POLICY TESTING OF THE C&D WASTE RECYCLING MODEL

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Abstract
The number of construction and demolition (C&D) waste in Bangkok, Thailand is increasing continuously. The C&D wastes, comprising of concrete, brick, metal, ceramics, roofing, gypsum, and wood, can be classified into recyclable and non-recyclable wastes. These wastes, if not completely recycled, will create the environmental problems, such as water and air pollution, as well as gas emission. This paper utilizes a system dynamics modeling technique to develop a C&D waste recycling model to examine the factors affecting the recycling decisions in the construction industry in Bangkok, Thailand. A policy testing relating to the environmental budget is performed to investigate the recycling program implementation over time.

Keywords: Construction and demolition waste, Policy testing, Recycling program, System dynamics modeling

1. INTRODUCTION

With the significantly increase in population in Bangkok, a number of buildings are built to support and accommodate Bangkok citizens (United Nations University 1996). Since the higher amount of building and infrastructure has been constructed, the number of construction and demolition (C&D) waste is increasing continuously (Pollution Control Department of Thailand 2010). The C&D waste can be classified into two categories: recyclable (70%) and non-recyclable (30%) wastes. It is, however, found that not all the recyclable wastes are recycled. The leftover is, thus, dumped into landfills. The improvement of C&D waste management helps reducing the amount of C&D wastes, thus, decreasing the requirement of landfills (Hao and Scott 2001).

Past research on C&D waste management has mainly focused on the separate aspects of waste management, including waste reduction, reuse, recycle and response (Lawson et al.

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2001). In this paper, a dynamic model of C&D waste is developed using the system dynamics modeling technique to assist the decision makers to better understand and make decisions regarding the C&D waste.

2. THE CONSTRUCTION AND DEMOLITION WASTE RECYCLING DYNAMIC MODEL

Chinda et al. (2013) developed the C&D waste recycling model, as shown in Figure 1. The model is separated into four sectors, namely 1) the “cost” sector, 2) the “recycled waste” sector, 3) the “labor and machine” sector, and 4) the “leftover of C&D waste” sector. In the “cost” sector model, the “total cost” is a function of the “cost inflow”, which is the summation of the “transportation cost”, the “labor cost”, the “machine cost”, and the “storage cost” (see equations 1 and 2).

Total_cost(t) = Total_cost(t-dt)+(Cost_inflow)*dt (1)

Cost_inflow = Transportation_cost+Labor_cost+Machine_cost+Storage_cost (2)

The “labor and machine productivity” sector describes the labors and machines used in the sorting and recycling processes. The number of labors and machines increase, in different proportion between large- and medium- sized companies, as the recycling program proceeds (see equations 3 to 7). These amount of labors and machines dictate the labor and machine costs the company spends. They are, however, constant when the total labor and machine productivity exceeds the amount of C&D wastes to be recycled, or when the “cost inflow” exceeds the “environmental budget”. Based on the Bereau of the Budget (2011), 1.8 percent of total budget, which is 40 billion Baht, is used as the maximum budget allowed for the recycling related activities.

Labor_and_machine_productivity = Maximum_labor_productivity+ Maximum_machine__productivity (3)

Maximum_labor_productivity = Maximum_number_of__labors_hired*(0.026*250) (4)

Maximum_machine__productivity = Maximum_number_of__machines_purchased* 0.508*8*250 (5)

Maximum_number_of__labors_hired = Maximum_number_of_labor_hired_for_ large_sized_company+Maximum_number_ of_labor_hired_for_medium_sized_company (6)

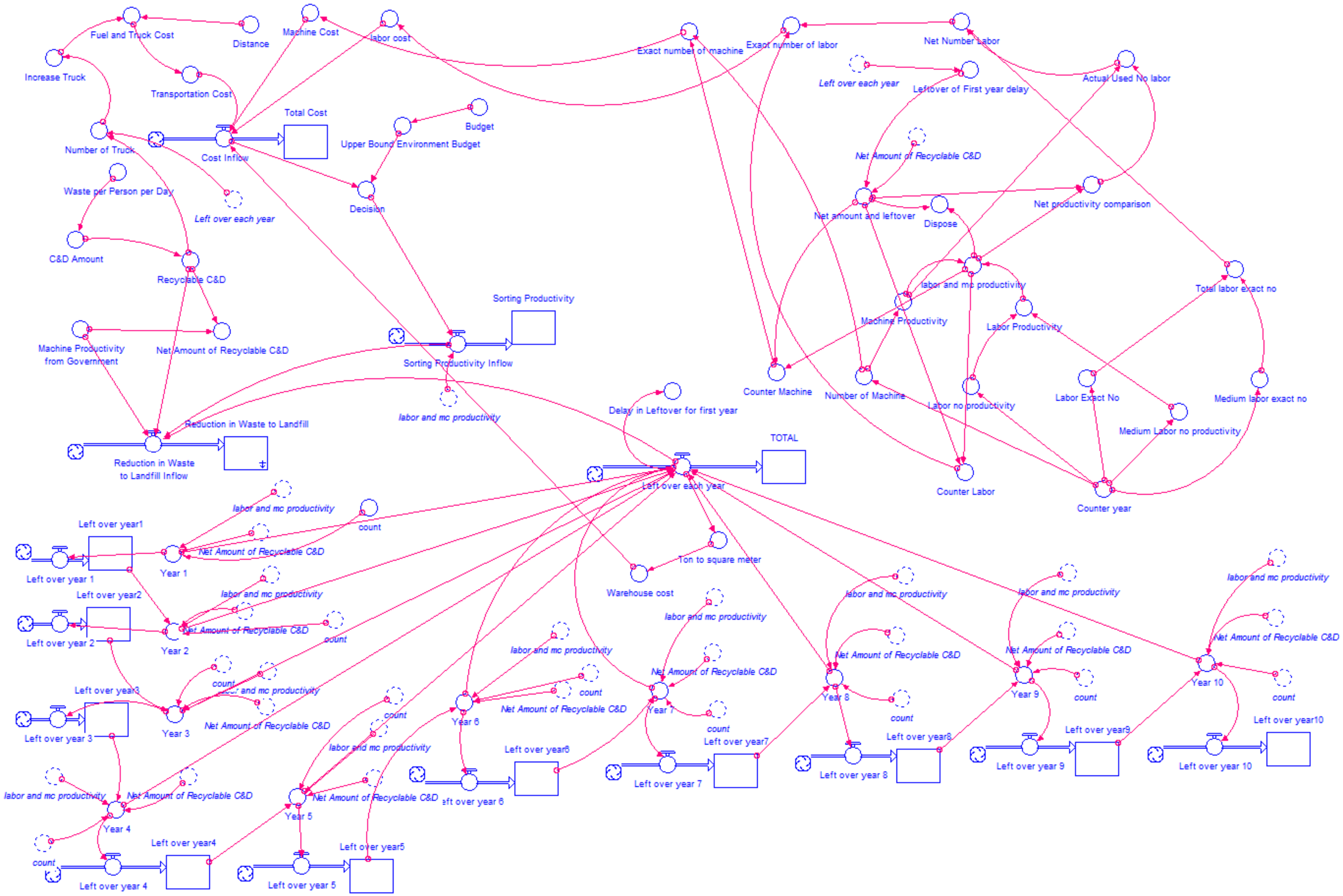

Figure 1: The C&D waste recycling dynamic model.

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Maximum_number_of__machines_purchased = 30*Counter_year (7)

The leftover model represents the leftover recyclable waste at the end of each year. It is calculated by subtracting the total amount of C&D waste with the recycled amount achieved from the labor and machine productivity (see equations 8 and 9).These leftovers are managed when there are available labors and machines. To explain, if the leftover amount in year 1, together with the amount of wastes generated in year 2, can be managed by labors and machines in year 2, then the leftover in year 2 is zero. This is vice versa if the labor and machine productivity is less than the amount of wastes to be sorted.

Total_leftover(t) = Total_leftover(t-dt)+(Leftover_amount)*dt (8)

Leftover_amount = (Year_1+Year_2+Year_3+Year_4+Year_5+Year_6+Year_7+
Year_8+Year_9+Year_10) (9)

Lastly, the recycled waste model represents the company's recycled amount, which depends mainly on the company's total productivity. Once all the C&D wastes are recycled, the total productivity remains constant, and the recyclable wastes to landfill become zero (see equation 10).

Amount of recyclable waste to landfill = (Total_recyclable_amount-
Government's_machine_productivity-
Company's_recycled_amount_inflow)+
Leftover_amount_each_year (10)

3. POLICY TESTING OF THE C&D WASTE RECYCLING MODEL

As mentioned earlier, the environmental budget available to implement the recycling program in the dynamic model is fixed at 40 billion baht. However, to reflect the real practices of the available budget, the policy testing is performed by varying the environmental budget from the lowest of five billion baht to the highest of 15 billion baht. This affects the number of labors the companies can hired, and the number of machines the companies can purchased.

Figure 2 and Table 1 show the simulation results of the policy testing. It is found that when the five billion baht of the environmental budget is considered, the company can recycle a maximum of 64,470 tons of wastes each year. This is due to the fact that there is not enough budget to hire more labors and buy more machines.

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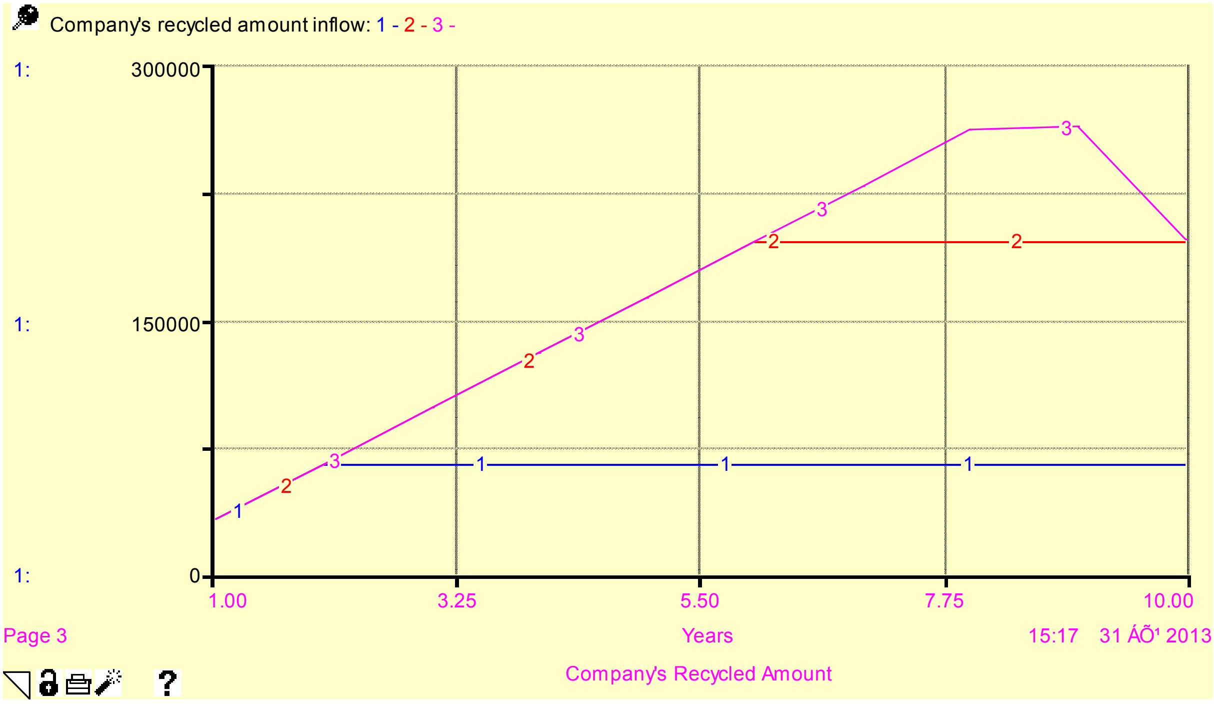

Note: "1" represents the 5 billion baht environmental budget, "2" represents the 10 billion baht environmental budget, and "3" represents the 15 billion baht environmental budget

Figure 2: Graphical results of the policy testing of different environmental budgets.

Table 1: Numerical results of the policy testing of different environmental budgets.

Year	5 billion baht environmental budget			10 billion baht environmental budget			15 billion baht environmental budget		
	Recycled amount (tons)	No. of labor	No. of machine	Recycled amount (tons)	No. of labor	No. of machine	Recycled amount (tons)	No. of labor	No. of machine
1	32,040	240	30	32,040	240	30	32,040	240	30
2	64,470	540	60	64,470	540	60	64,470	540	60
3	64,470	540	60	97,290	900	90	97,290	900	90
4	64,470	540	60	130,110	1,260	120	130,110	1,260	120
5	64,470	540	60	162,930	1,620	150	162,930	1,620	150
6	64,470	540	60	195,750	1,980	180	195,750	1,980	180
7	64,470	540	60	195,750	1,980	180	228,570	2,340	210
8	64,470	540	60	195,750	1,980	180	261,390	2,700	240
9	64,470	540	60	195,750	1,980	180	263,730	3,060	240
10	64,470	540	60	195,750	1,980	180	197,103.5	3,060	240

When the available budget is increased to a total of 10 billion baht, the company can recycle a maximum of 195,750 tons of wastes per year. This requires 1,980 labors, with 180 machines. This, however, does not cover all the amount of C&D waste, together with the leftover wastes, to be recycled. The company can recycle all the C&D wastes, as well as the leftover wastes, when the supported environmental budget is 15 billion baht. This requires 3,060 labors, with 240 machines.

It is noted that after year nine, the amount of recycle waste reduces from 263,730 tons to 197,103.50 tons. This reflects the real amount of C&D waste each year, with no leftover waste. However, the number of labors is kept constant at 3,060 persons after year nine (see Table 1). This could be explained that, with less waste to be recycled, some labors are transferred from the recycling activity to other related activities.

5. CONCLUSION

The C&D waste recycling dynamic model is developed using the system dynamics modeling. It consists of four sub-models, namely the cost, the labor and machine productivity, the leftover waste, and the recycled amount models. The model is simulated with different environmental budgets to reflect the amount of recycled wastes when this budget is low (not enough to hire more labors and purchase more machines) to high (can fulfill the resources requirement). The simulation results can be used as a guideline for making the recycling program implementation decision in the construction industry.

The C&D waste recycling dynamic model is, however, developed based on Thailand's data and information. Factors, such as inflation rate, employment rate, and environmental budget, used in the model are gathered mainly from Bangkok conditions, and must be adjusted accordingly to suit with each specific condition.

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