Original Article

Reverse logistics implementation in the construction industry: Paper waste focus

Natchari Rinsatitnon, Wissaruth Dijaroen, Thanutchaporn Limpiwun,
Gunchaporn Suktavee, and Thanwadee Chinda*

*School of Management Technology, Sirindhorn International Institute of Technology,
Thammasat University, Khlong Luang, Pathum Thani, 12000 Thailand*

Abstract

Thailand has an increasing demand for housing and infrastructure. This leads to increased amounts of construction and demolition (C&D) wastes. Most of the C&D wastes are reusable and recyclable. However, without proper waste management these wastes are mostly dumped into landfills without being sorted. This study utilizes a system dynamics (SD) approach to examine the feasibility of the reverse logistics implementation in C&D waste management in the long term. The focus material is paper waste, as it is one of the major wastes that can be recycled and remanufactured. The dynamic model consists of three reverse logistics options, including landfill, recycled, and remanufactured options. Costs involved in the implementation are labor, transportation, landfilling, recycling, and remanufacturing costs. Benefits, on the other hand, include sales of recycled and remanufactured products, energy savings, and green image savings. The simulation results reveal that the reverse logistics program should be implemented for at least three years to achieve positive net profit. The implementation should also be continued until the end of year 9 to be worth the investment, with the internal rate of return exceeding 12%. It is also suggested that the recycling and remanufacturing options should be promoted in long term in order to save landfill space and promote green image of the industry.

Keywords: construction and demolition waste, paper, reverse logistics, system dynamics

1. Introduction

Construction and demolition (C&D) waste is produced by various demolition and building activities, including road and rail construction, structural maintenance, and excavation of land associated with construction activities (Department of the Environment, Australian Government, 2010). It can be categorized into numerous components, such as brick, wood, concrete, cement, tile, glass, metals, paper, and plastic (Manowong & Brockman, 2015). Among those, wood, metal, paper, and plastic can mostly be reused and recycled (Figure 1).
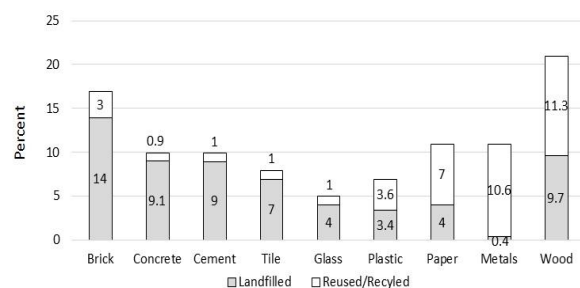

Figure 1. Construction waste profile and management in Thailand (Manowong & Brockman, 2015)

The growths in population and economy are related to increased construction; therefore, the amount of C&D waste also increases. Hong Kong as an example, one of the

*Corresponding author
Email address: thanwadee@siit.tu.ac.th

most compact and densely populated cities in the world, has expanded the metropolitan region, resulting in high amounts of C&D waste that must be effectively managed (Koenig, 2009).

The C&D waste in Thailand has also been continuously increasing, following the rapid increase in demand for housing and infrastructure. Statistical data indicate that the total C&D waste in Bangkok in 2001 was estimated at 2.03 million tons, or 0.53 kilograms per capita per day. In 2006, the overall C&D waste was approximately 6.57 million tons, indicating a rate of increase of around 37% per year (Figure 2) (Manowong & Brockman, 2011). However, it has been found that most of the C&D waste is not properly managed. In addition, Thailand has no regulations specifically dealing with C&D waste. The current environmental protection laws are applied as fundamental guidelines for waste handling, transportation and disposal, but they are not widely supported. Consequently, C&D waste is dumped into landfills without being sorted or recycled. This results in large amounts of waste in landfills, and C&D waste is also illegally dumped into public places or rivers, creating serious environmental damage.
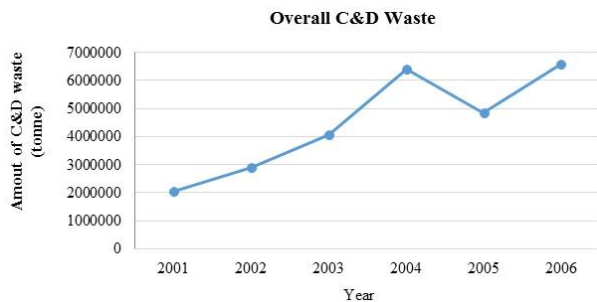

Figure 2.   Estimated overall C&D waste amount from 2001 to 2006 (Kamonpun, 2010)

This paper, therefore, aims at examining the reverse logistics implementation of C&D waste handling in the long term, utilizing a system dynamics approach. The material focused on in this study is paper, as it is one of the materials that can be reused, recycled and remanufactured. It is expected that this study helps the construction industry consider the reverse logistics implementation for management of C&D waste, among the various alternative strategies for C&D waste management in the long term.

2. Reverse Logistics of C&D Waste: Paper Focus

Reverse logistics is the process of planning, implementing, and controlling the efficient, cost effective flow of raw materials, in-process inventory, finished goods, and related information from the point of consumption to the point of origin for the purpose of recapturing value or proper disposal (Hawks, 2006). It can be classified into four options, which are: direct reuse, landfill, recycle, and remanufacture (Oyeshola & Shabbir, 2009).

- Direct reuse refers to retaining the prototype of material and simple processing such as material cutting, decontamination and other methods for processing (Zhao & Guo, 2016).

- Landfill refers to the final placement of waste in or on the land in a controlled or uncontrolled way according to different sanitary, environmental protection, safety and other requirements (Statistics Division, Department for Economic and Social Information and Policy Analysis, 1997).
- Recycle means the separating, collecting, processing, marketing and ultimately using material that would otherwise have been thrown away (The U.S. Environmental Protection Agency, 1995).
- Remanufacture is industrial processing, in which worn-out products are restored to like-new condition through a series of industrial processes (Lund, 1983).

Cochran *et al.* (2007) mentioned that landfilling is the final option used for construction waste disposal. Many of the items that end up in the landfill are however reusable or recyclable. Paper, for example, constitutes around 11% of the overall C&D waste in Thailand. According to Tischer *et al.* (2013), paper can be totally recycled. Most of the paper waste is generated from packaging materials, specifically cardboard, Figure 3 (Centre for Resource Management, BRE, 2005).

Paper material in C&D waste can be subjected to three reverse logistics options: landfill, recycle, and remanufacture (Manowong & Brockman, 2015). There are three major landfills in Bangkok, namely Sai Mai, Onnut, and Nongkam stations. Wastes are collected with 10-wheel trucks, and are dumped into landfills. Around 28% of paper waste can be recycled into cardboard, while approximately 28% can be remanufactured, mainly into paper pallets (T5 Paper Pallet, 2008).
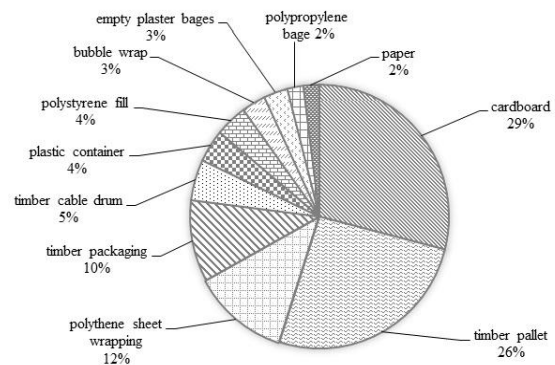

Figure 3.   Total packaging waste from construction sites

The above three reverse logistics options are used in this study to develop a system dynamics model to examine the reverse logistics implementation for paper waste in the long term.

3. System Dynamics Model of Reverse Logistics Implementation for Paper in the Construction Industry

The system dynamics model of reverse logistic implementation for paper in the construction industry has been

developed. It consists of four sub-models, which are "Labor Sortation", "Landfill", "Recycle", and "Remanufacture" sub-models.

3.1 Labor sortation sub-model

Labor is used in the sorting of paper waste. The number of laborers is calculated according to their sorting capacity and the amount of C&D waste. Sorting labor consists of existing and new laborers. According to Luanratna (2003) and Noonin (2004), new full time laborers spend eight hours per day in waste sorting, while existing laborers spend around one-fourth of the time to participate in the waste sorting process. One full-time laborer can sort 246 kilograms of C&D waste per day (Luanratana, 2003; Noonin, 2004). To be more specific, one full-time laborer can sort about 82 kilograms of paper waste per day; this is calculated based on the three major C&D waste materials (paper, plastic, and metal) that can be handled with the reverse logistics processes.

The Labor Sortation sub-model is illustrated in Figure 4. In the initial year, the amount of C&D waste is 6.56 million tons, and gradually increases by 12 percent each year (Provincial Offices for Natural Resources and Environment Nakhon Ratchasima, 2016; Ministry of Natural Resources and Environment, 2016). The increase in C&D waste requires more sorting labor. However, the available budget limits the labor used in the sorting process (Equations 1 - 3). In this model, when C&D waste amount exceeds the labor capacity, the leftover C&D waste is disposed to landfills (Equation 4).

New labor required = equivalent_total_labor_from_
construction_waste-existing_labor-
HISTORY (new_labor_stock,
COUNTER (1,100)-1)   (1)

New labor required under budget = budget/162000   (2)

New labor = MIN(New_labor_required__under_budget,
New_labor_required)   (3)

Leftover waste to landfills = (equivalent_total_labor_from_
construction_waste-total_
labor_per_year)*24.6   (4)

3.2 Landfill sub-model

The landfill sub-model is shown in Figure 5. This sub-model involves three major factors, including landfill charge, transportation to landfill, and maintenance cost. The landfill charge is currently set at 700 baht per ton, and increases at a rate of 12 percent per year (Provincial Offices for Natural Resources and Environment Nakhon Ratchasima, 2006; Ministry of Natural Resources and Environment, 2016). Transportation to landfill, on the other hand, consists of: 1) bought truck, 2) truck rental, and 3) other related costs.

According to the Department of Town and Country Planning (2014), the three major construction areas in Bangkok are Chatuchak, Wattana, and Sai Mai. The transportation of C&D waste from construction sites to landfills is summarized in Table 1. The total cost of 10-wheel trucks is calculated according to the purchased or rental truck costs. The number of 10-wheel trucks used depends on: 1) the capacity of the trucks, which is limited to 15 tons, 2) the available time per day (5 hours per day due to the traffic restrictions in Bangkok), and 3) the time between the construction sites to landfill, which is on average2.5 hours (Equation 5).

Number of 10-wheel trucks per day = ROUND(round_per_
day/Number_of_
rounds_of_one_10_
wheel_truck_in_one_
day)   (5)

Table 1. Average distances from construction sites to three major andfills (Department of Town and Country Planning, 2014)

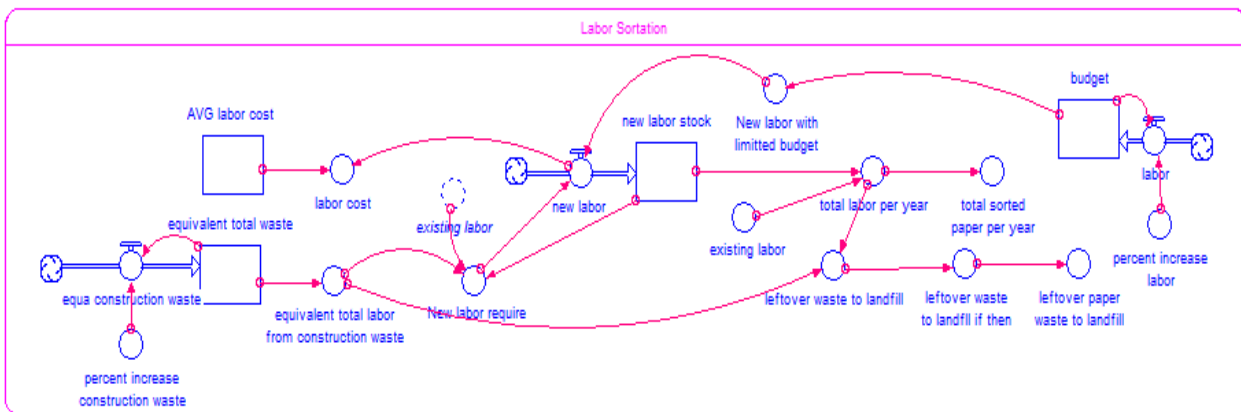| From/To	Onnut disposal center (kilometers)	Nongkam disposal center (kilometers)	Sai Mai disposal center (kilometers)
Chatuchak area	27.80	40.70	15.84
Wattana area	16.16	38.10	22.56
Sai Mai area	31.20	67.10	6.24

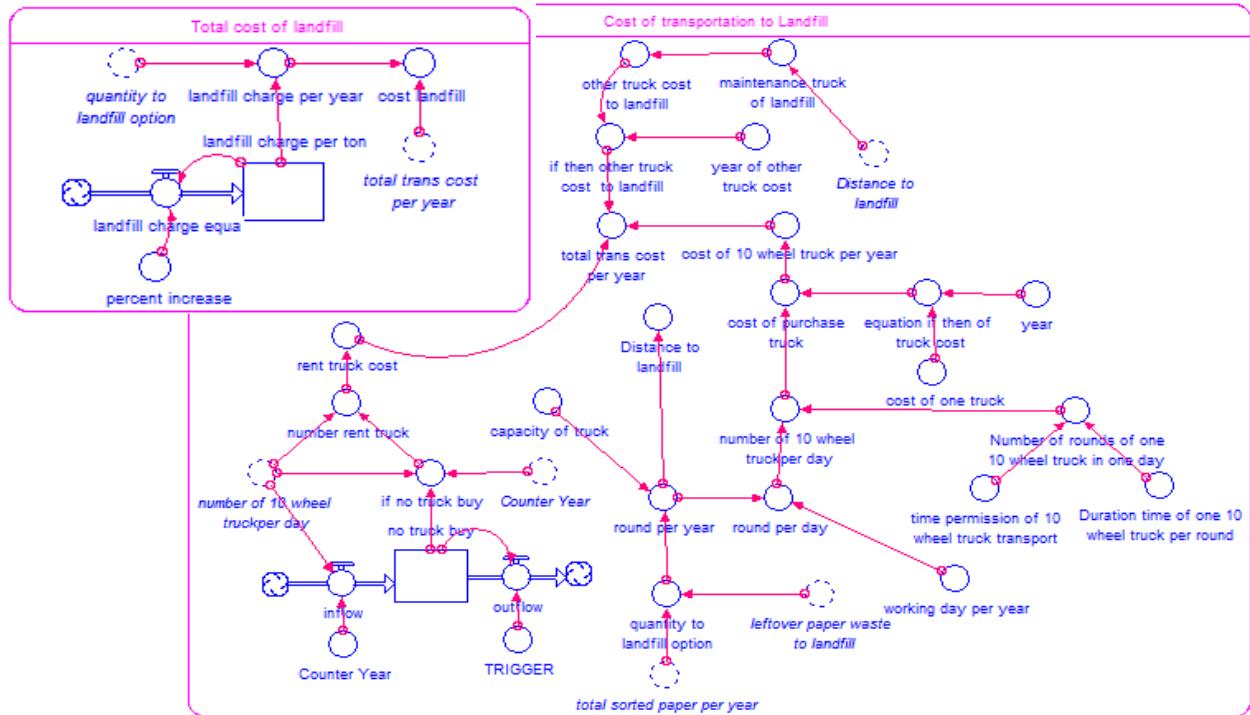

Figure 4. Labor Sortation sub-model

Figure 5.   Landfill sub-model

Based on Truck In Thai (2016) and Isuzu Chaicharoenkij Motors (2016), a truck costs 2.3 million baht, with an expected life span of 9 years (The U.S. Government's Office of Management and Budget, 2003) (Equation 6). Other related costs include maintenance and insurance costs. The maintenance cost is set at 6.35 baht per kilometer, while insurance cost is 16,311 baht per year (Department of Land and Transport, 2010; Thailand Development Research Institute, 2010) (Equation 7). Truck rental, on the other hand, costs 1.03 million baht per year (Equations 8 - 9).

$$\text{Cost of purchased truck} = (number\_of\_10\_wheel\_truck\_per\_day * equation\_if\_then\_of\_\_truck\_cost) \qquad (6)$$

$$\text{Other truck costs to landfill} = 16311 + maintenance\_truck\_\_of\_landfill \qquad (7)$$

$$\text{Number of rental trucks} = IF\ if\_no\_truck\_buy > = number\_of\_10\_wheel\_truck\_per\_day\ THEN0\ ELSE\ (number\_of\_10\_wheel\_truck\_per\_day-if\_no\_truck\_buy) \qquad (8)$$

$$\text{Rental truck cost} = 1030000 * rent\_truck \qquad (9)$$

3.3 Recycle sub-model

Figure 6 shows the recycle sub-model. There are two main sub-processes in this model: the craft paper and the cardboard processes.

For the craft paper process, the cost consists of the purchased machine cost of 1,585 million baht per unit and the annual rental machine cost of 158.48 million baht per unit, with a capacity of 155,000 tons per year (Chittanoon, 1997) (Equations10 - 11). The cardboard process, on the other hand, incurs the purchased machine cost of 4.26 million baht per unit and the annual rental machine cost of around 426,000 baht per unit, with a capacity of 420,000tons per year (Wiroonpan, 2014) (Equations12 - 14). The number of machines used depends on the amount of paper C&D waste to be recycled (Equations15 - 16).

$$\text{Invest craft machine} = IF\ year\_machine=0\ THEN\ cost\_of\_kraft\_all\_machine\ ELSE\ 0 \qquad (10)$$

$$\text{Cost rent craft machine} = no\_rent\_kraft\_machine * 158488542.7 \qquad (11)$$

$$\text{Invest cardboard machine} = IF\ year\_machine=0\ THEN\ cost\_of\_carrdboard\_\_all\_machine\ ELSE\ 0 \qquad (12)$$

$$\text{Cost rent cardboard machine} = no\_rent\_cardboard\_machine * 426757.8 \qquad (13)$$

$$\text{Cost of recycle process as cardboard} = cost\_of\_cardboard\_process + cost\_of\_kraft\_process \qquad (14)$$
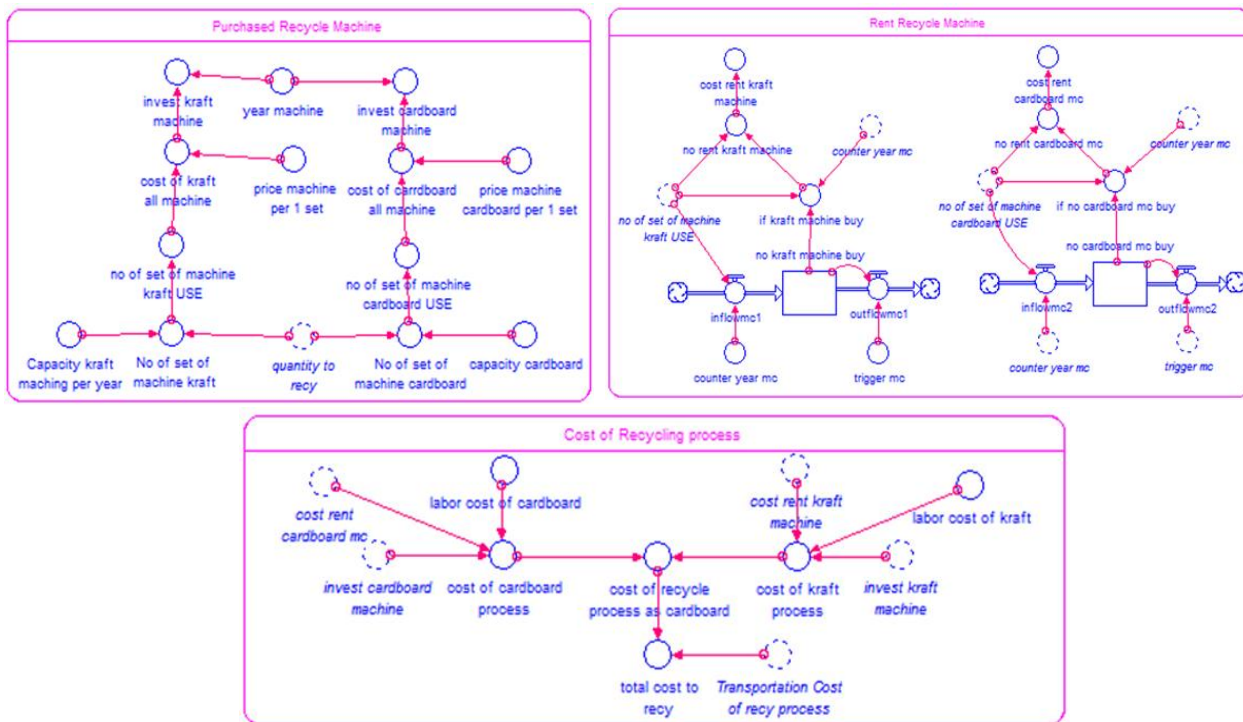
Figure 6.   Recycle sub-model

No rent craft machine = IF if_kraft_machine_buy> = no_of_ set_of_machine__kraft_USE THEN 0 ELSE no_of_of_machine_kraft_ USE-if_kraft_machine_buy   (15)

No rent cardboard mc = IF if_no_cardboard_mc_buy> = no_of_set_of_machine_cardboard_ USE THEN 0 ELSE no_of_set_of_ machine_cardboard_USE-if_no_ cardboard_mc_buy   (16)

        Recycling hasa number of benefits. Cardboard can be sold at a price of 25,200 baht per ton (Wiroonpan, 2014) (Equations17).

Benefit as revenue from cardboard = price_per_ton_of_ cardboard*quantity_ to_recy   (17)

        On top of that, electricity, water and fuel could be saved. Carbon dioxide (CO_2) emissions are also reduced. According to Riverpro Pulp and Paper (2016), recycling one ton of paper can save 4,800 kilowatts of electricity, 490 liters of fuel oil, and 29 cubic meters of water. The carbon dioxide emissions could also be reduced by 0.02 tons per one ton of recycling (Wachirarangsrikul, 2013).

3.4 Remanufacture sub-model

        Remanufacture sub-model is shown in Figure 7. There are three processes for craft paper, cardboard, and paper pallet. For the paper pallet process, the cost of the
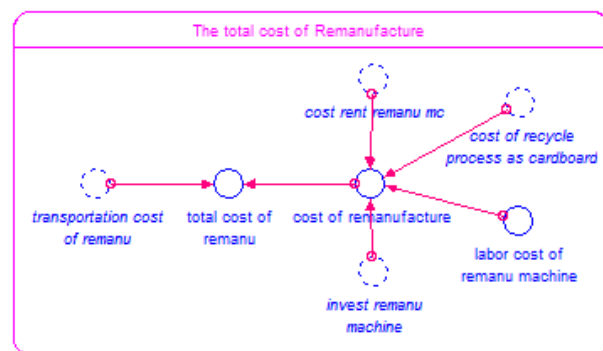

Figure 7.   Remanufacture sub-model

purchased machine is 1.71 million baht per unit, while the annual rental cost is 171,000 baht per unit (Sunkdon, 2016). The total cost of the remanufacturing process is shown in Equation 18. Paper pallets can be sold at 185 baht per unit. Remanufacture also saves electricity, water, fuel, and the costs are similar to those in recycle process.

Cost of remanufacture = invest_remanu_machine+ labor_ cost_of_remanu_machine+cost_rent_ remanu_machine +cost_of_recycle_ process_as_cardboard   (18)

4. Simulation Results

        The system dynamics model of reverse logistics implementation for paper in the construction industry was

simulated with the results summarized in Table 2 and Figure 8. In the initial year, new labor, trucks, and machines are procured to initiate the reverse logistics program implementation, leading to high total cost. Once the trucks and machines are purchased, they are used for nine and 10 years, respectively, before replacement is needed.

Total benefits are from cardboard and paper pallet sales, as well as the benefits of electricity, water, fuel, and the benefit of reducing water and carbon dioxide emission tax saving. Costs, on the other hand, include landfill cost, recycle cost, and remanufacture cost.

Table 2.   Results of the total cost, total benefit, net profit, and net present value

Year	Total cost (million baht)	Total benefit (million baht)	Net profit (million baht)	Net present value* (million baht)
Initial	5,005.02	0	-5,005.02	-
1	1,888.98	995.47	-893.50	-5,181.06
2	2,129.16	1,739.62	-389.54	-5,458.33
3	2,377.77	2,568.95	191.18	-5,336.83
4	2,719.49	3,493.12	773.63	-4,897.85
5	3,023.11	4,522.86	1,499.75	-4,138.03
6	3,472.48	5,670.15	2,197.66	-3,143.92
7	3,892.75	6,948.29	3,055.45	-1,909.88
8	4,471.40	8,372.12	3,900.72	-503.24
9	5,229.03	9,958.15	4,729.12	1,019.41
10	8,979.94	11,724.74	2,744.80	1,808.48
11	6,507.49	13,692.37	7,184.88	3,652.66
12	6,340.61	15,871.94	9,531.33	5,836.99
13	5,799.66	17,775.62	11,975.96	8,287.51
14	6,875.32	19,396.70	12,521.38	10,575.12

Note: Total cost = negative cash flow, total benefit = positive cash flow, net profit = net cash flow *Net present value is calculated at MARR = 12%
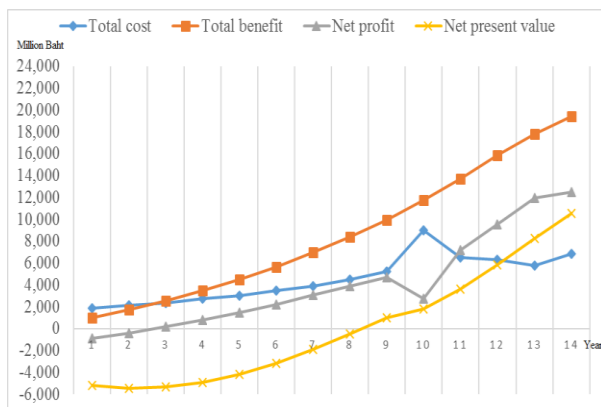
Note: Total cost = negative cash flow, total benefit = positive cash flow, net profit = net cash flow, Net present value is calculated at MARR = 12%

Figure 8.   Simulation results of total cost, total profit, net profit, and net present value

It is found that in the early years, the net profit is negative. This is due to high investment costs in trucks and machines. As the implementation program continues, the net profit increases. It takes three years for the net profit to become positive. It is interesting to note that the net profit decreases at the end of year 10, year 20, and every 10 year period. This has to do with the replacement of trucks and machines.

The internal rate of return (IRR) was also used to evaluate the feasibility of the implementation program. According to the Institute for Transport Studies, University of Leeds (2003), an IRR of at least 12 percent is considered feasible for most government projects. Figure 9 shows that the IRR of the program implementation is better than 12 percent at the end of year 9.

Tables 3 and 4 show the benefits and costs of the reverse logistics implementation. It can be seen that recycling and remanufacturing options create high benefits compared with their costs. Landfill option, on the other hand, incurs no benefit. Hence, the landfill option should be progressively reduced, while the recycling and remanufacturing options should be continually promoted in the long term.
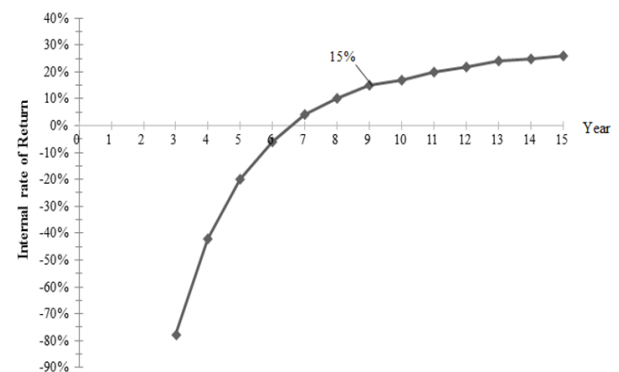

Figure 9.   Internal rate of return (IRR)

Table 3.   Benefits of recycling and remanufacturing

Year	Benefits (million baht)	
	Recycling	Remanufacturing
Initial	123.32	129.33
1	375.37	392.12
2	657.63	684.21
3	973.56	1,008.87
4	1,327.07	1,369.73
5	1,722.54	1,770.82
6	2,164.83	2,216.63
7	2,659.36	2,712.16
8	3,212.22	3,262.93
9	3,830.15	3,875.12
10	4,520.70	4,555.56
11	5,292.32	5,311.88
12	6,149.79	6,147.93
13	6,904.24	6,874.65
14	7,552.29	7,489.96
15	8,291.32	8,190.14

Table 4.　Landfill, recycling, and remanufacturing costs

Year	Costs (million baht)		
	Landfilling	Recycling	Remanufacturing
Initial	584.52	1,615.71	1,623.67
1	463.73	26.37	30.94
2	477.49	30.08	37.26
3	467.05	32.95	42.83
4	504.66	37.53	52.10
5	462.84	40.44	58.46
6	507.75	46.09	67.93
7	465.00	50.80	75.29
8	499.34	57.54	90.60
9	560.89	92.58	146.77
10	441.46	1,639.19	17,699.29
11	451.66	60.79	86.79
12	499.02	229.36	260.84
13	584.38	227.46	266.55
14	737.33	246.59	293.36
15	967.75	255.46	312.73

5. Conclusions

Due to the population growth in Thailand, construction has been increasing. This generates large amounts of C&D wastes. The majority of C&D wastes can be treated with reverse logistics options, namely reuse, recycling, and remanufacturing.

This study used a system dynamics approach to examine the feasibility of reverse logistics for paper waste in the long term. The simulation results show that the net present value is positive at the end of year 3, while the IRR is higher than 12 percent at the end of year 9. This implies that the reverse logistics implementation program is worth the investment when it is continued for at least nine years. The results also confirm the benefits of the recycling and remanufacturing options. Management should, therefore, encourage recycling and remanufacturing, and train more skilled labor for these, as well as provide financial support for the necessary machines and equipment.

The construction companies can use the simulation results as a guideline for reverse logistics implementation that would promote their green image and enhance their environmental performance.

Data used in the dynamic model represents the construction industry in Bangkok, Thailand. The study results reported are not directly applicable to a different environment, while the approach could be duplicated with appropriate parameters.

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