

The Development of the Construction and Demolition Waste Dynamic Model

T. Chinda, W. Engpanyalert, A. Tananoo, J. Chaikong, and A. Methawachananont

Abstract—With the higher amount of buildings and infrastructures in Bangkok, Thailand, the number of construction and demolition (C&D) waste is increasing continuously. These wastes, if not completely recycled, will create the environmental problems. This research paper concentrates on the use of a system dynamics modeling technique to develop a C&D waste recycling model. Data and related relationships were generated to develop the simulated equations to simulate the model to reflect real practices of the construction industry in Bangkok, Thailand. The simulation results reveal the improved C&D waste recycled over time.

Index Terms—Construction and demolition waste, recycling, system dynamics modeling

I. INTRODUCTION

Since higher amount of building and infrastructure has been constructed in Bangkok, Thailand, the number of construction and demolition (C&D) waste is increasing continuously [1]. The C&D wastes, comprising of concrete, brick, metal, ceramics, roofing, gypsum, and wood, can be classified into two categories: recyclable (70%) and non-recyclable (30%) wastes [2]. It is, however, found that not all the recyclable wastes are yet recycled, and are dumped into landfills. The improvement of C&D waste management, thus, helps reducing the amount of C&D wastes and landfill requirement [3].

Reference [2] mentioned an increasing trend of C&D waste generation of 26% from 2003-2006, following the increasing populations in Bangkok, Thailand. As C&D waste is one of the main solid waste generators in Bangkok, its impact on the environment has become an imperative issue to the stakeholders [4]. Past research has mainly focused on the separate aspects of waste management, such as waste reduction, reuse, and recycle [5]. In this research paper, a dynamic simulation model is developed, based on system dynamics methodology, to strategically plan the C&D waste management in Bangkok. The relationships between major factors inherently involved in C&D waste management, such as labors, machines, and related costs are considered. It is expected that the dynamic model assists decision makers to better understand and make decisions regarding the C&D waste recycling program.

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II. THE DEVELOPMENT OF CONSTRUCTION AND DEMOLITION WASTE DYNAMIC MODEL

In this paper, the system dynamics modeling is used to develop the C&D waste recycling model. The model consists of four sectors, namely “Cost”, “Recycled Waste”, “Labor and Machine”, and “Leftover of C&D Waste” sectors. Details of each sector are as following.

A. The Cost Sector

Fig. 1 shows 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”.

The “transportation cost”, as in (1), is based on the amount of trucks with their fuel costs. The “labor cost” depends mainly on the amount of labors used in the sorting and recycling processes, see (2). The “machine cost”, as in (3), in the same way, increases as the number of machine used in the sorting process increases. The “storage cost” refers to the cost the company pays to store the C&D waste before transferring to the next recycling steps, see (4).

$$\text{Transportation cost} = \text{Fuel_cost_to_recycle_shop} + \text{Truck_cost_to_recycle_shop} + \text{Fuel_and_truck_cost_for_truck_to_landfill} \quad (1)$$

$$\text{Labor cost} = \text{Exact_used_number_of_labor} * 300 * 250 \quad (2)$$

$$\text{Machine cost} = ((\text{MEAN}(28620, 39725)) * 30) * \text{Machine_purchasing} \quad (3)$$

$$\text{Storage cost} = \text{DELAY}(\text{Storage_capacity} * (150 * 12), 1, 0) \quad (4)$$

B. The Labor and Machine Productivity Sector

The “Labor and Machine Productivity” sector (as shown in Fig. 2) describes the labors and machines used in the sorting and recycling processes. The number of labors and machines are increasing as the recycling program proceeds, see (5), (6). 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”, see (7)-(9).

This environmental budget is the upper bound of budget the company could spend to implement the C&D waste recycling program. Based on references [6], [7], 1.8 percent of total budget is used to determine the upper bound, which is 40 billion Baht in this case.

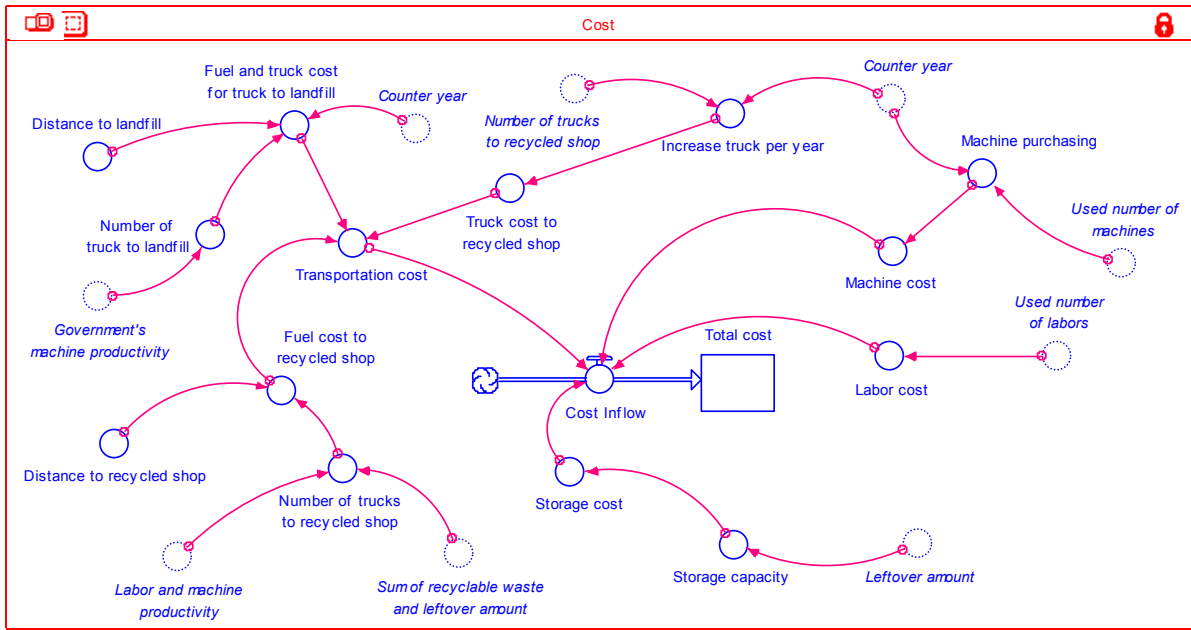


Fig. 1. The cost model.

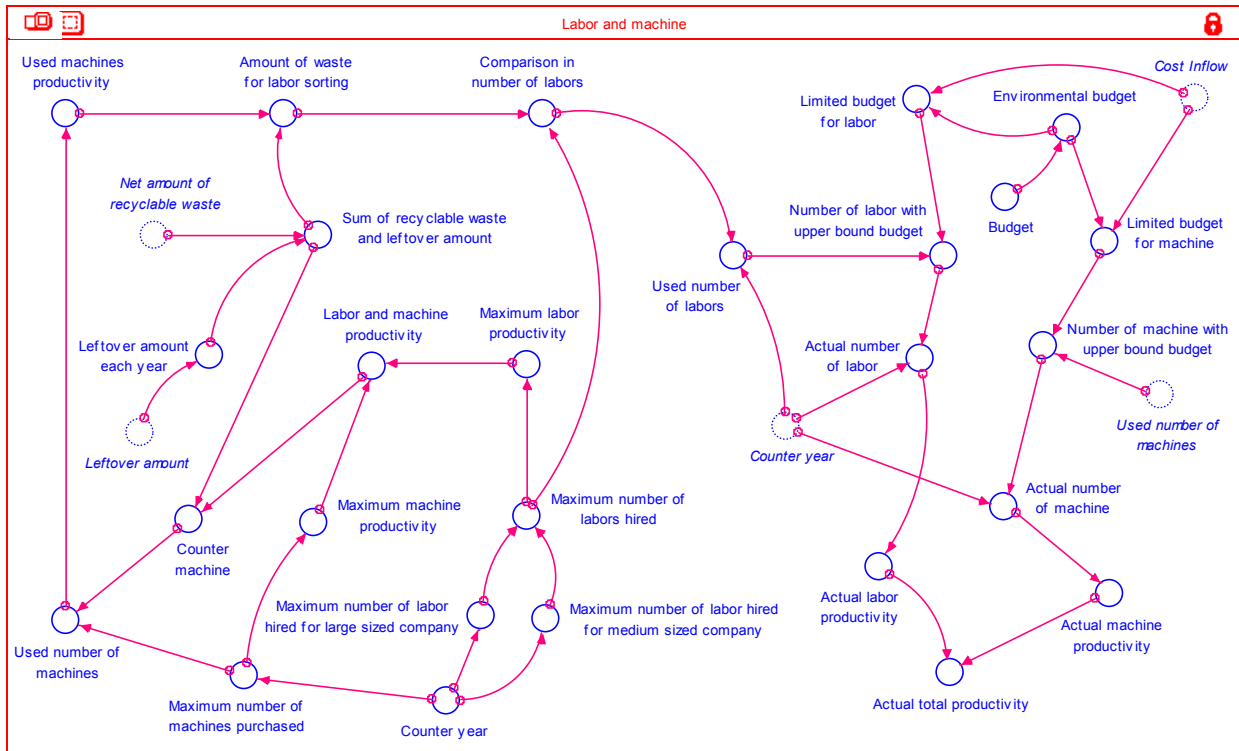


Fig. 2. The labor and machine productivity model.

Number of labor = MAX(history(Number_of_labor_with_upper_bound_budget,Counter_year),HISTORY(Number_of_labor_with_upper_bound_budget,Counter_year-1))

Number of machine = MAX(history(Number_of_machine_with_upper_bound_budget,Counter_year), HISTORY(Number_of_machine_with_upper_bound_budget,Counter_year-1),HISTORY(Number_of_machine_with_upper_bound_budget,Counter_year-2))

Actual labor productivity = Actual_number_of_labor*(0.026*250)

Actual machine productivity = Actual_number_of_machine*(0.508*8*250) (8)

(5) Actual total productivity = Actual_labor__productivity+ Actual_machine_productivity (9)

C. The Leftover Sector

In the early stage of recycling program, the amount of labor and machine are insufficient to sort the total recyclable waste. This, as a result, increases the leftover recycle amount at the end of each year. These leftovers are managed when there are available labors and machines. Fig. 3 shows the

Leftover model. The leftover amounts at the end of each year are calculated from the total amount of C&D wastes and the labor and machine productivity, see (10). The difference between the amount of wastes and the labor and machine productivities is the leftover of year 1, see (11). 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, as in (12).

$$\text{Labor and machine productivity} = \text{Maximum_labor_productivity} + \text{Maximum_machine_productivity} \quad (10)$$

$$\text{Leftover year 1} = \text{IF}(\text{Count_year}=1)\text{THEN}(\text{Net_amount_of_recyclable_waste} - (\text{Labor_and_machine_productivity})) \text{ELSE} (0) \quad (11)$$

$$\text{Leftover year 2} = \text{IF}(\text{Count_year}=2)\text{THEN IF}(\text{Net_amount_of_recyclable_waste} + \text{Leftover_year1} < \text{Labor_and_machine_productivity})\text{THEN}(0)\text{ELSE}(\text{Net_amount_of_recyclable_waste} + \text{Leftover_year1} - \text{Labor_and_machine_productivity})\text{ELSE}(0) \quad (12)$$

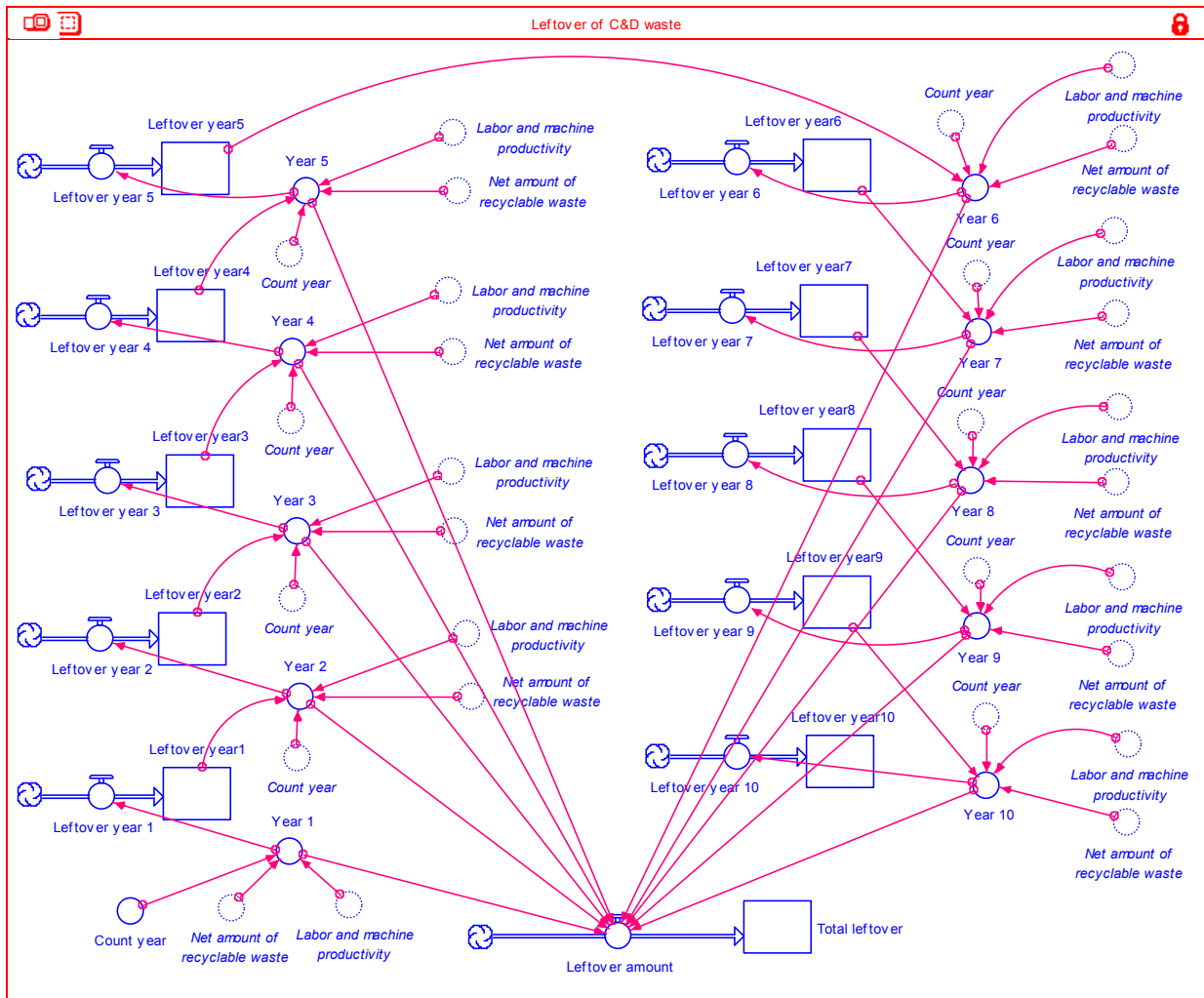


Fig. 3. The Leftover model.

D. The Recycled Waste Sector

Fig. 4 illustrates the relationships between the recycled waste and landfill. The “company’s recycled amount” or CRA is a function of the “actual total productivity”, the “leftover amount each year”, the “government’s machine productivity”, and the “total recyclable amount”, see (13)-(16). The amount of wastes recycled 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 becomes zero, as in (17). $\text{CRA} = \text{IF}((\text{Total_recyclable_amount} - \text{Government's_machine_productivity} + \text{Leftover_amount_each_year}) < \text{Actual_total_productivity})\text{THEN}((\text{Total_recyclable_}$

$$\text{amount} - \text{Government's_machine_productivity} + \text{Leftover_amount_each_year})\text{ELSE}(\text{Actual_total_productivity}) \quad (13)$$

$$\text{Actual total productivity} = \text{Actual_labor_productivity} + \text{Actual_machine_productivity} \quad (14)$$

$$\text{Leftover amount each year} = \text{DELAY}(\text{Leftover_amount}, 1, 0) \quad (15)$$

$$\text{Total recyclable amount} = \text{Amount_of_waste_generation} \times 0.7 \quad (16)$$

$$\text{Amount of recyclable waste to landfill} = (\text{Total_recyclable_amount} - \text{Government's_machine_productivity} - \text{Company's_recycled_amount_inflow}) + \text{Leftover_}$$

amount_each_year

(17)

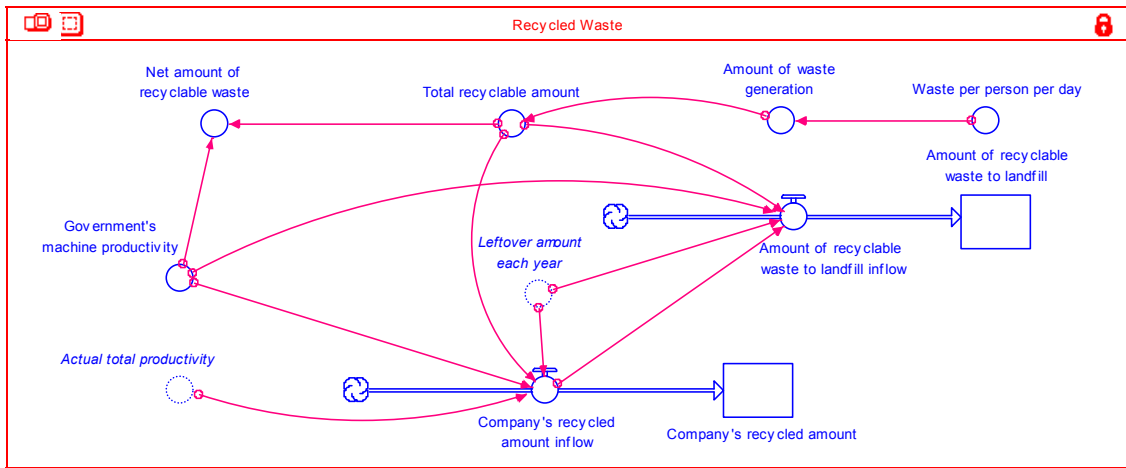


Fig. 4. The Recycled Waste model.

III. THE DYNAMICS SIMULATION RESULTS

The dynamic model of C&D waste is simulated with the STELLA program. The simulation results, as illustrated in Fig. 5 and Table I, show that the amount of recycled waste increases as time increases. This is due to the increases of labors and machines.

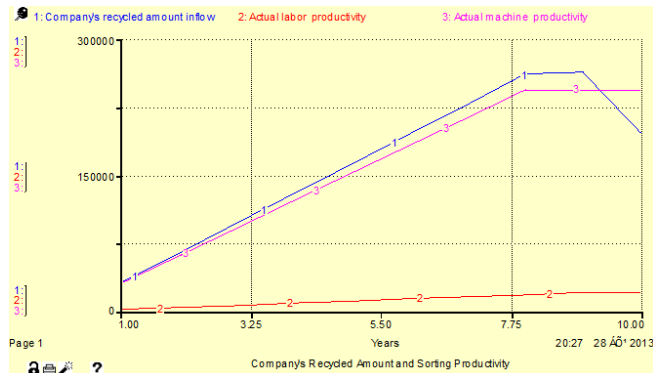


Fig. 5. The graphical results of the C&D waste dynamic model.

TABLE I: THE DYNAMIC SIMULATION RESULTS

Year	Company's Recycled Amount (tons)	Actual Labor Productivity (tons)	Actual Machine Productivity (tons)	Actual Number of Labor (persons)	Actual Number of Machine (units)
1	32,040	1,560	30,480	240	30
2	64,470	3,510	60,960	540	60
3	97,290	5,850	91,440	900	90
4	130,110	8,190	121,920	1,260	120
5	162,930	10,530	152,400	1,620	150
6	195,750	12,870	182,880	1,980	180
7	228,570	15,210	213,360	2,340	210
8	261,390	17,550	243,840	2,700	240
9	263,730	19,890	243,840	3,060	240
10	197,103.5	19,890	243,840	3,060	240

The company is capable of sorting all the recyclable waste (amount of waste initiated in a year plus the leftover) in nine years. This requires 3,060 labors and 240 machines (see Table I). The amount of recycled waste sorted in year 10 then drops to 197,103.50 tons to cover only the amount of waste initiated in that year (with the leftover amount of zero).

It is investigated that the labor and machine productivities are constant after year 9, without further hiring and purchasing, respectively. The total cost after year nine is, therefore, kept constant (see Table II). From year 10 onwards, some labors are, consequently, transferred from the sorting and recycling activities to other related activities (due to

decrease total waste to be sorted).

TABLE II: THE LABOR, MACHINE, AND TOTAL COSTS

Year	Total Cost (Baht)	Labor Cost (Baht)	Machine Cost (Baht)	Transportation Cost (Baht)	Storage Cost (Baht)
1	83,302,981.52	18,000,000	30,755,250	34,547,731.52	0
2	78,580,114.47	40,500,000	30,755,250	2,348,476.97	4,976,387.5
3	109,299,834.92	67,500,000	30,755,250	2,349,222.42	8,695,362.5
4	138,742,642.88	94,500,000	30,755,250	2,349,967.88	11,137,425
5	166,908,538.33	121,500,000	30,755,250	2,350,713.33	12,302,575
6	193,797,521.29	148,500,000	30,755,250	2,351,458.79	12,190,812.5
7	219,409,591.74	175,500,000	30,755,250	2,352,204.24	10,802,137.5
8	243,744,749.7	202,500,000	30,755,250	2,352,949.7	8,136,550
9	233,746,999.7	229,500,000	0	52,949.7	4,194,050
10	229,551,458.79	229,500,000	0	51,458.79	0

IV. CONCLUSION

The dynamic model of C&D waste is developed using the system dynamics modeling technique. The simulation results reveal the increase amount of recycled wastes over time, implying the decrease amount of waste to landfills. It must, however, be noted that the successful of C&D waste recycling program comes from the cooperation between the government and the construction industry.

There are limitations in this study. Factors used in the dynamic model, such as are the inflation and the employment rates; derive from data in Bangkok, Thailand. Different data may affect to simulation results. The developed model, however, can be adapted in different environments by adjusting data accordingly to the specific situations.

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