An Agent-Based Model of Waste Bank's Adoption Strategy

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Abstract

Waste management is still a worldwide concern. Yogyakarta – a city with the fourth population density rank in Indonesia, sends more than sixty thousand tons of waste to the landfill, which currently has to expand due to overloading capacity. In the last decade, the government has carried out various efforts, including promoting a waste bank program in each district. The program aims to reduce the amount of inorganic waste generated by households. Currently, the amount of waste processed is still under 20% due to a lack of participation. Thus, strategies to increase the number of people who adopt waste bank services are needed. This study aims to model the community adoption of waste bank services to obtain those strategies. An agent-based simulation approach is used by considering the behavior of sorting and selling the waste, its benefit and cost, the time for waste sorting, and the economic level. Four scenarios were evaluated, i.e., increasing the number of waste banks, reducing waste retribution charges, increasing waste incentives, and providing transportation facilities to collect waste. The results show that most of strategies can increase the adoption of the waste bank services, especially by adding more waste bank services in the residential area.

Keywords
waste management, waste bank adoption, agent-based model, inorganic waste

1. Introduction

Waste management still becomes a problem faced by many countries globally, for both developed and developing countries, starting from the upstream issues where the waste is generated and managing waste downstream to avoid worse environmental issues. It is because waste is the output of daily human activities on a household scale and a larger scale such as industry. Household waste management itself still becomes a challenge for many countries, especially in developing countries, as a lot or poor practices such as littering, burning the waste in open spaces, and low waste collection rate still occurs (Noufal et al. 2020). Various systems were developed to facilitate the waste management, such as household classification system (Meng et al. 2018), promoting waste education (Chen et al. 2020, Noufal et al. 2020), improving the infrastructure of waste management (Noufal et al. 2020), and providing incentives (Shaw and Maynard 2008).

Indonesia as a country with a population that is ranked fourth in the world, indeed contributes a large amount of waste. Unfortunately, the government and society still face various obstacles in managing waste. Apart from the management system itself, the level of public consumption and social behavior on treating the waste also contributes to many waste problems. This phenomenon is similar from one city to another, including in Yogyakarta, i.e. the city with the fourth rank of highest population density in Indonesia. According to the Department of Sanitation of Yogyakarta City, the amount of waste generated and disposed of in the landfill in 2016 is 64,399 tons in one year. Waste management done so far is only carried out through collection, transportation, and final disposal at the *Piyungan* integrated waste landfill (called TPST). Having inadequate waste management, system and facilities, this landfill tends to be operated as an open dump with little control. Therefore, it did cause the TPST to be overloaded, pollute the surrounding environment, and thus needs capacity expansion.

In the last ten years, there have been many activities that support waste management in Indonesia. One unique idea is to promote the waste bank program. This program aims to reduce the amount of inorganic and organic waste generated by the households, which initially includes collecting and sorting inorganic waste that still can be reused and recycled, which mostly has economic value. Some of the waste banks are recently also managing the organic waste through

various ways, such as composting and maggot cultivation. A group of people can carry out this program in any area. Unfortunately, many waste banks cannot sustain in the long term. In Yogyakarta, from 475 waste banks exist in the government list, the resident's participation is only 15%. This lack of participation leads to the small amount of waste deposited in the waste bank, i.e. less than 20%, which causes the waste bank to be financially unsustainable.

Two factors can contribute to resident's participation in waste management. The first is an internal factor, i.e. the person's behavior. This behavior is essential because many environmental problems result from the collective impact of human actions/decisions to survive, live and adapt (Akintunde 2017). The second is an external factor that influences the behavior, such as the facilities and regulations applied (Meng et al. 2019, Srun and Kurisu 2019). Strategies are needed to increase participation so that people are willing to adopt the waste bank services. This study aims to model the community adoption of waste banks to obtain a correct policy to increase community involvement by incorporating the behavior of sorting and selling the waste, its benefit and cost, the time required for waste separation, and the community economic level. As residents have their attributes and produce different decisions, the agent-based simulation approach is used to model. Some strategies are proposed, including increasing the number of waste banks, reducing the retribution charges, increasing waste incentives, and providing transportation facilities.

2. Literature Review (12 font)

Waste management has been an interesting topic in the literature review since the 1960s (Silchenko et al. 2015). Most of the research is conducted in developed countries, and US and European data have been used extensively. It means there are vast opportunities to explore this field in developing countries. Among those research, more than 50% were qualitative study, 31% used quantitative study, and the rest is mixed. As waste management is unique in each region, half of the studies are based on empirical data.

Studies related to household waste has been carried out by several researchers such as Meng et al. (2018, 2019), Al Mamun et al. (2018), Almazán-Casali et al. (2019), Bortoleto et al. (2012), Fan et al. (2019), Xu et al. (2017), Padilla and Tujillo (2018). Several approaches can be used to solve problems related to waste management. Kum et al. (2005) conducted research to identify deficiencies in solid waste management (SWM) in Phnom Penh City with strategic and systems approach. In another study, Almazán-Casali et al. (2019) used Choice Experiment (CE) to analyze people's wishes to participate in disposing of household waste. Mosler and Martens (2008), in their research using agent-based modeling (ABM) to test various strategies from environmental campaigns to understand and test their impact on attitudes of environmental protection. Related to the household waste management, some research focusing on factors that influence people's behavior in disposing of trash. These factors are divided into two, namely internal/intrinsic factors and factors external/extrinsic. The internal factors include the willingness to participate (Meng et al. 2019), sensitivity to the environment (Meng et al. 2019, Srun and Kurisu 2019), social responsibility (Meng et al. 2019, Srun and Kurisu 2019), public knowledge (Srun and Kurisu 2019). In contrast, the external factors include environmental facilities and services, social pressure and regulations (Meng et al. 2019, Matsumoto 2014, Wu et al. 2017).

Subjective norms and knowledge on municipal solid waste have a strong correlation positive impact on separating waste by the community (Vassanadumrongdee and Kittipongvises 2018). Xu et al. (2017) explain that the government's monetary rewards, coercion, and punishments can stimulate changes in people's recycling behavior. Gender, age, and the income of each individual can also result in behavioral changes. Research conducted by Padilla and Trujillo also supports the results of this study (2018) that the higher the socioeconomic class, the greater the effort to separate solid waste. Level education of the household and having internet access at home play an important role in attitudes towards segregation of household waste. Al Mamun et al. (2018) argue that morality is not a significant factor in rational action. Thus recycling, as a sensible act, need not be motivated by moral obligation. Discomfort and distrust of municipal solid waste collection is a major obstacle to waste segregation. (Vassanadumrongdee and Kittipongvises 2018). Almazán-Casali (2019) found that cost had a marginal negative effect on service selection waste collection. Some factors can significantly affect the waste sorting activities, i.e. economic level factors (Meng et al. 2019, Seacat and Boileau 2018, Riswan et al. 2011, Al Mamun et al. 2018), environmental influences (Meng et al. 2019, Ofstad et al. 2017, Varotto and Spagnolli 2017, Srun and Kurisu 2019), availability of facilities (Meng et al. 2019, Srun and Kurisu 2019), and time to dispose of the waste (Meng et al. 2019).

3. Methods

This research focuses on analyzing people's behavior and processes community decision-making on household waste using an agent-based modeling simulation. This study simulates several strategies that aim to reduce the amount of waste in the landfill at Yogyakarta City, Indonesia, by increasing the amount of waste that goes to the waste bank considering the economic level, environmental influences, facilities, and time to dispose of the waste.

There are three agents used in the model, i.e. resident, waste bank, and private waste collector. The model covers 552 residents. The real problem is scaled-down, with each resident represents 300 households. Referring to Meng et al. (2018) and the interview to a local waste management practitioner, each resident has three behaviors. Those are people who do not do any waste separation (no sorting), people who do waste separation (sorting), and people who sell the waste after being separated (selling after sorting). Each residential agent also has different affordability in paying the retribution charges, based on their economic level. There are three economic levels used in this model, i.e. low (7% of the population), middle (65% of the population), and high (28%of population). These values are used to determine the value perception about money or the willingness to spend the money. The higher the value, the more meaningful each cent of money for them, usually owned by low-income residents.

There are 56 waste banks built in the model for the waste banks agent, distributed in each district. The scale used is one agent of a waste bank in the model representing 8 to 9 in an actual situation. A private waste collector is an additional agent who collects the waste from door to door. The baseline model assumed that their buying price is the same as waste banks. The only difference is in the way the waste is collected. When a resident participates in waste bank services, he will bring the waste to the nearest waste bank services. At the same time, if he chooses to sell the waste to private waste collectors, no distance traveled as the private waste collectors will pick up the waste. Which agent is selected by the resident is assumed to be dependent on the highest price offered.

Residential agents produce waste each week, and they can sell the waste to the waste bank or the private waste collector. As mentioned previously, the residents will choose the one with the highest price. The price then will be used to calculate the benefit-cost utility and further summed up with the time utility and neighbor utility into the total resident utility (Figure 1). The utility function is adopted from Meng et al. (2018) and presented as follows:

$$U_{total} = U_{bc} + U_{time} + U_{neighbour} \quad (1)$$

$$U_{bc} = [(M \times Pr \times K_{sell} \times K_{ec}) - (R \times K_{ec}) - (Y \times 2 \times 5)] \times BP \quad (2)$$

$$U_{time} = -(T_{sep} \times K_{sep} + T_{dis} + Y \times 2 \times 0{,}07) \times BT \quad (3)$$

$$U_{neighbour} = N_{effect} \times BN \quad (4)$$

U_{total} is the respondent's total utility, which consists of benefit-cost utility, time utility, and neighbor utility. M denotes the amount of waste generated by a resident, Pr denotes waste price per kg, R denotes retribution charges per week, Y denotes distance between resident and waste bank/private waste collector, T_{sep} and T_{dis} are the time needed for sorting the waste and bring it to waste bank/private waste collectors; K_{sell}, K_{ec}, and K_{sep} are coefficient of willingness to sell the waste, willingness to spend money and willingness to do waste sorting, respectively, and N_{effect} denotes social pressure from neighborhood who has behavior of selling after sorting.

The total utility is then compared to the average utility of all residents with the same behavior. If the resident's total utility is higher than the average utility on each behavior, then the resident will change the behavior to a higher level (e.g., from no sorting; or from sorting to selling after sorting); or to a lower level. If there is a behavior shifting, then the behavior's average utility is also updated as well as the total amount of waste collected in waste banks.

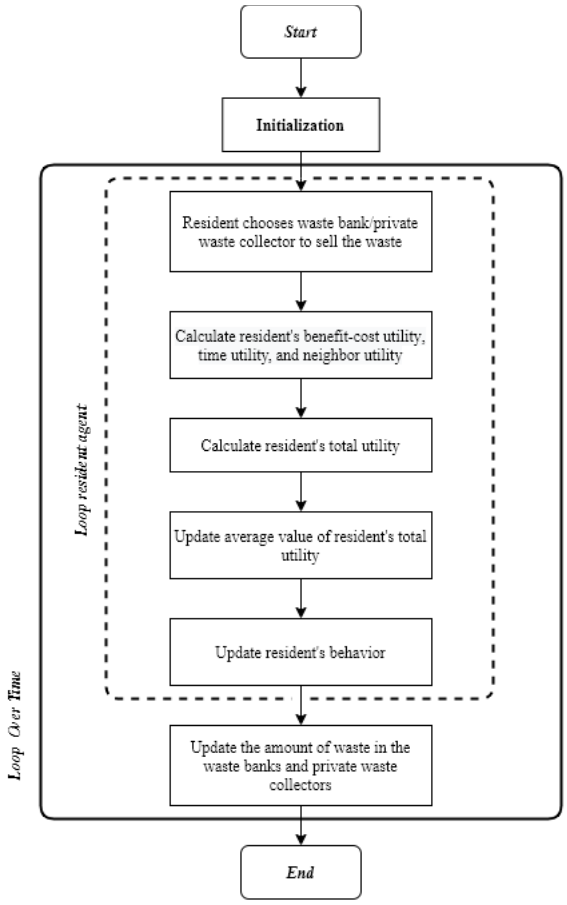

Figure 1. Simulation process

The emergence of the model is the amount of waste in all waste banks and private waste collectors and the number of residents in each behavior. The amount of waste generated in the model is validated by using actual data of waste collected in all waste banks.

There are four scenarios developed to see the possibility of increasing the participation of waste bank services:

1. Increase the number of waste banks based on the distance from resident's location. It aims to see whether the distance between the waste bank and the resident can encourage the resident to sell after sorting.
2. Increase waste incentives by 20% or increasing the price offered by waste banks. By increasing the price, it is expected that the residents will be interested in joining the services.
3. Reduce retribution charges for the resident that are participating in waste bank services. In this scenario, the residents who have participated in the waste bank services will have retribution charges reduction.
4. Add transportation facilities in each waste bank so that the resident can save transportation to the waste bank.

The simulation was conducted up to 240 tick, with one tick represents one week. Waste banks' location is fixed in each district in Yogyakarta city, and the location of residents is randomly assigned. The model was built and run using Netlogo 6.1.1.

4. Results and Discussion

The total amount of waste deposited in the waste banks generated by the model was compared to the actual data. Statistically, it has no significant difference with the actual amount of waste data collected in waste banks ($t(99) = 1.08$, $p>.05$). Thus, the model can be used for running the four scenarios built. Figure 2 – 4 shows scenario's

comparison on the number of waste successfully collected in the waste banks and the number of residents in each behavior.

Total amount of waste collected in waste banks

From all of the scenarios, increasing the number of waste banks leads to a higher amount of waste collected in waste banks at about 1.5% from the current condition (BAU = business as usual) (Figure 2). By having more waste bank services in the resident's surrounding area, it is likely to increase the social pressure from the neighbourhood, as more residents use the services. It hence could persuade the residents to sell the waste. On the other hand, increasing the incentives and providing waste banks' transport facility resulting in less than 0.5% increase of waste collected to waste banks.

Figure 2 also shows that all scenarios can increase the amount of waste collected in waste banks, except the strategy of reducing retribution charges. It could occur because the amount of waste retribution charges regulated in Yogyakarta for each month is not large, which is between 4,000 IDR up to 15,000 IDR. This amount is just around a few cents up to one dollar USD. The amount of money saved from retribution charges and the benefit they gained from selling the waste at a standard price seems to have little meaning compared to the effort they must spend to sort and bring the trash to the waste bank. Therefore reducing the retribution charges cannot sustain in the long term.

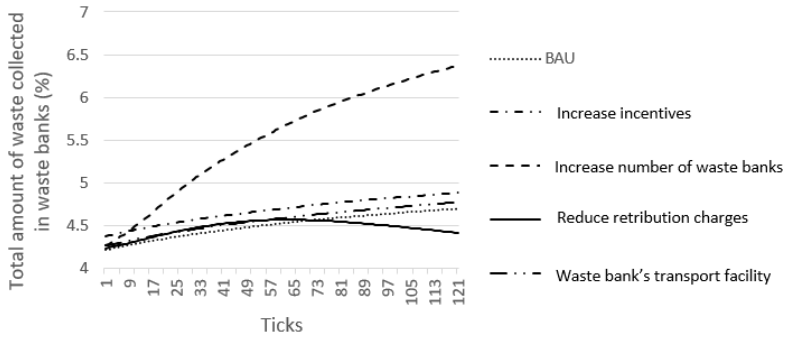

Figure 2. Scenario comparison: the total amount of waste collected in the waste bank (in %)

The number of residents in each behavior

Figure 3 shows the number of residents in each scenario on each behavior. This figure reveals that adding the number of waste bank services in the surrounding area of residents could reduce the number of residents who do not separate their waste significantly (Figure 3(a)). The behavioral change also occurs for the residents who only do waste sorting but not selling them (Figure 3(b)). Consequently, the number of residents selling their waste to the waste banks increases (Figure 3(c)). As more waste banks exist, there will be less distance between residents and the waste bank's location, more income from selling the waste, and more social pressure from the neighborhood to join the services. In the scenario of reducing the retribution charges, in line with Figure 2, the number of residents not doing waste sorting increases significantly, which means that more people change their behavior from doing sorting and selling after sorting to the behavior of not doing the sorting. It may happen because the reduction of retribution charges is not significant for the residents compared to the effort of doing waste sorting and selling it. The other two scenarios, i.e. increasing incentives (price of waste) and providing transport facility, do not significantly affect behavioral changes.

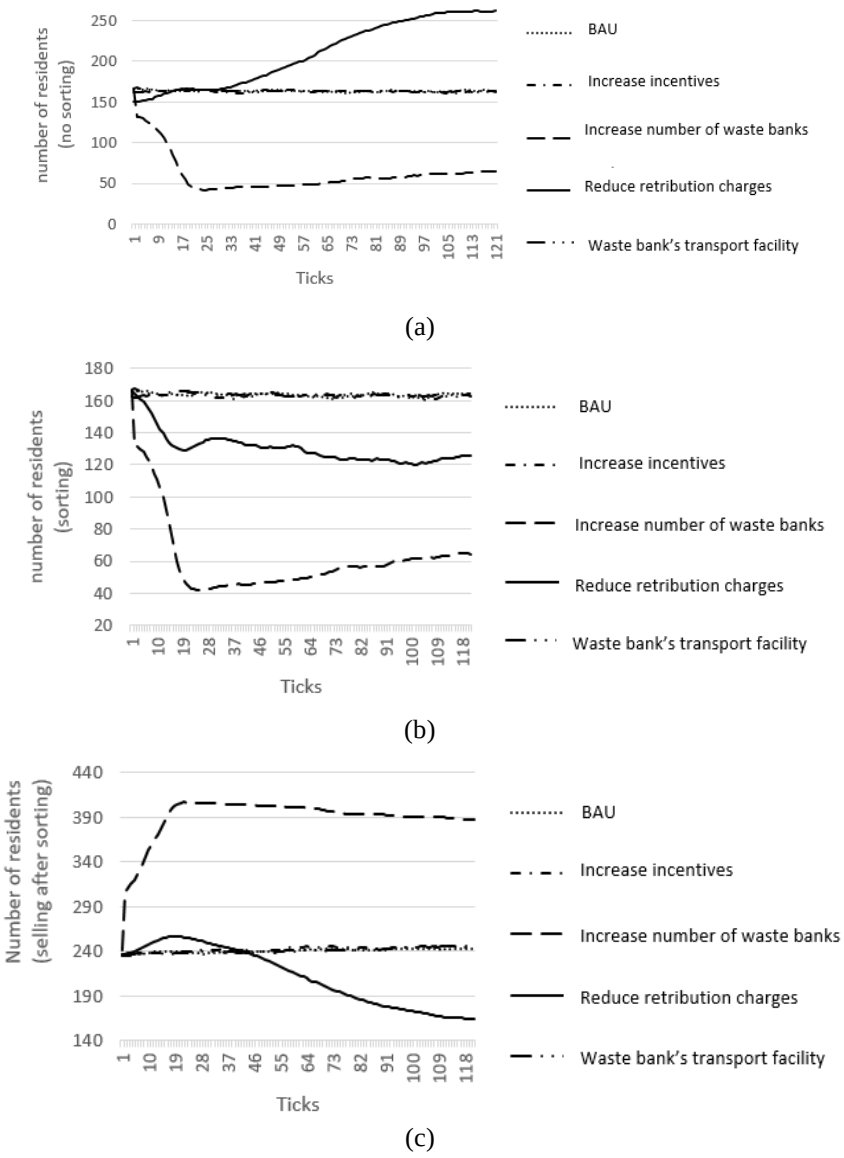

Figure 3. Scenario comparison: number of residents; (a) no sorting; (b) sorting only; (c) selling after sorting

The effect of resident's economic level

Based on the economic level, the vulnerable to behavioral changes are at the low economic class. It is because they are more sensitive to the money they spent or gained in daily life. Figure 4 indicates more fluctuation of this category compared to the other economic levels. Residents in the middle economic class fluctuate less than the residents in the high economic one. In this model, the value of willingness to spend money for both categories is assumed to be the same, whereas the retribution charges are higher for the latest. It may lead residents at a high economic level to be more sensitive to behavioral changes.

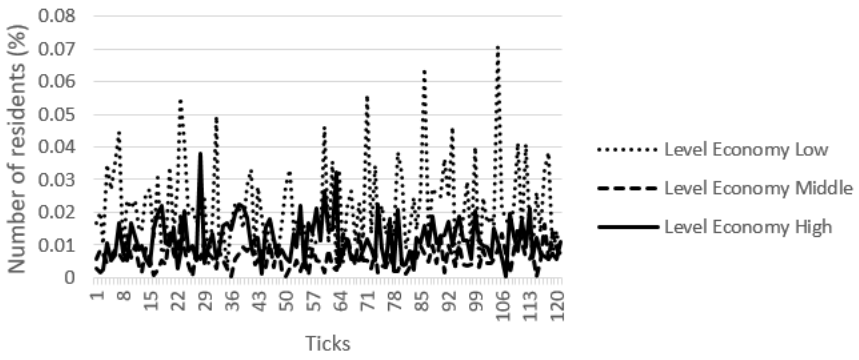

Figure 4. Behavioral changes based on the resident's economic level

6. Conclusion

An agent-based model for evaluating waste bank's adoption strategy has been developed. This model represents the condition in Indonesia where the waste management system improvement is widely opened. Waste bank services have become a solution for reducing waste to landfills, which currently still have little control over proper waste processing. The waste bank's practices are still lacking participation from residents. Therefore, the model has evaluated four scenarios to increase the participation in these services, i.e. adding waste bank services, increasing waste incentives, reducing retribution charges, and providing transport facilities in the waste banks to pick up the waste from residents. From all four scenarios, adding waste bank services to the resident's area has the highest effect compared to the other three. From this strategy, residents can have less distance to bring their waste to the service's location, the economic benefit from selling the waste, and social pressure from their neighborhood, which can persuade them to participate in waste banks' services. Although the model has successfully evaluated some strategies to increase waste banks' participation, some limitations need to be highlighted. First, the waste in the model is generalized, so is its price. While each type of waste could have different prices, incorporating this aspect may lead to different strategies for persuading the residents to join the services. Second, the waste banks are currently assumed to do daily operations regardless of income earned. Further research could have a threshold on the minimum requirement for waste banks to open the services.

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