FEASIBILITY STUDY OF CONSTRUCTION AND DEMOLITION WASTE RECYCLING PROGRAM USING SYSTEM DYNAMICS MODELLING APPROACH

BY

DAT TIEN DOAN

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE (ENGINEERING AND TECHNOLOGY)

SIRINDHORN INTERNATIONAL INSTITUTE OF TECHNOLOGY

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A Thesis Presented

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Submitted to

Sirindhorn International Institute of Technology

Thammasat University

In partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE (ENGINEERING AND TECHNOLOY)

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MAY 2015

Acknowledgements

I would like to express my sincerest gratitude to my advisor, Asst. Prof. Thanwadee Chinda, for all of her support that made my research an achieved success. Her intellectual knowledge, supportive advice, suggestions, and infinite encouragements are truly highly appreciated.

Absolutely, I wish to express my cordial gratitude to the committee members, Asst. Prof. Pisit Chanvarasuth, Asst. Prof. Nattharika Rittippant, and Asst. Prof. Cheema Soralump. Their suggestions, comments, and initiative ideas are very helpful to make this research better. It is my greatest honor to have them as thesis committees.

Inevitably, with several administrative assistances from the department secretariats, P' Ahe, P' Nok Chitra, P' Pla, and P' Koi, my study has gone smoothly. Their routine devotions contribute to my academic successful.

Special thanks to my fellow postgraduate students, Dieu, Chaiwat, and Nghia, for their kindness, friendship and support. In addition, the assistance from people who work in construction companies in Bangkok are very crucial to my study. I would like to sincerely acknowledge them for accepting my interviews.

I also thank the Sirindhorn International Institute of Technology, Thammasat University, for offering me with the scholarship. From then, I have a chance to carry out my research in a prestigious institute.

Finally, I would like to extend my deepest gratitude to my parents for their unconditional love, eternal support, and encouragement.

Abstract

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by

DAT TIEN DOAN

Bachelor of Engineering, Ho Chi Minh University of Technology, 2013

In Thailand, many infrastructures have been built, such as building and roads to meet the needs of the rapid development of economy. This, in turn, leads to the higher construction and demolition waste. Recycling program is, therefore, needed to properly manage the waste to avoid landfill shortage and future environmental problems. This research study investigates the feasibility of the construction and demolition waste recycling program in Bangkok, Thailand, using a system dynamics modeling technique. The model consists of two main elements, namely the total benefits and the total costs. The total benefits element consists of five sectors, namely saving in the fuel cost to landfill, saving in landfill charge, saving in levelling cost, saving in virgin materials, and green image. Also, five sectors, including the labor cost, the training cost, the truck cost, the fuel cost, and the processing cost, are under the total costs element.

The simulation results show that it takes 14 years for the recycling program to worth the investment. Saving in landfill charge and saving in green image are the key benefits in the recycling program. On the other hand, labor cost and truck cost are two major costs. Four different strategies, focusing on "buying rate", "worker percentage", "recycling rate", and "green image rate", are also examined in the policy testing analysis to assist construction companies to identify the most effective policy for program implementation. The results indicate that the "recycling rate" and "green image rate" parameters have high impacts on the construction and demolition waste recycling program. If the recycling rate is improved, and the taxes in air and nose pollution are strictly imposed, the companies can make the profit in ten years.

The developed dynamic model helps in better understanding the construction and demolition waste situation in Bangkok, and plan for an effective waste management in long-term.

Keywords: construction and demolition waste, recycling program, system dynamics, Bangkok

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Chapter 1
Introduction

1.1 Construction and Demolition Waste

Construction and demolition (C&D) waste has been an issue of global concern. Based on the historical record, C&D waste management had attracted increasing attention during the period of 2000-2009, from just four studies to 16 studies per year (Yuan & Shen, 2011). This field has been receiving efforts from researchers in many countries. The demand in the extensive building and infrastructure development projects is more imperative in developing economies than in developed nations. Thailand, for example, expended a tremendous budget to develop its infrastructure, almost 95 billion Baht in 2012 (Bureau of the Budget, 2012) . Fifty two world-class projects worth RM 67.2 billion will be built up in Malaysia by 2020 (Mirawati et al., 2015). Such enormous construction activities will lead to the large amount of C&D waste generation, forcing researchers in those countries to pay more attention to search the way to effectively manage it.

C&D waste has constituted the majority of the total waste disposed in landfills. According to Rodrigues et al. (2013), approximately 31% of all waste generated in the EU was the C&D waste. It occupied over 50% of the total waste in a typical UK landfill (Ferguson, 1995), and up to 30% in Australian landfills (Craven et al., 1994). Completing projects in the shortest time is the contractors' top priority instead of developing the concept of recycling building materials (Tam & Tam, 2006). Therefore, most of the C&D waste is dumped into landfills without experiencing the waste separation steps, though 95% of it can be recycled (Wang et al., 2008).

Improper C&D waste treatment will lead to the wasteful exploitation of natural resources and energy, as construction activities consume approximately 40% of total natural resources, and around 40% of energy (Wang et al., 2008). Additionally, the landfill shortage and contaminated environment will be inevitable in the short-term. Hong Kong landfills, for instance, will run out of landfill space in 2015 if the rate of C&D waste disposal remains the same (Hao et al., 2008).

To improve C&D waste management, a considerable number of studies have been conducted in many regions. Cheng and Ma (2013), for example, developed the building information modeling-based system to estimate and plan for the demolition and renovation waste in Hong Kong. Ding and Xiao (2014) carried out the research to estimate the quantification and composition of building-related C&D waste in Shanghai, China. Li et al. (2014) built a dynamic model to evaluate the possible impacts arising from the application of prefabrication technology on construction waste reduction, and the subsequent waste handling activities in Shenzhen, China. Wang et al. (2015) developed a model to assess the effect of various waste management strategies and policies at the design stage on waste reduction.

Compared to other countries, C&D waste management in the construction industry in Thailand is still in its early stages, and yet to mature. As a capital and the most densely-populated city of Thailand, Bangkok generated around one-fourth of the total waste in Thailand, while approximately 1.5 million tons of C&D waste are created each year (Chinda et al., 2012; Doan & Chinda, 2015). Few studies, however, were carried out to ameliorate the C&D waste situation. Kofoworola and Gheewala (2009), for instance, estimated the construction waste generation in Thailand from 2002 to 2005. They forecasted that up to 4,000 jobs will be created and approximately $3x10^5$ GJ per year in the final energy consumed could be saved if all construction waste is recycled. WBCSD (2009) reported that the record of the amount of the C&D waste recovery in Thailand was still unavailable.

1.2 Problem Statement

C&D waste is increasing year by year, and this can cause the environmental problems as well as the landfill shortages. The majority of construction companies in Thailand are still struggling in implementing the C&D waste recycling program. One of the major issues is the high cost of the program implementation. Feasibility study is, therefore, needed to examine the C&D waste recycling program implementation in long-term. The potential scenarios in the recycling program implementation to improve the C&D waste management are also required.

1.3 Aim and Significance of the Research

This research study aims to develop a system dynamics model to examine the feasibility of C&D waste recycling program implementation in Bangkok, Thailand in long-term. Key benefits and costs as well as their interrelationships are used in model development. Different recycling strategies are also tested with the model to plan for the best program implementation.

It is expected that the government and construction companies use this research study results as a guideline to plan for their recycling program to create a sustainable waste management, leading to the saving in landfill space and environment.

Chapter 2
Construction and Demolition Waste

2.1 Construction Industry

"Construction industry is an aggregate of many specialized groups working together to build, maintain, repair, renovate, and demolish buildings, highways, dams, bridges, viaducts and any other structures" (Pinto, 2014). It always plays a vital role in the economic development in every countries around the world. In China, it is forecasted that the construction industry will occupy around 5.2% of GDP in 2015 (EUSMEC, 2013). In Australia, the industry had the GDP contribution of 6.8% in 2008-2009 (ABS, 2010). In Thailand, the figure was 2.5% of the total GDP in 2009 (Thai News Service, 2009) .

In contrast to other sectors of the national economy, the characteristics of the construction industry are seen as unique (Ofori, 1990). Figure 2.1 illustrates the eleven main traits of the industry. It has complex interrelationships with the rest sectors of the economy (Ofori, 1990). According to Ofori (1990), the government is the major customer of this industry in comparison with others; the total demand for construction is strictly controlled by the government. The industry consumed a lot of resources and energy (Ofori, 1990). According to Wang et al. (2008), construction activities consumed approximately 40% of total natural resources and around 40% of energy in China. In Thailand, almost 100,000 million Baht was allocated to develop the infrastructure in 2012 (Bureau of the Budget, 2012). The industry is also affected by weather, as construction activities usually take place outdoor (Ofori, 1990). With an extreme weather, the productivity is low, thereby slowing down the work pace (Ofori, 1990).

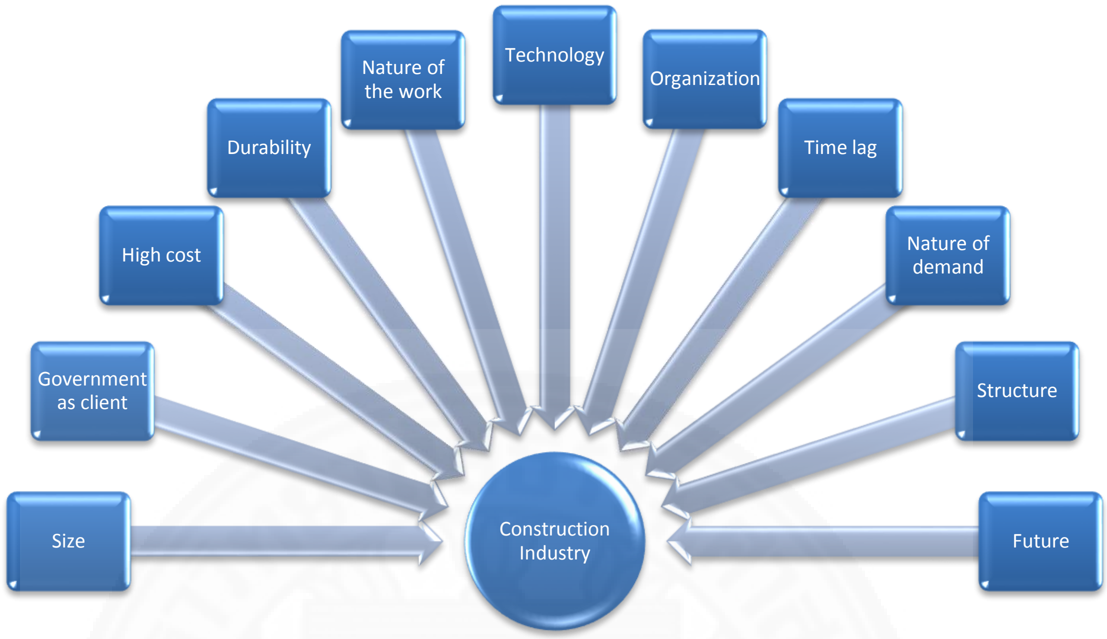


Figure 2.1 Characteristics of construction industry (Ofori, 1990)

2.2 C&D Waste

"C&D waste is waste released when buildings and other constructions such as roads and bridges are built, renovated and demolished" (Wei-hong et al., 2004). In today's society, many infrastructures have been built to meet the needs of the rapid development of economy, leading to large amount of C&D waste generation.

According to Sorpimai (2008), C&D waste is divided into two types, recyclable and non-recyclable waste. Although 95% of the C&D waste can be recycled, most of it is sent to landfills (Wang et al., 2008). Many studies have been conducted to manage waste. The 3R policy, for example, is promoted worldwide to urge the waste management program (Lakhan, 2014; Matter et al., 2015). To make this policy effective, the tipping fees for C&D waste disposal in many countries have been dramatically increased. For instance, the landfill charge had been increased over ten times in the UK, from 7£/ton in 1996 to 72£/ton in 2013 (HM Revenue & Customs, 2013). In Thailand, the fee increased from 149 Bath/ton in 1995 to 535 Bath/ton in 2014 (Manomaivibool, 2005). In Australia, besides tipping fees, construction companies have to pay other environmental related charges, including those for air pollution, gas emission, and noise pollution charges. Such charges were estimated to be more than 50% of landfill space charge (Tam, 2008).

2.2.1 C&D Waste in Bangkok, Thailand

Based on Sorpimai (2008), almost 1.5 million tons of C&D waste were generated in Bangkok during the period of 2000-2006 (see Table 2.1). One person, on average, generates approximately 0.35 kg of C&D waste each day.

Table 2.1 Overall C&D waste quantity estimated, 2000-2006 (Sorpimai, 2008)

Year	Construction waste (tons)	Demolition waste (tons)	Overall C&D waste (tons)	Per capital per day (kg)
2000	386,430	966,535	1,352,965	0.36
2001	385,305	963,535	1,348,584	0.35
2002	352,683	882,783	1,235,467	0.32
2003	339,673	849,337	1,189,001	0.30
2004	345,697	860,798	1,206,496	0.30
2005	419,742	1,047,535	1,476,277	0.35
2006	428,701	1,073,284	1,501,986	0.36

Only two main landfills (i.e. Khampangsan and Phanomsara Kham) are currently utilized to handle all waste in Bangkok (see Figure 2.2). If the amount of waste is still increased, Thailand will face the shortage of landfills and the polluted environment in the near future.

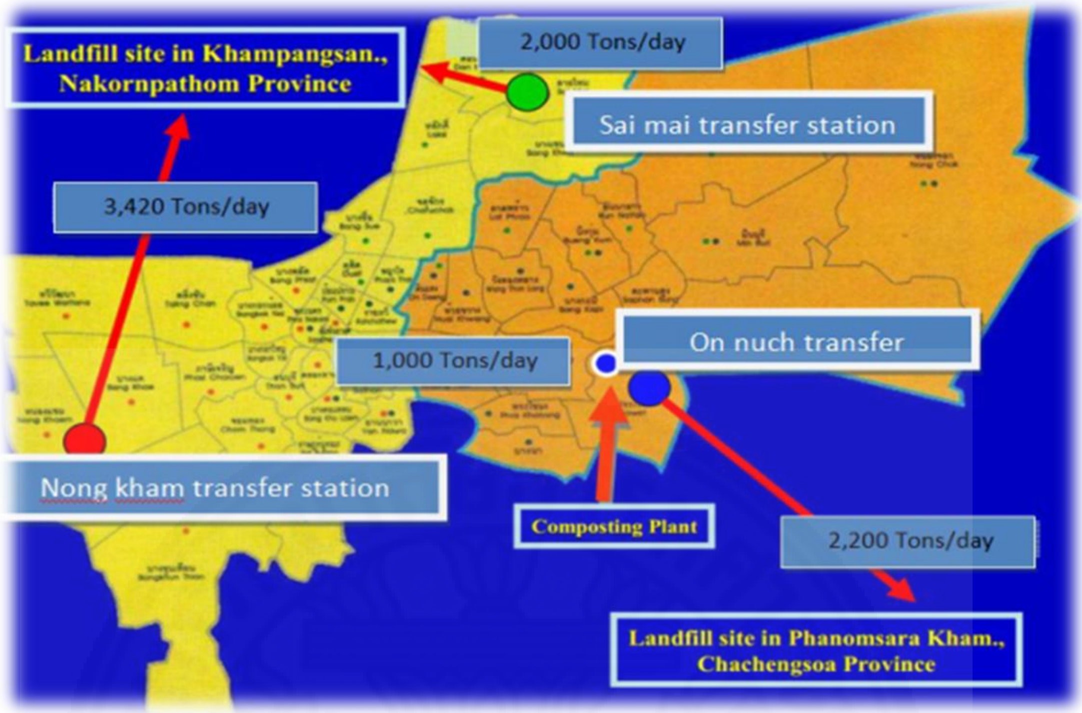


Figure 2.2 Landfills for Bangkok's waste disposal (Chinda et al., 2012)

2.2.2 C&D Waste Estimation in Bangkok

C&D waste is created on: 1) residential building in construction area, 2) non-residential building in construction area, 3) residential building in demolition area, and 4) non-residential building in demolition area (see Table 2.2). Hence, the total amount of C&D waste is the sum of such four categories (see Equations 2.1 to 2.5) (Sorpimai, 2008).

Table 2.2 Average proportion of five main types of C&D waste (PCD, 2007)

Type	Construction area		Demolition area	
	Residential Building (%)	Non-Residential Building (%)	Residential Building (%)	Non-Residential Building (%)
Concrete/Brick	90.43	68.76	92.61	93.70
Metal	4.94	21.94	3.21	4.89
Ceramics	2.72	0.34	2.07	0.22
Wood	0.05	7.37	0.12	0.02
Others	1.86	1.59	1.99	1.17

$$CW_{Ri} = \frac{M_i x G_j x P_R}{1000 x C_j} \tag{2.1}$$

$$CW_{Ni} = \frac{M_i x G_j x P_N}{1000 x C_j} \tag{2.2}$$

$$DW_{Ri} = \frac{M_i x R x G_j x P_R}{1000 x C_j} \tag{2.3}$$

$$DW_{Ni} = \frac{M_i x R x G_j x P_N}{1000 x C_j} \tag{2.4}$$

$$\text{C\&D waste}_i = CW_{Ri} + CW_{Ni} + DW_{Ri} + DW_{Ni} \tag{2.5}$$

where CW_{Ri} = Amount of residential construction waste type i (ton)

G_j = Construction GRP in year i, (Baht) (see Table 2.3)

M_i = Average weight of waste type i, (kg/m^2) (see Table 2.4)

P_R = Average percentage of residential building construction area (63.77%) in Bangkok

C_j = Cost of construction per unit area, (Baht/m^2) (see Table 2.5)

CW_{Ni} = Amount of non-construction waste type i (ton)

P_N = Average percentage of non-residential building construction area (36.23%) in Bangkok

DW_{Ri} = Amount of residential demolition waste type i (ton)

R = Rate of demolition area (10% of construction building area) (PCD, 2007)

DW_{Ni} = Amount of non-residential demolition waste type i (ton)

$C\&D\ waste_i$ = Amount of C&D waste type i (ton)

Table 2.3 Bangkok and Vicinities' construction Gross Regional Product (GRP) (NESDB, 2012)

Year	Construction GRP (Million Baht)
2009	102,519
2010	119,496
2011	116,527
2012	116,276

Table 2.4 Average weight of five main types of C&D waste per unit construction area (PCD, 2007)

	Construction Area		Demotion Area	
Type	Residential Building (kg/m^2)	Non-residential Building (kg/m^2)	Residential Building (kg/m^2)	Non-residential Building (kg/m^2)
Concrete	43.13	17.25	718.81	1,597.63
Brick	7.72	3.70	193.07	92.46
Metal	2.78	6.68	31.58	88.18
Ceramics	1.53	0.10	20.39	4.04
Wood	0.03	2.25	1.18	0.37
Total	55.19	29.98	965.03	1,778.68

Table 2.5 Average cost of construction per unit area (Thai Appraisal Foundation, 2014)

	Residential Building ($Baht/m^2$)				Non-Residential Building ($Baht/m^2$)			
Year	High	Medium	Low	Average	High	Medium	Low	Average
2009	12,768	10,635	8,855	10,753	22,600	16,333	7,050	15,327
2010	12,958	10,790	8,985	10,911	23,040	16,600	7,150	15,597
2011	13,442	11,190	9,310	11,314	24,120	17,552	7,550	16,397
2012	14,105	11,735	9,770	11,870	25,320	18,389	7,950	17,220

Calculation results reveal the amount of C&D waste in Bangkok in 2009 to 2012 (see Table 2.6). It indicates that around 1.5 million tons of C&D waste were generated each year, or around 4,100 tons per day.

Table 2.6 Total C&D waste amount by material, 2009-2012

Material	Amount of C&D waste (tons)			
	Year 2009	Year 2010	Year 2011	Year 2012
Concrete	1,128,201.48	1,294,595.91	1,211,126.99	1,151,494.12
Brick	195,693.45	224,693.26	210,841.73	200,501.92
Metal	62,412.58	71,609.34	66,954.28	63,655.14
Ceramics	22,904.52	26,306.60	24,721.19	23,511.21
Wood	6,417.79	7,354.45	6,834.66	6,495.16
Total	1,415,629.82	1,624,559.56	1,520,478.86	1,455,657.55

2.2.3 Main Types of C&D Waste

There are five main types of C&D waste, including concrete/bricks, metal, gypsum, wood, and paper. They make up more than 95% of C&D waste in Bangkok (see Tables 2.7 and 2.8). In this research study, however, concrete and brick are mainly considered as they contribute over 90% of the total C&D waste (PCD, 2007; Sorpimai, 2008; Kofoworola & Gheewala, 2009).

Table 2.7 The main types of C&D waste quantity in Bangkok, 2002-2005 (Kofoworola & Gheewala, 2009)

No.	Material (10^3 tons)	2002	2003	2004	2005	Average (%)
1	Concrete/bricks	354.8	517.2	634.1	586.7	46.0
2	Wood	105.9	154.4	189.2	175.1	14.0
3	Gypsum	48.4	70.6	86.5	80.1	6.0
4	Paper/cardboard/plastics	34.9	50.8	62.3	57.6	5.0
5	Insulation/EPS	14.5	21.1	25.9	24.0	2.0
6	Metal	10.2	14.9	18.3	16.9	1.0
7	Unknown composition	206	300.3	368.1	340.5	26.0

Table 2.8 The main types of C&D waste quantity in Bangkok, 2000-2006 (Sorpimai, 2008)

Year	Total (tons)				
	Concrete/Brick	Metal	Ceramics	Gypsum	Wood
2000	848,361	48,708	20,344	5,774	5,967
2001	846,117	48,555	20,292	5,758	5,942
2002	774,013	44,472	18,558	5,266	5,456
2003	745,849	42,807	17,886	5,075	5,241
2004	760,664	43,469	18,255	5,180	5,272
2005	922,548	52,844	22,131	6,279	6,441
2006	940,746	54,064	22,556	6,401	6,637
	Total (%)				
Average	90.11	5.17	2.16	0.61	0.63

Chapter 3
Benefit and Cost Elements of C&D Waste Recycling Program

3.1 Data Collection

Benefit and cost elements are used to develop the dynamic model of C&D waste recycling. Both primary and secondary data are gathered. For primary data, the in-depth interviews with experts, who are managers and engineers in transportation and construction companies in Bangkok, are conducted. Medium-and large-sized companies are the target groups, as they have the ability to invest in the recycling program. The interview questions comprise two parts. Part 1 considers interviewees' demographic information. Part 2 comprises 15 questions related to transportation and construction activities (see interview questions in Appendix A). Some examples of the questions are shown as below:

.

- What is the ratio of rented to bought trucks in your company?

☐ <20% rented ☐ 20-30% rented ☐ 31-40% rented ☐ 41-50% rented

☐ Others (Please specify)……

Note: If there are 10 trucks in your company, and that three of them are from rental, the answer is 30%.

- What is the salvage value of a truck (Baht)?

☐ < 125,000 ☐ 125,000-175,000 ☐ 175,001-225,000 ☐ 225,001-275,000

☐Others (Please specify)……

For secondary data, various literatures, not only in Thailand, but also in other countries, are obtained to gather necessary information for the research. For instance, Tam (2008) mentioned that saving in air and noise pollution is equivalent to 34.2% of the landfill space charge in Australia. Hameed and Chini (2010) stated that the processing cost is approximately half of the virgin aggregate in the USA.

3.2 Benefit Element

Based on primary and secondary data collected, five main benefits are used in this research study (see Table 3.1). According to Begum et al. (2006), and Kofoworola and Gheewala (2009), the fuel cost could be saved when the recycling program is implemented. Begum et al. (2006) also mentioned the saving in landfill charge in the waste recycling program implementation. Tam and Tam (2006) stated that saving in levelling and virgin materials could bring an enormous amount of money to construction companies. Tam (2008) examined the saving in green image in Australia.

Table 3.1 Benefit element information

	Saving	Unit	Source
Landfill Charge	464	Baht/ton	(Manomaivibool, 2005)
Sand	262.36	Baht/m^3	(MoC, 2014)
Aggregate	555.88	Baht/ton	(MoC, 2014)
Carbon tax rate	450	Baht/ton CO_2	(Wachirarangsrikul et al., 2013)
Air, noise pollution	34.2%	Landfill space charge	(Tam, 2008)

3.3 Cost Element

Key costs relating to C&D waste recycling program implementation are list in Table 3.2. According to Tam and Tam (2006), labor and transportation costs are the main costs in the C&D waste recycling program implementation. Processing cost was also mentioned by Hameed & Chini (2010).

Table 3.2 Cost element information

	Cost	Unit	Source
Worker' wage	300	Baht/person	(PRD, 2013)
Training cost	12,200	Baht/person	(Wongpanit, 2013)
Fuel cost (NPV)	12.5	Baht/kg	(EPPO, 2014)
Buy/Rent ratio	75/25		In-depth Interview
New truck	2,450,000	Baht/truck	In-depth Interview
Truck rental	95,000	Baht/truck/month	In-depth Interview
NGV installation	425,000	Baht/truck	In-depth Interview
Truck insurance	50,000	Baht/truck	In-depth Interview
Driver	22,500	Baht/driver/month	In-depth Interview
Route	2,500	Baht/truck/5 years	(APEC, 2011)
Tire	2	Baht/truck/km	In-depth Interview
Regular maintenance	2	Baht/truck/km	In-depth Interview
Big maintenance	100,000	Baht/truck/5 years	In-depth Interview

Chapter 4
The Dynamic Model of C&D Waste Recycling

4.1 System Dynamics Modelling

System dynamics (SD) is a method employed to analyze the large-scale complex management problems, and evaluate the long-term behavior of real-world systems (Hao et al., 2008). Interrelationships among variables are examined to assist users to improve the validity and effectiveness of the decision-making process (Hao et al., 2008). The method has been applied in a wide variety of disciplines (see Table 4.1). Minegishi and Thiel (2000), for example, described the consequences of the dioxin infection to the supply chain of the chicken industry, using SD modelling. Aslani et al. (2014) developed a SD model of renewable energy resources in Finland to investigate the dependency and security of energy supply.

In the waste management area, Hao et al. (2007) investigated the C&D waste management on-site through SD modelling by studying waste generating factors and waste levels. Sufian and Bala (2007) utilized a SD modelling technique to estimate the amount of urban solid waste, the collection capacity, and the electricity generation in Dhaka, Bangladesh. Chaerul et al. (2008) employed a SD approach to determine the interactions among various components affecting the hospital waste creation to minimize the risk to public health. Kollikkathara et al. (2010) developed a SD model to study the relationships between three main factors, including the solid waste generation, the landfill capacity, and the economic cost to provide valuable insights into the urban waste-management process..

The above studies prove the use of SD in modelling the C&D waste recycling program in this research study.

Table 4.1 Literature review of the use of SD modelling technique

Area	Topic	Year	Author
Food	System dynamics modeling and simulation of a particular food supply chain	2000	(Minegishi & Thiel, 2000)
	A system dynamics modeling framework for the strategic supply chain management of food chains	2005	(Georgiadis et al., 2005)
	A system dynamics analysis of food supply chains – Case study with non-perishable products	2011	(Kumar & Nigmatullin, 2011)
Economic	A note on the integration of system dynamics and economic models	2002	(Smith & van Ackere, 2002)
	Effect of floating pricing policy: An application of system dynamics on oil market after liberalization	2011	(Wu et al., 2011)
Energy	Dynamics of the UK natural gas industry: System dynamics modelling and long-term energy policy analysis	2009	(Chi et al., 2009)
	How to do structural validity of a system dynamics type simulation model: The case of an energy policy model	2010	(Qudrat-Ullah & Seong, 2010)
	Role of renewable energy policies in energy dependency in Finland: System dynamics approach	2014	(Aslani et al., 2014)
Transportation	A system dynamics approach to land use/transportation system performance modeling part I: methodology	2003	(Haghani et al., 2003)
	System Dynamics Model of Urban Transportation System and Its Application	2008	(Wang et al., 2008)

Area	Topic	Year	Author
Waste Management	Modeling of urban solid waste management system: The case of Dhaka city	2007	(Sufian & Bala, 2007)
	System Dynamics Model of Urban Transportation System and Its Application	2008	(Wang et al., 2008)
	A simulation model using system dynamic method for construction and demolition waste management in Hong Kong	2007	(Hao et al., 2007)
	A system dynamics approach for hospital waste management	2008	(Chaerul et al., 2008)
	A system dynamic modeling approach for evaluating municipal solid waste generation, landfill capacity and related cost management issues	2010	(Kollikkathara et al., 2010)
	The Validation of Municipal Solid Waste Dynamic Model in Bangkok	2014	(Manasakunkit & Chinda, 2014)

4.2 Components of the SD Model

There are four elements in SD modelling: stock, flow, converter, and connector (Zhao et al., 2011) (see Figure 4.1). The stock represents the major accumulation in the system. It is affected by the rate of change of the inflow (positive flow) and outflow (negative flow). The converter is used for miscellaneous calculations in the model, while connectors are the information link, representing the cause and effect within the model (Zhao et al., 2011).

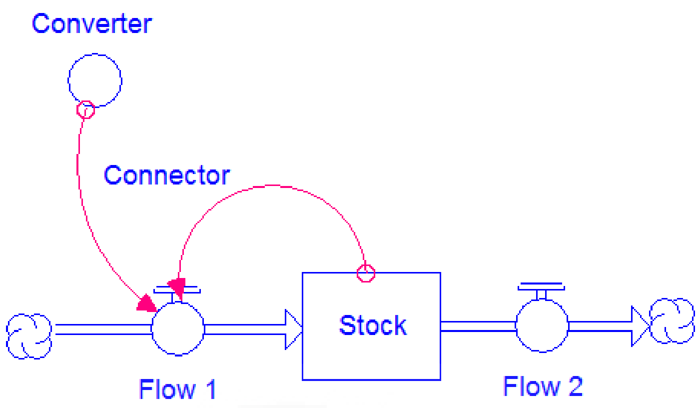


Figure 4.1 Basic elements of the system dynamics

4.3 SD Modelling Software

A number of softwares have been employed in SD modelling, including iThink®, Dynamo®, AnyLogic®, and Vensim®. In this research paper, iThink® is used to develop the dynamic model of C&D waste recycling, as its intuitive icon-based interface, its popularity, and its great graphical depictions (Yuan, 2012).

4.4 Dynamic Model of C&D Waste Recycling

In this research study, the dynamic model of C&D waste recycling is developed using a SD approach. It consists of three elements (benefits, costs, and results) with 11 sectors (see Figures 4.2 and 4.3). Benefits includes five sectors, namely 1) saving in fuel cost to landfill, 2) saving in landfill charge, 3) saving in levelling cost, 4) saving in virgin materials, and 5) green image. The costs also consists of five main sectors, namely 1) labor cost, 2) training cost, 3) truck cost, 4) fuel cost, and 5) processing cost. Last sector is the results sector.

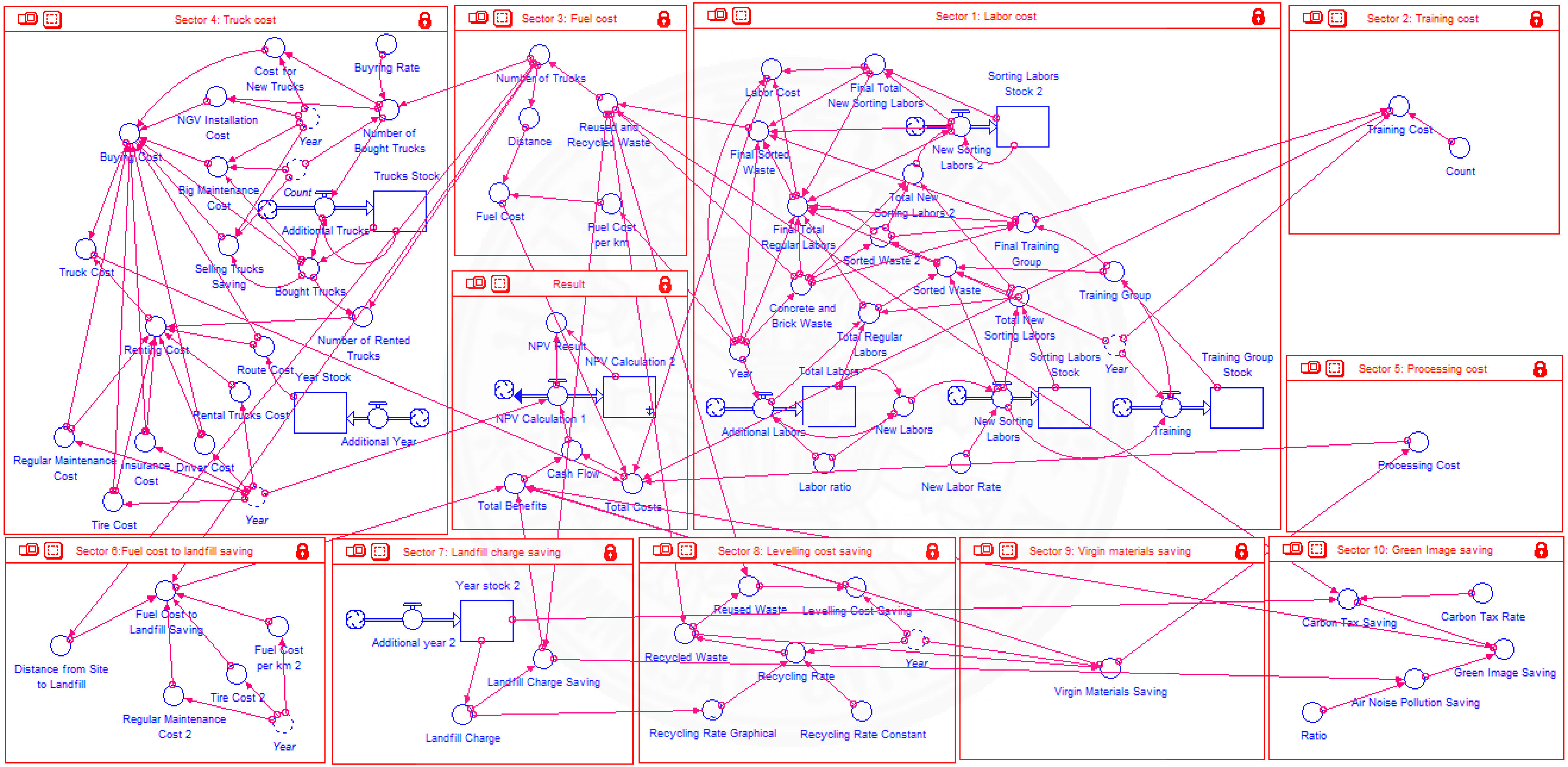


Figure 4.2 The dynamic model of C&D waste recycling

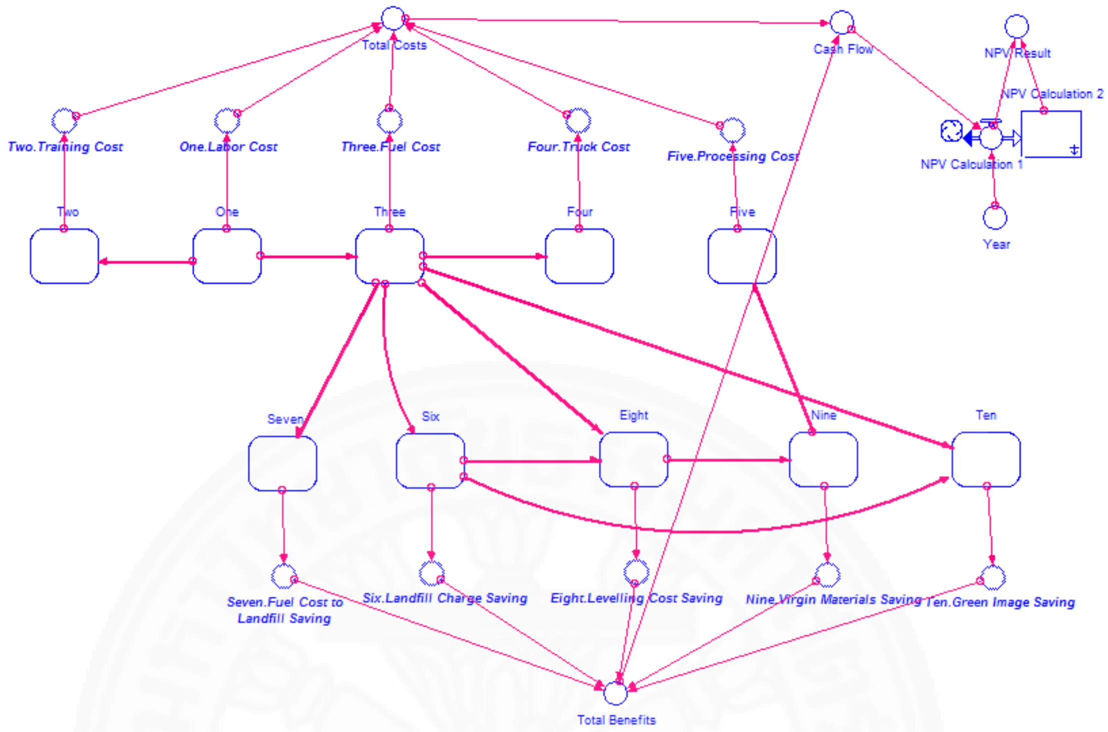


Figure 4.3 Eleven sectors of the dynamic model of C&D waste recycling

4.5 Benefit Element

4.5.1 Saving in Fuel Cost to Landfill Sector

The distance from construction sites to two main landfills are much greater than that from sites to sites, so a considerable amount of money can be saved when the C&D waste recycling program is implemented. This sector is displayed in Figure 4.4 and Equation 4.1.

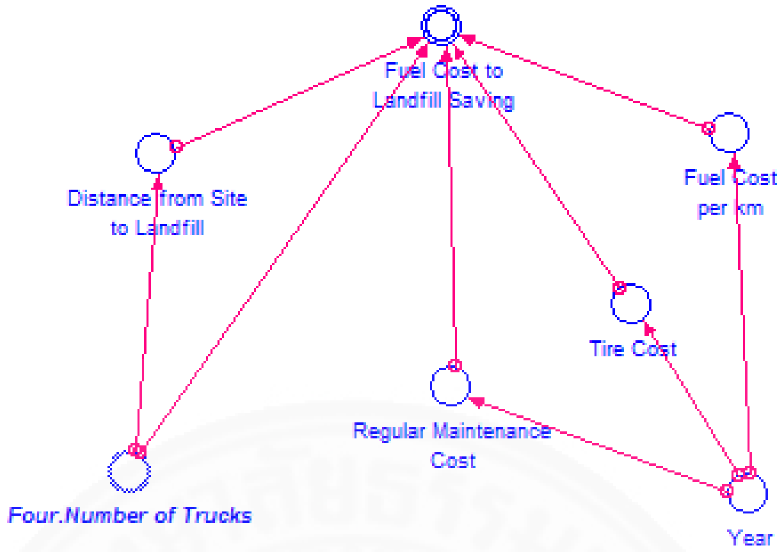


Figure 4.4 Saving in fuel cost to landfill sector

Fuel_Cost_to_Landfill_Saving = Distance_from_Site_to_Landfill*
Fuel_Cost_per_km + Four.Number_of_Trucks *
(Regular_Maintenance_Cost + Tire_Cost) (4.1)

4.5.2 Saving in Landfill Charge Sector

Landfill charge has been increased by 1.5 times, reaching 464 Baht/ton from 1995 to 2014 (Manomaivibool, 2005). Definitely, the landfill charge will experience a dramatic increase in the near future due to the large amount of waste generation and landfill shortages. Once recycling program is implemented, it is expected that a large amount of money can be saved (see Figure 4.5 and Equation 4.2).

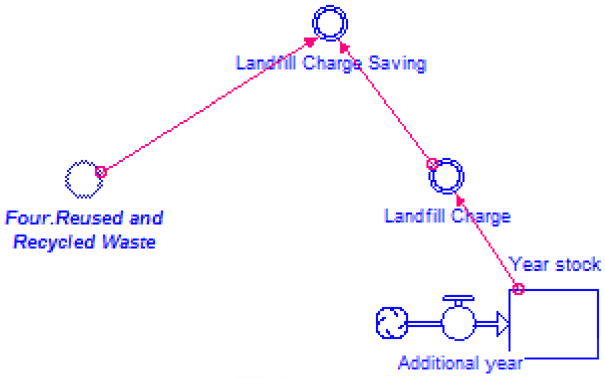


Figure 4.5 Saving in landfill charge sector

Landfill_Charge_Saving = Four.Reused_and_Recycled_Waste*Landfill_Charge (4.2)

4.5.3 Saving in Levelling Cost Sector

Figure 4.6 shows the saving in levelling cost sector. It depends mainly on the total amount of sorted waste per year. This amount is calculated from the difference between the sorted waste and the recycled waste, and it is used to replace sand in levelling the foundation, see Equations 4.3 to 4.5. Sand cost is currently at 262.36 baht/m^3 with the increasing rate of 8.6% per year (MoC, 2014).

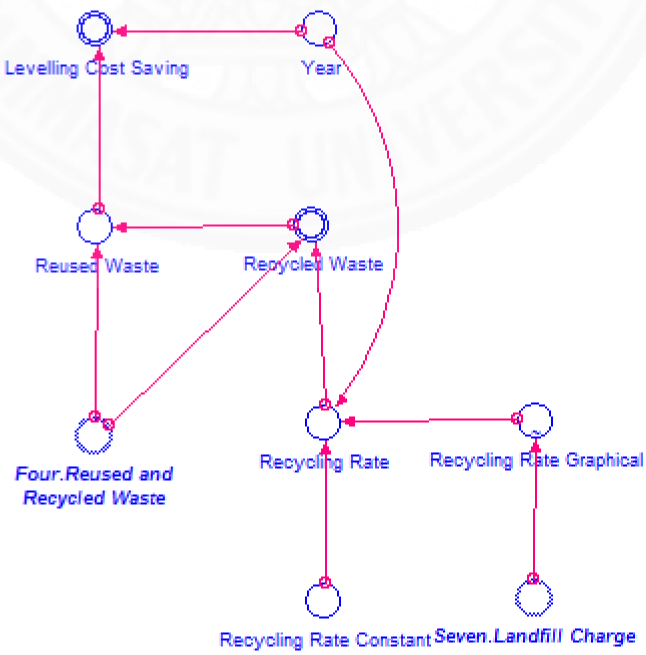


Figure 4.6 Saving in levelling cost sector

Recycled_Waste = IF Four.Reused_and_Recycled_Waste > Four.Reused_and_Recycled_Waste * Recycling_Rate THEN Four.Reused_and_Recycled_Waste * Recycling_Rate ELSE Four.Reused_and_Recycled_Waste (4.3)

Reused_Waste = IF (Four.Reused_and_Recycled_Waste - Recycled_Waste) > 0 THEN (Four.Reused_and_Recycled_Waste- Recycled_Waste) ELSE 0 (4.4)

Levelling_Cost_Saving = Reused_Waste/1.4*262.36*1.086^Year (4.5)

4.5.4 Saving in Virgin Materials Sector

When C&D waste is recycled, it is crushed and used to replace the new aggregate. Figure 4.7 shows the saving in virgin materials sector. In Equation 4.6, the price of aggregate is 555.88 Baht/ton, with the increasing rate of 11.9 % per year (MoC, 2014).

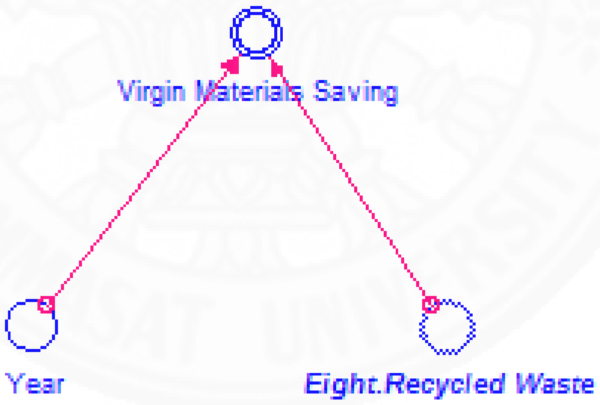


Figure 4.7 Saving in virgin materials sector

Virgin_Materials_Saving = Eight.Recycled_Waste*555.88*1.119^Year (4.6)

4.5.5 Green Image Sector

Figure 4.8 shows the green image sector. According to TWB (2014) , Thailand is one of the countries considering imposing carbon tax (see Figure 4.9). The average carbon tax rate in Thailand is expected to be 450 Baht per ton CO2 (Wachirarangsrikul et al., 2013), and it is forecasted to increase by 65% every 5 years.

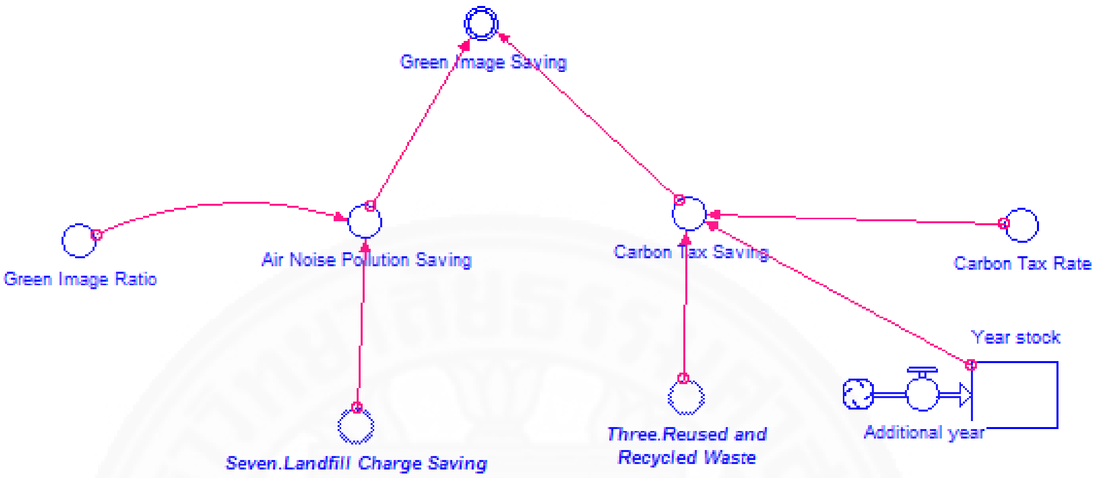


Figure 4.8 Green image sector

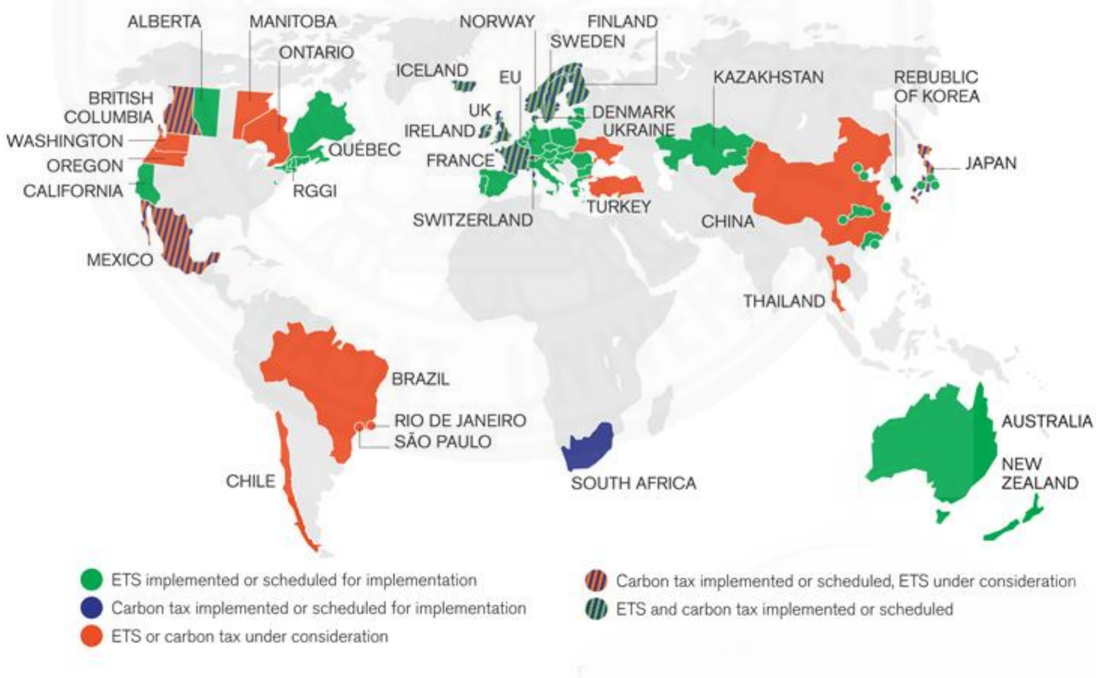


Figure 4.9 Carbon tax consideration (Thai News Service, 2014)

Based on the DECCW (2010), the net benefit of reuse and recycling 1 ton of concrete and brick waste can reduce 0.02 ton CO_2 (see Equation 4.7). Besides that, saving in air and noise pollution is also counted. According to Tam (2008), saving in air and noise pollution is equivalent to 34.2% of landfill charge (see Equations 4.8 and 4.9).

Carbon_Tax_Saving = Carbon_Tax_Rate * 1.65^Year_stock * Four.Reused_and_Recycled_Waste * 0.02 (4.7)

Air_Noise_Pollution_Saving = Seven.Landfill_Charge_Saving*Ratio (4.8)

Green_Image_Saving = Air_Noise_Pollution_Saving+Carbon_Tax_Saving (4.9)

4.5.6 Total Benefits

The total benefits of the recycling program is the sum of the five benefits mentioned above (see Figure 4.10 and Equation 4.10).

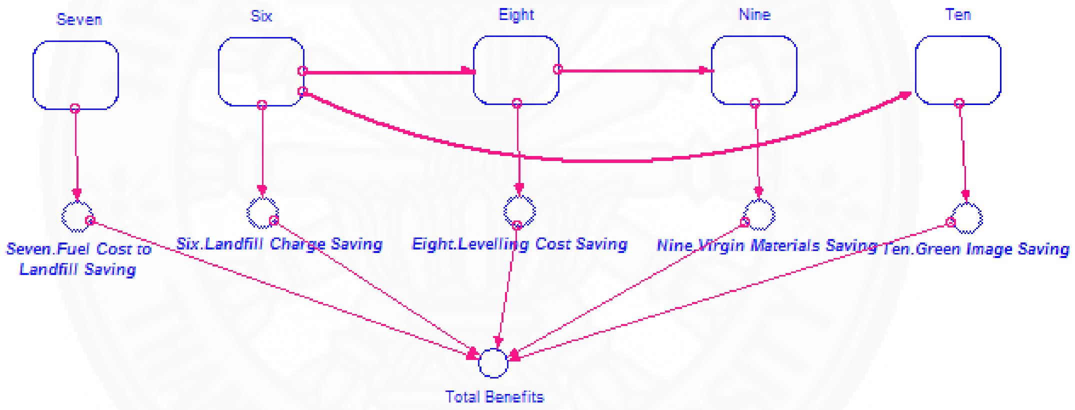


Figure 4.10 Total benefits

Total_Benefits = Seven.Fuel_Cost_to_Landfill_Saving + Six.Landfill_Charge_Saving + Eight.Levelling_Cost_Saving + Nine.Virgin_Materials_Saving + Ten.Green_Image_Saving (4.10)

4.6 Cost Element

4.6.1 Labor Cost Sector

Workers are needed in the waste sorting process. With the tremendous amount of C&D waste created each year, a great deal of workforce, both full-time and part-time, must be recruited to work in the sorting activity (see Figure 4.11).

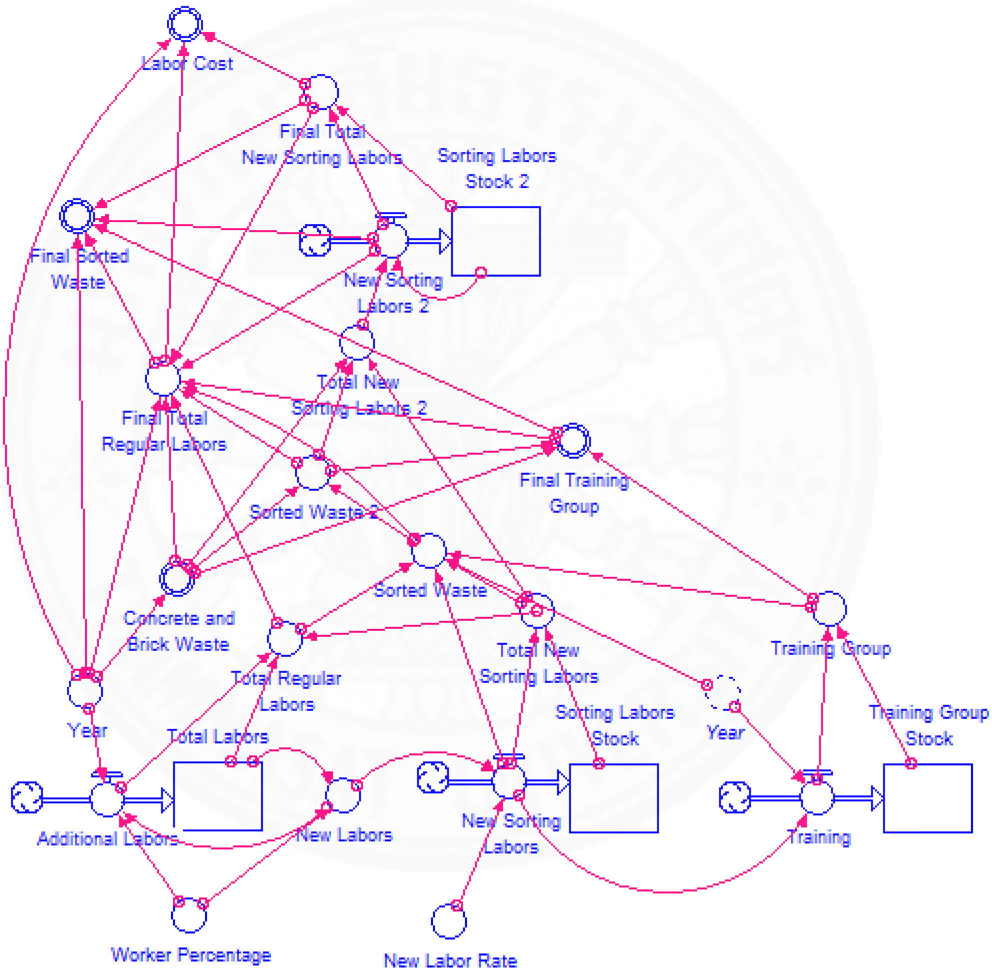


Figure 4.11 Labor cost sector

Equation 4.11 calculates the amount of sorted waste. The worker productivity is set as 0.246 kg/day (Chinda et al., 2013). There are 245 working days per year (BoT, 2014). As separated process is still not widely implemented in Thailand, the specific training is needed to enhance the workers' productivity. The workers who have to attend the training course for five days, work in the recycling activity for 240 days a year (Wongpanit, 2013).

Sorted_Waste = IF Year=0 THEN 0 ELSE IF Year=1 THEN 0.246*
(Total_New_Sorting_Labors*240+Total_Regular_Labors*245)
ELSE 0.246*((Total_Regular_Labors+
Total_New_Sorting_Labors- Training_Group –
New_Sorting_Labors)*245+(Training_Group +
New_Sorting_Labors)*240) (4.11)

When all C&D waste is sorted and separated, construction companies need to stop recruiting new full-time recycling workers, leading to the total labor cost (see Equation 4.12).

Labor_Cost = IF Year = 0 THEN 0 ELSE
(Final_Total_New_Sorting_Labors +
Final_Total__Regular_Labors)*245*300*1.023^Year (4.12)

Staring from year 1, the labor cost depends on the total number of workers, number of working days per year, wage per woker per day, and the inflation rate. In this research study, the worker's wage is 300 Baht/day, which is the minimum wage that a worker will receive per day (PRD, 2013). The average inflation rate in Thailand in the last five years is at 2.3% (GDPI, 2013).

Equations 4.13 to 4.17 state the number of regular and new workers. Currently, there are 184930 construction employees, with an increasing trend of 2.5% per year (BoT, 2013). Based on Chittithaworn et al. (2011), 4/5 of the full-time workers work in medium and large companies, and that 65.3% of them work in operation level (Italian-Thai, 2013).

Total_Regular_Labors = ROUND ((Total_Labors + Additional_Labors -
Total_New_Sorting_Labors)*1.6/8) (4.13)

Additional_Labors = IF Year=0 THEN ROUND (184930 * Worker_Percentage/5*4*1.025) ELSE New_Labors (4.14)

New_Labors = ROUND (0.025*Total_Labors* Worker_Percentage/5*4 (4.15)

Total_New_Sorting_Labors = Sorting_Labors_Stock+New_Sorting_Labors (4.16)

New_Sorting_Labors = ROUND (New_Labors*New_Labor_Rate) (4.17)

All new recruited labors working in the recycling sector must attend the training course to improve the productivity in the first year. In the following years, this group will train the new staffs (see Equations 4.18 and 4.19).

Training_Group = Training_Group_Stock+Training (4.18)

Training = IF Year=1 THEN New_Sorting_Labors ELSE 0 (4.19)

4.6.2 Training Cost Sector

To increase the workers' productivity, new workers need to be trained (see Figure 4.12). This group of workers then train new workers in the following years. They must, however, attend the training course every three years to update with the new separation method (Occupation and Environmental Safety Office, 2014). Based on Wongpanit (2013), the most well-known recycling company in Thailand, five days training course costs 12,200 Baht per worker, see Equation 4.20.

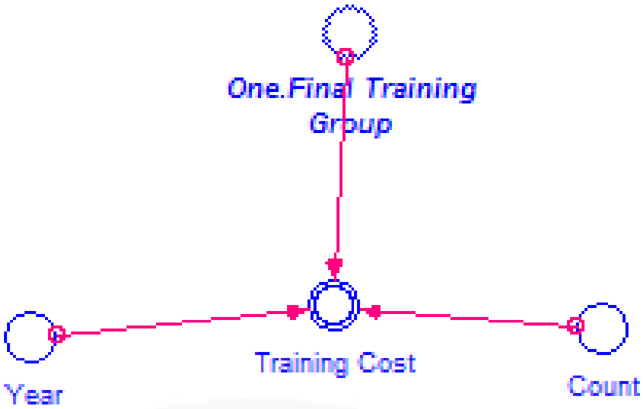


Figure 4.12 Training cost sector

Training_Cost = IF Count=2 THEN One.Final_Training_Group

*12200*1.023^Year ELSE 0 (4.20)

4.6.3 Truck Cost Sector

The number of needed trucks for the recycling program is influenced by the amount of waste that workers separated and the truck capacity. Trucks are bought or rented depend on the companies' financial availability (see Figure 4.13).

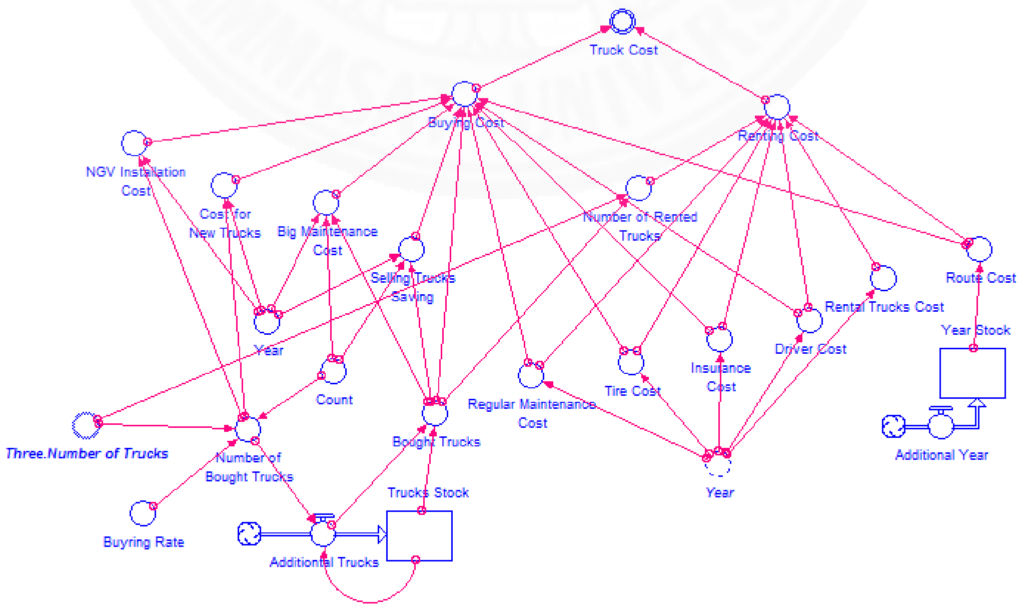


Figure 4.13 Truck cost sector

When a new truck is bought, a number of associated costs must be considered (see Table 4.2). The new truck is normally installed with the Natural Gas Vehicle (NGV) engine to save fuel cost. Also, driver cost, truck insurance cost, route cost, tire cost, regular maintenance cost, and major maintenance cost are counted (see Equation 4.21).

Table 4.2 Types of truck cost

	Cost	Unit	Source
Buy/Rent ratio	75/25		In-depth Interview
New truck	2,450,000	Baht/truck	In-depth Interview
Truck rental	95,000	Baht/truck/month	In-depth Interview
NGV installation	425,000	Baht/truck	In-depth Interview
Truck insurance	50,000	Baht/truck	In-depth Interview
Driver	22,500	Baht/driver/month	In-depth Interview
Route	2,500	Baht/truck/5 years	(APEC, 2011)
Tire	2	Baht/truck/km	In-depth Interview
Regular maintenance	2	Baht/truck/km	In-depth Interview
Big maintenance	100,000	Baht/truck/5 years	In-depth Interview

Buying_Cost = NGV_Installation_Cost + Cost_for__New_Trucks +
Big_Maintenance_Cost Selling_Trucks__Saving +
(Regular_Maintenance_Cost + Tire_Cost + Insurance_Cost +
Driver_Cost + Route_Cost)*Bought_Trucks (4.21)

Rented truck incurs similar costs, except that the truck and NGV installation costs are replaced with the rental cost (see Equations 4.22 and 4.23).

Renting_Cost = (Regular_Maintenance_Cost + Route_Cost + Tire_Cost +
Insurance_Cost+Driver_Cost + Rental_Trucks_Cost)*
Number_of_Rented_Trucks (4.22)

Truck_Cost = Buying_Cost+Renting_Cost (4.23)

4.6.4 Fuel Cost Sector

In construction sites, the limited site space is the barrier for the recycling program implementation (Poon et al., 2001). When the C&D waste is separated, it is then transported to the recycling sites to save the construction sites space (see Figure 4.14). This incurs the fuel cost (see Equations 4.24 to 4.28).

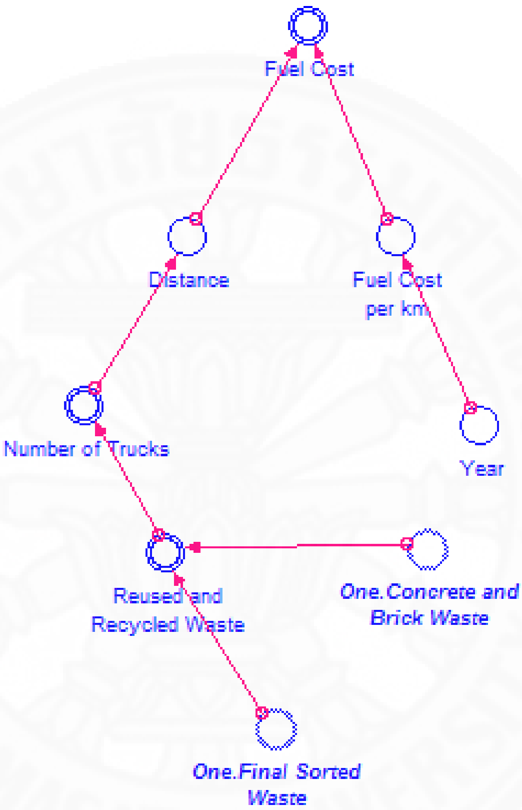


Figure 4.14 Fuel cost sector

Fuel_Cost = Distance*Fuel_Cost_per_km (4.24)

Distance = Number_of_Trucks*3*245*22.84 (4.25)

Fuel_Cost_per_km = IF Year=0 THEN 0 ELSE 12.5*1.058^Year/2.2 (4.26)

Number_of_Trucks = IF (Reused_and_Recycled_Waste/12.5)/(245*3)> ROUND ((Reused_and_Recycled_Waste/12.5)/(245*3)) THEN ROUND ((Reused_and_Recycled_Waste/12.5)/(245*3))+1 ELSE ROUND ((Reused_and_Recycled_Waste/12.5)/(245*3)) (4.27)

Reused_and_Recycled_Waste = MIN (One.Concrete_and__Brick_Waste,
One.Final_Sorted_Waste) (4.28)

The average distance from site to site in Bangkok is around 22.84 km (NESDB, 2013). Trucks can travel from site to site three times a day. The fuel cost (NGV fuel) is 12.5 Baht/kg, with an average increasing rate of 5.8% per year (EPPO, 2014). Fuel consumption is around 2.2 km/kg (Jaroonrat, 2014).

4.5.5 Processing Cost Sector

According to Hameed and Chini (2010), the processing cost is approximately half of the virgin aggregate cost (see Figure 4.15 and Equation 4.29).

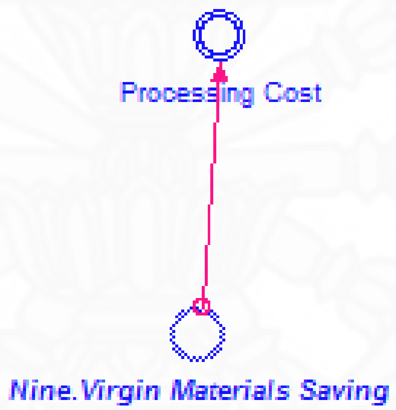


Figure 4.15 Processing cost sector

Processing_Cost = Nine.Virgin_Materials_Saving/2 (4.29)

4.5.6 Total Costs

The total costs of the recycling program is the sum of the five main costs, see Figure 4.16 and Equation 3.30.

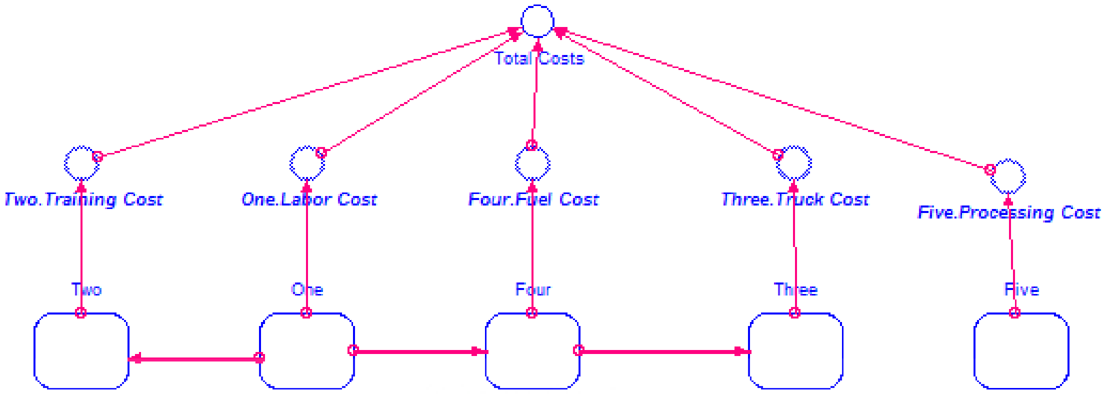


Figure 4.16 Total costs

Total_Costs = Two.Training_Cost+One.Labor_Cost+Four.Fuel_Cost+
Three.Truck_Cost+Five.Processing_Cost (4.30)

4.7 Net Present Value (NPV) and Internal Rate of Return (IRR)

NPV and IRR are the popular methods to determine the feasibility of a project (Weber, 2014). With the NPV method, decision makers can compare the amount of money invested today with the future returns after taking the "time value of money" into account (Weber, 2014). The project worth investing in when the value of the NPV is at least 0. IRR, on the other hand, is used to define the investment's profitability (Weber, 2014). The project is considered feasible when the IRR value is greater than the actual discount rate, which is usually set as 12% for government projects (Yescombe, 2007).

The two methods are widely used in many projects, including waste management projects. Choy et al. (2005), for example, carried out a research to investigate the feasibility of the preliminary process design of the production of activated carbon from the bamboo scaffolding waste based using both NPV and IRR methods. HZC (2012) also used these methods to examine the feasibility and economic viability for the integrated waste to energy system in Greater Malang, Indonesia.

These two methods are employed in this research study to examine the feasibility of the C&D waste recycling program implementation in long-term.

CHAPTER 5

Simulation Results and Policy Testing Analysis

5.1 Simulation Results

The dynamic model of C&D waste recycling is run and the simulation results are illustrated in Figures 5.1 to 5.3, and Table 5.1. It is clear that in the early years of the recycling program, the value of the total costs is much higher than that of the total benefits. This is because the construction companies need to invest a large amount of money in recruiting labors and buying trucks, while the benefits gained from program implementation is still small. The gap between the total costs and the total benefits is, however, smaller in the following years and become zero at the end of year 9. However, the value of NPV is not positive until the end of year 14, while the IRR value is greater than 12% at the end of year 17.

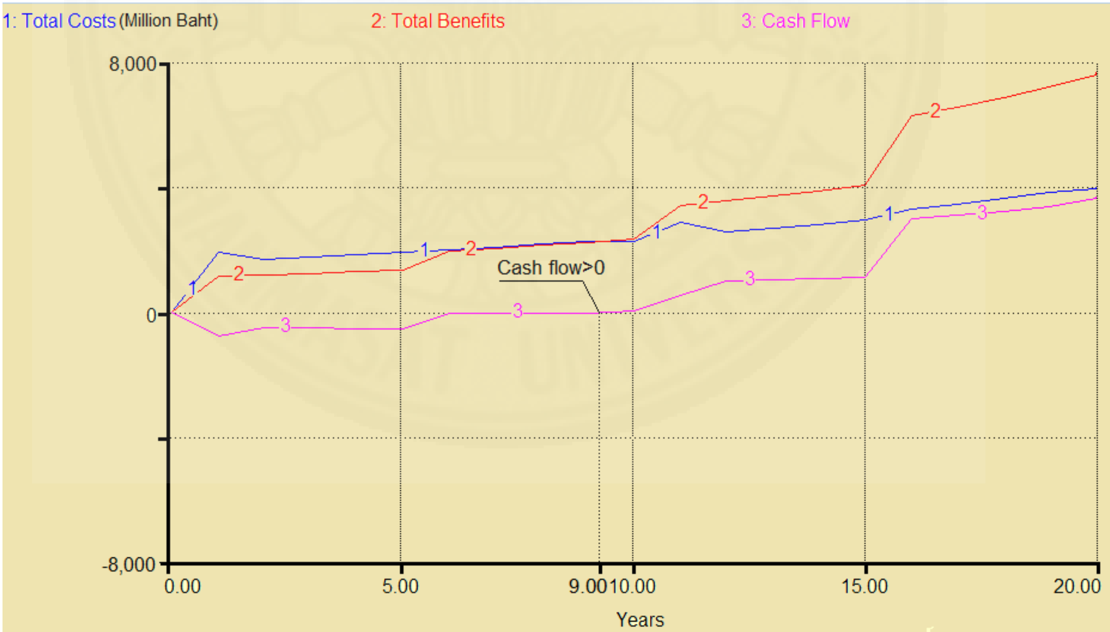


Figure 5.1 Cash flow results of the recycling program

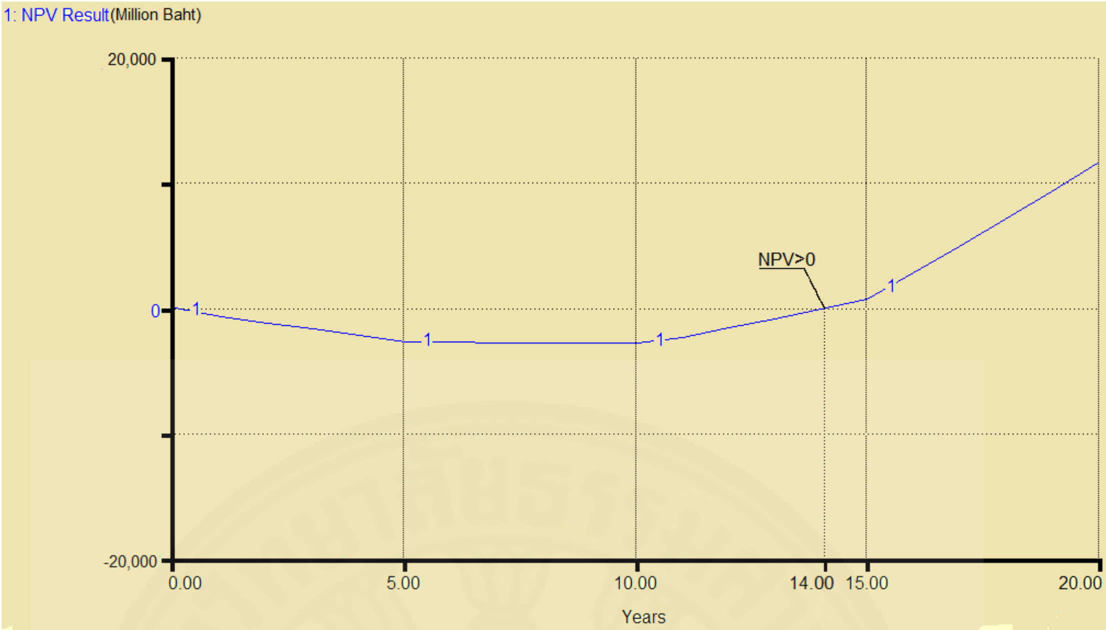


Figure 5.2 NPV results of the recycling program

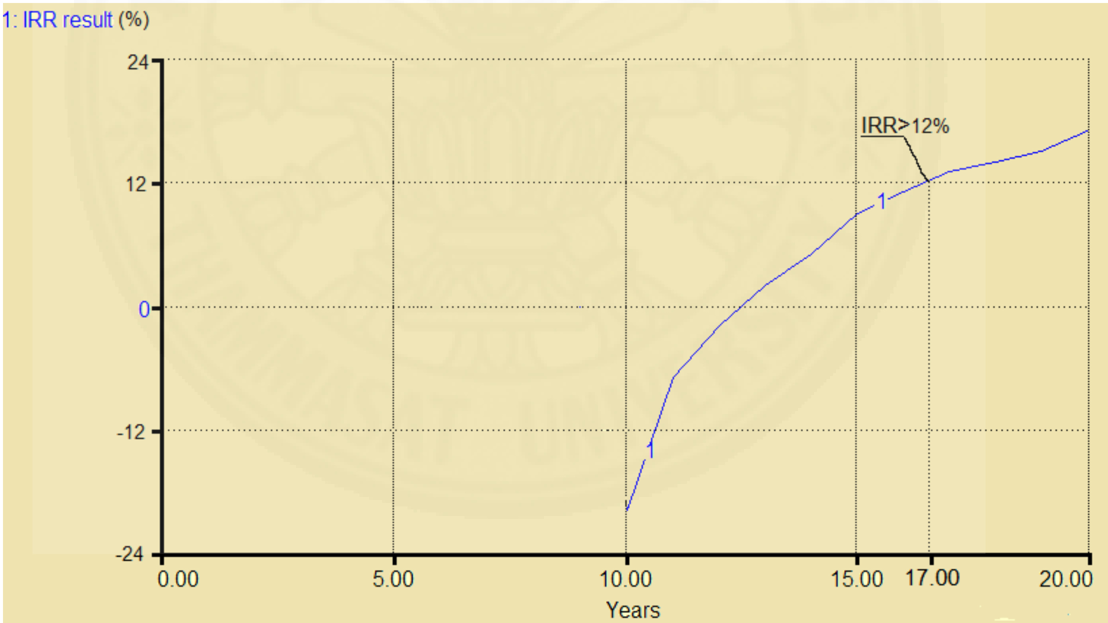


Figure 5.3 IRR results of the recycling program

Table 5.1 The simulation results of the C&D waste recycling program

Year	Total Costs	Total Benefits	Cash Flow	NPV	IRR
0	1,922,707,403.02	1,144,551,786.32	-778,155,616.70	-760,660,426.88	N/A
1	1,696,346,198.16	1,190,144,355.00	-506,201,843.17	-1,244,356,380.99	N/A
2	1,763,413,832.42	1,239,340,701.10	-524,073,131.33	-1,733,870,241.53	N/A
3	1,833,888,642.44	1,292,474,058.61	-541,414,583.83	-2,228,212,133.20	N/A
4	1,917,778,336.14	1,349,875,664.87	-567,902,671.27	-2,735,081,147.51	N/A
5	2,000,487,258.66	1,969,183,083.19	-31,304,175.47	-2,762,392,830.76	N/A
6	2,082,891,399.44	2,047,636,719.31	-35,254,680.13	-2,792,459,640.03	N/A
7	2,167,710,064.96	2,132,478,866.19	-35,231,198.77	-2,821,830,884.69	N/A
8	2,257,129,217.04	2,224,367,703.13	-32,761,513.91	-2,848,529,163.18	N/A
9	2,281,137,439.67	2,324,032,358.33	**42,894,918.66**	-2,814,358,806.55	N/A
10	2,886,559,205.50	3,430,905,433.63	544,346,228.13	-2,390,478,492.79	-20%
11	2,573,594,600.52	3,570,142,523.49	996,547,922.97	-1,631,917,364.81	-7%
12	2,686,904,984.16	3,721,395,691.67	1,034,490,707.52	-862,178,605.27	-2%
13	2,806,052,883.91	3,885,663,942.63	1,079,611,058.72	-76,927,687.75	2%
14	2,948,245,390.04	4,064,520,929.28	1,116,275,539.24	**716,736,716.23**	5%
15	3,297,894,277.86	6,286,729,758.14	2,988,835,480.28	2,794,001,558.20	9%
16	3,470,449,045.97	6,575,173,386.39	3,104,724,340.43	4,903,296,316.22	11%
17	3,657,719,664.18	6,893,033,370.17	3,235,313,705.99	7,051,893,443.62	**13%**
18	3,857,435,771.23	7,240,301,515.44	3,382,865,744.21	9,247,971,243.83	14%
19	3,970,958,232.98	7,622,367,698.46	3,651,409,465.48	11,565,087,706.46	15%
20	7,155,600,340.61	14,703,875,909.33	7,548,275,568.72	16,247,389,893.67	17%

5.2 Policy Testing

In this research study, the behavior-sensitivity test is referred to as the policy testing analysis. It concentrates on the sensitivity of model behavior to changes in parameter values (Forrester & Senge, 1980). It is typically conducted by experimenting with different parameter values and analyzing their impact on behavior (Forrester & Senge, 1980). According to Forrester & Senge (1980), it is one of the methods used to build the confidence in SD models.

Four key parameters, two in benefit element and two in cost element, are selected to investigate the influence of each parameter on the model behavior, see Table 5.2. At each run, the values of these parameters are adjusted in order to examine both the pessimistic and optimistic scenarios in the model. It is expected that the construction companies earn the profit in the earlier years when the values of the parameters increase.

Table 5.2 Values of four parameters in the policy testing analysis

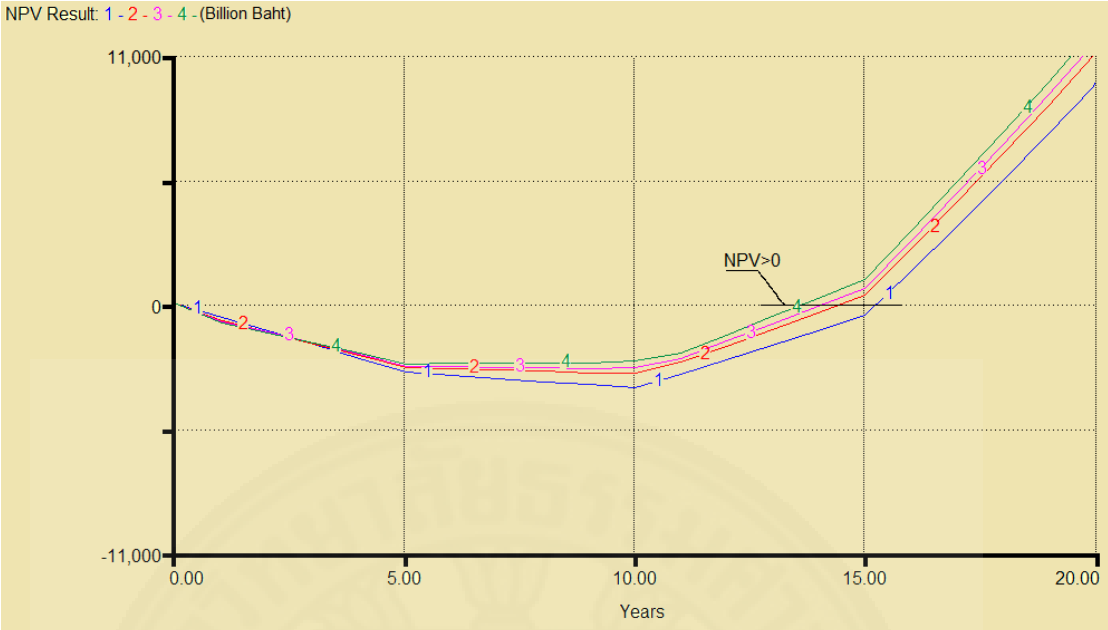
Parameter name	Description	Value
Buying rate[1]	The ratio of the bought trucks to the total trucks	0%, 55%, 75%, and 100%
Worker percentage[2]	The ratio of operational workers to the total employees	40%, 50%, 65.3%, and 70%
Recycling rate[3]	The ratio of recycled C&D waste to the total C&D waste	0%, base model, 3.7% each year, and 100%
Green image rate[4]	The saving in air and noise pollution as a percentage of the landfill charge	0%, 34.2%, 50%, and 70%

1: If the companies buy two trucks in the total of 10 needed truck, the buying rate is 20%.
2: If there are two operational workers in the total of 10 employees in a company, the worker percentage is 20%.
3: If two tons out of 10 tons C&D waste are recycled, the recycling rate is 20%.
4: If the saving in air and noise pollution is 20% of the saving in the landfill space charge, the green image rate is 20%.

5.2.1 Buying Rate Parameter

The "buying rate" refers to the ratio of the bought trucks to the total trucks. This rate depends on the capital and the size of the company. In the base model, 75% of the needed trucks in the C&D waste recycling program implementation are bought. This proportion varies from 0% (the situation when the companies rent all the needed trucks) to 100% (companies purchase all the trucks).

Figure 5.4 and Table 5.3 show the simulation results of the NPV when the values of the "buying rate" are changed. It is clear that when the "buying rate" value increases, the NPV result increases. The NPV value is positive at the end of year 15 when the "buying rate" is 0%. This NPV value, however, becomes positive two years earlier when the companies fully purchase the trucks. Therefore, the construction companies could earn more profits when they buy all new trucks at the beginning. This is due to the high cost of the truck rental in long-term.



Note: 1: Buying rate = 0, 2: Buying rate = 55%,

3: Buying rate = 75%, 4: Buying rate = 100%

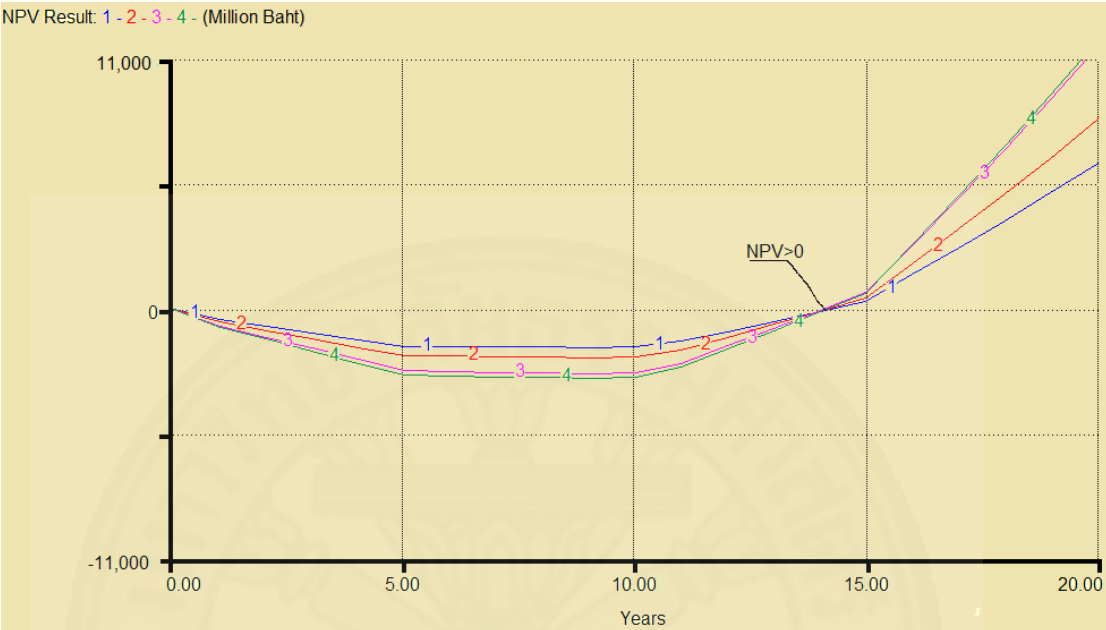
Figure 5.4 The NPV results when the values of "buying rate" are changed

Table 5.3 The NPV results when the values of "buying rate" are changed

Year	NPV Results with different "buying rate" values			
	0%	55%	75%	100%
0	-588,895,426.88	-715,550,426.88	-760,660,426.88	-817,915,426.88
1	-1,185,451,380.99	-1,228,886,380.99	-1,244,356,380.99	-1,263,991,380.99
2	-1,787,825,241.53	-1,748,040,241.53	-1,733,870,241.53	-1,715,885,241.53
3	-2,395,027,133.20	-2,272,022,133.20	-2,228,212,133.20	-2,172,607,133.20
4	-3,004,856,147.51	-2,805,931,147.51	-2,735,081,147.51	-2,645,156,147.51
5	-3,145,027,830.76	-2,862,882,830.76	-2,762,392,830.76	-2,634,847,830.76
6	-3,287,954,640.03	-2,922,589,640.03	-2,792,459,640.03	-2,627,294,640.03
7	-3,430,185,884.69	-2,981,600,884.69	-2,821,830,884.69	-2,619,045,884.69
8	-3,569,744,163.18	-3,037,939,163.18	-2,848,529,163.18	-2,608,124,163.18
9	-3,704,121,306.55	-3,048,033,806.55	-2,814,358,806.55	-2,517,771,306.55
10	-3,082,450,992.79	-2,572,103,492.79	-2,390,478,492.79	-2,159,820,992.79
11	-2,453,849,864.81	-1,847,742,364.81	-1,631,917,364.81	-1,357,939,864.81
12	-1,814,071,105.27	-1,112,203,605.27	-862,178,605.27	-544,881,105.27
13	-1,158,780,187.75	-361,152,687.75	-76,927,687.75	**283,689,812.25**
14	-483,675,783.77	**401,311,716.23**	**716,736,716.23**	1,116,874,216.23
15	**1,463,629,058.20**	2,444,376,558.20	2,794,001,558.20	3,237,459,058.20
16	3,442,963,816.22	4,519,471,316.22	4,903,296,316.22	5,390,073,816.22
17	5,461,600,943.62	6,633,868,443.62	7,051,893,443.62	7,581,990,943.62
18	7,527,718,743.83	8,795,746,243.83	9,247,971,243.83	9,821,388,743.83
19	9,650,750,206.46	11,061,787,706.46	11,565,087,706.46	12,203,200,206.46
20	14,558,602,393.67	15,804,814,893.67	16,247,389,893.67	16,810,897,393.67

5.2.2 Worker Percentage Parameter

The ratio of operational workers is currently set as 65.3% (Italian-Thai, 2013). This parameter can, however, be adjusted to suit the situation of each company. In this research study, the parameter varies from 40% to 70%. The results, as shown in Figure 5.5 and Table 5.4, show that at the beginning years, the lower proportion of the "worker percentage" parameter results in the NPV value, closer to zero. In the latter years, however, the higher "worker percentage" value leads to the higher NPV value and better benefit. This is because more workers are hired and trained, leading to higher recycling rate.



Note: 1: Worker percentage = 40%, 2: Worker percentage = 50%,
3: Worker percentage = 65.3%, 4: Worker percentage = 70%

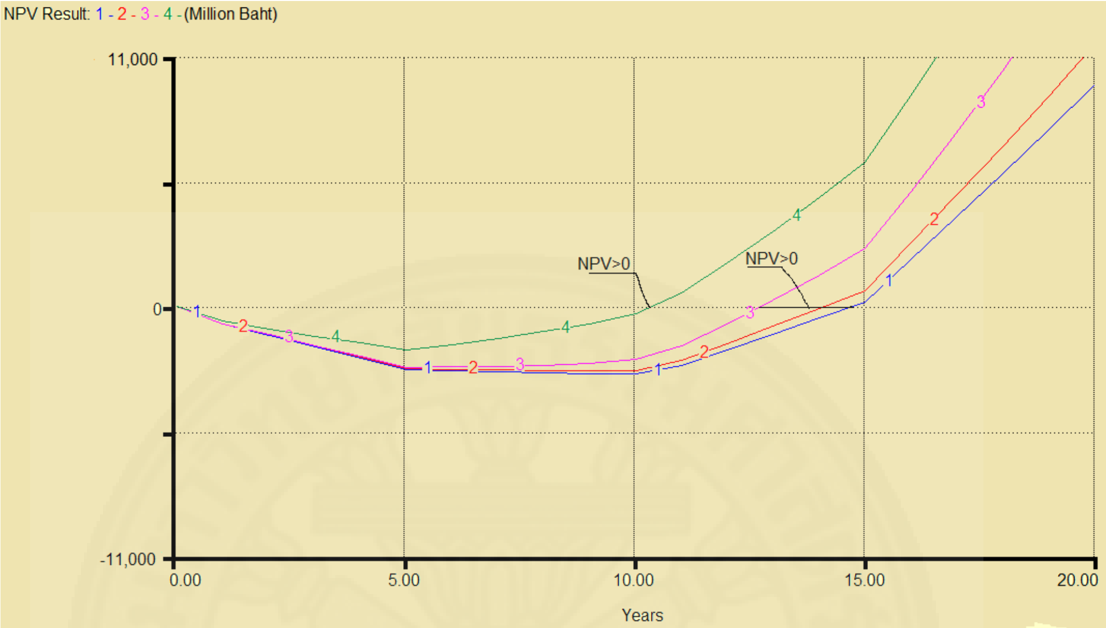
Figure 5.5 The NPV results when the values of "worker percentage" are changed

Table 5.4 The NPV results when the values of "worker percentage" are changed

Year	NPV Results with different "worker percentage" values			
	40%	50%	65.3%	70%
0	-465,075,021.61	-581,486,125.64	-760,660,426.88	-817,872,628.89
1	-756,941,719.38	-948,750,808.54	-1,244,356,380.99	-1,336,726,634.40
2	-1,050,586,447.96	-1,318,818,418.28	-1,733,870,241.53	-1,862,244,046.61
3	-1,345,342,868.45	-1,690,896,429.54	-2,228,212,133.20	-2,393,374,489.70
4	-1,646,068,038.44	-2,071,018,658.29	-2,735,081,147.51	-2,938,455,731.80
5	-1,659,502,093.60	-2,089,170,025.75	-2,762,392,830.76	-2,967,541,426.69
6	-1,674,271,095.12	-2,109,629,378.34	-2,792,459,640.03	-2,999,545,189.29
7	-1,688,425,688.76	-2,129,157,781.88	-2,821,830,884.69	-3,030,720,700.99
8	-1,700,084,751.85	-2,146,263,729.94	-2,848,529,163.18	-3,058,899,841.46
9	-1,674,149,024.25	-2,116,324,411.97	-2,814,358,806.55	-3,020,648,396.21
10	-1,429,392,290.37	-1,802,192,864.40	-2,390,478,492.79	-2,569,227,627.27
11	-992,993,382.18	-1,242,862,558.08	-1,631,917,364.81	-1,764,122,026.16
12	-551,653,023.47	-677,309,529.69	-862,178,605.27	-951,443,014.80
13	-103,644,859.70	-101,848,200.37	-76,927,687.75	-127,327,166.42
14	**346,842,582.50**	**478,229,252.83**	**716,736,716.23**	**700,655,787.17**
15	1,518,080,602.48	1,990,944,501.48	2,794,001,558.20	2,848,515,246.81
16	2,701,864,883.71	3,522,471,537.00	4,903,296,316.22	5,015,093,942.04
17	3,901,987,478.09	5,077,860,496.62	7,051,893,443.62	7,208,828,752.98
18	5,122,442,677.84	6,662,990,969.46	9,247,971,243.83	9,437,167,553.60
19	6,405,243,049.47	8,331,526,869.94	11,565,087,706.46	11,777,169,888.02
20	8,980,462,908.01	11,691,399,029.24	16,247,389,893.67	16,459,472,075.23

5.2.3 Recycling Rate Parameter

In this research study, this parameter is set as 0% (the pessimistic situation) to 100% (the optimistic situation). The results are illustrated in Figure 5.6 and Table 5.5. It is clear that the lower the recycling rate, the smaller the NPV value. It take 10 years for construction companies to make the profit if the recycling rate is 100%, while it takes four years longer if the is no recycling rate. In the latter case, the C&D waste is only used for levelling purpose.



Note: 1: Recycling rate = 0%, 2: Recycling rate = base case,

3: Recycling rate = 3.7%, 4: Recycling rate = 100%

Figure 5.6 The NPV results when the values of "recycling rate" are changed

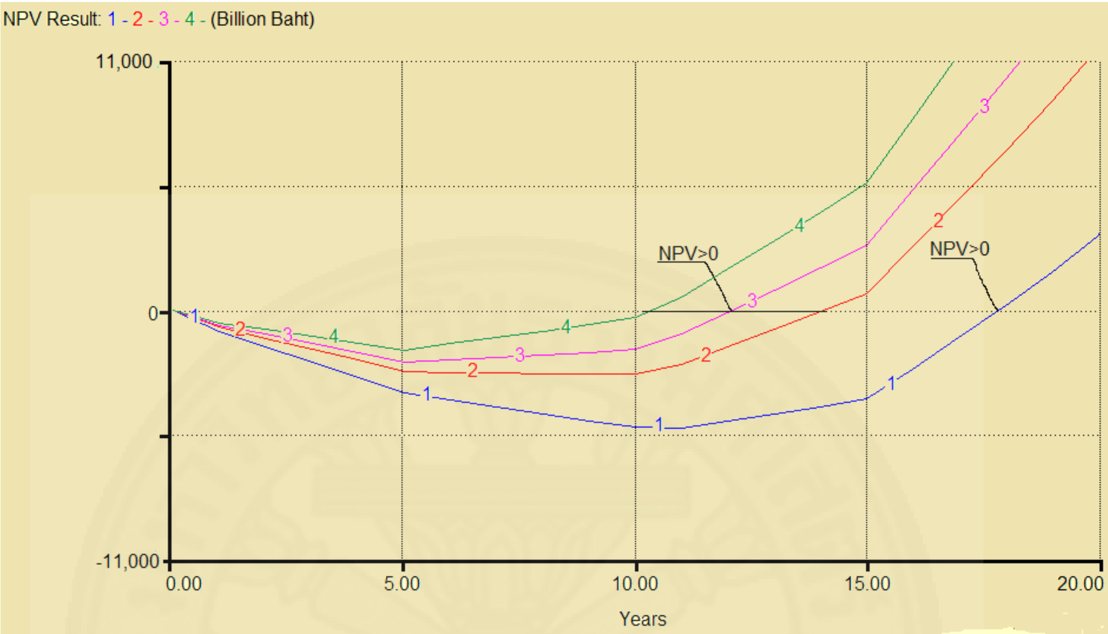
Table 5.5 The NPV results when the values of "recycling rate" are changed

Year	NPV Results with different "recycling rate" values			
	0%	Based case	3.7%	100%
0	-766,556,597.59	-760,660,426.88	-761,851,563.49	-639,393,513.66
1	-1,257,156,258.17	-1,244,356,380.99	-1,241,433,166.43	-981,100,503.48
2	-1,754,719,200.69	-1,733,870,241.53	-1,719,727,057.69	-1,305,068,389.58
3	-2,258,410,414.82	-2,228,212,133.20	-2,193,575,932.99	-1,607,122,179.23
4	-2,776,102,491.07	-2,735,081,147.51	-2,668,085,002.80	-1,891,392,599.04
5	-2,822,598,755.79	-2,762,392,830.76	-2,654,767,903.54	-1,668,459,296.28
6	-2,874,749,865.57	-2,792,459,640.03	-2,626,589,277.84	-1,410,456,987.24
7	-2,929,482,656.87	-2,821,830,884.69	-2,575,893,000.30	-1,109,010,491.88
8	-2,985,242,985.79	-2,848,529,163.18	-2,495,739,574.51	-756,621,407.28
9	-2,984,309,446.75	-2,814,358,806.55	-2,322,097,388.23	-288,907,740.55
10	-2,613,977,053.43	-2,390,478,492.79	-1,734,895,562.89	**614,273,380.09**
11	-1,916,444,733.02	-1,631,917,364.81	-767,726,434.04	1,919,095,809.60
12	-1,216,157,821.51	-862,178,605.27	**264,982,820.39**	3,310,489,463.15
13	-509,829,939.13	-76,927,687.75	1,378,123,739.40	4,802,170,698.10
14	**194,265,394.66**	**716,736,716.23**	2,576,885,427.95	6,397,556,761.18
15	2,076,209,812.83	2,794,001,558.20	5,056,972,585.57	9,289,877,428.41
16	3,964,345,799.72	4,903,296,316.22	7,664,707,130.31	12,322,049,278.34
17	5,862,791,196.43	7,051,893,443.62	10,424,965,866.24	15,514,508,697.92
18	7,776,190,975.52	9,247,971,243.83	13,366,341,320.56	18,890,178,285.30
19	9,774,157,005.48	11,565,087,706.46	16,586,001,876.69	22,539,082,864.14
20	13,188,610,597.76	16,247,389,893.67	21,444,311,439.81	27,811,780,949.13

5.2.4 Green Image Rate Parameter

In this research study , this parameter is adjusted from 0% to 70% (the maximum percentage of saving in air, noise, gas pollution) (Tam, 2008).

Figure 5.7 and Table 5.6 illustrate the simulation results. It is clear that in the optimistic situation (green image rate of 70%), the program takes 10 years to make the profit, while it takes 7 years longer for the pessimistic situation (no green image rate).



Note: 1: Green image rate = 0%, 2: Green image rate = 34.2%,

3: Green image rate = 50%, 4: Green image rate = 70%

Figure 5.7 The NPV results when the values of "green image rate" are changed

Table 5.6 The NPV results when the values of "green image rate" are changed

Year	NPV Results with different "green image rate" values			
	0%	34.2%	50%	70%
0	-948,243,614.93	-760,660,426.88	-673,999,187.95	-564,301,417.16
1	-1,617,840,424.56	-1,244,356,380.99	-1,071,811,121.10	-853,399,399.72
2	-2,291,592,805.66	-1,733,870,241.53	-1,476,208,939.98	-1,150,055,393.70
3	-2,968,526,745.48	-2,228,212,133.20	-1,886,195,440.98	-1,453,262,919.18
4	-3,656,347,831.99	-2,735,081,147.51	-2,309,466,714.32	-1,770,714,267.26
5	-3,979,562,371.12	-2,762,392,830.76	-2,200,074,739.01	-1,488,279,686.16
6	-4,302,873,644.34	-2,792,459,640.03	-2,094,666,035.70	-1,211,382,992.24
7	-4,622,853,511.19	-2,821,830,884.69	-1,989,779,495.84	-936,549,889.71
8	-4,937,546,267.74	-2,848,529,163.18	-1,883,427,693.82	-661,780,264.25
9	-5,188,776,887.34	-2,814,358,806.55	-1,717,405,424.19	-328,856,838.93
10	-5,231,542,325.81	-2,390,478,492.79	-1,077,940,230.76	**583,500,607.27**
11	-4,935,413,902.49	-1,631,917,364.81	-105,740,601.79	1,826,128,718.48
12	-4,623,944,771.09	-862,178,605.27	**875,713,366.06**	3,075,576,620.93
13	-4,292,811,012.93	-76,927,687.75	1,870,761,099.91	4,336,189,945.04
14	-3,949,140,371.87	**716,736,716.23**	2,872,317,359.27	5,600,900,451.73
15	-2,607,667,233.30	2,794,001,558.20	5,289,509,362.47	8,448,380,000.77
16	-1,227,480,138.67	4,903,296,316.22	7,735,643,333.40	11,320,892,722.22
17	**198,650,692.84**	7,051,893,443.62	10,218,011,439.60	14,225,755,738.30
18	1,678,834,125.52	9,247,971,243.83	12,744,824,064.58	17,171,220,040.20
19	3,286,562,164.23	11,565,087,706.46	15,389,669,682.11	20,230,912,689.26
20	6,811,591,367.85	16,247,389,893.67	20,606,618,452.38	26,124,629,286.19

Chapter 6
Conclusions and Recommendations

6.1 Conclusion

Bangkok's construction industry generated approximately 1.5 million tons of C&D waste per year during 2009-2012. Most of it was disposed illegally though it could be reused or recycled. To develop a sustainable industry, the interactions and causal relationships among the key benefits and costs of the recycling program implementation are investigated. The dynamic model of C&D waste recycling is developed to evaluate the feasibility of the C&D waste recycling program implementation in long-term.

The simulation results of the developed model show that construction companies start to make the profit at the end of year 14. It is found that the saving in landfill charge and saving in virgin materials are the key benefits. The landfill charge has risen sharply in recent years, up to 65% in the last five years on average. If C&D waste is effectively treated, billions Baht could be saved. Also, good quality recycled aggregate could be used to substitute the virgin materials.

In contrast, a large amount of money is needed to invest in the recycling program to buy and rent trucks, as well as to recruit full-time workers for the recycling program implementation. The values of key costs are ranked from the highest to the lowest, as followings: 1) Labor cost, 2) Processing cost, 3) Truck cost, 4) Fuel cost, and 5) Training cost. In developing countries, a large number of workers are employed, instead of sorting machine utilization, leading to very high labor cost. Those labors are required to have sorting training to enhance their performance and productivity. The earlier batches of labors can, however, train the latter batches, resulting in saving in training cost.

Four different strategies to implement the C&D waste recycling program implementation are also analyzed in this research study. The results show that by improving the "recycling rate" and "green image rate", the NPV results become positive in shorter years. This can be set as a guideline to the construction companies, as well as the government, to plan for their recycling program. If the company can fully recycle all C&D waste, together with implement the air and noise pollution protection scheme, the companies can gain benefits in ten years.

6.2 Contribution

The developed dynamic model of C&D waste recycling program implementation could be used as a guideline for both construction companies and the government to plan for their recycling programs. It provides a better understanding of the dynamic interactions of the key benefits and costs of the C&D waste recycling program implementation. By examining different strategies on the recycling program, construction companies are able to make the best decision to achieve its best benefit in long-term. The results of this research study could also be considered as a baseline information for the government to support for all necessary resources to effectively implement the C&D waste recycling program.

6.3 Limitation

This research study is conducted based on Bangkok perspective. The model should, therefore, be adjusted before applying in other geographical areas. Some values used in the model analysis are also not primary values from Thai information. For example, green image benefit data is adapted from that studied in Australia, and the trend of recycling rate is based on the research in America and England. Apart from that, some important benefits and costs of the C&D waste recycling program, such as the recycling tax and the company image, are not considered in this model, due to the lack of available information.

6.4 Recommendation

To effectively plan for the C&D waste recycling program implementation, the accurate C&D waste amount must be used. It is, therefore, recommended that the construction companies should record their waste amount to be used as a model input.

The simulation results show that the landfill charge and green image benefits play important roles in the success of the recycling program. The government should, if possible, consider imposing a drastic landfill charge. It is also found that at the beginning years of the recycling program, companies have to invest a large capital for labors and trucks. The government could support the ongoing of the program by reducing the related tax or subsidizing some costs. This may, in turn, lead to the higher number of construction companies participating in the recycling program implementation.

The developed model of C&D waste recycling program implementation concentrates primarily on the C&D waste in Bangkok. Future study could be carried out to investigate the C&D waste in other developing or developed countries.

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Appendices

Appendix A
Interview Questions

Part 1. Background Information

1. Type of your company

☐ Construction ☐ Logistics ☐ Others (Please specify)……

2. Your position in company

☐ Manager ☐ Engineer ☐ Supervisor ☐ Workers

☐ Others (Please specify)……

3. Size of your company

☐ ≤ 50 employees ☐ ≤ 200 employees ☐ >200 employees

Part 2. Please select the best answer for each question

1. How many tons can a 10-wheel truck carry (tons)?

☐ <10 ☐ 10-15 ☐ 16-20 ☐ 21-25

☐ Others (Please specify)……

2. How much is a new 10-wheel truck (Baht)?

☐ <2,000,000 ☐ 2,000,000-2,400,000 ☐ 2,400,001-2,600,000 ☐ 2,600,001-2,800,000

☐ Others (Please specify)……

3. How many kilometers can a truck driver drive on average per day (km)?

☐ <200 ☐ 200-250 ☐ 251-300 ☐ 301-350

☐ Others (Please specify)……

4. What is the ratio of rented to bought trucks in your company?

☐ <20% rented ☐ 20-30% rented ☐ 31-40% rented ☐ 41-50% rented

☐ Others (Please specify)……

Note: If there are 10 trucks in your company, and that three of them are from rental, the answer is 30%

5. What is the maintenance cost of a truck per km (including engine oil, wipers, lights, filters etc.) (Baht)?

☐ 1-3 ☐ 4-6 ☐ 7-9 ☐ Others (Please specify)….

6. What is an average tire cost per km (Baht)?

☐ 1-3 ☐ 4-6 ☐ 7-9 ☐ Others (Please specify)….

7. What is the insurance cost per truck per year (Baht)?

☐ <17,000 ☐ 17,000-25,000 ☐ 25,001-40,000 ☐ 40,001-60,000

☐ Others (Please specify)……

8. What is the rental cost per truck per month (Baht)? (If rented)

☐ <70,000 ☐ 70,000-80,000 ☐ 80,001-90,000 ☐ 90,001-100,000

☐ Others (Please specify)……

9. What is the truck driver's wage per month (Baht)?

☐ <20,000 ☐ 20,000-25,000 ☐ 25,001-30,000 ☐ 30,001-35,000

☐ Others (Please specify)……

10. If NGV is installed, what is the installation cost per truck (Baht)?

☐ <300,000 ☐ 300,000-350,000 ☐ 350,001-400,000 ☐ 400,001-450,000

☐ Others (Please specify)…...

11. How long can a truck be used before its major maintenance (including exhaust, driveline, suspension, drive axles etc.) (years)?

☐ After 1-2 ☐ After 3-4 ☐ After 5-6 ☐ Others (Please specify) ….

12. What is the cost of its major maintenance (Baht)?

☐ < 25,000 ☐ 25,000-75,000 ☐ 75,001-125,001 ☐ 125,000-175,000

☐ Others (Please specify)……

13. What is a truck life before it is sold (years)?

☐ 5 years ☐ 7 ☐ 10 ☐ Others (Please specify) ….

14. What is the salvage value of a truck (Baht)?

☐ < 125,000 ☐ 125,000-175,000 ☐ 175,001-225,000 ☐ 225,001-275,000

☐Others (Please specify)……

Question 15 is only for construction company.

15. What is the landfill charge to transport 1 full truck load of C&D waste to landfill in Bangkok (Baht)?

☐ < 5,000 ☐ 5,000-6,000 ☐ 6,001-7,000 ☐ 7,001-8,000

☐ Others (Please specify)……

Thank you for your help

Appendix B

SD Equations of the Saving in the Fuel Cost to Landfill Sector

Year_stock(t) = Year_stock(t - dt) + (Additional_year) * dt

INIT Year_stock = 0

INFLOWS:

Additional_year = PULSE(1,5,5)

Landfill_Charge = 463.67*1.65^Year_stock

Landfill_Charge_Saving = Three.Reused_and_Recycled_Waste*Landfill_Charge

Appendix C
SD Equations of the Saving in the Landfill Charge Sector

Distance_from_Site_to_Landfill = Three.Number_of_Trucks*3*245*113.13

Fuel_Cost_per_km = IF Year=0 THEN 0 ELSE 12.5*1.058^Year/2.2

Fuel_Cost_to_Landfill_Saving = Distance_from_Site_to_Landfill*Fuel_Cost_per_km+Three.Number_of_Trucks*(Regular_Maintenance_Cost+Tire_Cost)

Regular_Maintenance_Cost = IF Year=0 THEN 0 ELSE 2*1.023^Year*113.13*3*245

Tire_Cost = IF Year=0 THEN 0 ELSE 2*1.023^Year*113.13*3*245

Year = COUNTER (0,100)

Appendix D

SD Equations of the Saving in Levelling Cost Sector

Levelling_Cost_Saving = Reused_Waste/1.4*262.36*1.086^Year

Recycled_Waste = IF Three.Reused_and_Recycled_Waste>Three.Reused_and_Recycled_Waste*Recycling_Rate THEN Three.Reused_and_Recycled_Waste*Recycling_Rate ELSE Three.Reused_and_Recycled_Waste

Recycling_Rate = IF (IF Recycling_Rate_Constant=0 OR Recycling_Rate_Constant=0.037 OR Recycling_Rate_Constant=1 THEN Recycling_Rate_Constant*Year ELSE Recycling_Rate_Graphical)<1 THEN IF Recycling_Rate_Constant=0 OR Recycling_Rate_Constant=0.037 THEN Recycling_Rate_Constant*Year ELSE Recycling_Rate_Graphical ELSE 1

Recycling_Rate_Constant = .5

Reused_Waste = IF (Three.Reused_and_Recycled_Waste-Recycled_Waste) > 0 THEN (Three.Reused_and_Recycled_Waste-Recycled_Waste) ELSE 0

Year = Counter(0,100)

Recycling_Rate_Graphical = GRAPH(Six.Landfill_Charge)
(0.00, 0.00), (500, 0.05), (1000, 0.09), (1500, 0.11), (2000, 0.19), (2500, 0.21), (3000, 0.56), (3500, 0.7), (4000, 0.78), (4500, 0.79), (5000, 0.8)

Appendix E
SD Equations of the Saving in Virgin Materials Sector

Virgin_Materials_Saving = Eight.Recycled_Waste*555.88*1.119^Year

Year = COUNTER (0,100)

Appendix F

SD Equations of the Green Image Sector

Year_stock(t) = Year_stock(t - dt) + (Additional_year) * dt

INIT Year_stock = 0

INFLOWS:

Additional_year = PULSE(1,5,5)

Air_Noise_Pollution_Saving = Six.Landfill_Charge_Saving*Ratio

Carbon_Tax_Rate = 450

Carbon_Tax_Saving =
Carbon_Tax_Rate*1.65^Year_stock*Three.Reused_and_Recycled_Waste*0.02

Green_Image_Saving = Air_Noise_Pollution_Saving+Carbon_Tax_Saving

Ratio = 0.342

Appendix G
SD Equation of the Labor Cost Sector

Sorting_Labors_Stock(t) = Sorting_Labors_Stock(t - dt) + (New_Sorting_Labors) * dt

INIT Sorting_Labors_Stock = 0

INFLOWS:

New_Sorting_Labors = ROUND (New_Labors*New_Labor_Rate)

Sorting_Labors_Stock_2(t) = Sorting_Labors_Stock_2(t - dt) + (New_Sorting_Labors_2) * dt

INIT Sorting_Labors_Stock_2 = 0

INFLOWS:

New_Sorting_Labors_2 = Total_New_Sorting_Labors_2-Sorting_Labors_Stock_2

Total_Labors(t) = Total_Labors(t - dt) + (Additional_Labors) * dt

INIT Total_Labors = 0

INFLOWS:

Additional_Labors = IF Year=0 THEN ROUND (184930*Worker_Percentage/5*4*1.025) ELSE New_Labors

Training_Group_Stock(t) = Training_Group_Stock(t - dt) + (Training) * dt

INIT Training_Group_Stock = 0

INFLOWS:

Training = IF Year=1 THEN New_Sorting_Labors ELSE 0

Concrete_and__Brick_Waste = IF Year=0 THEN 0 ELSE 1351996.04*1.007^(Year+2)

Final_Sorted_Waste = IF Year=0 THEN 0 ELSE IF Year=1 THEN 0.246*(Final_Total_New_Sorting_Labors*240+Final_Total__Regular_Labors*245)

ELSE 0.246*((Final_Total__Regular_Labors+Final_Total_New_Sorting_Labors-Final_Training_Group-New_Sorting_Labors_2)*245+(Final_Training_Group+New_Sorting_Labors_2)*240)

Final_Total_New_Sorting_Labors = Sorting_Labors_Stock_2+New_Sorting_Labors_2

Final_Total__Regular_Labors = IF Concrete_and__Brick_Waste>Sorted_Waste THEN Total_Regular_Labors ELSE IF Year=0 THEN 0 ELSE IF Year=1 THEN IF ROUND((Sorted_Waste_2-0.246*Final_Total_New_Sorting_Labors*240)/(245*0.246))<(Sorted_Waste_2-0.246*Final_Total_New_Sorting_Labors*240)/(245*0.246) THEN ROUND((Sorted_Waste_2-0.246*Final_Total_New_Sorting_Labors*240)/(245*0.246))+1 ELSE ROUND((Sorted_Waste_2-0.246*Final_Total_New_Sorting_Labors*240)/(245*0.246)) ELSE IF ROUND((Sorted_Waste_2-0.246*(Final_Training_Group+New_Sorting_Labors_2)*240-0.246*245*(Final_Total_New_Sorting_Labors+Final_Training_Group+New_Sorting_Labors_2))/(245*0.246))<(Sorted_Waste_2-0.246*(Final_Training_Group+New_Sorting_Labors_2)*240-0.246*245*(Final_Total_New_Sorting_Labors+Final_Training_Group+New_Sorting_Labors_2))/(245*0.246) THEN ROUND ((Sorted_Waste_2-0.246*(Final_Training_Group+New_Sorting_Labors_2)*240-0.246*245*(Final_Total_New_Sorting_Labors+Final_Training_Group+New_Sorting_Labors_2))/(245*0.246))+1 ELSE ROUND ((Sorted_Waste_2-0.246*(Final_Training_Group+New_Sorting_Labors_2)*240-0.246*245*(Final_Total_New_Sorting_Labors+Final_Training_Group+New_Sorting_Labors_2))/(245*0.246))

Final_Training_Group = IF Concrete_and__Brick_Waste=Sorted_Waste_2 THEN 0 ELSE Training_Group

Labor_Cost = IF Year = 0 THEN 0 ELSE (Final_Total_New_Sorting_Labors+Final_Total__Regular_Labors)*245*300*1.023^ Year

New_Labors = ROUND (0.025*Total_Labors*Worker_Percentage/5*4)

New_Labor_Rate = 0.0156

Sorted_Waste = IF Year=0 THEN 0 ELSE IF Year=1 THEN 0.246*(Total_New_Sorting_Labors*240+Total_Regular_Labors*245) ELSE 0.246*((Total_Regular_Labors+Total_New_Sorting_Labors-Training_Group-New_Sorting_Labors)*245+(Training_Group+New_Sorting_Labors)*240)

Sorted_Waste_2 = IF Concrete_and__Brick_Waste>Sorted_Waste THEN Sorted_Waste ELSE Concrete_and__Brick_Waste

Total_New_Sorting_Labors = Sorting_Labors_Stock+New_Sorting_Labors

Total_New_Sorting_Labors_2 = IF Concrete_and__Brick_Waste=Sorted_Waste_2 THEN 0 ELSE Total_New_Sorting_Labors

Total_Regular_Labors = ROUND ((Total_Labors+Additional_Labors-Total_New_Sorting_Labors)*1.6/8)

Training_Group = Training_Group_Stock+Training

Worker_Percentage = 0.653

Year = COUNTER(0,100)

Appendix H

SD Equations of the Training Cost Sector

Count = COUNTER(1,4)

Training_Cost = IF Count=2 THEN One.Final_Training_Group*12200*1.023^Year ELSE 0

Year = COUNTER(0,100)

Appendix I

SD Equations of the Fuel Cost Sector

Distance = Number_of_Trucks*3*245*22.84

Fuel_Cost = Distance*Fuel_Cost_per_km

Fuel_Cost_per_km = IF Year=0 THEN 0 ELSE 12.5*1.058^Year/2.2

Number_of_Trucks = IF (Reused_and_Recycled_Waste/12.5)/(245*3)> ROUND((Reused_and_Recycled_Waste/12.5)/(245*3)) THEN ROUND((Reused_and_Recycled_Waste/12.5)/(245*3))+1 ELSE ROUND((Reused_and_Recycled_Waste/12.5)/(245*3))

Reused_and_Recycled_Waste = MIN (One.Concrete_and__Brick_Waste,One.Final_Sorted_Waste)

Year = COUNTER (0,100)

Appendix J
SD Equations of the Truck Cost Sector

Trucks_Stock(t) = Trucks_Stock(t - dt) + (Additiontal_Trucks) * dt

INIT Trucks_Stock = 0

INFLOWS:

Additiontal_Trucks = Number_of__Bought_Trucks-Trucks_Stock

Year_Stock(t) = Year_Stock(t - dt) + (Additional_Year) * dt

INIT Year_Stock = 0

INFLOWS:

Additional_Year = PULSE(1,1,5)

Big_Maintenance__Cost = IF Count=5 THEN Bought_Trucks*100000 *1.023^ Year ELSE 0

Bought_Trucks = Trucks_Stock+Additiontal_Trucks

Buying_Cost = NGV_Installation_Cost+Cost_for__New_Trucks+Big_Maintenance__Cost-Selling_Trucks__Saving+(Regular_Maintenance_Cost+Tire_Cost+Insurance_Cost+Driver_Cost+Route_Cost)*Bought_Trucks

Buyring_Rate = 0.75

Cost_for__New_Trucks = Number_of__Bought_Trucks*2450000*1.023^Year

Count = COUNTER(0,10)

Driver_Cost = IF Year=0 THEN 0 ELSE 22500*12*1.023^Year

Insurance_Cost = IF Year=0 THEN 0 ELSE 50000* 1.023^Year

NGV_Installation_Cost = Number_of__bought_trucks*425000*1.023^Year

Number_of_Rented__Trucks = Three.Number_of_Trucks-Bought_Trucks

Number_of__Bought_Trucks = IF Count=1 THEN ROUND (Three.Number_of_Trucks*Buyring_Rate) ELSE 0

Regular_Maintenance_Cost = IF Year=0 THEN 0 ELSE 2*1.023^Year*22.84*3*245

Rental_Trucks_Cost = IF Year=0 THEN 0 ELSE 95000*12*1.023^Year

Renting_Cost = (Regular_Maintenance_Cost+Route_Cost+Tire_Cost+Insurance_Cost+Driver_Cost+Rental_Trucks_Cost)*Number_of_Rented__Trucks

Route_Cost = PULSE(2500,2,5)*1.023^(Year_Stock-1)

Selling_Trucks__Saving = IF Count=0 THEN Bought_Trucks*562500*1.023^Year ELSE 0

Tire_Cost = IF Year=0 THEN 0 ELSE 2*1.023^Year*22.84*3*245

Truck_Cost = Buying_Cost+Renting_Cost

Year = COUNTER (0,100)

Appendix K
SD Equations of the Processing Cost Sector

Processing_Cost = Nine.Virgin_Materials_Saving/2

Appendix L

SD Equations of the NPV Results

NPV_Calculation_2(t) = NPV_Calculation_2(t - dt) + (NPV_Calculation_1) * dt
INIT NPV_Calculation_2 = 0
INFLOWS:
NPV_Calculation_1 = Cash_Flow/1.023^Year

Cash_Flow = Total_Benefits-Total_Costs

NPV_Result = NPV_Calculation_2+NPV_Calculation_1

Total_Benefits =
Seven.Fuel_Cost_to_Landfill_Saving+Six.Landfill_Charge_Saving+Eight.Levelling_Cost_Saving+Nine.Virgin_Materials_Saving+Ten.Green_Image_Saving

Total_Costs =
Two.Training_Cost+One.Labor_Cost+Three.Fuel_Cost+Four.Truck_Cost+Five.Processing_Cost

Year = COUNTER(0,100)

Appendix M

Glossary

The list of terms and definitions is shown below.

Term	Definition
C&D waste	It is waste released when buildings and other constructions, such as roads and bridges, are built, renovated, and demolished (Wei-hong et al., 2014).
Recycling	It is the process when waste is used to produce new products.
NGV	It is the short term of Natural Gas Vehicle.
Route cost	It is the cost paid to transport freight using road transportation.
Regular maintenance cost	It is the cost paid for regular maintenances, including engine oil, wipers, lights, filters etc.
Major maintenance cost	It is the cost paid for major maintenances, including exhaust, driveline, suspension, drive axles etc.
Aggregate	It represent materials used in construction, such as sand, gravel, crushed stone, slag, and recycled crushed concrete.
Saving in virgin materials	It is the saving when concrete/brick waste is recycled and used to replace the virgin materials.
Saving in levelling	It is the saving when concrete/brick waste is used to replace sand for foundation levelling.
Green image	It is the saving when companies save the carbon tax and air and noise pollution charges.
Buying rate	It is the ratio of the bought trucks to the total trucks.
Worker percentage	It is the ratio of operational workers to the total employees.

Recycling rate	It is the ratio of recycled C&D waste to the total C&D waste.
Green image rate	It is the saving in air and noise pollution, as a percentage of the landfill charge.