

Cost Model of Activity Oriented Municipal Solid Waste Management: Integration of Activity Based Costing/Management and Causal Loop Diagram

Dedi Dermawan *, Agus Mulyadi, Sajidi Wardana

Industrial Engineering Departement, Universitas Muhammadiyah Riau, Pekanbaru, 28294, Indonesia

* Corresponding Author: dedi@umri.ac.id

ARTICLE INFO

Article history

Received July 29, 2025

Revised October 2, 2025

Accepted October 10, 2025

Keywords

ABC/M;

Cost Management;

MSW;

Causal Loop Diagram;

ABSTRACT

The increasing generation of municipal solid waste (MSW) in Pekanbaru, a densely populated city in Riau Province, has led to higher waste management costs. In 2023, the city generated 1,011 tons of waste daily, with management costs reaching around IDR 93 billion. Traditional cost calculation methods are often inaccurate, failing to account for the activities involved in MSW management. This study develops an activity-based cost management model using Activity-Based Costing/Management (ABC/M) to map costs to specific waste management activities, combined with Causal Loop Diagrams (CLD) to analyze activity relationships and formulate a mathematical cost model. The application of ABC/M identified four primary waste management activities: collection, transportation, processing, and disposal. The results show a total waste management cost of approximately IDR 91 billion, with CLD revealing dynamics such as the impact of incentives on recycling rates and the balancing effects of transportation and waste bank usage on waste generation. This study contributes provides a novel cost model for municipal waste management, offering both theoretical and practical contributions for improving cost efficiency and resource allocation.

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1. Introduction

MSW remains a long-standing problem in many developing countries (Ferronato & Torretta, 2019; Henry et al., 2006; Suthar & Singh, 2015), particularly in urban areas. This problem is caused by the influence of local social, cultural, and economic conditions (Becattini, 2017; Gupta et al., 2015; Wardekker et al., 2023). This is evident in population growth, increased activity, and changes in consumption patterns, which directly lead to increases in the volume, type, and characteristics of waste (Rahmawati & Syamsu, 2021). MSW originates from the remains of daily human activities and/or natural processes in solid form in urban areas (Mawardi Heru Prasetyo et al., 2024). Normatively, the increase in MSW is expected to rise in tandem with the growing population each year (Utami et al., 2022). Similarly, Pekanbaru, the capital of Riau Province, has the largest population of 1.123.348 people (Indonesia, 2022; Statistik, 2020). This has led to an increase in the amount of MSW generated. However, solid waste management in Pekanbaru remains suboptimal, resulting in various environmental and health issues (Afriyanni, 2022). Daily MSW in this city continues to increase from

year to year, as shown in Fig. 1. Graph of fluctuations in daily waste generation in Pekanbaru from 2019 to 2023. With a significant increasing trend, reaching a peak in 2020 of 1,097 tons per day (R. T. Wahyuni et al., 2025; Yenni et al., 2025). The amount of MSW decreased in 2021 to 967.49 tons due to the impact of COVID-19 (Olawade et al., 2024). However, it increased again in 2023 to 1,011.01 tons per day, reflecting the increasingly pressing problems in MSW management.

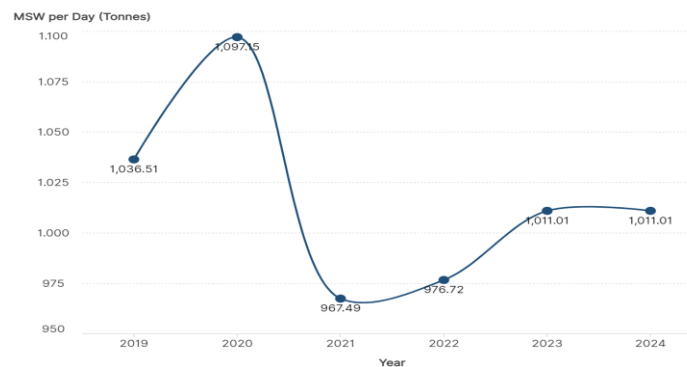


Fig. 1. MSW of Generation per day in Pekanbaru

MSW management is a complex and dynamic activity. This complexity is influenced by various aspects, including regulations, institutions, finance, technical elements, and community participation (Artika & Chaerul, 2020; Wilson et al., 2006). Currently, MSW management in Pekanbaru is limited to recycling and sanitary landfills (Meirizha et al., 2025). This affects the resulting management costs. Limited waste management costs pose a challenge, as the government has a limited budget. This involves the availability of waste processing facilities. Pekanbaru is the region with the largest per capita allocation of waste management budgets in Indonesia (Angganita, 2025; Natalia, 2025), yet waste management remains suboptimal. Waste management costs in Pekanbaru are still calculated using traditional methods, which rely on a general approach to cost determination. This method calculates management costs based on rough estimates without considering the specific activities involved in each stage of waste management in detail. As a result, cost calculations tend to be inaccurate and do not reflect the efficiency or impact of each activity in the waste management process. However, the majority of earlier research on MSW management in Indonesia has not adequately addressed the methodological accuracy of cost computation, instead focusing on descriptive elements like waste generation data, budget allocation, or infrastructure availability. This creates a knowledge gap on how particular waste management practices affect overall expenses.

Therefore, analysis and modeling are necessary to optimize waste management costs in Pekanbaru. ABC/M is a method that maps costs to activities within a company and then allocates the costs of these activities and services to management, allowing them to be used for planning, cost control, and decision-making. This method for determining costs that is quite accurate (Durán & Durán, 2018). ABC/M can be profitable and reliable for short-term planning as well as suitable for long-term planning (Khataie, 2011; H. C. Wahyuni et al., 2025). CLD is an approach that focuses on cause-and-effect relationships between variables or components in a system (Mawardi Heru Prasetyo et al., 2024). CLD is very useful for examining the causal relationships between elements in the loop, the influence of a component on another, and whether the effects are unidirectional or inverse (Abdullah, 2018). Furthermore, CLD can help inform policies aimed at improving system performance (Mulyadi et al., 2023). Therefore, the use of the CLD model can help managers understand the complex dynamics of the various variables involved (Husain et al., 2025). ABC/M's precise cost allocation and CLD's system dynamics capture are underutilized in MSW management research, particularly in developing nations such as Indonesia. ABC/M has been employed in corporate or industrial settings, while CLD has been used more in policy analysis and system

simulation. To the authors' knowledge, no study has utilized ABC/M and CLD to simulate city-level MSW costs in Indonesia. This connection is essential for a more accurate cost model and a dynamic representation of waste management activity links. This gap highlights the need for a methodology that enhances cost accuracy and provides systemic insight into MSW policy. This paper examines the application of traditional Costing methods in Pekanbaru, which often fail to reflect the complexity and interdependency of waste management accurately. The objective of this research is to develop an integrated cost model for Pekanbaru by combining ABC/M and CLD. The integration of ABC/M and CLD modeling in waste management offers the potential to generate more sustainable and cost-efficient waste management solutions. This article begins with an introduction, followed by the method, the results, and the discussion, and concludes with a conclusion.

2. Method

This study employs an activity-oriented MSW management cost model that integrates two key methods: ABC/M and CLD, as illustrated in Fig. 2.

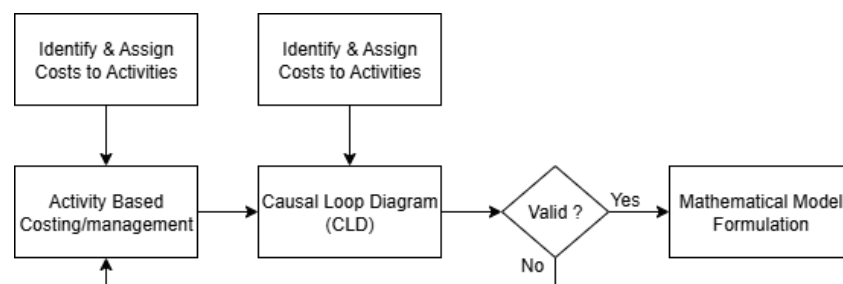


Fig. 2. Research Flowchart. Data are then classified into key MSW activities: collection, transportation, processing, and final disposal

The research flowchart presented in Fig. 2, begins with data collection including records of MSW volumes, budgetary allotments, and operating expenses from DLHK Pekanbaru, followed by interviews & Official DLHK Documents. The Observations were conducted at landfill facilities, waste banks, and TPS, as well as interviews with staff of DLHK. Data are then classified into key MSW activities: collection, transportation, processing, and final disposal. Each activity is analysed using the ABC/M approach to ensure accurate cost calculation. ABC/M can be defined as a costing approach based on a company's activities (Utama et al., 2025). According to (Gervais et al., 2010), this method allows for more precise cost calculations by mapping the activities that influence costs. In the context of waste management, each activity, such as collection, sorting, processing, and disposal, can be identified in detail, and its costs can be calculated. This allows for a clearer understanding of resource allocation and efficient cost management (Alabbadi & Areiqat, 2010).

After grouping waste management activities, the next step is to create a CLD that illustrates the cause-and-effect relationships between various elements within the waste management system. This diagram facilitates a deeper understanding of how interacting factors within the system influence overall waste management costs and outcomes. As explained by Sterman (2000) in Liu (2010), a CLD helps illustrate the dynamic interactions between elements within a system, such as waste generation, management policies, and community behavior toward waste, which can directly or indirectly influence the system. A CLD contains variables connected by arrows depicting causal relationships, with each link marked with a (+ or -) sign, as shown in Fig. 3 (Buntuan, 2010; Widodo et al., 2010). The arrow indicates the direction of the causal relationship between variable A and variable B. A positive (+) sign indicates that a change in variable A will lead to a change in variable B in the same direction. Conversely, a negative (-) sign indicates that a change in variable C will lead to a change in variable D in the opposite direction.

Furthermore, causal relationships that form a cycle are marked with a special symbol. If the cycle has an even number of negative links, it is called a reinforcing feedback loop (+), indicating an imbalance in the system. Meanwhile, suppose the cycle has an odd number of negative links. In that case, it is referred to as a balancing feedback loop (-), indicating the system's attempt to return to equilibrium (Mulyadi et al., 2023). To ensure data validity and reliability, triangulation was applied by comparing data from DLHK reports, direct field observations, and interview results.

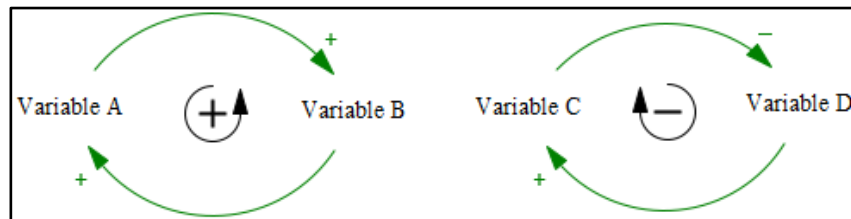


Fig. 3. Relationship of CLD. A CLD contains variables connected by arrows depicting causal relationships, with each link marked with a (+ or -) sign

3. Results and Discussion

3.1. Traditional Cost Calculation

In the current waste management cost calculation, DLHK Kota Pekanbaru employs a traditional method, where cost allocation is not detailed and is based solely on the volume of waste generated in the city. This approach does not account for the individual activities or resources involved in waste management, resulting in a generalized estimate of costs. The total cost for waste management in Pekanbaru for 2023, according to this traditional method, amounts to IDR 93.491.119.576. The detailed information shown in Table 1.

Table 1. Calculation of Current MSW Costs in Pekanbaru Using Traditional Methods

No	Description	Amount (IDR)
1	Waste Reduction through Limitation. Recycling. and Reuse	IDR 1.076.095.740
2	Waste Handling through Sorting. Collection. Transportation. Processing. and Final Disposal at Landfills (TPA/TPST/SPA)	IDR 91.283.906.836
3	Operational Expenses	IDR 880.750.000
4	Goods and Services Expenditures	IDR 250.367.000
	Total	IDR 93.491.119.576

In 2023, the total annual waste generation in Pekanbaru was recorded at 369.019.82 tons. The traditional method of the waste management system provides an overall estimate of the yearly cost, but it lacks the granularity needed to identify inefficiencies or opportunities for cost reduction. The traditional method limits the ability to pinpoint specific areas where resource allocation can be optimized or where additional investments might yield better long-term benefits. The total cost per ton of waste management is IDR 253.349.86, but without a more detailed cost structure, the effectiveness of waste reduction and resource utilization remains uncertain.

3.2. Activity Based Costing/Management (ABC/M) Cost Calculation

ABC/M is a comprehensive cost allocation system that assigns costs based on the activities involved in managing MSW. This method allocates waste management costs using multiple cost drivers, each associated with specific groups of activities within the waste management process. In this study, the waste management process involves four key activities: waste collection, waste

transportation, waste processing, and final disposal (Diamantina, 2010). Each of these activities plays a crucial role in the overall cost structure of waste management. The activities that occur and can be identified in the MSW management process. Activities are determined based on the results of previous literature and field studies.

The determination of cost drivers is based on their direct cause-and-effect relationship with the respective activities involved in the waste management process. In this research, identifying cost drivers plays a crucial role in accurately allocating costs to specific activities. Through interviews conducted with the DLHK Kota Pekanbaru, detailed information on the cost drivers for each activity was gathered in Table 2. Based on Table 2, for example, the calculation of waste collection labor costs is obtained by multiplying 730 work hours/year by IDR 37.931.507 per hour, resulting in IDR 27.690.000.000. The most significant cost component in MSW management is waste transportation, amounting to IDR 56.032.624.742, followed by waste collection labor costs of IDR 27.690.000.000. Meanwhile, expenses related to waste processing, such as waste bank activities, are relatively small, indicating that recycling efforts are still limited.

Table 2. MSW Management Cost Activities and Cost Drivers

No	Activity	Activity Cost	Cost Driver	Cost/Cost Drivers	Total Cost (IDR)	
1	Waste Collection	TPS Maintenance Costs	Waste Quantity	110.705.95 Tons/Year	5.000	553.529.730
		Waste Cart Maintenance Costs	Waste Quantity	10.512 Tons/Year	150.000	1.576.800.000
		Motor Cart Maintenance Costs	Waste Quantity	1.314 Tons/Year	1.000.000	1.314.000.000
		Motor Cart Fuel Costs	Number of Units	25 Units	3.650.000	91.250.000
		Waste Collection Labor Costs	Work Hours	730 Hours/Year	37.931.507	27.690.000.000
2	Waste Transportation	Vehicle Rental Costs	Waste Quantity	284.700 Tons/Year	196.813	56.032.624.742
3	Waste Processing	Waste Bank Customer Payment Costs	Waste Quantity	295.22 Tons/Year	613.846	181.217.206
		Waste Bank Maintenance Costs	Waste Quantity	295.22 Tons/Year	75.000	22.141.200
		Waste Bank Labor Costs	Work Hours	2.920 Hours/Year	109.418	319.500.000
4	Final Disposal	Landfill Maintenance Costs	Waste Quantity	259.896 Tons/Year	10.000	2.598.960.000
		Heavy Equipment Maintenance Costs	Waste Quantity	259.896 Tons/Year	2.216	576.000.000
		Heavy Equipment Operator Labor Costs	Work Hours	6.205 Hours/Year	30.000	186.150.000
		Final Disposal Labor Costs	Work Hours	6.205 Hours/Year	9.267	57.500.000
		Electricity Costs	Kilowatt Hours (KWh)	24.000 KWh/Year	1.445	34.672.800

*TPS = Waste Temporary Shelter Site

The MSW management activities in Pekanbaru can be categorized into four levels of activities. These levels are classified based on the nature and scope of the tasks involved in the waste management process. The detailed categorization of these activities is presented in [Table 3](#).

Table 3. Categorization of MSW Management Activity Costs in Pekanbaru

No	Activity Cost	Amount (IDR)	Activity Level	Cost Driver
1	Motor Cart Fuel Costs	91.250.000	Unit-Level Activity	Number of Units
2	Vehicle Rental Costs	56.032.624.742	Batch-Level Activity	Amount of Waste
3	Waste Bank Customer Payment Costs	181.217.206	Product-Level Activity	Amount of Waste
4	Waste Cart Maintenance Costs	1.576.800.000		Amount of Waste
5	Motor Cart Maintenance Costs	1.314.000.000		Amount of Waste
6	Waste Collection Labor Costs	27.690.000.000		Work Hours
7	Waste Bank Labor Costs	319.500.000	Facility-Level Activity	Work Hours
8	Heavy Equipment Maintenance Costs	576.000.000		Amount of Waste
9	Heavy Equipment Operator Labor Costs	186.150.000		Work Hours
10	Final Disposal Labor Costs	57.500.000		Work Hours
11	Electricity Costs	34.672.800		Number of KWh
12	TPS Maintenance Costs	553.529.730		Amount of Waste
13	Waste Bank Maintenance Costs	22.141.200		Amount of Waste
14	Landfill Maintenance Costs	2.598.960.000		Amount of Waste

*TPS = Waste Temporary Shelter Site

After identifying the activities according to their respective levels, the next step is to determine the cost drivers for each waste management activity. As seen in [Table 4](#), the cost drivers represent the factors that directly influence the costs of each activity. By calculating the total for each cost driver across all activities, it becomes possible to allocate costs more precisely, offering a clearer picture of where resources are being consumed and helping to identify areas for cost optimization. This step is crucial for enhancing the efficiency of cost distribution and ensuring more effective management of waste resources in Pekanbaru.

Table 4. Cost Drivers for Each Solid Waste Management Activity

Description	Solid Waste Collection	Solid Waste Transportation	Solid Waste Processing	Final Disposal	Total
Number of Units	25	-	-	-	25
Amount of Waste (Tons)	122.531.95	284.700	590.43	519.792	927.614.38
Work Hours	730	-	2.920	12.410	16.060
Number of KWh	-	-	-	24.000	24.000

The Cost Pool Rate refers to the rate of waste management costs per unit of the cost driver, calculated for a specific group of activities. The pool rate is determined by dividing the total cost of management for a particular group of activities by the activity base (measurement factor) of that group. This calculation enables a more accurate allocation of the expenses across various levels of activity and cost drivers.

The next step is to calculate the total waste management costs based on activities by assigning a group rate to each cost driver. The costs for each cost group will be tracked across relevant activities. Once the rate per group is known, the cost calculation is performed by multiplying the group rate by the number of cost drivers for each activity. The results of the waste management cost calculation are explained in [Table 5](#). Furthermore, a comparison of waste management costs using the traditional system and the ABC/M M method is presented in [Table 6](#), demonstrating the differences in cost allocation and efficiency between the two methods. Details of the ABC/M calculations can be found in [Appendix 1](#).

Table 5. Group Pool Rates for Each MSW Management Activity

Unit-Level	
<i>Cost Pool I</i>	<i>Total Cost (IDR)</i>
Motor Cart Fuel Costs	91.250.000
Total Cost	91.250.000
Number of Units	25
Pool Rate I	3.650.000
Batch-Level	
<i>Cost Pool II</i>	<i>Total Cost (IDR)</i>
Vehicle Rental Costs	56.032.624.742
Waste Bank Customer Payment Costs	181.217.206
Total Cost	56.213.841.948
Amount of Waste (Tons)	927.614,38
Pool Rate II	60.600,44
Product-Level	
<i>Cost Pool III</i>	<i>Total Cost (IDR)</i>
Waste Cart Maintenance Costs	1.576.800.000
Motor Cart Maintenance Costs	1.314.000.000
Heavy Equipment Maintenance Costs	576.000.000
Total Cost	3.466.800.000
Amount of Waste (Tons)	927.614,38
Pool Rate III	3.737,33
<i>Cost Pool IV</i>	<i>Total Cost (IDR)</i>
Waste Collection Labor Costs	27.690.000.000
Waste Bank Labor Costs	319.500.000
Heavy Equipment Operator Labor Costs	186.150.000
Final Disposal Labor Costs	57.500.000
Total Cost	28.253.150.000
Work Hours	16.060
Pool Rate IV	1.759.224,78
<i>Cost Pool V</i>	<i>Total Cost (IDR)</i>
Electricity Costs	34.672.800
Total Cost	34.672.800
Number of KWH	24.000
Pool Rate V	1.444,7
Facility-Level	
<i>Cost Pool VI</i>	<i>Total Cost</i>
TPS Manitenance Costs	553.529.730
Waste Bank Maintenance Costs	22.141.200
Landfill Maintenance Costs	2.598.960.000
Total Cost	3.174.630.930
Amount of Waste (Tonnes)	927.614,38
Pool Rate VI	3.422,4

Table 6. Comparison of MSW Management Costs

Traditional System	<i>ABC/M</i>	Gap	Description
Rp 93.491.119.576	Rp 91.234.345.678	Rp 2.256.773.898	Overcosting

3.3. Causal Loop Diagram (CLD)

The formation of a CLD or causative diagram regarding the influence of solid waste management costs in Pekanbaru, with a depiction of the causal relationship between variables, is based on the variables defined in the ABC/M stage. In this study, there are four submodels that include waste collection costs, waste transportation costs, waste processing costs, and final Disposal costs, as shown in [Table 7](#), [Table 8](#), [Table 9](#), and [Table 10](#).

Table 7. Sub-Model of Waste Collection Cost

Variable	Unit
MSW Collection Costs	IDR
TPS Maintenance Costs	IDR
Waste Cart Maintenance Costs	IDR
Motor Cart Maintenance Costs	IDR
Motor Cart Fuel Costs	IDR
Waste Collection Labor Costs	IDR
Waste Generation	Tons/Year
Number of TPS	Units
Number of Waste Carts	Units
Number of Motor Carts	Units
Number of Workers	People
Work Hours	Hours

Table 8. Sub-Model of Waste Transportation Cost

Variable	Unit
MSW Transportation Costs	IDR
Number of Waste Transport Vehicles	Units
Amount of Waste Transported	Tons/Year

Table 9. Sub-Model of Waste Processing Costs

Variable	Unit
MSW Processing Costs	IDR
Waste Incentive Costs	IDR
Waste Bank Labor Costs	IDR
Waste Bank Maintenance Costs	IDR
Amount of Waste-to-Waste Bank	Tons/Year
Number of Waste Banks	Units
Number of Workers in the Waste Bank	People
Society Motivation	Unitless

Therefore, a CLD of the overall cost of solid waste management in Pekanbaru has been constructed to illustrate the cause-and-effect relationships between various elements in the waste management system. This CLD provides a comprehensive overview of how costs associated with different waste management activities, such as collection, transportation, processing, and final disposal, are interrelated and impact the total expenses incurred by the local government. The cause-and-effect relationships demonstrated in this CLD facilitate an understanding of the complex dynamics of urban waste management, particularly in identifying critical points that influence cost efficiency. This model also provides deeper insight into how various policies or changes in the system, for example, increasing the amount of recycled waste or increasing the frequency of waste

collection, can directly impact costs. With this diagram, managers can more easily formulate policies that can optimize waste management, thereby reducing waste and increasing the effectiveness of waste management costs in Pekanbaru.

Table 10. Sub-Model of Final Processing Cost

Variable	Unit
Final MSW Processing Costs	IDR
Landfill Labor Costs	IDR
Landfill Operational Costs	IDR
Electricity Costs	IDR
Landfill Maintenance Costs	IDR
Heavy Equipment Operational Costs	IDR
Heavy Equipment Maintenance Costs	IDR
Number of Landfill Workers	People
Number of Heavy Equipment Units	Units
Number of Heavy Equipment Operators	People
Amount of Waste to Landfill	Tons/Year

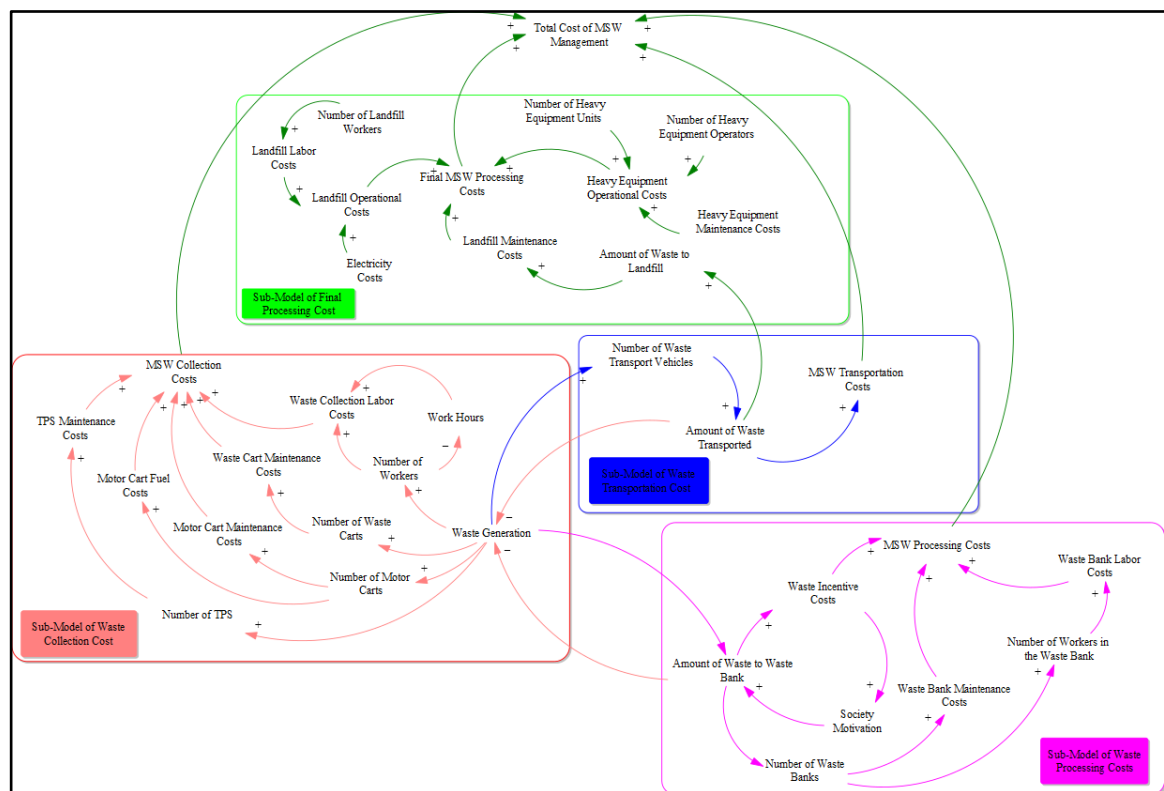


Fig. 4. CLD of MSW in Pekanbaru

After constructing a CLD model that describes the cause-and-effect relationships between elements in the waste management system, the next step is to convert the model into a more structured mathematical formulation. This mathematical formulation is designed to provide a more precise quantitative representation of the interactions between variables in the costs of MSW management in Pekanbaru. With this formulation, each activity in the waste management process, such as collection, transportation, processing, and final processing, can be calculated in greater detail. Table 11 shows the mathematical formulation of waste collection costs, which include TPS maintenance, cart and motor cart maintenance, fuel, and labor costs.

Table 11. Mathematical Model Formulation of Waste Collection Costs

Variable	Formula
MSW Collection Cost	Maintenance cost of TPS + maintenance cost of waste carts + maintenance cost of motor carts + fuel cost of motor carts + labor cost for waste collection
TPS Maintenance Cost	(Building repair cost of TPS x frequency/year) + (Truck container painting cost of TPS x frequency/year) + (Truck container welding repair cost of TPS x frequency/year)
Waste Cart Maintenance Cost	(Repair cost of waste cart wheels x frequency/year) + (Wheel repair cost of waste cart x frequency/year) + (Body maintenance cost of waste cart x frequency/year) + (Body repair cost of waste cart x frequency/year)
Motor Cart Maintenance Cost	(Engine maintenance cost x frequency/year) + (Wheel maintenance cost of motor cart x frequency/year) + (Body maintenance cost of motor cart x frequency/year) + (Body repair cost of motor cart x frequency/year)
Motor Cart Fuel Cost	(Number of units x frequency/year) x Fuel price
Labor Cost for Waste Collection	(Labor wage x frequency/year) x Number of workers
Number of Motor Carts	25 Units
Number of Workers	1,300 People

Table 12 shows that the number of vehicles, truck capacity, and the number of trips primarily determine transportation cost. This formulation highlights that the efficiency of transportation strongly depends on optimizing fleet size and utilization rate.

Table 12. Mathematical Model Formulation of Waste Transportation Costs

Variable	Formula
MSW Transportation Cost	Number of transport vehicles x Rental price per partner
Number of Waste Transport Vehicles	Amount of waste transported (ton/day) / (Truck capacity per day (ton/day/unit) x Number of trips per day)
Amount of Waste Transported	77.80%
Truck Capacity per Day	15 Ton/day/unit
Number of Trips per Day	3 Trips

Table 13 indicates that incentive payments, labor, and maintenance of waste banks drive waste processing costs.

Table 13. Mathematical Model Formulation of Waste Processing Costs

Variable	Formula
Solid Waste Processing Cost	Waste incentive cost + bank waste labor cost + bank waste maintenance cost
Waste Incentive Cost	IDR 613.85/Kg
Bank Waste Labor Cost	(Labor wage x frequency/year) x Number of workers in the bank waste
Bank Waste Maintenance Cost	Number of bank waste units x frequency/year
Number of Bank Waste Units	15 Units
Number of Workers in Bank Waste	30 People

The findings of this study highlight that waste transportation and labor costs account for the majority of overall MSW management expenses in Pekanbaru. This result is consistent with previous studies, which have reported that waste transportation accounts for the most significant proportion of MSW management budgets in developing cities due to the distance and logistical complexity involved (Gupta et al., 2015; Henry et al., 2006). Similarly, the reliance on labor for collection aligns with findings from Ferronato & Torretta (2019), who emphasized that human resources remain a critical factor in urban waste management systems in developing countries. The application of ABC/M provides a more accurate allocation of costs compared to traditional methods, as it considers the actual drivers of waste management activities. This supports the argument of Alabbadi & Areiqat (2010) Kaplan & Anderson (2007), who highlighted the strength of ABC/M in improving cost transparency

and decision-making. The finding that the traditional method leads to overcosting by IDR 2.25 billion reinforces the importance of activity-based approaches in identifying inefficiencies (Elshaer, 2022). Table 14 presents the formulation of final Disposal costs, including landfill operations, maintenance, electricity, and the use of heavy equipment.

Table 14. Mathematical Model Formulation of Waste Final Processing Costs

Variable	Formula
Final MSW Processing Cost	TPA operational cost + TPA maintenance cost + heavy equipment operational cost
TPA Labor Cost	(Labor wage x Number of TPA workers) x 12
TPA Operational Cost	Electricity cost + TPA labor cost
Electricity Cost	Amount of KWH/year x Electricity price/KWH
TPA Maintenance Cost	(Road maintenance cost x frequency/year) + (TPA building maintenance cost x frequency/year) + (TPA scale maintenance cost x frequency/year) + (Electrical repair cost in TPA x frequency/year)
Heavy Equipment Operational Cost	(Number of heavy equipment x maintenance cost of heavy equipment) + Operator labor cost
Heavy Equipment Maintenance Cost	(Number of heavy equipment x maintenance cost of heavy equipment) x frequency/year
Number of TPA Workers	25 People
Number of Heavy Equipment	6 Units
Number of Heavy Equipment Operators	12 People

Furthermore, the use of CLD in this study reveals the reinforcing and balancing feedback loops within Pekanbaru's waste management system. These results align with those of Artika & Chaerul, (2020) and Suryani et al., (2020), who argue that CLD helps capture dynamic interactions and support policy design. In particular, the reinforcing loop between incentive costs and recycling rates highlights the potential for policy interventions to encourage community participation. In contrast, the balancing loops demonstrate how transportation and waste bank utilization can mitigate waste accumulation. Overall, integrating ABC/M with CLD contributes to the literature by bridging cost accounting and system dynamics approaches. This integration not only enhances cost accuracy but also provides a systems perspective, offering more profound insights into how interventions in one activity may influence overall efficiency. Thus, this study contributes to the academic discourse on sustainable MSW management by combining financial accuracy with dynamic system analysis.

4. Conclusion

Based on the analysis, the calculation of MSW management costs in Pekanbaru for 2023 indicates that the traditional method yields a total cost of IDR 93,491,119,576, with a waste generation of 369,019.82 tons, resulting in a cost per ton of IDR 253,349.86. Meanwhile, the ABC/M method, which calculates costs based on the primary activities of waste management such as collection, transportation, processing, and final disposal, results in a total cost of IDR 91,234,345,678 or IDR 247,234.27 per ton. The difference of IDR 2,256,773,898 suggests that the traditional method is subject to over costing, as it tends to allocate costs more broadly and less accurately. The ABC/M method proves superior in providing precise and detailed cost calculations. The developed CLD illustrates the interconnections between the sub models of waste collection, transportation, processing, and final disposal, revealing the dynamic relationships that directly affect the overall waste management costs. The CLD uncovers both balancing and reinforcing loops, which highlight how different actions in one area of waste management can either stabilize or exacerbate the system's overall performance. This study demonstrates that integrating ABC/M with CLD provides not only more accurate cost calculations but also a better understanding of the dynamic interactions in municipal solid waste management. Practically, this model can help local governments optimize their

waste management budgets, reduce inefficiencies, and design policies that encourage recycling and sustainable practices. However, this research is limited to a case study in Pekanbaru. For Future research, Integrating System Dynamics (SD) models could offer a more comprehensive and dynamic approach to waste management analysis. Unlike the static nature of the CLD, SD can better represent the feedback loops and delays inherent in waste management systems, providing a more realistic simulation of how changes in one part of the system may affect other components over time.

Author Contribution: All authors contributed equally to the main contributor to this paper. All authors read and approved the final paper.

Funding: This research was funded by RISE TMU Batch VIII 2024

Acknowledgment: We want to express our sincere gratitude to the Dinas Lingkungan Hidup dan Kebersihan Kota Pekanbaru for their support and cooperation in providing valuable data and information for this research.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix 1

Activity Level	Cost Driver	Cost Allocation Process	Waste Collection	Waste Transportation	Waste Processing	Final Disposal	Total (IDR)
Unit	Number of Units	3650000 x 25	IDR 91.250.000				IDR 91.250.000
Total Activity (Unit Level)							IDR 91.250.000
Batch	Waste Amount	60600,44 x 123845,95	IDR 7.425.490.171				IDR 56.213.841.948
		60600,44 x 284700		IDR 17.252.946.033			
		60600,44 x 590,43			IDR 35.780.441		
		60600,44 x 519792				IDR 31.499.625.304	
Total Activity (Batch Level)							IDR 56.213.841.948
Product	Waste Amount	3737,33 x 123845,95	IDR 457.942.180				IDR 3.466.800.000
		3737,33 x 284700		IDR 1.064.017.531			
		3737,33 x 590,43			IDR 2.206.639		
		3737,33 x 519792				IDR 1.942.633.651	
	Work Hours	1759224,78 x 730	IDR 1.284.234.091				IDR 28.253.150.000
		1759224,78 x 2920			IDR 5.136.936.364		
		1759224,78 x 12410				IDR 21.831.979.545	
	Amount of KWH	1444,7 x 24000				IDR 34.672.800	IDR 34.672.800
Total Activity (Product Level)							IDR 31.754.622.800
Facility	Amount of Waste	5422,4 x 123845,95	IDR 419.348.508				IDR 3.174.630.930
		5422,4 x 284700		IDR 974.346.072			
		5422,4 x 590,43			IDR 2.020.671		
		5422,4 x 519792				IDR 1.778.915.678	
Total Activity (Facility Level)							IDR 3.174.630.930
Total Cost of MSW Management							IDR 91.234.345.678

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