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Original Article

Feasibility study of reverse logistic of steel waste in the construction industry

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Abstract

Construction and demolition (C&D) waste are increasing due to population and economic growth. Most of C&D waste materials, including steel waste, can be managed with the reverse logistics (RL), including directly reuse, recycling, and remanufacturing. However, most waste is dumped into landfills which cause environmental problems. This study examines the implementation of reverse logistics of steel waste in the construction industry utilizing a system dynamics approach. The dynamic model consists of six sub-models. The simulation results reveal that in the initial years, the net profit value of the RL implementation program is negative due to high investments in labors, trucks, and machines. It takes five years for the net profit to be positive, and eight years to achieve the internal rate of return of 12%. The construction company can use the developed dynamic model as a guideline to better understand RL implementation and plan for better implementation programs.

Keywords: construction industry, feasibility study, reverse logistics, steel, waste

1. Introduction

Construction and demolition (C&D) materials consist of the debris generated during the construction, renovation, and demolition of buildings, roads, and bridges (United States Environmental Protection Agency, 2016). The majority of C&D waste is from the broken pieces of materials used during construction and their packaging, as well as other types of waste materials generated by construction activities. C&D waste is mainly comprised of concrete, wood, metal, paper, plastic, and glass (Kumbhar *et al.*, 2013). Most waste materials of wood, metal, paper, and plastic can recycled and reused directly (Manowong & Brockmann, 2015). Figure 1 shows the composition of C&D waste in Thailand.

With the dramatic increase in population, there has been a higher demand for residential housing and facilities that has resulted in more construction activities. The construction industry in China, for example, is expected to grow by 4.5% annually, overtaking the USA as the most important market for construction. Similarly, Thailand has become a promising investment location (Figure 2).

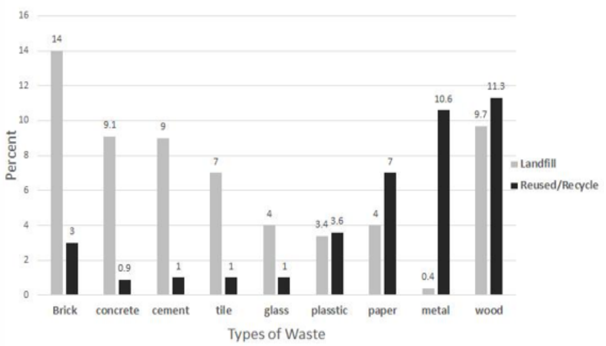

Figure 1. Composition of C&D waste materials in Thailand (Manowong and Brockmann, 2015).

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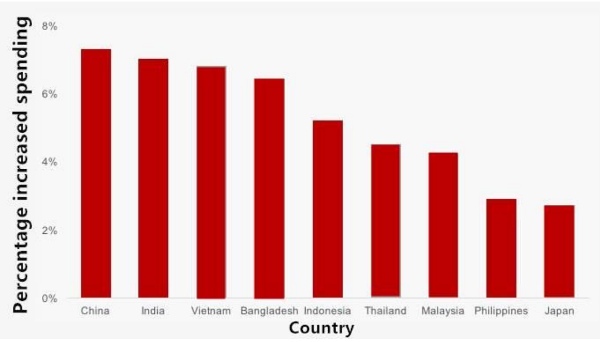

Figure 2. Growth of construction spending in 2014–2019 (Building Radar, 2016).

A larger population and higher demand for residential housing also cause the demolition of old buildings for further improvement or area expansion. These activities result in high amounts of C&D waste (Burger, 2016). However, it has been found that most of the waste materials are not properly managed. In Thailand, no regulations exist to specifically deal with C&D waste. In addition, current environmental protection laws are found to be rarely enforced. Consequently, C&D waste materials are dumped into landfills without being sorted or recycled which has created long-term environmental problems (Manowong & Brockmann, 2015).

Therefore, this study aims to examine the implementation process of reverse logistics for C&D waste materials for the long term utilizing a system dynamics approach. This study focuses on steel because it is a material that can be recycled, remanufactured, and reused directly. It is expected that the study results will assist construction companies in planning for reverse logistic implementation and improve C&D waste management in the long term.

2. Reverse Logistics: Steel Focus

Reverse logistics (RL) is the process of planning, implementing, and controlling the effective flow of raw materials, in-process inventory, finished goods, and related information, from the point of consumption to the point of origin (Lambert *et al.,* 2011). Most industries use RL to gain benefits in various ways. However, only a few construction companies implement RL to focus on the reuse and recycling options.

According to the Iron and Steel Institute of Thailand (2015), the construction industry is the major consumer of steel, representing approximately 53.4% of demand in Thailand. According to Biddle (2011), 45, 45, and 10% of waste steel will be recycled, remanufactured, and reused directly, respectively. On the other hand, unsorted waste steel is dumped into landfills.

- Recycling option: Scrap steel is collected at construction sites and sent to facilities designed for the recycling processes. Most furnaces in Thailand are the electric arc furnace that can produce an output amount equivalent to the input amount (Department of Primary Industries and Mines, 2016; National Metal and Materials Technology Center, 2015). The products from the recycling process are billet, bloom, and slab (Department of Industrial Works, 2016). Billets and blooms are used to produce materials, such as steel bar, steel wire, steel frame, and hot-rolled coil.
- Remanufacturing option: Remanufacturing includes the disassembling of a product and re-utilization of its components as a new product after quality checks (Kohpaiboon & Jongwanich, 2012). In this study, scrap steel will be remanufactured into food cans through the cold-forming and coating processes (Food Network Solution, 2016).
- Direct reuse option: Direct reuse transfers leftover steel from one site to another site to be used as virgin material.
- Landfill option: Steel waste that is not implemented with an RL option will be disposed of into landfills.

The four RL options are used to develop a system dynamics model of steel waste to examine the implementation in long term.

3. System Dynamics Model of Reverse Logistics of Steel Waste in the Construction Industry

The system dynamics model for the implementation of reverse logistics of steel waste in the construction industry consists of six sub-models.

3.1 Labor sub-model

The labor sub-model is shown in Figure 3. Labor is used to sort the C&D waste materials. Full-time labor can sort approximately 246 kg of waste per day (Equation 1). Existing labor, however, spends only one-fourth of the time to cooperate in the waste-sorting process (Luanratana, 2003; Noonin, 2004) (Equation 2). The amount of full-time labor hired each year depends on the amount of C&D waste, and the available environmental budget (Italian-Thai Development, 2014; Siam Cement, 2014) (Equations 3-5).

$$\text{Equivalent total waste labor} = (\text{Increasing waste} \times 0.29)/24.6 \quad (1)$$

$$\text{Existing labor} = 27449/4.25 \quad (2)$$

$$\text{Add labor from budget} = \text{Increasing budget}/162000 \quad (3)$$

$$\text{Amount of labor}(t) = \text{Amount of labor}(t - dt) + (\text{New labor}) \times dt \quad (4)$$

$$\text{New labor} = \text{MIN}(\text{add labor from budget, add labor from exist}) \quad (5)$$

3.2 Transportation sub-model

The transportation sub-model is shown in Figure 4. This sub-model is used in the four RL options. The main costs include truck fees, fuel prices, and associated costs (Chinda *et al.,* 2013). Truck fees consist of truck purchasing and truck

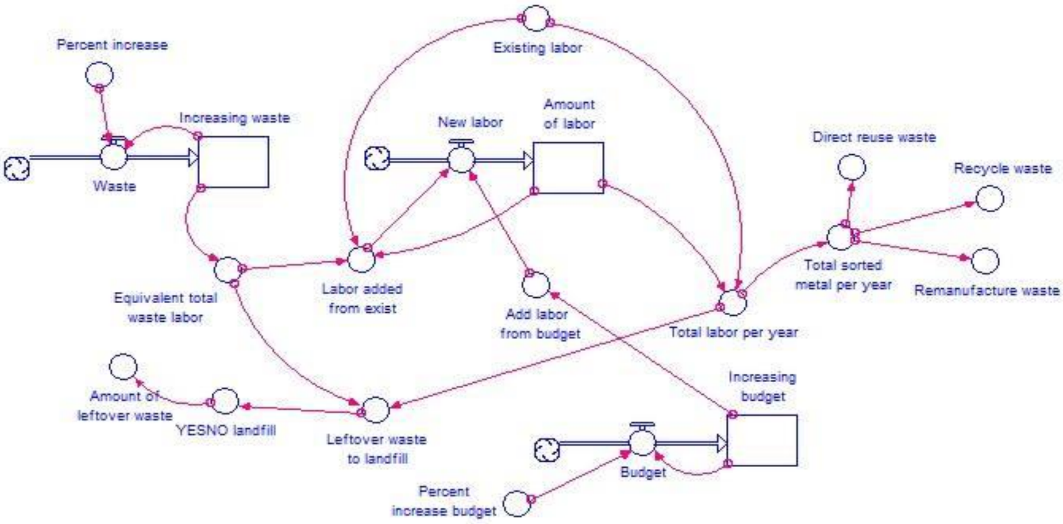

Figure 3. Labor sub-model.

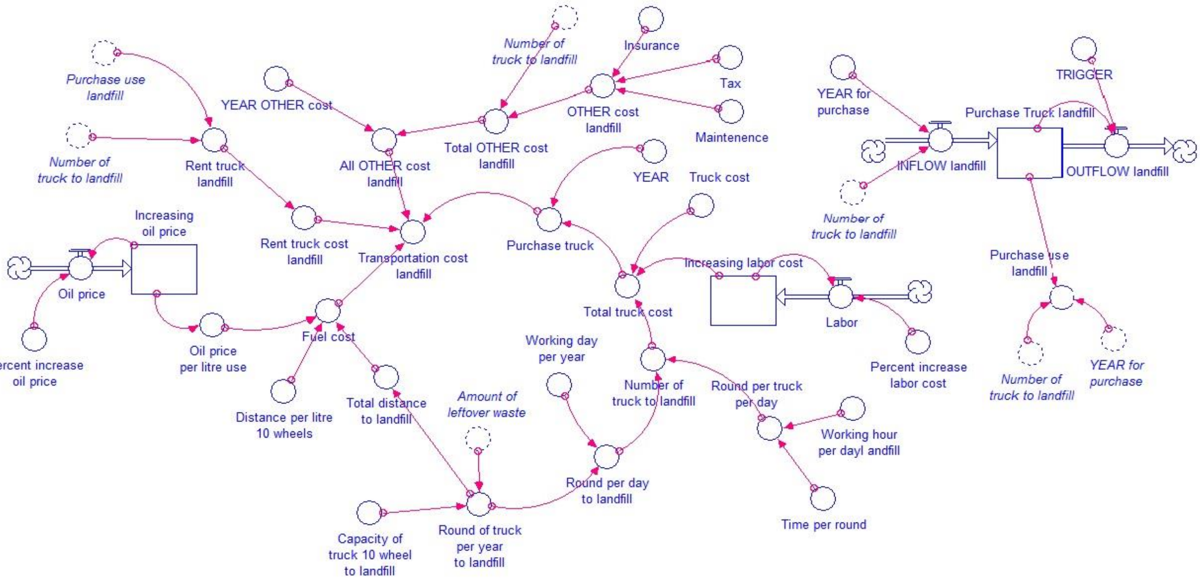

Figure 4. Transportation sub-model.

rental costs. A new truck costs 2.3 million baht, with a life span of nine years. On the other hand, truck rental is used if more capacity is needed each year. This incurs a rental truck cost of 1 million baht per year (Equations. 6-7).

Purchase use landfill = IF YEAR_for_purchase = 0 THEN Number of trucks to landfill ELSE Purchase trucks landfill (6)

Purchase use remanufacture = IF YEAR for_ purchase = 0 THEN Number of trucks remanufature con ELSE Purchase remanufacture (7)

The number of trucks used depends on the travel time due to traffic restrictions in Bangkok, and distance (Thai Traffic Police Official, 2016) (Equations. 8-9). Fuel price consists of oil price and distance in each sub-model (Equation 10). Other costs consist of insurance, tax, and maintenance costs (Equation 11).

Rent truck reycle = IF Purchase use reycle >= Number of trucks recycle THEN 0 ELSE Number of_ trucks recycle - Purchase use reycle (8)

Rent truck direct reuse = IF Puchase use direct reuse >=Number of trucks direct reuse con THEN 0 ELSE Number of turck direct reuse con - Puchase use direct reuse (9)

Fuel_cost = (Total distance to landfill/ Distance per liter 10 wheels) x Oil price per liter use (10)

OTHER cost landfill = Insurance + Tax + Maintenance (11)

3.3 Recycle sub-model

The recycle sub-model is illustrated in Figure 5. Scrap steel is transported to the smelters and rolling machines. A smelter costs 177 million baht, with a 10-year life span. Average machine rental costs are 17.7 million baht per year. Rolling machine costs are 1 million baht per unit with a rental cost of 0.7 million baht per year (Jiangsu Haotai Import and Export Trading Company, 2016; JPN Rollformer Company, 2016) (Eqs.12-15).

Total cost of electric arc machine = Electric_arc_machine_cost x Number_of_electric_per_year_use (12)

Total cost of rolling machine = Rolling_machine_cost x Number of rolling machine per year (13)

Rent cost electric arc = Rent electric arc x 17778513.75 (14)

Rent cost rolling machine = Rent rolling machine x (MEAN (15000, 1402250)) (15)

The number of machines used in this option depends on the amount of waste steel to be recycled, labor sorting capacity, and capacity of the smelters and rolling machines (Equation 16). Machine rental is considered during the life cycle period if higher capacity is needed (Equation 17).

Number of electric arc per year use = ROUND (Number of Electric arc per year/ Round of electric arc per year) (16)

Rent electric arc = IF Purchase use electric arc machine >= Number of electric per year use THEN 0 ELSE Number of electric per year use - Purchase use electric arc machine (17)

3.4 Remanufacture sub-model

The remanufacture sub-model is shown in Figure 6. In this option, three machines are used in the production processes. The smelter and rolling machines are used in the recycle process and the can-maker machine have a unit cost of 1.9 million baht (Jiujiang Excellent Packaging Machinery Company, 2016) (Equations. 18-20). Remanufactured product, which is the can, is sold at 1.75 baht per unit (Zhang zhou Tianbaolong Food Company, 2016) (Equation 21).

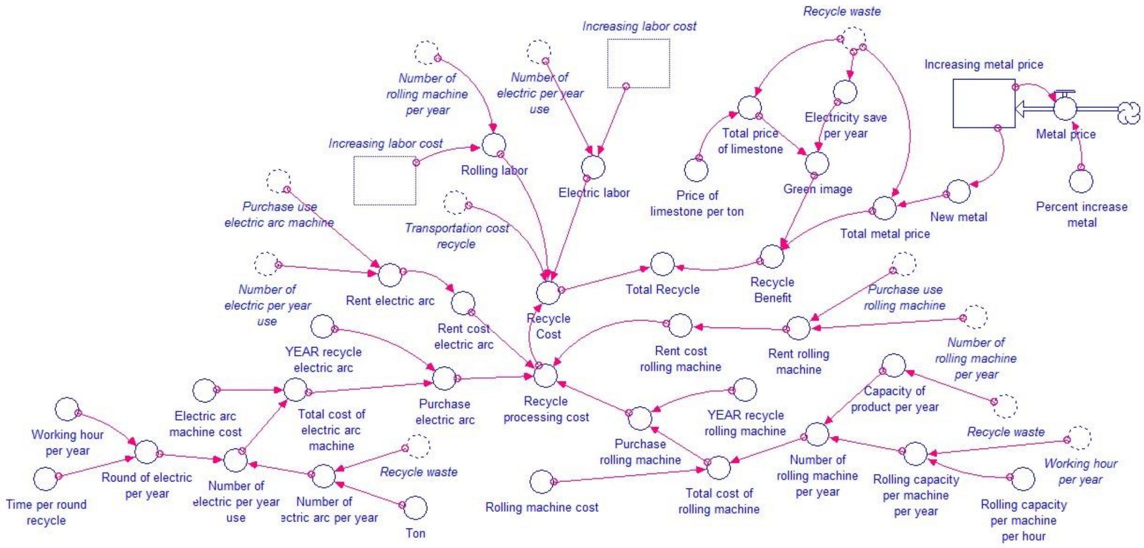

Figure 5. Recycle sub-model.

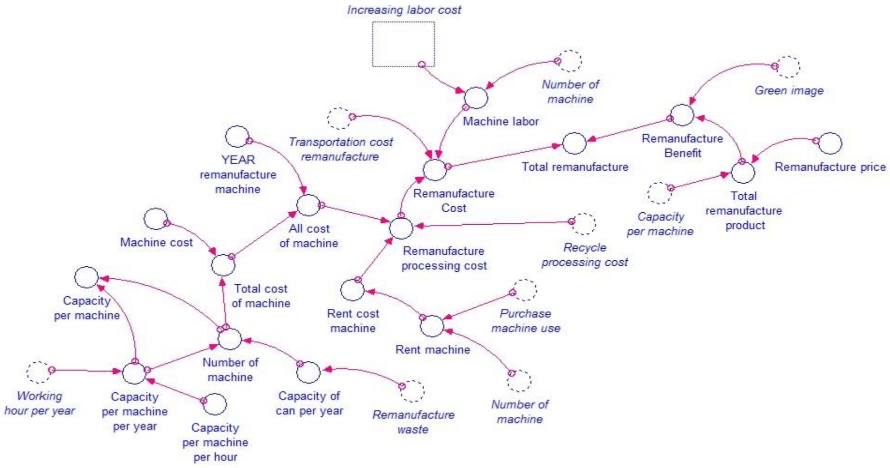

Figure 6. Remanufacture sub-model.

3.5 Direct reuse sub-model

Direct reuse is a site to site process (Figure 7). The major cost for this option is the transportation cost. The use of this RL option helps reduce the cost of virgin materials (Equation 22).

$$\text{Metal\_price} = \text{Increasing\_metal} \times \text{Avg\_metal\_price} \quad (22)$$

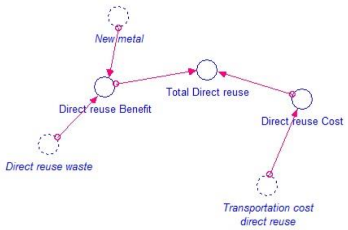

Figure 7. Direct reuse sub-model.

3.6 Landfill sub-model

Unsorted wastes will be transferred to landfills (Figure 8). According to the Provincial Offices for Natural Resources and Environment Nakhon Ratchasima (2016), landfill charge is set at 700 baht per ton, with an increasing rate of 5% per year (Equation 18).

$$\text{Landfill charge} = \text{Increasing landfill charge} \times \text{Percent increase landfill charge} \quad (23)$$

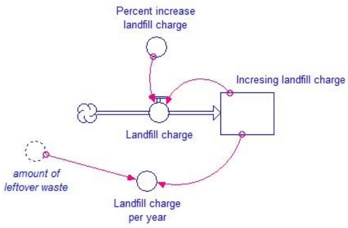

Figure 8. Flow of landfill charge.

4. Simulation Results

The dynamic model of RL of steel waste is simulated. The simulation results are shown in Figure 9. Total costs include labor, transportation, recycling, remanufacturing, direct reuse, and landfill costs. Total benefits, on the other hand, include sales of virgin materials (direct reuse), recycled, and remanufactured products, and savings in carbon tax and energy consumption.

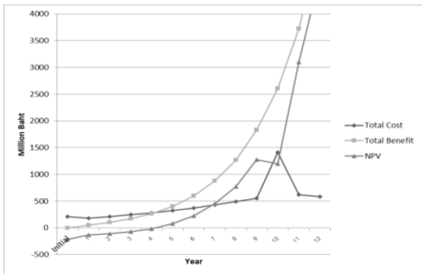

Figure 9. Graph of total costs, total benefits, and net profit.

The results show that the net profit is negative in the first year. This is the result of initial investments in labor, machine, and transportation for the RL implementation program. Once the program continues, the benefits increase. It takes approximately five years for net profit to be positive.

A closer look at the benefits (Figure 10) reveals that the sales of recycled products, in the form of steel bar, steel wire, and steel frame, yield the highest benefit. This is due to the high sales prices of these products in the market.

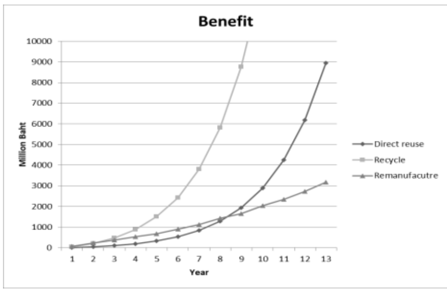

Figure 10. Graph of three main benefits.

The highest cost is the labor cost (Figure 11). The minimum wage of labor in the construction industry is high compared with the other costs (Social and Quality of Life Database System, 2016). The transportation and machine costs, on the other hand, oscillate every 10 years based on the repurchasing processes of trucks and recycling and remanufacturing machines.

The internal rate of return (IRR) is also used to examine the feasibility of the RL implementation program. According to Chileshe *et al.* (2016), the IRR of at least 12% is commonly used in public projects to measure the feasibility. In this study, the program should be implemented for at least eight years to be feasible (Figure 12).

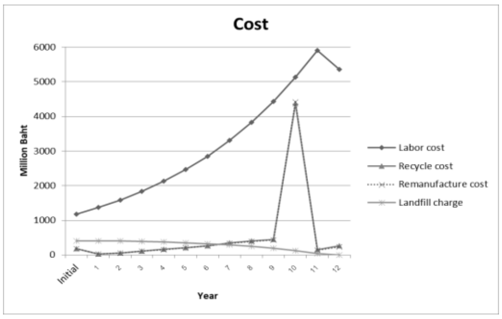

Figure 11. Graph of four main costs.

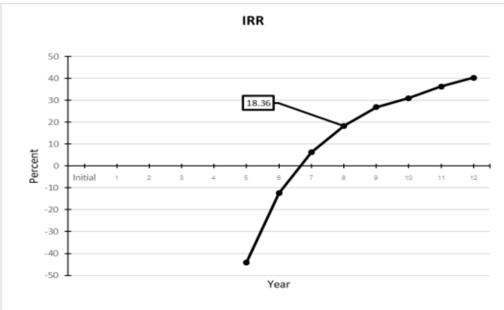

Figure 12. Graph of IRR.

5. Discussion and Conclusions

An increase in population results in more construction projects and C&D waste materials. This study examines the reverse logistics implementation of steel waste through the recycling, remanufacturing, and direct reuse methods utilizing a system dynamics modeling. The dynamic model consists of six sub-models, namely the labor, transportation, recycle, remanufacture, direct reuse, and landfill sub-models.

The simulation results reveal that in the initial years, the net profit is negative due to high investments in skilled labor, transportation vehicles, and machines. Once the program is implemented, benefits increase through the sales of virgin materials (direct reuse), sales of recycled and remanufactured products, and savings in carbon tax and energy consumption. The net profit becomes positive at the end of year 5. To achieve a minimum attractive rate of return of 12%, on the other hand, the program should continue until the end of year 8. This is partly consistent with a study by Chinda *et al.* (2013) that reported the implementation of a 10-year construction waste recycling program results in the IRR of over 20%. Doan and Chinda (2016) also mentioned that a construction waste program in Thailand should be implemented for at least 14 years to make the investment worthwhile.

The recycling option provides the highest benefit among the four RL options. This is confirmed by Bolden *et al.* (2013) that recycling of construction materials saves natural resources and energy, and reduces solid waste, air and water pollutants, and greenhouse gases, leading to higher profit for the industry. Shen *et al.* (2004) mentioned that recycling and reuse are two common methods used in waste management. Doan and Chinda (2016) also mentioned that a high recycling rate leads the construction industry to higher profit in the long term. Management should, therefore, encourage more steel recycling, train workers with necessary sorting skills, and financially support RL implementation.

The developed dynamic model can be used as a guideline for the construction companies to plan their RL implementation to raise the green image and enhance the company's performance.

Further study can be conducted to deeply investigate costs of the recycling processes to increase confidence in the recycling program implementation.

The dynamic model of reverse logistics of steel waste was developed based on data from Thai construction companies. The use of the model in different environments might need data adjustment.

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