STRATEGIES FOR MUNICIPAL SOLID WASTE MANAGEMENT IN SURANAREE MILITARY CAMP

Capt. Kobchok Hussadee

A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of

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กลวิธีการจัดการขยะมูลฝอยชุมชนในค่ายสุรนารี

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วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิศวกรรมศาสตรมหาบัณฑิต

สาขาวิศวกรรมสิ่งแวดล้อม

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CAPT. KOBCHOK HUSSADEE: STRATEGIES FOR MUNICIPAL SOLID WASTE MANAGEMENT IN SURANAREE MILITARY CAMP, THESIS ADVISOR : RANJNA JINDAL, Ph.D. 121 PP. ISBN 974-533-218-6

SOLID WASTE/ WASTE GENERATION RATE/ RECYCLE/ SOLID WASTE MANAGEMENT/ LANDFILL

Suranaree Military Camp, which lies in Nakhon Ratchasima city in the north-eastern part of Thailand, has had a tremendous increase in its solid waste generation due to the increasing population as well as the improvement in living conditions. Wastes are managed by the military themselves by open dumping and burning in the vacant area, which is a labor-intensive and uncontrolled way. The main objectives of this study were to evaluate the suitable strategies for better solid waste management and to investigate the potential of solid wastes recycling and reuse in the camp. With the questionnaire survey, and waste samples collection and analysis, the results showed that solid wastes generated was 0.41 kg/c/d. The highest component (61 %) was found to be combined food waste and yard waste. The average bulk density measured on collected waste samples was 202.4 kg/m^3, and the chemical characteristics: moisture content, total solids, volatile solids, ash, organic carbon, hydrogen, and nitrogen were 54.2%, 45.8%, 75.6%, 24.3%, 42.0%, 4.7%, and 1.1 %, respectively. Phosphorus, calorific value, and C/N ratio were found to be 167.7 ppm, 4,232.8 kcal/kg, and 38.2:1, respectively. Recycling is not practiced in the area. On an average, only 5 % of the total waste are recycled by the residents and 10 % by the scavengers in the landfill area. STELLA simulation approach was used for strategies analysis for various options, which included: current disposal method, increasing landfill efficiency through improved technology, waste recycling promotion with landfilling, composting process with landfilling, and incineration followed by landfilling of residual ash. The results indicated that Suranaree Military Camp needed improvement in their waste management through adequate recycling and proper disposal methods. The best disposal method could be composting process. This is due to the high fraction of food waste and yard waste generated in the camp.

สาขาวิศวกรรมสิ่งแวดล้อม ลายมือชื่อนักศึกษา……….……..………….…….

ปีการศึกษา 2545 ลายมือชื่ออาจารย์ที่ปรึกษา……..………………..….

ร้อยเอก กอบโชค หัสดี : กลวิธีการจัดการขยะมูลฝอยชุมชนในค่ายสุรนารี (STRATEGIES FOR MUNICIPAL SOLID WASTE MANAGEMENT IN SURANAREE MILITARY CAMP), อ. ที่ปรึกษา : Ranjna Jindal, Ph.D. 121 หน้า. ISBN 974-533-218-6

ค่ายสุรนารีซึ่งตั้งอยู่ในตัวเมืองจังหวัดนครราชสีมา ภาคตะวันออกเฉียงเหนือของประเทศไทยมีการเพิ่มขึ้นของการเกิดขยะมูลฝอยอย่างมากมาย เนื่องจากการเพิ่มขึ้นของประชากรและความเป็นอยู่ที่พัฒนาขึ้น การจัดการขยะเป็นไปโดยค่ายสุรนารีเอง ด้วยการทิ้งและเผาในที่ว่าง ซึ่งใช้แรงงานคนทั้งหมด และไม่มีการควบคุมแต่อย่างใด วัตถุประสงค์หลักของการศึกษานี้เพื่อประเมินกลวิธีการจัดการขยะที่เหมาะสมสำหรับการจัดการขยะที่ดีขึ้น และศึกษาความเป็นไปได้ของการรีไซเคิลและการนำขยะกลับมาใช้ใหม่ภายในค่ายจากแบบสอบถามและการสำรวจรวมถึงการรวบรวมเก็บตัวอย่างขยะมาวิเคราะห์ ผลการศึกษาพบว่ามีอัตราการเกิดขยะ 0.41 กก./คน/วัน ร้อยละ 61 ของขยะทั้งหมดเป็นขยะประเภทเศษอาหารรวมกับเศษขยะจากสนามหญ้า (เศษหญ้าและเศษใบไม้) ค่าเฉลี่ยของความหนาแน่นของขยะคือ 202.4 กก./ลบ.ม. และ ส่วนประกอบทางเคมีคือ ร้อยละ 54.2, 45.8, 75.6, 24.3, 42, 4.7 และ 1.1 สำหรับ ความชื้น, ของแข็ง, ของแข็งระเหย, เถ้า, อินทรีย์คาร์บอน และไนโตรเจน, ตามลำดับ ฟอสฟอรัสมีค่า 167.7 ppm ค่าความร้อนเป็น 4,232.8 กิโลแคลลอรี/กก. และอัตราส่วนของคาร์บอนต่อไนโตรเจนเป็น 38.2:1 ยังไม่มีการ รีไซเคิลในพื้นที่มากนัก มีเพียงร้อยละ 5 ของขยะทั้งหมดถูกรีไซเคิลโดย ผู้อยู่อาศัย ส่วนร้อยละ 10 โดยคนเก็บขยะขายที่พื้นที่ฝังกลบ โปรแกรม STELLA ได้ถูกนำมาใช้เพื่อศึกษากลวิธีการจัดการขยะดังนี้ วิธีการกำจัดในปัจจุบัน, การเพิ่มคุณภาพของพื้นที่ฝังกลบโดยการปรับปรุงเทคโนโลยี, การส่งเสริมให้มีการรีไซเคิล

ขยะและการฝังกลบ, การนำขยะมาทำปุ๋ยหมักกับการฝังกลบ และ การเผาด้วยเตาเผาขยะตามด้วยการฝังกลบ ผลการศึกษาพบว่า ค่ายสุรนารีควรมีการปรับปรุงการจัดการขยะมูลฝอยโดยการรีไซเคิลและการกำจัดขยะที่เหมาะสม การจัดการขยะที่ดีที่สุดสำหรับค่าย สุรนารีคือการนำขยะมาทำปุ๋ยหมัก เนื่องมาจากสัดส่วนที่สูงมากของขยะที่เกิดขึ้นเป็นเศษอาหารและเศษขยะจากสนามหญ้า (เศษหญ้าและเศษใบไม้)

สาขาวิศวกรรมสิ่งแวดล้อม ลายมือชื่อนักศึกษา……….…….….……….……..…….

ปีการศึกษา 2545 ลายมือชื่ออาจารย์ที่ปรึกษา……..…….………….…..

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Capt. Kobchok Hussadee

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List of Symbols and Abbreviations

ADB	=	Asian Development Bank
B	=	The number of people born in one year
BMA	=	Bangkok Metropolitan Area
c	=	Capita
C	=	Carbon
cal	=	Calorie
cm	=	Centimeter
CO	=	Carbon dioxide
d	=	Day
D	=	The number of people died in one year
DSCV	=	Dry Solid Calorific Value
e	=	percent error
g	=	Gram
GR	=	Rate of population growth
H	=	Hydrogen
I	=	The number of people moving in the area in one year
K	=	Constant
kg	=	Kilogram
kg/c/d	=	Kilogram per capita per day
kg/d	=	Kilogram per day

List of Symbols and Abbreviations (continued)

kg/m^3	=	Kilogram per cubic meter
km	=	Kilometer
kcal	=	Kilocalorie
LSCV	=	Lower Solid Calorific Value
m	=	Meter
m^2	=	Meter square
m^3	=	Cubic meter
m_i	=	Waste generation rate at each source, (weight/time),
n	=	Number of samples
N	=	Number of office or residential units
O	=	the number of people moving out the area in one year
P	=	Total population in the mid year
PCD	=	Pollution Control Department
p_i	=	Number of generation sources,
Q	=	Municipal solid waste generation rate, (weight/capita/time).
US $	=	United States dollar
VS	=	Volatile solids
W	=	Total quantity of wastes generated, (weight/time),
W_i	=	Quantity of wastes generated at each source, (weight/time),
yr	=	year

Chapter I

Introduction

1.1 General

The Suranaree Military Camp (SMC), which lies in Nakhon Ratchasima city in the north-eastern part of Thailand, has a population of approximately 30,000 (Nakhon Ratchasima District Office, 2000). Because of tremendous increase in the population of the camp and improving living conditions, its solid waste generation has been increasing year by year.

The sources of solid waste in this camp are mainly residences for military personnel and their families, and offices located within the camp. The waste at Suranaree Military Camp is so far managed by the military themselves by open dumping and burning in a large area inside the camp. The present collection and disposal system is labor-intensive and uncontrolled. The small portion of solid waste is disposed off at the low-lying areas. Also, the collected waste is dumped in vacant area along the road before landfilling, where it remains for extended period of time. This has become the source of air and water pollution, as well as creating potential breeding place for the disease causing insects, such as flies, mosquitoes and rodents. Moreover, due to the biodegradation of waste, unpleasant odor is produced which vitiates the environment of the camp.

As the amount of solid wastes in landfill at Suranaree Millitary Camp has been increasing day by day, the military is looking for alternative methods of waste management, such as waste reduction, recycling of reusable material (like paper, metal, glass and plastic, etc.), incineration, and composting. One of the most attractive methods for waste reduction is recycling of the materials from the waste stream.

In Suranaree Military Camp, no attention has been paid to the solid waste management and no proper data on waste generation rate and composition has ever been recorded. Such data is the basic need for the planning of waste management system and to evaluate the alternative methods for waste reduction and disposal.

Solid waste management includes the collection, separation, transportation, and disposal with suitable techniques that are hygenic and environmentally safe. All of these steps require institutional capabilities to deal with the ever-increasing quantity of the solid waste. Various tools may be used to plan strategies for alternative methods of solid waste management at Suranaree Military Camp, i.e. computer simulation programs. Using a simulation approach, such as STELLA program, may be applied for solid waste management strategies evaluation at SMC. Subsequently, alternative methods for waste reduction and disposal can be assessed and implemented.

1.2 Objectives

The main objectives of this study were:

1.2.1 to assess the current situation of solid waste management practices at the Suranaree Military Camp,

1.2.2 to investigate the potential of solid wastes recycling and reuse at the camp, and

1.2.3 Using a simulation approach as a tool to do the preliminary evaluation of the suitable strategies for better solid waste management at the Suranaree Military

Camp by using STELLA simulation approach.

1.3 Scope

In order to accomplish the objectives of this study following steps were included in the research scope:

1.3.1 The quantity of solid wastes generated in Suranaree Military Camp was estimated.

1.3.2 The solid waste samples were analyzed for the evaluation of physical and chemical characteristics. Parameters measured included: bulk density, moisture content, total solids, volatile solids, ash, organic carbon, hydrogen, nitrogen, phosphorus, calorific value, and C/N ratio.

1.3.3 Current status of solid waste management in Suranaree Military Camp was investigated by questionnaire surveying method.

1.3.4 Among the solid waste components, paper, glass, plastics and metals were evaluated for recycling and reuse.

1.3.5 Recommendation for a suitable strategy for solid waste management was made by using STELLA simulation approach.

Chapter II

Literature Review

2.1 Solid Waste

Solid wastes comprise all the waste arising from human and animal activities that are normally solid or semi-solid and are discarded as useless or unwanted. The term solid waste as used is all-inclusive, encompassing the heterogeneous mass of throwaways from the urban community as well as the more homogeneous accumulation of agricultural, industrial, and mineral wastes (Tchobanoglous et al., 1993). From a general definition point of view, any “waste” is an unwanted “thing” which needs to be disposed. From a systems point of view, the term waste may be defined as: any unnecessary input to, or any undesirable output from any system. Solid wastes are the waste materials in solid state form and constitute the most heterogeneous collection of substances possible (Jindal et al., 1997).

2.2 Solid Waste Management

Tchobanoglous et al. (1993) defined solid waste management as a discipline associated with the control of generation, storage, collection, transfer, and transportation, processing and disposal of solid waste in such a way that is in accordance with the best principals of public health, economics, engineering conservation aesthetics and other environmental considerations and also responsive to public attitudes. Integrated approach to solid waste management is aimed at 1) to minimize the production of the solid wastes, 2) to expand waste collection services, 3) to maximize waste recycling and reuse, 4) to promote safe waste disposal, and 5) evaluation and upgrading of existing facilities.

Jindal et al. (1997) stated that the factors affecting solid waste management in any country basically could be classified into three categories: geographical, socio-culture, and economic. More specifically, some of the important factors in solid waste management are the following: a) location and topography, b) land area, c) climate and season cycles, d) population and population density, e) rural infrastructure, and f) urban infrastructure.

In most developing countries of Asia or countries where national priorities stress economic development with less attention to urban sanitation and environmental concerns, simply taking out and dumping wastes at sites available nearby had been practiced for solid waste management, especially in metropolises. Some cities sent their wastes to rural areas for agricultural use or land disposal, depending upon the local conditions and regional situation.

The solid waste in Bangkok Metropolitan Area is disposed of by landfill, incineration, composting or recycling (BMA, 2000). Presently, Muang District of Nakhon Ratchasima Municipality is still utilizing open dumping for waste disposal by using land in the Suranaree Military Camp Area. (Nakhon Ratchasima Municipality, 2000)

Chiang Mai City in the northern part of Thailand has had a lot of problems of rubbish. Chiang Mai municipality was still in search for ways for its sustainable waste management practice, apart from a landfill in Kaset Banmai, San Sai, about 20 km from town. In an attempt to solve the waste problem, the Mayor of Chiang Mai had hired a group of Environmental Engineering experts to conduct a site selection study or constructing a permanent sanitary landfill (Khaikaew, 1997).

Khon Kaen City in the northeastern part of Thailand had also been facing the garbage disposal problem. In March 1997, Khon Kaen municipality's rubbish dump was reported to be almost full. Despite this, no one seemed to know where to locate a new dumpsite since all sub-districts were against having it in their areas. The present site, about 17 km from the town, was supposed to have operated for 15 years, from 1987 to 2002 (Antaseeda, 1997).

In Thailand, frequently used solid waste disposal methods by the metropolitan municipalities, district municipalities, and subdistrict municipalities are 51.43% by unsanitary landfill, 20.0% by open dumping on land and open burning, 10.89% by sanitary landfill and 3.81% by incineration (Wongwattanapaibun et al., 2000).

2.3 Sources and Types of Solid Wastes

Lardinois and Van de Klundert (1993) stated that the quantity of household waste accounted for nearly 75% in total of urban solid waste. Therefore, this is a remarkable source when calculating the volume of waste in the future.

Tchobanoglous et al. (1993) stated that municipal solid waste includes all the waste produced in a community except industrial and agricultural waste. The sources of waste are related to land use and zoning. The most important categories are residential, commercial, institutional, construction, demolition, industrial, open areas, treatment plants and the agricultural. Municipal solid waste (MSW) generating facilities, activities, and locations in a community are given in Table 2.1.

Table 2.1 Sources of solid waste within the community.

Source	Typical Facilities Activities or Location where Waste are Generated	Types of solid Waste
Residential	Single family and multi family detached dwelling s, low, medium and high rise apartment, etc.	Food waste, paper, cardboard, textile, leather, yard waste, wood glass, tin cans, aluminum, other metals, ashes, (including bulky items, consumers electronics, white goods, yard waste collected separately, batteries, oil, and tires), household hazardous waste.
Commercial	Store, restaurants, markets, offices building, hotel, motel, print shops, service station, auto repairs shop, etc.	Paper, cardboard, plastic, wood, food waste, glass, metals special waste, hazardous waste etc.
Institutional	School, hospitals, prisons governmental centers.	As above in commercial.
Construction and Demolition	New construction sites, rode repair / revolution sites, razing of building, broken pavements.	Wood, steel, concrete, dirt, etc.
Municipal services (excluding reatment Facilities)	Street cleaning. Landscaping, catch basin cleaning, parks and beaches, other recreational areas.	Special waste, rubbish, streets sweepings, landscapes, and tree trimming, catch basin debris, general waste from park beaches and recreational areas.
Treatment Plant sites Municipal Incinerators	Water, waste waster, and, industrial treatment processes, etc.	Treatment plant wastes, principally composed of residual sludge.
Municipal Solid Waste	All of the above	All of the above
Industrial Waste	Construction, fabrication, light, and heavy manufacturing, refineries, chemical plants, power plants, demolition, etc.	Industrial process waste wastes, scraps material, etc. Non industrial wastes including food wastes rubbish ash demolition and construction wastes, hazardous wastes.
Agricultural	Field and row crops, orchards, vineyard dairies, feedlots, farms, etc.	Spoiled food wastes, agriculture wastes, rubbish, and hazardous wastes.

[a] For comparison, the source of waste and waste classifications, used in the early 1990s.

[b] The term municipal solid waste (MSW) normally is assumed to include all of the wastes generated in a community with the exception of industrial process wastes and agricultural solid wastes.

Source: Tchobanoglous et al. (1993)

Several categories of solid wastes are defined as follows:

a) Residential and commercial wastes: Residential and commercial solid wastes consist of the organic (combustible) and inorganic (noncombustible) solid wastes from residential areas and commercial establishments. Typically, for the organic fraction, they consist of materials such as food waste, paper of all types, cardboard, and inorganic fraction consists of items such as glass, tin cans, aluminum, ferrous metal and dirt, etc.

b) Special Wastes: Special wastes from residential and commercial source include bulky items, consumer's electronic white goods, yard wastes that are collected separately, batteries, oil, and tires. These wastes were usually handled separately from other residential and commercial wastes.

c) Hazardous Wastes: Wastes or combinations of wastes that pose a substantial present or potential hazard to human health or living organisms have been defined as hazardous wastes.

d) Institutional Wastes: Institutional source of solid waste include government centers, school, prisons, and hospitals. Excluding manufacturing wastes from prisons, and medical wastes form hospital, the solid wastes generated at these facilities are quite similar to MSW. In most hospitals, medical wastes are handled and processed separately form other solid wastes.

e) Construction and Demolition Wastes: Wastes from construction, remodeling, and repairing of the residences, commercial buildings and other structures are classified as construction waste. The composition is variable but may include dirt, stones, concrete, bricks, lumber, etc. Wastes from razed buildings, broken-out streets, sidewalks, bridges, and other structures are classified as demolition wastes.

The composition of demolition wastes is similar to construction wastes, but may include broken glass, plastics, and reinforcing steel.

f) Municipal Services: Other community wastes, resulting form the operation and maintenance of municipal facilities and the provision of other municipal services, include street sweepings, rode side litter, landscape and tree trimmings, catch-basin debris, dead animals etc.

g) Treatment Plant Wastes and Other Residues: The solid and semisolid wastes from water, wastewater and industrial waste treatment facilities are termed treatment plant wastes. The specific characteristics of this material vary, depending on the nature of the treatment process. Material remaining form the combustion of wood, coal, coke, and other combustion wastes are categorized as ashes and residues. They are normally composed of fine, powdery materials, cinders, clinkers and small amount of burned and partially burned materials.

h) Industrial Solid Wastes: Sources and types of solid wastes generated at industrial site, are grouped according to their Standard Industrial Classification (SIC).

i) Agricultural Wastes: Wastes and residues resulting from diverse agricultural activities-such as the planting and harvesting of row, file, tree and vine crops; the production of milk; the production of animals for slaughter, and the feedlots-are collectively called agricultural wastes.

2.4 Solid Waste Generation

The total annual amount of solid wastes produced in a country depend on many factors such as (Jindal et al., 1997): a) population of the country, b) standard of living, c) social and cultural traditions of the people, and d) degree of industrialization.

There is a close relationship between the income level of a country and the amount of solid waste produced per capita per day. The average waste generation rates in five Asian cities during 1980-1990 are given in Table 2.2.

Table 2.2 Average waste generation in five Asian cities.

City	Per capita waste generation (kg/d)	Population in (1000)	Daily waste generation (tons/d)
Bangkok (1980)	0.88	5,717	5,040
Jakarta (1990)	0.82	8,000	7,570
Kanpur (1990)	0.80	1,785	1,430
Karachi (1990)	0.50	8,750	4,400
Manila (1990)	0.50	7,833	3,900

Source: Habitat (1994)

The municipal solid waste generations were different among the five cities relating to the characteristics, and the economic and social development patterns of the cities. Boonpragob (1996) estimated the solid waste generation rates in Thailand at 0.88 kg/c/d for metropolitan areas (e.g., Bangkok), 0.67 kg/c/d for other cities, and 0.54 kg/c/d for sanitary districts. The generation rates in each zone of the country for the years 1990 and 1992 was reported by Srisathit (1995) as illustrated in Table 2.3.

According to another report in Thailand in year 2000, population in the nation-wide municipal areas produced on an average 1.34 kg/c/d solid waste. The average density of solid waste was 252 kg/m^3. Most of the components of solid waste were food waste, paper, and plastics. The municipal solid waste collection services had the

Table 2.3 Average solid waste generation rates in Thailand.

Part	The average of solid waste generation rate (kg/capita/day)	
	1990	1992
Northern	0.877	0.64-1.64
Northeast	1.008	0.40-1.45
Eastern	1.070	-
Southern	0.783	0.86-2.07
Middle	0.897	0.60-2.13

Source: Srisathit (1995)

area coverage of 95.34%, and the quantity of solid waste was collected at 50.37%tons/day/municipality (Wongwattanapaibun et al., 2000).

At present, the population of Khon Khan municipality generates about 200 tons of garbage a day with about 600 kg of it being medical waste from clinics and private hospitals. A Khon Khan University's study had also predicted that the quantity of garbage will increase by 13% a year (Antaseeda, 1997).

Over 37,000 tons of solid waste per day was generated in Thailand in 1999 as shown in Figure 2.1, which illustrates solid waste generation in Thailand between 1992-1999.

2.5 Solid Waste Collection

Collection is the first fundamental function of solid waste management. Solid waste collection is referred to the gathering of solid wastes from places such as residential, commercial, institutional, and industrial areas, as well as public parks. There are, generally, two methods of collection (Tchobanoglous et al., 1993):

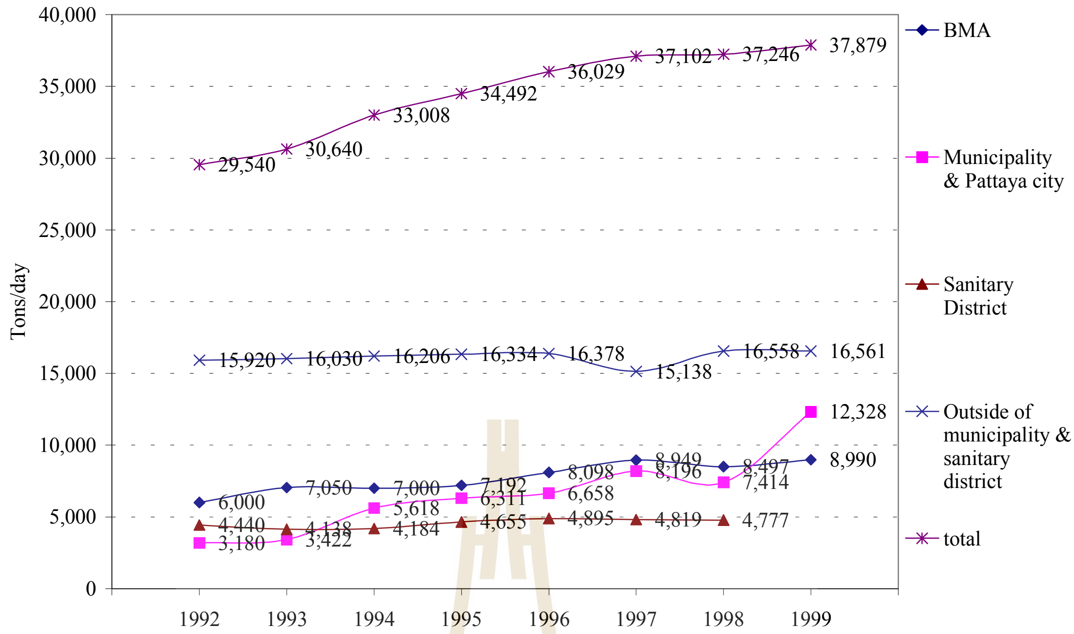


Figure 2.1 Solid waste generation in Thailand between 1992-1999.

Source: Pollution Control Department of Thailand (2000)

1. Hauled-container system: the containers are hauled from the collection point to the final point of disposal, processing facility, or transfer station.

2. Stationary-container system: the containers are emptied into collection vehicles at the point of collection.

Jindal et al. (1997) stated that the waste collection system includes the collection of wastes from specific collection points e.g. community bins, and transportation to the processing and/or disposal sites by using refuse collection vehicles and collection crew. In Asian countries, a variety of refuse collection vehicles are in use. In general, these vehicles could be grouped into two types:

1. Vehicles which move through narrow streets and by lanes and do not travel a long distance before unloading their contents at a transfer station, processing

or disposal facility.

2. Vehicles which move through wider roads and travel long distances before discharging their contents at processing or disposal sites.

In Asian countries, both types of vehicles are used. A combination of short distance type vehicles to transport the wastes to the transfer stations where the load may be discharged into another set of vehicles for long distance hauling to the treatment/disposal facilities, gives optimum results.

2.6 Solid Waste Transfer Stations and Transportation

Transportation is referred to the hauling of solid waste to relatively far distances from the collection areas or transfer stations. The distance traveled may be up to the final point or processing facility.

As the distance from the collection system to the processing facility or disposal site (collectively called destination point) increases, the cost of hauling or transportation also increases. There would eventually be a certain transport distance, where management must decide whether or not a transfer station was necessary. A transfer station is a facility where the wastes collected may be stored temporarily or transferred from the smaller collection vehicles to bigger transport vehicles for transportation to the destination point. There are two general types of transfer stations: direct discharge transfer and storage transfer station. In the first type, collection vehicles dump their loads directly into the larger transportation vehicles; in the latter, the solid wastes are emptied into storage pits or platforms, the wastes are then later loaded into big transport vehicles for hauling to the destination point.

2.7 Solid Waste Processing and Recovery

Processing is the second fundamental function of solid waste management. Processing improves the efficiency of solid waste disposal and prepares solid waste for subsequent recovery of material and energy. In the not-too-distant past, disposal of solid wastes included open dumps, sanitary landfills, and disposal at sea. However, because of environmental problems associated with open dumps and sea disposal, the only acceptable method of solid waste disposal at present seems to be sanitary landfilling. Apart from disposal, some of the materials in solid waste could also be recovered and recycled for manufacture of the same or new products. For example, instead of mining silica for glass manufacture, recovered glass may be remelted. Also, recovered paper can be reprocessed to produce new paper. The organics from solid wastes could be processed biologically to produce compost. Electricity could also be recovered from solid waste.

The recovery of solid waste components for possible use as raw materials is called recycling or salvaging. The future of recycling would be either certain or uncertain. In as much as there is resistance on the part of industrial community to use recycled materials in product manufacture, it is also felt that processing virgin raw material is more economical than processing recycled material.

2.8 Treatment and Disposal of Solid Wastes

Disposal is the third fundamental function of solid waste management. In the not-too-distant past, dumps and disposal at sea were practiced. At present, however, because of inherent environmental problems associated with these methods, they are no longer practiced. Various methods of solid waste disposal include sanitary landfilling, recycling and reuse, composting and incineration.

2.8.1 Sanitary Landfilling

The sanitary land fill method is an engineered burial of refuse. It consists essentially of spreading waste on the ground, compacting it, and covering it with soil at the end of the working day or other suitable intervals for wastes other than sanitary solid wastes.

Sanitary landfilling, in the true sense, is the land disposal along the lines of controlled tipping with additional environmental protection measures, e.g. hydrogeologically secured sites, leachate control for ground water safety, and surface water protection, etc (Jindal et al., 1997).

Hirshfeid et al. (1992) stated that the sanitary landfilling is the most common method used for municipal solid waste. However, many landfill owners underestimated the costs of landfill disposal considering the land operating costs, ignoring the social and physical costs associated with landfilling. In their report, Hirshfeid (1992) described two types of external impacts of landfills as physical and social impacts.

Physical impacts are those which are directly occurring due to generation of landfill products e.g., contamination of ground water and surface water, production of gases, and fires. The protection from leachate is very difficult and that is the gravest risk associated with landfills.

Social impacts includes increased traffic, visible air pollution, noise, esthetic degradation and limited use of land after filling. In general the presence of landfill will reduce present and future uses of both landfill and the surrounding lands.

After closing it may continue to settle for long period of time thus limiting the use of site. The losses of property value are ultimately paid by the residents living close to the landfill site. Though it is very difficult to determine the true costs of landfill, but efforts must be made to evaluate the maximum impacts of the landfill.

Tchobanoglous et al. (1993) stated that the most difficult task in solid waste management is the selection of proper landfill site. They said that following factors must be considered for evaluating the potential sites for the long-term disposal of the solid waste: 1) haul distance, 2) location restrictions, 3) avaliable land area, 4) site access, 5) soil conditions and topography, 7) climatological conditions, 8) surface water hydrological conditions, and 9) local environmental conditions. The final decision is made on the detail designs, financial as well as on the basis of environmental impact assessment, the factors to be considered for design of landfill are given in Table 2.4.

2.8.2 Recycling and Reuse

The term "Recycling" is defined in 1970 edition of Oxford dictionary. At present, recycling has contemporary meanings such as recovery and reuse of materials from waste (Gurdeep, 1992), the process of utilizing one or more of the components (including chemical energy) of discarded or waste material, and the concept of recycling applied to a forest tree involves its use for recreation, shelter, furnishing etc.

Stedge and John (1994) carried out the economic analysis of different recycling systems. They compared bag-based program with curbside sort program and a drop-off program. They found that the efficiency of bag based system was better although the curbside sort was found to divert a large percentage of residential

Table 2.4 Factors to be considered for the design of landfill.

Factor	Remarks
Access	Paved all weather roads to landfill sites, temporary roads to loading area.
Land area	Area should be large enough to hold all community wastes for minimum of 5 year but preferably 10 to 25 years, area for buffer strips or zone must also be included.
Landfilling method	Method will vary with terrain available covers most common methods are Excavated cell/trench, Area Canyon
Completed landfill Characteristics	Finished slope of landfill, 3 to 1; height to bench, if used 50 to 70 ft; slope of final cover 3 to 6%.
Surface drainage	Install drainage ditches to divert surface water runoff: maintain 3 to 6% grade on finished landfill cover to prevent pounding: develop plan to divert storm water from lined but unused portion of landfill.
Intermediate cover material	Maximize use of onsite soil material such as compost produced from yard waste and municipal solid waste can also be used to maximize the land fill capacity typical waste to cover ratio vary from 5 to 1 to 10 to 1.
Final cover	Use multilayer design; slope of final landfill cover, 3-6 %.
Landfill liner	Single clay layer (2 to 4 ft) or multi layer design incorporating the use of geomembrane cross slop for terrace type leachate collection system, 1 to 5% maximum flow distance over terrance, 100 ft; slop of drainage channels 0.5 to 1.0% slop for piped type leachate collection system 1 to 2% size of perforated pipe spacing, 20 ft.

Source: Tchobanoglous et al. (1993)

Table 2.4 Factors to be considered for the design of landfill. (continued)

Factor	Remarks

Cell design and construction	Each days waste should form one cell cover at the end of the day 6 in of earth or other suitable material; typical cell width 10 to 30 ft; typical lift height including cover, 10 to 14 ft, slop of working face 2:1 to 3:1
Ground waster protection	Divert any underground spring; if required, install perimeter drains, wells point system or other control measures.
Landfill gas management	Develop landfill gas management plan including extraction well, manifold collection system, condensate collection facilities, the vacuum blowers facilities; and or energy production facilities operating vacuum at well head 10 in of water.
Leachate collection	Determine maximum leachate flow rate and size leachate collection pipe and/or trenches; size leachate pumping facilities; select collection pipe material to withstand static pressure corresponding to the maximum height of the landfill.
Leachate treatment	Based on expected quantities of leachate and local environmental condition select appropriate treatment process.
Environmental Requirements	Install vadose zone gas and liquid monitoring facilities; install up and down gradients ground water monitoring facilities; locate ambient air monitoring stations.
Equipment requirements	Number and type of the equipment will vary with the type of landfill.
Fire Prevention	Water onsite; if nonportable, out let be marked clearly; proper cell separation prevents continuous burn through if combustion occurs.

Source: Tchobanoglous et al. (1993)

waste stream than the bag based system; the cost per ton of the bag based system is lower than the curbside. They found that the cost of drop-off system was very low, but its efficiency was not acceptable. The bag-based program was more efficient in areas with high household density. Summarized results of the study are given in Table 2.5.

Table 2.5 Summary of the results of a comparative recycling study.

Net cost/ton	Bag Based	Curbside-sort Adjusted	Drop-off
	\$76.27	\$131.38	\$19.63
Diversion Rate	20.40%	32.71%	3.69%
Efficiency Factor of Collection	3.74	4.017	5.51

Source: Stedge and John (1994)

Gerhard (1994) carried out a study on waste minimization and recycling strategies and their chances of success by using different scenarios combining with ecological and economical aspects with facts and trends of human ethnology. He found that household waste fraction can be reduced by 10 % due to waste minimization and by 40 % to 50 % due to recycling. He also concluded that waste minimization and recycling could be successful by the cooperation of the public.

2.8.3 Composting

Natural decomposition and stabilization of solid organic materials has been taking place in the ecosystem ever since the evolution of life on earth. With the forward leaps of civilization and advancement of scientific knowledge, efforts are now being directed towards controlling and optimizing the process in such a way as to make it more efficient, effective, and beneficial for mankind. The processes that had been evolved as a result, are referred to as “composting” and the final product called “compost” (Jindal et al., 1997).

Lohani et al. (1984) stated that composting is the oldest method of organic waste disposal and defined it as decomposition of heterogeneous organic matters by microorganisms in moist warm, aerobic environment, in degradation and reduction of organic matter into a sanitary nuisance-free humus like material, which can be used as fertilizer, soil conditioner, or bulking agent for reclamation cover material for the landfill. They pointed out that process was suitable for the developing countries due to following reasons: 1) it is a simple method, 2) small amount of residue is left for the landfill, 3) it is easily adaptable in local condition, 4) compost has low toxic substances, and 5) it meets the requirement of the hygienic conditions. They also pointed out the conditions required for the successful operations of composting as follows: 1) support from the government authorities especially those related with agriculture, 2) suitability of the solid waste for composting, 3) price of the product to be reasonable, and 4) compost-production source to be near the market.

2.8.4 Incineration

Incineration could be defined as a controlled combustion process for burning wastes. During the process, combustible portion of the waste is oxidized and vaporized leading to carbon dioxide emission, and non-combustibles and ash remain as residues. Proper incineration ensures the prevention of air pollution and other related problems (Jindal et al., 1997).

Incineration is the waste treatment process with great particulate and gaseous emissions. Therefore, dust extractor and flue gas scrubbers are required which involve large amount of capital expenditure and higher operation and maintenance cost (Willing, 1979, quoted in Shafique, 1996).

Theodore and Reynolds (1987) described that incineration involves the oxidative conversion of the combustion material to gases suitable for release in the atmosphere. The harmful gases must be removed before releasing to the air.

Brent (1991) said that the capital cost for the control of air pollution is about 10 to 20 percent of total investment cost for incineration.

Different methods of treatment, processing and disposal are applied in the countries of Asia and Pacific region. The most widely used method is landfilling or open dumping. In larger cities, availability of land for waste disposal is the major problem. In Japan and Singapore, around 65% of the waste are incinerated with energy recovery. Waste Characteristics of these countries have relatively high calorific value due to the presence of high percentage of paper, plastics, and other combustibles, and low moisture content. Low-income countries use open dumping as a disposal method. Disposal methods in different counties of Asia Pacific region are given in Table 2.6 (Asian Development Bank, 1995).

Table 2.6 Disposal methods for municipal waste in selected countries.

Country / Territory	Disposal Methods			
	Land Disposal (%)	Incineration (%)	Composting (%)	Others (%)
Hong Kong	65	30	-	5
Japan	22	74	0.1	3.9
Singapore	35	65	-	-
Thailand	80	5	10	5

Source: Asian Development Bank (1995)

Energy and materials use and their associated pollution could be pared drastically by reducing the amount of waste generated, by encouraging the direct reuse of products, and by recycling – the process of converting discards into new products. Modifying consumption and waste disposal habits would also help to check other alarming and possibly irreversible changes to biosphere such as depletion of stratospheric ozone protecting the earth from harmful ultraviolet rays (Jindal et al., 1997). Table 2.7 presents the summary of waste disposal/treatment methods in some Asian countries.

Table 2.7 Solid waste disposal methods in some Asia countries.

Methods	Countries			
	China	Singapore	Thailand	Japan
Crude open Dumping	Being practiced		70% MSW	
Controlled Tipping		40% MSW		
Sanitary landfilling	Few places	40.2% MSW	20% MSW	22% municipal waste
Disposal to canals, rivers, lakes			Canals rivers	
Incinerator		59 % MSW	±1% MSW	With heat recovery 75% of MSW; Residue burned in landfill Small no. of electricity generating
Composting	Manual mechanical	Some	Mechanical ± 10% MSW	1-2% MSW
Anaerobic digestion	Being practiced			
Recycling and resources Recovery	Informal government organized	Formal organized	Being practiced	Well organized successful

Source: Jindal et al., 1997

2.9 Solid Waste Management at Suranaree Military Camp

Suranaree Military Camp (SMC) is the central army camp of Northeastern region, located in Nakhon Ratchasima, Thailand. The camp consists of many important official Military Services (forscom and logistical group). The large population of Suranaree Military Camp generates substantial quantity of solid waste. At present, Suranaree Military Camp does not have appropriate waste management plan. The current solid waste management practices at the Suranaree Military Camp are summarized as follows:

Generation rate: There is no statistical data regarding the waste generation rate available for waste management within the camp. It is still unclear that whose responsibility is the solid waste management at the camp. Waste generation rate estimation is still questionable for the camp. Based on the information about the average amount of wastes being collected and transported by the trucks to the dumping site, the approximate generation rates in the camp were estimated to be varying between 4,152-4,635 kg/d (Kriengkasem, 2002; Putdhimanee, 2002).

Storage method: Each household in the residential area and each military office have their own waste storage containers. Types of storage devices include: improvised oil drums or similar metal containers, baskets, and plastic buckets.

Collection Method: Suranaree Military Camp has a main control unit with several subunits responsible for waste collection. Each subunit collectes waste from different offices by emptying the storage containers into trucks as shown in Figure 2.2. The collection frequency is approximately 1 - 2 times / week. Each collection truck has a crew of 4-5 men, who put the garbage from the containers into the truck and wastes are sent to the open dumping area.

Figure 2.2 Suranaree Military Camp's waste collection method.

Disposal method: Suranaree Military Camp's solid waste disposal method is crude open dumping on a vacant site in the south of residences and offices in the Camp as shown in Figure 2.3. There is no waste seperation prior to dumping. The waste, which could be recovered and recycled go directly to the dump site. The degradable waste and some hazardous waste create leachate which may contaminate groundwater.

Problems:

a) Suranaree Military Camp does not have skilled and knowledgeable persons for solid waste management.

Figure 2.3 Suranaree Military Camp's open dumping site.

b) Waste management unit does not understand and care for adequate solid waste management method.

c) There is no funding for appropriate solid waste management method.

d) Solid waste management is not an important issue for the superior commanders.

2.10 A Modeling Approach

There are two basic phases in systems simulation; one involving the construction of a model and the second concerned with the use of the model in developing or controlling the real system. Steps in system simulation are described as follows (Jongkaewwattana, 1995):

Step 1: Problem identification, statement of objectives and system definition

Since we are now concerned with system dynamics in which it can be applied to problems that are also dynamic i.e. they involve the behavior that change over time. After the objectives are being set, next step is to identify the specified system in terms of its properties i.e. boundary, system variables, and their relationships.

Step 2: Collecting and analysis of data

The mechanistic model is to a large extent dependent on the data available or on the feasibility of generating data within the time limits set by the research.

Step 3: Model construction

The first move in model construction is to summarize the details of system from step 1 and present them as "causal loop diagram". Causal loop diagram needs to be expressed as a series of relationships and equations in a computer language using information from step 2.

Step 4: Model validation

Model validation involves a testing of the model constructed in step 3. The model needs to mimic the real system sufficiently well to fulfill the purposes for which it was developed.

Step 5: Sensitivity analysis

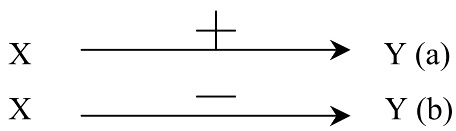
Sensitivity analysis is a procedure carried out on the completed and, at least partly, validated model which involves exploring the operation and performance of the model. In successive runs of the model under identical environmental conditions, the value of a parameter may be changed.

Step 6: Application of the model

After passing the validation and sensitivity analysis steps, the model can be implemented confidently to achieve the purposes set at the earlier step. Generally, the model would help in management strategies of a real system like farming system and population control system. Moreover, the model could also provide knowledge regarding the understanding of the system which can guide the research program.

2.10.1 Causal Loop Diagram:

Generally, any component of a system, if being influenced by any means, would respond. In another words, if there is a cause then there would be an effect. Causal thinking in terms of cause-and–effect and feedback is a key to organizing ideas in a system dynamics study. Typically, an arrow symbol with positive (+) sign or negative (-) sign are used to present cause and effect among system components as shown below:



Causal link from X to Y (a) can be described as that variable X influences variable Y. However, such influence is a positive effect. This means that if a change in X causes change in Y, change of both X and Y is in the same direction i.e. if X increases then Y also increases and vice versa. In contrast, the causal link from X to Y (b) illustrates negative causal link. Hence, an increase in X would cause a decrease in Y and vice versa (Jongkaewwattana, 1995).

Figure 2.4 illustrates a simple population dynamic system which consists of three components i.e. birth rate, death rate, and total population. There are two feedback loops in the system, one is the positive and the other is negative. The positive feedback loop is the loop that links between birth rate (unit is number of births per year) and total population. This positive loop suggests that birth rate increases total population size. Consequently, the increasing population size could also enhance birth rate. The negative feedback loop is the loop that links between death rate (unit is number of deaths per year) and total population. As we can see that an increasing death rate would decrease population size. However, as the population size increases, the chance of getting high death rate is also high. So the negative (-) sign is assigned to the link between death rate and total population but positive (+) sign is assigned to the link between the total population and death rate.

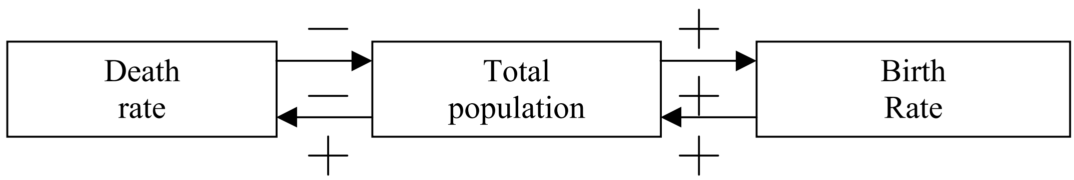


Figure 2.4 Casual-loop diagram that contains both positive and negative links.

2.10.2 STELLA Simulation Program

STELLA is a computer program that is used for obtaining the correlation between the various interrelated variables. STELLA has 3 features defined as follows:

1. Map and Model
2. Simulate and Analyze
3. Create a user-interface

The software works when the mental models are mapped, and then transform the maps into computer-simulated models. The interface level has tools for creating and engaging end-user interface for the models. Finally, equations are associated with the model as opposed to viewing each equation separately from within individual entity dialog boxes on the causal loop. In this study, causal loops were used in the program. The program gives equations. Then the values of variables were entered to run the program.

Chapter III

Methodology

3.1 General

In order to achieve the research objectives, the methodology employed in this study was based on the steps as presented in schematic diagram in Figure 3.1.

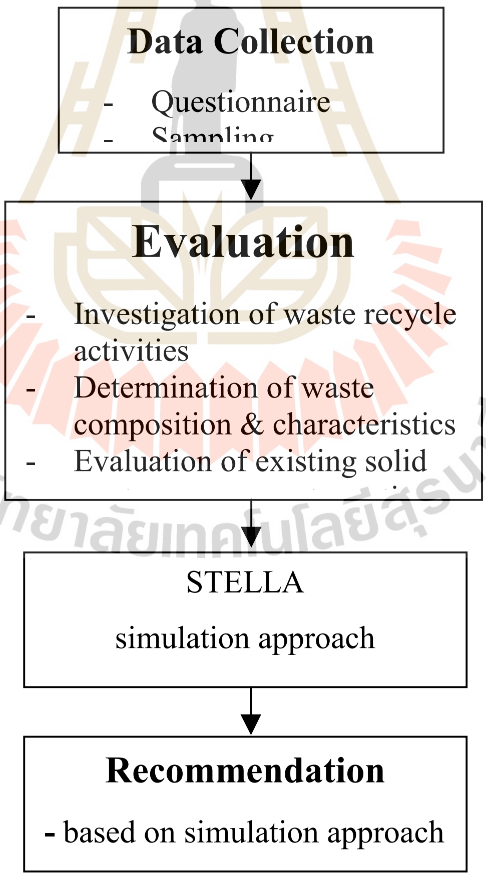


Figure 3.1 Schematic diagram of methodology.

3.2 Experimental Location

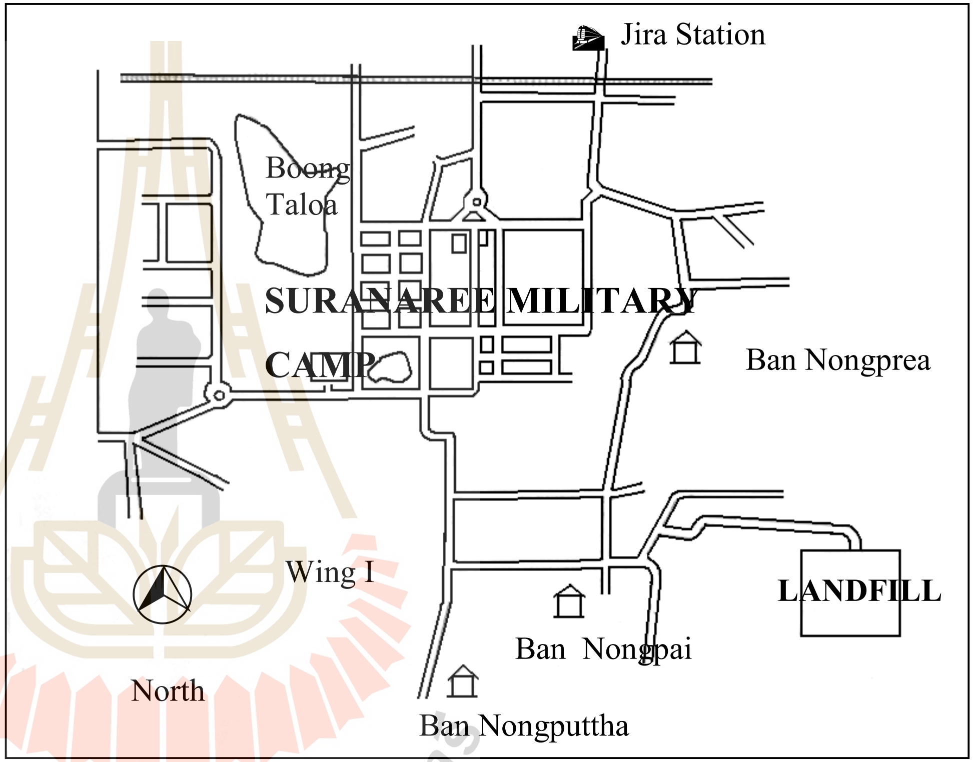
Suranaree Military Camp is located in Nakhon Ratchsima city, northeastern region of Thailand as shown in Figure 3.2.

3.3 Data Collection

The required information about solid waste management in Suranaree Military Camp were categorized into 2 groups; they are 1) primary data and 2) secondary data. The secondary data was obtained from 2 involved firms; they are 1) first Headquarter of 2nd army area and 2) headquarter of 21st military circle. The required secondary data were as follows: population and existing situation of solid waste management in the camp, which included: waste generation rates, waste collection, waste transfer and transport, waste disposal site and modes of disposal, current regulation on waste disposal, status of recycling in the camp. Concerning the primary data, they were collected by means of interviewing and site investigations. The key informants to be interviewed were classified into 2 groups, namely offices and residences. Quarters or residential areas in Suranaree.

Military Camp were categorized in to 2 groups based on the level of command as follows: residences of the non-commissioned officers, residences of the commissioned officers. The main items to be used for interviewing were as follows: number of persons in the household, quantity and type of solid waste per day, solid waste recycle approach, method of storage, collection and transportation, and method of disposal. Regarding the site investigation, the main activities carried out were estimation. of solid waste generation rates, analysis of physical components and bulk density of solid waste samples taken from the waste generated in the Suranaree

a) Nakhon Ratcasima, Thailand



b) Suranaree Military Camp

Figure 3.2 Experimental location.

Military Camp, analysis of chemical composition of waste were C, H, N, ash, moisture content and combustibles content, as well as calorific values. The questionnaire used for the interviewing is shown in appendix A.

The appropriate number of samples for interviewing was determined by the following equation (Yamane, 1973) :

$$n = \frac{N}{1 + Ne^2} \qquad (3.1)$$

where,

n = number of samples

N = number of offices or residential units

e = percent error

Suranaree Military Camp has approximately 17 main divisions with 12 large offices and 5 small offices along with the related residential units. The number of samples required for large and small office units were estimated to be 12 and 5, respectively. Related to the total of 17 selected units, there are 349 commissioned officer households, and 2,131 non-commissioned officer households. After using equation (3.1), the number of households required for interviewing were obtained as 80 households for commissioned officers residential area and 100 households for non-commissioned officers residential area. The official units and households selected for interviewing were randomly choosen to cover the total study area, thus the information collected was representative of the whole population.

3.4 Generation Rate

The total quantity of municipal solid waste generated can be determined by the following equations (Yoosuk, 1988):

$$w_i = m_i \times p_i \tag{3.2}$$

$$w = \sum_{i=1}^{n} w_i \tag{3.3}$$

$$Q = \frac{w}{\text{total population}} \tag{3.4}$$

Where: w = Total quantity of wastes generated, (weight/time),

w_i = Quantity of wastes generated at each source, (weight/time),

m_i = Waste generation rate at each source, (weight/time),

p_i = No. of generation sources,

Q = Municipal solid waste generation rate, (weight/capita/time).

Information on the various items of equations (3.2)-(3.4) were obtained through the questionnaire survey and rechecked from field work.

3.5 Sampling Plan

The samples were collected over three weeks time period from all sources generating waste in the camp during weekdays and weekends. Three samples per week were taken from each source, 2 on weekdays and 1 on the weekend for residences, and twice on weekdays for offices. Sampling schedule is presented in Table 3.1.

The samples were analyzed for he physical properties, which consisted of Bulk density and the waste composition, as well as for the chemical characteristics.

Table 3.1 Sampling schedule.

Type of source	No. of sources	Week days		Weekend	Total no. of samples/ week
		Tuesday	Thursday	Sunday	
1. Offices	5	/	/		10
2. Residential blocks of the non-ommissioned officer (NCO)	7	/	/	/	21
3. Residential blocks of commissioned officer (CO)	7	/	/	/	21
Total					52

Laboratory analysis for waste composition was done on the composite samples of each sampling day.

3.6 Samples' Preparation

In order to determine the physical and chemical composition of solid wastes, the samples collected from the waste generating sources were prepared for analysis by using the quartering method. This method involved: piling commingled waste in cone shape and cut into four equal sections.

Two diagonal sections (a + d) and (b + c) were combined and mixed. The samples were put in to two plastic bags and taken to the laboratory for analysis.

3.7 Physical Parameters

Physical parameter studied in this research were bulk density, and physical classification. Physical classification of wastes were classified as follows:

Combustibles	Non-combustibles
a) Food waste and yard waste	a) Metal
b) Paper	b) Glass
c) Plastics	c) Hazardous waste
d) Rubber	d) Stone and cement tiles
e) Leather	e) Others, i.e. bones
f) Textile	
g) Wood	

(See definition details in Appendix B)

3.8 Chemical Parameters

The Chemical parameters analyzed for this study included: Moisture content (%), Volatile solids (%), Elemental Carbon (%), Elemental Hydrogen (%), Nitrogen (%), Phosporus, and Calorific Value. Various steps of the physical and chemical analysis of waste composition are shown in Figure 3.3.

3.9 Simulation Approach

A computer program called STELLA was used to simulate the strategies. Casual loop diagram was constructed for STELLA simulation. Loop diagram was then converted to a flow diagram with equation translation methods. Sensitivity analysis were accomplished by exploration of the operation and performance of the

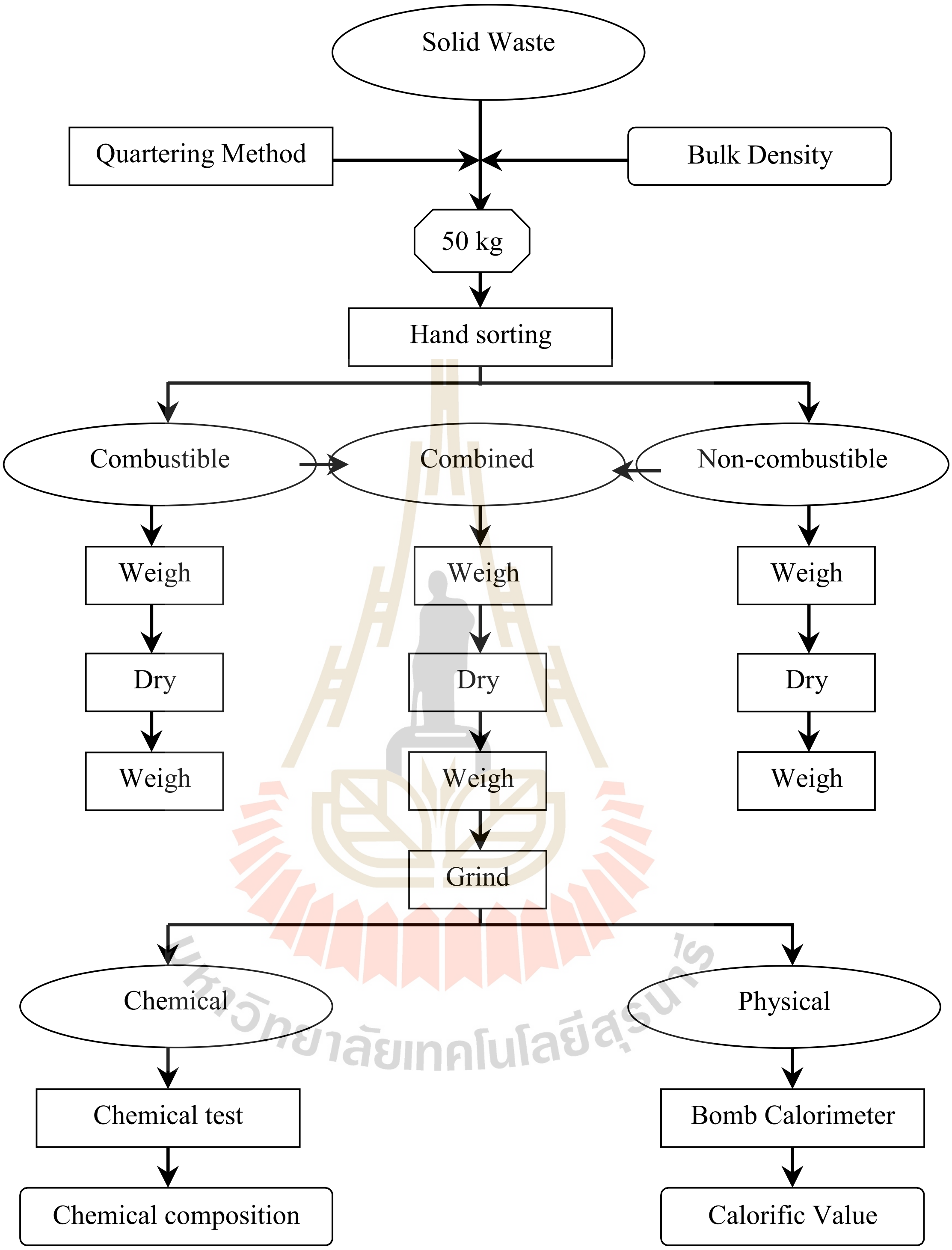


Figure 3.3 Flow chart of characteristics analysis.

model. That is, in the successive runs of the model under identical conditions, the value of a parameter is changed. The outputs from the runs were analyzed in order to determine whether the changed parameter values were of material consequence. The model, which was a good representation of the real system, would produce a reasonable change of the outputs. Overview of system simulation through modeling approach is illustrated in Figure 3.4.

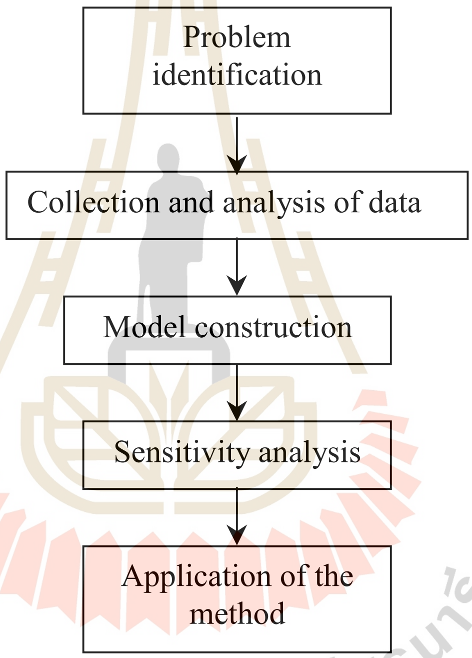


Figure 3.4 Overview of system simulation though modeling approach.

Chapter IV
Results and Discussion

4.1 Surveying Results on Solid Waste Management at Suranaree Military Camp

The results of interviewing and gathering the questionnaires from the offices and the commissioned officers' (CO) and non-commissioned officers' (NCO) residences in the Suranaree Military Camp (SMC) are shown in Tables 4.1–4.3.

Table 4.1 Solid waste management information from offices.

Question No.	Question	Response
1	How many members are in this office?	confidential
2	How much waste do you generate? (kg/c/d)	0.23 (average)
3	Do you know about solid waste management?	Yes - 25 No - 75
4	How do you feel about waste management in SMC?	Satisfied – 16 (95%) Unsatisfied – 1 (5%)
5	Do you practice recycle in your office?	Yes – 20 No - 80
6	How much waste do you recycle?	≈ 5% of the total waste

Table 4.2 Solid waste management information from CO's residences.

Question No.	Question	Response
1	How many family members are staying in this house?	3.9 (average)
2	Howmuch waste do you generate? (kg/c/d)	0.5 (average)
3	How do you feel about waste management in SMC?	Satisfied – 76 (95%) Unsatisfied – 4 (5%)
4	Do you know about solid waste management?	Yes - 21 No - 79
5	Do you practice recycle in your household?	Yes - 24 No - 76
6	How much waste do you recycle?	≈ 5% of the total waste

Table 4.3 Solid waste management information from NCO's residences.

Question No.	Question	Response
1	How many family members are staying in this house?	4.2 (average)
2	Howmuch waste do you generate? (kg/c/d)	0.4 (average)
3	How do you feel about waste management in SMC?	Satisfied – 91 (91%) Unsatisfied – 9 (9%)
4	Do you know about solid waste management?	Yes - 15 No - 85
5	Do you practice recycle in your household?	Yes - 15 No - 85
6	How much waste do you recycle?	≈ 5% of the total waste

4.1.1 General Information

There are approximately 2,500 households in Suranaree Military Camp and most of them have a single family. An average of 4 people are per household with the estimated solid waste generation of 0.5 kg/day and 0.4 kg/day for commissioned officers' and non-commissioned officers' residences, respectively. Not many people have the knowledge about waste management. The results of the survey showed that 21 % of the people in the commissioned officers' residences knew about solid waste management, while only 15 % of the people in non-commissioned officers' residences were aware of it.

4.1.2 Solid Waste Storage, Collection, and Disposal

Storage bins (Figure 4.1) are placed in front of each residence and solid wastes are collected 1-2 times/week by the military's trucks as shown in Figure 4.2. Final waste disposal method used in Suranaree Military Camp is landfilling (Figure 2.3 and additional pictures in Appendix C). Most of the surveyed residence groups were satisfied with their waste management, which was 95 % and 91 % of the people in the commissioned officers' residences and non-commissioned officers' residences, respectively. Unsatisfied people requested higher efficiency and consistency of waste collection. The thorough picking up while collecting waste is also needed to be improved. Moreover, some families still use open burning method for waste disposal.

4.1.3 Waste Recycling

Waste separation at the source is not practiced at the camp. Thus, formal recycling has not been promoted. Only 24 % and 15 % of the people in the commissioned officers' residences and non-commissioned officers' residences, respectively, practice recycling in their households. The average amount of waste

Figure 4.1 Waste bins.

Figure 4.2 Waste collection truck.

recycled was found to be 5 % of total waste generated. According to the results of the interviewing, recycling is not a well-known waste reduction practice in Suranaree Military Camp. However, prior to landfilling, some more recycling is accomplished by the scavengers as shown in Figures 4.3 and 4.4. The waste recycled by scavengers was estimated to be approximately 10 % of the total waste being disposed in the landfill.

Figure 4.3 Scavenging at the landfill area.

4.2 Population Growth Rate

The calculation for the current population in Suranaree Military Camp is shown as follows:

Figure 4.4 Waste recycled by scavengers.

[number of households in commissioned officers' residences

× number of people per household]

+

[number of households in non-commissioned officers' residences

× number of people per household]

+

total number of privates at the camp

=

$$(349 \times 3.9) + (2{,}131 \times 4.2) + 2500 = 12{,}812 \text{ people}$$

Thus, the current population at the Suranaree Military Camp was calculated to be 12,812 .

Rate of population growth and average rate of total population change, were obtained by the following relationship (PCD, 1995):

$$GR = \frac{(B - D + I - O)}{P} \times K \qquad (4.1)$$

where,

GR	=	rate of population growth
B	=	the number of people born in one year
D	=	the number of people died in one year
I	=	the number of people moving in the area in one year
O	=	the number of people moving out of the area in one year
P	=	total population in the mid year
K	=	constant ≈ 1,000

From the population record at the Muang Nakhon Ratchasima District office and equation (4.1), net growth rate of Suranaree Military Camp was estimated to be 0.00343 %.

4.3 Waste Generation Rate

In the field investigations to obtain the waste generation rate at Suranaree Military Camp, three groups of waste sources for sampling were selected; they were offices, and the commissioned officers' and non-commissioned officers' residences. Based on the results, the average per capita waste generation rate was estimated to be 0.48 kg/c/d (as generated).

The generation rate obtained from the field investigation included the waste which has immediate face value and are separated by the house holders like newspapers, magazines, metals, glasses (beverage bottles), etc. These components are mostly sold to scavengers who come and collect them from individual households. Some amount of food waste is thrown into sewer or fed to the ducks, chickens, and street dogs, etc., (traditional practice). The generation rate, based only on total collected waste material and not the total generated solid wastes would be 0.41 kg/c/d, as shown in Table 4.4. No separate collection for hazardous waste is practiced at Suranaree Military Camp. With time, the battery waste has increased in the domestic waste.

The compositions of waste samples collected (shown in Table 4.4) indicated that the highest fraction of waste generated was combined food waste and yard waste, which was 60.96 %. Per capita generation rates of food waste from commissioned officers' and non-commissioned officers' residences were not significantly different, while, offices' and residences' per capita waste generation rates of food waste were slightly different. The main differences in waste generation rates of various fractions from offices' and residences' zones were found to be in rubber, leather, and stones and cement tiles. Among the residence zones, waste generation rates were not different on weekdays and weekend.(Tables D.2-D.6 in Appendix D)

The total current amount of waste generated was estimated to be 6.15 ton/d (with 12,812 people in Suranaree Military Camp). In 1999, the total amount of solid waste generated in Thailand was 37,879 ton/d and in Bangkok, 8,990 ton/d (PCD, 2000). Everywhere, waste generation rate has increased yearly. In 1996, Nakhon Ratchasima Municipality had a population of 211,182 (Nakhon Ratchasima Municipality, 1998), while the total solid waste collected by the municipality was only 60,867 ton/y or 166.8 ton/d. Thus, waste generated in Suranaree Military Camp is 3.14 % of collected waste in Nakhon Ratchasima Municipality.

Table 4.4 Generation rates of various solid waste fractions in Suranaree Military Camp (wet weight basis).

Sample No.	Items	Generation Rate %							
		Residences						Offices	Average
		CO			NCO				
		Weekday	Weekend	Average	Weekday	Weekend	Average	weekday	
	Combustible								
1	Food waste and yard waste	64.16	65.41	64.79	65.01	65.58	65.30	52.79	60.96
2	Paper	9.17	12.76	10.97	11.13	12.11	11.62	28.79	17.13
3	Plastic	13.34	15.43	14.39	13.93	16.37	15.15	13.80	14.45
4	Rubber	-	0.03	0.02	1.54	-	0.77	0.20	0.33
5	Leather	-	0.46	0.23	-	-	-	0.29	0.17
6	Textiles	1.31	0.90	1.11	1.17	1.23	1.20	0.20	0.84
7	Wood	0.23	0.14	0.19	0.20	-	0.10	0.25	0.18
	Non-Combustible								
8	Metal	0.51	1.07	0.79	1.46	0.95	1.21	1.55	1.18
9	Glass	9.58	3.74	6.66	4.91	3.71	4.31	1.52	4.16
10	Hazardous waste[1]	1.20	0.06	0.63	0.60	-	0.30	0.57	0.50
11	Stone and cement tiles	0.30	-	0.15	0.05	-	0.03	0.04	0.07
12	Others, i.e. bones	0.20	-	0.10	-	0.05	0.03	-	0.04
13	Density (kg/m^3)	197.53	210.91	204.22	249.87	270.53	260.20	142.63	202.35
14	Per capita waste (kg/c/d)	0.45	0.61	0.53	0.39	0.53	0.46	0.23	0.41

[1] Hazardous waste include batteries, spray paint cans, DDT, fluorescent light bulbs, etc.

4.4 Physical and Chemical Analysis

Major distinguishable components found in domestic waste samples at Suranaree Military Camp were food waste, leaves, paper, plastics, rubber, glass, metals, etc. (details in Appendix D).

4.4.1 Physical Composition

Based on the results of waste samples separation, physical composition of domestic waste in Suranaree Military Camp is shown in Table 4.5. The average density of domestic solid waste at SMC was obtained to be 202.35 kg/m^3. Estimated domestic waste density in Suranaree University of Technology (SUT) was reported to be approximately 204 kg/m^3 (Somsri, 2002), while for Nakhon Ratchasima Municipality (1998), it was approximately 290 kg/m^3.

4.4.2 Chemical Composition

Based on the results of the laboratory analyses of the samples collected from the selected sources, the characteristics of solids waste at Suranaree Military Camp are shown in Table 4.6.

Total solids content in the Suranaree Military Camp domestic waste was not much different from those of Suranaree University of Technology and Nakhon Ratchasima Municipality, which were found to be 37.3 % wet basis (Somsri, 2002), and 44.4 % wet basis (Nakhon Ratchasima Municipality, 1998), respectively. The differences in chemical characteristics of the waste at Suranaree Military Camp as compared with the two others were found to be for volatile solids (VS) and ash. Volatile solids in Suranaree University of Technology and Nakhon Ratchasima Municipality wastes were found to be 30.1 % (Somsri, 2002) and 29 % (Nakhon Ratchasima Municipality, 1998), respectively, while for Suranaree Military Camp, it

Table 4.5 Physical composition of domestic waste in Suranaree Military Camp.

No.	Items	Average weight % wet basis
	<u>Combustible</u>	
1	Food waste and yard waste	60.96
2	Paper	17.13
3	Plastic	14.45
4	Rubber	0.33
5	Leather	0.17
6	Textiles	0.84
7	Wood	0.18
	<u>Non-Combustible</u>	
8	Metal	1.18
9	Glass	4.16
10	Hazardous waste	0.50
11	Stone and cement tiles	0.07
12	Others, i.e. bones	0.04
13	Density (kg/m^3)	202.35

Table 4.6 Chemical Characteristics of domestic waste in Suranaree Military Camp.

No.	Parameters	Chemical composition	
		% average (dry basis)	% average (wet basis)
1	Moisture	-	54.19
2	Total solids	-	45.81
3	Volatile solids	75.65	34.58
4	Ash	24.35	11.23
5	Carbon	42.03	-
6	Hydrogen	4.73	-
7	Nitrogen	1.10	-
8	Phosphorus (ppm)	167.70	-
9	Calorific value (kcal/kg) (DSCV)	4,232.80	-
10	C/N ratio	38.21	-

was found to be 34.6 %. Moreover, based on one study at SMC, it was found that 50.23 % of waste was organic and 49.77 % was inorganic (Kriengkasem, 2002).

4.5 Strategy Studies

In order to evaluate the appropriate solid waste management strategy at Suranaree Military Camp, five cases were simulated using STELLA program by incorporating the all possible management options, including:

Case I current disposal method (open dumping with little recycling)

Case II Increasing landfill efficiency through improved technology

Case III waste recycling promotion with landfilling

Case IV composting process with landfilling, and

Case V incineration followed by landfilling of residual ash.

The remaining available area for landfilling each year is an indicator of waste management benefits of the disposal option. Casual loop diagrams were constructed for each strategy studied. They were converted to flow diagrams by equations translations and were used to represent the interactions in the proposed scheme. The correlation between each element was linked and the equations were substituted to estimate the final amount of waste disposed to the landfill. Principal elements used for the simulation included the following:

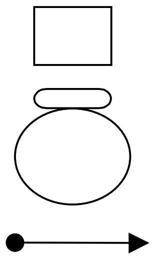
a) initial population and net growth rate,

b) waste generation rate,

c) recycle potential, and

d) possible waste volume reduction

There were three types of structures to represent variables, namely:



stock variable,

rate of flow variables, and

connector.

Stock variables represent input and output, which are changed by the rate of flow variables as the model is running. Connectors represent the system dynamic links and reflect the assumptions about "what depends on what." Equation translation for specific case studies are shown in Appendix E. Figure 4.5 shows the schematic layout of casual loop diagram.

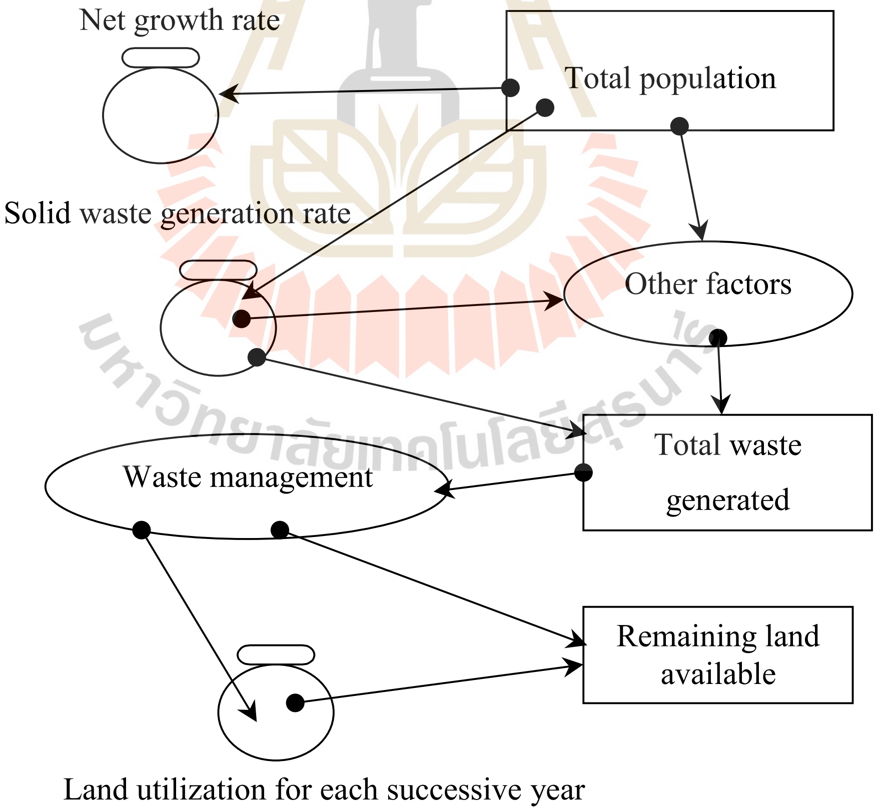


Figure 4.5 Schematic layout of casual loop diagram.

Case I: Current disposal method (open dumping with little recycling)

The results of the survey indicated that the total current population of Suranaree Military Camp was 12,812 with the waste generation rate of 0.48 kg/c/d. Net growth rate was calculated to be 3.41/1000/y or 0.0034 %. Very little recycling (5%) was observed in the area. The main waste disposal methods was found to be landfilling (dumping in the prepared area).

Currently, the total area available for waste disposal is 321,736.5 m^2. This is the area excluding buffer zone and it is specifically accounted for waste dumping. Figure 4.6 shows the schematic layout of the current practice.

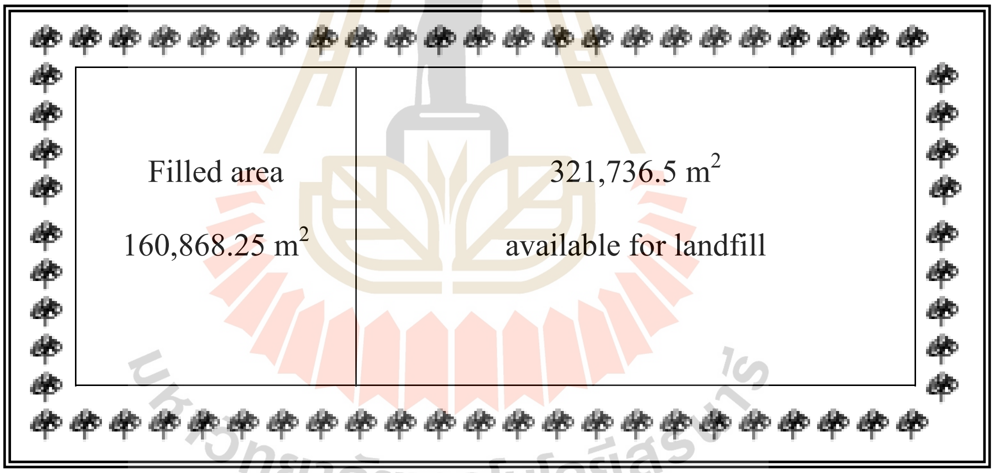


Figure 4.6 Schematic layout of Suranaree Military Camp's landfill area.

The simulation loop (Figure 4.7) shows the relationships between total population, net growth rate, the amount of solid waste generated, the total waste being disposed to the landfill, and the area available for landfilling. As the amount of waste generated increased with the total population, total waste disposed increased and so the remaining area available for waste disposal decreased simultaneously.

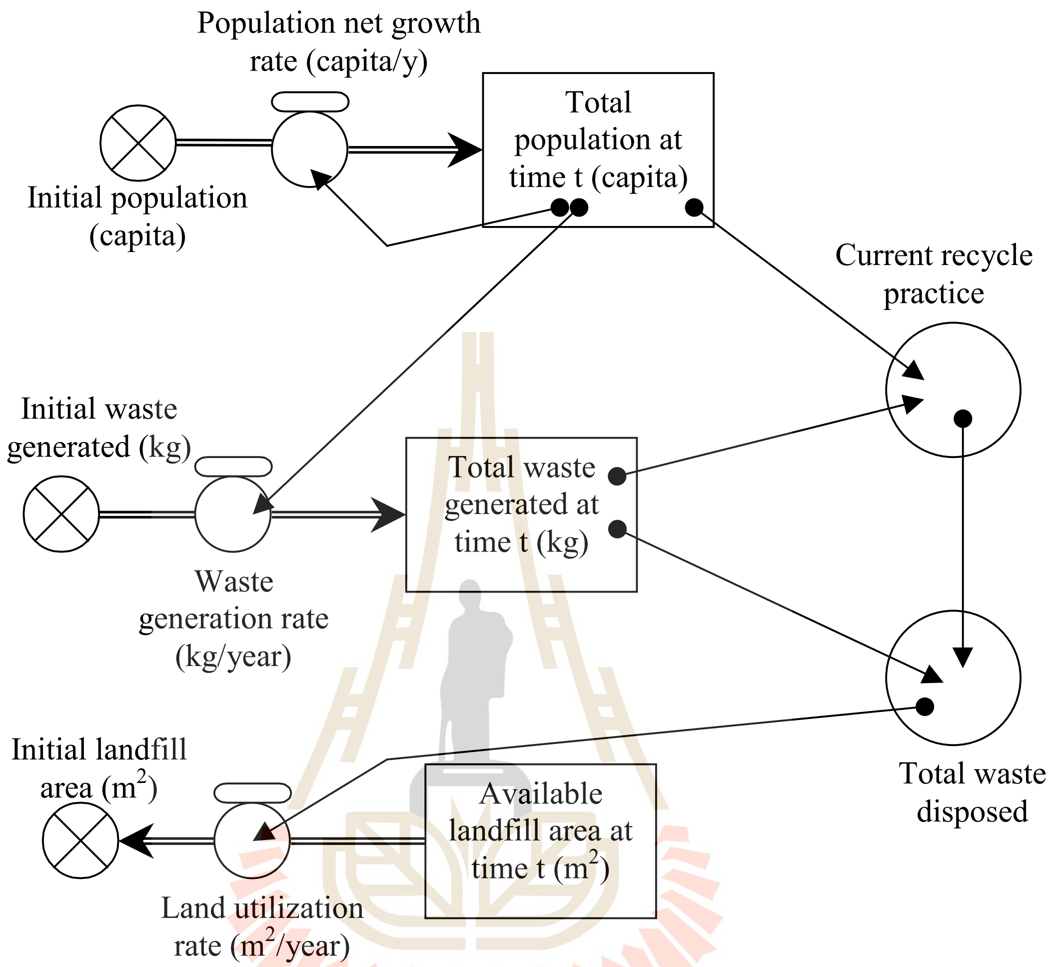


Figure 4.7 Schematic diagram for case I: Current situation; and case II: Increasing landfill efficiency through improved landfill technology.

The total population each year was calculated from the relationship between the current population and the net growth rate. The total waste generated was also calculated yearly according to the total new population each year, and waste generation rate of 0.48 kg/c/d. Total waste disposed was calculated by subtracting the total amount of waste recycled from the total waste generated. Finally, the land utilization for each successive year was calculated by using the following information:

a) solid waste density = 202.35 kg/m^3

b) degree of compaction = 1:20

c) depth of the landfill = 3 m

This information was obtained by the laboratory study and through interviewing the landfill workers. Table 4.7 shows the results of the simulation run and Figure 4.8 shows the area utilization for landfill application.

Table 4.7 Simulation results for case I.

Years		Total population (people)	Waste generated (kg)	Waste recycled (kg)	Total waste disposed (kg)	Available landfill area (m^2)
0	2002	12,812.0	6,149.8	674.9	5,474.8	321,736.50
1	2003	12,856.0	12,299.5	1,290.1	11,009.4	318,620.31
2	2004	12,900.0	18,470.4	1,907.4	16,563.0	312,347.46
3	2005	12,944.3	24,662.4	2,526.8	22,135.6	302,917.95
4	2006	12,988.7	30,875.7	3,148.4	27,727.3	290,291.31
5	2007	13,033.2	37,110.2	3,772.0	33,338.2	274,508.01
6	2008	13,077.9	43,366.2	4,397.8	38,968.4	255,527.58
7	2009	13,122.8	49,643.6	5,025.8	44,617.8	233,309.55
8	2010	13,167.8	55,942.5	5,655.9	50,286.7	207,894.39
9	2011	13,213.0	62,263.1	6,288.1	55,974.9	179,241.63
10	2012	13,258.3	68,605.3	6,922.6	61,682.7	147,391.74
11	2013	13,303.8	74,969.3	7,559.2	67,410.1	112,223.31
12	2014	13,349.4	81,355.1	8,198.0	73,157.1	73,817.28
13	2015	13,395.2	87,762.8	8,839.0	78,923.9	32,173.65
14	2016	13,441.1	94,192.5	9,482.2	84,710.4	-
15	2017	13,487.2	100,644.3	10,127.6	90,516.7	-

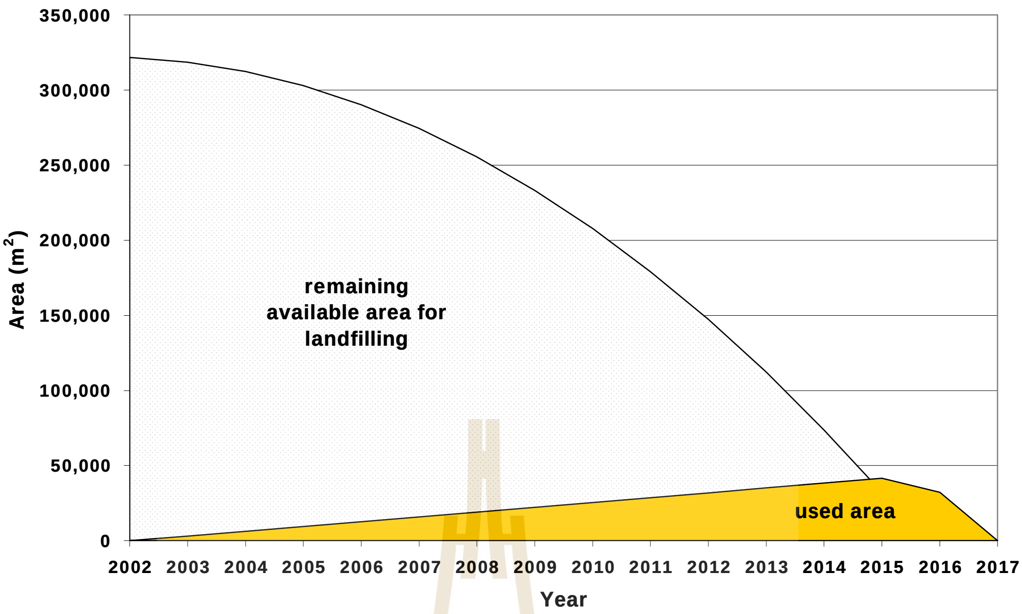


Figure 4.8 Land utilization for case I.

Case II: Increasing landfill efficiency through improved technology

Landfilling can be improved by increasing the degree of compaction and landfill depth. Degree of compaction could be increased up to 20 % and according to Table 2.5, the depth of the landfill could be increased up to 4 m (typical lift height including cover, 10 to 14 ft or 3.048 m to 4.2672 m). As the other conditions for case II are same as for case I, Figure 4.7 also shows simulation loop this case.

Currently, Suranaree Military Camp's landfill is an unsanitary landfill. Therefore, some adjustment is needed according to Table 2.5. Several designing factors for conventional landfill are, for example, installing drainage ditches to divert surface water runoff and landfill liner of clay about 2-4 ft. Each days waste should form one cell cover at the end of the day 6 in of earth or other suitable material. Installation of perimeter drains and wells point system or other control measures are also needed. Development of landfill gas management plan including extraction well, manifold collection system, condensate collection facilities, the vacuum blowers facilities; and or energy production facilities operating vacuum at well head 10 in of water are required. Determination of maximum leachate flow rate and size leachate collection pipe and/or trenches; size leachate pumping facilities; select collection pipe material to withstand static pressure corresponding to the maximum height of the landfill are very important. Also, the final cover is recommended to use multilayer design and slope should be 3-6 %.   The following figures show schematic layouts of the convention landfill trench method.

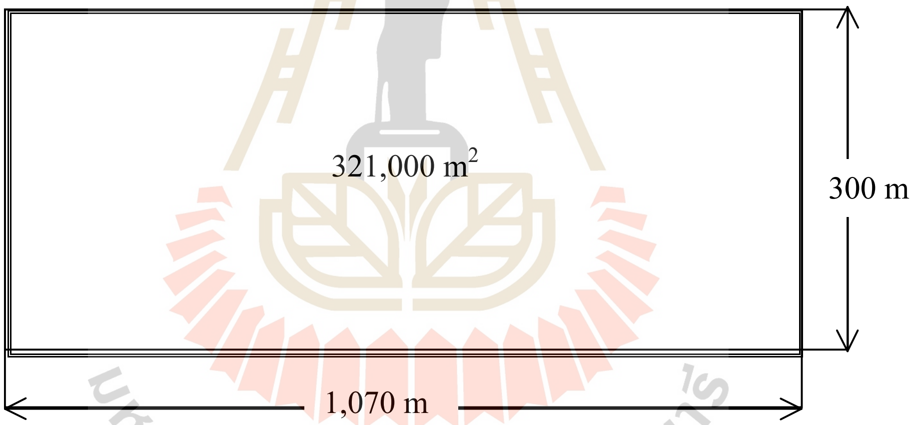


Figure 4.9 Schematic layouts of the convention landfill trench method (top view).

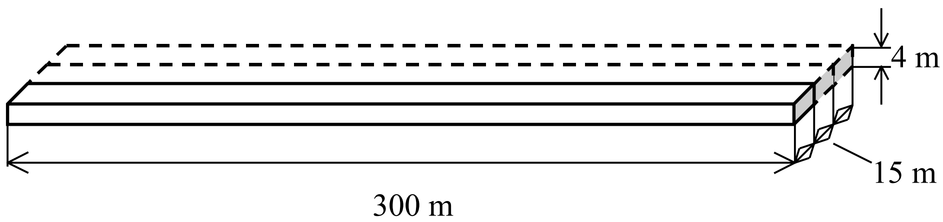


Figure 4.10 Schematic layout of each trench.

Each trench is 300 m × 15 m × 4 m (length × width × depth) and the total area for landfilling is 321,000 m^2. Recalculation from the case I study was accomplished using STELLA simulation for this strategy. Improvement in landfill process may increase remaining available area for disposal in each year. Table 4.8 shows the results of the simulation run and Figure 4.9 shows the area utilization for landfill application. With this landfill layout, almost 54 trenches will be filled at the end of year 2017.

Table 4.8 Simulation results for case II.

Years		Total population (people)	Waste generated (kg)	Waste recycled (kg)	Total waste disposed (kg)	Available landfill area (m^2)
0	2002	12,812.0	6,149.8	674.9	5,474.8	321,736.50
1	2003	12,856.0	12,299.5	1,290.1	11,009.4	319,753.47
2	2004	12,900.0	18,470.4	1,907.4	16,563.0	315,787.41
3	2005	12,944.3	24,662.4	2,526.8	22,135.6	309,838.32
4	2006	12,988.7	30,875.7	3,148.4	27,727.3	301,865.73
5	2007	13,033.2	37,110.2	3,772.0	33,338.2	291,910.11
6	2008	13,077.9	43,366.2	4,397.8	38,968.4	279,930.99
7	2009	13,122.8	49,643.6	5,025.8	44,617.8	265,887.90
8	2010	13,167.8	55,942.5	5,655.9	50,286.7	249,821.31
9	2011	13,213.0	62,263.1	6,288.1	55,974.9	231,731.22
10	2012	13,258.3	68,605.3	6,922.6	61,682.7	211,617.63
11	2013	13,303.8	74,969.3	7,559.2	67,410.1	189,399.60
12	2014	13,349.4	81,355.1	8,198.0	73,157.1	165,158.07
13	2015	13,395.2	87,762.8	8,839.0	78,923.9	138,852.57
14	2016	13,441.1	94,192.5	9,482.2	84,710.4	110,442.63
15	2017	13,487.2	100,644.3	10,127.6	90,516.7	79,968.72

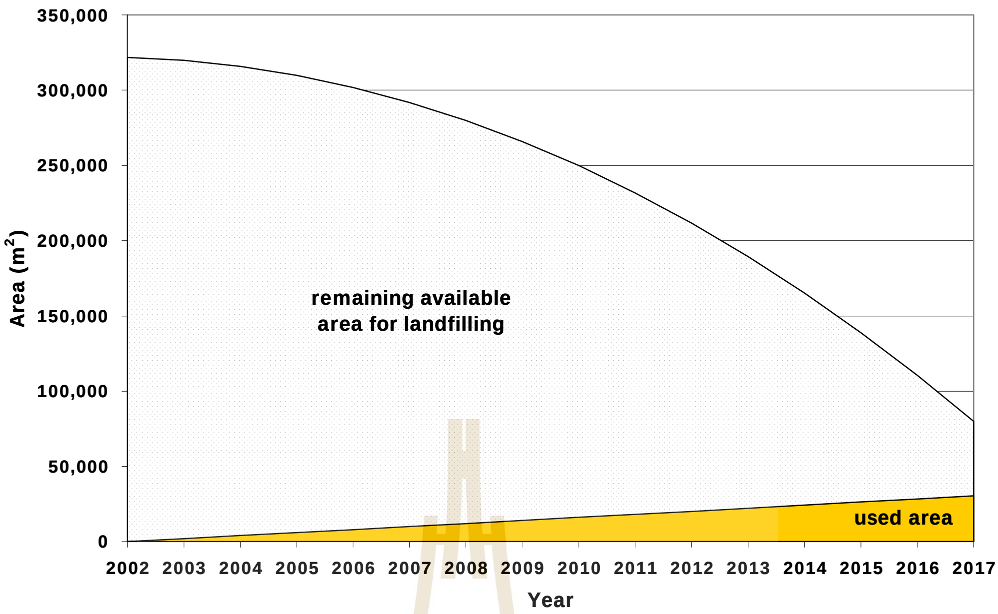


Figure 4.11 Land Utilization for case II.

Case III: Waste recycling promotion with landfilling

Currently, waste recycling at Suranaree Military Camp is very low, and so it is worth promoting. Generally, the potential of waste recycling is 30 % of the total waste (Nakhon Ratchasima Municipality, 1998). Table 4.9 shows the recycling potential of some waste components at SMC. From Table 4.9, the amount of recyclable waste seems to be up to 37.3 % of the total waste. The military are very determinant and effective in achieving their goals. Thus, if the military promote a recycling program within the camp and 70 % of the goal is accomplished, then waste recycled would be 26.1 % of the total waste generated at the camp prior to landfilling. However, the scavengers would still continue picking up some of the remaining recyclable waste components at the landfill site.

While applying the casual loop diagram for case III (Shown in Figure 4.12),

Table 4.9 Waste recycling potential at SMC.

Items	Average weight (%)	Recyclable weight (%)
Food waste and yard waste	61.0	-
Paper	17.1	17.1
Plastic	14.5	14.5
Rubber	0.3	0.3
Leather	0.2	-
Textiles	0.8	-
Wood	0.2	-
Metal	1.2	1.2
Glass	4.2	4.2
Hazardous waste	0.5	-
Stone and cement tiles	0.1	-
Others, i.e. bones	-	-
Total	100.0	37.3

the same conditions were applied as in case II for population, waste generation rate, and landfilling methods. Table 4.10 shows the simulation results of case.

Recycling program promotion could reduce the total amount of wastes being disposed each year in the landfill. Thus, the land utilization rate could be expected to be lower than before. This strategy can also gain benefits in resource recovery and reuse within each household. With case II landfill layout, almost 53.5 trenches will be filled at the end of year 2017.

After 15 years, the results between case II and III indicated only 1,335.51 m^2 difference in filled landfill area. The total waste disposed in the landfill for case II is

762,496.87 kg without recycle program and 758,595.56 kg for case III with recycle promotion. Only 3,901.3 kg different in total waste disposed into the landfill, which

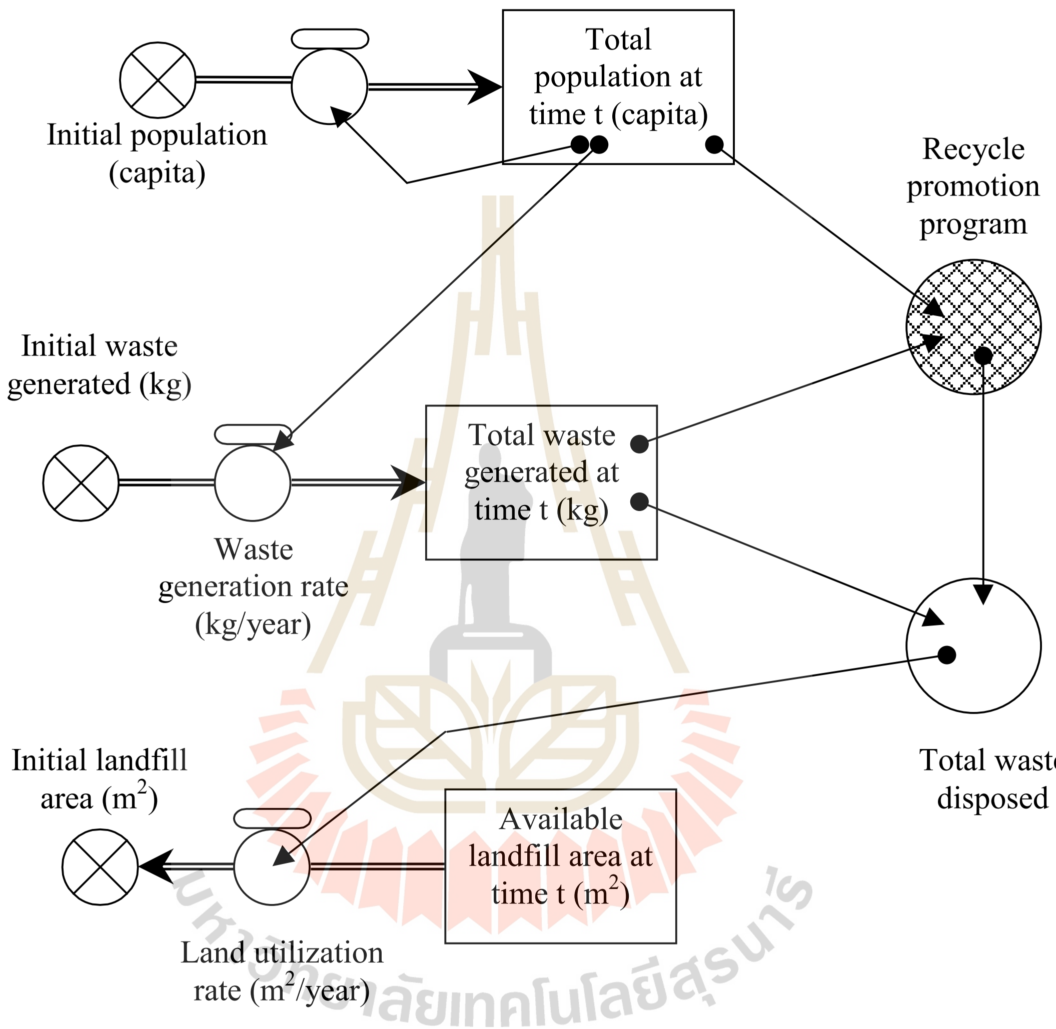


Figure 4.12 Schematic diagram for case III: waste recycling promotion.

can be concluded that having recycle promotion program can decrease very little land utilization. This conclusion also indicated that the military cannot gain much benefit from having a transfer station with recycle facility. Thus the recycle promotion program is a good option for individual household. With the help of the military, such as providing leaflet including knowledge and benefits of recycling.

Table 4.10 Simulation results for case III.

Years		Total population (people)	Waste generated (kg)	Waste recycled (kg)	total waste disposed (kg)	Available landfill area (m^2)
0	2002	12,812.0	6,149.8	674.9	5,474.8	321,736.50
1	2003	12,856.0	12,299.5	1,544.0	10,755.5	319,753.47
2	2004	12,900.0	18,470.4	2,162.2	16,308.2	315,908.82
3	2005	12,944.3	24,662.4	2,782.5	21,879.9	310,040.67
4	2006	12,988.7	30,875.7	3,404.9	27,470.8	302,149.02
5	2007	13,033.2	37,110.2	4,029.4	33,080.8	292,274.34
6	2008	13,077.9	43,366.2	4,656.1	38,710.1	280,376.16
7	2009	13,122.8	49,643.6	5,284.9	44,358.6	266,454.48
8	2010	13,167.8	55,942.5	5,915.9	50,026.6	250,468.83
9	2011	13,213.0	62,263.1	6,549.1	55,714.0	232,500.15
10	2012	13,258.3	68,605.3	7,184.4	61,420.9	212,427.03
11	2013	13,303.8	74,969.3	7,821.9	67,147.4	190,330.41
12	2014	13,349.4	81,355.1	8,461.6	72,893.5	166,169.82
13	2015	13,395.2	87,762.8	9,103.5	78,659.3	139,945.26
14	2016	13,441.1	94,192.5	9,747.6	84,444.9	111,656.73
15	2017	13,487.2	100,644.3	10,393.9	90,250.3	81,304.23

38.2:1. This C/N ratio is in fact, very suitable for composting process before landfilling. As recycling occurred before waste disposal, case II conditions were also applied for this simulation. Separation of organic fractions of the waste for composting could be done. Suranaree Military Camp's solid wastes contain the average of 60 % organic fraction, thus separation prior to disposal transport, can increase composting efficiency. Thus, a combined food waste, yard waste, and paper (78.1 % of the total waste) can be composted. Casual loop diagram and equation translation were applied as for case I, excluding landfill improvement and recycling program. The simulation loop for case IV is shown in Figure 4.13. This strategy added the value to waste management; they are profitable compost end products , and resource recovery. Table 4.11 show the STELLA simulation results for this strategy.

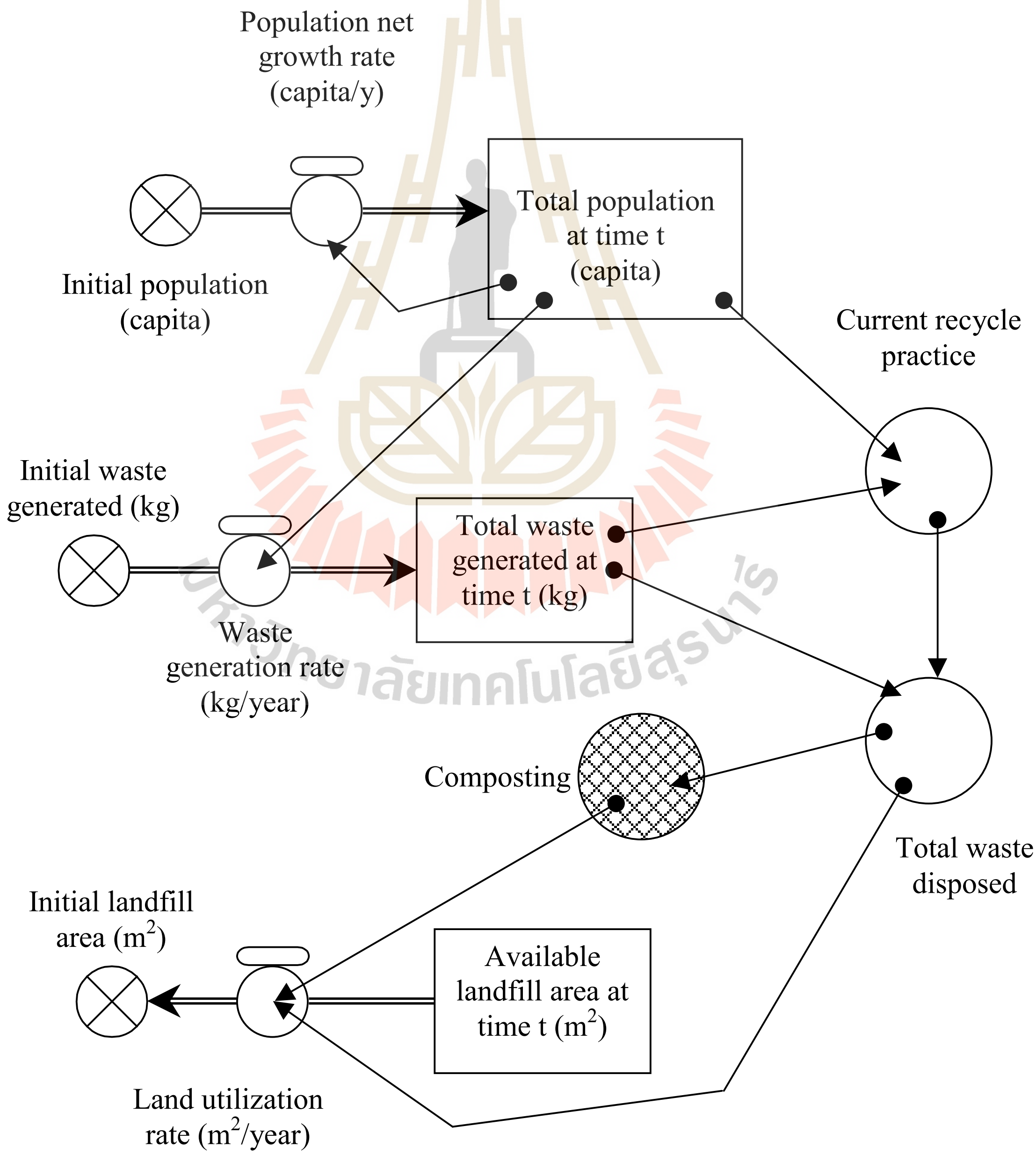


Figure 4.13 Schematic diagram for case IV: composting process.

Table 4.11 Simulation results for case IV.

Years		Total population (people)	waste generated (kg)	Waste recycled (kg)	Total waste disposed (kg)	Waste composted (kg)	Available landfill area (m^2)
0	2002	12,812.0	6,149.8	674.9	5,474.8	4,275.8	321,736.50
1	2003	12,856.0	12,299.5	1,290.1	11,009.4	8,598.3	321,169.92
2	2004	12,900.0	18,470.4	1,907.4	16,563.0	12,935.7	320,077.23
3	2005	12,944.3	24,662.4	2,526.8	22,135.6	17,287.9	318,377.49
4	2006	12,988.7	30,875.7	3,148.4	27,727.3	21,655.0	316,151.64
5	2007	13,033.2	37,110.2	3,772.0	33,338.2	26,037.1	313,318.74
6	2008	13,077.9	43,366.2	4,397.8	38,968.4	30,434.3	309,959.73
7	2009	13,122.8	49,643.6	5,025.8	44,617.8	34,846.5	305,993.67
8	2010	13,167.8	55,942.5	5,655.9	50,286.7	39,273.9	301,501.50
9	2011	13,213.0	62,263.1	6,288.1	55,974.9	43,716.4	296,402.28
10	2012	13,258.3	68,605.3	6,922.6	61,682.7	48,174.2	290,736.48
11	2013	13,303.8	74,969.3	7,559.2	67,410.1	52,647.3	284,463.63
12	2014	13,349.4	81,355.1	8,198.0	73,157.1	57,135.7	277,624.20
13	2015	13,395.2	87,762.8	8,839.0	78,923.9	61,639.5	270,218.19
14	2016	13,441.1	94,192.5	9,482.2	84,710.4	66,158.8	262,205.13
15	2017	13,487.2	100,644.3	10,127.6	90,516.7	70,693.6	253,625.49

At the end of year 2017, there would be 253,625.5 m^2 remaining empty. The remaining available are could be used for composting. With the same landfill layout from case II and the total area used for landfill is 68,111.01 m^2, 16 trenches would be used and thus the remaining area for composting process is 248,000 m^2 as shown in Figure 4.14.

The maximum waste to be composted would be in year 2017 and the waste load was calculated to be 193.7 kg/d. Windrow composting with mechanical mixing and turning could be used as shown in Figure 4.15. The period required for compost

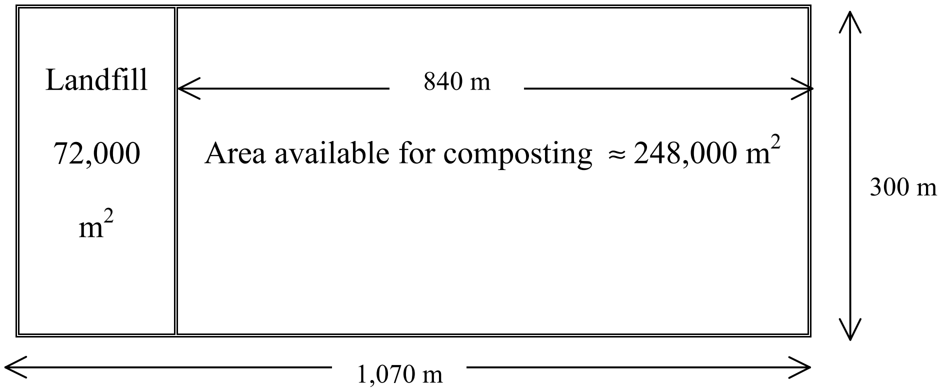


Figure 4.14 Schematic layouts of the available area for case III.

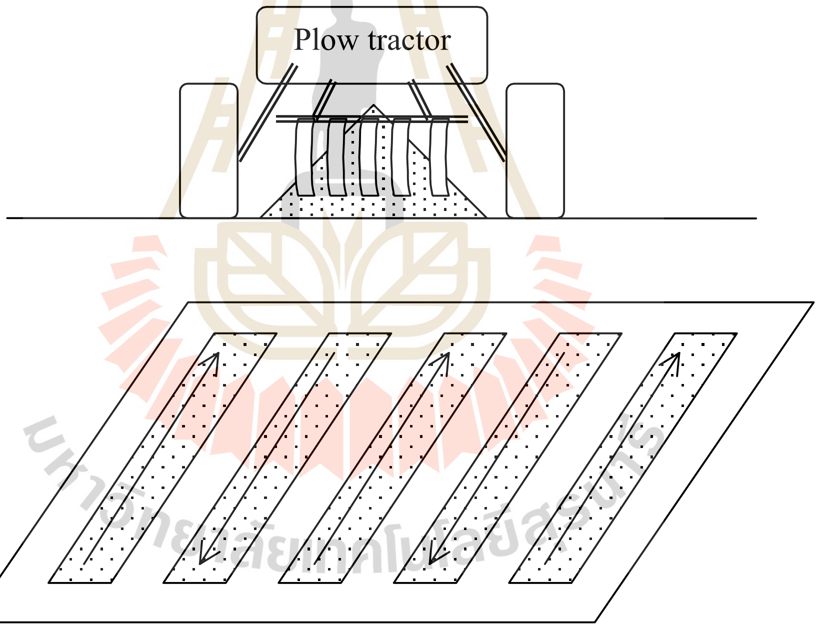


Figure 4.15 Open windrow composting.

stabilization varies according to the frequency of pile turning, being 20-40 days, and temperature over 65 °C in the center of the compost pile can be reached (Polprasert, 1996).

Figure 4.16 shows schematic layout of windrow dimension for a mixture of composting materials. Adding some nitrogen rich material can be applied to decrease C/N ratio from 38.2:1 to be between 25-30:1. Several rows of 15 × 3 × 1.5 m (length × width × height) composting piles could be accomplished. The area required for 15 rows with 3 m-width roads around and between rows would be 1,683 m^2. Small area could be use for facilities, for example, equipment storage area, waste shreding area and harvested storage area. Figure 4.17 show a possible design for land utilization for case IV.

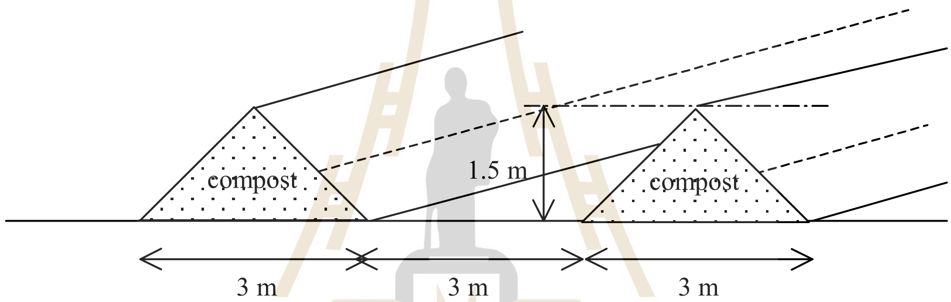


Figure 4.16 Schematic layout of windrow dimension for a mixture of composting materials.

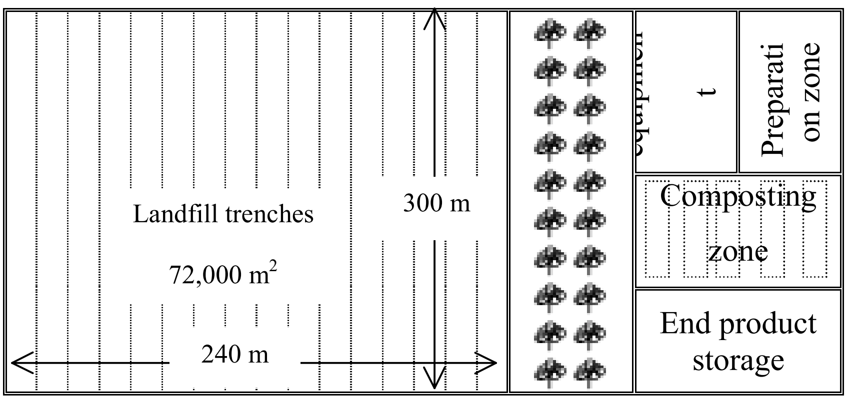


Figure 4.17 Schematic layout of conventional landfill with composting zone.

Case V: Incineration followed by landfilling of residual ash

The volume reduction of waste for the land utilization optimization is always of a great interest. Therefore, incineration is a good disposal option for volume reduction. At the SMC, the calorific value of waste collected was found to be 4,232.8 kcal/kg (DSCV) or 1215.4. kcal/kg (LSCV). LSCV higher than 1,000 cal/g is recommended to be good for incineration (Padungsirikul, 1994). The average waste reduction through incineration at Suranaree Military Camp was calculated to be 66.1 % of the total waste disposed as shown in Table 4.12.

Table 4.12 Waste reduction through incineration.

Items	Average weight (%)	Remaining weight (%)[a]	Reduction (%)
Food waste and yard waste	61.0	5.0	95.0
Paper	17.1	6.0	94.0
Plastic	14.5	10.0	90.0
Rubber	0.3	10.0	90.0
Leather	0.2	10.0	90.0
Textiles	0.8	2.5	97.5
Wood	0.2	1.5	98.5
Metal	1.2	90.5	9.5
Glass	4.2	98.9	1.1
Hazardous waste	0.5	100.0	-
Stone and cement tiles	0.1	5.0	95.0
Others, i.e. bones	-	68.0	32.0
Average percent reduction			66.1

[a] Based on the typical data of waste incineration (Tchobanoglous, 1993)

For the simulation study of this option, casual loop diagram and equation translation were applied as for case I, excluding landfill improvement and recycling program. Figure 4.18 shows casual loop diagram for case V.

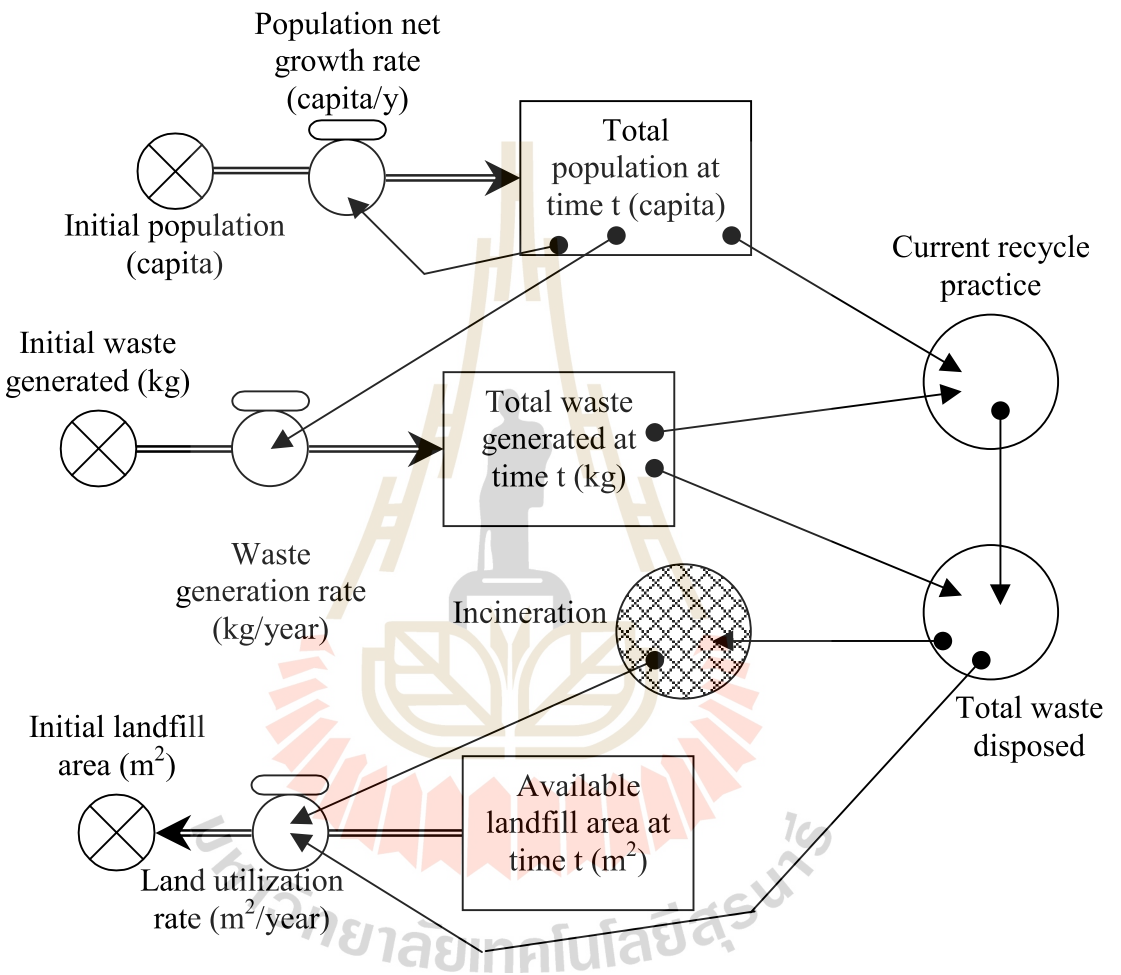


Figure 4.18 Schematic diagram for case V: incineration.

Table 4.13 shows the simulation results for case V. The results indicated that 60,193.6 kg of waste in year 2017 would be incinnerated, and a week load was calculated to be 1,154.4 kg/wk or 164.91 kg/d. The total waste disposed to landfill for 15 years which would be hazardous wastes was calculated to be 762,496.9 kg, and the area required for secured landfill would be 114,853.86 m^2. Thus, 26 trenches are required and it is calculated to be 117,000 m^2.

Table 4.13 Simulation results for case V.

Years		Total population (people)	waste generated (kg)	Waste recycled (kg)	Total waste disposed (kg)	Waste incinerated (kg)	Available landfill area (m^2)
0	2002	12,812.0	6,149.8	674.9	5,474.8	3,640.8	321,736.50
1	2003	12,856.0	12,299.5	1,290.1	11,009.4	7,321.3	320,805.69
2	2004	12,900.0	18,470.4	1,907.4	16,563.0	11,014.4	318,903.60
3	2005	12,944.3	24,662.4	2,526.8	22,135.6	14,720.2	316,070.70
4	2006	12,988.7	30,875.7	3,148.4	27,727.3	18,438.7	312,306.99
5	2007	13,033.2	37,110.2	3,772.0	33,338.2	22,169.9	307,572.00
6	2008	13,077.9	43,366.2	4,397.8	38,968.4	25,914.0	301,865.73
7	2009	13,122.8	49,643.6	5,025.8	44,617.8	29,670.9	295,228.65
8	2010	13,167.8	55,942.5	5,655.9	50,286.7	33,440.6	287,579.82
9	2011	13,213.0	62,263.1	6,288.1	55,974.9	37,223.3	279,000.18
10	2012	13,258.3	68,605.3	6,922.6	61,682.7	41,019.0	269,408.79
11	2013	13,303.8	74,969.3	7,559.2	67,410.1	44,827.7	258,886.59
12	2014	13,349.4	81,355.1	8,198.0	73,157.1	48,649.5	247,352.64
13	2015	13,395.2	87,762.8	8,839.0	78,923.9	52,484.4	234,847.41
14	2016	13,441.1	94,192.5	9,482.2	84,710.4	56,332.4	221,370.90
15	2017	13,487.2	100,644.3	10,127.6	90,516.7	60,193.6	206,882.64

The remaining ash also required landfilling as a final disposal method. Table 4.14 shows the remaining ash for each year. The total ash dispose to landfill would be 54,984.6 kg. Specific weight of ash is 1,255 lb/yd^3 or 744.5915 kg/m^3 (Tchobanoglous, 1993). The total volume of ash disposed is calculated to 73.8 m^3. Thus the area required for ash disposal is 24.6 m^2, which require only 0.5 % of a single trench. Therefore, the total waste to be disposed in the landfill was calculated to be 115,178.2 kg and the area required for the remaining waste would be 4,668.85 m^2 after 15 years. This complied 26 trenches and would cover the area of 117,000 m^2. The calculation indicated that there is plenty area remaining for incineration. Thus, it is not necessary for monofills type landfill for ash. The secured landfill could be used for both hazardous waste and ash. Figure 4.19 shows the area available for case V.

Table 4.14 The remaining ash (kilograms).

Year	Waste type				
	Food waste and yard waste	Paper	Plastic	Rubber	Leather
-	111.0	37.4	52.8	1.1	0.7
1	223.3	75.1	106.2	2.2	1.5
2	335.9	113.0	159.7	3.3	2.2
3	449.0	151.0	213.4	4.4	2.9
4	562.4	189.2	267.4	5.5	3.7
5	676.2	227.5	321.5	6.7	4.4
6	790.4	265.9	375.8	7.8	5.2
7	905.0	304.4	430.2	8.9	5.9
8	1,019.9	343.1	484.9	10.0	6.7
9	1,135.3	381.9	539.7	11.2	7.4
10	1,251.1	420.9	594.8	12.3	8.2
11	1,367.2	459.9	650.0	13.4	9.0
12	1,483.8	499.1	705.4	14.6	9.7
13	1,600.8	538.5	761.0	15.7	10.5
14	1,718.1	578.0	816.8	16.9	11.3
15	1,835.9	617.6	872.8	18.1	12.0

Table 4.14 The remaining ash (kilograms). (continued)

Year	Waste type				
	Textiles	Wood	Metal	Glass	Stone and cement tiles
-	0.7	0.1	39.5	151.2	0.2
1	1.5	0.2	79.5	304.1	0.4
2	2.2	0.3	119.6	457.5	0.6
3	2.9	0.4	159.9	611.4	0.7
4	3.7	0.6	200.2	765.9	0.9
5	4.4	0.7	240.8	920.9	1.1
6	5.2	0.8	281.4	1,076.4	1.3
7	5.9	0.9	322.2	1,232.5	1.5
8	6.7	1.0	363.2	1,389.1	1.7
9	7.4	1.1	404.2	1,546.2	1.9
10	8.2	1.2	445.5	1,703.8	2.1
11	9.0	1.3	486.8	1,862.1	2.2
12	9.7	1.5	528.3	2,020.8	2.4
13	10.5	1.6	570.0	2,180.1	2.6
14	11.3	1.7	611.8	2,339.9	2.8
15	12.0	1.8	653.7	2,500.3	3.0

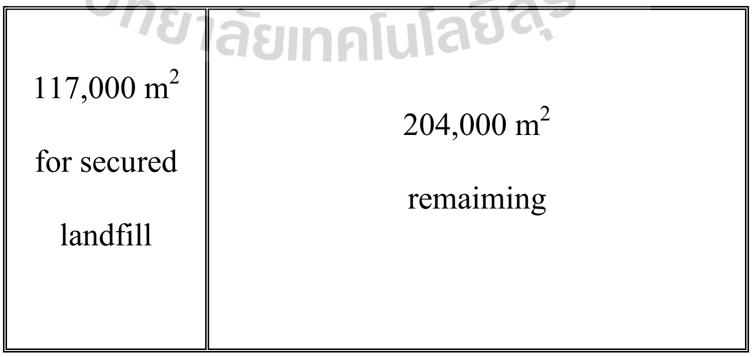


Figure 4.19 Area available for case V.

According to the guideline in Appendix F, “How to Choose an Incinerator” by WEBSE Technology, wastes to be incinerated are type 1 and type 2 classification. The moisture content of this waste is 54.19 % with 5.95 % non-combustible and it gives 7,621 Btu/lb.

Several options could be accomplished for incinerator design with 7 hours daily burning time; they are:

1) burning wastes once a week:

Density of waste is 202.35 kg/m^3 (12.62 lbs./ft^3) and the amount of waste to be burnt weekly is 1,154.4 kg/week (2,544.97 lbs./week) or 5.7 m^3/week (7.5 yd^3/day). With daily burning time of 7 hours, the incinerator capacity is estimated to be 164.92 kg/hr (363.57 lbs./hr).

2) burning wastes as collected (every other day):

The amount of waste to be burnt every other day is 329.82 kg/ 2 days (727.12 lbs./ 2days) or 1.6 m^3/week (57.62 yd^3/ 2 days). With 7 hour burning time, the incinerator capacity is 47.12 kg/hr (103.87 lbs./hr). The volume of waste would be 0.24 m^3/hr or 8.24 ft^3/hr.

3) burning wastes daily:

Density of waste is 202.35 kg/m^3 (12.62 lbs./ft^3) and the amount of waste to be burnt weekly is 1,154.4 kg/week (2,544.97 lbs./week) or 5.7 m^3/week (7.5 yd^3/day). With daily burning time of 7 hours, the weekly burning time is calculated to be 35 hours/week. The incinerator capacity is estimated to be 33 kg/hr (7.3 lbs./hr). The volume of waste would be 0.17 m^3/hr or 0.58 ft^3/hr.

Waste being burnt could be dried while piling on ground prior to incineration. The required drying zone would be estimated according to incinerator operating option. The drying zone would require liner to prevent contamination and drainage systems for liquid collection installation. The maximum area for drying zone 11.41 m^2 with the depth of 0.5 m. This storage/drying zone can reduced some moisture from solid waste. Care must be taken according to smell and pests contamination. Waste are assumed to be dried, thus, they are combustible and contains less than 10 % by weight of plastic, then, installation of main ignition burner is and option. If the incinerator is fist ignited from cold daily and closed-down at night, then the after-burner is highly recommended. According to Appendix F, types of incinerator could be:

- Class I: portable, packaged, completely assembled, direct fed incinerators, having not over 5 ft^3 storage capacity, or 25 lbs./hour burning rate, suitable for type 2 waste.

- Class IA: portable, packaged or job assembled, direct fed incinerators 5 ft^3 to 15 ft^3 primary chamber volume; or a burning rate of 25 lbs./hr up to, but not including 2 ft^2 burning area, suitable for type 2 waste; or a burning rate of 25 lbs./hr of 25 lbs/hour up to, but not including, 75 lbs./hr of type 3 waste.

- Class III: a direct fed incinerator with a burning rate of 100 lbs./hr and over and it is suitable for type 1 or type 2 waste.

Selection of thermal processing system is a complex and expensive undertaking. Most system are built on some form of a "turnkey" contract, where a single contractor assumes complete responsibility for design and construction of the system. Alternatively, some systems are built under a full service contract, where the contractor designs, builds and operates the system for a fixed number of years (Tchobanoglous, 1993). The size of the incinerator is depended on the type of the incinerator, its performance and efficiency. The complete setup includes flue gas treatment system. The amount of flue gas emission and its rate depend on the efficiency of the incinerator. Thus, the design of an incinerator would also required experimental examination. In such case, approximate design for the area utilization could be estimated and it is shown in Figure 4.20.

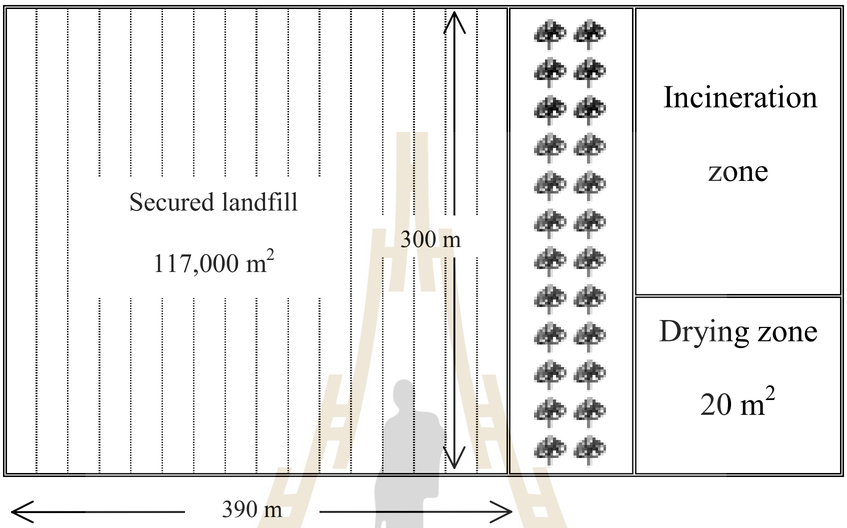


Figure 4.20 Case V area utilization.

4.6 Case Studies Discussion

The area available for landfilling at the end of each year represents the benefit of the applied waste management option and strategy. The increasing trend in land utilized for landfilling each year indicated increase in waste generated. This could be mostly due to the increasing population. In all cases, the net growth rate in population was taken to be constant.

Moreover, Suranaree Military Camp is profitable from allowing Nakhon Ratchasima Municipality to use some of the land for landfiling. The existing wastewater treatment unit could be used for the complete management system. Waste water from both landfills could be joined and treated prior to discharge.

The relationships between the land area utilized and the remaining area available for landfilling, and time, over a period of 15 years (2002-2017) for all 5 cases are shown in Figures 4.21 and 4.22, respectively. The simulation results (Figure 4.21) showed that, for case I, there would be no land available for landfilling in the year 2017. With increasing landfill efficiency as in Case II, the land available in year 2017 could be 19.8 acres. If waste recycling is applied within the camp, the land available in the year 2017 could be 20.1 acres. Using composting as an integrated waste management option at the camp, there will be 62.7 acres left in year 2017. Finally, if incineration is used as the main disposal method, 51.1 acres would be still available for waste landfilling in 2017. This results were obtained by using the landfill trenches depth of 3 m for case IV and V.

The results of the simulations indicated that the most beneficial disposal method at Suranaree Military Camp could be composting of organic fractions and landfilling of the remaining wastes. The amount of waste to be disposed in the landfill could be reduced substantially by utilizing composting, and thus, the land available left for landfilling would be the maximum for this case. However this conclusion is valid only if there was waste separation prior to landfilling. Waste separation could be the most beneficial because food waste and yard waste were the largest fractions of the solid wastes generated at Suranaree Military Camp. In addition, composting process can also be profitable in terms of gaining soil conditioner and fertilizers, as the end products of the waste stabilization.

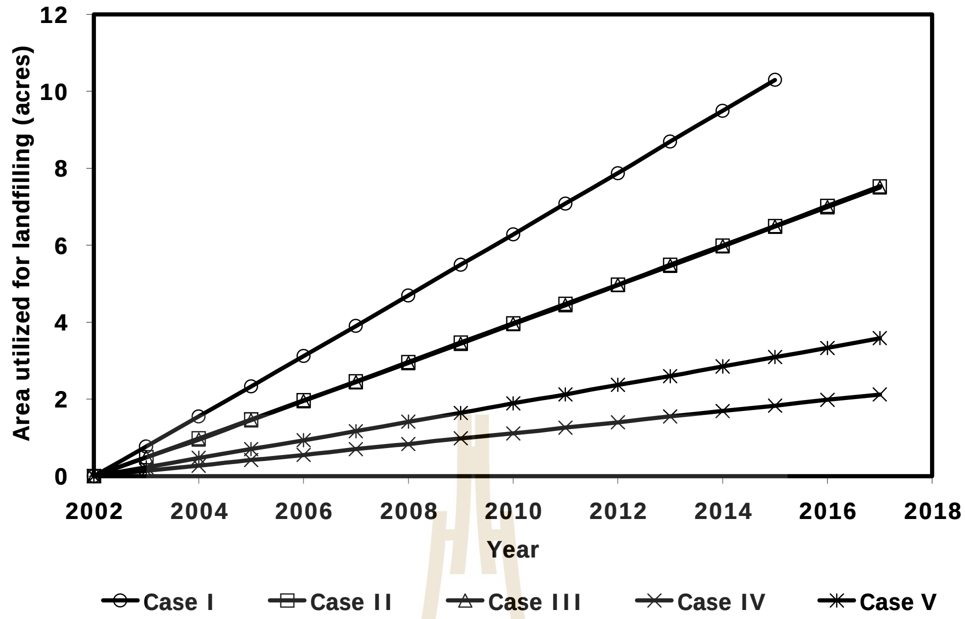


Figure 4.21 The relationship between landfill utilization and time for all strategies.

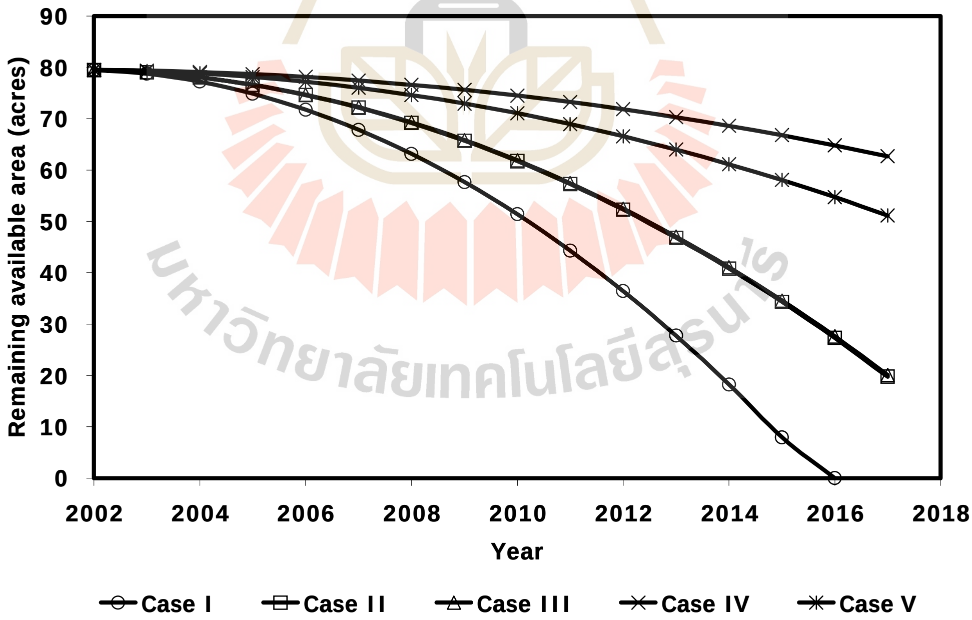


Figure 4.22 The relationship between available area and time for all strategies.

It should be also be taken into account that, incineration is the most expensive process when comparing it with all other possible options. However, the large volume reduction through incineration is still beneficial. Moreover, difficulties of waste separation and recycling program could be avoided. Thus, if there are no waste separation and waste recycling, incineration could be the best disposal option available for the military to manage their wastes at Suranaree Military Camp. However, if the military is not in such urgent need of land, a high cost process is not appropriate for their waste management. Thus, considering the current land available at the military camp, incineration may not be the best option due to the cost of incinerator construction.

Waste recycling can also reduce some amount of waste to be disposed and landfilling improvement can reduce land utilization rate. Combining two methods can also mitigate solid waste problem in Suranaree Military Camp. Thus, if both options were practiced along with either composting or incineration, the higher reduction of waste to be disposed in landfill would certainly be accomplished.

Chapter V

Conclusions and Recommendations

5.1 Conclusions

The total number of questionnaires given out in Suranaree Military Camp for this study was 17 for main divisions offices, 80 for commissioned offices'households, and 100 for non-commissioned offices'households. The results indicated low awareness about solid waste management and lower knowledge on waste recycle.

The net population growth rate was calculated to be 0.00343 %, and the current population of the camp was estimated to be 12,812. Waste generation rate in the military camp was estimated to be 0.48 kg/c/d. The actual amount of wastes disposed at the landfill site were found to be 0.41 kg/c/d.

Waste composition, as collected, included the following: food waste, yard waste, paper, plastic, rubber, leather, textiles, wood, metal, glass, hazardous waste, stone and cement tiles, and others. The highest component was found to be combined food waste and yard waste, which was 60.96 %.

The average bulk density of solid waste at Suranaree Military Camp was determined to be 202.4 kg/m^3. The chemical composition included 54.2%, 45.8%, 75.6%, 24.3%, 42.0%, 4.7%, and 1.1 % for moisture content, total solids, volatile solids, ash, organic carbon, hydrogen, and nitrogen, respectively. Phosphorus was found to be 167.7 ppm, dry solid calorific value (DSCV) was 4,232.8 kcal/kg, and C/N ratio as 38.2:1.

Recycling is not practiced in the area. An average of 5 % of the total waste are recycled by the residents and 10 % by the scavengers around the landfill area.

The five strategy options for simulation studies included: case I: current disposal method, case II: increasing landfill efficiency through improved landfill technology, case III: waste recycling promotion with landfilling, case IV: composting process with landfilling of inorganic waste, and case V: incineration followed by landfilling of residual ash.

Based on the results of this study it could be concluded that, Suranaree Military Camp needs improvement of their landfill methodology, and the best disposal method could be composting of the organic fractions and landfilling of the remaining wastes. This is due the high fraction of food waste and yard waste generated in the camp.

5.2 Recommendations

At present, there is no proper procedure for hazardous waste handling in the Suranaree Military Camp. So, this type of waste is also dumped in the existing landfill. If proper strategy is applied, the Military would have plenty of land available. A small area can be used as secured landfill for hazardous waste. Moreover, the available land can also be used to handle Nakhon Ratchasima Municipality solid waste.

Solid waste management in Suranaree Military Camp is needed to be improved, more strategies should be studied. The combinations of various cases can also be investigated. Moreover, as the cost effective management is an important factor, so design and cost estimation are also of great interest.

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Appendix A

Questionnaires

Questionnaire for Offices

1. Name (ชื่อ):...

2. How many members are in this office?……………………………….……

□□□□ □□□□□□□□ □□ □ □□□□□□ □□□□□□□□□ □

total… … … … … male… … … … … female… … … … … children…………….

ทั้งหมด ชาย หญิง เด็ก

3. How much waste do you generate?…………………………………………………

ปริมาณขยะที่ท่านทิ้งในแต่ละวัน (กก./คน/วัน)

4. What types of waste that your office generate?……………………………………..

ขยะที่ทิ้งเป็นประเภทใดบ้าง

5. How do they feel about waste management in Suranaree Military Camp?

ท่านมีความรู้สึกอย่างไรกับการจัดการขยะในค่ายสุรนารี

☐ Satisfied (พอใจ) ☐ Unsatisfied (ไม่พอใจ)

Opinion (□□ □□ □ □□)

…...…………………………………………………………………

6. Do you know about solid waste management?

ท่านมีความรู้ในเรื่องการจัดการขยะหรือไม่

☐ Yes (มี) ☐ No (ไม่มี)

☐ landfill ☐ incinerator

การฝังกลบ การเผา

☐ composting ☐ others……………………………………………...

การหมัก อื่น ๆ

7. Do you practice recycle in your office?

ในบ้านของท่าน มีการรีไซเคิลขยะหรือไม่

☐ Yes (มี) ☐ No (ไม่มี)

8. How much waste (%) do you recycle?……………………………………………..

ปริมาณขยะที่ท่านรีไซเคิล (ร้อยละ)

Questionnaires for residential area

1. Name (ชื่อ):……………………………………………………………………….

2. How many family members are staying in this house?…………………………….……

มีจำนวนสมาชิกกี่คนอาศัยอยู่ในบ้านของท่าน

total…………… male…………… female…………… children…………….

ทั้งหมด ชาย หญิง เด็ก

3. How much waste do you generate?……………………………………………………

ปริมาณขยะที่ท่านทิ้งในแต่ละวัน (กก./คน/วัน)

4. What types of waste in your house generate?……………………………………….

ขยะที่ทิ้งเป็นประเภทใดบ้าง

5. How do they feel about waste management in Suranaree Military Camp?

ท่านมีความรู้สึกอย่างไรกับการจัดการขยะในค่ายสุรนารี

☐ Satisfied (พอใจ) ☐ Unsatisfied (ไม่พอใจ)

Opinion (□□ □□ □ □□)

…...……………………………………………………………………

6. Do you know about solid waste management?

ท่านมีความรู้ในเรื่องการจัดการขยะหรือไม่

☐ Yes (มี) ☐ No (ไม่มี)

☐ landfill ☐ incinerator

การฝังกลบ การเผา

☐ composting ☐ others……………………………………….....

การหมัก อื่น ๆ

7. Do you practice recycle in your household?

ในบ้านของท่าน มีการรีไซเคิลขยะหรือไม่

☐ Yes (มี) ☐ No (ไม่มี)

8. How much waste (%) do you recycle?……………………………………………....

ปริมาณขยะที่ท่านรีไซเคิล (ร้อยละ)

Appendix B

Waste Components' Definitions

.Table C.1 Samples' bulk density (kg/m^3).

sample	Week # 1									
	Offices		Residences							
	weekday		CO Weekday		CO Weekend		NCO weekday		NCO weekend	
1	52	51	224	256	243	255	200	244	224	228
2	57	54	218	257	237	253	245	265	230	234
3	56	62	227	258	244	250	237	225	217	255
4	58	57	218	225	247	229	246	216	235	217
5	54	59	230	224	240	251	215	233	220	241
6	75	61	215		255		204	241	227	209
7	63		218		242		209		225	
8			223							
AVG	59.3	57.3	221.6	244.0	244.0	247.6	222.3	237.3	225.4	230.7
STDV	7.7	4.2	5.2	17.8	5.8	10.6	19.8	17.0	6.0	16.6
RSD	13.1	7.4	2.3	7.3	2.4	4.3	8.9	7.2	2.7	7.2
Week # 2										
1	70	78	213	238	216	216	222	255	244	254
2	54	69	215	235	220	255	257	287	215	245
3	68	74	266	229	209	274	264	234	268	254
4	75	76	246	245	213	238	258	265	265	248
5	77	79	259	266	206	254	235	258	248	254
6	78	65	247	244		237	236	245	214	248
7		64	265	222			268	247	254	265
8			245				248	255	268	
9	70.3	72.1	244.5	239.9	212.8	245.7	248.5	255.8	247.0	252.6
10	8.9	6.1	20.6	14.1	5.5	19.9	16.1	15.7	22.0	6.6
AVG	12.7	8.5	8.4	5.9	2.6	8.1	6.5	6.2	8.9	2.6
STDV	1.5	1.0	4.7	4.3	3.5	6.2	7.5	16.7	8.5	3.7
RSD	2.8	1.7	2.7	1.9	1.7	3.1	4.2	8.6	4.8	2.0

Table C.1 Samples' bulk density (kg/m^3). (continued)

sample	Week # 3									
	Offices		Residences							
	weekday		CO: weekday		CO: weekend		NCO: weekday		NCO: weekend	
1	77	79	215	248	245	248	221	245	224	214
2	76	81	215	287	213	257	232	213	223	217
3	78	87	245	258	227	224	212	211	217	216
4	69	75	264	254	213	226	201	202	218	228
5	77	79	254	224	224	213	204	215	208	234
6	79	65	214	278	221	246	255	256		217
7				249		235	201	234		228
8								258		
AVG	76.0	77.7	234.5	256.9	223.8	235.6	218.0	229.3	218.0	222.0
STDV	3.6	7.3	22.5	20.8	11.8	15.6	19.9	21.9	6.4	7.8
RSD	4.7	9.4	9.6	8.1	5.3	6.6	9.1	9.6	2.9	3.5

Table C.2 Waste samples' composition for offices area during weekdays.

Components	Week # 1				week # 2				week # 3			
	sample 1		sample 2		sample 1		sample 2		sample 1		sample 2	
	Weight (kg)	%	Weight (kg)	%	Weight (kg)	%	Weight (kg)	%	Weight (kg)	%	Weight (kg)	%
Food and yard waste	2.21	62.08	3.34	61.15	2.61	52.25	2.55	51.36	1.90	44.50	2.10	46.05
Paper	1.15	32.30	1.40	25.65	1.50	30.03	1.30	26.18	1.20	28.10	1.40	30.70
Plastic	0.20	5.62	0.40	7.33	0.50	10.01	0.80	16.11	1.00	23.42	0.90	19.74
Rubber	-	-	-	-	-	-	0.04	0.70	0.02	0.47	-	-
Leather	-	-	-	-	0.01	0.20	0.02	0.40	0.02	0.47	0.01	0.22
Textile	-	-	-	-	0.06	1.20	-	-	-	-	-	-
Wood	-	-	-	-	0.08	1.50	-	-	-	-	-	-
Metal	-	-	0.17	3.11	0.05	1.00	0.16	3.22	0.10	2.34	-	-
Glass	-	-	0.10	1.83	0.14	2.80	0.10	2.01	-	-	0.10	2.19
Hazardous	-	-	0.05	0.92	0.05	1.00	-	-	0.03	0.70	0.04	0.88
Stone	-	-	-	-	-	-	-	-	-	-	0.01	0.22
Other	-	-	-	-	-	-	-	-	-	-	-	-
TOTAL	3.56	100.00	5.46	100.00	5.00	100.00	4.97	100.00	4.27	100.00	4.56	100.00

Table C.3 Waste samples' composition for commissioned officers' residential area during weekdays.

Components	Week # 1				week # 2				week # 3			
	sample 1		sample 2		sample 1		sample 2		sample 1		sample 2	
	Weight (kg)	%	Weight (kg)	%	Weight (kg)	%	Weight (kg)	%	Weight (kg)	%	Weight (kg)	%
Food and yard waste	15.10	68.48	13.20	65.35	10.70	62.65	13.80	63.68	9.50	60.66	9.10	63.41
Paper	1.30	5.90	1.10	5.45	1.60	9.37	2.30	10.61	1.80	11.49	1.70	11.85
Plastic	4.20	19.05	2.40	11.88	2.50	14.64	2.70	12.46	2.30	14.69	2.10	14.63
Rubber	-	-	-	-	-	-	-	-	-	-	-	-
Leather	-	-	-	-	-	-	-	-	-	-	-	-
Textile	0.05	0.23	-	-	0.35	2.05	0.41	1.89	0.25	1.60	0.30	2.09
Wood	-	-	-	-	-	-	0.30	1.38	-	-	-	-
Metal	-	-	0.20	0.99	0.23	1.35	0.17	0.78	-	-	-	-
Glass	1.00	4.54	3.00	14.85	1.70	9.95	1.40	6.46	1.20	7.66	1.12	7.80
Hazardous	0.35	1.59	0.06	0.30	-	-	0.50	2.31	0.44	2.81	-	-
Stone	-	-	0.20	0.99	-	-	0.08	0.37	0.07	0.45	-	-
Other	0.05	0.23	0.04	0.20	-	-	0.01	0.06	0.10	0.64	0.03	0.21
TOTAL	22.05	100.00	20.20	100.00	17.08	100.00	21.67	100.00	15.66	100.00	14.35	100.00

Table C.4 Waste samples' composition for non-commissioned officers' residential area during weekdays.

Components	week # 1				week # 2				week # 3			
	sample 1		sample 2		sample 1		sample 2		sample 1		sample 2	
	Weight (kg)	%	Weight (kg)	%	Weight (kg)	%	Weight (kg)	%	Weight (kg)	%	Weight (kg)	%
Food and yard waste	9.46	66.02	10.03	68.18	9.70	63.24	11.30	67.34	9.10	68.02	8.75	62.46
Paper	1.40	9.77	1.80	12.24	2.10	13.69	1.48	8.82	1.80	13.45	1.70	12.13
Plastic	1.90	13.26	1.89	12.85	1.89	12.32	1.90	11.32	1.87	13.98	1.85	13.20
Rubber	-	-	-	-	-	-	0.40	2.38	-	-	1.05	7.49
Leather	-	-	-	-	-	-	-	-	-	-	-	-
Textile	0.30	2.09	-	-	0.31	2.02	0.46	2.74	0.08	0.60	0.07	0.50
Wood	-	-	-	-	-	-	-	-	0.06	0.45	0.11	0.79
Metal												
Glass	0.10	0.70	0.35	2.38	0.26	1.70	0.05	0.30	0.15	1.12	0.29	2.07
Hazardous	1.10	7.68	0.55	3.74	1.00	6.52	1.10	6.56	0.22	1.64	0.10	0.71
Stone	0.05	0.35	0.09	0.61	0.08	0.51	0.09	0.54	0.10	0.73	0.09	0.64
Other	0.02	0.14	-	-	-	-	-	-	-	-	-	-
TOTAL		-	-	-	-	-	-	-	-	-	-	-
	14.33	100.00	14.71	100.00	15.34	100.00	16.78	100.00	13.38	100.00	14.01	100.00

Table C.5 Waste samples' composition for commissioned officers' residential area during the weekend.

Components	week # 1		week # 2		week # 3	
	Weight (kg)	%	Weight (kg)	%	Weight (kg)	%
Food and yard waste	15.40	66.49	13.10	62.80	11.00	70.57
Paper	3.40	14.68	2.70	12.94	1.35	8.66
Plastic	2.70	11.66	3.20	15.34	2.78	17.84
Rubber	0.01	0.04	-	-	0.01	0.04
Leather	0.09	0.39	0.09	0.43	0.09	0.58
Textile	0.09	0.39	0.35	1.68	0.09	0.58
Wood	-	-	0.08	0.38	-	-
Metal	0.02	0.09	0.47	2.25	0.12	0.77
Glass	1.45	6.26	0.87	4.17	0.12	0.77
Hazardous	-	-	-	-	0.03	0.19
Stone	-	-	-	-	-	-
Other	-	-	-	-	-	-
TOTAL	23.16	100.00	20.86	100.00	15.59	100.00

Table C.6 Waste samples' composition for non-commissioned officers' residential area during the weekend.

Components	week # 1		week # 2		week # 3	
	Weight (kg)	%	Weight (kg)	%	Weight (kg)	%
Food and yard waste	11.35	66.49	11.00	63.79	10.00	67.07
Paper	2.13	12.48	1.98	11.48	1.80	12.07
Plastic	2.87	16.81	2.90	16.82	2.30	15.43
Rubber	-	-	-	-	-	-
Leather	-	-	-	-	-	-
Textile	0.10	0.59	0.18	1.04	0.30	2.01
Wood	-	-	-	-	-	-
Metal	0.17	1.00	0.21	1.22	0.09	0.60
Glass	0.45	2.64	0.95	5.51	0.42	2.82
Hazardous	-	-	-	-	-	-
Stone		-	0.03	0.14	-	-
Other	-	-	-	-	-	-
TOTAL	17.07	100.00	17.25	100.00	14.91	100.00

Table C.7 Waste samples' chemical analysis for offices area during the weekdays.

	week # 1				Week # 2				Week # 3			
Sample 1	1	2	3	average	1	2	3	average	1	2	3	average
dish	63.10	63.82	32.86	53.26	63.82	60.88	31.89	52.20	33.34	27.50	45.27	35.37
sample + dish	71.28	74.18	39.95	61.80	68.01	65.12	37.24	56.79	34.87	29.36	47.45	37.22
after 103 ^{o}C	68.03	72.66	38.29	59.66	65.70	62.23	33.69	53.87	34.03	28.23	45.99	36.08
after 550 ^{o}C	65.11	69.38	35.27	56.58	64.27	61.25	32.45	52.66	33.45	27.62	45.40	35.49
Moisture	39.76	14.73	23.42	25.97	55.20	68.31	66.36	63.29	54.89	60.81	66.96	60.89
Ts	60.24	85.27	76.58	74.03	44.80	31.69	33.64	36.71	45.11	39.19	33.04	39.11
Vs	59.23	37.13	55.63	50.66	75.99	72.77	68.89	72.55	84.13	83.36	81.94	83.14
Ash	40.77	62.87	44.37	49.34	24.01	27.23	31.11	27.45	15.87	16.64	18.06	16.86
P	179	192	205	192	167	168	190	175	171	181	185	179
N	1.07	1.04	1.05	1.05	1.10	1.08	1.11	1.10	1.08	1.03	1.09	1.07
Sample 2												
dish	32.40	35.44	33.11	33.65	33.24	49.32	31.09	37.88	44.81	28.85	33.24	35.63
sample + dish	44.72	52.60	49.98	49.10	38.15	57.98	36.12	44.09	45.76	29.80	34.15	36.57
after 103 ^{o}C	40.34	46.52	45.24	44.03	35.10	53.15	33.70	40.65	45.34	29.35	33.80	36.16
after 550 ^{o}C	36.07	42.87	40.56	39.83	33.60	50.25	31.65	38.50	44.88	28.92	33.31	35.70
Moisture	35.56	35.41	28.10	33.02	62.13	55.79	48.20	55.38	43.61	47.47	39.06	43.38
TS	64.44	64.59	71.90	66.98	37.87	44.21	51.80	44.62	56.39	52.53	60.94	56.62
VS	53.86	32.90	38.60	41.79	80.86	75.69	78.53	78.36	86.80	86.75	88.15	87.23
Ash	46.14	67.10	61.40	58.21	19.14	24.31	21.47	21.64	13.20	13.25	11.85	12.77
P	161	167	176	168	190	193	196	193	173	175	180	176
N	1.08	1.06	1.05	1.06	1.14	1.16	1.17	1.16	1.10	1.09	1.04	1.08

Table C.8 Waste samples' chemical analysis for commissioned officers' residential area during the weekdays.

	week # 1				Week # 2				Week # 3			
Sample 1	1	2	3	average	1	2	3	average	1	2	3	average
dish	53.40	59.62	28.85	47.29	57.40	32.40	59.62	49.81	28.74	49.32	28.74	35.60
sample + dish	80.79	82.24	46.68	69.90	61.54	37.12	66.53	55.06	30.10	50.64	34.25	38.33
after 103 ^{o}C	66.80	69.76	36.10	57.56	60.50	35.96	63.21	53.23	29.41	50.00	33.06	37.49
after 550 ^{o}C	58.88	61.45	30.94	50.42	58.28	34.07	60.64	51.00	28.79	49.37	32.45	36.87
Moisture	51.06	55.15	59.34	55.19	25.02	24.53	48.02	32.52	50.55	48.18	21.54	40.09
Ts	48.94	44.85	40.66	44.81	74.98	75.47	51.98	67.48	49.45	51.82	78.46	59.91
Vs	59.10	81.96	71.21	70.76	71.66	53.03	71.71	65.47	91.73	92.68	14.07	66.16
Ash	40.90	18.04	28.79	29.24	28.34	46.97	28.29	34.53	8.27	7.32	85.93	33.84
P	162	168	180	170	159	171	186	172	174	174	177	175
N	1.55	1.30	1.61	1.49	1.57	1.58	1.49	1.55	1.47	1.45	1.38	1.43
Sample 2												
dish	49.32	31.09	31.90	37.43	28.85	45.27	63.10	45.74	31.89	33.86	61.84	42.53
sample + dish	62.25	46.93	43.36	50.85	32.04	48.36	69.35	49.91	33.31	35.42	63.30	44.01
after 103 ^{o}C	54.02	36.44	36.63	42.36	30.10	46.49	65.81	47.47	32.64	34.68	62.71	43.34
after 550 ^{o}C	49.91	31.65	32.42	37.99	29.14	45.49	63.63	46.08	32.04	34.02	62.01	42.69
Moisture	63.65	66.22	58.67	62.85	60.84	60.54	56.57	59.32	47.48	47.54	40.23	45.09
TS	36.35	33.78	41.33	37.15	39.16	39.46	43.43	40.68	52.52	52.46	59.77	54.91
VS	87.47	89.42	88.90	88.60	77.47	82.18	80.57	80.07	80.30	80.54	81.01	80.61
Ash	12.53	10.58	11.10	11.40	22.53	17.82	19.43	19.93	19.70	19.46	18.99	19.39
P	167	172	186	175	180	183	189	184	163	168	170	167
N	1.34	1.27	1.52	1.38	1.71	1.58	1.62	1.64	1.37	1.35	1.29	1.34

Table C.9 Waste samples' chemical analysis for non-commissioned officers' residential area during the weekdays.

	week # 1				Week # 2				Week # 3			
Sample 1	1	2	3	average	1	2	3	average	1	2	3	average
dish	61.84	67.92	60.88	63.55	61.84	60.88	33.24	51.99	61.84	60.88	33.24	51.99
sample + dish	65.51	70.85	64.57	66.98	63.63	62.19	35.03	53.62	63.63	62.19	35.03	53.62
after 103 ^{o}C	65.12	70.59	64.21	66.64	63.49	62.13	34.79	53.47	63.49	62.13	34.79	53.47
after 550 ^{o}C	62.49	68.34	61.36	64.07	62.08	61.02	33.60	52.23	62.08	61.02	33.60	52.23
Moisture	10.57	8.73	9.91	9.74	7.72	4.50	13.35	8.52	7.72	4.50	13.35	8.52
Ts	89.43	91.27	90.09	90.26	92.28	95.50	86.65	91.48	92.28	95.50	86.65	91.48
Vs	80.17	84.19	85.45	83.27	85.76	89.30	76.85	83.97	85.76	89.30	76.85	83.97
Ash	19.83	15.81	14.55	16.73	14.24	10.70	23.15	16.03	14.24	10.70	23.15	16.03
P	159	161	175	165	135	139	152	142	151	156	158	155
N	0.98	0.99	1.00	0.99	1.10	1.08	0.98	1.05	0.98	0.87	0.85	0.90
Sample 2												
dish	45.27	33.24	44.81	41.11	45.27	44.80	63.82	51.30	45.27	44.80	63.82	51.30
sample + dish	47.66	35.15	46.83	43.21	47.24	46.36	66.64	53.41	47.24	46.36	66.64	53.41
after 103 ^{o}C	47.19	34.95	46.56	42.90	46.83	46.11	65.35	52.77	46.83	46.11	65.35	52.77
after 550 ^{o}C	45.48	33.44	45.01	41.31	45.41	44.92	63.97	51.43	45.41	44.92	63.97	51.43
Moisture	19.76	10.34	13.33	14.48	20.60	15.54	45.75	27.29	20.60	15.54	45.75	27.29
TS	80.24	89.66	86.67	85.52	79.40	84.46	54.25	72.71	79.40	84.46	54.25	72.71
VS	88.89	88.11	88.32	88.44	90.99	90.92	90.33	90.75	90.99	90.92	90.33	90.75
Ash	11.11	11.89	11.68	11.56	9.01	9.08	9.67	9.25	9.01	9.08	9.67	9.25
P	140	141	160	147	150	151	158	153	149	153	160	154
N	0.90	0.95	0.97	0.94	0.98	0.95	1.01	0.98	0.99	0.97	0.95	0.97

Table C.10 Waste samples' chemical analysis for commissioned officers' residential area during the weekend.

	week # 1				Week # 2				Week # 3			
Sample 1	1	2	3	average	1	2	3	average	1	2	3	average
dish	63.10	49.32	28.85	47.09	47.38	31.09	30.47	36.31	47.38	31.09	30.47	36.31
sample + dish	66.33	53.69	32.39	50.81	50.81	33.21	34.34	39.45	50.81	33.21	34.34	39.45
after 103 ^oC	64.67	51.06	30.85	48.86	49.70	32.53	32.73	38.32	49.70	32.53	32.73	38.32
after 550 ^oC	63.74	49.83	30.04	47.87	48.04	31.32	31.01	36.79	48.04	31.32	31.01	36.79
Moisture	51.33	60.17	43.64	51.71	32.25	32.19	41.77	35.40	32.25	32.19	41.77	35.40
Ts	48.67	39.83	56.36	48.29	67.75	67.81	58.23	64.60	67.75	67.81	58.23	64.60
Vs	59.44	70.55	40.77	56.92	71.43	83.74	76.19	77.12	71.43	83.74	76.19	77.12
Ash	40.56	29.45	59.23	43.08	28.57	16.26	23.81	22.88	28.57	16.26	23.81	22.88
P	163	165	173	167	153	157	158	156	169	171	176	172
N	1.13	1.08	1.07	1.09	0.89	0.90	0.90	0.90	0.90	0.92	0.92	0.91
Sample 2												
dish	28.74	33.86	75.75	46.11	32.46	33.98	29.28	31.90	32.46	33.98	29.28	31.90
sample + dish	37.03	39.41	84.82	53.75	38.55	46.96	34.23	39.91	38.55	46.96	34.23	39.91
after 103 ^oC	32.10	36.86	79.32	49.43	35.23	36.19	31.33	34.25	35.23	36.19	31.33	34.25
after 550 ^oC	31.07	36.18	78.34	48.53	32.72	34.23	29.56	32.17	32.72	34.23	29.56	32.17
Moisture	59.46	45.93	60.58	55.32	54.45	82.98	58.55	65.33	54.45	82.98	58.55	65.33
TS	40.54	54.07	39.42	44.68	45.55	17.02	41.45	34.67	45.55	17.02	41.45	34.67
VS	30.50	22.43	27.64	26.86	90.35	88.68	85.94	88.32	90.35	88.68	85.94	88.32
Ash	69.50	77.57	72.36	73.14	9.65	11.32	14.06	11.68	9.65	11.32	14.06	11.68
P	149	157	171	159	139	141	155	145	163	167	177	169
N	1.02	0.98	1.00	1.00	0.83	0.86	0.87	0.85	0.89	0.91	0.92	0.91

Table C.11 Waste samples' chemical analysis for non-commissioned officers' residential area during the weekend.

	week # 1				Week # 2				Week # 3			
Sample 1	1	2	3	average	1	2	3	average	1	2	3	average
dish	27.50	31.89	32.40	30.60	30.60	31.96	41.81	34.79	30.60	31.96	41.81	34.79
sample + dish	30.21	36.62	36.56	34.46	33.50	34.14	44.95	37.53	33.50	34.14	44.95	37.53
after 103 ^{o}C	28.60	33.43	33.97	32.00	31.80	33.11	43.23	36.04	31.80	33.11	43.23	36.04
after 550 ^{o}C	27.82	32.30	33.21	31.11	30.78	32.25	42.07	35.03	30.78	32.25	42.07	35.03
Moisture	59.60	67.46	62.40	63.15	58.79	47.51	54.70	53.67	58.79	47.51	54.70	53.67
Ts	40.40	32.54	37.60	36.85	41.21	52.49	45.30	46.33	41.21	52.49	45.30	46.33
Vs	71.43	73.54	48.08	64.35	85.10	74.83	81.89	80.61	85.10	74.83	81.89	80.61
Ash	28.57	26.46	51.92	35.65	14.90	25.17	18.11	19.39	14.90	25.17	18.11	19.39
P	139	169	172	160	171	179	184	178	161	164	164	163
N	1.24	1.38	1.35	1.32	0.90	0.92	0.91	0.91	0.87	0.85	0.84	0.85
Sample 2												
dish	33.35	57.40	33.02	41.25	38.84	37.61	31.84	36.09	38.84	37.61	31.84	36.09
sample + dish	36.06	59.31	35.41	43.60	40.69	39.84	35.42	38.65	40.69	39.84	35.42	38.65
after 103 ^{o}C	34.50	58.38	34.00	42.29	40.23	39.29	33.93	37.82	40.23	39.29	33.93	37.82
after 550 ^{o}C	33.49	57.52	33.15	41.38	39.34	38.06	32.70	36.70	39.34	38.06	32.70	36.70
Moisture	57.69	48.90	58.80	55.13	24.69	24.68	41.64	30.33	24.69	24.68	41.64	30.33
TS	42.31	51.10	41.20	44.87	75.31	75.32	58.36	69.67	75.31	75.32	58.36	69.67
VS	87.74	88.04	86.64	87.47	64.14	73.07	58.56	65.26	64.14	73.07	58.56	65.26
Ash	12.26	11.96	13.36	12.53	35.86	26.93	41.44	34.74	35.86	26.93	41.44	34.74
P	181	186	188	185	150	179	181	170	161	163	171	165
N	1.49	1.53	1.21	1.41	0.85	0.82	0.88	0.85	0.81	0.83	0.84	0.83

Table C.12 Calorific value results.

Week	Location	Time	Sample No.	Weight (g)	Calorific value (cal/g)
1	office	weekday	1	0.7148	4,221.56
			2	0.8218	4,235.50
			3	0.9025	3,862.14
	CO	weekday	1	0.7258	5,578.66
			2	0.6465	5,753.21
			3	0.8047	4,897.21
	CO	weekend	1	0.6551	4,325.35
			2	0.7560	5,565.33
			3	0.9917	2,541.25
	NCO	weekday	1	0.9957	3,325.94
			2	0.9985	3,587.41
			3	0.9983	4,016.31
	NCO	weekend	1	0.9856	2,198.58
			2	0.8423	2,768.31
			3	0.5584	3,879.26
2	office	weekday	1	0.6884	4,657.48
			2	0.8879	4,130.69
			3	0.9988	4,015.15
	CO	weekday	1	0.6790	4,998.13
			2	0.6550	4,532.35
			3	0.5448	5,632.25
	CO	weekend	1	0.6697	2,983.34
			2	0.9980	5,655.66
			3	0.9852	6,446.54
	NCO	weekday	1	0.6567	4,545.10
			2	0.6575	4,696.55
			3	0.7550	3,346.64

Table C.12 Calorific value results. (continued)

Week	Location	Time	Sample No.	Weight (g)	Calorific value (cal/g)
	NCO	weekend	1	0.8798	4,564.35
			2	0.7848	5,615.46
			3	0.6884	4,654.40
3	office	weekday	1	0.7548	3,647.64
			2	0.6987	5,345.68
			3	0.9787	5,485.46
	CO	weekday	1	0.8587	5,687.14
			2	0.5778	2,645.36
			3	0.8974	2,775.23
	CO	weekend	1	0.7482	2,874.34
			2	0.7899	3,565.98
			3	0.8745	2,757.21
	NCO	weekday	1	0.7898	2,670.39
			2	0.5468	2,544.37
			3	0.8990	5,654.55
	NCO	weekend	1	0.8764	2,565.33
			2	0.9840	5,151.37
			3	0.7546	5,877.27
average				0.7990	4,232.83
standard deviation				0.1400	1,164.98
RSD				17.5191	27.52

Appendix C

Waste Sample's Characteristics

Appendix D

Casual Loop Diagrams and Equation Translation

Case I: Current situation

▭ landfill_area(t) = landfill_area(t - dt) - (used_area) * dt

INIT landfill_area = 79.5

OUTFLOWS:

used_area = (Total_waste_disposed-(Total_waste_disposed*0.05))*1/202.35*7*52*1/3/4047

▭ total_population(t) = total_population(t - dt) + (net_growth_rate) * dt

INIT total_population = 12812

INFLOWS:

net_growth_rate = total_population*0.343/100

▭ waste_generated(t) = waste_generated(t - dt) + (sw_gen_rate) * dt

INIT waste_generated = 12812*0.48

INFLOWS:

sw_gen_rate = total_population*0.48

◯ recycle = total_population*0.195*0.48*0.05
+waste_generated*0.10

◯ Total_waste_disposed = waste_generated-recycle

Where,

t = time, years

dt = time duration, years

landfill_area = available landfill area, acres

used_area = area used for landfill, acres

Total_waste_disposed = total amount of waste disposed to the landfill, kg

0.05 = degree of compaction in the landfill

202.35 = solid waste bulk density, kg/m^3

7 = number of days in one week

52 = number of weeks in one year

3 = depth of the landfill, m

1/4047 = converting m^2 to acres

total_population = total population, capita

net_growth_rate = total population changed, capita/y

waste_generated = waste generated as collected, kg/d

sw_gen_rate = solid waste generation rate, kg/c/d

recycle = amount of waste recycled, kg

0.195 = average percentage of people who practice recycle

0.48 = solid waste generation rate, kg/c/d

0.05 = % recycle from households

0.10 = % recycled by scavengers

Case II: Increasing landfill efficiency through improved landfill technology

landfill_area(t) = landfill_area(t - dt) + (- used_area) * dt

INIT landfill_area = 79.5

OUTFLOWS:

used_area = (Total_waste_disposed-(Total_waste_disposed*0.2))

*1/202.35*7*52*1/4.0/4047

total_population(t) = total_population(t - dt) + (net_growth_rate) * dt

INIT total_population = 12812

INFLOWS:

net_growth_rate = total_population*0.343/100

waste_generated(t) = waste_generated(t - dt) + (sw_gen_rate) * dt

INIT waste_generated = 12812*0.48

INFLOWS:

sw_gen_rate = total_population*0.48

recycle = total_population*0.195*0.48*0.05 +waste_generated*0.10

Total_waste_disposed = waste_generated-recycle

Where,

0.2 = degree of compaction in the landfill

4 = depth of the landfill, m

Case III: Waste recycling promotion

landfill_area(t) = landfill_area(t - dt) + (- used_area) * dt

INIT landfill_area = 79.5

OUTFLOWS:

used_area = (total_waste_disposed-(total_waste_disposed*0.2)) *1/202.35*7*52*1/4.0/4047

total_population(t) = total_population(t - dt) + (net_growth_rate) * dt

INIT total_population = 12812

INFLOWS:

net_growth_rate = total_population*0.343/100 waste_generated(t) = waste_generated(t - dt) + (sw_gen_rate) * dt

INIT waste_generated = 12812*0.48

INFLOWS:

sw_gen_rate = total_population*0.48

recycle_program = total_population*0.195*0.48*pulse(0.05,0,0)
+total_population*0.195*0.48*pulse(0.261,1,1)
+waste_generated*0.10

total_waste_disposed = waste_generated-recycle_program

where,

recycle_program = the total amount of waste recycled after promoting the recycle program, kg

(0.05,0,0) = initially 5 % recyclable

(0.261,1,1) = 26.1 % recycle from year 1 for each successive year

Case IV: Composting process

landfill_area(t) = landfill_area(t - dt) + (- used_area) * dt

INIT landfill_area = 79.5

OUTFLOWS:

used_area = (Total_waste_disposed-composting-
(Total_waste_disposed*0.05))
*1/202.35*7*52*1/3/4047

total_population(t) = total_population(t - dt) + (net_growth_rate) * dt

INIT total_population = 12812

INFLOWS:

net_growth_rate = total_population*0.343/100

waste_generated(t) = waste_generated(t - dt) + (sw_gen_rate) * dt

INIT waste_generated = 12812*0.48

INFLOWS:

sw_gen_rate = total_population*0.48

composting = Total_waste_disposed*0.781

recycle = total_population*0.195*0.48*0.05
+waste_generated*0.10

Total_waste_disposed = waste_generated-recycle

Where,

composting = the amount of waste being composted, kg

0.781 = % of waste can be composted

Case V: Incineration

landfill_area(t) = landfill_area(t - dt) + (- used_area) * dt

INIT landfill_area = 79.5

OUTFLOWS:

used_area = (Total_waste_disposed-incineration-
(Total_waste_disposed*0.05))*1/202.35*7*52
*1/3/4047

total_population(t) = total_population(t - dt) + (net_growth_rate) * dt

INIT total_population = 12812

INFLOWS:

net_growth_rate = total_population*0.343/100

▭ waste_generated(t) = waste_generated(t - dt) + (sw_gen_rate) * dt

INIT waste_generated = 12812*0.48

INFLOWS:

sw_gen_rate = total_population*0.48

○ incineration = Total_waste_disposed*0.661

○ recycle = total_population*0.195*0.48*0.05

+waste_generated*0.10

○ Total_waste_disposed = waste_generated-recycle

Where,

incineration = the amount of waste going to be incinerated, kg

0.661 = % reduction of incinerated waste

Appendix E

How to Choose an Incinerator

How to Choose an Incinerator

The basis for satisfactory incinerator operation is the proper analysis of the waste to be destroyed, and the selection of proper equipment to best destroy that particular waste.

The changing pattern and immense volume of Commercial and Industrial Refuse together with an acute shortage of tipping space, increasing labour costs and the enforcement of the 'Clean air Act' by local Authorities, highlight the need for efficient, reliable incineration; for plant that has been designed and built to the highest engineering standards and with the present and future needs of the customer constantly in the Designer's mind.

Despite the advancement of modern technology there still remain manufactures whose incinerators are the products of outdated designs, old fashioned thinking and early century type "By Guess and By God" engineering. Incinerators of this class, in which no thought has been given to improving their functional reliability by introducing new ideas, materials and methods, or to reducing labour and maintenance costs by employing tested techniques borrowed from other associated industries, can only be classed as an "expensive box of fire-bricks" and are frequently condemned by Environmental Health Inspectors and H.M. Factory Inspectors.

What is an Incinerator

An engineered apparatue capable of safely withstanding heat and designed to efficiently reduce recognized types of waste at as specified rates, and from which the residues contain little or no combustible material.

What Makes One Type, or Make, of Incinerator Better than Another

The method of Design, Furnace Construction and Manufacture. A good incinerator is one that regularly attains a high standard of Combustion Efficiency when burning a specific class of waste. To achieve this standard consistently the Design and Construction MUST ensure that:-

1. Air and fuel are mixed in correct theoretical proportion.

2. Air and fuel, especially combustible gases, are thoroughly mixed together.

3. Internal temperatures must be sufficient for the spontaneous ignition of both the waste material and its gaseous components (e.g. Smoke and Fumes)

4. Furnace volumes must be large enough to provide the necessary retention time needed to achieve complete combustion.

5. Furnace propotions, and the type of refractory materials used, must be choosen to ensure that ignition temperature are maintained and 'fly-ash' emission is completely minimized.

6. Maintenance can be simply accomplished by the renewal of all parts when required.

7. When operated in accordance with the Manufacturer's Instructions the Incinerator will satisfy the requirements of the 'CLEAN AIR ACT' and the 'SAFETY AT WORK ACT'

8. The Incinerator is easy to install and simple to operate.

Do I Need a 'Main Ignition Burner'

If the class of waste being burnt gives off sufficient heat to maintain the required ignition temperature at the furnace Walls - then a Main Ignition Burner would not needed since the heat absorbed by the refractory lining would be sufficient to ignite newly charged waste PROVIDING this material is dry, readily combustible and contains less than 10% by weight of plastic.

If the waste to be burnt is wet and / or has a low Heating Value (under 8,500 B.T.U. per lb fired - SEE 'Classification of Wastes) a Main Ignition Burner MUST BE FITTED.

Do I Need an 'After-Burner'

It depends where you are located and what type of waste you intend burning. Incinerators not fitted with 'After-Burners' tend to give off some smoke when :-

1. They are first ignited from cold.

2. Their Combustion Chamber is over-loaded with rubbish and the incinerator is being forced to burn more waste than it was designed to handle.

3. Closed-down for the night.

If you Premises are in an isolated part of the Country - you may avoid detection by the Environmental Health Officer; if located in a City or Town you would be well advised to fit an 'After - Burner'

Note:

Our 'Multiple-Chamber' Incinerators are designed so that you can fit BOTH a Main Ignition Burner and an After Burner AT ANT TIME DURING THE WORKING-LIFE OF THE INCINERATOR.

This facility is provided to enable users to increase the incinerator's Burning Capacity so as to enable it to cope with moderate increases of waste after the unit has been installed.

What are Packaged -Type Burners'

"Packaged" Burners are complete units, requiring only fuel (gas or oil) and an electric power connection. Each burner is fitted with an Air Blower, enabling the effectiveness of the flame to be increased, and various safety devices.

When fitted the Thermal Output of each Burner is carefully matched to the Capacity of the Incinerator, and the Class of Waste to be destroyed.

How Do I Decide What Size of Incinerator I Require

The basis for satisfactory incinerator operation is the proper analysis of the waste to be destroyed, and the selection of proper equipment to best destroy that particular waste.

Proceed as follows:-

1. Check 'CLASSIFICATION OF WASTE CHART' to determine your type of waste.

2. Note Average Weight pr Cu. Ft. of Waste from chart.

3. Estimate Quantity of Waste to be burnt per 5-day week and convert this Quantity to Total Weight.

4. Decide Number of Hours Each Day that waste is to be burnt and multiply by 5 days to obtain Weekly Burning Time.

5. Divide total Weekly Weight of Waste (3) by the total Weekly Burning Time (4) to determine the Hourly Burning Capacity required of the incinerator.

How Do I Decide What Type of Incinerator I Need

The factors which decide the Type of Incinerator required are : -

- The CLASS of Waste to be burnt.
- The QUANTITY of Waste to be burnt.
- The CONDITION of Waste to be burnt.
- The LOCATION of your Premises.
- Whether the REQUIREMENTS of the 'CLEAN AIR ACT' are rigorously enforced by your Environmental Health Officer.

For example, if you only want to burnt Waste Paper (e.g. School Classroom Waste) two or three times a week then our inexpensive rang of 'RUSTPROOF OUTDOOR INCINERATORS' should satisfy your needs. These incinerators cannot be fitted with either Main Ignition or After - Burners. If you require to burn Class '0', '1', or '2' Waste only Two or Three Times a Week our Vertical 'Retort -type' "INFURNIRATOR", fitted with Burners, should prove satisfactory. For burning Class '0', '1', '2', '3' and '4' Waste on a regular daily basis then we would strongly recommend one of our 'MULTIPLE CHAMBER, HORIZONTAL FLOW INCINERATORS'

Because of special design features which ensures perfect smokeless combustion, reduce maintenance costs and eliminate the need for total renewal in later years, our 'MULTIPLE CHAMBER HORIZONTAL FLOW INCINERATORS' are regarded by many Authorities as being "ideal for most waste disposal applications" and are used by Hospitals, Municipal Authorities, and Industry.

Will My Incinerator Operator Need Special Training

No- providing he, or she, follows the Operating Instruction and supplied by the Manufacturer. All CMTS incinerators are simple to use and require NO PREVIOUS OPERATING EXPERIENCE.

Speciman 'Incinerator Capacity' Calculation.

1. Classification of Waste (from chart) = Type '0'
2. Weight Per Cubic Foot (from chart) = 8 –10 (If wholly DRY - use 8 lbs.per.cu.ft.)
3. Amount of Waste to be burnt Weekly = Two - 3 ¼ cub.yd. skips
4. Total Weekly Weight of Waste = 3 ¼ cu.yd. x 27 x 8 lbs x 2 = 1,404 lbs.
5. Daily Burning Time = 7 hours
6. Weekly Burning Time = 5 days x 7 Hours = 35 Hours Per Week.

7. Incinerator Capacity = Weekly Weight of Waste / Weekly Burning Time

= 1,404 lbs. / 35 hours. = 40lbs Per Hour

8. Main Ignition Burner Required ? = No. (Waste wholly dry)

9. After Burner Required ? = Highly Recommended.

10. Type of Incinerator ? =

11. Can Main Ignition Burner be fitted

afterwards if condition and / or quantity of waste alters ? = Yes…to existing fitting.

Classifiation of Wastes and Incinerators

The basis for satisfactory incinerator operation is the proper analysis of the waste to be destroyed, and the selection of proper equipment to best destroy that particular waste.

As a guide, mixtures of waste most commonly encountered have been classified into types of waste, together with the B.T.U. values and moistures contents of the mixtures. A concentration of one specific waste in the mixture may change the B.T.U. value and/or the moisture content of the mixture. A concentration of more than 10% by weight of catalogues, magazines, or packaged paper will change the density of the mixture and affect burning rates.

Similarly, incinerators have been classified, by their capacities and by the type of waste they are capable of incinerating.

Classification of Wastes

Type 0 - Trash, a mixture of highly combustible waste such as paper, cardboard, cartons, wood boxes, and combustible floor sweepings, from commercial and industrial activities. The mixture contain up to 10% by weight of plastic bags, coated paper, laminated paper, treated corrugated cardboard, oily rags and plastic or rubber scraps. This type of waste contains 10% moisture, 5% incombustible solids and has a heating value of 8500 B.T.U. per pound as fired.

Type 1- Rubbish, a mixture of combustible waste such as paper, cardboard cartons, wood scrap, foliage and combustible floor sweepings, from domestic, commercial and industrial activities. The mixture contains up to 20% by weight of restaurant or cafeteria waste, but contains little or no treated papers, plastic or rubber wastes. This type of waste contains 25% moisture, 10% incombustible solids and has a heating value of 6500 B.T.U. per pound as fired.

Type 2 - Refuse, consisting of an approximately even mixture of rubbish and garbage by weight. This type of waste is common to apartment and residential occupancy, consisting of up to 50% moisture, 7% incombustible solids, and has a heating value of 4300 B.T.U. per pound as fired.

Type 3 - Garbage, consisting of animal and vegetable wastes from restaurants, cafeterias, hotels, hospitals markets and like installations. This type of waste contains up to 70% moisture, up to 5% incombustible solids, and has a heating value of 2500 B.T.U. per pound as fired.

Type 4 - Human and animal remains, consisting of carcasses, organs and solid organic wastes from hospitals, laboratories abattoirs, animal pounds, and similar sources, consisting of up to 85% moisture, 5 % incombustible solids, and having a heating value of 1000 B.T.U. per pound as fired.

Type 5 - By-product waste, gaseous, liquid or semi-liquid, such as tar, paints, solvents, sludge, fumes, etc., from industrial operations. B.T.U. values must be determined by the individual materials to be destroyed.

Type 6 - Solid by-product waste, such as rubber, plastics, wood waste, etc., from industrial operations. B.T.U. values must be determined by the individual materials to be destroted.

Classifications of Incinerators

Class I - Portable, packaged, completely assembled, direct fed incinerators, having not over 5 cu.ft. storage capacity, or 25lbs. Per hour burning rate, suitable for type 2 Waste.

Class IA - Portable, packaged or job assembled, direct fed incinerators 5 cu. Ft. to 15 cu. Ft. primary chamber volume; or a burning rate of 25lbs. Per hour up to, but not including 2 sq. ft. burning area, suitable for Type 2 Waste; or a burning rate of 25lbs. Per hour of 25lbs. Per hour up to, but not including, 75lbs. Per hour of Type 3 Waste.

Class II - Flud-fed, single chamber incinerators with more than 2 sg.ft. burning area, suitable for Type 2 Waste. This type of incinerator is served by one vertical flue functioning both as a chute for charging waste and to carry the products of combustion to atmosphere. This type of incinerator installed in apartment houses or multiple dwellings not more than five stories high.

Class IIA - Chute - fed multiple chamber incinerators, with more than 2 sq.ft. burning area, suitable for Type 1 or Type 2 Waste. (Not recommended for industrial wastes.) This type of incinerator is served by a vertical chute for charging waste from two or more floors above the incinerators and a separate flue for carrying the products of combustion to atmosphere.

Class III - Direct fed incinerators with a burning rate of 100 lbs. Per hour and over, suitable for Type), Type 1 or Type 2 Waste.

Class IV - Direct fed incinerators with a burning rate of 75lbs. Per hour or over, suitable for Type 3 waste.

Class V - Municipal incinerators suitable for Type 0, Type 1, Type 2, or Type 3 Wastes, or a combination of all four wastes, and are rated in tons per hour or tons per 24 hours.

Class VI - Crematory and pathological incinerations, suitable for Type 4 Waste.

Class VII - Incinerators designed for specific by-product wastes, Type 5 or Type 6.

Table E.1 shows the various B.T.U. values of materials commonly encountered in incinerator designs. The values given are approximate and may vary based on their exact characteristics or moisture content.

Table E.1 B.T.U. values.

Waste	B.T.U. Value /lb. as fired	Wt. In lbs. Per cu. Ft. (loose)	Wt. In lbs Per cu. Ft.	Content by weighting percentage	
				ash	moisture
Type 0 Waste	8,500	10		5	10
Type 1 Waste	6,500	10		10	25
Type 2 Waste	4,300	20		7	50
Type 3 Waste	2,500	35		5	70
Type 4 Waste	1,000	55		5	85
Kerosene	18,900		50	.5	0
Benzene	18,210		55	.5	0
Toluene	18,440		52	.5	0
Hydrogen	61,000		.0053	0	0
Acetic Acid	6,280		65.8	.5	0

Table E.1 B.T.U. values. (continued)

Waste	B.T.U. Value /lb. as fired	Wt. In lbs. Per cu. Ft. (loose)	Wt. In lbs Per cu. Ft.	Content by weighting percentage	
				ash	moisture
Methyl Alcohol	10,250		49.6	0	0
Ethyl Alcohol	13,325		49.3	0	0
Turpentine	17,000		53.6	0	0
Naphtha	15,000		41.6	0	0
Newspaper	7,975	7		1.5	6
Brown paper	7,250	7		1.0	6
Magazines	5,250	35		22.5	5
Corrugated paper	7,040	7		5.0	5
Plastic coated paper	7,340	7		2.6	5
Coated milk cartons	11,330	5		1.0	3.5
Citrus rinds	1,700	40		.75	75
Shoe Leather	7,240	20		21.0	7.5
Butyl sole	10,900	25		30.0	1
composition	20,000	40-60	60	0	0
Polyethylene	13,000	2	2	0	0
Polyurethane (foamed)					
Latex	10,000	45	45	0	0
Rubber waste	9,000-	62-125		20-30	
Carbon	11,000		138	0	0
Wax paraffin	14,093		54-57	0	0
1/3 wax - 2/3 paper	18,621	7-10		3	1
	11,500				
Tar or asphalt	17,000	60		1	0
1/3 tar - 2/3 paper	11,000	10-20		2	1
Wood sawdust (pine)	9,600	10-12		3	10
Wood sawdust	7,800 -	10-12		3	10
Wood bark (fir)	8,500	12-20		3	10
Wood bark	9,500	12-20		3	10
	8,000 -				
	9,000				
Corn cobs	8,000	10-15		3	5
Rags (silk or wool)	8,400-	10-15		2	5
Rags (linen or cotton)	8,900	10-15		2	5
Animal Fats	7,200	50-60			0
	17,000				

http://www.cmtsproduct.com/Products/FAQ.asp, Solution by WEBSE Technology

Biography

Capt. Kobchok Hussadee was born on December 7, 1973, in Nakhon Ratchasima, North Eastern of Thailand. After grade 10 at Rajsima Vittayalai, Nakhon Ratchasima, Thailand, he went to Bangkok to finish 12th grade at Armed Forces Academies Preparatory School (AFAPS). In 1992, the author started studying in an engineering program at Chulachomklao Royal Military Academy (CRMA), Nakhonnayok and received a Bachelor Degree of Engineering in Civil Engineering. Subsequently, he had started studying in a Masters Program in Environmental Engineering at Suranaree University of Technology, in 1999.