# THE DEVELOPMENT OF A BASIC DYNAMIC MODEL OF HOUSEHOLD WASTE RECYCLING

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**Abstract**
Thailand, one of the developing countries in Southeast Asia, has witnessed an accumulating problem in waste management and disposal. Twenty percent of municipal solid waste generation in country comes from Bangkok. This is due to the high amount of householders in Bangkok. While landfilling is a major method of waste disposal, the country faces the problem of the landfill shortage that leads to a number of environmental impacts. Householders are considered one of the key persons in recycling the recyclable waste in Bangkok. This paper, therefore, utilizes the system dynamic modeling technique to analyzing the relationships among various factors of household waste management in Bangkok, Thailand. Different recycling strategies are simulated, and the results help in better understanding of household waste situation, and planning for household waste management.

**Keywords**: Householders, Municipal Solid Waste, Recycle, System Dynamic Modeling

## 1. INTRODUCTION

Municipal solid waste (MSW) is materials also known as rubbish, generated from household and industrial sources that have no use in its present form or condition (Cotter 2000). It is found that with the economic development, the urbanization and the living standard in cities, the quantity of MSW increased (Khajuria et al. 2010). Thailand, one of the developing countries in Southeast Asia with a current population of 69 million, has witnessed an accumulating problem in waste management and disposal (Thaniya 2009). The country's MSW generation shows an increasing trend parallel to the growth of economic urbanization and population (Visvanathan et al. 2004). The country currently generates 40 thousand tons of waste per day, in which, 20 percent of them come from Bangkok (Administrative Strategy Division 2011). This is due to the high amount of households in Bangkok. The majority of these wastes are then disposed of into landfill (Manomaivibool 2005).

While the amount of wastes keeps increasing, the amount of landfill keeps decreasing. The scarcity of landfill might lead to a number of environmental impacts, such as water and air pollution and gas emission (Pohland and Harper 1985; Muttamara et al. 2004). Apart from that, the higher land cost, the opposition of landfill siting, and more restrictive environmental regulations regarding the siting and operation of landfills, lead to more consideration of waste management (Leao et al. 2001).

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Despite the efforts to reduce and recover the MSW, landfilling is still the most usual destination for MSW in Bangkok (Manomaivibool 2005). Nonetheless, the monitor of landfill for waste disposal has not been fully studied and, in particular, quantified. This paper, therefore, aims at analyzing the relationships among various factors of household waste management in Bangkok, Thailand, using the system dynamic modeling technique. It is expected that the developed model helps in better understanding of household waste situation, and planning for household waste management.

## 2. CHARACTERISTICS OF MSW IN BANGKOK

The amount of MSW generation in Bangkok was doubled in 2011, reaching 9,237 tons per day (Administrative Strategy Division 2011). According to the Administrative Strategy Division (2009), 60 percent of the total waste could be recycled. These include mainly glass, plastic and paper. It is, however, found that only three percent of them are actually recycled at the transfer stations (see Figure 1), and the rest of them are sent to landfill.

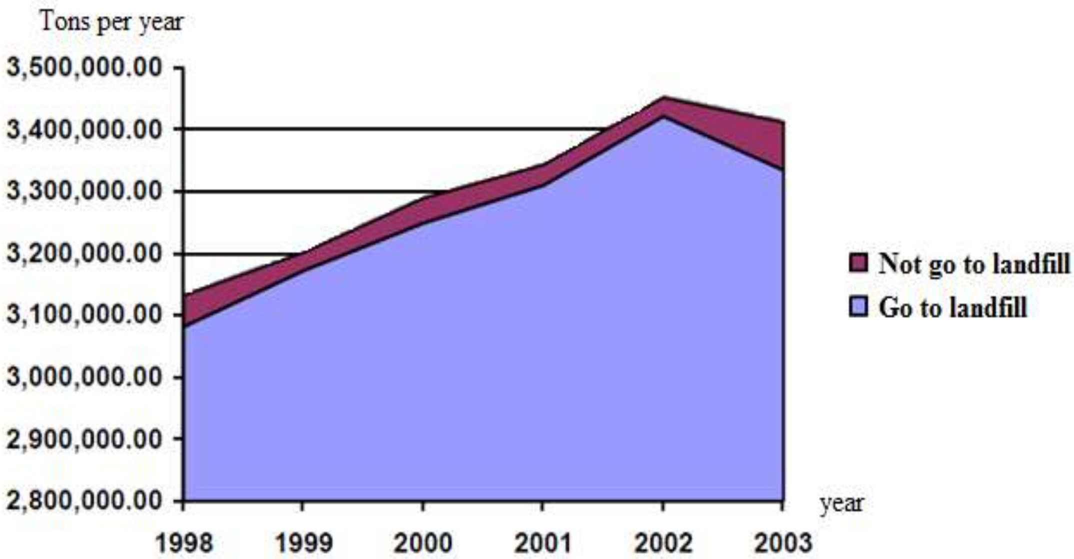



**Figure 1:** Proportion of waste at transfer stations that go to landfill (Manomaivibool 2005)

The collected MSW in all areas in Bangkok is sent to three transfer stations, namely 1) Tharaeng station, 2) Nongkhaem station, and 3) Onnuch station, before tranfering to the Kampaengsan and Phanomsarakham landfills located in nearby provinces (Manomaivibool 2005).

Based on Administrative Strategy Division (2011), the amount of wastes at each transfer station in 2011 was as shows in Figure 2. This information will later be used in the development of a basic dynamic model of household waste recycling utilizing the system dynamic modeling method. This method is a mathematical modeling technique for framing, understanding, and discussing complex issues and problems (Forrester 1958). It is a system analysis applied with dynamic problems arising in complex social, managerial, economic, or ecological systems (Forrester 1958). It is one of the popular techniques used in modeling the waste management project (Pons et al. 2009; Ojoawo et al. 2012). Pons et al. (2009), for example, developed the dynamic model for predicting the MSW generation in Andorra. Ojoawo et al. (2012) developed the dynamic model to define the amount of wastes and gas generation in Nigeria over a 100-year period.

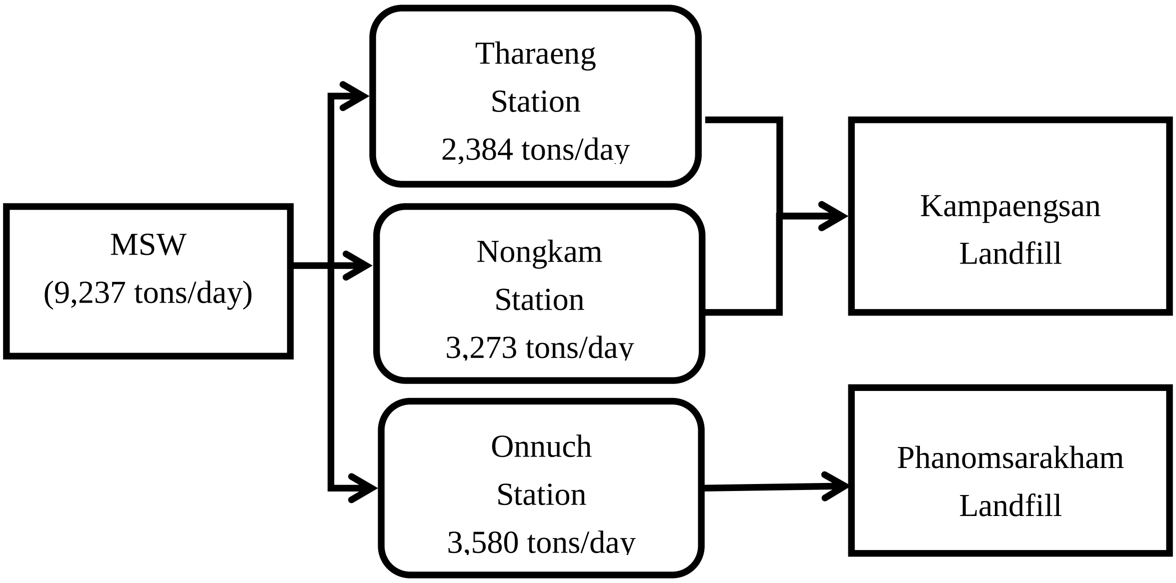
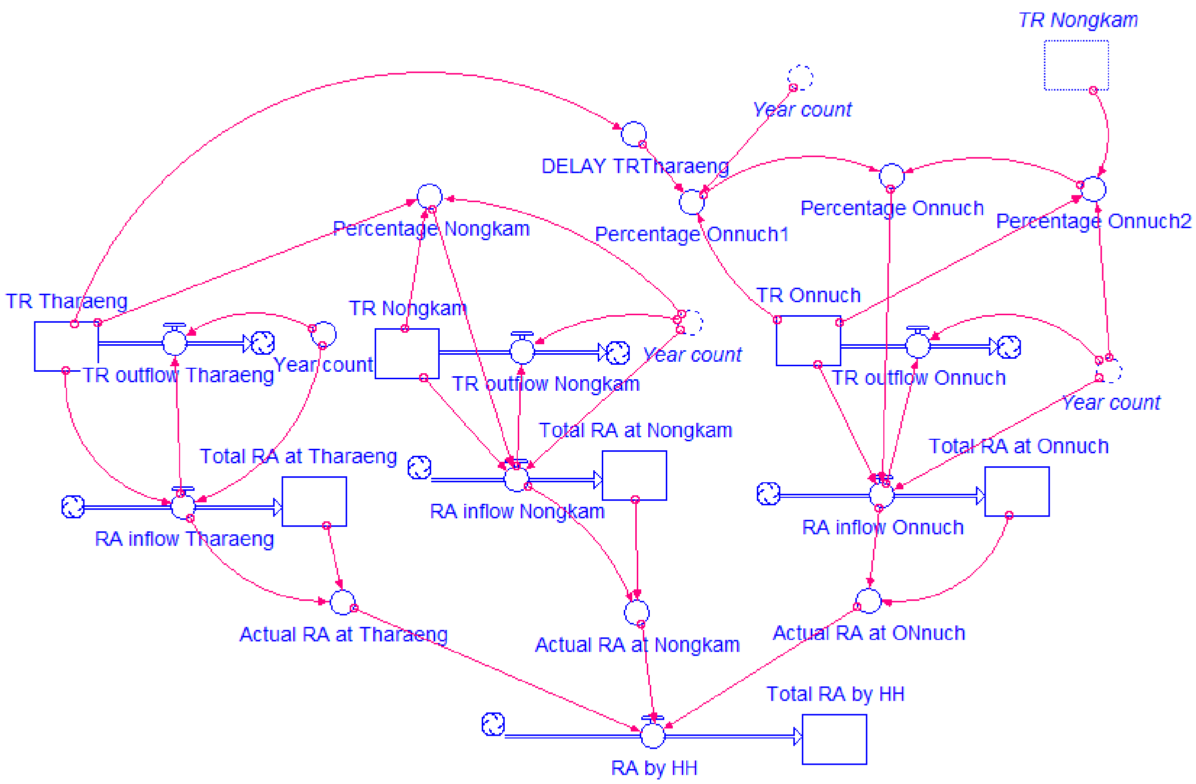



**Figure 2:** Proportion of wastes at the three transfer stations (Administrative Strategy Division 2011)

## 3. THE DYNAMIC MODEL OF HOUSEHOLD WASTE RECYCLING

Household is a major source of MSW generation (Manomaivibool 2005). While the householders generate more wastes, the wastes in system increase. As mentioned earlier, the major portion of these wastes could be recycled. It is assumed that, with a number of recycling programs implemented in Bangkok, less wastes will be disposed of and dumped into landfill. This leads to the conceptual model of household waste recycling (see Figure 3). The model is divided into four sub-models, include 1) The Tharaeng station model, 2) The Nongkam station model, 3) The Onnuch station model, and 4) The total recycled waste by household model.

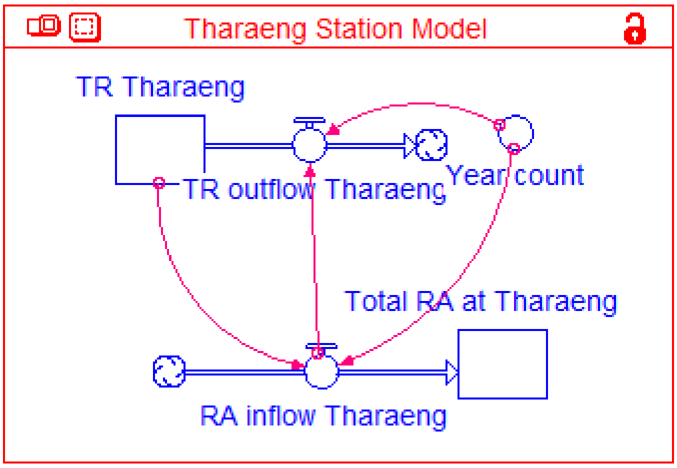



*Notes: TR=Total Recyclable Waste, RA=Recycled Waste Amount, HH=Householder*

**Figure 3:** The dynamic model of household waste recycling

## 3.1 The Tharaeng Station Model

The Tharaeng station model, as shown, in Figure 4, consists of two stocks, namely the "TR_Tharaeng" (the total recyclable amount of waste at Tharaeng station) and the "Total_RA_at_Tharaeng" (the total recycled amount achieved at Tharaeng station) stocks (see equations 1 and 2).




*Notes: TR=Total Recyclable Waste, RA=Recycled Waste Amount*

**Figure 4:** The Tharaeng station model

TR_Tharaeng(t) = TR_Tharaeng(t-dt)+(-TR_outflow_Tharaeng)*dt (1)

Total_RA_at_Tharaeng(t) = Total_RA_at_Tharaeng(t-dt)+
(RA_inflow_Tharaeng)*dt (2)

Based on the Institute for Local Government Initiatives (2003), the Nonthaburi Town Municipality (2004) and the Rayong Town Municipality (2010), the first year of recycling program implementation, resulted in few households incorporate in the recycling program (around one percent of all total recyclable waste). Once the program continued to be promoted, the amount of recycled waste in year 2 increased to 10 percent more of the efforts spent in year 1. The recycled amount achieved in year 3 increased to 25 percent more of those achieved in the past two years.

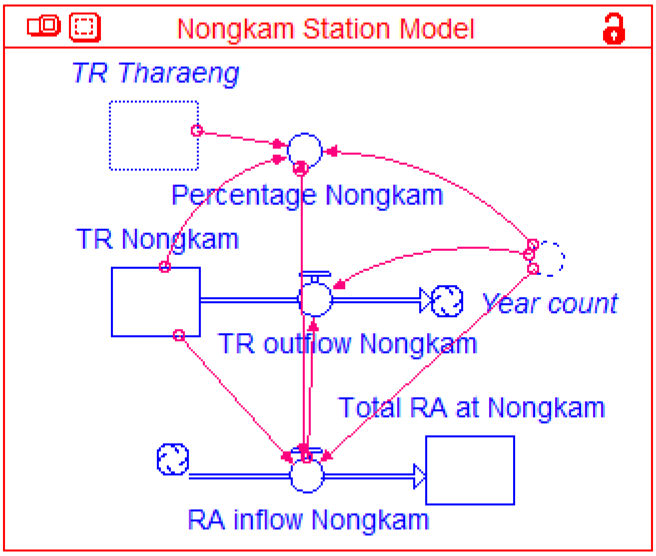
The percentage of recycled amount achieved in the $4^{th}$ year, however, decreased to 15 percent, as more government projects are introduced to the householders. This reduced the householders' attention to recycle wastes. Nevertheless, the percentage of householders participated in the recycling program increased by three percent every year after the $4^{th}$ year (see equations 3 and 4).

RA_inflow_Tharaeng = If (Year_count=1) then (TR_Tharaeng*0.01) else
if (Year_count=2) then ((0.10*TR_Tharaeng)) else if
(Year_count=3) then (0.25*TR_Tharaeng) else if
(Year_count=4 ) then (0.15*TR_Tharaeng) else
(TR_Tharaeng*(0.15+((0.03)*(Year_count-4)))) (3)

TR_outflow_Tharaeng = If (year_count>=1) then RA_inflow_Tharaeng else 0 (4)

## 3.2 The Nongkam Station Model

The Nongkam station model (see Figure 5) consists of two stocks, namely the "TR_Nongkam" (the total recyclable amount of waste at Nongkam station) and the "Total_RA_at_Nongkam" (the total recycled amount achieved at Nongkam station) stocks (see equations 5 and 6).




*Notes: TR=Total Recyclable Waste, RA=Recycled Waste Amount*

**Figure 5:** The Nongkam station model

TR_Nongkam(t) = TR_Nongkam(t-dt)+(-TR_outflow_Nongkam)*dt (5)

Total_RA_at_Nongkam(t) = Total_RA_at_Nongkam(t-dt)+
(RA_inflow_Nongkam)*dt (6)

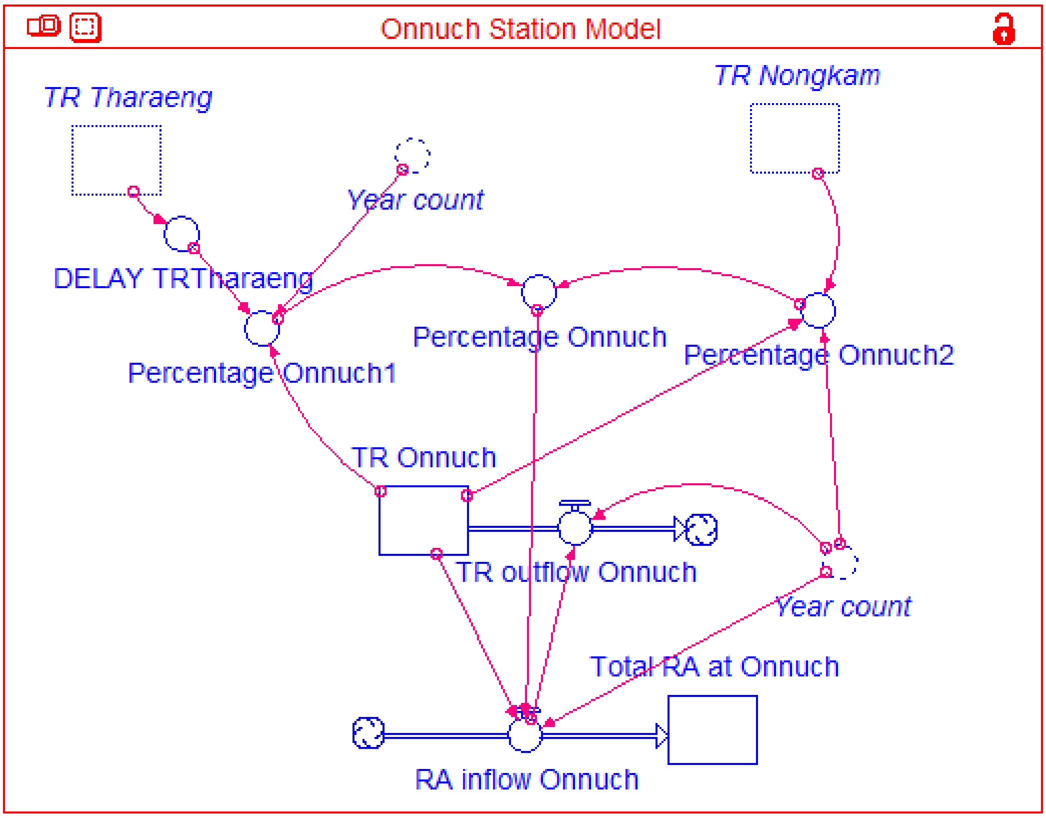
The recycling program is initiated at the Nongkam station in year 2. This is based on the assumption of using the Tharaeng station as a case study for the Nongkam station. The recycled amount achieved at this station is, therefore, a proportion of those attained at the Tharaeng station. This proportion is adjusted, in this case, by multiplying with 0.728, based on the total recyclable wastes of the three transfer stations. (see equations 7 and 8)

RA_inflow_Nongkam = If (Year_count=1) then (0) else if (Year_count>=2) then
(TR_Nongkam*Percentage_Nongkam*0.728) else 0 (7)

TR_outflow_Nongkam = If (year_count>=2) then RA_inflow_Nongkam else 0 (8)

## 3.3 The Onnuch Station Model

The Onnuch station model (see Figure 6) consists of two stocks, namely the “TR_Onnuch” (the total recyclable amount of waste at Onnuch station) and “Total_RA_at_Onnuch” (the total recycled amount achieved at Onnuch station) stocks (see equations 9 and 10).




*Notes: TR=Total Recyclable Waste, RA=Recycled Waste Amount*

**Figure 6:** The Onnuch station model

TR_Onnuch(t) = TR_Onnuch(t-dt)+(-TR_outflow_Onnuch)*dt (9)

Total_RA_at_Onnuch(t) = Total_RA_at_Onnuch(t-dt)+
(RA_inflow_Onnuch)*dt (10)

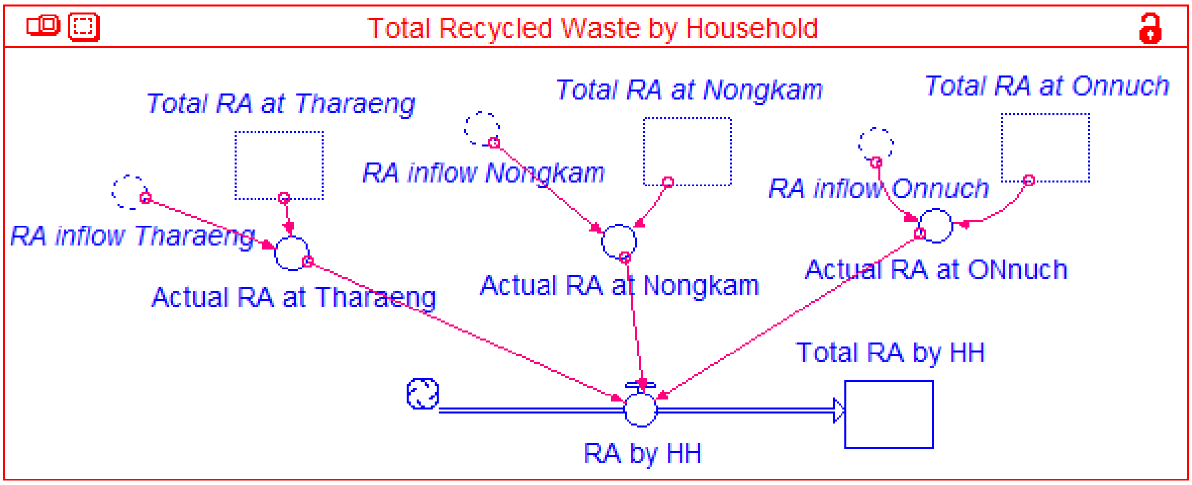
The recycling program is initiated at the Onnuch station in year 3. This is based on the assumption of using the Tharaeng and Nongkam stations as the case study for the Onnuch station. The recycled amount achieved at this station is, therefore, a proportion of those attained at the Tharaeng and Nongkam stations. This proportion is adjusted, in this case, by multiplying with 0.666, based on the total recyclable wastes of the three transfer stations, as shown in equations 11 and 12.

RA_inflow_Onnuch = If (Year_count<=2) then (0) else if (Year_count>=3)
then (TR_Onnuch*Percentage_Onnuch*0.666) else 0 (11)

TR_outflow_Onnuch = If (year_count>=3) then RA_inflow_Onnuch else 0 (12)

## 3.4 Total Recycled Waste by Household Model

The total recycled waste by household model (see Figure 7) consists of the "Total_RA_by_HH" (the total amount of recycled waste by householders) stock (see equation 13). This stock accumulated the recycled amount from the "RA_by_HH" inflow, which represents the total amount of recycled waste from the three transfer stations per year (see equation 14).




*Notes: TR=Total Recyclable Waste, RA=Recycled Waste Amount, HH= Household*

**Figure 7:** The total recycled waste by household model

$$Total\_RA\_by\_HH(t) = Total\_RA\_by\_HH(t - dt) + (RA\_by\_HH) * dt \quad (13)$$

$$RA\_by\_HH = Actual\_RA\_at\_Tharaeng + Actual\_RA\_at\_Nongkam + Actual\_RA\_at\_Onnuch \quad (14)$$

# 4. SIMULATION RESULTS

The household waste recycling dynamic model is simulated to examine the results of recycling program implementation overtime. The simulation results, as illustrated in Figure 8 and Table 1, reveal that the amount of recycled wastes from the three transfer stations increase as time increases. This is due to the success in the recycling program implementation.

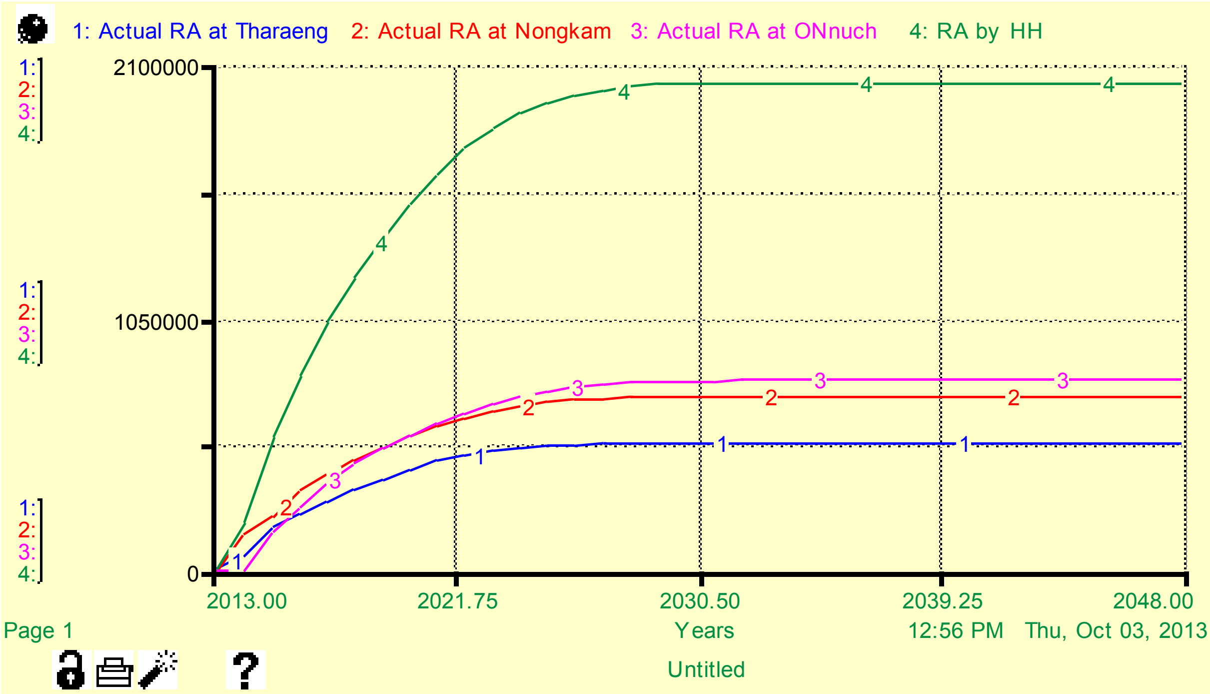



**Figure 8:** The recycled amount by householder in three transfer stations from year 2013-2047

Table 1 shows a steep curve of the recycled amount from year 2013 to 2027. After that, the amount of recycled wastes increase slowly, as it is very hard to achieve 100 percent recycled implementation. In this study, it takes 34 years to recycle all the recyclable wastes.

The Tharaeng station is capable in recycling all the recyclable wastes in 26 years (year 2039) as it has the least amount of wastes among the three transfer stations. Three years after that, the Nongkam station, which imitates the Tharaeng station program, could sort all the recyclable wastes (year 2042). Lastly, the Onnuch station can recycle all the wastes in 34 years. This implies that in year 2047, the wastes that go to landfill will contain zero percent of recyclable waste (which is 2,033,043.93 tons/year). It is therefore confirmed that encouraging the householders to recycle helps in reducing huge amount of wastes.

**Table 1**: The recycled amount by householder in each transfer station (tons/year)

| Year | Tharaeng station | Nongkam station | Onnuch station | Total recycled amount |
|---|---|---|---|---|
| 2013 | 5,246.10 | 0 | 0 | 5,246.10 |
| 2014 | 57,182.45 | 146,328.58 | 0 | 203,511.03 |
| 2015 | 174,039.25 | 223,939.61 | 160,752.62 | 558,731.49 |
| . | . | . | . | . |
| . | . | . | . | . |
| . | . | . | . | . |
| | | | | |
| 2027 | 521,356.91 | 711,700.24 | 768,983.38 | 2,002,040.53 |
| 2028 | 523,015.80 | 715,639.71 | 776,726.90 | 2,015,382.41 |
| 2029 | 523,876.47 | 717,918.92 | 781,624.92 | 2,023,420.31 |
| 2030 | 524,294.38 | 719,165.44 | 784,572.24 | 2,028,032.05 |
| 2031 | 524,483.53 | 719,808.72 | 786,258.34 | 2,030,550.60 |
| 2032 | 524,562.98 | 720,121.40 | 787,174.88 | 2,031,859.26 |
| 2033 | 524,593.77 | 720,264.29 | 787,648.11 | 2,032,506.17 |
| 2034 | 524,604.72 | 720,325.57 | 787,880.21 | 2,032,810.50 |
| 2035 | 524,608.26 | 720,350.21 | 787,988.39 | 2,032,946.86 |
| 2036 | 524,609.29 | 720,359.49 | 788,036.37 | 2,033,005.15 |
| 2037 | 524,609.56 | 720,362.76 | 788,056.67 | 2,033,028.99 |
| 2038 | 524,609.62 | 720,363.85 | 788,064.88 | 2,033,038.36 |
| 2039 | 524,609.64 | 720,364.19 | 788,068.08 | 2,033,041.90 |
| 2040 | 524,609.64 | 720,364.29 | 788,069.28 | 2,033,043.21 |
| 2041 | 524,609.64 | 720,364.32 | 788,069.71 | 2,033,043.67 |
| 2042 | 524,609.64 | 720,364.33 | 788,069.87 | 2,033,043.84 |
| 2043 | 524,609.64 | 720,364.33 | 788,069.93 | 2,033,043.90 |
| 2044 | 524,609.64 | 720,364.33 | 788,069.95 | 2,033,043.92 |
| 2045 | 524,609.64 | 720,364.33 | 788,069.95 | 2,033,043.92 |
| 2046 | 524,609.64 | 720,364.33 | 788,069.95 | 2,033,043.92 |
| 2047 | 524,609.64 | 720,364.33 | 788,069.96 | 2,033,043.93 |

## 4. CONCLUSION

The developed dynamic model of household waste recycling helps in better understanding of the municipal solid waste situation in Bangkok, and planning for waste management. It takes, in this case, 34 years to recycle all the recyclable waste at the three transfer stations. The recycle program should, therefore, be encouraged.

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