# The Validation of Municipal Solid Waste Dynamic Model in Bangkok

Chaiwat Manasakunkit, and Thanwadee Chinda

***Abstract*****—**Bangkok, the capital of Thailand faces the issues of municipal solid waste management over the years. These wastes, if not completely recycled, will create the environmental problems. Many researches are conducted to manage wastes. A dynamic model of municipal solid waste, one of the waste management tools was developed using system dynamic modeling approach. There is, however a need to validate the model to be able to use in real practices. In this study, therefore the three validity methods, including the dimensional consistency, the extreme conditions, and the behavior sensitivity tests are performed. The results confirm the validation of the model, with the confident in the future use.

***Keywords*****—** Municipal solid waste, system dynamic modeling, validity methods, waste management.

## I. Introduction

WITH the rapid population increased in Asian developing countries, municipal solid waste generation and management becomes a major social and environmental issue [1]. Thailand, situated in the heart of the Southeast Asian mainland, is approaching as newly industrialized country status with increasing number of population, both locals and tourists [2]. According to [3], the higher number of population, the more municipal solid waste it is. While landfilling is a major method of waste disposal, the city faces the problem of the landfill shortage that leads to a number of environmental impacts [4]. This has aggravated the problems of municipal solid waste management.

Due to those issues, the Bangkok Metropolitan Administration (BMA) needs a comprehensive solution to overcome municipal solid wastes and disposal problem in the city [4], [5]. The dynamics model of municipal solid waste in Bangkok, Thailand, was developed using the system dynamics approach [6], [7]. The model, however, needs to be validated and verified to ensure the sensitivity of the model. This paper, therefore, aims to validate the dynamic model of municipal solid waste using three common methods, namely the dimensional consistency, the extreme conditions, and the behavior sensitivity tests. It is expected that the validated model assists the decision makers to better understand and make effective waste management plan.

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## II. The Municipal Solid Waste Dynamic Model

The municipal solid waste dynamic model (Fig. 1) consists of four sub-models, namely 1) the Householders dynamic model, 2) the Government Officers dynamic model, 3) the Recycled Shop Workers dynamic model, and 4) the Total Recycled Wastes dynamic model [6], [7]. The Householders dynamic model represents the amount of recycled wastes collected from the householders implementing the recycling program (see (1)). In this study, the amount of recycled wastes is accumulated from the three areas, namely Tharaeng, Nongkam and Onnuch, in Bangkok, Thailand (see (2)). The cooperation of the householders in the recycling program was set as 4, 5, 7.5, and 12.5 percent in the first four years, respectively, and varies for 0 to 3 percent afterwards, as in (3) [8].

$$\begin{aligned}\text{Total\_RA\_by\_HH}(t) = {} & \text{Total\_RA\_by\_HH}(t - dt) + \\ & (\text{RA\_by\_HH}) * dt\end{aligned} \tag{1}$$

$$\begin{aligned}\text{RA\_by\_HH} = {} & \text{Real\_RA\_at\_Th} + \text{Real\_RA\_at\_Nk} \\ & + \text{Real\_Ra\_at\_On}\end{aligned} \tag{2}$$

$$\begin{aligned}\text{RA\_inflow\_Th} = {} & \text{If } (\text{TR\_Th} > 1) \text{ then (If} \\ & (\text{Year\_count} = 1) \text{ then } (0.04 * \\ & \text{TR\_Th}) \text{ else if } (\text{Year\_count} = 2) \\ & \text{then } ((0.05 * \text{TR\_Th})) \text{ else if} \\ & (\text{Year\_count} = 3) \text{ then } (0.075 * \\ & \text{TR\_Th}) \text{ else if } (\text{Year\_count} = 4) \\ & \text{then } (0.125 * \text{TR\_Th}) \text{ else} \\ & (\text{TR\_Th} * \text{Total\_random\_percentage}) \\ & \text{else } (\text{TR\_inflow\_Th})\end{aligned} \tag{3}$$

The Government Officers dynamic model describes the recycled amount achieved from fulltime government officers (see (4) and (5)). This model considers hiring more government officers to sort the recyclable wastes. The process continues as long as the benefits of hiring officers, compared to the costs incurred, are high (see (6), (7) and (8)). Benefits represent the saving in the transportation cost to landfill and the money derived from selling the recycled wastes. Conversely, costs represent the wage of fulltime government officers and the transportation cost to the recycled shops [4], [5].

Based on [9], the hired amount of fulltime officers varies from 2 to 12 percent each year. However, the hired amount must not exceed 400 persons per year based on the allowed environmental-related budgets of the Department of Environment Bangkok in the last six years [9].

$$\text{Total\_RA\_by\_GO}(t) = \text{Total\_RA\_by\_GO}(t - dt) + (\text{RA\_by\_GO}) * dt \tag{4}$$

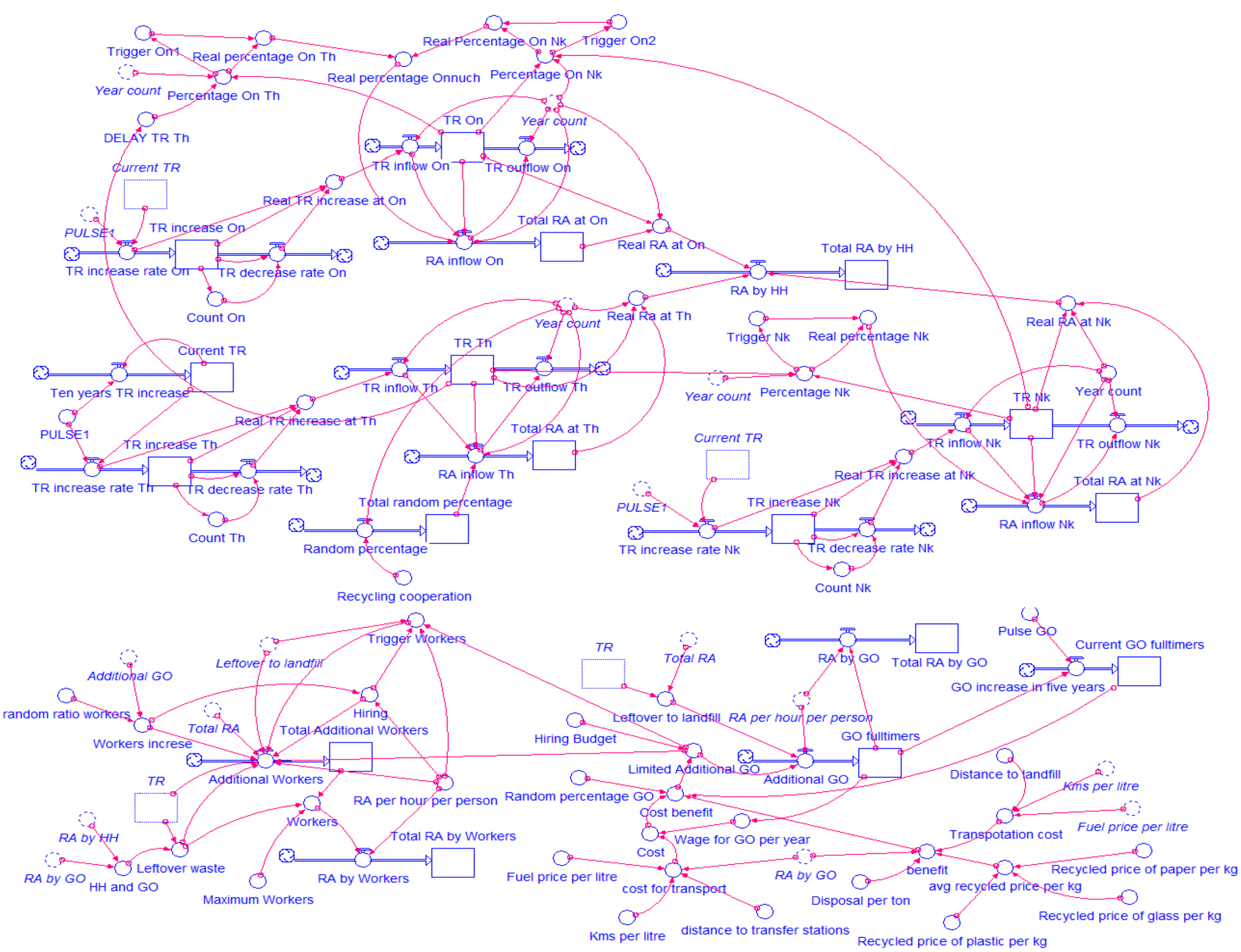
$$\text{RA\_by\_GO} = (\text{RA\_per\_hour\_per\_person} * 8 * \text{GO\_fulltimers} * 246) \tag{5}$$

$$\text{GO\_fulltimers}(t) = \text{GO\_fulltimers}(t - dt) + (\text{Additional\_GO}) * dt \tag{6}$$

$$\text{Additional\_GO} = \text{if } (\text{Leftover\_to\_landfill} > 0) \text{ then } \text{MIN}(\text{INT}((\text{Leftover\_to\_landfill}) / ((\text{RA\_per\_hour\_per\_person}) * 246 * 8)), \text{INT}(\text{Limited\_Additional\_GO})) \text{ else } (0) \tag{7}$$

$$\text{Cost\_benefit} = \text{if } (\text{Cost} > \text{benefit}) \text{ then } (0) \text{ else if } (\text{Cost} < \text{benefit}) \text{ then } (\text{Current\_GO\_fulltimers} * \text{Random\_percentage\_GO}) \text{ else } (0) \tag{8}$$

The Recycled Shop Workers dynamic model represents the amount of recycled wastes sorted by the recycled shops' workers at transfer stations (see (9) and (10)). Based on [10], the amount of workers must not exceed 9,000 persons due to the limited space at the transfer stations (see (11)). Once the amount of recyclable wastes reduces to half, the number of recycled shop workers varies from 6,000 – 9,000 persons per year (see (11)). This is due to the less attraction of the workers in the sortation of the recycled wastes.




Note: TR = Total recyclable wastes RA = Recycled wastes amount HH = Householders Th = Tharaeng
Nk = Nongkam On = Onnuch GO = Government officers Workers = Recycled shop workers

Fig. 1 The municipal solid waste dynamic model

$$\text{Total\_RA\_by\_Workers}(t) = \text{Total\_RA\_by\_Workers}(t - dt) + (\text{RA\_by\_Workers}) * dt \quad (9)$$

$$\text{RA\_by\_Workers} = \text{Real\_additional\_workers} * (\text{RA\_per\_hour\_per\_person}) * 8 * 365 \quad (10)$$

$$\text{Real\_additional\_workers} = \text{If (Leftover\_waste} = 0) \text{ then (If (Total\_Additional\_Workers} > 9000) \text{ then } 9000 \text{ else Total\_Additional\_Workers) else random}(6000,9000,1) \quad (11)$$

Lastly, the Total Recycled Wastes dynamic model represents the sum of recycled amounts achieved from three dynamic models (see (12)). Its maximum amount must, however, not exceed the amount of the total recyclable wastes.

$$\text{Total\_RA} = \text{If (Total\_TR} > (\text{RA\_by\_GO} + \text{RA\_by\_HH} + \text{RA\_by\_Workers})) \text{ then } (\text{RA\_by\_GO} + \text{RA\_by\_HH} + \text{RA\_by\_Workers}) \text{ else Total\_TR} \quad (12)$$

## III. The Validation of The Dynamic Model of Municipal Solid Waste

Validation is one of the most important parts of the system dynamics modeling. No model can be accepted unless it has passed the validation tests, as they guarantee the development of high quality and robust model [11], [12].

In this study, the evaluation tests are performed to each sub-model using the three basic evaluation tests, including the dimensional consistency, the extreme condition, and the behavior sensitivity tests [13]. The two former tests examine the possible errors and oversights of the model, while the latter one helps in understanding the influence of each variable on the model behavior. Details of each test are as below.

### *A. Dimensional Consistency Test*

The dimensional consistency test is a powerful test to establish the internal validity of model. It checks if the units measure of variables on both sides of the equation are equal [13]. It also checks whether dimensions of variables in the model correspond to the unit they express in the real world.

The test is conducted using the built-in function of program in the system dynamics software called Ithink. The results show that all units in the four sub-models (Householders, Government Officers, Recycled Shop Workers, and Total Recycled Wastes) are dimensional consistent.

### *B. Extreme Conditions Test*

The extreme conditions test is a very strong procedure for evaluating system dynamics models structure. It checks whether the behavior of the model in extreme conditions matches the behavior of the real system in same situations [13]. For example, if the recycled amount of the Householders, Government Officers, and Recycled Shop Workers dynamic model are zero, then the total recycled amount should be zero.

In the Householders dynamic model, the extreme condition test is carried out with the assumption that the percentage of the cooperation in the recycling program is zero. This results in the recycled amount of zero (Fig. 2), which is contrast from the recycled amount achieved in the base run simulation (see Fig. 3). This behavior is consistent with the real situation when the householders do not implement the recycling program, and that the amounts of recycled wastes from the householders are not achieved.

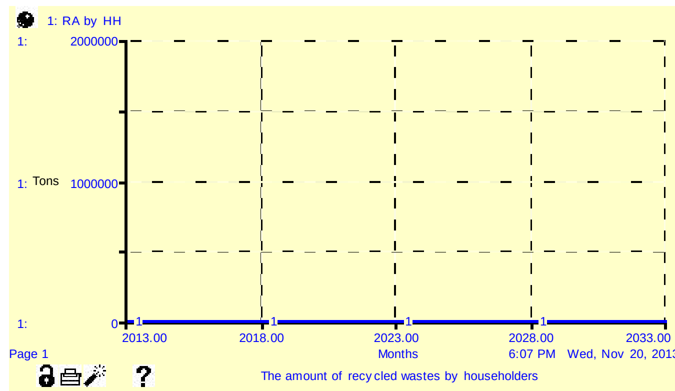



Fig. 2 The recycled amount by householders when the percentage of the cooperation by householders is zero

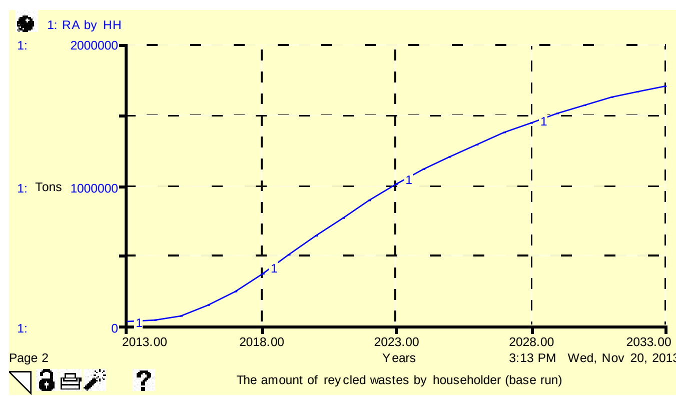



Fig. 3 The base run results of the recycled amount by householders

In the Government Officers dynamic model, the extreme conditions test is carried out, with the assumption that the additional fulltime officers are zero. When the government decides not to hire more fulltime officers, the amount of recycled wastes will be equal to those sorted by the current officers (1,785 persons, with the capacity of 107,779 tons per year) (see Fig. 4). This is, again, contrast with the results achieved in the base run simulation (see Fig. 5). This, in real situation, happens when the government does not have budget available to hire more fulltime officers, and that the amount of recycled wastes will not be increased.

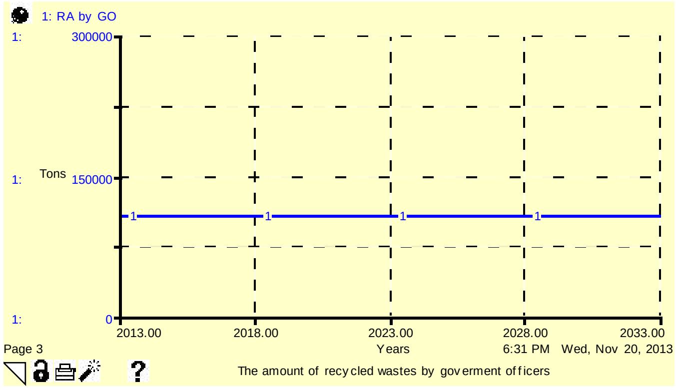



Fig. 4 The recycled amount by government officers when the additional fulltime officers are zero

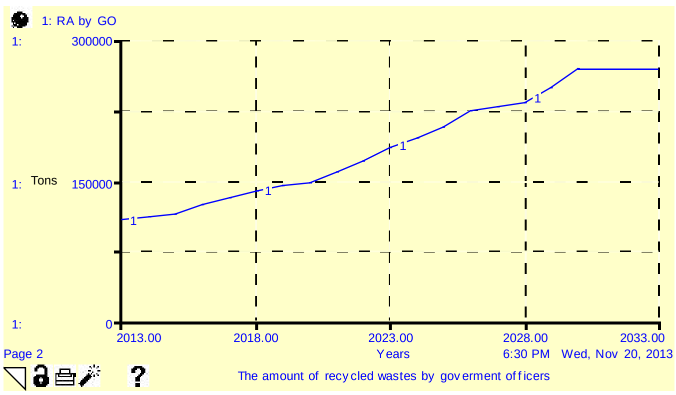



Fig. 5 The base run results of the recycled amount by government officers

In the Recycled Shop Workers dynamic model, the extreme conditions test is also conducted with the amount of additional workers are zero. With no additional workers, the amount of recycled wastes sorted by the workers will be constant (Fig. 6), which is different from the results in the base run simulation (see Fig. 7).

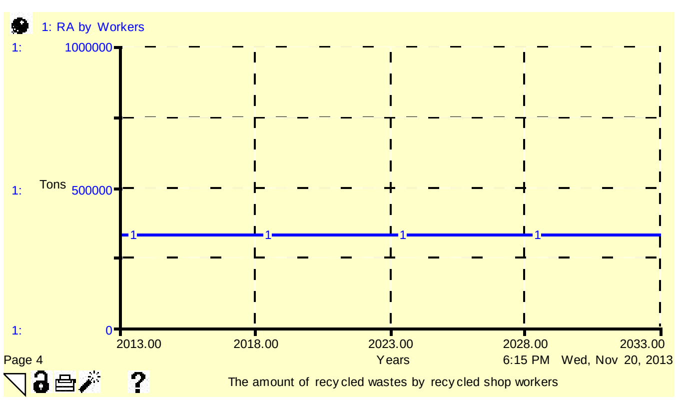



Fig. 6 The recycled amount by recycled shop workers when the additional workers are zero

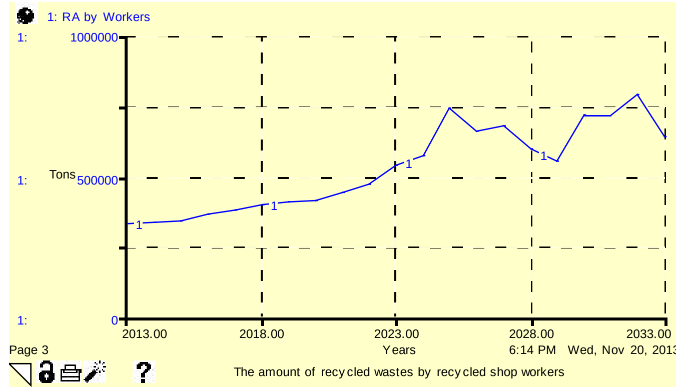



Fig. 7 The base run results of the recycled amount by recycled shop workers

With the extreme conditions tests in the Householders, Government Officers, and Recycled Shop Workers dynamic models, the amount of total recycled wastes in the Total Recycled Wastes dynamic model are as shown in Fig. 8. This is contrast to the results in the base run simulation (see Fig. 9).

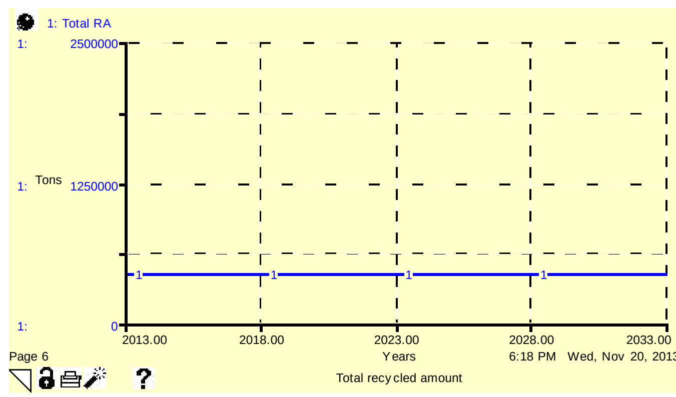



Fig. 8 The total recycled amount when the extreme conditions tests in three sub-models are conducted

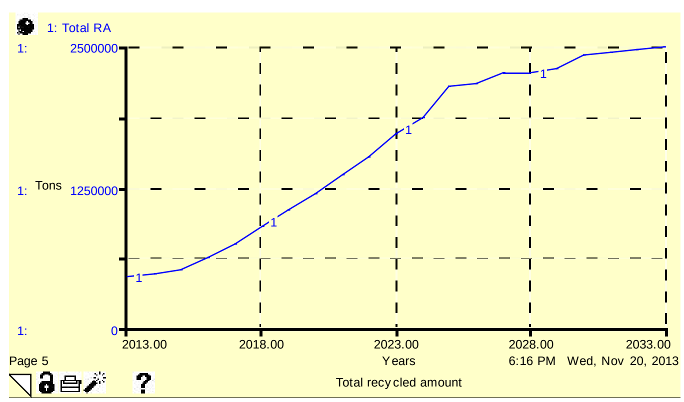



Fig. 9 The base run results of the total recycled amount

### *C. Behavior Sensitivity Test*

The behavior sensitivity test focuses on sensitivity of model when parameters are changed [13]. It examines if small changes cause significant change in the model behavior. If the model is not sensitive to the changes of some parameters, the model can be proved as reliable.

The sensitivity test is conducted with the Householders dynamic model by changing the cooperation percentage in the recycling program. This percentage depends mainly on the successful of the program implementation. In this study, the percentage after year 4 varies from the lowest of 1 percent to the highest of 5 percent. The simulation results (Fig. 10 and 11) show that with higher cooperation percentage, the amount of recycled wastes is higher. This is vice versa with the low cooperation percentage.

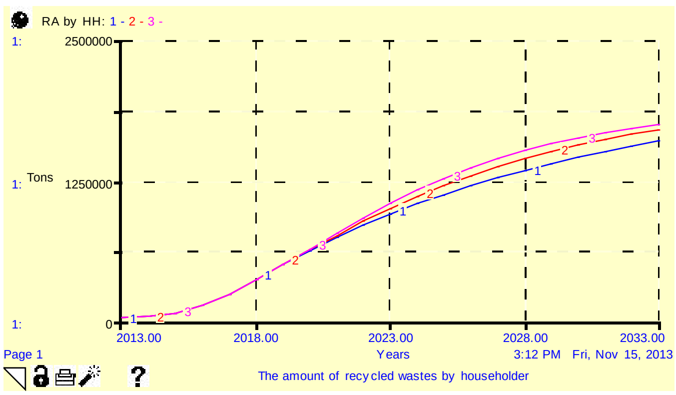



Fig. 10 The sensitivity results of the recycled amount by householders

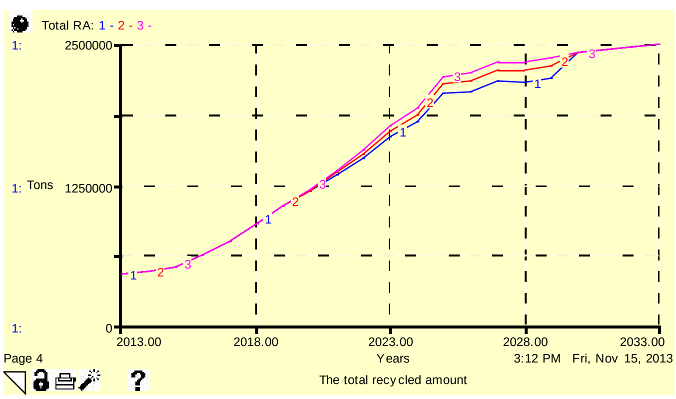



Fig. 11 The total recycled amount when the cooperation percentage of householders are changed

In the Government Officers dynamic model, the behavior sensitivity test is conducted by varying the maximum number of additional fulltime officers the government can hire, from the lowest of 200 to the highest of 400. The graphical results (Fig. 12 and 13) show that when the maximum number of additional officers is high, the capacity of recycling wastes by government is high. This is contrast with the low number of officers.

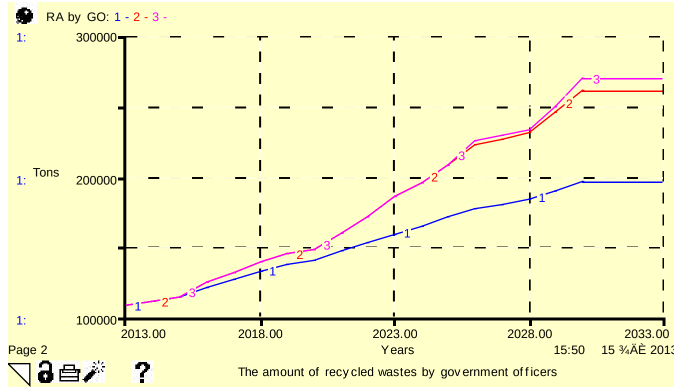



Fig. 12 The sensitivity results of the recycled amount by government officers

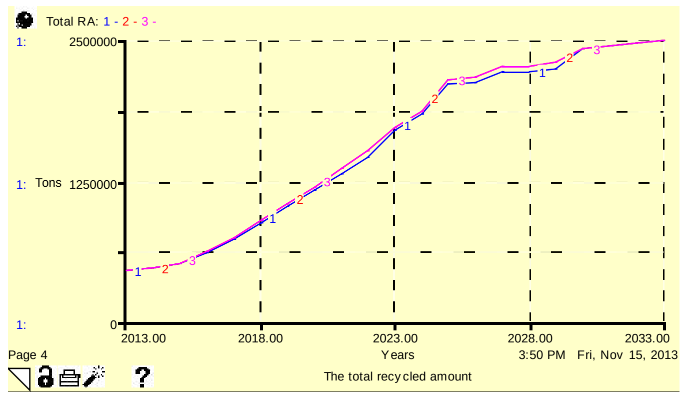



Fig. 13 The total recycled amount when the maximum number of additional fulltime officers are changed

The same sensitivity is also conducted in a similar way of that in the Recycled Shop Workers dynamic model. The maximum number of workers allowed in the transfer stations varies from 6,000 to 9,000 persons. The results in Fig. 14 and 15 reflect the recycled wastes amount.


Fig. 14 The sensitivity results of the recycled amount by recycled shop workers

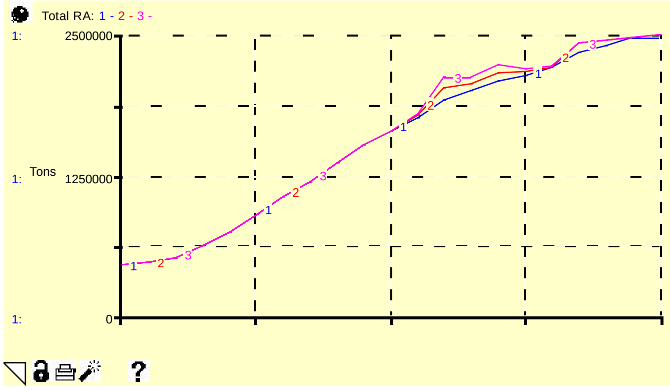



Fig. 15 The total recycled amount when the maximum number of workers are changed

## IV. Conclusion

Model validation is an important aspect of system dynamics modeling. In this study, the three validation tests are performed. The dimensional consistency test confirms the units of all four sub-models. The extreme condition test shows that the four sub-models reflect the real situations. The results from the behavior sensitivity test also prove the non-sensitive models.

The validated model of municipal can then be used to test policies, related to the recycling program, so that the organization can plan for its implementation.

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