Design of Integrated Waste Management Model of Medan City With Dynamic System Approach

Bag Kinantan 1, A Rahim Matondang 2 and Juliza Hidayati 3

1, 2, 3 Industrial Engineering Departement, Universitas Sumatera Utara

Abstract. Garbage problems occur due to the imbalance between waste production in the community and the government’s ability to manage the waste. The old pattern of collect–transport–dispose will give more burden to the system because of the increasing needs of infrastructures. This study aims to develop the integrated waste management model of Medan City with dynamic system approach. To be able to apply the new waste management model, the active roles of community are needed; therefore, it is necessary to know how far the perception and participation of community in the waste management nowadays. Based on the Law No. 18 of 2008 that the waste management starts from the source level (community) that is by reducing, reusing and recycling. The result of the study showed that the community perception on the waste management was good enough, but the participation was still very low both direct and indirect participation. The implementation of waste bank scenario and independent composter per–neighborhood can decrease the waste production entering the landfill (TPA) up to 13.5% and decrease the need of waste truck from 394 units to 333 units. The total cost of waste processing also decrease in amount of 180,257,000,000 in 10 years.

1. Introduction

Waste is the remaining from human activities. The continuity increasing of population growth factor and accompanied by the consumptive lifestyle are thought to be the causes of the high volume of the waste. The consumptive culture of today’s society has a huge part in increasing the types and qualities of the waste [1].

The problem in the management of urban waste occurs due to the imbalance between the production and the capability to manage it; the waste volume continues to increase in line with the population growth, changes in the quality of life and the dynamics of community activities. Waste problem relates to other development issues such as population, social, economic and land acquisition. These issues will have a profound impact on health, public order and security, and others. Therefore, the implementation of management of waste should be in an integrated way with other development issues [2].

In addition, the pattern of urban waste management, particularly in Indonesia, still adopts the system of collecting – transporting – disposing [3] or so called end of pipe system, in which some officers collect, transport and dispose the waste to the determined processing location. These activities will only add larger burden to the final landfill (TPA), while the capacity of the landfill has its limitation.

Moreover, TPA with open dumping system also produces various problems in environment and health. Decomposition of organic material can produce methane gas which can cause fires and explosions, and contribute to global warming. The chemical and biological processes in TPA can
produce leachates which can contaminate the surface and ground water. Not yet to mention the process of waste burning which produces smoke and contributes to the air pollution [4].

The enactment of Law Number 18 The year of 2008, as the basis of systematic and sustainable of waste management, expects the waste management system will no longer apply the end of pipe system, but the process of waste management starts from the source level by reducing and managing the waste in an integrated way prior to final disposing to the TPA. Also, there is expectation that waste is no longer a burden, but has economic value which can provide additional income for the community.

This paper focuses on the development of integrated waste management model of Medan City with the 3R approach (reduce, reuse, recycle) and dynamic system.

2. Integrated Waste Management
Integrated Waste Management can be defined as the selection and application of appropriate technique, technology and management program to achieve the specific goal of waste management. There are 4 basic waste management strategies released by the Environmental Protection Agency of United States, among others: (1) Reduction of waste at the source level, (2) Recycling and composting, (3) Combustion (facilities to convert waste into energy), and (4) landfills [5]

For waste management in Indonesia, according to [6] stated that the community assessment of the local government commitment in waste management is relatively less. The related department in response to the waste problem always returns to the technical issues such as budget, lack of infrastructure, without speaking of human and cultural aspect. Therefore, the solution made by the local government is not only preparing the master plan of drainage arrangement, but also the human and cultural aspect which play important role to be noticed without minimizing the technical aspect.

3. Existing System of Waste Management in Medan City
The current waste management system in Medan City still applies the old pattern that is collect-transport-dispose system. The entire management is conducted by the government through Cleanliness and Landscaping Agency. In the current system, the community is not directly involved, only pay the waste management levies. And the process of reduction of waste generation into the Landfills (TPA) focuses on scavengers activities either those are in the Landfills (TPA) or in the TPS (temporary disposal area). If continue using this system, it will burden the TPA. With the current development of Medan City, it will be very difficult to get replacement land for the current TPA. Details of the current system can be seen in the figure 1

![Diagram of Waste Management System](image-url)

**Figure 1** Existing Model.
4. Propose System of Integrated Waste Management of Medan City
With an integrated system approach, a conceptual model of integrated waste management system of Medan City is developed. The approach used is to involve the community actively by developing waste bank and independent composter in every neighborhood (LK) in Medan City. With this approach, it is expected that the reduction of waste generation into landfills (TPA) can be reduced so that the load in the landfills can be decreased, the economic life of landfills increases, and community also get income from the sales of waste processing (compost) and the sales of recycled waste. The need for vehicles transporting the waste can be reduced gradually and in the end the total cost of waste management of Medan City can be reduced. Details of conceptual model of integrated waste management of Medan City can be seen in the Figure 2

![Propose Integrated Waste Management Model Medan City](image)

*Figure 2. Propose Integrated Waste Management Model Medan City.*

5. Development Model of Dynamic System
5.1 Causal Loop Diagram
Causal loop diagram is a diagram shows the causal relationship and the interrelationship of main variable to be included in the model structure. The causal relationship in the causal is depicted with arrow. Positive marked arrow indicates the correlation of the variable is directly proportional which means that if there is addition of value on that variable will cause the addition value to the variable that influenced. On the other hand, the negative marked arrow indicates the relationship inversely which means the addition of value to that variable will cause a decrease in the value of the variable it is influencing. [7]
5.2 Submodel System

Based on the causal loop and main model system, it is determined some supporting submodel. The submodel includes: submodel of waste generation, submodel of waste reduction, submodel of transporting and submodel of cost. The division of submodel is done to make easy the process of analysis model to determine the alternative increasing of waste reduction in Medan City.

5.3 Simulation Model

Simulation model is conducted by using vensim software. Ventana Simulation (Vensim) is one of the tools which can do scenario on model through process of experiment model. Vensim is simulation software designed to assist company to find optimum solution in variety of situations that require analysis and the need to know all the possible outcomes of the implementation or decisions in the future.

5.3.1 Landfills Scenario. Landfills scenario is a reclamation in Landfills without recycling. In Landfills scenario, process of waste reduction is done by informal sector (bestari and scavengers). The informal sector separates the products which still have economic value such as plastic, paper and metal. But, the process of separation of these waste stops until they get only what they are looking for. While the separation of organic and inorganic waste is not done further. The percent of reduction obtained from informal sector is still so small that this scenario can not be relied upon as a long–term plan. There should be other alternative scenario which can give better percent of reduction than the current conventional method.

5.3.2 Recycling Scenario. The waste recycling scenario to be implemented in this model is the waste bank or “bank sampah” (BS) and independent compositer or “komposter mandiri” (KM). Both scenarios are chosen as the alternative 3R–based of waste management. Besides, these scenarios will involve the massive community so that the mandate of Law No. 18 of 2008 can be implemented; the waste management starts from the source level that is the community. Recycling scenario is a scenario involving all facilities of waste reduction ranging from waste bank, independent compositer, compost house and informal sector (scavenger). Waste residue from compost house is also taken into account.
6. Result and Discussion

6.1 Perception and Participation

6.1.1 Perception. Perception is the ability of brain in translating stimulus input into the human senses. In the human perception, there are different point of views in sensing. There are people who perceive something either good or bad. Positive or negative perception will affect the action of human in visible or real [8].

There are 16 statements which are divided into 3 groups. The first group is the perception on the implementation of 3R, the second group is the perception on the household waste management, and the third group is the perception on waste recycling.

All of the answers are centered on the “agree” answer. After conducting the assessment of community perception, it is known that the scores of perception are already high, this is seen from the proportion of the community with high perception reaching up to 78.9%, while those with low perception scores only 6.3%

6.1.2 Participation. Community participation in the household waste management (settlement) is the involvement of the community in the process of waste management carried out directly or indirectly. The act of participating in the waste management activity cannot be separated from various factors exist in the individual as part of the community. The factors can be internal or external.

Individual internal factors are age, gender, education level, occupation, income, knowledge and experience. While the external factors are the role of government/public figures in spreading the information about waste management and the available facilities/infrastructure. [9] (Tansatrisna, 2014).

There are different level in each practice of participation. This level when compared to each other will form a continuum line from the point of non participation to the point of full control of community. To make clear the process of participation and non participation, the eight rungs on ladder citizen participation was applied according to [10].

In this study there are 11 questions related to direct participation and 7 questions related to indirect participation. With score 1 - 4, so the score for direct participation is 1045 - 4180. While for the indirect participation, the score is between 665 - 2660. The score of community participation either directly or indirectly can be seen in Figure 4.

| Direct Participation Score | Indirect Participation Score |
|-----------------------------|-----------------------------|
| Citizen Control             | Citizen Control             |
| Delegated Power             | Delegated Power             |
| Partnership                 | Partnership                 |
| Placation                   | Placation                   |
| Consultation                | Consultation                |
| Informing                   | Informing                   |
| Therapy                     | Therapy                     |
| Manipulation                | Manipulation                |

![Figure 4. The Score of Community Participation.](image)

Based on the Figure 4, it is seen that for the direct participation, the citizen of Medan City is in the level of consultation, this means that the community can give their opinion to the government eventhough there is no guarantee that their opinion will be taken into consideration in the decision taking.
While the indirect participation, in relation with giving suggestion or discussion about settlement waste management, following counseling and training on waste management and waste levies. From the total score collected from the respondents, it is seen that the total score is in the second rung. This means that the community do not participate indirectly in the waste management. From the 7 questions, only the statement regarding waste levies that the community participate actively. (56.8% answer).

6.2 Simulation of Dynamic System
Simulation is implemented in 10 years, starts from 2017 until 2027. Dynamic system model focuses on the increasing of waste reduction so that it can reduce the load of landfills and reduce the need of waste transportation truck. The simulation is carried out by applying a predefined scenarios which are Landfills scenario and Recycling Scenario.

6.2.1 Landfills Scenario. Landfills scenario is a reclamation in Landfills without recycling. In landfills scenario, process of waste reduction is done by informal sector (bestari and scavengers). The percent of reduction obtained from informal sector is still so small that this scenario can not be relied upon as a long–term plan. Description of simulation can be seen in the Table 1.

In table 1 the total of waste production resulted from citizen of Medan City is 603, 904 Ton, increasing in amount of 0.99% per year and in the 10th year, the total of waste production of Medan City will be 665,243 ton. With the amount of truck 204 units in year 2017 and addition of trucks to compensate for the growth of waste of Medan City, therefore, it is required 394 Units of waste Typper Truck with capacity of 7 m3 at the end of the tenth year.

Total cost in year 2017 is Rp. 129,930,000,000 and increase in amount of 6.5% every year, so the total cost in the 10th year will be Rp. 220,275,000,000. Reduction by informal sector is 4740.2 ton/year.
Table 1 Simulation Result of Landfills Scenario

| Years of projection | Reduction (Ton/Year) | Total Waste Reduction (Ton/year) | Total Waste Production In Medan (Ton) | Reduction Percentage (%) | Total Cost (Rp. 000) |
|---------------------|----------------------|---------------------------------|--------------------------------------|--------------------------|---------------------|
|                     | TPA                  | TPS                             | Waste Bank                           | Independent Composter    | House of Compost     |
| 0                   | 2017                 | 0                               | 4740,42                              | 0                        | 0                   | 4740,42             | 603.394             | 0.79                | 129.930.000        |
| 1                   | 2018                 | 0                               | 4740,42                              | 0                        | 0                   | 4740,42             | 609.082             | 0.78                | 138.963.000        |
| 2                   | 2019                 | 0                               | 4740,42                              | 0                        | 0                   | 4740,42             | 614.870             | 0.77                | 147.996.000        |
| 3                   | 2020                 | 0                               | 4740,42                              | 0                        | 0                   | 4740,42             | 620.763             | 0.76                | 157.029.000        |
| 4                   | 2021                 | 0                               | 4740,42                              | 0                        | 0                   | 4740,42             | 626.763             | 0.76                | 166.061.000        |
| 5                   | 2022                 | 0                               | 4740,42                              | 0                        | 0                   | 4740,42             | 632.875             | 0.75                | 175.094.000        |
| 6                   | 2023                 | 0                               | 4740,42                              | 0                        | 0                   | 4740,42             | 639.101             | 0.74                | 184.127.000        |
| 7                   | 2024                 | 0                               | 4740,42                              | 0                        | 0                   | 4740,42             | 645.447             | 0.73                | 193.159.000        |
| 8                   | 2025                 | 0                               | 4740,42                              | 0                        | 0                   | 4740,42             | 651.916             | 0.73                | 202.192.000        |
| 9                   | 2026                 | 0                               | 4740,42                              | 0                        | 0                   | 4740,42             | 658.513             | 0.72                | 211.225.000        |
| Final               | 2027                 | 0                               | 4740,42                              | 0                        | 0                   | 4740,42             | 665.243             | 0.71                | 220.275.000        |

6.2.2 Recycling Scenario. The waste recycling scenario to be implemented in this model is the waste bank (BS) and independent compositer (KM). Both scenarios are chosen as the alternative 3R–based of waste management.

6.2.2.1 Waste Bank Scenario. There are two scenarios to be developed in this simulation, first scenario is based on the data of time series and second scenario is based on the target number of reduction facilities that is adjusted to the number of neighborhood (LK) in Medan City. This is done to facilitate the coordination process in community level.

Based on the current data, the number of waste bank in Medan is 87 units (Main Waste Bank Sicanang, 2017) with 20 units growth per year and average customer per waste bank is head of family (KK). So that within 10 years, the total number of waste bank in Medan City is 287 units. With the average number of fix customer, the total reduction of waste obtained from waste bank is 133.6 ton a year and increase in amount of 23% per year.

After conducting the second scenario that is by planning the number of waste bank has the same amount with the number of neighborhood (LK) in Medan City (2001 LK), it is planned within 10 years the whole neighborhood has 1 unit of waste bank. The average increase of waste bank is 200 waste banks per year and average number of fix customers 25 KK, obtained waste reduction and this facilities increase in average 46% per year. Reduction increases from first year 133.6 ton to 3203.75 ton within 1 year.

If this second scenario is developed again, by increasing the assumption of the number of waste bank customers to 50 KK per waste bank, then the reduction obtained from waste bank facility becomes even higher. The result of scenario of waste bank using preliminary data can be seen in Table 2, while the development of scenario of waste bank can be seen in Table 3.
Table 2 Simulation Result of Recycling Scenario Using Preliminary Data

| Years Of Projection | Year | Reduction (Ton/Year) | TPA  | TPS  | Waste Bank | Independent Composter | House of Compost | Total Waste Reduction (Ton/Year) | Total Waste Production In Medan (Ton) | Reduction Percentage (%) | Total Cost (Rp. 000) |
|---------------------|------|----------------------|------|------|------------|------------------------|------------------|---------------------------------|--------------------------------------|------------------------|----------------------|
|                     | 0    | 2017                 | 4740.42 | 133.6 | 0          | 11.8                   | 4885.8          | 603.394                         | 1.47%                                | 103.307.000            |
|                     | 1    | 2018                 | 4740.42 | 164.3 | 3940.7     | 11.8                   | 8857.2          | 609.082                         | 1.62%                                | 117.629.000            |
|                     | 2    | 2019                 | 4740.42 | 195.0 | 7881.4     | 11.8                   | 12828.6         | 614.870                         | 1.82%                                | 131.798.000            |
|                     | 3    | 2020                 | 4740.42 | 225.7 | 11822.1    | 11.8                   | 16800.0         | 620.763                         | 2.07%                                | 145.812.000            |
|                     | 4    | 2021                 | 4740.42 | 256.4 | 15762.8    | 11.8                   | 20771.4         | 626.763                         | 2.38%                                | 159.674.000            |
|                     | 5    | 2022                 | 4740.42 | 287.1 | 19703.5    | 11.8                   | 24742.8         | 632.875                         | 2.77%                                | 173.381.000            |
|                     | 6    | 2023                 | 4740.42 | 317.8 | 23644.2    | 11.8                   | 28714.2         | 639.101                         | 3.26%                                | 186.935.000            |
|                     | 7    | 2024                 | 4740.42 | 348.5 | 27584.8    | 11.8                   | 32685.6         | 645.447                         | 3.87%                                | 200.334.000            |
|                     | 8    | 2025                 | 4740.42 | 379.2 | 31525.5    | 11.8                   | 36657.0         | 651.916                         | 4.63%                                | 213.581.000            |
|                     | 9    | 2026                 | 4740.42 | 409.9 | 35464.2    | 11.8                   | 40628.3         | 658.513                         | 5.58%                                | 226.673.000            |
| Final               | 2027 |                    | 4740.42 | 440.6 | 39406.9    | 11.8                   | 44599.7         | 665.243                         | 6.77%                                | 239.612.000            |

Table 3 Simulation Result of Recycling Scenario with Improvement Assumption

| Years Of Projection | Year | Reduction (Ton/Year) | TPA  | TPS  | Waste Bank | Independent Composter | House of Compost | Total Waste Reduction (Ton/Year) | Total Waste Production In Medan (Ton) | Reduction Percentage (%) | Total Cost (Rp. 000) |
|---------------------|------|----------------------|------|------|------------|------------------------|------------------|---------------------------------|--------------------------------------|------------------------|----------------------|
|                     | 0    | 2017                 | 4740.42 | 267.1 | 0          | 11.8                   | 5019.4          | 603.394                         | 0.8%                                 | 103.282.000            |
|                     | 1    | 2018                 | 4740.42 | 881.2 | 7881.4     | 11.8                   | 13514.8         | 609.082                         | 2.2%                                 | 115.290.000            |
|                     | 2    | 2019                 | 4740.42 | 1495.2 | 15762.8    | 11.8                   | 22010.2         | 614.870                         | 3.6%                                 | 126.989.000            |
|                     | 3    | 2020                 | 4740.42 | 2109.2 | 23644.2    | 11.8                   | 30505.6         | 620.763                         | 4.9%                                 | 138.382.000            |
|                     | 4    | 2021                 | 4740.42 | 2723.3 | 31525.6    | 11.8                   | 39001.1         | 626.763                         | 6.2%                                 | 149.466.000            |
|                     | 5    | 2022                 | 4740.42 | 3337.3 | 39407.0    | 11.8                   | 47496.5         | 632.875                         | 7.5%                                 | 160.244.000            |
|                     | 6    | 2023                 | 4740.42 | 3951.3 | 47288.4    | 11.8                   | 55991.9         | 639.101                         | 8.8%                                 | 170.714.000            |
|                     | 7    | 2024                 | 4740.42 | 4565.4 | 55169.6    | 11.8                   | 64487.3         | 645.447                         | 10.0%                                | 180.877.000            |
|                     | 8    | 2025                 | 4740.42 | 5179.4 | 63051.0    | 11.8                   | 72982.8         | 651.916                         | 11.2%                                | 190.732.000            |
|                     | 9    | 2026                 | 4740.42 | 5793.5 | 70932.4    | 11.8                   | 81478.2         | 658.513                         | 12.4%                                | 200.280.000            |
| Final               | 2027 |                    | 4740.42 | 6407.5 | 78813.8    | 11.8                   | 89973.3         | 665.243                         | 13.5%                                | 209.520.000            |

6.2.2.2 Independent Composter Scenario. Independent composter scenario is the development of organic waste processing facility into compost. This facility is placed in each neighborhood. In this scenario it is planned the procurement of independent composter takes places gradually over 10 years. The average procurement of independent composter is 200 units/year. The price of independent composter is Rp. 50,000,000 with capacity of 3 m³.

Circulation of composting is conducted for 4 weeks, the percentage of compost produced is 78% of the total entering organic waste and 22% of the rest becomes the residue disposed to TPA. The simulation result of independent composter gives waste reduction 3940.69 ton in the first year and increase to 39406.9 in the tenth year.
When the scenario is changed by increasing the circulation of composting from 4 weeks to 2 weeks, the increasing of the reduction becomes double.

From the total cost incurred by the implementation of of this scenario together with waste bank scenario is the amount of Rp. 103,307,000,000 and in the tenth year is Rp. 209,520,000,000.

7. Conclusion
To be able to implement the integrated waste management system it is required the active role of community. Application of 3R in this study is the development of facility of waste reduction in the source of waste production, that is by develop waste bank and independent composter.

Through the model development as well as analysis of waste reduction produced in each facility of waste management show that the percentage of waste reduction from all facilities is 13.5 % from the total of waste production of Medan City in a year. This figure is achieved in the tenth year by planning the development facilities gradually that is 200 facility in 200 neighborhoods every year.

There is a total cost saving of waste management of Medan City in amount of Rp. 180,257,000,000 in 10 years or averagely saving in amount of Rp. 18,025,700,000.

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