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WASTE REDUCTION THROUGH INTEGRATED WASTE MANAGEMENT MODELING AT MUSTIKA RESIDENCE (TANGERANG)

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Abstract
In Indonesia, there are classic issues about waste that are highlighted due to the country's critical conditions. Uncontrolled population growth and regional development have led to massive waste production. One popular practice in waste management is located at integrated waste management site (TPST). This practice has been implemented successfully by TPST Mustika Iklhas, a small community operation in Tangerang. Though different from previous operations, its success is achieved by active community participation, far away from government intervention. This study looks at management practices in TPST Mustika Ikhlas. The method used to address real and complex problems is called system dynamics. This method uses life cycle thinking to address the waste management practice in Mustika Residence. Once the model was constructed, a simulation was carried out within 1,080 days. In this study, exponential behaviors were generated in the main variables such as waste, inorganic waste, and compost. However, organic waste exhibited oscillation behavior due to its processing time needed to convert to compost. From the results and discussion, we conclude that integrated waste management in TPST Mustika Ikhlas has been effective in reducing waste through conversion to inorganic waste and compost. Intervention to Business-As-Usual (BAU) should focus on two leverage variables: retribution and TPST cash flow.

Keywords: model; system dynamics; Tangerang; waste management; waste reduction

1. Introduction

In 2014, 54% of the world's population lived in urban areas. This is a large increase from previous urban rates, which were only 30% in 1950 (UN, 2014). By 2050, the urban share will increase to 66% of the world's population (UN, 2014). These trends are reflected in Indonesia. In 2010, half of Indonesia's population (49.8%) lived in urban areas. By 2025, it is estimated that 68% of the population will be urban residents (World Bank, 2016).

The rate of increase in population is directly proportional to the activities that increase waste amounts. In 2012, the amount of waste generated from an urban population of 3 billion was around 1.2 kg per person per day, or around 1.3 billion tons per year. By 2025, the city population is predicted to increase to 4.3 billion and will produce around 1.42 kg per capita per day, which is equivalent to 2.2 billion tons per year (Hoornweg & Bhada-Tata, 2012). In Indonesia, waste production is about 187,366 tons per day, equal to 0.76 kg per person per day (Chaerul, Tanaka, & Shekdar, 2007), and it is expected to increase in 2020 (Kardono, 2007). According to the Ministry of Environment, in 2008, recycled garbage accounted for only 2.26% of waste, with 2.01% in a temporary disposal site (TPS) and 1.6% at the disposal site (Ministry of Environment of Indonesia, 2008). The waste produced is mostly from household activities (Damanhuri & Padmi, 2010; Karak, Bhagat, & Bhattacharyya, 2012; Rawlins, Beyer, Lampraia, & Tumiwa, 2014). Therefore, waste management should focus on managing household waste.

The recommended way to handle waste is to implement integrated waste management (Sunarto & Sulistyaningsih, 2018). Integrated waste management combines technologies such as sorting, composting, recycling, incineration, and landfill, and adapted to the situation and conditions of local the community. Research suggests that waste management based on community involvement is the best form of waste management and involves active participation of the community to manage waste (Machmacha, Herat, & Mudzingwa, 2011). With this system, it is possible to increase government capacity, which is inadequate to carry out waste management due to the economic problems faced by the government (Mubaiwa, 2006). The community engagement program begins with the education and awareness of the community, increasing the residents' desire to participate, taking the initiative in reducing the waste produced (Machmacha et al., 2011), and recycling community waste into higher economic value such as compost. If this kind of management program is implemented in Indonesia, it can reduce waste generation (by weight), further reducing transportation costs and extending the life of the final disposal site (TPA) (UNEP, 2017).

To assist community participation, government interventions are usually needed to help management run and handle operations—for example, the municipal solid waste management in Padang (Raharjo et al., 2017), a waste bank in Malang (Wulandari, Utomo, & Narmaditya, 2017; Maryati, Arifiani, Humaira, & Putri, 2018), and urban waste management in Depok (Ismiyati, Purnawan, & Kadarisman, 2016). By implication, the community will not experience self-financed waste management (Donia, Mineo, & Sgroi, 2018) due to its dependency on local government. Previous studies have focused less on the self-financed community in waste management; there is always government intervention in continuous pattern, which will create low resilience communities.

To fill the gap, we believe integrated waste management should stand alone and be independent from government intervention. In fact, government has difficulties covering the actual implementation in a small community, usually covering only a relatively small population in a narrow residential area. Integrated waste management site (TPST) Mustika Ikhlas, which combines community-based integrated waste management with the 3R principle (Reduce, Reuse, Recycle) was built at Mustika Residence (Tangerang) in 2004 and started operations in June, 2005. In 2015, TPST Mustika Residence managed some 6,920 kg of waste per day per a 3,520 population unit (family). The management team processes the sorting and composting. The waste management is carried out by an informal unit (Xue, Wen, Bressers, & Ai, 2019), formed as a Self-Help Group (KSM). Moreover, the financial burden is fully supported by the community, while the local government supports the disposal of residues from TPST to the TPA. The conditions of TPST remain far from ideal; there are still many obstacles, including labor shortages, lack of financial support, and poor socialization.

There is an approach that may solve this problem. Waste management is a complex management system that involves interactions between several components. System dynamics, introduced by J.W. Forrester (Forrester, 1988), may help to conceptually and rationally analyze these kinds of complex structures, interactions, and modes of behavior of a system and its sub-systems. We can then explore, assess, and forecast their impact in an integrated and holistic manner (Kollikkathara, Feng, & Yu, 2010). This thinking can also contribute to the policy-making process on a regional or project scale (Yuan, Chini, Lu, & Shen, 2012).

Based on the problems, formulation, and concerns described above, we believe the realities of of waste management in TPST Mustika Ikhlas are captured best through integrated waste management modeling using a system dynamics approach. This study presents the methods, results, and discussion (model structure 1, model structure 2, simulation and validation, and intervention), as well as our conclusions.

2. Methods

As outlined in several steps described in Figure 1, our methodology uses system dynamics. System dynamics most closely captures the reality or real conditions of waste management in TPST Mustika Ikhlas. System dynamics were chosen because it has become a way to promote social participation in dynamic public policy (Costanza & Ruth, 1998; Stave, 2002), without accepting direct and real consequences (Shultz II et al., 1999). Moreover, this method is effective in capturing real-world conditions, which is full of complexities (Soesilo, 2018). Also, this intervention can test several alternative solutions for implementation in order to compare with BAU or current policy (Sterman, 2002; Haghshenas, Vaziri, & Gholamialam, 2015; Soesilo & Karuniasa, 2016).

The data are gathered from primary sources, which come directly from the management and workers of TPST Mustika Ikhlas located at Tangerang. The data are from a 3-year period, as the simulation is conducted in a 3-year period. Several assumptions are made: The population growth rate remains constant every day and is derived from the annual population growth rate; the sorting time from the generation of waste to non-organic and organic waste is considered non-existent because the value is not significant; all inorganic waste and compost are considered to be sold on that same day; no limit is placed on the organic and inorganic waste that can be sorted from waste generation; and other related assumptions.

Problem formulation was completed in the previous section (Introduction). The problem is then translated into model structure, starting from the Causal Loop Diagram (CLD) until the Stock Flow Diagram (SFD). The CLD illustrates the relationship between related variables. In other words, this model structure is developed from scratch. Meanwhile, SFD is a more complex model structure generated with software called Powersim Studio 10. This software is chosen due to its capability to create an easy-to-access, intuitive, graphical, and user-friendly interface (Williams, Lansey, & Washburne, 2009). Some terminologies are used such as stock, flow, constant, and auxiliary (Sterman, 2002). These terminologies are described in common symbols used in Powersim Studio 10, which are described in detail in Soesilo & Karuniasa (2016) and Soesilo (2018). The SFD is then simulated and validated. Validation is done by checking the consistency between CLD and SFD, visual validation, and

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statistical validation with Absolute Mean Error (AME) compared with a 10% tolerance. Finally, simple intervention is suggested in order to optimize the model in relation to waste reduction efforts.

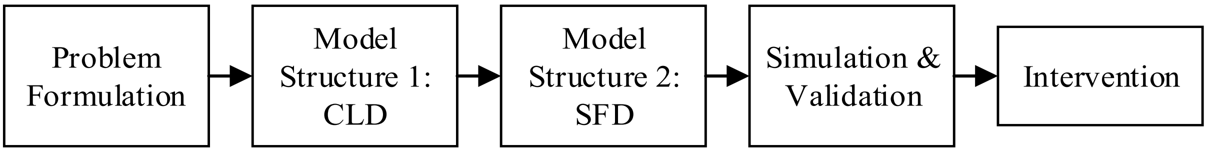

Figure 1. Steps of system dynamics

3. Results and Discussions

To be able to create the CLD, related data have to be collected. In this case, data are about the business processes of the TPST, including the amount of waste, the processing of waste, financial condition of TPST, the workers, and the local population. All data are converted as needed. The results and discussions follow the order in the steps of system dynamics described earlier.

3.1 Model Structure 1: CLD

The CLD is constructed in Figure 2. The link between variables indicates a relationship; meanwhile, the sign inside the circle means the type of correlation, whether positive correlation or negative correlation. “Population growth” correlates positively to “population” because it is the derived from the population number, and vice versa. “Population” correlates positively to “waste” because the larger the population, the larger the amount of waste produced. “Waste” itself correlates positively to inorganic waste, organic waste, and residue because waste is sorted into those three kinds of waste. “Organic waste” correlates positively to “compost” because composting is the next processing after waste is sorted into organic waste. Together with “inorganic waste,” “compost” correlates positively with “sales of inorganic waste and compost” because the more inorganic waste and compost generated the more sales are created. “Sales of inorganic waste and compost” correlates negatively to “TPST cash flow” because the revenues from sales are directly given to workers, so it acts as cash out. “TPST cash flow” correlates positively to “worker” because the more positive the cash flow, the more ability there is to hire more workers. Lastly, “worker” correlates negatively to “waste” because the more a worker works, the less waste is generated.

The main variables are waste, TPST cash flow, worker, and population. Waste is driven by population. This is a logic relationship since higher population leads to higher consumption. Population itself is related to the population growth rate (reinforcing loop R1). Other reinforcing loops (R2 and R3) are created as waste is being sorted and processed. Some wastes become residue, while others become inorganic waste and compost that have economic value. The compost creation is effective in reducing wastes, which are not processed (Surjandari, Hidayatno, & Supriatna, 2009). The sales of inorganic waste and compost correlate negatively with TPST cash flow because the sales benefit is given directly to the worker (cash out of TPST cash flow). TPST cash flow will then drive worker (in this case, number of worker). Finally, a negative correlation also occurred between worker and waste. The more worker, the less waste generated.

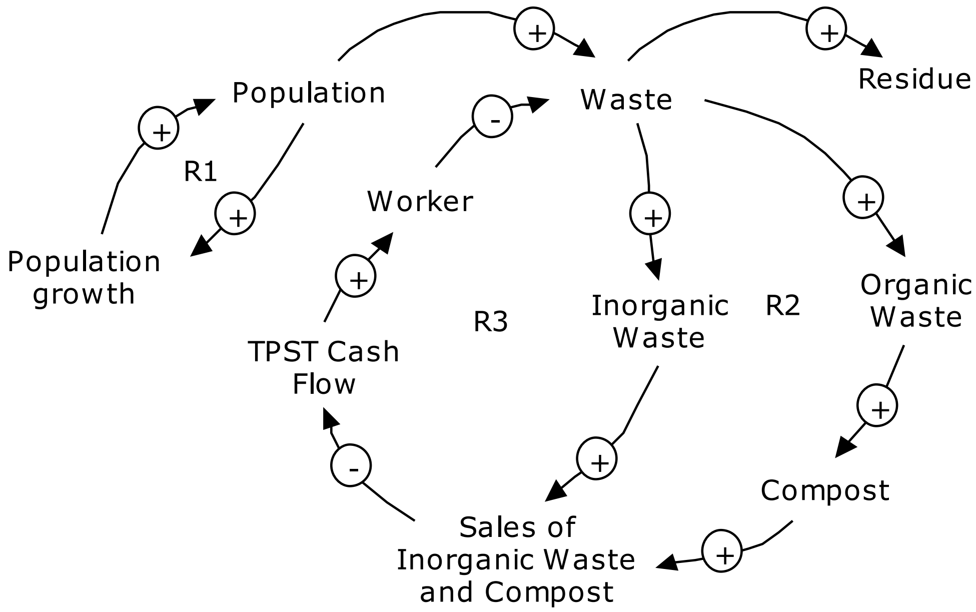

Figure 2. CLD of waste management in TPST Mustika Ikhlas

3.2 Model Structure 2: SFD

SFD (Figure 3) is constructed based on CLD, completed with several supporting variables in terms of stock, flow, and feedback (Sterman, 2002). To make it easy to understand, the main variables are divided by colors: yellow for waste, green for TPST cash flow, purple for worker, and red for population. This structure is ready for simulation and validation.

Figure 3 shows several subsystems divided by colors that contribute to the whole model. Every subsystem explains the real condition based on the constructed CLD, addressed with several additional variables regarding its purposes in the system. Some additional variables are needed to obtain the relevant or logical units, which are very important to the mathematical equations used (Chlot et al., 2011).

The red color in the SFD structure reflects the local population. This "population" is a stock whose value continues to change with time units. The "population" has only in-flow in the form of the "population growth" because changes in population values tend to be positive, meaning the "population" tends to grow as the unit of time progresses. The word "growth" in population growth is used because its value is actually the difference between the rate of population reduction and the actual rate of population growth. The "population growth" adds to the population because the rate of population growth is greater than the rate of population reduction. "Population growth" is then, in practice, influenced by "population" itself and "rate of growth." The "rate of growth" based on reference data has variations, so the shape is an auxiliary.

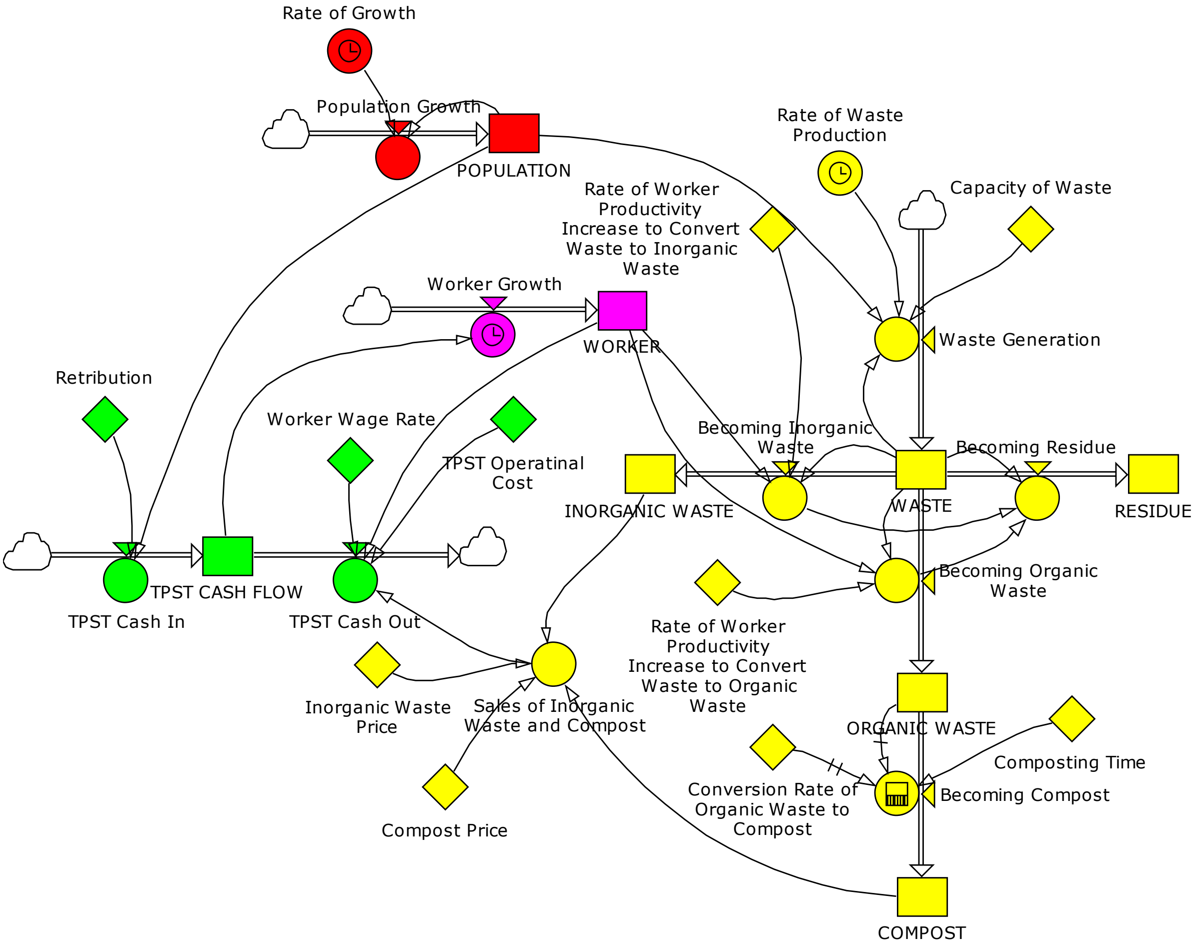

Figure 3. SFD of waste management in TPST Mustika Ikhlas

The yellow color in the SFD structure reflects the dynamics of "waste," both in the form of increasing "waste" and reducing "waste." The increase in "waste" is realized as in-flow of "waste generation." This in-flow is influenced by the "population, "rate of waste production," "capacity of waste," and the "waste" itself. Meanwhile, the reduction in "waste" is manifested in three variables of out-flow waste generation ("becoming inorganic waste," "becoming organic waste," and "becoming residue") which at the same time are three in-flow variables for the stock of "inorganic waste," stock of "organic waste," and stock of "residue". The concept of this division is called the waste sorting process (Noer & Hakim, 2016). This sorting of inorganic and organic waste is based on the types of household waste that are commonly produced (Damanhuri & Padmi, 2010). The relationship between these stocks becomes realistic because the waste generation in reality is classified as inorganic waste, organic waste, and residue. Sorting into the stock of "inorganic waste" is influenced by "worker" and "rate of worker productivity increase to convert waste to inorganic waste". Sorting into "organic waste" stocks is influenced by "worker" and "rate of worker productivity increase to convert waste to organic waste." Meanwhile, sorting into "residue" is affected into "inorganic waste" and also into "organic waste." Especially for "organic waste," the management is continued to stock of "compost" through an intermediate out-flow of "inorganic waste" which at the same time also becomes in-flow of "compost." Finally, the auxiliary results of the "sales of inorganic waste and compost" are influenced by "inorganic waste" and "compost" itself along with "inorganic waste price" and "compost price."

The green color in the SFD structure reflects the balance sheet of the relevant TPST. In accordance with the concept of money balance in environmental economics (Common & Stagl, 2005; Suparmoko, 2016), there are additional variables, as well as variables that are reducing from the condition of the money supply. In the context of the SFD that was built, the variable that was added to was the TPST in-flow balance sheet, which was later called the "TPST cash-in," while the reducing variable became the TPST cash balance out-flow, which was later called the "TPST cash-out." The "TPST cash-in" is influenced by "population" and "retribution." Meanwhile, "TPST cash-out" is influenced by the "TPST operational cost," "worker," "worker wage rate," as well as the proceeds of "sales of inorganic waste and compost."

Finally, the purple color in the SFD structure reflects the dynamics of the TPST worker in question. This purple SFD structure is quite simple because it involves only two variables, namely the "worker growth" and "worker" itself. The "worker" variable acts as stock. The variable "worker growth," in reality, has a value that is not continuous, so it requires a special approach in entering data and patterns of calculation. Non-continuous is defined as the "worker" variable and must have a round number.

3.3 Simulation and Validation

If all the variables in SFD have been filled in properly and accordingly, the next step is to do the simulation. Simulations are carried out for daily periods because the Project Setting has been set with a time unit "days" before this SFD is constructed. Meanwhile, the simulation is carried out from start time 0 to stop time 1,080, with a time step of 1. In other words, the simulation is carried out per day for 1,080 days. The number 1,080 is chosen because the reference data only provides data for 3 years or equal to 1,080 days. Consistency with this reference data is important because the next stage of modeling is conducting validation, one of which is done through comparison with data and reference patterns (Soesilo & Karuniasa, 2016). Before being completely simulated, the model is usually tested for structural validation and validation of dimensional consistency.

For results, most main variables show exponential behaviors, such as waste (Figure 4), inorganic waste (Figure 5), and compost (Figure 6). This behavior reflects the real conditions that occurred in TPST Mustika Ikhlas. Although waste reduction was successful, TPST Mustika Ikhlas still faces problems with an increasing amount of waste in the future. There is a unique behavior that is captured in the organic waste variable. As illustrated by Figure 7, it displays an oscillation behavior, containing waiting time to become compost.

Moreover, validation is necessary to make sure that the model built is reliable. Validation is done in several types, including structural validation, visual validation, and statistical validation.

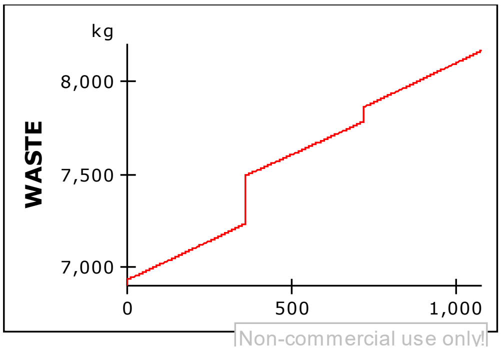

Figure 4. Simulation result of waste

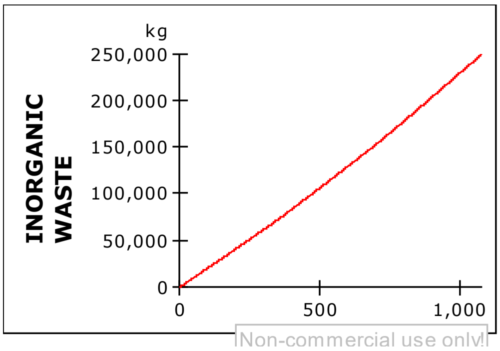

Figure 5. Simulation result of inorganic waste

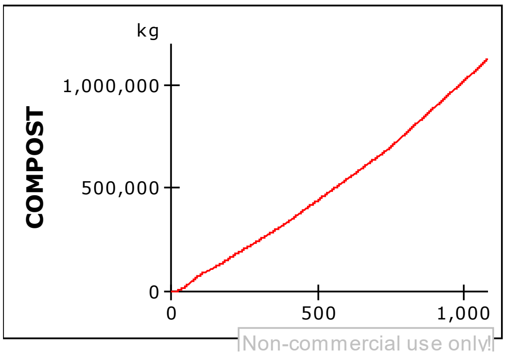

Figure 6. Simulation result of compost

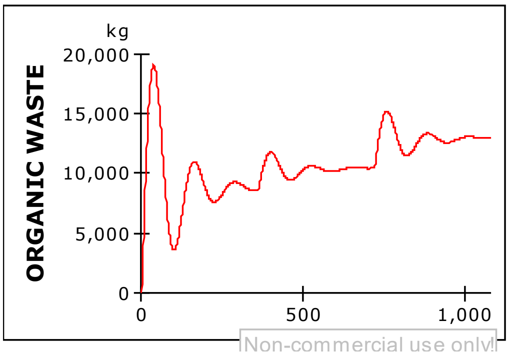

Figure 7. Simulation result of organic waste

Based on structural validation, the model is valid, because the model structure is consistent between CLD and SFD. Meanwhile, visual validation shows that both simulation results and reference data shows the same behavior (Figure 8), which is exponential, so therefore the model is valid visually. The black line acts as simulation results; meanwhile, the yellow line acts as reference data. The differences are only the matter of amplitude of the behavior. Figure 8 is actually the same with Figure 4, which acts as the source of three kinds of output as Figure 5, Figure 6, and Figure 7, therefore create similar behavior. Finally, the model is also valid statistically since the AME of variable waste is only 2.11%, far below 10% tolerance.

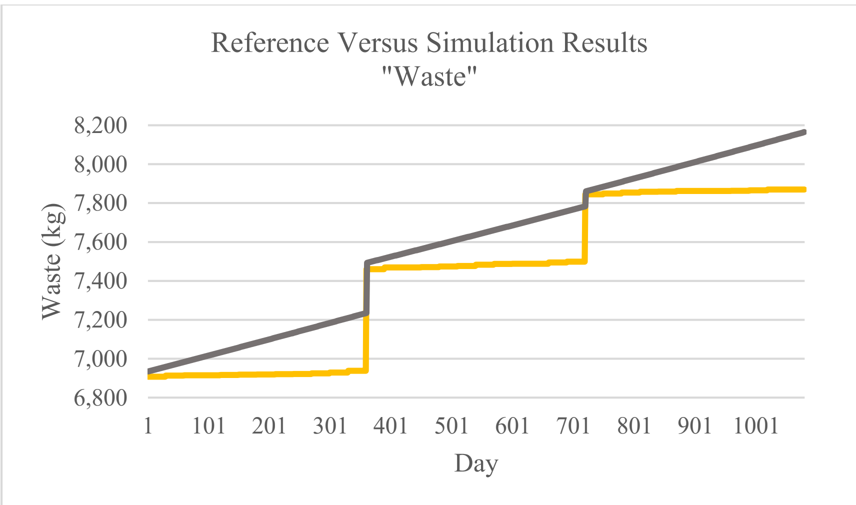

Figure 8. Reference data (yellow line) versus simulation results of waste (grey line)

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3.4 Intervention

Intervention to the model is applied in leverage variables. In this model, the leverage variables chosen are retribution and TPST cash flow. These two variables are chosen after several trials-and-errors to the model simulation. As the main goal is to decrease reside transferred to final disposal site, residue tend to decrease significantly although only little intervention is done in these two variables. These two variables need intervention from stakeholders; management has no external funding sources and depends most recently on internal capital. The waste management initiative should explore economic options—for example, through taxing such as retribution. In a related manner, environmental science offers a concept called payments for environmental services. It develops incentive mechanisms between environmental service providers (TPST management) and environmental service consumers (Common & Stagl, 2005; Suparmoko & Suparmoko, 2011; Prokofieva, Wunder, & Vidale, 2011). The BAU and intervention differences are shown in Table 1.

Table 1. Data for BAU versus intervention scenario

Leverage Variables (Unit)	BAU	Intervention
Retribution (rupiah/family/day)	400	500
TPST cash flow (rupiah)	0	1,000,000

Running the simulation of the intervention scenario shows a significant increase of variable inorganic waste and compost (Table 2). This means that compost production has the potential to be implemented even at the home level (Loan, Takahashi, Nomura, & Yabe, 2019). It would need further research. At the same time, this scenario reduces variable residue. In other words, the intervention will reduce the amount of waste transferred to TPA. It would be very helpful to reduce the environmental burden of TPA Jatiwaringin where the residue from TPST Mustika Ikhlas is usually transferred to. Alongside the model constructed, future waste management should include information system-based technology (Patil, Mohite, Patil, & Joshi, 2017). The challenge is how to adopt this system to the local society.

Table 2. BAU versus intervention scenario of inorganic waste and compost

Day	BAU Scenario of Inorganic Waste (kg)	Intervention Scenario of Inorganic Waste (kg)	BAU Scenario of Compost (kg)	Intervention Scenario of Compost (kg)
0	0	0	0	0
360	74,172.15	86,761.88	301,598.91	455,780.17
720	156,906.42	183,240.59	669,123.07	996,021.18
1080	249,460.52	290,213.64	1,126,621.86	1,634,953.54
1440	345,626.34	401,358.55	1,604,192.15	2,301,058.89
1800	445,525.36	516,818.18	2,100,358.67	2,993,080.85

4. Conclusions

Based on the results and discussions, we conclude that waste management at TPST Mustika Ikhlas is best captured by a system dynamics model. From the model, we have shown that:

a. Waste management in TPST Mustika Ikhlas successfully reduced waste, although there are still areas for future improvements.
b. The model shows valid, exponential behaviors.
c. Intervention should focus on variable retribution and TPST cash flow.

Integrated waste management is a role model that can be implemented in other regions and communities in Indonesia. Managerial social cohesion is a key to success, even if there is no government intervention. Our conclusions have several limitations. Waste quantities are translated from annual data, not daily data. Also, the model does not consider the whole life cycle of waste management. Finally, any residue (and its transportation to a final disposal site) is not addressed in the model. Therefore, we hope future research involves a more holistic approach.

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