflow consistency and environmental performance. The study's scientific contribution lies in demonstrating the applicability of Lean Six Sigma within community-based waste systems, providing a replicable model for integrating process improvement methodologies into local sustainability practices.

Keywords: Environment, Lean Six Sigma, Supply chain productivity, Sustainability, Waste management

1. Introduction

Waste management is a crucial challenge in every country due to the ever-increasing volume of global waste, so a policy is needed to achieve Zero Waste through integrated waste management [1]. To support the achievement of Zero Waste, it is important to formulate a sustainable practice strategy to support the transition to a circular economy [2]. Regarding waste management, there are five sequences that can be carried out: reducing waste at its source, reusing materials, recycling, energy recovery, and landfilling [3]. Waste management innovations have been proven to support a circular economy [4] and generate profits from transforming waste into value-added commercial products [5].

Despite various waste management initiatives, Indonesia has not yet managed to effectively manage its waste, resulting in very high levels of residual waste and environmental risks. Community-based waste management facilities such as the 3R Waste Management Facility (TPS3R) have emerged as a strategic solution to improve waste management effectiveness and reduce dependence on landfills. Optimizing the management of a good supply chain network is important to transform waste into more valuable products [6]. Furthermore, waste-to-energy technology can also be used as an alternative to optimize waste management to reduce dependence on landfills by converting waste into energy [7]. However, the reality found during observations and discussions with relevant parties shows that the operational effectiveness of waste management is often hampered by inadequate standardization, a limited workforce, and inefficient waste distribution systems.

Lean Six Sigma (LSS) through the DMAIC (Define, Measure, Analyze, Improve, Control) framework offers a structured approach to addressing waste management issues by minimizing waste, reducing process variation, and increasing productivity. Several previous studies have demonstrated the effectiveness of LSS in various manufacturing and service sectors, highlighting the potential to improve waste supply chain performance and support circular economy principles. LSS has been shown to be effective in reducing waste in food manufacturing processes, significantly improving quality and efficiency [8]. The integration of Lean and Six Sigma principles has also been shown to increase supply chain productivity and minimize waste in waste management systems [9]. The LSS approach has also proven important in transforming waste supply chains into more efficient systems, although empirical studies in landfill facilities have not been widely conducted [10]. Value stream mapping (VSM) is one of the tools with the highest level of use and impact in LSS implementation in industry [11]. Several researchers have also proven that integrating LSS with VSM has been proven to be successful in increasing operational efficiency at Industry 4.0 workstations [12] and providing room for efficiency improvements in waste management in the steel industry [13]. In addition, VSM integration with SIPOC and fishbone diagram in the DMAIC context has also been implemented in the food industry sector as a comprehensive initial analysis tool for quality control [14].

In Semarang City, community-based waste facilities (TPS3R) process only around 60% of the total incoming waste, leaving approximately 2.4 tons unprocessed daily. Operational inefficiencies, such as irregular sorting, lack of standard procedures, and limited data monitoring, have contributed to low process performance. Therefore, integrating Lean Six Sigma into waste management evaluation is essential to systematically identify and minimize process waste while improving supply chain productivity.

LSS has been proven to increase supply chain effectiveness in the manufacturing industry [15], support the implementation of green manufacturing [16], and reduce environmental impacts along the supply chain [17]. LSS has also been proven to contribute to supporting the achievement of Green Supply Chain Management [18], [19]. Although LSS is primarily applied in industrial settings, its structured problem-solving framework can also enhance the operational discipline and sustainability performance of community-based waste systems. Prior studies have demonstrated that adapting LSS tools to environmental contexts helps reduce waste generation and improve service efficiency in public sectors.

The findings of this study are expected to provide insights and contributions in optimizing more effective waste management strategies to realize sustainable urban development, which is in line with the principles of a circular economy and efforts to increase national productivity.

2. Research method

This study uses a case study approach to evaluate the effectiveness of Lean Six Sigma (LSS) in improving waste management processes and increasing supply chain effectiveness. LSS integration has been shown to support the effectiveness of sustainable supply chains [20] and can improve operational efficiency in the context of global supply chains [21]. The methodology used follows the DMAIC (Define, Measure, Analyze, Improve, Control) framework, which is a structured and data-driven reference that has been widely applied in various industrial sectors for continuous process improvement.

2.1. Research framework

This research consists of five sequential phases following the Lean Six Sigma DMAIC framework, as presented in Figure 1:

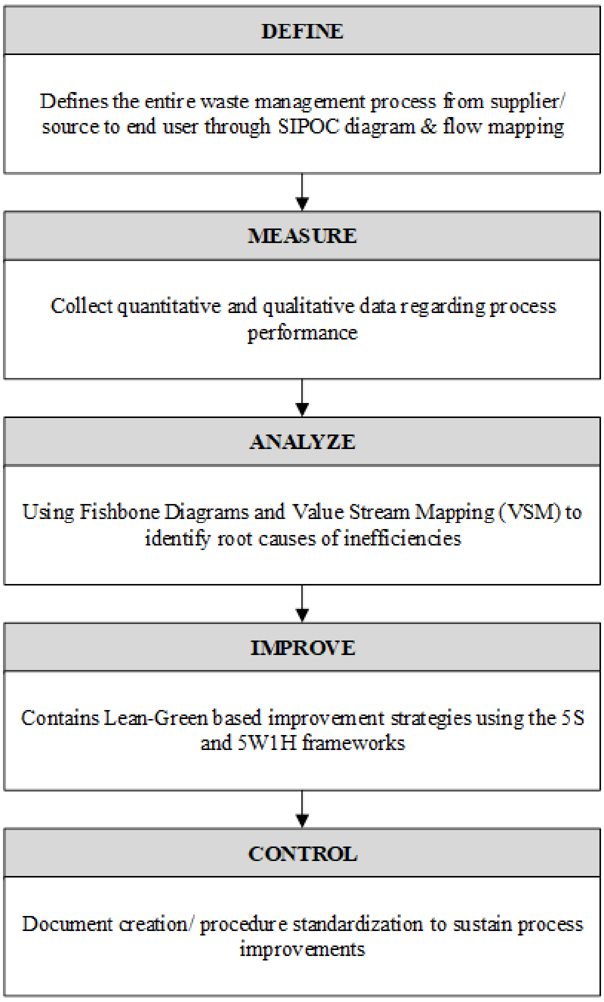

Figure 1. Research framework of Lean Six Sigma integration

A detailed explanation of the research framework presented in Figure 1 is provided as follows.

1. Define: defines the entire waste management process from supplier/source to end user through SIPOC (Supplier, Input, Process, Output, Customer) diagram as the initial phase of the DMAIC framework [22]. The SIPOC diagram in the Define phase can also be used to identify inputs that need to be improved in order to achieve improvements in the process and output [23]. The flow mapping process is also used in this phase to understand the process as a whole [24], build a process baseline [25] and describe the details of the steps in the main process in the SIPOC diagram [26], [27], to prepare metrics in the Measure phase [28].
2. Measure: collect quantitative and qualitative data regarding process performance, including waste volume, collection frequency, process time, and material flow.
3. Analyze: using two approaches: fishbone diagrams and value stream mapping (VSM). Fishbone diagrams are used to identify the root causes of various variables in waste management [29], [30]. Meanwhile, the integration of the value stream mapping model is used to support the analysis of continuous process improvement in waste management [31].
4. Improve: contains Lean-Green-based improvement strategies to increase the sustainability and effectiveness of the supply chain in waste management. The development and implementation of targeted improvement strategies use the 5S framework (Sort, Set in order, Shine, Standardize, Sustain) to build a

culture of continuous improvement [32]. Meanwhile, the 5W1H framework (What, Why, Where, When, Who, How) is used to optimize resources and redesign more effective and efficient process flows [33].

5. Control: is the phase of determining document creation/procedure standardization [34], emphasizing control mechanisms [35] and key performance indicators (KPIs) to maintain performance [36] and sustain process improvements [37] and maintain sustainable supply chain performance. Established standard operating procedures (SOPs) must be adhered to [38] and implemented properly [39] to maintain continuous process improvement [40]. So this phase emphasizes standardization, process control, and deviation monitoring [41].

2.2. Data collection

This research uses primary and secondary data collection methods with the following details:

- Primary data: data collected through direct field observation, interviews with the head and management team of TPS3R, and direct measurements related to the waste management process at the TPS3R DR unit in Semarang City. Primary data were collected through daily waste volume measurement and semi-structured interviews with six TPS3R officers and two management staff. Measurement accuracy was validated by comparing field records with monthly operational reports.
- Secondary data: data collected indirectly through TPS3R operational reports, TPS3R waste management performance history, regulatory documents, and other literature relevant to Lean Six Sigma in waste management and supply chain management.

2.3. Case study context

The case study was conducted at one of the community-based waste management facilities in Semarang City, Indonesia, namely TPS3R DR. The TPS3R carries out several activities, namely municipal waste processing through the stages of sorting, recycling, and reuse. This unit serves as a representative model for decentralized waste management systems in urban areas. The focus of this case study is to identify inefficiencies in operational flows and improve supply chain effectiveness through Lean Six Sigma interventions.

2.4. Data analysis tools

To support data-based decision making, several analytical tools and techniques were used in this research, namely:

1. SIPOC diagram: to determine the system scope and identify the main process elements [42], [43].
2. Fishbone diagram: to map and visualize potential root causes of problems [44], [45].
3. Value stream mapping: to map process flows and detect inefficient processes [46], [47].
4. 5S (Sort, Set in Order, Shine, Standardize, Sustain): to organize the workplace, cut down on inefficiencies, and keep the environment clean and structured for smoother operations [48], [49].
5. 5W1H (What, Why, Where, When, Who, How): provides a simple framework to understand problems from all angles and turn them into clear, actionable solutions [50].
6. Standard operating procedures (SOPs): offer clear guidelines that reduce variation, improve accountability, and ensure improvements last over time [51], [52].

3. Results and discussion

3.1. Overview of current waste management performance

The DR Waste Management Facility (TPS3R DR) serves as a waste management facility at the sub-district level, serving the Pedurungan Lor area and its surroundings. Incoming waste comes from various sources, including households, banks, offices, and universities, with the majority of the waste being household waste. The waste collection system utilizes a combination of three-wheeled motorcycles and pickup trucks, operated by four field officers, and involves community participation through an independent drop-off system.

The initial processing process includes manual sorting of organic and inorganic waste. Organic waste is processed into compost and animal feed, while inorganic waste is processed differently depending on its economic value. Valuable waste, such as bottles, is sold to collectors, while non-economic plastic is incinerated to ash and used as a mixture for brick making. Residual waste that cannot be processed independently is transported to the Jatibarang Landfill. Processed products are then marketed to the community, while residual waste is handled by authorities. For reporting, incoming and outgoing waste volumes are recorded, and operational reports are then submitted to the sub-district office. Figure 2 shows how community-based waste management turns everyday waste into valuable resources. Starting from households and offices, waste is sorted, collected, and processed—organic materials become compost or animal feed, while inorganic waste is recycled. Through monitoring and reporting, the system not only reduces landfill waste but also builds community awareness and responsibility for a cleaner, more sustainable environment.

Figure 2. Waste management flow in TPS3R DR

Although the system has been running quite well, initial analysis shows that there are problems. in the waste management process at TPS3R DR, Waste management is not yet effective and efficient, which has the potential to trigger environmental pollution. These problems include suboptimal sorting because it is still done manually without technological support, and some economically valuable waste is still mixed with residue. Then, processing is still limited, namely, the capacity for compost and animal feed processing is not balanced with the volume of waste input, so some organic waste still ends up as residue. The effectiveness of the management process is still less than optimal, so the proportion of residual waste disposed of to the landfill is still relatively high, with an average weight of residual waste of 2000 kg per month, from a total input of around 6000 kg per month. Inorganic waste processing also still faces obstacles due to the combustion process, which is not environmentally friendly. Furthermore, the distribution of processed products is not yet integrated because it is still local in scale, resulting in less than optimal profit potential. Regarding the control and evaluation system, it is also not comprehensive, because it is still limited to volume and sales aspects of waste management, but has not comprehensively measured environmental impacts, operational efficiency, and stakeholder satisfaction. These findings indicate that community-based waste management facilities often encounter numerous operational constraints in their implementation due to limited resources and standardization.

3.2. Define phase findings – SIPOC analysis and flow mapping

The SIPOC (Supplier-Input-Process-Output-Control) diagram maps the entire waste processing process at the TPS3R DR, from the source/supplier producing the waste to the end-customer or recycling partner. The results of a detailed analysis of the waste chain supply from upstream to downstream are shown in Table 1, While the process flow diagram is shown in Figure 3.

Table 1. SIPOC diagram

S (Suppliers)	I (Inputs)	P (Process)	O (Outputs)	C (Customers)
A. Households: specifically in the area of Pedurungan Lor Village. B. Bank: Bank Central Asia (BCA) BSB branch. C. Offices: around the TPS service area. D. University: University of Semarang (USM).	A. Organic waste: food scraps and kitchen waste. B. Inorganic waste: plastic bottles, cardboard, and residual waste.	**Waste Collection Process** A. Transportation and fleet: collection is done using 8 units of three-wheeled motorcycles and 1 pick-up truck. B. Collecting staff: there are 4 TPS3R DR employees assigned to collect waste. C. Drop-off system: residents directly deliver their waste to the TPS (independent drop-off). **Waste Processing/Treatment** A. Organic waste is processed into animal feed and compost, while inorganic waste is processed based on its type. B. Plastic bottles and cardboard that are considered economically valuable are sold to collectors. C. Plastic with no economic value is burned to become an ash product. D. Residual waste (that cannot be processed) is temporarily stored before being disposed of at the Final Disposal Site (TPA).	a. Organic: animal feed and compost b. Inorganic goods with economic value c. Ash products d. Residual waste	A. General public B. Scrap collectors C. Companies D. Final Disposal Site (TPA) (the authorities)

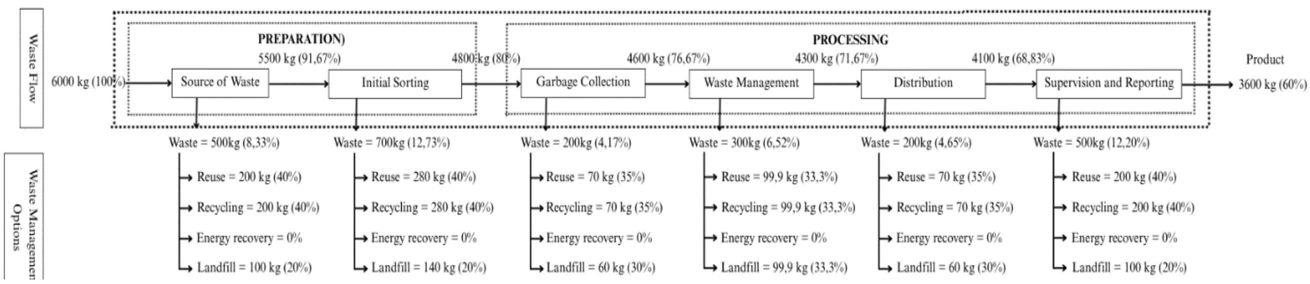

Figure 3. Process flow diagrams

The SIPOC analysis in Table 1 provides a clearer picture of the waste management process at the Semarang Waste Management Facility (TPS3R) in Semarang, from the source of the waste to who ultimately benefits. The waste generated comes from several sources, including households, offices, banks, and universities, producing various types of waste. The system includes a mixture of organic waste, such as food scraps and kitchen waste, and inorganic waste, such as plastic, bottles, cardboard, and other waste. This mix makes sorting the waste stream an appropriate step for effective downstream waste management. The waste management process takes place in two main stages. First, waste is collected by TPS officers using small three-wheeled vehicles and pick-up trucks, or by residents using a drop-off system. Second, the waste is processed: organic materials are converted into compost or animal feed, recyclables are sold to collectors, non-recyclable plastics are incinerated into ash, and unprocessed waste is temporarily stored before being sent to the final disposal site. From these processes, the system produces outputs with social and economic value. Communities benefit from the compost and animal feed, collectors and companies derive value from the recycled materials, and local governments manage the final disposal of the residue.

In Figure 3, the process flow diagram shows that from approximately 6000 kg of daily waste, approximately 3600 kg (±60%) of processed products are produced. Then approximately 2400 kg (±40%) is lost at various stages, although not all of it becomes pure waste. Of the total amount of unprocessed waste, most of it can still be reused, around 850 kg (±35.4%), and recycled 850 kg (±35.4%), and the remaining small part is burned to ash, and most of it is disposed of in the final disposal site. Overall, the SIPOC framework shows that this community-based waste management system has been implemented in a fairly structured manner and has created significant value. However, there is still room for improvement, particularly in reducing the amount of residual waste going to landfills. Meanwhile, the Process Flow Diagram shows that there are still gaps in process efficiency, especially at the collection and sorting stages, where the majority of waste still ends up in landfills.

3.3. Measure phase findings – fishbone diagram and VSM

The Measure phase focuses on obtaining a comprehensive overview of the waste management system's performance, both quantitatively and qualitatively. Its primary objectives are to establish a performance baseline, identify critical process points, and quantify the magnitude of problems that require priority improvement. This stage combines two approaches, namely the fishbone diagram and value stream mapping, as seen in Figure 4 and Figure 5.

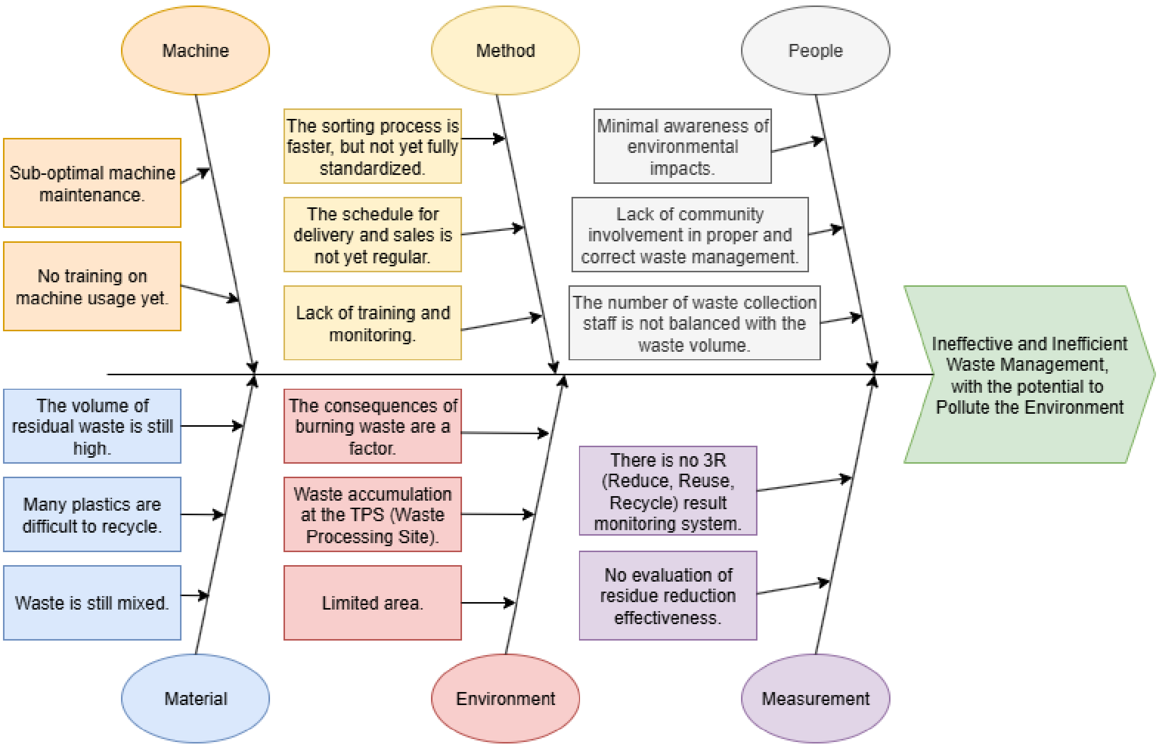

Figure 4. Fishbone diagram

Figure 4 highlights several interconnected root causes behind ineffective and inefficient waste management. Key issues stem from poor machine maintenance, unstandardized methods, and limited staff awareness, leading to unprocessed and mixed waste. Environmental and monitoring gaps, such as the absence of a proper 3R evaluation system, further contribute to pollution risks and reduced overall performance.

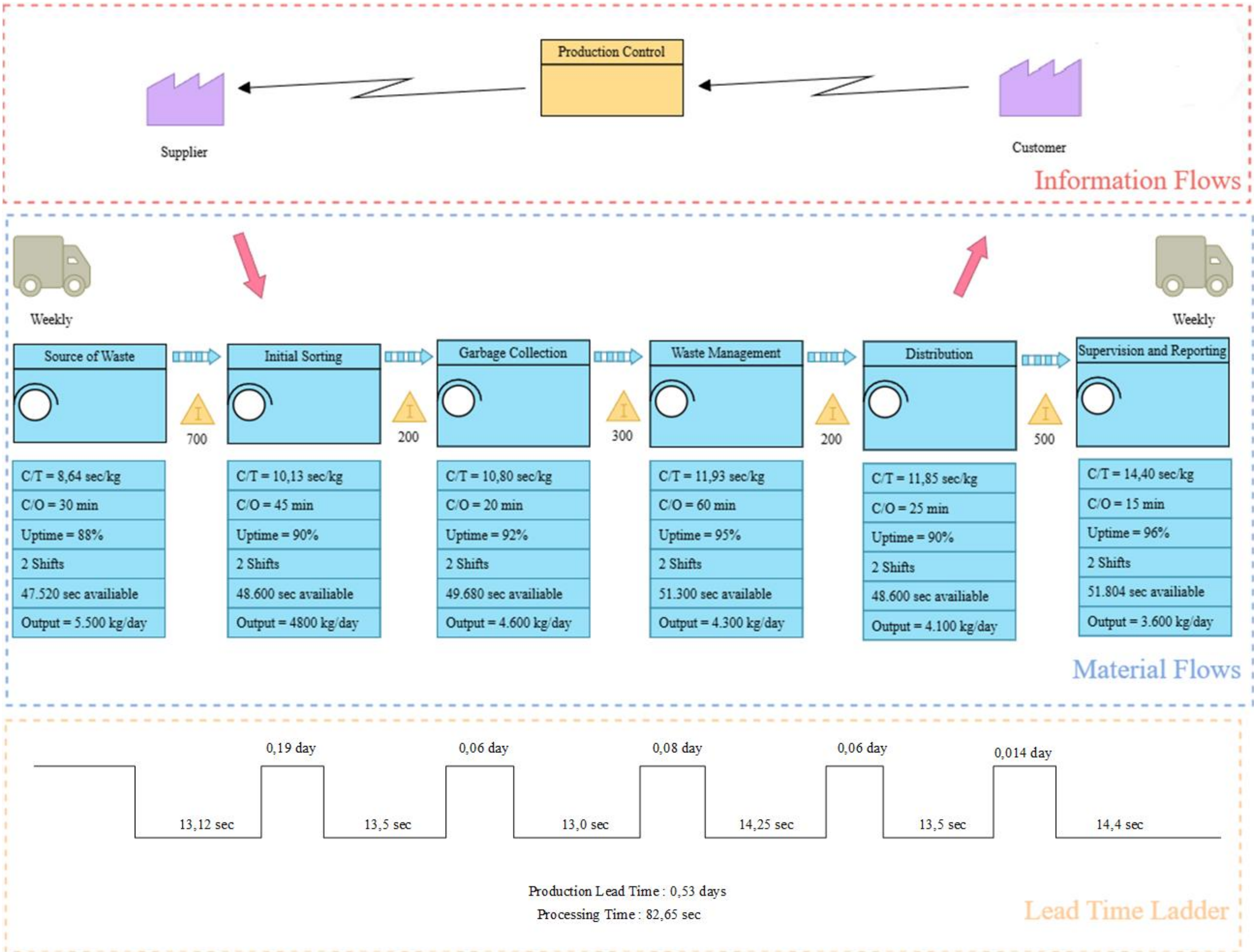

Figure 5. Value stream mapping

From the value stream mapping (VSM) results in Figure 5, it can be seen that of the total 6,000 kg of waste per day entering TPS3R, only around 3,600 kg (60%) is successfully recycled through the collection, sorting, management, distribution, supervision, and reporting processes. Meanwhile, around 2,400 kg (40%) is still wasted as residue, plastic waste that is difficult to recycle, or ends up in landfills and incinerators. Process time measurements show that the system is relatively efficient, with a total lead time of 0.53 days and a processing time of 82.65 seconds/kg of waste. However, there is a significant bottleneck at the supervision and reporting stage, which has the highest cycle time of 14.40 seconds/kg.

Interestingly, even though the distribution and supervision stages do not directly process waste, there is a material loss of around 200–300 kg per day, or around 5–8% of distribution output. This material loss is more influenced by managerial and market factors than technical issues. For example, some compost and animal feed are not distributed due to limited distribution networks, resulting in the products piling up at the Waste Management Site (TPS3R), their quality declining, and ultimately being deemed unsaleable. Similar cases also occur when collectors reject low-quality products, such as immature compost or recycled plastic that does not meet standards.

Furthermore, there are also administrative losses. Data shows a discrepancy between the amount distributed (3,900 kg/day) and the amount recorded as output (3,600 kg/day). This discrepancy indicates a weak recording, monitoring, and reporting system. In other words, losses at the distribution-supervision stage are more reflective of managerial gaps in areas such as quality control, documentation, and market access. Therefore, future improvements should focus on improving product quality, strengthening the monitoring system, and expanding the distribution network to ensure that processed products are fully absorbed and do not become residue.

Fishbone Diagram Results in Figure 4 confirmed that the root of the problem stems not only from technical factors, but also from managerial and systemic ones. From a machine perspective, maintenance is suboptimal, and operator training is lacking. From a method perspective, the sorting process is fast but not standardized, while distribution and sales schedules remain irregular. Human resource factors also play a significant role, ranging from low environmental awareness, minimal community involvement, to a workforce that is disproportionate to daily waste volume. From a material perspective, non-recyclable plastic is the main contributor to residue, with significant volumes generated daily. This condition is exacerbated by environmental factors such as limited land and the risk of waste accumulation at landfills (TPS). Meanwhile, from a measurement perspective, a monitoring system for the results of the 3Rs (Reduce, Reuse, Recycle) is not yet available, and the effectiveness of residue reduction has never been evaluated.

By combining the findings from VSM and fishbone, it can be concluded that the system efficiency is still low (60%), with quite large material losses (2,400 kg/day), where the details presented in Table 2. From this, it can be concluded that the TPS3R problem is not only a technical issue, such as fleet or machinery, but also concerns public awareness, workforce involvement, operational standards, and market access for recycled products. The results of this measurement will form a crucial foundation for the next stage, Analyze, so that improvements can be focused on the most impactful areas.

Table 2. Summary of measure phase results

Process Stage	Input (kg/day)	Output (kg/day)	Loss/Residue (kg/day)	Efficiency (%)	Key Issues (Fishbone)
Source of Waste	6,000	5,500	500	91.67%	Public awareness is low, sorting from the source is not yet consistent
Early Sort	5,500	4,800	700	87.27%	Fast but not standardized process, limited human resources at high volumes
Collection	4,800	4,600	200	95.83%	Limited fleet, irregular pick-up schedule
Management	4,600	4,300	300	93.48%	High volume of residue, non-recyclable plastics dominate
Distribution	4,300	4,100	200	95.35%	Limited market, unstable selling price
Supervision & Reporting	4,100	3,600	500	87.80%	cycle time (14.4 seconds/kg), weak monitoring system
Total System	6,000	3,600	2,400	60.00%	Technical factors (fleet & machinery), material (high residue), managerial (monitoring)

3.4. Analyze phase finding – 5S & 5W1H

The implementation of 5S at TPS3R DR shows that some principles have been implemented, but are not yet consistent. According to

Table 3, in the Seiri and Seiton stages, the separation and arrangement of sorting equipment have been carried out, but have not fully followed standards, so that confusion often occurs in the field. The Seiso stage related to cleanliness is in place, but is not routinely scheduled, which makes the work area less than optimal. Furthermore, Seiketsu and Shitsuke are the biggest challenges: there is no standard operating procedure (SOP), monitoring system, or reward system that encourages workers to maintain good habits. This condition indicates that 5S has not yet functioned optimally as a sustainable work culture.

Table 3. 5S

Step	Implementation at DR Waste Processing Site (TPS 3R)
Seiri (Sort)	Separate tools and waste that are truly useful.
Seiton (Set in Order)	Arrange sorting tools and containers according to the type of waste.
Seiso (Shine)	Schedule routine and periodic weekly cleaning of the TPS area.
Seiketsu (Standardize)	Standardize the sorting SOPs and collection schedules.
Shitsuke (Sustain)	Instill the 5S habit and create a reward system for workers to maintain 5S.

Based on the 5W1H results in Table 4, the main problem lies in the inefficiency of the sorting and distribution processes. The main causes are the absence of standard operating procedures (SOPs), inadequate training, and weak management. This problem occurs in the sorting area of TPS 3R. DR (Recycling and Recovery) takes place daily after waste collection. The parties involved are the staff and the management team, but their roles are not yet optimal. The proposed solution is to develop clear standard operating procedures (SOPs), provide regular training, and establish a more structured monitoring and task allocation system. This will improve process efficiency, improve product quality, and minimize the risk of material loss.

Table 4. 5W1H

Question	Answer
What?	The sorting and distribution process is not efficient.
Why?	Because there are no SOPs and training, as well as a lack of management.
Where?	The sorting area of TP S3R DR, Semarang
When?	Every day, after waste collection
Who?	The TPS staff is responsible for sorting and the management team.
How?	Create SOPs, provide routine training, and implement a structured division of tasks (monitoring).

3.5. Control phase findings – standardization and monitoring

This phase is used to ensure that improvements made can be maintained through ongoing monitoring and standardization, with the aim of maintaining consistency and sustainability of the initiated improvements. Recommended steps are presented in Table 5.

Table 5. Standard operating procedure (SOP)

Activity	Control Tools / Standards
Process monitoring	Use a daily checklist for 5S activities (collection and sorting schedules).
Performance evaluation	Create performance indicators (amount of waste processed, compost quality, etc.).
Internal audit	Conduct an audit once a month on SOPs and implementation performance.
Periodic training	At least once every 3 months for new/old staff.
Visual management	Install information boards, color zones, and visual SOPs.

In the Control phase, the primary focus is on ensuring the consistency of the improvements made. This is achieved through several key steps, as summarized in Table 5, such as using daily checklists to monitor 5S activities, evaluating performance using measurable indicators (e.g., the amount of waste processed and the quality of compost), and monthly internal audits to ensure SOPs are being effectively implemented. Additionally, regular quarterly training for both new and existing staff helps maintain skill standards, while visual management, including information boards and color zones, makes work instructions clearer in the field. Overall, this control system emphasizes a balance between daily monitoring, performance evaluation, periodic audits, ongoing training, and visual communication. If implemented consistently, these five elements will strengthen the sustainability of improvements at the TPS3R, reduce the potential for backsliding, and increase accuracy and consistency in waste management.

3.6. Discussion

This study demonstrates that applying Lean Six Sigma through the DMAIC framework provides valuable insights into the performance of community-based waste management systems. The Measure phase revealed that although TPS3R DR processes approximately 6,000 kg of waste per day, only 3,600 kg (60%) is recovered into usable products, while the remaining 2,400 kg (40%) is lost as residuals or rejected materials. Losses are particularly significant at the initial sorting stage (700 kg/day), supervision and reporting (500 kg/day), and at the source (500 kg/day), underscoring the importance of upstream consistency and effective monitoring.

Further comparison with previous studies shows that the efficiency level of TPS3R DR (60%) is notably lower than the performance improvements reported in earlier Lean Six Sigma applications. For example, Widiwati et al. [8] demonstrated that implementing LSS in food manufacturing increased process quality and reduced waste significantly, while Achillas and Vlachokostas [9] reported that integrated waste management systems supported by LSS principles can substantially enhance circular economy performance. Similarly, Yu et al. [10] highlighted that technological and managerial integration can reduce residual waste and improve overall system efficiency. In contrast, the present study reveals that community-based waste facilities face unique bottlenecks, such as irregular sorting, limited monitoring capacity, and unstable recycling markets, that are less prominent in industrial settings. These findings extend earlier LSS research by showing that, although LSS tools remain effective, their impact is strongly shaped by local operational constraints. This study, therefore, contributes new empirical evidence that adapting LSS to decentralized waste systems requires balancing technical improvements with community engagement, capacity building, and standardized operational procedures.

The analysis further highlights that inefficiencies are not solely technical but strongly rooted in managerial and systemic issues. Inconsistent source-level separation, lack of standardized operating procedures, insufficient monitoring, and unstable recycling markets all contribute to reduced efficiency. By integrating tools such as fishbone, VSM, 5S, and 5W1H, the research identified targeted solutions, ranging from the introduction of clear SOPs, capacity-building training for workers, and continuous monitoring, to strengthening distribution networks for recycled products. The proposed SOPs emphasize waste segregation procedures, regular performance monitoring, and preventive maintenance schedules. Although the SOPs have not yet been fully implemented, simulation-based evaluation indicates that their adoption could further improve operational efficiency by approximately 10%. These findings emphasize that Lean Six Sigma, traditionally applied in manufacturing, is equally powerful in enhancing the productivity and sustainability of community-based environmental management systems.

This study was limited to one community-based waste facility. Therefore, future research could expand comparative analysis across multiple TPS3R units to improve generalizability. The proposed Lean Six Sigma approach can be utilized as a structured tool for managers to standardize processes, monitor efficiency, and integrate data-driven decision-making in community-based waste management operations.

4. Conclusions

The research concludes that TPS3R DR's current waste management system operates at only 60% efficiency, with significant material loss of 2,400 kg/day. The critical bottlenecks, sorting, supervision, and source-level waste separation, highlight the need for systemic improvements that go beyond technical fixes. By employing

Lean Six Sigma tools, particularly 5S and 5W1H, the study proposes actionable strategies including standardization through SOPs, regular training and capacity building, stronger monitoring and evaluation mechanisms, and expanded market linkages for recycled products.

In practical terms, the integration of Lean Six Sigma into waste management not only improves supply chain productivity but also enhances environmental performance by reducing landfill dependency and maximizing resource recovery. This demonstrates the potential of Lean Six Sigma as a replicable framework for advancing sustainable waste management in other community-based settings.

Declaration of competing interests

The authors declare that they have no financial interests or personal relationships that could influence the results or interpretation of this study. This study is based entirely on objective data and analysis related to the evaluation of waste management at the TPS3R DR in Semarang City.

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Author contribution

Pramudi Arsiwi, Tita Talitha, and Safarudin Ramdhani were responsible for the research concept development and development of the outputs, while Sahana Pramukti, Hanifah Septiani Wulandari, Elsa Diah Saputri, and Fitri Indah Rahayu assisted in field data collection and data analysis. Pramudi Arsiwi is also responsible for the journal output of this research as the corresponding author.

Ethical approval statement

This research has been approved and conducted in accordance with applicable research ethics standards. All procedures involving relevant parties, such as polling station officers and the community, were conducted with informed consent and without coercion.

Informed consent

All parties involved in data collection, particularly through interviews, were provided with clear information regarding the purpose of this study, and their consent to participate was obtained both verbally and in writing. The personal data collected will be kept confidential and used solely for the scientific purposes of this study.

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