INTEGRATION OF STAKEHOLDER AND SPATIAL ANALYSES FOR SOLID WASTE MANAGEMENT

Pimprapai Piphatnawakul

A Thesis Submitted in Partial Fulfillment of the Requirements for the

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การบูรณาการการวิเคราะห์เชิงพื้นที่และผู้มีส่วนได้ส่วนเสีย
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INTEGRATION OF STAKEHOLDER AND SPATIAL ANALYSES FOR SOLID WASTE MANAGEMENT

Suranaree University of Technology has approved this thesis submitted in partial fulfillment of the requirements for the Degree of Doctor of Philosophy.

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การจัดการด้านการขนส่งขยะภายใต้การดูแลขององค์กรปกครองส่วนท้องถิ่นที่สำคัญ 11 แห่งในจังหวัดพิษณุโลก กำลังประสบปัญหาปริมาณขยะรายวันพิ่มขึ้นตลอดเวลาในขณะที่แหล่งกำจัดขยะมีอยู่อย่างจำกัด การจัดการด้านการขนส่งขยะที่ขาดประสิทธิภาพ อาทิ เส้นทางขนส่งและจำนวนขยะที่ส่งไปยังแหล่งฝังกลบที่ไม่เหมาะสมจะส่งผลกระทบทางด้านสิ่งแวดล้อมโดยรอบแหล่งฝังกลบขยะ รวมทั้งการก่อให้เกิดความอ่อนไหวในเส้นทางขนส่งซึ่งจะส่งผลกระทบต่อผู้ที่ใช้เส้นทางและอาศัยโดยรอบ การศึกษาในครั้งนี้เป็นการบูรณาการของการวิเคราะห์เชิงพื้นที่ และปัจจัยที่เกี่ยวข้องในการจัดการขนส่งขยะ โดยใช้การวิเคราะห์โครงข่ายถนน การวิเคราห์ความอ่อนไหวของเส้นทางขนส่งที่เหมาะสม การวิเคราะห์การตัดสินใจแบบหลายวัตถุประสงค์ในเชิงพื้นที่ และการจัดลำดับความสำคัญรูปแบบการขนส่งขยะด้วยวิธี PROMETHEE ร่วมกับผลการวิเคราะห์ผู้มีส่วนได้ส่วนเสีย

กลุ่มผู้มีส่วนได้ส่วนเสียทั้ง 15 กลุ่มได้จากผลการสำรวจผู้มีส่วนเกี่ยวข้องทั้งหมด ค่าน้ำหนักประจำกลุ่มได้จากการวิเคราะห์ด้วยแบบจำลอง Salience และตรรกะคลุมเครือแบบ Mamdani หน่วยงานรัฐบาลด้านสิ่งแวดล้อมและองค์กรปกครองส่วนท้องถิ่นรวมถึงองค์กรชุมชนจะมีค่าน้ำหนักสูงสุด อยู่ระหว่าง 2.52-2.54 โดยผู้คัดแยกขยะตามแหล่งฝังกลบมีค่าน้ำหนักต่ำสุดอยู่ที่ 0.495 ตำแหน่งของสถานีขนส่งชั่วคราวได้จากกระบวนการ GIS weighted centering เส้นทางที่เหมาะสมสำหรับการขนส่งขยะจากสถานีขนส่งไปยังแหล่งผังกลบทั้งหมด 99 เส้นทางได้จากการวิเคราะห์โครงข่ายที่ใช้ระยะทางเป็นกุญแจที่ส่งผลต่อค่าขนส่ง ค่าดัชนีความอ่อนไหวประจำเส้นทางที่เหมาะสมได้จากค่าคะแนนบนพื้นฐานของจำนวนสิ่งอำนวยความสะดวกและปริมาณประชาชนที่ใช้บริการผ่านทางกระบวนการวิเคราะห์เชิงพื้นที่ด้วย GIS เส้นทางที่เหมาะสม ค่าผลกระทบด้านสิ่งแวดล้อมของสถานีขนส่งและแหล่งฝังกลบ รวมถึงค่าดัชนีความอ่อนไหวประจำเส้นทางได้รับการจัดเตรียมในรูปแบบตารางแมทริกซ์นำเข้าสู่กระบวนการจัดสรรปริมาณขยะและคัดเลือกแหล่งฝังกลบที่เหมาะสมด้วยการวิเคราะห์โปรแกรมเชิงเส้นที่สนองต่อฟังก์ชันวัตถุประสงค์ที่ให้ผลน้อยที่สุดต่อ ต้นทุนค่าขนส่ง ผลกระทบทางด้านสิ่งแวดล้อม ความอ่อนไหวของเส้นทางการขนส่งขยะ และวัตถุประสงค์แบบผสมผสาน ภายใต้ข้อจำกัดปริมาณขยะ ณ สถานีขนส่งและความจุรายวันของแหล่งฝังกลบตามอายุการใช้งาน 3 ปี และ 5 ปี

ผลจากการจัดสรรและการคัดเลือกแหล่งฝังกลบทำให้ได้ผลลัพธ์โดยรวมของค่าขนส่ง ค่าดัชนีผลกระทบสิ่งแวดล้อมและความอ่อนไหวของแต่ละฟังก์ชันวัตถุประสงค์ได้รับการตรวจสอบความสมเหตุสมผล และนำไปใช้วิเคราะห์ร่วมกับความคิดเห็นจากการสำรวจและค่าน้ำหนักประจำกลุ่มผู้มีส่วนได้ส่วนเสีย ด้วยวิธี PROMETHEE เพื่อจัดลำดับและคัดเลือกรูปแบบการขนส่งที่ดีที่สุดของฟังก์ชันวัตถุประสงค์ต่างๆ รูปแบบการขนส่งที่เหมาะสมที่สุดมาจากวัตถุประสงค์ที่กำหนดให้มีค่าโดยรวมน้อยที่สุดของค่าขนส่ง ดัชนีผลกระทบด้านสิ่งแวดล้อมและความอ่อนไหวโดยพิจารณาจากค่าผลต่างของค่าเหนือกว่าและด้อยกว่าสูงสุด (0.41) รูปแบบการขนส่งที่เหมาะสมน้อยที่สุดเป็นของฟังก์ชันวัตถุประสงค์ที่กำหนดให้มีค่าดัชนีผลกระทบสิ่งแวดล้อมน้อยที่สุด ซึ่งมีค่าผลต่างของค่าเหนือกว่าและด้อยกว่าอยู่ที่ -0.46 ผลจากการสำรวจความคิดเห็นร่วมกับการใช้น้ำหนักของผู้มีส่วนเสียระบุให้อายุการใช้งานของแหล่งฝังกลบ 5 ปีดีกว่า 3 ปี ผลการศึกษาที่ได้รายงานในเบื้องต้นครอบคลุมถึงการบรรลุวัตถุประสงค์ของการศึกษาในครั้งนี้ทั้งหมด

สาขาวิชาภูมิสารสนเทศ　　　　ลายมือชื่อนักศึกษา Pimprapai

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PIMPRAPAI PIPHATNAWAKUL : INTEGRATION OF STAKEHOLDER AND SPATIAL ANALYSES FOR SOLID WASTE MANAGEMENT. THESIS ADVISOR : ASST. PROF. SUNYA SARAPIROME, Ph.D. 207 PP.

WASTE TRANSPORTATION MANAGEMENT/ STAKEHOLDER ANALYSIS/ NETWORK ANALYSIS/ VULNERABILITY ASSESSMENT/ LINEAR PROGRAMMING/ PROMETHEE

Waste transportation management in 11 major local administrative units of Phitsanulok province is experiencing a problem on ever-increasing generated waste amount while a number of disposal sites (DSs) is limited available. Inefficient waste transportation management e.g. transportation route and waste allotment which are not optimum can lead to promoting environmental impact (EI) of DSs and the surroundings including vulnerability subject to people who live both sides of and travel along transportation routes. The study proposed integration of stakeholder and spatial analyses related to waste transportation management. The methods cover analyses of road network, vulnerability, and spatial multi-criteria decision, including PROMETREE method to rank transportation patterns.

Fifteen stakeholder groups were obtained from questionnaire surveyed among active relevant groups. Stakeholder preference was analyzed using salience model and Mamdani fuzzy logic. Environmental agencies of government and local administrative units including community-based organizations were voted to have the highest preference of 2.52-2.54 while scavenger has the lowest of 0.495. The temporary transfer station (TS) of each local administrative unit was located using GIS weighted centering.

Ninety nine optimum paths were obtained by network analysis using distance affecting transportation cost (TC) as an impedance. Vulnerability index (VI) along optimum path was spatially analyzed by GIS based on a number of facilities both sides of a path and amount of their servicing people. Optimum paths, EI of pairs of TSs and DSs, and VI along optimum paths were prepared as matrixes to input into waste allocation and allotment using Linear programming analysis to serve objective functions of minimized transportation cost, environmental impact, vulnerability along optimum paths, and their combinations. The analysis worked under the constraints of waste amount at TSs and daily capacity of DSs based on 3- and 5-year service lives.

Results of waste allocation and allotment were criteria outcomes of TC, EI, and VI of each objective function. They were proved to be valid before incorporating with stakeholder opinions and preferences in the PROMETHEE process to ranking transportation patterns from multi-objective functions. Transportation pattern of the objective of minimized TC, EI, and VI was ranked to be the most optimum, considering from the maximum difference between leaving and entering flows (0.41). The least optimum pattern was from the objective of minimized EI with the flow difference of -0.46. From additional stakeholder opinion survey incorporating with their preferences revealed that 5-year DS service life was preferred to 3-year service life. The study results reported above confirmed that all study objectives were completely achieved.

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LIST OF ABBREVIATIONS

SWM	=	Solid Waste Management
NA	=	Network Analysis
TC	=	Transportation Cost
EI	=	Environmental Index
VI	=	Vulnerability Index
TS	=	Transfer Station
DS	=	Disposal Site
SAO	=	Subdistrict Administrative Organization
EOR 3	=	Environmental Office Region 3
RTSD	=	Royal Thai Survey Department
RHD	=	Royal Highway Department
DEQP	=	Department of Environmental Quality Promotion
HIA	=	Health Impact Assessment
SIA	=	Social Impact Assessment
CM	=	City Municipality
TM	=	Town Municipality
SM	=	Subdistrict Municipality
MODA	=	Multi-objective Decision Analysis
PCD	=	Pollution Control Department
DOH	=	Department of Health

LIST OF ABBREVIATIONS (Continued)

DOLA	=	Department of Local Administration
GHG	=	Greenhouse Gas
LFG	=	Landfill Gas
SA	=	Stakeholder Analysis
MCDA	=	Multi-criteria Decision Analysis
OWA	=	Ordered Weighted Averaging
GIS	=	Geographic Information System
COG	=	Center of Gravity
LP	=	Linear Programming
MCDM	=	Multi-criteria Decision Making
MODA	=	Multi-objective Decision Analysis

CHAPTER I

INTRODUCTION

1.1 Background problems and significance of the study

Recently, waste disposal becomes global serious problem due to its ever-increasing amount around the world, particularly from big cities. World cities generate about 1.3 billion tons of solid waste per year. This volume is expected to increase to 2.2 billion tons by 2025 (Hoornweg and Bhada-Tata, 2012). Chinda, Leewattana and Leeamnuayjaroen (2012) reported that in 2007 Thailand is ranked to be the top in generating huge amount of solid waste in the developing countries in the Southeast Asia. Waste disposal problem in the country becomes greater with time and unavoidable issue. Wrong practice in waste disposal management has been currently causing adversely environmental impact.

In many countries, laws and regulations have been implemented by government and authorities to manage and reduce the impact of waste to the environment. In Thailand, however, there are some existing laws related to waste management and recycling, but are not yet effectively implemented. Despite such progress, solid waste problems still impose an increasing pressure on cities and remain one of the major challenges in urban environmental management (Contreras, Hanaki, Aramaki and Connors, 2008). There is no single solution to the problem since each city has different characteristics in waste management and various kinds of stakeholder. One of the big solutions is how to choose suitable method and site including how to compromise or make stakeholders satisfying with the management. Groups of stakeholder and their opinions can be considered as social factor of the management.

There are many actors or stakeholders affected by solid waste management decisions, some of whom receive the negative and some the positive consequences. The composition of these "stakeholder groups" varies according both the problem in question and its solution. The role of stakeholder groups has transformed over time from being merely recipients of impacts to playing an important function in the design, implementation and promotion of solid waste management (SWM) (Contreras et al., 2008).

SWM is not only an important environmental task, but also involve several socio-cultural and economic matters. The components of SMW include reducing the wastes, reusing, recycling, energy recovery, incineration and landfilling (Moeinaddini, Khorasani, Danehkar, Darvishsefat and Zienalyan, 2010). Despite the great use of recyclable materials, final waste disposal to landfill remains the most common practice for waste management because it is simple and relatively inexpensive (Kim and Owens, 2010).

In provincial level of Thailand, SMW regarding to environment impact will cover impact on site due to intrinsic physical characteristics of land, disposal methods at site, transportation management in terms of selected route and waste amount. Disposal methods at site generally include landfill, incineration, and controlled dump. As known, environmental vulnerability on transportation route will be examined based on population affected by transportation activity. Locations of facilities which are centers of people such as schools, hospitals, shopping malls, government institutions, etc. are prone to varying intensity of environmental impact regarding to size of population and distance away from route. As well, transportation route selection and waste amount management will certainly affect to economic point of view in term of transportation cost. Site selection and transportation management can be the issue that can cause conflicts among groups of stakeholders. Based on scientific and engineering practice, physical characteristics of land are considered very important in disposal site selection. But in fact, local policy can influence on site selection. Socio-economic problem related to conflicts of stakeholders is very important as well. Therefore, to solve this real world problem, integration of physical, policy, social, and economic problems should be seriously taken care of when waste management planning and implementation are performed.

Phitsanulok province consists of 102 local administrations and generates about 860 tons per day. It is regarded as one of the big provinces of Thailand, which produces tremendous amount of waste daily and is encountering difficulty on seeking efficient solution for waste management. Recently, only 37 local administrations can have proper and systematic service on waste management, while other 65 local administrations have no such a service (สำนักงานสิ่งแวดล้อมภาคที่ 3, 2013). Fortunately, there have been 22 active waste disposal sites available in the province that can handle all solid waste generated recently. Disposal methods of these sites include landfill, controlled dump, and incineration, which in turn generate different environmental impact. To this date, there is no serious requirement for additional new waste disposal site in the near future.

The present study will propose integration of spatial analyses and factors for SWM. The methods will cover stakeholder analysis, network analysis, spatial multi objective analysis, and PROMETREE. These methods will be performed on all kinds of factors, i.e. physical, policy, social, and economic.

1.2 Research objectives

The main goal of this study is to properly manage waste transportation in local administrative units, having full service function on this matter, of Phitsanulok province of Thailand using NA and multi-objective functions based on minimized TC, EI, and VI and outranking of patterns of waste management using PROMETHEE. Four objectives of this study are as follows:

1.2.1 To perform stakeholder analysis for waste management,

1.2.2 To select temporary transfer station (TS) of each local administrative unit or their groups using GIS weighted centering,

1.2.3 To evaluate vulnerability index (VI) on optimum paths of transfer stations (TSs) to disposal sites (DSs) based on population and locations of facilities; and

1.2.4 To analyze ranking of patterns of waste management based on transportation cost (TC), environmental impact (EI), and VI using stakeholder preferences and PROMETHEE method.

1.3 Scope and limitations of the study

1.3.1 The study area covers 11 areas of subdistrict administrative organizations (SAO) and municipalities of Phitsanulok province which generate big amount of MSW. It does not include areas of administrative organizations where waste amount generated is too small, less than 3.5 tons/day (as recorded by EOR 3), and is disposed by random burning.

1.3.2 Type of vehicles, speed and schedule will not be concerned in transportation analysis because of their varying availability in organizations.

1.3.3 Stakeholder analysis will be performed by interview and questionnaire to individuals and groups of stakeholder residing in Phitsanulok province.

1.3.4 Environment impacts will be considered at DS and TS based on waste amount and disposal method and along transportation route based on vulnerability of facilities. They included school, hospital, shopping mall, market, government institute, and tourist attraction. The vulnerability along optimum route will be scored based on population of facilities and their distance to road.

1.3.5 The data on amount of waste used for analysis are based on the record of Environmental Office Region 3 (EOR 3). They will not cover the reuse and recycle amount which are processed before transportation or at the DS.

1.3.6 Existing DSs are selected within 30 kilometers away from the study area from the list of EOR 3. As suggested by EOR 3, 30 kilometers is a distance a truck can go back and forth in a day and it is economically worth.

1.3.7 GIS data on road of the study area is adopted and refined from Royal Thai Survey Department (RTSD) and Royal Highway Department (RHD) which was digitized by Department of Environmental Quality Promotion (DEQP) (2003).

1.3.8 Some roads in dense populated area will not be used for waste transportation or optimum path analysis due to recommendation of stakeholders.

1.3.9 Factors involved in decision making in waste transportation allotment cover physical factor in form of environmental impact, policy factor when dealing with TS location and ranking transportation pattern, social factor in form of vulnerability along route, economic factor in terms of distance, cost of transportation, and waste amount.

1.3.10 Environment impact in this study will not cover official HIA (Health Impact Assessment) and SIA (Social Impact Assessment).

1.3.11 To comply with the actual practice of truck management, costs of transportation along optimum paths will be estimated based on double of distances of any paths.

1.3.12 The outranking of transportation patterns has no way to be validated. The result was compromised from different subjective satisfaction among groups of stakeholders. Every opinion of stakeholder was never ignored and was input into the processes of MCDA.

1.3.13 Transportation cost from households to TSs cannot be estimated due to lack of basic information on a number of households, their ability of waste generation, and transportation cost and routes of households to TSs. Therefore, comparison of criteria outcomes from optimum and actual transportation patterns cannot be performed.

1.4 Study area

1.4.1 Geographic location

The study area is located at some part of Meuang district in Phitsanulok province, Thailand. It consists of 11 SAOs and municipalities which include Phai Kho

Don, Phlai Chumphon, Wat Chan, Bueng Phra, Tha Thong, Aranyik, Tha Pho, Ban Khlong, Nai Mueang, Hua Ro, and Ban Krang (Figure 1.1). The area covers approximately 300 km^2. This area chiefly reflects the problem on MSW disposal of the province due to its big amount generation and poor management.

The road network data in form of GIS data layer is required as significant input for the analysis. The data layer captured from maps of scale 1:50,000 of RTSD and RHD by DEQP (2003) can provide current status of the theme. It is therefore adopted with refining and topological checking for analysis in this study. The road network and distribution of the selected DSs are displayed in Figure 1.2.

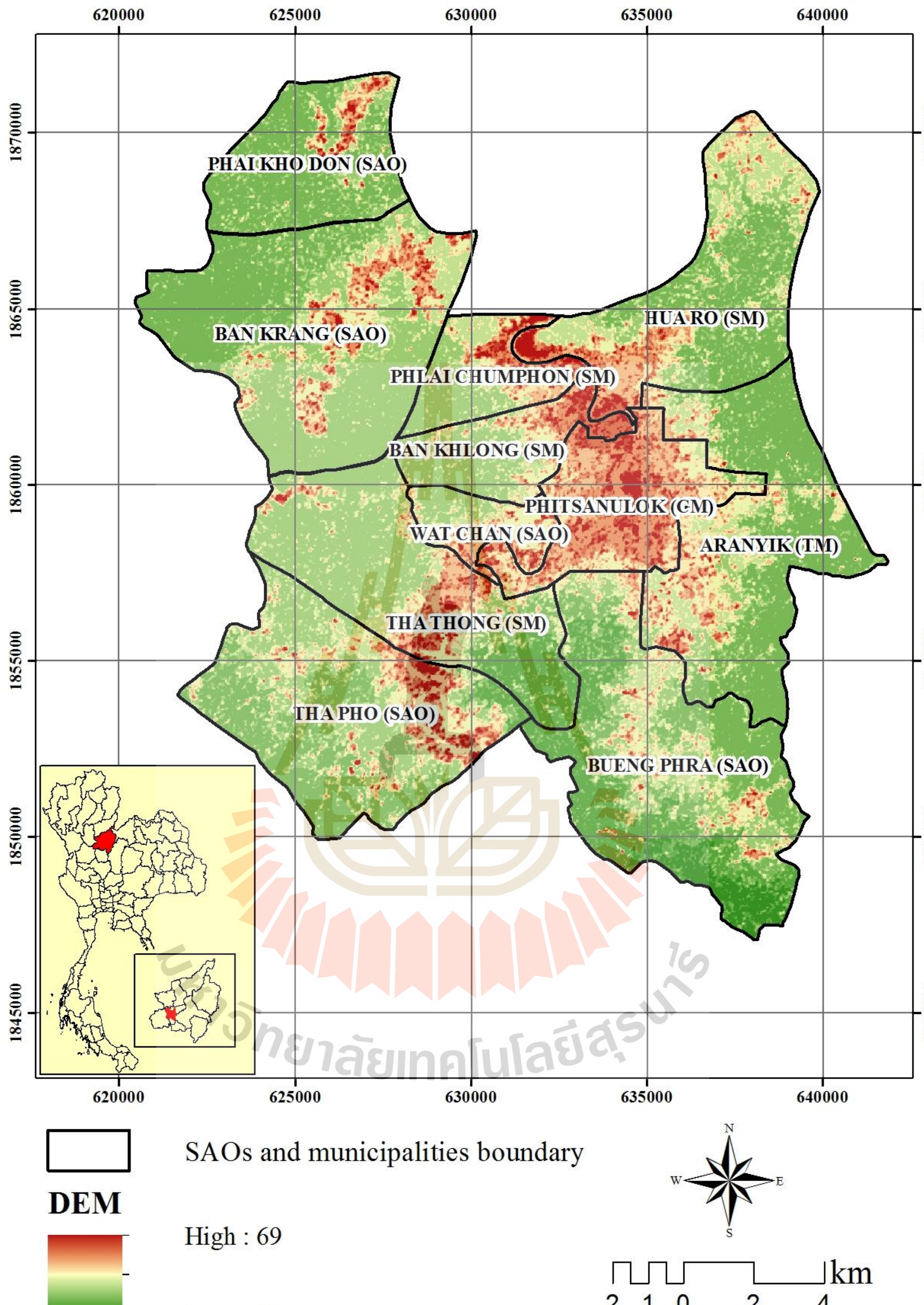


Figure 1.1 SAOs and municipalities of the study area.

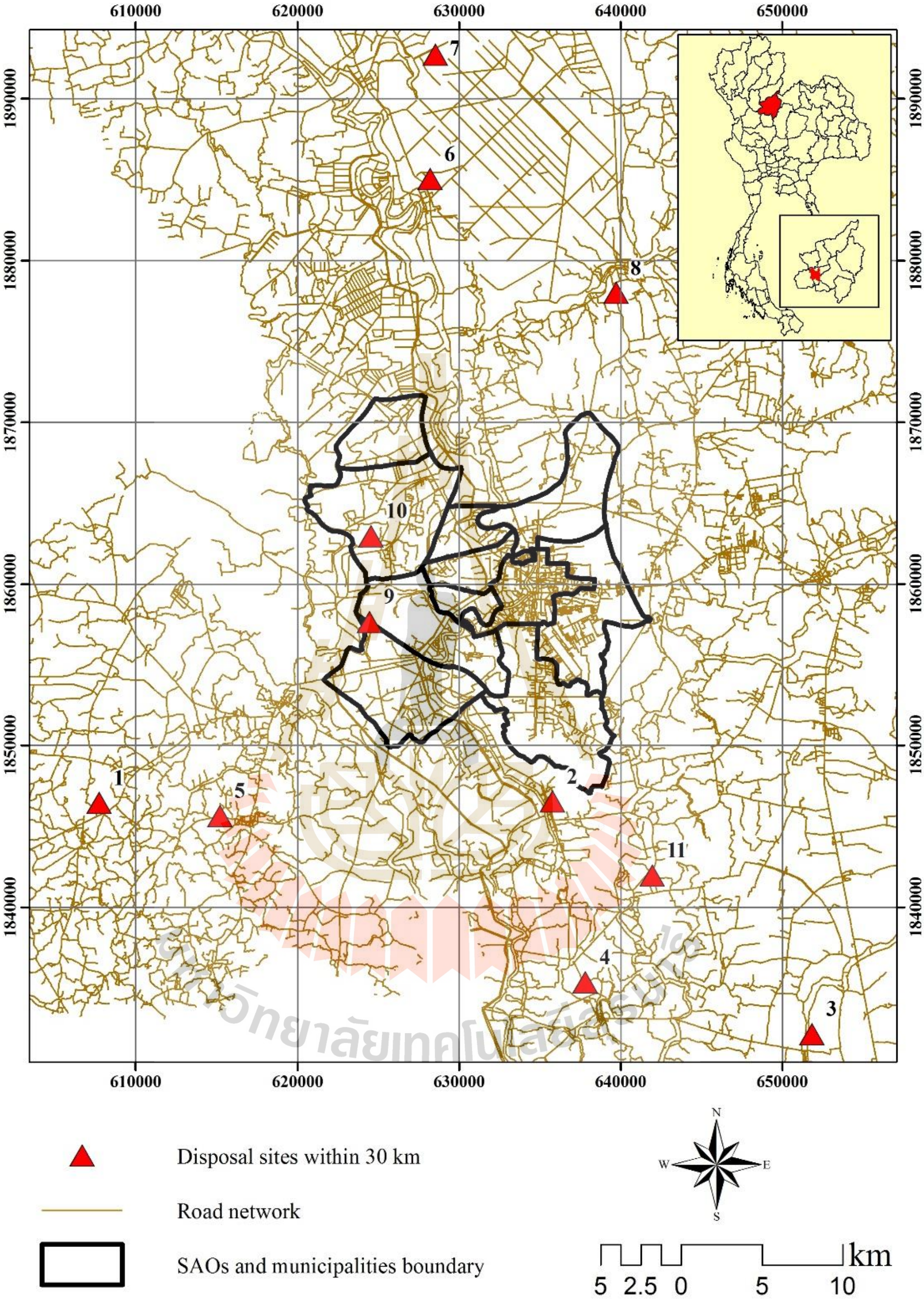


Figure 1.2 Road network and distribution of DSs within 30 km of the study area.

According to the record of สำนักงานสิ่งแวดล้อมภาคที่ 3, there have been 22 DSs available in the province. There are only 11 DSs chosen for the study (Table 1.1). They are located within 30 km away from the study area which is the limited distance in economic point of view for waste transportation. Only two of them is sanitary landfill while others are currently developed from open dump to be controlled dump which has more measures for environmental protection.

Table 1.1 Detail of disposal sites chosen for waste management of the study.

No.	Organization of site	Easting	Northing	Area	Disposal Method
1	Phitsanulok municipality	607723	1846447	223	Sanitary landfill
2	Banmai municipality	635779	1846537	7	Controlled dump
3	Nuenkum municipality	651825	1832148	10	Controlled dump
4	Bangkrathum municipality	637805	1835352	7	Controlled dump
5	Plakrad municipality	615201	1845643	15	Controlled dump
6	Phromphiram municipality	628205	1885046	23	Controlled dump
7	Wongkong municipality	628542	1892739	10	Controlled dump
8	Watbot municipality	639718	1878014	31	Controlled dump
9	Thapho municipality	624463	1857661	17	Sanitary landfill
10	Bankrang SAO	624559	1862971	7	Controlled dump
11	Thatan SAO	641947	1841960	2	Controlled dump

1.4.2 Population and waste generation

According to the report of สำนักงานสิ่งแวดล้อมภาคที่ 3 (2556), it describes that the rate of waste generation in any administrative area will be related to the number of population and level of civilization or income which is based on type of administration of the area. Area with the more income has a tendency to generate more waste per head by statistics. Table 1.2 show the list of administrative units, their population, waste generation rate and amount, including sites to dispose. According to this table, it is interesting to note that, currently, sites chosen to dispose are not systematically random and do not depend on optimum distance.

Table 1.2 Population, waste generation rate and amount of administrative units, including sites to dispose.

Administrative unit	Population	Waste generation (Kg/person/day)	Waste amount	Site to dispose
Phitsanulok CM	69,906	1.89	132,122.34	1
Aranyik TM	29,825	1.15	34,298.75	Wang thong site
Phlai chumphon SM	7,109	1.02	7,251.18	9
Ban khlong SM	12,963	1.02	13,222.26	9
Tha Thong SM	13,136	1.02	13,398.72	1
Hua Ro SM	22,898	1.02	23,355.96	9
Phai kho don SAO	4,052	0.91	3,687.32	1
Wat Chan SAO	8,067	0.91	7,340.97	9
Tha Pho SAO	22,773	0.91	20,723.43	9
Beung Phra SAO	17,555	0.91	15,975.05	9
Ban Krang SAO	12,152	0.91	11,058.32	10

Note: City Municipality (CM), Town Municipality (TM), Subdistrict Municipality (SM), Subdistrict Administrative Organization (SAO).
Population source: Department of Provincial Administration, Ministry of Interior (December, 2015).
Number in column of “site to dispose” is referred to “No.” column in Table 1.1.

1.5 Benefits of the study

1.5.1 Groups of stakeholders relevant to SWM and their preferences that can be used as a guide for the same kind of study in other areas which have the same structure of stakeholder.

1.5.2 Temporary TS location of each local administrative unit or their groups using GIS weighted centering,

1.5.3 Transportation patterns, characterized by active TS-DS pairs, optimum path of each pair, waste allocation and allotment, resulted from LP analyses with objective functions of minimized TC, EI, VI, and their combinations under constraints of 3-year and 5- year capacities of DSs and waste generated of each TS.

1.5.4 Ranked waste transportation patterns using stakeholder preferences and criteria outcomes of TC, EI, and VI resulted from LP analyses of different objective functions.

CHAPTER II

LITERATURE REVIEWS

The main related concepts and theories of this study can be summarized in this chapter. They include definitions of solid waste management, Stakeholder analysis for municipal solid waste, network analysis, MODA for waste allotment management, Procedure of outranking methods. Previous studies are also gathered and discussed.

2.1 Solid waste management

The process of solid waste management practices is very complex as it involves many technologies and disciplines associated with the control of generation, handling, storage, collection, transfer, transportation, processing, and disposal of solid waste (Tchobanoglous and Kreith, 2002).

All methods for solid waste management practices are described briefly as follows:

2.1.1 Policy and regulations for municipal waste management

In Thailand policy and Regulations for municipal waste management (CCACI, 2013) will cover levels, namely, national, provincial, and local.

1) National waste management policy

Legislation governing MSW management: There are three major laws relating to municipal solid waste management: 1) Public Health Act B.E. 2535 by the Ministry of Public Health, 2) Enhancement and Conservation of National Environmental Quality Act B.E. 2535 by the Ministry of Natural Resources and Environment, and 3) Cleanliness and Tidiness of the Country Act B.E. 2535 by the Ministry of Interior. Overall, the Pollution Control Department (PCD) and the Department of Health (DOH) will monitor and evaluate the performance of the municipality on waste management under the national laws, and the Department of Local Administration (DOLA) will cooperate with the two departments to control and monitor waste management activities of municipalities. These authorities can order the closure of dumpsites that do not meet standards and can punish the mayor and other staff for disciplinary offences. On the other hand, residents can also complain to the authorities if the residents are not satisfied with the service or if they find that the authorities do not comply with the law. In a serious case, the authorities may need to compensate residents if there is found to be serious damage.

2) Provincial level

All national level Laws, Regulations, Ordinances and Guidelines relevant to SWM are applicable at provincial level aimed at improving Waste Management in general: 3Rs (reduce, reuse, recycle) including promotion of waste reduction and separation at source, waste material recovery for composting, materials and energy use. Thailand will try to improve final disposal sites, and will also privatize waste management services, introduce the polluter pays principle and increase public participation.

3) Local level

For this level the management activity will follow all National level Laws, Regulations, Ordinances and Guidelines relevant to SWM which are applicable at provincial level as well.

2.1.2 Waste collection

Waste collection is the collection of solid waste from point of production (residential, industrial, commercial, institutional) to the point of treatment or disposal. Municipal solid waste is collected in several ways (Hoornweg and Bhada-Tata, 2012).

Rachita Sharma and Sharma (2015) states that collection of MSW broadly involves following steps:

Stage I: Collection of waste from a non-point source: This stage includes door-to-door collection of waste. Mostly collection is done by garbage collectors who are employees under contract to the government. Garbage collectors employed under local governing bodies collect the waste manually generated at the household level and dump that in the community bins at specified street corners.

Stage II: Collection from point source: Waste collected from point source is deposited to definite point sources i.e. communal bins. Communal bins are placed in apartment complexes, near markets, and in other appropriate locations like hotels, shopping complex, public places like gardens, religious places are other definite point sources. Vehicles collects waste from these point sources and then transport it to transfer stations and disposal sites whichever is near. For better MSW management garbage should be lifted frequently from these point sources. Frequency in lifting garbage from these points really matters otherwise garbage pile will create other problems. It is challenging task particularly in metros.

Stage III: Transportation to disposal sites: Transfer refers to the movement of waste or materials from collection points to disposal sites. Depending on the distance to be covered, transportation of waste from collection point to disposal sites is carried out by using different types of vehicles. Transfer stations are centralized facilities where waste is unloaded from smaller collection vehicles and re-loaded into larger vehicles so that it can be transferred to a disposal or processing site.

2.1.3 Waste transfer and transfer station

MSEA, USAID, and EEPP (2003) state that waste transfer is a supplemental transportation system that is an adjunct to collection route vehicles, which may reduce overall waste collection and transportation costs. Transfer is beneficial when the cost to haul waste directly from the collection route to the processing or disposal facility is greater than the combined costs of hauling from the route to the transfer station and then transferring the solid waste to the final destination. Transfer and transportation systems vary significantly among transfer stations, but they all consist of the following components:

1) A site near waste collection routes.

2) A receiving area where waste collection vehicles discharge their loads.

3) Equipment to move waste from the receiving area and load it into larger vehicles.

4) Transportation equipment, typically a semi-tractor and transfer trailer, to transport waste from the transfer station to the processing or disposal facility.

5) Equipment to unload waste from the transport vehicles (if not self-unloading) at the processing or disposal facility.

2.1.4 Waste disposal methods and environmental impact

The disposal of MSW is assumed to be based on wet weight. Each waste disposal category was calculated using waste generation figures for the individual country (Hoornweg and Bhada-Tata, 2012).

2.1.4.1 Source reduction

Waste or source reduction initiatives (including prevention, minimization, and reuse) seek to reduce the quantity of waste at generation points by redesigning products or changing patterns of production and consumption. A reduction in waste generation has a two-fold benefit in terms of greenhouse gas emission reductions. First, the emissions associated with material and product manufacture are avoided. The second benefit is eliminating the emissions associated with the avoided waste management activities (Hoornweg and Bhada-Tata, 2012).

2.1.4.2 Recycle and recovery

The key advantages of recycling and recovery are reduced quantities of disposed waste and the return of materials to the economy. In many developing countries, informal waste pickers at collection points and disposal sites recover a significant portion of discards (Hoornweg, Lam and Chaudhry, 2005). Related GHG emissions come from the carbon dioxide associated with electricity consumption for the operation of material recovery facilities. Informal recycling by waste pickers will have little GHG emissions, except for processing the materials for sale or reuse, which can be relatively high if improperly burned, e.g. metal recovery from waste (Hoornweg and Bhada-Tata, 2012).

2.1.4.3 Composting

Composting with windrows or enclosed vessels is intended to be an aerobic (with oxygen) operation that avoids the formation of methane associated with anaerobic conditions (without oxygen). When using an anaerobic digestion process, organic waste is treated in an enclosed vessel. Often associated with wastewater treatment facilities, anaerobic digestion will generate methane that can either be flared or used to generate heat and/or electricity. Generally speaking, composting is less complex, more forgiving, and less costly than anaerobic digestion. Methane is an intended by-product of anaerobic digestion and can be collected and combusted. Experience from many jurisdictions shows that composting source separated organics significantly reduces contamination of the finished compost, rather than processing mixed MSW with front-end or back-end separation (Hoornweg and Bhada-Tata, 2012).

2.1.4.4 Landfill

The waste or residue from other processes should be sent to a disposal site. Landfills are a common final disposal site for waste and should be engineered and operated to protect the environment and public health. Landfill gas (LFG), produced from the anaerobic decomposition of organic matter, can be recovered and the methane (about 50% of LFG) burned with or without energy recovery to reduce GHG emissions. Proper landfilling is often lacking, especially in developing countries. Landfilling usually progresses from open-dumping, controlled dumping, controlled landfilling, to sanitary landfilling (Hoornweg and Bhada-Tata, 2012).

2.1.4.5 Incineration

Incineration of waste (with energy recovery) can reduce the volume of disposed waste by up to 90%. These high volume reductions are seen only in waste streams with very high amounts of packaging materials, paper, cardboard, plastics and horticultural waste. Recovering the energy value embedded in waste prior to final disposal is considered preferable to direct landfilling - assuming pollution control requirements and costs are adequately addressed. Typically, incineration without energy recovery (or non-autogenic combustion, the need to regularly add fuel) is not a preferred option due to costs and pollution. Open-burning of waste is particularly discouraged due to severe air pollution associated with low temperature combustion (Hoornweg and Bhada-Tata, 2012).

2.1.4.6 Controlled Dumps

A controlled dump is a non-engineered disposal site where improvement is implemented on the operational and management aspects rather than on facility or structural requirements, which would otherwise require substantial investment. Controlled dumps evolved due to the need to close open dumpsites and replace them with improved disposal facilities, and in consideration of the financial constraints of Local Administrative Units. Controlled disposal of wastes may be implemented over existing wastes (from previous open dumping operations) or on new sites (UNEP, 2005).

2.1.4.7 Open dumping/open burning

Developing countries municipal solid waste which consists of a wide variety of materials such as food waste, paper, plastic, building material and metal scrap is openly dumped on waste sites. Burning of waste is a common practice to decrease the volume of waste and recover valuable items such as metals from waste. Dumping sites does not fulfill sanitary landfill requirements and only used as open dumping grounds without pollution controlling facilities and leachate treatment. Invasive smell, flies, insects and impacts on ground water, soil and nearby population are common issues. Burning of waste on site contribute towards release of toxic contaminants in the air while leachate contaminate the groundwater (Hafeez et al., 2016).

2.1.5 Vulnerability assessment of facilities on route

Panwhar, Pitt and Anderson (2000) state that vulnerability of the facilities which lie along each segment of route corridor for hazardous waste transportation, is calculated as the linear relationship between the population of the facility and its distance from that road segment. Population of each school is the enrollment according to the different types of school (elementary, junior, high etc.). The distance taken is the shortest distance from each facility to the route. The risk associated with the route is calculated taking the exponential probability function, which assumes the rate of accident as constant throughout the route. So the scoring or weight for the each segment of the route is the multiplication of the vulnerability of the facilities by the risk associated with that particular segment:

Scoring (of each segment) = Vulnerability of the facilities

Vulnerability of the Facilities Table 2.1 shows an example interrelationship of the two parameters (population of the facility and its distance from the road segment). As shown, the relative risk becomes lower as the distance from the road increases and it becomes higher with increasing population of the facility.

Table 2.1 Relative vulnerability of facilities of distance and population (Panwhar et al., 2000).

	Distance of Facility to Route (miles)			
Population:	0.5	1	5	10
500	4	2	0.4	0.2
1,000	8	4	0.8	0.4
5,000	40	20	4	3

From Table 2.1 it is obvious that: Population α Vulnerability, and Distance α 1/Vulnerability. The relative linear function from Table 1 is therefore:

$$f(p, d) = p /(250)d \quad (1)$$

Where, p is the population of the facility, d is the distance from the road link and 1/250 is a constant.

For MSW transportation, odor, leachate, and aesthetic view can still disturb people who live nearby and travel along the route. This is also considered as vulnerability affecting to facilities, which in turn to involving people. To fit for MSW transportation the vulnerability could be reduced to one-fourth of the hazardous waste and can be formulated as:

$$f(p, d) = p /(1000)d \quad (2)$$

2.2 Stakeholder analysis for municipal solid waste

2.2.1 Definition

There are definitions of stakeholder and stakeholder analysis of which their meanings are basically similar as examples given below:

Stakeholders are any group of people, organized or unorganized, who share a common interest or stake in a particular issue or system who can be at any level or position in society, from global, national and regional concerns down to the level of household or intra-household, and be groups of any size or aggregation (Grimble and Wellard, 1997).

Stakeholders are persons, groups or institutions with interests in a project or programme. Primary stakeholders are those ultimately affected, either positively (beneficiaries) or negatively (for example, those involuntarily resettled). Secondary stakeholders are the intermediaries in the aid delivery process. This definition of stakeholders includes both winners and losers, and those involved or excluded from decision-making processes (ODA, 1995).

Any individual, group, or institution who has a vested interest in the natural resources of the project area and/or who potentially will be affected by project activities and have something to gain or lose if conditions change or stay the same (Golder and Gawler, 2005).

Stakeholder Analysis (SA) is a methodology used to facilitate institutional and policy reform processes by accounting for and often incorporating the needs of those who have a “stake” or an interest in the reforms under consideration. With information on stakeholders, their interests, and their capacity to oppose reform,

reform advocates can choose how to best accommodate them, thus assuring policies adopted are politically realistic and sustainable (World Bank, 2010).

Stakeholder analysis is the identification of a project's key stakeholders, an assessment of their interests, and the ways in which these interests affect project riskiness and viability. It is linked to both institutional appraisal and social analysis: drawing on the information deriving from these approaches, but also contributing to the combining of such data in a single framework. Stakeholder analysis contributes to project design through the logical framework, and by helping to identify appropriate forms of stakeholder participation (ODA, 1995).

2.2.2 Procedure of stakeholder analysis (steps)

The simple question is often addressed why stakeholder analysis is important. Golder and Gawler (2005) states that a stakeholder analysis can help a project or programme identify:

1) The interests of all stakeholders who may affect or be affected by the project.

2) Potential conflicts or risks that could jeopardies the initiative;

3) Opportunities and relationships that can be built on during implementation;

4) Groups that should be encouraged to participate in different stages of the project;

5) Appropriate strategies and approaches for stakeholder engagement; and

6) Ways to reduce negative impacts on vulnerable and disadvantaged groups.

A stakeholder analysis focuses on identifying those groups of people who may directly or indirectly be affected by a project. They will participate in each stage of project development e.g. initiative, implementation, monitoring, etc. The analytical result would be able to inform different levels of influence from individual groups and how intensive the conflict or agreement of interests among groups of stakeholders is. This can indicate how solid a project is in terms of survival and sustainability.

According to many researchers (Golder and Gawler, 2005; Mayers, 2005; Ronald K. Mitchell, 1997) stakeholder analysis aims at determining the priority of groups of stakeholders, operating through brainstorming, questionnaires, discussions or individual interviews, and focus group workshop.

2.2.3 Key stakeholder identification

Identifying the key stakeholders is extremely important to the success of the analysis. Based on the resources available, the working group should decide on the maximum number of stakeholders to be interviewed by beginning with an open list that can be reduced, if necessary (Schmeer and Kammi, 1999).

The stakeholder identification process should be reassessed regularly throughout the project to ensure that no groups or individuals have been missed. This may involve identifying new stakeholders that need to be engaged as the research progresses or as stakeholder needs and priorities change over the course of the research. In the early stages of the project it could be beneficial to enter into dialogue with scientists working in other disciplines and/or groups or individuals who are likely to oppose the research, as this may help identify potential conflicts that could arise. It is important to ensure that groups or individuals that are considered to be potential sources of conflict are not left out of the engagement process simply because they have opposing views (Durham, Baker, Smith, Moore and Morgan, 2014).

Starting with the key questions could assist in target-orientated identification. The key questions to be asked in any of key stakeholder identification approaches possibly include (Mayers, 2005):

- Who are potential beneficiaries?
- Who might be adversely affected?
- Who has existing rights?
- Who is likely to be voiceless?
- Who is likely to resent change and mobilize resistance against it?
- Who is responsible for intended plans?
- Who has money, skills or key information?
- Whose behavior has to change for success?

The methods that will help identify stakeholders that can influence or be affected by the problem or action identified. The methods are (Chevalier and Buckles, 2008):

1) *Identification by experts.* Use staff, key agencies (such as non-governmental organizations), local people, or academics who have a lot of knowledge about the situation to identify stakeholders.

2) *Identification by self-selection.* Use announcements at meetings, in newspapers, on local radio or other media to invite stakeholders to come forward. This will attract those who believe they will gain from communicating their views and are able to do so.

3) *Identification by other stakeholders*. Ask them to suggest other key stakeholders who share their views and interests, as well as those who may have a different way of looking at the issues.

4) *Identification using written records and population data.* Census and population data may provide useful information about the numbers of people by age, gender, religion, residence, and so on. Stakeholder information may be obtained from directories, organizational charts, surveys, reports or written records issued by local authorities, donor agencies, government bodies, experts, academics, nongovernmental organizations, business and industry, and so on.

5) *Identification using oral or written accounts of major events.* By asking some of them to describe the major events in the history of a problem and the people who were involved in these events.

6) *Identification using checklists.* Using the checklists according to the project needs.

Durham et al. (2014) suggests useful tools for identifying key stakeholders as follows:

- Brainstorming with other organizations that have been involved in similar activities or those working in similar locations.
- Consulting with colleagues to share knowledge about who may have an interest in the research.
- Developing a "mind map" that can be used to identify suitable stakeholders; assessing secondary data (e.g. historical records, media articles).
- Utilizing government statistics and data (e.g. census information).

- Initiating self-selection by promoting the engagement process and encouraging individuals with an interest to come forward.
- Consulting with forums used by government and other organization (e.g. local authorities, town councils, emergency services etc.).

Figure 2.1 is an example displaying a list of stakeholders involving in stakeholder participation in solid waste management with particular reference to South Asia as a result of identification process.

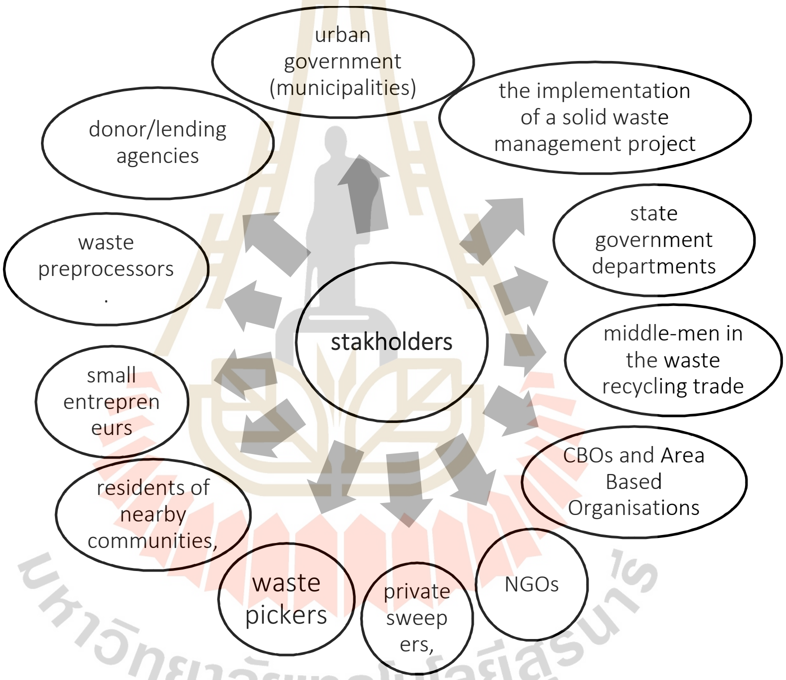


Figure 2.1 Example of stakeholder identification (Snel and Ali, 1999).

2.2.4 Classification of stakeholder

Once the stakeholders are identified as a list, they should be separated into groups indicating their different priorities in relation to the necessity of engagement. Not every stakeholder or stakeholder group needs to be involved to the same degree, or at the same time and the same stakeholder may be of differing relevance at different stages of the research or when working with another group. By considering the relevance of the stakeholders to the project it is possible to establish which might be best to contribute and which will be affected, and therefore critical to involve.

2.4.2.1 Salience model

Stakeholder salience is a very useful addition to Stakeholder theory. It can explain stakeholder behavior according to three major attributes (Mitchell et al., 1997), namely power, legitimacy, and urgency. Power is to influence the organization or project deliverables (coercive, financial or material, brand or image). Legitimacy indicates the relationship and actions in terms of desirability, properness or appropriateness. Urgency informs the requirements in terms of criticality and time sensitivity for the stakeholder.

Based on the combination of these attributes, groups of stakeholders can be classified and their priorities can be assigned as shown in Figure 2.2 Level of priority can be further classified by Rupen Sharma and PMP (2010) as displayed in Table 2.2.

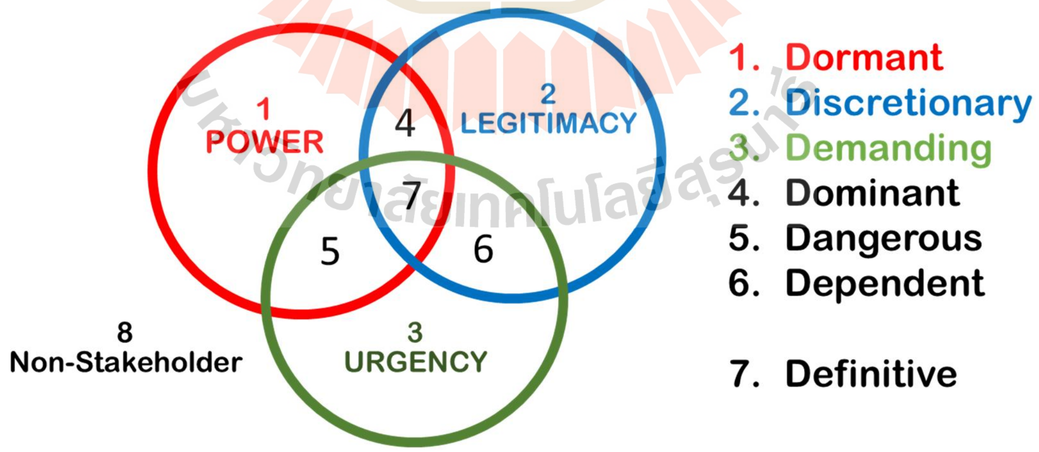


Figure 2.2 Salience model (Mitchell et al., 1997).

Table 2.2 Level classification of priority (Rupen Sharma and PMP, 2010).

Level 3 (High Priority)	7 – Definitive Power, Legitimacy & Urgency		
Level 2 (Medium Priority)	4 – Dominant Power & Legitimacy	5 – Dangerous Power & Urgency	6 – Dependent Legitimacy & Urgency
Level 1 (Low Priority)	1 – Dormant Power	2 – Discretionary Legitimacy	3 – Demanding Urgency

Characteristics of groups of these stakeholders can be described as follows:

Dormant Stakeholders - Possess power to impose their will through coercive, utilitarian or symbolic means, but have little or no interaction /involvement as they lack legitimacy or urgency.

Discretionary Stakeholders - Likely to recipients of corporate philanthropy. No pressure on managers to engage with this group, but they may choose to do so. Examples are beneficiaries of charity.

Demanding Stakeholders - Those with urgent claims, but no legitimacy or power. Irritants for management, but not worth considering. Examples are people with unjustified grudges, serial complainers or low return customers.

Dominant Stakeholders - The group that many theories position as the only stakeholders of an organization or project. Likely to have a formal mechanism in place acknowledging the relationship with the organization or project e.g. Boards of directors, HR department, public relations.

Dangerous Stakeholders - Those with powerful and urgent claims will be coercive and possibly violent. For example employee sabotage or coercive/unlawful tactics used by activists. Note that Mitchell et al. identify these stakeholders, but don't require them to be acknowledged & thus awarded legitimacy.

Dependent Stakeholders - Stakeholders who are dependent on others to carry out their will, because they lack the power to enforce their stake. For example local residents impacted. Advocacy of their interests by dominant stakeholders can make them definitive stakeholders.

Definitive Stakeholders - An expectant stakeholder who gains the relevant missing attribute. Often dominant stakeholders with an urgent issue, or dependent groups with powerful legal support. Finally those classed as dangerous could gain legitimacy e.g. democratic legitimacy achieved by a nationalist party.

2.4.2.2 Fuzzy salience model

According to (Poplawska, Labib, Reed and Ishizaka, 2015), the methodology is based on two phases deconstructed into 2 steps for the first phase followed by 3 steps in the second phase and is displayed in Figure 2.3.

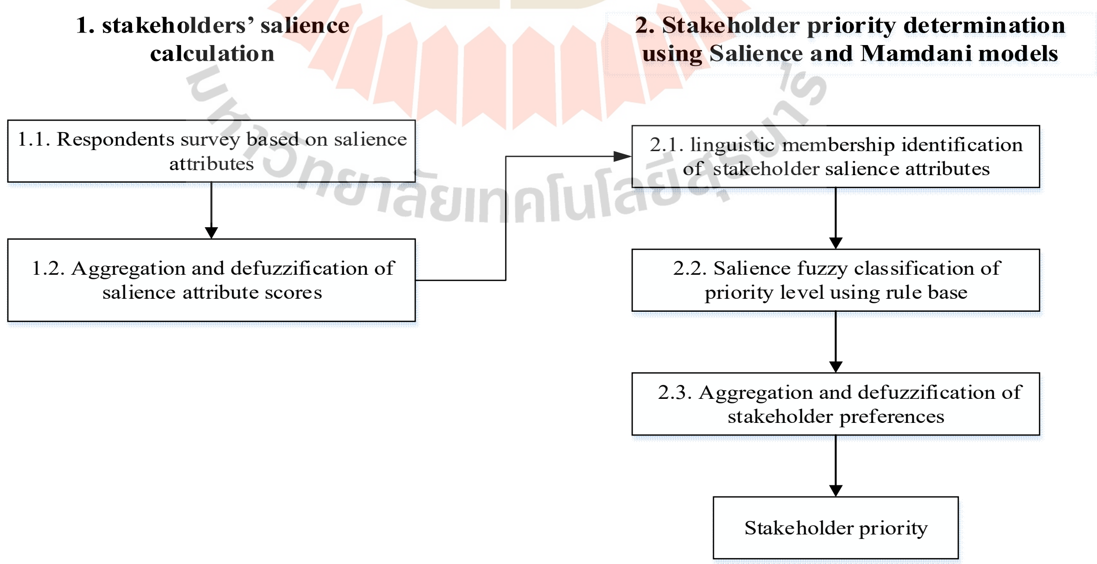


Figure 2.3 The process of Fuzzy salience model.

1) Salience Model

The first phase calculates the stakeholders' salience calculation.

1.1) Evaluations: Respondents are asked to evaluate the importance of every stakeholder with respect to the attributes of power, legitimacy and urgency on a Likert scale ranging from 0 (none) to 3 (high) with the intermediate levels 1 (low) and 2 (medium).

1.2) Respondents' aggregation and defuzzification: The evaluations of all respondents in terms of 3 attributes are aggregated into a unique score by calculating the average value. The upper and lower in range (max and min) of each attribute are also taken. The profile scores of groups of stakeholder are obtained by defuzzification of each attribute using equation of the weighted average method:

$$Y = (min_i + 2*average + max_i)/4 \quad (3)$$

2) Stakeholder priority determination using Salience and Mamdani models

The second phase is determination of stakeholder priority by Mamdani fuzzy model, one of fuzzy inference system. The model is often applied in a sustainability context as it is intuitive and allows appropriate modelling of human input (Phillis and Andriantiatsaholiniaina, 2001).

2.1 Linguistic membership identification of stakeholder salience attributes: Fuzzy membership functions are defined. The trapezoidal functions are used to represent attributes' uncertain values as displayed in Figure 2.4 This process fuzzify the crisp entry value of each attribute to be a fuzzy class.

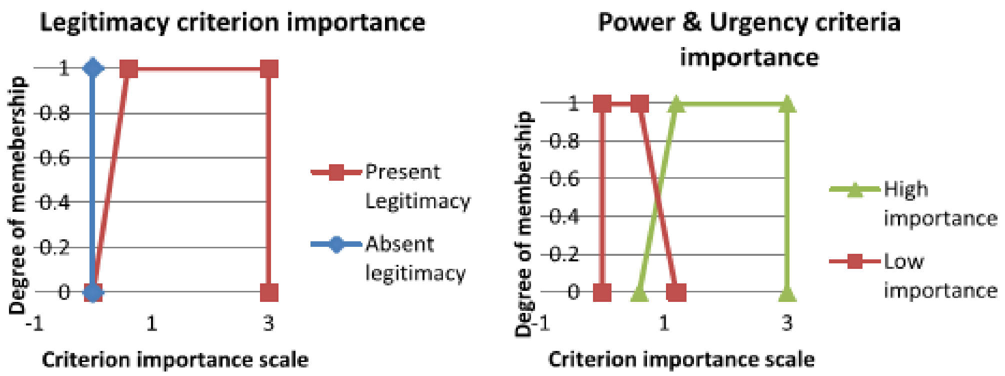


Figure 2.4 The membership functions of the linguistic importance of attributes (Poplawska et al., 2015).

2.2 Salience fuzzy classification of priority level using rule base: The fuzzy if - then rules are developed based on combination of fuzzy classes of 3 attributes of stakeholder group (Table 2.3). The rules are applied to obtaining groups and their priority level classes, e.g. low (Dormant, Discretionary, Demanding), moderate (Dominant, Dangerous, Dependent), high (Definitive), and none (Non-stakeholder). The priority level classes are in linguistic fuzzy terms and their membership degree can be displayed in Figure2.5.

Table 2.3 The fuzzy if - then rules (Poplawska et al., 2015).

Salience	**If-then rules applied in the study**		
	Rule no.	**Antecedent part**	**Consequent part**
Low	1	If legitimacy is absent and power is high and urgency is low	Then stakeholder is Dormant
	2	If legitimacy is present and power is low and urgency is low	Then stakeholder is Discretionary
	3	If legitimacy is absent and power is low and urgency is high	Then stakeholder is Demanding
Moderate	4	If legitimacy is present and power is high and urgency is low	Then Stakeholder is Dominant
	5	If legitimacy is absent and high and urgency is High	Then stakeholder is Dangerous

Table 2.3 The fuzzy if - then rules (Poplawska et al., 2015) (Continued).

Salience	If-then rules applied in the study		
	Rule no.	Antecedent part	Consequent part
Moderate	6	If legitimacy is present and power is low and urgency is high	Then stakeholder is Dependent
High	7	If legitimacy is present and power is high and urgency is high	Then stakeholder is Definitive
None	8	If legitimacy is absent and power is low and urgency is low	Then stakeholder is non stakeholder

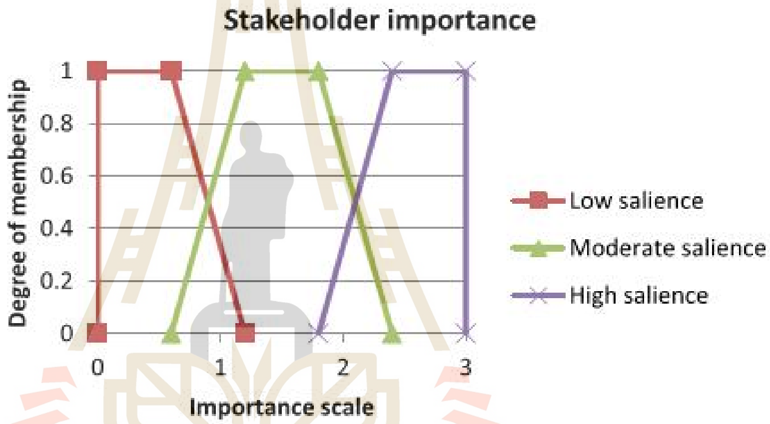


Figure 2.5 Salience priority levels of stakeholders.

2.3 Aggregation and defuzzification of stakeholder preferences: Aggregation based on rule(s) of each combination of 3 attributes is operated using fuzzy Min while aggregation of salience classes is operated using fuzzy Max. This aggregated result of each stakeholder is defuzzified using the center of gravity (COG) method. The defuzzified scores indicate stakeholder priorities and can be used in further MCDA for any purposes required by certain activities.

2.2.5 The Mamdani Fuzzy

Fuzziness is a type of imprecision describing a set of objects or elements that do not have sharply defined boundaries. Such imprecisely defined sets of objects are called fuzzy sets. The concepts of fuzzy number and linguistic variable provide the base for the fuzzy MCDA. There are two main types of approaches for performing a combination of linguistic information: approximation and symbolic methods. The approximation, or indirect approach, uses the membership functions associated with the linguistic terms. The trapezoidal or triangular membership functions are typically employed to capture the vagueness of the linguistic terms. The direct or symbolic approach makes direct use of labels for computing. It is based on the premise that the set of linguistic terms is an ordered structure uniformly distributed on a scale. An extension of the Ordered Weighted Averaging (OWA) using the concept of fuzzy linguistic quantifiers provides an example of the direct approach to GIS-MCDA (Malczewski and Rinner, 2015).

The representation of Mamdani fuzzy inference system is shown in Figure 2.6, In this case (Peña-Reyes and Sipper, 1999), there are two crisp inputs, x_0 and y_0, and three sets of membership functions, A_j, B_j and C_j, $j = 1, 2$, each set of which represent the rule A_j and $B_j \Rightarrow C_j$, where the conjunction "and" is interpreted to mean the fuzzy intersection. The minimum of the fuzzy inputs in the first two columns gives the levels of the firing (shown by the dashed lines) and their impact on the inference results (shown by the shaded areas in the third column). Taking the union of the shaded areas of the first two rows of column three results in the fuzzy set show in the third row, which represents the overall conclusion.

Defuzzification converts the fuzzy overall conclusion into a numerical value that is a best estimate in some sense. In general, the center of gravity (COG) approach, which defines the numerical value of the output to be the abscissa of the center of gravity of the union, is often applied. In practice, this is computed as: $\sum_j w_j x_j$, where the weight w_j is the relative value of the membership function at x_j, that is, $w_j = \mu(x_j)/\sum_j \mu(x_j)$.

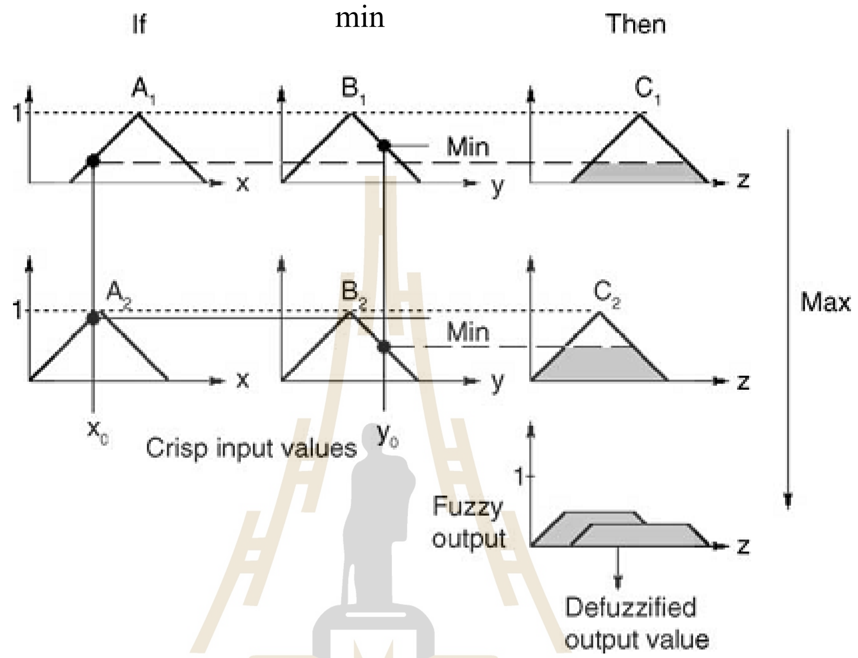


Figure 2.6 Mamdani fuzzy inference system (Peña-Reyes and Sipper, 1999).

2.3 Network analysis

A network is referred to as a pure network if only its topology and connectivity are considered. If a network is characterized by its topology and flow characteristics (such as capacity constraints, path choice and link cost functions) it is referred to as a flow network. A transportation network is a flow network representing the movement of people, vehicles or goods (Bell and lida, 1997).

The network module (ESRI, 1995) of Arc/Info GIS software is used with the planned infrastructure to find the shortest or minimum impedance path through a network. The speed of the vehicle is taken as the arc impedance and no turn impedance is being used. Optimizing the MSW collecting routes is important, because of its high percentage in expenditures of collection and transportation sector out of the total amount for the waste management, about 60 to 80 percent, based on the estimations. Therefore, a simple upgrade in this section could have a significant impact on the total cost of waste management Tchobanoglous (1993). NA is particularly useful for routing applications that require finding the best route between the origin and the destination. The best route may be shortest, the safest, or the most scenic, depending on purpose of travel (Lo and Yeung, 2002). Most of the previous work related to optimal routing model is proposed to determine the minimum cost efficient collection paths for transporting the solid wastes to the landfill (Ghose, Dikshit and Sharma, 2006).

2.3.1 Shortest path analysis

Shortest path analysis finds the path with the minimum cumulative impedance between nodes on a network. Because the link impedance can be measured in the distance or time, a shortest path may represent the shortest route or fastest route. Shortest path analysis typically beings with an impedance matrix in which a value represent the impedance matrix in which a value represents the impedance of a direct link between two nodes on a network and an ∞ (infinity) means no direct connection. The problem is to find the shortest distance (least cost) from a node to all other nodes (Chang, 2014).

Dijkstra's Algorithm

The Dijkstra's Algorithm was discovered by Edsger Wybe Dijkstra, a Netherland's mathematician, for computing shortest path distance of weighted graph (Evans, Minieka, 1992, quoted in Aunphoklang, 2012). Dijkstra's algorithm is a labelsetting algorithm in that a label is permanent at all iterations. The main idea underlying the Dijkstra shortest path algorithm is explained as the following steps.

Step 1: Initially, all arcs and vertices are unlabeled. Assign a number $d(x)$ to each vertex x to denote the tentative length of the shortest path from s to x that uses only labeled vertices as intermediate vertices. Initially, set $d(s) = 0$ and $d(x) = \infty$ for all $x \neq s$.. Let y denotes the last vertex that was labeled. Label vertex s and let $y = s$.

Step 2: For each unlabeled vertex x, redefine $d(x)$ as follows:

$$d(x) = \min\{d(x), d(y) + a(y,x)\}.$$

This can be performed efficiently by scanning the forward star of node y since only these nodes will be affected. If $d(x) = \infty$ for all unlabeled vertices x, then stop because no path exists from s to any unlabeled vertex. Otherwise, label the unlabeled vertex x with the smallest value of $d(x)$. Also label the arc directed into vertex x from a labeled vertex that determined the value of $d(x)$ in the above minimization. Let $y = x$.

Step 3: If vertex t has been labeled then stop, since a shortest path from s to t has been discovered. This path consists of the unique path of labeled arcs from s to t. If vertex t has not been labeled yet, repeat step 2.

2.3.2 Closest facility

Closest facility is a network analysis that finds the closest facility among candidate facilities to any location on a network. The analysis first computes the shortest paths from the select location to all candidate facilities, and then chooses the closest facility among the candidates. Figure 2.7 shows, for example, the closest fire station to a street address. A couple of options may be applied to the closest facility problem. First, rather than getting a single facility, the user may ask for a number of closest facilities. Second, the user may specify a search radius in distance or travel time, thus limiting the candidate facilities (Chang, 2014).

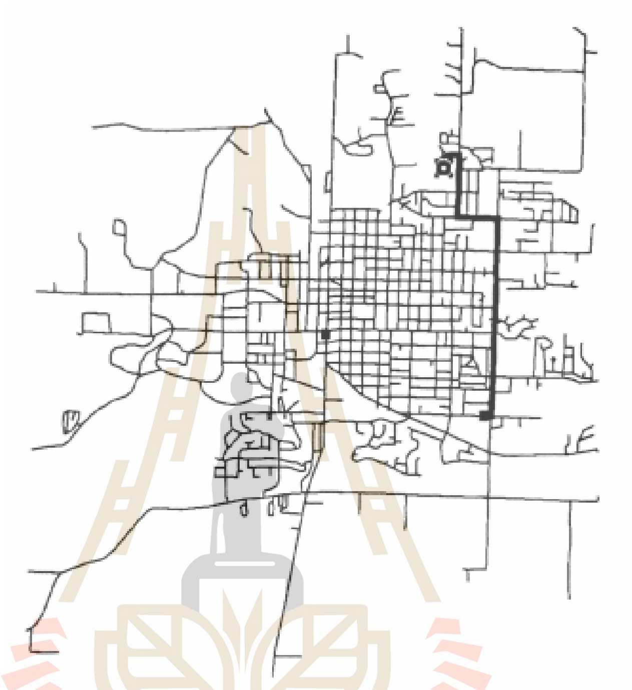


Figure 2.7 Shortest path from a street address to it is closest fire station (Chang, 2014).

2.4 MODA for waste transportation management

Multi-objective problems are problems with two or more, usually conflicting, objectives. The main difference from single-objective optimization is that a multi-objective problem does not have one single optimal solution, but instead has a set of optimal solutions, where each represents a trade-off between objectives (Justesen, 2009).

Multi-objective optimization (or multi-criteria optimization) deals with optimization in the presence of more than one (usually conflicting) objective functions (criteria). In multi-objective optimization problems there is no a single optimal solution (that simultaneously optimizes all the criteria), but a set of equally good alternatives with different trade-offs, also known as Pareto-optimal (or non-dominated or efficient) solutions (Mavrotas, Gakis, Skoulaxinou, Katsouros and Georgopoulou, 2015).

The expected processes of multi-objective decision analysis in near future research is performed using optimized objective function of linear programming (LP). The objective function should cover analysis of multi-objectives, i.e. transportation cost and environmental impact on optimum routes and sites for waste transfer and disposal. Variation of amount and allotment of solid waste transported to stations and sites will be managed to achieve optimum transportation cost and environmental impacts.

Linear Programming

Gupta (2009) explained the general concept of the linear programming deals with that class of programming problems for which all relations among the variables are linear. The relations must be linear, both in the constraints and in functions to be optimized. A linear problem includes a set of simultaneous linear equations which represent the conditions of the problem and a linear function which expresses the objective function of the problem. The linear function which is to be optimized is called the objective function and the conditions of the problem expressed as simultaneous linear equation are referred as constraints.

The following example case presents minimization as the optimization function of a single objective. Any general LP problem can be expressed in accepted form as:

minimize

$$z = \min(c_1x_1 + c_2x_2 + \ldots + c_nx_n); \tag{4}$$

subject to

$$\left.\begin{aligned} &a_{11}x_1 + a_{12}x_2 + \ldots + a_{1n}x_n \geq b_1; \\ &a_{21}x_1 + a_{22}x_2 + \ldots + a_{2n}x_n \geq b_2; \\ &\quad\quad\quad\quad\quad\quad . \\ &\quad\quad\quad\quad\quad\quad . \\ &\quad\quad\quad\quad\quad\quad . \\ &a_{m1}x_1 + a_{m2}x_2 + \ldots + a_{mn}x_n \geq b_m; \end{aligned}\right\} \tag{5}$$

and

$$x_1, x_2, \ldots, x_n \geq 0. \tag{6}$$

LP consists of the following three parts.

(1) Objective function: here $c_1x_1 + c_2x_2 + \ldots + c_nx_n$; is the objective function (or criterion function) to be minimized and will be denoted by z. The coefficients $c_1, c_2, \ldots, c_n$ are the (known) cost coefficients and $x_1, x_2, \ldots, x_n$ are the decision variables (unknown) to be determined.

(2) Constraint set: the inequality $\sum_{j=1}^{n} a_{ij}x_j \geq b_i$ denotes the ith constraint set. In practice, the condition of constraints can be $\geq$, or $=$, or $\leq$ as long as it serves the objective of optimization.

The coefficients a_{ij} for $i=1,2,...,m,\ j=1,2,...,n$ are called the technological coefficients. The coefficients are usually expressed in matrix form of A.

$$A=\begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & & \vdots \\ a_{m1} & a_{m2} & \cdots & a_{mn} \end{bmatrix}$$

The column vector whose *i*th component is b_i, which is referred to as the right-hand-side vector, represents the minimal requirement to be satisfied.

(3) Non-negativity constraints: the constraints $x_1,x_2,...,x_n \geq 0$ are the non-negativity constraints. A set of variables $x_1,...,x_n$ satisfying all the constraints is called a feasible point or a feasible vector. The set of all such points constitutes the feasible region or feasible space.

2.5 Procedure of outranking methods

2.5.1 Definition

The outranking methods are based on a pairwise comparison of alternatives for each evaluation criterion. The underlying assumption of these methods is that the decision maker's preference structure can be represented by outranking relations, which are defined for each pair of alternatives A*i* and A*j*. The *i*th alternative outranks the *j*th alternative if there is enough evidence to declare that A*i* is at least as good as A*j* on the majority of the criteria, while there is no essential evidence to show that the statement is false with respect to the remaining criteria (Malczewski and Rinner, 2015). Outranking methods can be used to combine quantitative and qualitative data for making decisions. It is possible to use different scales for the values inserted in the model (Greco, 2005).

2.5.2 PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluations)

There are several variants of the PROMETHEE method including PROMETHEE I, II, III, IV, V, and VI. PROMETHEE I and II have been integrated into GIS (Malczewski and Rinner, 2015). Therefore, these two forms of the method are discussed herein. Steps of PROMETHEE I and II for outranking can be displayed in Figure 2.8.

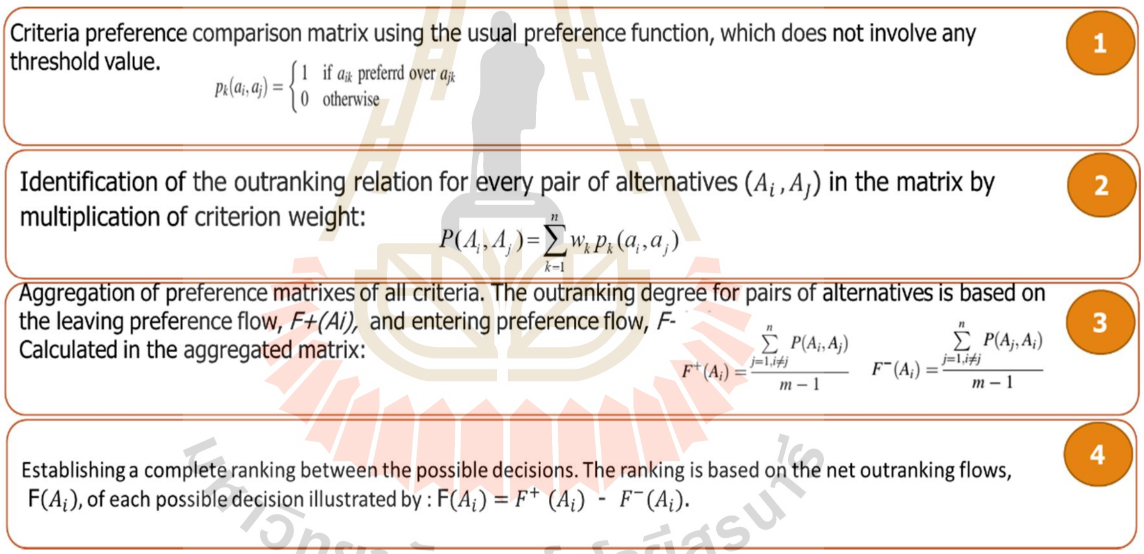


Figure 2.8 Steps to rank alternative using PROMETHEE.

The methods use the following procedure for identifying the outranking relation for a pair of alternatives (A_i, A_j):

$$P(A_i, A_j = \sum_{k=1}^{n} w_k p_k (a_i, a_j), \quad (7)$$

where P(A_i , A_J): is the outranking degree of a pair of alternatives, w_k is the kth criterion weight, and $p_k(a_i, a_j)$ is the preference function of the kth criterion. The form of the preference function is determined by the type of the criterion and the threshold values, which take into account the impreciseness (fuzziness) of the criterion values. Brans et al. (1984) suggest six types of the preference: the usual (or strict), U-shape (threshold), V- hape (linear over range), level (stair-step), V-shape with threshold (linear with threshold), and Gaussian functions. The simplest form is the usual preference function, which does not involve any threshold value. It is defined as follows:

$$p_k(a_i, a_j) = \begin{cases} 1 & \text{if } a_{ik} \text{ preferrdover } a_{jk} \\ 0 & \text{otherwise} \end{cases} \tag{8}$$

where a_{ik}, and a_{jk} are the values associated with the *i*th and *j*th alternatives for the *k*th criterion, respectively. Table 2.5 gives the preference values, $p_k(a_i, a_j)$, for the data shown in Table 2.4.

Table 2.4 Input data for the PROMETHEE example.

		Criteria		
		c_1 (%)	c_2 (Km)	c_3 (Scale)
Alternatives	A_1	18	1.2	M
	A_2	10	1.5	L
	A_3	5	1.8	H
	A_4	12	2.0	H
Weights	w_k	0.45	0.35	0.20
Min or max		Min	Min	Max
Scale intervals		100	60	30

Note L= low, M = medium, H = high

For example, for the criterion to be minimized, the value of a_{21}= 10% is preferred over a_{11} = 18%, and consequently, $p_1(a_1, a_2)$ = 0 and $p_1(a_2, a_1)$ = 1. Given the preference structures for the three criteria, the value of P(A_i , A_J) can be computed using Eq. 7. For example, P(A_i , A_J) = (0 × 0.45) + (1 × 0.35) + 1 × 0.20) = 0.55 (see Table 2.6).

Table 2.5 The preference values, $p_k\left(a_i, a_j\right)$, for the data in Table 2.4.

(a)					(b)					(c)				
C_1	A_1	A_2	A_3	A_4	C_2	A_1	A_2	A_3	A_4	C_3	A_1	A_2	A_3	A_4
A_1	-	0	0	0	A_1	-	1	1	1	A_1	-	1	0	0
A_2	1	-	0	1	A_2	0	-	1	1	A_2	0	-	0	0
A_3	1	1	-	1	A_3	0	0	-	1	A_3	1	1	-	0
A_4	1	0	0	-	A_4	0	0	0	-	A_4	1	1	0	-

The pairwise comparisons of four alternatives with respect to three criteria: (a) C_1, (b) C_2, and (c) C_3

Table 2.6 The results of PROMETHEE for the data in Table 2.5.

Alternative		j				$F^+(A_i)$	$F(A_i)$	Rank
		A_1	A_2	A_3	A_4			
i	A_1	-	0.55	0.35	0.35	0.417	-0.166	3
	A_2	0.45	-	0.35	0.80	0.533	0.066	2
	A_3	0.65	0.65	-	0.80	0.700	0.467	1
	A_4	0.65	0.20	0.00	-	0.283	-0.367	4
	$F^-(A_i)$	0.583	0.467	0.233	0.650			

The outranking degree for pairs of alternatives, P(A_i , A_J), the leaving flow, $F^+(A_i)$, the entering flow, $F^-(A_i)$, and the net flow, F (A_i)

Given the outranking values, P(A_i , A_J), the PROMETHEE procedure evaluates each alternative based on the leaving and entering preference flows:

$$F^{+}(A_i) = \frac{\sum_{j=1, i \neq j}^{n} P(A_i, A_j)}{m-1} \quad (9)$$

$$F^{-}(A_i) = \frac{\sum_{j=1, i \neq j}^{n} P(A_i, A_j)}{m-1} \quad (10)$$

where $F^{+}(A_i)$ and $F^{-}(A_i)$ are the leaving (or positive) and entering (or negative) flows, respectively, and m is the number of alternatives. The preference of an alternative over all other alternatives is measured by the leaving flow, whereas the preference of all other alternatives over an alternative is measured by the entering flow. The positive outranking flow expresses how each alternative is outranking all the others. The alternative is better if it has higher positive flow. The negative outranking flow expresses how each alternative is outranked by all the others. The alternative is better if it has smaller negative flow.

In the PROMETHEE I method, the alternatives are ranked using the leaving and entering flows. This results in a partial ordering of the alternatives. A complete ordering in PROMETHEE II is obtained by calculating the net flow:

$$F(A_i) = F^{+}(A_i) - F^{-}(A_i) \quad (11)$$

The most preferred alternatives are the ones with the higher net flows, whereas the alternatives with the lower net flows are considered as the least preferred ones. Table 2.6 shows the values of $F^{+}(A_i)$, $F^{-}(A_i)$. and $F(A_i)$. For example, the flows alternative (A_1) are obtained as follows: the leaving flow $F^{+}(A_1)$, = (0.55 + 0.35 + 0.35) /3 = 0.417, the entering flow $F^{-}(A_1)$.= (0.45 + 0.65 + 0.65) / 3 = 0.583, and the net flow F(A_1). = 0.417 − 0.583 = − 0.166. The PROMETHEE procedure results in the complete ordering of the alternatives: $A_3 > A_2 > A_1 > A_4$.

PROMETHEE has been combined with Geographic Information Systems and spatial models for land use suitability assessment and sustainable forest management. PROMETHEE can be used to compare the impact of alternative policies generated by other tools like physical assessment tools, modelling tools and environmental appraisal tools. PROMETHEE can also be used in combination with stakeholder analyses and is capable to support the evaluation of alternative policies/plans/projects in policy impact assessment

2.6 Previous studies

Caniato, Vaccari, Visvanathan and Zurbrügg (2014) assessed the strengths and weaknesses of a solid waste management scheme requires an accurate analysis and integration of several determining features. They used social network analysis and stakeholder analysis (SA) methods applied to better understand actors' role and actions, analyses driving forces and existing coordination among stakeholders, as well as identify bottlenecks in communication which affect daily operations or strategic planning for the future way forward. The results of an analysis of On-Nuch infectious waste incinerator in Bangkok, Thailand. Stakeholders were interviewed and asked to prioritize characteristics and relationships which they consider particularly important for system development and success of the scheme. The survey results suggest that stakeholders are generally satisfied with the system operation, though communication should be improved. Moreover, stakeholders should be strategically more involved in system development planning, according to their characteristics, to prevent negative reactions.

Poplawska et al. (2015) discusses the various stakeholder management models that are available on a case study organization within the extractive sector in relation to the decision making associated with corporate social responsibility. Then presents the new framework that we have developed based on fuzzy logic, and illustrates the application of them framework. The 3-D surface aids in the rating and selection of key stakeholders in different scenarios. From a list of attributes, the relevant criteria are selected by the decision maker. These preferences are used for the evaluation of criteria and subsequent assessment of stakeholders. This is all accomplished by applying a set of fuzzy logic rules. For the purpose of this study, fuzzy membership functions were assigned based on the respondents' judgments. Considering the fuzzy decision rules, the stakeholders' map emphasizing their salience is produced.

De Feo and De Gisi (2010) studied about verify the efficacy of using an innovative criteria weighting tool (the ‘‘priority scale”) for stakeholders involvement to rank a list of suitable municipal solid waste (MSW) facility sites with the multi-criteria decision making (MCDM) technique known as analytic hierarchy process (AHP). In this study, in order to pursue both the technical (select the best site) and social aims (all the stakeholders have to give their aware contribution), the use of the “priority scale” is suggested as a tool to easily collect non-contradictory criteria preferences by the various decision-makers. The proposed method was applied to the siting of a composting plant in an area suffering from a serious MSW emergency, which has lasted for over 15 years, in the Campania Region, in Southern Italy.

Eskandari, Homaee and Mahmodi (2012) presented an approach for landfill siting based on conflicting opinions among environmental, economical and socio-cultural expertise. In order to gain optimized siting decision, the issue was investigated in different viewpoints. Based on opinion sampling and questionnaire results of 35 experts familiar with local situations, the national environmental legislations and international practices, 13 constraints and 15 factors were built in hierarchical structure. Factors divided into three environmental, economical and socio-cultural groups. The importance of each group of criteria in its own vision was assigned to be higher than two other groups. The final suitability map was obtained after crossing three resulted maps in different visions and reported in five suitability classes for landfill construction. And in the last stage, a comprehensive field visit was performed to verify the selected site obtained from the proposed model. This field inspection has confirmed the proposed integrating approach for the landfill siting.

Ghose, Dikshit and Sharma (2006) applied GIS based transportation model for solid waste disposal in Asansol municipality, India. This research applied GIS Network Analysis model based on the criteria includes: population density, waste generation capacity, road network, storage bins, and collection vehicles. It is developed and used to finding the shortest or minimum path for transporting the solid wastes to the landfill sites based on minimum cost/distance. The result show as the model can be used as a decision support tool by the municipal authorities for efficient management of the daily operations for moving solid wastes, load balancing within vehicles, managing fuel consumption and generating work schedules for the workers and vehicles.

Galante, Aiello, Enea and Panascia (2010) study about the localization and dimensioning of transfer stations, which constitute a necessary intermediate level in the logistic chain of the solid waste stream, from municipalities to the incinerator. To determine a set of values for the decision variables in order to minimize both costs and environmental impact. The design of the integrated waste management system is hence approached in a multi-objective optimization framework. To determine the best means of compromise, goal programming, weighted sum and fuzzy multi-objective techniques have been employed. The proposed analysis highlights how different attitudes of the decision maker towards the logic and structure of the problem result in the employment of different methodologies and the obtaining of different results.

Yu, Solvang and Li (2015) presented a bi-objective dynamic linear programming model is developed for decision making and supporting in the long-term operation of municipal solid waste management system. The proposed mathematical model simultaneously accounts both economic efficiency and environmental pollution of municipal solid waste management system over several time periods, and the optimal tradeoff over the entire studied time horizon is the focus of this model. For application of the model is applied to determine the optimal waste allocation plan of a municipal solid waste management system in a continuous five time periods. The studied area includes three communities, and the municipal solid waste management system is constituted by three local collection centers, two regional distribution centers, two incineration plants and one landfill.

Banias, Achillas, Vlachokostas, Moussiopoulos and Tarsenis (2010) presented methodological framework is aiming towards optimal location of units of alternative construction and demolition waste management and it is following the path of multicriteria analysis. For the problem under study, ELECTRE III technique is adopted. The decision process presented requires the adoption of a number of logical steps mainly, clarification of the decision criteria for selecting the optimal location (economical, environmental and social), the definition of their relative significance and data assembly. The approach allows a robust parameter analysis in order to evaluate and compare in detail all available alternatives. On top of that, sensitivity analysis is also available, since parameter values in real life applications originate from estimations which are sometimes more or less reliable.

Makan and Mountadar (2013) examined alternate schemes and analyzed aiming at the improvement of MSW management in small urban municipalities in Morocco. These schemes are estimated by developing and applying the PROMETHEE method consisting in a multi-criteria analysis of the parameters and the constraints bound to the financial, technical, environmental and social-institutional aspects. Thus, 10 alternate management schemes were compared and ranked according to their performance and their efficiency. The obtained results will certainly help the decision-makers to make a decision for the best management scheme which hold in account particularities of every region, commune or municipality in Morocco.

Balali, Zahraie and Roozbahani (2014) addresses how the best system can be selected using AHP and PROMETHEE family of multiple criteria decision-making techniques. These techniques have been utilized in this study for selecting the appropriate structural system among 3D Panel with light walls in building frames, LSF, ICF, Tunnel Formwork system, and Tronco in a low rise multi-housing project in Iran. A questionnaire has been designed to collect engineering judgments and experts' opinions on various parameters such as weight of different criteria. The team of experts who has cooperated in this research includes engineers and managers of consultants, contractors, and owners who are involved in different low rise multi-housing projects in Iran. A comparison between the two techniques has been carried out based on the consistency of the results, the required amount of interactions with the decision-makers, and ease of understanding. For the case study of this research, 3D Panel with light walls in building frames has been selected as the most appropriate structural system. The PROMETHEE II has been selected as the preferred method for the appropriate structural system selection process since its results are consistent, easy to understand, and require less information from decision-makers compared to AHP.

CHAPTER III

RESEARCH PROCEDURES

The study was focused mainly on stakeholder analysis, MODA, and PROMETHEE for solid waste management. The analyses such as network analysis and vulnerability assessment were operated to obtain input data and information for above mentioned analyses. The conceptual framework of the study is shown in Figure 3.1.

As mentioned above, this study contains 4 research objectives: the first is to perform stakeholder analysis for waste management. The second is to select temporary TS of each zone by GIS weighted centering. The third is to evaluate VI on optimum paths between temporary TSs and DSs using vulnerability assessment based on population and locations of facilities. The fourth is to analyze ranking of patterns of waste management based on TC, EI, and VI using stakeholder preferences and PROMETREE method. The research procedure in detail is described as follows:

3.1 Data collection and preparation

The input GIS data required for the study as listed in Table 3.1 were collected and prepared to be in suitable form of input for further processes.

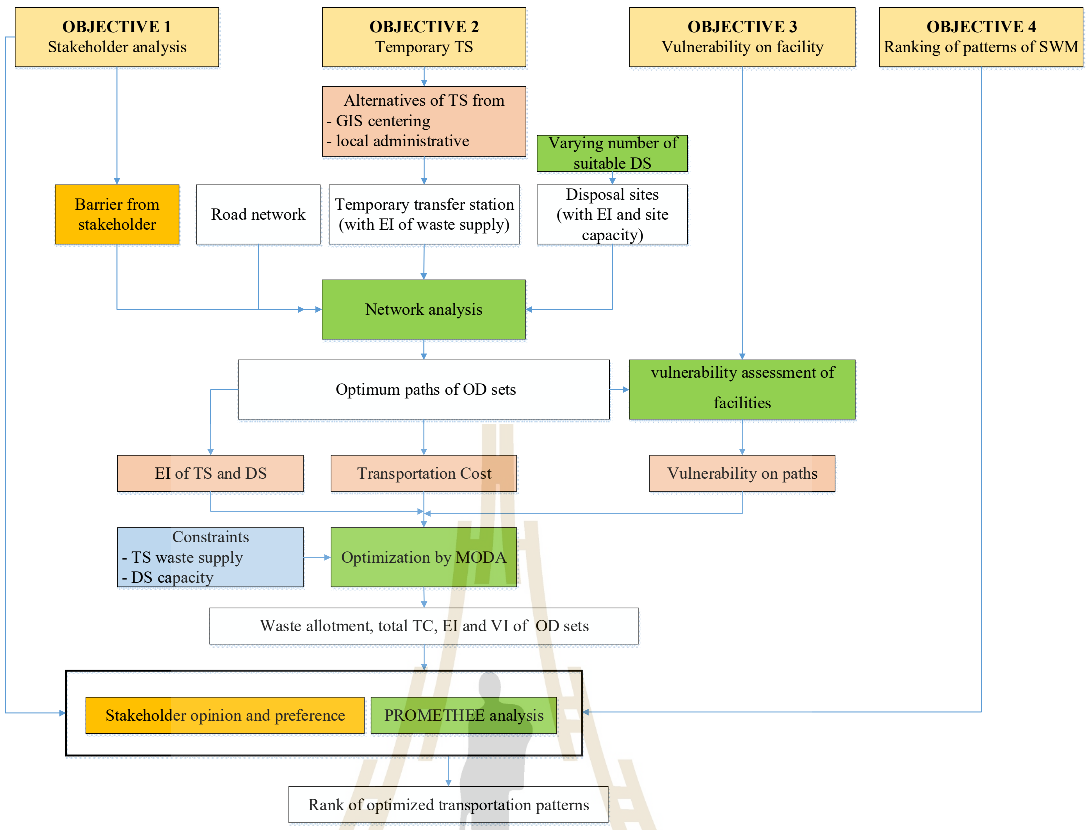


Figure 3.1 Conceptual framework: Multi-objective decision analysis (MODA) and PROMETHEE analysis.

Table 3.1 Required GIS data, their sources, and acquiring.

Data category	Format	Year	Source
Disposal site	Point	2016	Environmental office region 3 / Provincial offices for natural resources and environment Phitsanulok.
Transfer station	Point	Current	Temporary locating using GIS weighted mean centering from group of village, stakeholder.
Road network	Line	2003	Department of Environmental Quality Promotion (DEQP).
Facilities	Point Attribute	2016	DEQP Field survey, report, and interview.
Administrative unit boundary	Polygon	2007	Department of provincial administration (DOPA)
Village	Point	2007	Department of provincial administration (DOPA)

To locate temporary transfer station (TS) to maximize waste collection efficiency within every administrative unit or their group(s), the weighted mean centering process was used to determine X Y coordinate as follows:

$$\overline{X} = \frac{\sum_{i=1}^{N} W_i X_i}{\sum_{i=1}^{N} W_i} \qquad (12)$$

$$\overline{Y} = \frac{\sum_{i=1}^{N} W_i Y_i}{\sum_{i=1}^{N} W_i} \qquad (13)$$

where W_i is the weight of observation, or waste amount in this case; and X_i and Y_i are coordinates of villages.

As known, topology of the road network data layer, as a significant input in NA, should be seriously checked to allow proper NA. The problem found most often is that the lines are not connected especially at the crossroads or intersection, incurred unable to the NA. Topological rules added were “must not overlap”, “must not intersect”, and “must not have dangles (where is not the end of line)”. The rule of “must not overlap” is used where line segments should not be duplicated. For the rule “must not intersect”, line features from the same feature class should not cross or overlap each other. For the rule of “must not have dangles”, a line feature must touch lines from the same feature class (or subtype) at both endpoints. An endpoint that is not connected to another line is called a dangle and must be corrected, except where is end of line (ESRI, 2014). The complete topological checked road network data layer was further used to create network dataset for the NA.

The facilities include schools, government institutions, shopping malls, market, hospitals, and tourist attraction sites. The population of the facilities can be obtained from the report and interview. It is added into the attribute table of the layer. The distance from road and population will be used for facility vulnerability analysis.

3.2 Stakeholder analysis

The present study mainly focused on using all groups of stakeholder in playing an important role by participating in every step of decision making on waste management. Therefore, stakeholder analysis should be performed first so that groups of stakeholder and their preferences can be identified and determined. This was carried out by survey through questionnaire and interview. The involving groups of stakeholder were firstly identified according to written records and publications, self-synthesis, and experts' comments. The list of candidate groups appeared in questionnaire. The questionnaire was designed first to allow candidate groups to add or withdraw involving group(s). Secondly, among the groups, the design allowed them to weight role to each other in 3 attributes i.e. power, legitimacy and urgency. The responding information received was for input of fuzzy salience model. The fuzzy salience model as discussed in 4.2.4 was applied for the analysis to obtain a set of preferences of the groups. This set of preferences was used later for ranking of patterns of transportation management acquired from MODA. Steps of stakeholder analysis could be simplified and displayed in Figure 3.2.

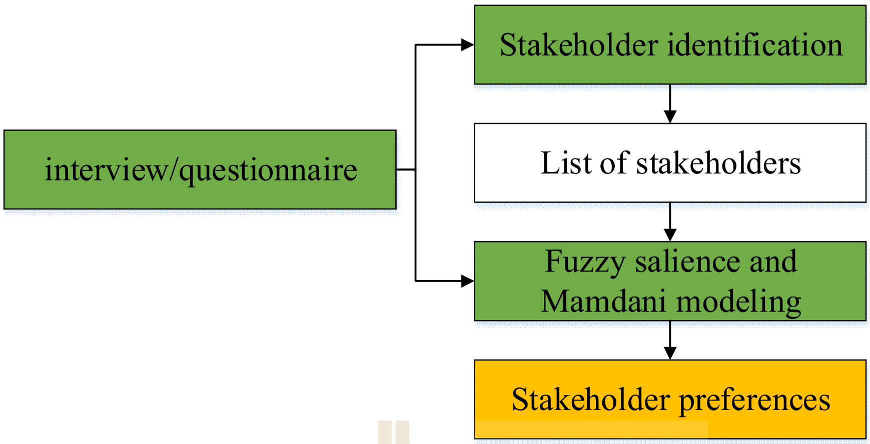


Figure 3.2 The process of stakeholder analysis.

3.3 Optimum paths of OD set using network analysis

Closest facility function of the network analysis was performed. Input data of the analysis were data layers of 9 temporary TSs as the origins and 11 locations of disposal sites as the destinations, and road network. The impedance of links in road network is the length (distance). Analytical results were the matrix of shortest paths between each TS to each DS. Barrier links were set as removed links of the road network, according to comments of stakeholders, before input into the analysis. The matrix was input for all objective functions in MODA.

3.4 Environmental impact evaluation of TSs and DSs

EI of both TSs and DSs were evaluated. As already mentioned in the scope and limitation of the study, the TS locations were temporary for transportation analysis. Therefore, EI of TSs of all administrative units was dependent on waste amount generated in the units that made their impact different.

EI of DSs was adopted from the study of Phinyoyang (2016). He evaluated EI of DSs in this study based on 3 groups of criteria namely, PCD criteria, specific environmental characteristics, and disposal methods. All scores of groups of criteria were normalized and aggregated to indicate EI of intrinsic and man-made properties of sites using weighted linear combination. This impact was enhanced by adding up normalized waste amount generated of administrative units. This resulted as the matrix of normalized EI of each pair of TS and DS which was further used as input of LP analysis.

3.5 Relative vulnerability assessment of facilities on optimum paths

The input data required for the relative vulnerability assessment were facility locations and their servicing population. The higher vulnerability on paths indicates more chance that waste transportation can cause adverse impact on people both sides of them. The relation between vulnerability and distance and population of facilities as mentioned in equation (2) was proposed to calculate vulnerability. Buffered distances (0.5, 1, 5, and 10 Km) from facilities intersecting to links of optimum paths were determined. Vulnerability scoring of each link is based on summation of facility population(s) interacting with buffered distance(s). The result was prepared in form of the matrix of vulnerability on optimum paths between TSs and DSs used as input into LP analysis.

The process of vulnerability assessment on optimum paths in this study can be displayed as shown in Figure 3.3.

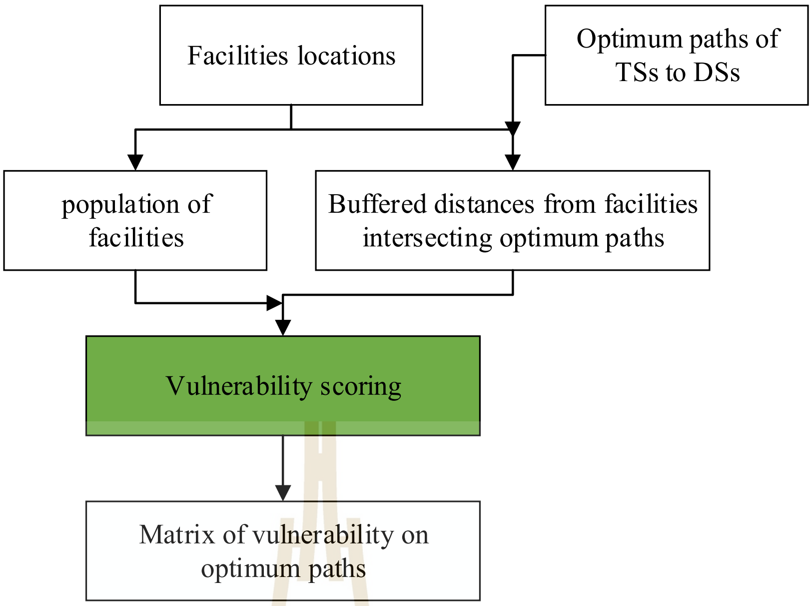


Figure 3.3 The process of vulnerability assessment of facilities.

3.6 MODA for waste transportation management

Linear programming was used for MODA. Objectives of the analysis included minimization of TC, EI between TSs and DSs, vulnerability on optimum paths, and their combinations under certain and varying constraints. These constraints include daily capacities of each DS based on 3- and 5- year service lives, supply amount of each TS, and a number of active TSs and DSs which can be varied. Objective analysis can be operated either single objective or multi-objective at a time. Results of each analysis are patterns of waste transportation or a matrix showing daily allotment of waste amount from each TS to DS(s). Analytical results can be compared and allow decision maker to choose preferable transportation patterns based on different objectives and varying constraints of different service lives. Stakeholders should play an important role on choosing or ranking transportation patterns. The method for pattern ranking of this study was PROMETHEE.

The objectives of the MODA are minimization of TC, EI, VI, and their combinations. The analysis of objectives was performed having daily waste supply at TS as common constraint. Distance, EI, and VI should be normalized to be between 0-1. This makes them to be comparable unit while performing linear programming.

3.6.1 Linear programming for minimized TC objective function

This objective analysis is the estimate of waste transportation allotment as to minimize the total TC from TSs to DSs. The cost is dependent on the product of waste amount and normalized distance of optimum path from a given pair of TS and DS. Transportation cost per unit of weight and distance is considered as a constant value used to multiply with the product of allotted waste amount and distance to obtain total TC.

The linear programming model working as TC minimization function can be expressed as the following equations:

Minimized TC:

$$\min\left(\sum_{ts=1}^{n}\sum_{ds=1}^{m} WTC_{ts/ds} * D_{ts/ds} * Q_{ts/ds}\right) \tag{14}$$

Subject to constraints:

$$\sum_{ts=1}^{n} Q_{ts/ds} = S_{ts} \qquad \text{for} \forall_{ts}; \tag{15}$$

$$\sum_{ds=1}^{m} Q_{ts/ds} \leq C_{ds} \qquad \text{for} \forall_{ds}; \tag{16}$$

$$\sum_{ds=1}^{m} ds = N_{ds} \qquad \text{for} \forall_{ds}; \tag{17}$$

$$Q_{ts/ds} \geq 0 \qquad \text{for} \forall_{ts/ds}; \tag{18}$$

where TC is total cost of waste transportation (Baht),

ts is a number of TS, ts = 1, 2, 3, …, ts,

ds is a number of DS, ds = 1, 2, 3, …, ds,

S_{ts} is the supply of waste amount at TS (Ton),

C_{ds} is the capacity of DS (Ton),

N_{ds} is a number of DS required,

$D_{ts/ds}$ is normalized distance from TS to DS,

$WTC_{ts/ds}$ is unit waste transportation cost per ton from TS to DS (cost/ton/kilometer),

$Q_{ts/ds}$ is waste amount transported from TS to DS.

Remark: as mentioned in above paragraph, $WTC_{ts/ds}$ can be dropped out while performing analysis and used later while calculating total transportation cost.

3.6.2 Linear programming for minimized EI objective function

This objective analysis is the estimate of waste transportation allotment as to minimize EI on TSs and DSs. The impact is the product of waste amount and normalized EI of a given pair of TS and DS. The linear programming model working as the EI optimization function can be expressed as the following equations:

Minimized EI:

$$\min\left(\sum_{ts=1}^{n}\sum_{ds=1}^{m} EI_{ts/ds} * Q_{ts/ds}\right) \tag{19}$$

where EI is total environmental impact of TSs and DSs,

$EI_{ts/ds}$ is normalized EI of a given pair of TS and DS (EI/ton),

The analysis shares a common set of constraints of the first objective.

3.6.3 Linear programming for minimized VI objective function

This objective analysis is the estimate of waste transportation allotment as to minimize VI. The vulnerability is the product of waste amount and normalized VI of a given path of TS and DS. The linear programming model working as the vulnerability minimization function can be expressed as the following equations:

Minimized VI:

$$\min\left(\sum_{ts=1}^{n}\sum_{ds=1}^{m} VI_{ts/ds} * Q_{ts/ds}\right) \tag{20}$$

where VI is total vulnerability on active paths

$VI_{ts/ds}$ is normalized vulnerability on a given path of TS and DS (VI/ton),

The analysis shares a common set of constraints of the first objective.

3.6.4 Linear programming for minimizing TC and EI

This objective analysis is estimation of waste transportation allotment as to minimize TC and EI form TSs to DSs. The linear programming model working as the multi-objective function for optimization of TC and EI can be expressed in form of the equations as follows:

Minimized TC and EI:

$$\min\left(\sum_{ts=1}^{n}\sum_{ds=1}^{m} WTC_{ts/ds} * D_{ts/ds} * Q_{ts/ds} + \sum_{ts=1}^{n}\sum_{ds=1}^{m} EI_{ts/ds} * Q_{ts/ds}\right) \tag{21}$$

The analysis shares a common set of constraints of the first objective.

3.6.5 Linear programming for minimizing EI and VI

This objective analysis is estimation of waste transportation allotment as to minimize EI and VI form TSs to DSs. The linear programming model working as the multi-objective function for optimization of EI and VI can be expressed in form of the equations as follows:

Minimized TC and VI:

$$\min\left(\sum_{ts=1}^{n}\sum_{ds=1}^{m} EI_{ts/ds} * Q_{ts/ds} + \sum_{ts=1}^{n}\sum_{ds=1}^{m} VI_{ts/ds} * Q_{ts/ds}\right) \tag{22}$$

The analysis shares a common set of constraints of the first objective.

3.6.6 Linear programming for minimizing TC, EI, and VI

This objective analysis is estimation of waste transportation allotment as to minimize TC, EI, and VI. The linear programming model working as the multi-objective function for optimization of TC, EI, and VI can be expressed in form of the equations as follows:

Minimized TC, EI, and VI:

$$\min\left(\begin{array}{l}\sum_{ts=1}^{n}\sum_{ds=1}^{m} WTC_{ts/ds} * D_{ts/ds} * Q_{ts/ds} + \sum_{ts=1}^{n}\sum_{ds=1}^{m} EI_{ts/ds} * Q_{ts/ds} \\ + \sum_{ts=1}^{n}\sum_{ds=1}^{m} VI_{ts/ds} * Q_{ts/ds}\end{array}\right) \tag{23}$$

The analysis shares a common set of constraints of the first objective.

3.7 MODA result comparison and validation

3.7.1 Result comparison

Total daily TC, EI, and VI resulted from LP analysis based on minimized objective functions under daily capacity constraints of 3-year and 5-year service life of DSs were compared. Comparison between 3-year and 5-year service lives of DSs of each criterion, the less value is the better.

The percentage of difference ((5-year value – 3-year value)*100/5-year value) in each criterion was also compared. The more positive percentage indicates which objective provides the better 3-year option of the criterion. Oppositely, the more negative percentage indicates which objective provides the better 5-year option of the criterion. The sum of these criteria percentages can tell which objective provides the better option (3-year or 5-year). The more positive sum indicates the better 3-year option of that certain objective function. The more negative sum indicates the better 5-year option of that certain objective function.

For cross criteria comparison, the result were compared based on percentage of the difference between the maximum and minimum values of 3-year or 5-year option of each criterion divided by the maximum value. The higher percentage indicates the better response criterion when using different objective functions in the set.

3.7.2 LP result validation

Validation of the LP results was concerned with waste allocation to serve minimization objectives of TC, EI, and VI with respect to distance, EI, and VI between pairs of TSs and DSs, respectively. For allotment serving minimized TC, active pairs of TSs and DSs were selected in order from the shorter distance and so on until the waste from a given TS is all disposed. Two kinds of ordered selections were arranged by ordering distance from the shortest to the longer in (a) a list of a TS to all DSs (9 pairs) and (b) a list of all pairs of all TSs and DSs (99 pairs), for validation (a) and validation (b) methods, respectively. A number of active pair selection was performed under the constraint of DS daily capacity. If a DS was selected to serve a given TS and its daily capacity was not enough for a daily waste from the TS, the next DS in the order was selected until all amount of daily waste from the TS was disposed. For a list of all pairs of all TSs and DSs, TSs could be alternately selected to perform according to the order of optimum paths of all pairs.

To validate results of waste allotment by LP referring to minimized EI, and VI, the method was the same as the above one referring to minimized TC. But EI, and VI of pairs of TS and DS were used instead of distance of optimum path.

The total TC, EI, and VI from waste allotment using validation methods described above should not be lower than corresponding results from the LP.

3.8 Rank of transportation patterns using PROMETHEE

Transportation patterns obtained from MODA were ranked by PROMETHEE method. For a proper ranking, the method considered criteria outcomes of alternatives and criteria weighs incorporating with preferences of stakeholders. Criteria outcomes of patterns consist of total TC, EI, and VI of different objective functions under daily capacities of 3-year and 5-year service lives. These patterns were varied according to variation of single and multi-objective analyses. These results from single and multi-objective functions were considered as alternatives to be ranked.

Sets of criteria weights were obtained by interviewing of stakeholder groups. These sets of weights became a set of stakeholder-criteria weights by incorporating with stakeholder preferences, normalizing, and averaging the sum of products.

According to the PROMETHEE process discussed in detail in 2.5.2, the method firstly performed mutual comparison of alternatives based on each transportation pattern or criteria outcome. The minimum is considered the better and scored as 1, 0 otherwise. The results were multiplied by stakeholder-criteria weights and then, the preference values of the aggregation of all criteria, leaving flow, $F^{+}(A_i)$, entering flow, $F^{-}(A_i)$, and net flow, F (A_i) were calculated. The ranking was finally performed using the difference of $F^{+}(A_i) - F^{-}(A_i)$.

The outranking of transportation patterns has no way to be validated. The result was compromised from different subjective satisfaction among groups of stakeholders. Every opinion of stakeholder was never ignored and was input into the processes of MCDA.

3.9 Stakeholder decision making on DS service lives

Output results from LP and PROMETHEE including additional advantage and disadvantage between 3- and 5-year service lives of DS (Table 3.2) were reported to each group of stakeholders in questionnaire to let them make decision which one was preferred. The weights of criteria in the Table 3.2 from all groups were normalized and averaged to obtain the preferred service life of DS.

Table 3.2 Advantage and disadvantage between 3- and 5- year service lives of DS.

No.	**Considered criteria**	**3-year service life**	**5-year service life**
1	Daily transportation cost	less	more
2	Service life	shorter	longer
3	Number of DS in service for risk warranty	less	more
4	Available time for new DSs searching and selection	less	more
5	EI of DS and VI along transportation route	more	less
6	Emergency case handling (e.g. DS is suddenly shut down due to acute EI)	harder to handle	easier to handle

Daily transportation costs of both service lives were obtained from MODA-LP process. Less number of DSs were active for 3- year service life because bigger amount of waste can be allotted and allocated to a given site. Therefore, it can take more risk when hazards occur on a site or sites, for example flooding or fire. More EI and VI can be involved when more waste amount is transported along a given route and allocated to a given DS. A site can be suddenly closed when acute pollution dispersion is detected. A spare site can take time to prepare for full service.

CHAPTER IV

RESULT AND DISCUSSION

This Chapter reports and discusses results from stakeholder and spatial analyses for solid waste management based on transportation cost, environmental impact of sites, and vulnerability on optimum routes of transportation. Results from (1) data collection and preparation, (2) stakeholder analysis for municipal solid waste, (3) optimum routes using network analysis, (4) MODA for waste transportation management, (5) MODA result comparison and validation, and (6) rank of transportation patterns using PROMETHEE are described and discussed.

4.1 Input data

The input data for analytical processes were firstly refined and manipulated in order that they could be used properly and effectively to serve the research objectives. GIS techniques were used to prepare, manipulate, and determine spatial data and attributes of criteria for the analyses.

4.1.1 Capacity of DSs

Capacity of a DS is compacted waste (ton/day). According to Phinyoyang (2016), capacity of DS was estimated for 3-year and 5-year of service life on 50% of the site area. Another 50% of the area is normally used as operating area such as embankment, road, water sump, and tree barrier. Weight of compacted waste is

1.2 times of transported waste weight. Waste generated rates of local administrative units of sites locating outside waste generation area of the study were subtracted from site capacities before analysis of objective function. Estimated daily capacity of DSs are listed in Table 4.1.

Table 4.1 Total capacity of DSs with 3-year and 5-year (Phinyoyang, 2016).

DS No.	Organization of site	Total capacity 3-year (Ton/day)	Total capacity 5-year (Ton/day)
DS01	Phitsanulok municipality	205.48	205.48
DS02	Banmai municipality	26.38	15.35
DS03	Nuenkum municipality	12.50	4.62
DS04	Bangkrathum municipality	9.29	3.78
DS05	Plakrad municipality	25.75	13.93
DS06	Phromphiram municipality	44.12	25.99
DS07	Wongkong municipality	14.90	7.02
DS08	Watbot municipality	55.08	30.65
DS09	Thapho SAO	33.49	20.10
DS10	Bankrang SAO	15.76	9.46
DS11	Bantan SAO	12.79	7.28
	SUM	**455.56**	**343.65**

Remark: the service life of Phitsanulok municipality DS was officially designed to be 10 years long and the daily organization at the site is limited to this amount. Therefore its daily capacity is assumed constant.

4.1.2 Temporary transfer station

By using GIS weighted mean centering process, 11 temporary TSs could be located in 11 administrative unit. According to policy and some available existing TSs, Phitsanulok-Thatong and Phai kho don-Ban Krang were grouped to be 2 TSs. Examining with existing land use, Phitsanulok-Thatong, Phai kho don-Ban Krang, and

Aranyik TSs were relocated to the optimum positions under the supervision of officers of administrative units. The locations of temporary TSs are displayed in Figure 4.1. All of temporary TSs were finally located on agricultural land. Their generated waste amounts were estimated and displayed in Table 4.2.

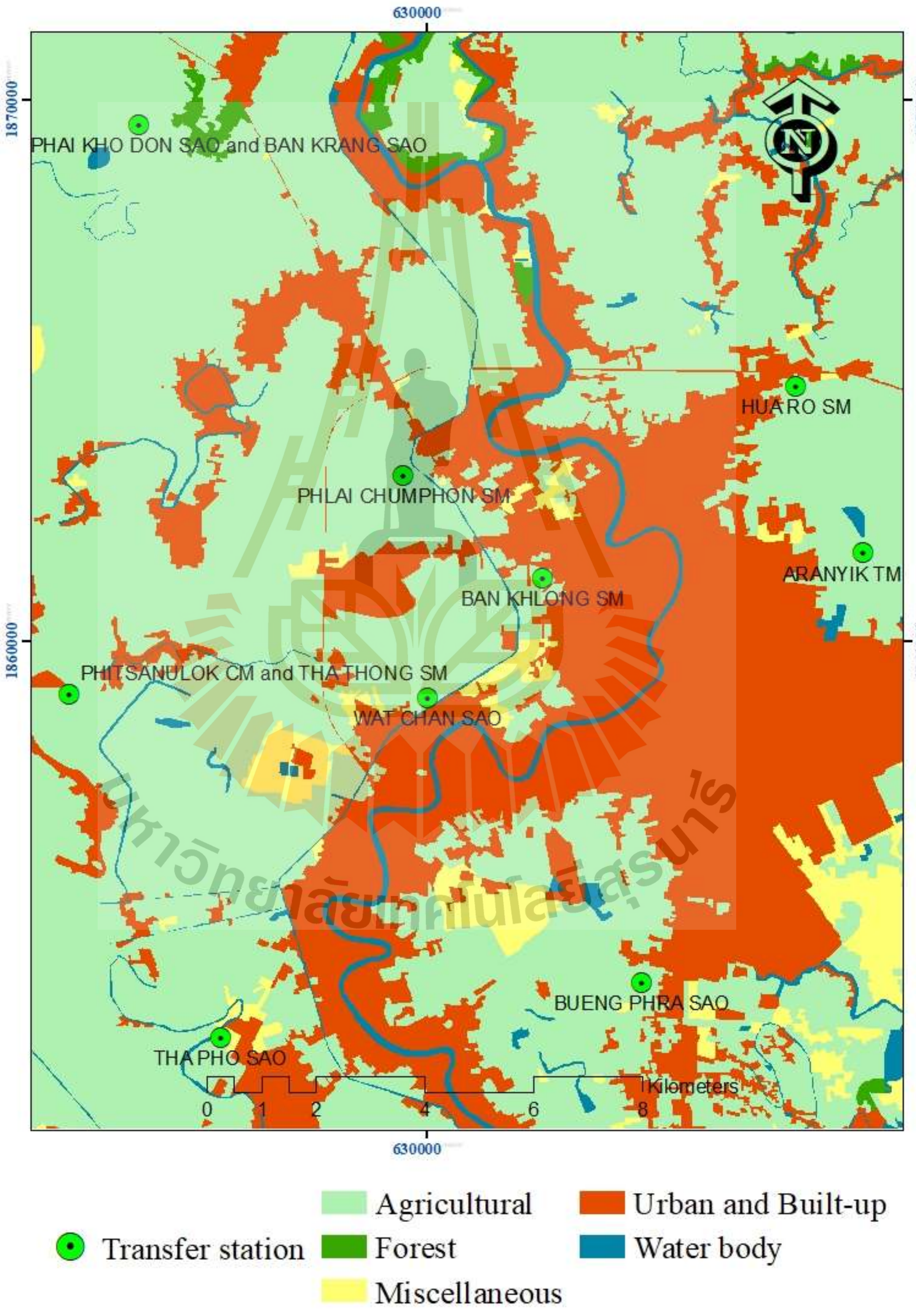


Figure 4.1 Temporary transfer stations.

Table 4.2 Temporary TS and waste amount.

TS No.	Administrative unit	Waste amount (Tons)
TS01	Phitsanulok and Thatong	145.52
TS02	Aranyik	34.30
TS03	Phlai chumphon	7.25
TS04	Ban khlong	13.22
TS05	Hua Ro	23.35
TS06	Phai kho don and Ban Krang	14.74
TS07	Wat Chan SAO	7.34
TS08	Tha Pho SAO	20.72
TS09	Beung Phra SAO	15.97

Remark: waste amount was estimated in Table 1.2

4.1.3 Road network data

The road network data layer of MOT and DEQP in the study area were edited, updated, and topology checked to create the clean and effectual road network dataset for the NA., resulting in 3 layers of road network, road junction, and road edges datasets as shown in Figure 4.2.

(a) Road network (b) Road_ND_Junction (c) Road_ND_Edges

Figure 4.2 Network dataset for used in the NA: (a) road network, (b) road junction, and (c) road edges datasets.

4.1.4 The facilities

The facilities with more than 500 people in service (Panwhar, Pitt, and Anderson, 2000) were selected. In the study area there were 38 facilities including schools, government institutions, shopping malls, market, hospitals, and tourist attraction sites were obtained from the report and field survey 2017. The facilities distribution and their population or an average number of people in service are displayed in Figure 4.3 and Table 4.3. They were prepared as GIS data layer and attribute. The layer together with road network layer of optimum routes were further used for vulnerability analysis of routes.

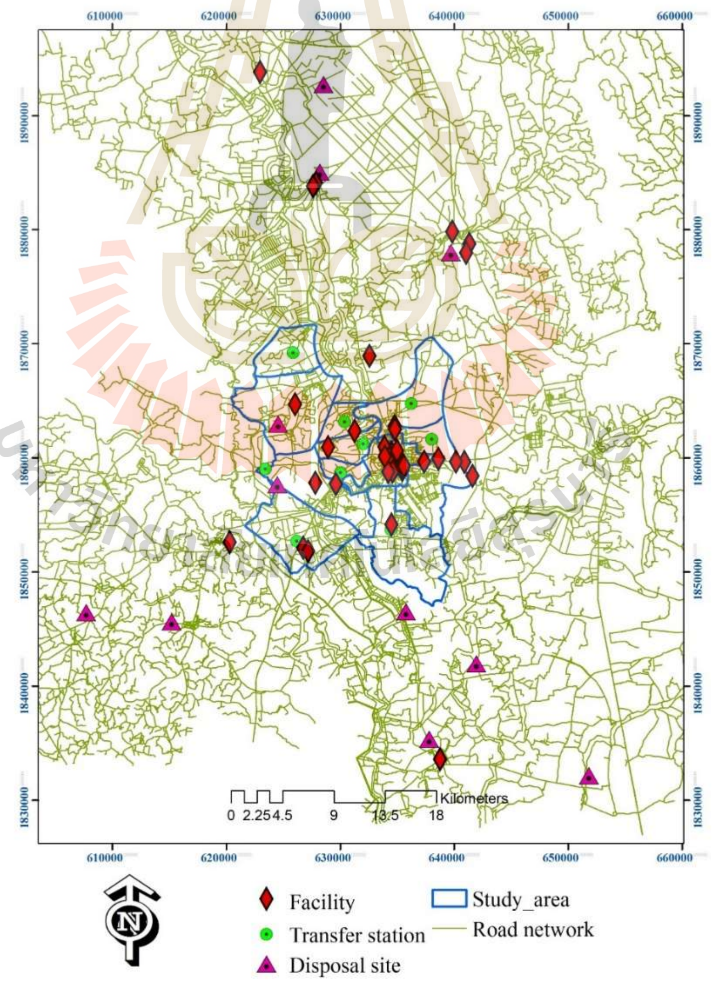


Figure 4.3 The location of facility.

Table 4.3 The facility and population.

No.	Name of facility	Population
1	Rajamangala University of Technology Lanna Phitsanulok	1,254.00
2	Bankrangwittayakom school	500.00
3	Wat Phra Sri Rattanamahatat Woramahawihan	2,484.00
4	Jakarnboon school	1,863.00
5	Janokrong school	2,155.00
6	Chalermkwansatree school	3,210.00
7	Saint Nicholas school	1,400.00
8	Naresuan university secondary demonstration school	1,000.00
9	Phisanulok university	1,500.00
10	Naresuan university hospital	1,488.00
11	Naresuan university	6,715.00
12	Triamudom Suksa School of the North	1,289.00
13	Anuban Phitsanulok school	2,500.00
14	Buddhachinnarajpittaya school	2,171.00
15	Phadungpanya school	1,700.00
16	Buddhachinnaraj hospital	1,480.00
17	Pitsanuej hospital	1,200.00
18	Phromphiramwittaya school	1,197.00
19	watbot school	589.00
20	watbot hospital	1,200.00
21	watbotsuksa school	551.00
22	Phitsanulok pittayakom school	3,310.00
23	Nongtomsuksa school	468.00
24	Phitsanulok technical college	550.00
25	Phitsanulok vocational college	3,577.00
26	Bungphra Phitsanulok commercial college	1,450.00
27	Watsriwisuttharam school	851.00
28	Piramutid school	798.00

Table 4.3 The facility and population (Continued).

No.	Name of facility	Population
26	Bungphra Phitsanulok commercial college	1,450.00
27	Watsriwisuttharam school	851.00
28	Piramutid school	798.00
29	Bangrakamwittayasuksa School	795.00
30	Princess Chulabhorn's College Phisanulok	791.00
31	Bangkrathumpithayakom school	829.00
32	Prachasongkroe school	1,039.00
33	Tesco Lotus phitsanulok	12,060.00
34	Big C supper center	10,080.00
35	Makro	3,420.00
36	Index living mall	2,213.00
37	Lotus extra	12,450.00
38	Central Plaza	15,708.00

4.2 Stakeholder analysis

The analysis includes key stakeholder identification, scoring key stakeholders based on salience model attributes, linguistic membership classification, priority level identification based on rules, and aggregation and defuzzification to obtain stakeholder preferences (see 2.2 and 3.2). The preferences of stakeholder groups were further used in PROMETHEE outranking of patterns of waste transportation management.

4.2.1 Key stakeholder identification

From literature review and interviews of some stakeholders, an inventory of 16 initial stakeholders were listed as shown in Table 4.4. The 4th Infantry Division (Royal Thai Army) was included in the inventory as the Adhoc team which forces positive change in this activity, for example, transforming open dump to be controlled dump and active manipulation of waste management in the area.

Table 4.4 List of stakeholder for waste management of the study.

No.	Stakeholder	Abbreviation
1	Environmental Office Region 3	EOR 3
2	Provincial Offices for Natural Resources and Environment Phitsanulok	PNRE
3	Phitsanulok Health Provincial Office	Health
4	4th Infantry Division (Royal Thai Army)	RTA
5	Local Administrative Organization	LAO
6	Province Office for Local Administration	POLA
7	Non-Governmental Organization	NGO
8	Community-Based Organizations	CO
9	Volunteers Natural Resources and Environment	Volunteer
10	Academicians/ Researcher	Academic
11	Waste picker	Waste picker
12	Private Sector Companies	Private sector
13	residents of nearby disposal site and optimum route	RES_DS
14	Residential waste generators	RES_waste
15	Media	Media
16	Environmental Consulting Companies	Consulting

Questionnaire of 8 questions was designed (questionnaire A1 of Appendix A) and distributed among stakeholder groups to respond and results were shown in Table 4.5. The first 5 stakeholder groups with higher scores of each question were selected to be key stakeholder groups of this activity. The representative of each group who responded the questionnaire can be single or many, e.g. 17 section chiefs from 17 local administrative units, 2 from media group, 3 section chief from EOR 3, etc. Some groups, i.e. Health, POLA, RTA, and Volunteer, have only one representative because he/she is only one in charge in this activity of the organizations. Anyone who is not in charge cannot be an effectual representative of stakeholder groups. Additionally, the score of stakeholder groups from this questionnaire was not related to stakeholder preferences. Scores in percentage of each stakeholder group indicate more or less they should involve in the activity. However, these scores will not directly express their significance of roles and preferences.

Finally, scores of each group were summed and ranked to be totally 16 groups and are listed in Table 4.6. The group of environmental consulting companies was scored to be the lowest. Plus, from the past record there is no available environmental consulting company active in this province. Therefore, it has no representative and was not included in the list of identified key stakeholder groups.

Table 4.5 The top 5 key stakeholders from each question in questionnaire.

No.	Stakeholder	score	Percent (%)
1)	Who are potential beneficiaries from good waste management?		
1	RES_waste	255	28.94
2	RES_DS	202	22.93
3	LAO	141	16.00
4	Private	60	6.81
5	CO	48	5.45

Table 4.5 The top 5 key stakeholders from each question in questionnaire (Continued).

No.		Stakeholder	score	Percent (%)
2)	Who might be adversely affected?			
	1	RES_DS	188	20.28
	2	RES_waste	173	18.66
	3	LAO	110	11.87
	4	PNEP	93	10.03
	5	Health/Private	79	8.52
3)	Who is the legal authority for waste management?			
	1	LAO	293	31.68
	2	EOR3	141	15.24
	3	PNEP	140	15.14
	4	Health	136	14.70
	5	POLA	92	9.95
4)	Who has existing rights?			
	1	RES_waste	202	22.42
	2	CO	186	20.64
	3	RES_DS	154	17.09
	4	NGO	68	7.55
	5	PNEP	64	7.10
5)	Who may be a supporter of anti-waste management operations?			
	1	NGO	258	29.28
	2	CO	197	22.36
	3	Media	116	13.17
	4	RES_DS	105	11.92
	5	RES_waste	56	6.36
6)	Who is responsible for the intended plans?			
	1	PNEP	220	24.04
	2	EOR3	188	20.55
	3	LAO	140	15.30
	4	Health	108	11.80
	5	RES_waste	61	6.67
7)	Who has skills or key information?			
	1	EOR3	260	28.70
	2	PNEP	214	23.62
	3	Health	99	10.93
	4	LAO	85	9.38
	5	Academic	81	8.94

Table 4.5 The top 5 key stakeholders from each question in questionnaire (Continued).

No.	Stakeholder	score	Percent (%)
8)	Who should provide budget support?		
1	LAO	228	25.50
2	EOR3	147	16.44
3	PNEP	128	14.32
4	POLA	101	11.30
5	NGO	76	8.50

Table 4.6 List of stakeholder and stakeholder's role for waste management of the study.

NO.	**Stakeholder**	**score**	**percentage**	**representative**
1	LAO	234.05	13.72	17
2	PNEP	227.48	13.33	3
3	EOR3	217.89	12.77	3
4	RES_waste	186.92	10.96	13
5	RES_DS	158.92	9.31	9
6	Health	136.04	7.97	1
7	CO	122.12	7.16	6
8	NGO	91.05	5.34	2
9	Private	85.92	5.04	3
10	POLA	68.52	4.02	1
11	Academic	46.12	2.70	3
12	Waste picker	34.30	2.01	3
13	Voluntree	33.04	1.94	1
14	RTA	29.00	1.70	1
15	Media	23.42	1.37	2
16	Consulting	11.40	0.67	0
Total		**1,706**	**100**	**68**

4.2.2 Scores of stakeholders regarding to Salience model attributes

Poplawska et al. (2015) suggested that the preferences of stakeholder group should be evaluated according to attributes of power, urgency and legitimacy. Questionnaires were distributed among key stakeholders to score to other groups based on the attributes as results shown in Table 4.7. Average, lower and upper ranges scores of attributes of each group were defuzzified to be profile score as shown in Table4.8. Roles in different attributes of each group could be observed in Figure 4.4. The highest roles of power, urgency, and legitimacy fall into LAO, PNRE, Health, and POLA, respectively. The waste picker has the lowest role of all attributes.

Table 4.7 Respondents' answers (S*i*, *i* = 1-15) in respect to legitimacy, power and urgency of each types of stakeholders for waste management (Scale 0 - 3, none = 0 low = 1, medium= 2, high= 3).

stakeholders	Attributes	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	average
EOR 3	Power	2.33	1.00	1.00	1.00	2.53	1.00	2.50	2.17	2.00	2.75	2.33	2.33	2.56	2.38	1.50	1.96
	Urgency	3.00	2.33	3.00	3.00	2.47	3.00	2.50	2.83	2.00	2.75	3.00	2.00	2.67	2.77	1.50	2.59
	Legitimacy	2.67	1.67	3.00	3.00	2.12	3.00	2.00	2.33	2.00	2.25	2.00	2.00	2.33	2.31	2.00	2.31
PNRE	Power	2.67	1.00	1.00	1.00	2.53	2.00	2.50	2.50	2.00	2.75	2.67	3.00	2.67	2.54	1.50	2.16
	Urgency	3.00	2.33	3.00	3.00	2.47	3.00	2.50	2.83	2.00	2.75	3.00	3.00	2.67	2.85	1.50	2.66
	Legitimacy	2.67	1.67	3.00	3.00	2.24	3.00	2.00	2.50	2.00	2.25	2.33	2.00	2.33	2.38	2.00	2.36
Health	Power	2.00	2.33	1.00	2.00	2.00	2.00	2.50	2.50	2.00	1.75	2.33	2.33	2.33	2.38	2.00	2.10
	Urgency	2.67	2.33	3.00	3.00	2.12	3.00	2.00	2.83	2.00	2.25	2.33	2.67	2.44	2.69	1.50	2.46
	Legitimacy	2.33	2.00	3.00	3.00	1.65	3.00	1.50	2.50	2.00	1.75	2.00	3.00	2.33	2.46	2.00	2.30
RTA	Power	2.33	3.00	3.00	2.00	2.88	1.00	2.00	2.67	3.00	2.00	3.00	2.67	2.11	2.46	2.00	2.41
	Urgency	2.00	2.00	3.00	2.00	2.18	1.00	1.50	2.50	2.00	1.50	2.67	2.00	1.89	2.46	0.50	1.95
	Legitimacy	1.67	2.00	3.00	3.00	2.47	2.00	1.00	2.33	2.00	1.25	1.67	2.00	2.11	2.54	0.50	1.97
LAO	Power	3.00	3.00	3.00	3.00	2.65	3.00	2.50	3.00	3.00	3.00	3.00	3.00	2.56	2.69	2.00	2.83
	Urgency	3.00	2.67	3.00	3.00	2.24	2.00	2.50	3.00	3.00	2.75	2.67	3.00	2.56	2.77	2.00	2.68
	Legitimacy	3.00	1.67	3.00	3.00	2.24	2.00	1.00	2.67	2.00	2.25	2.33	3.00	2.22	2.62	1.50	2.30
POLA	Power	1.66	1.67	1.00	3.00	2.24	2.00	2.50	2.83	2.00	2.00	2.67	2.67	2.67	2.62	1.00	2.17
	Urgency	3.00	2.67	3.00	3.00	2.18	3.00	2.50	2.67	2.00	2.25	2.67	2.67	2.11	2.46	2.00	2.55
	Legitimacy	3.00	2.33	3.00	3.00	2.41	3.00	2.00	2.67	2.00	2.25	2.33	2.67	2.78	2.38	2.50	2.55
NGOs	Power	0.33	0.33	0.00	0.00	0.82	0.00	0.00	0.83	0.00	0.50	1.33	1.33	0.78	1.38	0.50	0.54
	Urgency	1.67	2.00	1.00	1.00	1.82	0.00	1.00	2.17	2.00	1.75	2.33	2.00	1.78	1.54	2.50	1.64
	Legitimacy	2.00	1.00	1.00	2.00	1.76	1.00	2.50	2.17	2.00	2.75	2.67	2.00	2.33	2.08	1.50	1.92
CO	Power	0.33	1.00	0.00	1.00	1.24	0.00	1.50	2.33	2.00	0.50	2.00	2.33	1.89	1.85	2.00	1.33
	Urgency	2.33	2.00	1.00	2.00	1.65	1.00	1.50	2.83	3.00	2.50	2.33	1.67	2.00	2.00	2.50	2.02
	Legitimacy	2.33	1.33	1.00	3.00	2.24	2.00	3.00	2.33	3.00	3.00	2.33	1.67	2.67	2.38	2.00	2.29

Table 4.7 Respondents' answers (S*i*, *i* = 1-15) in respect to legitimacy, power and urgency of each types of stakeholders for waste management (Scale 0 - 3, none = 0 low = 1, medium= 2, high= 3) (Continued).

stakeholders	Attributes	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	average
Volunteer	Power	0.33	0.67	0.00	1.00	0.94	0.00	1.00	1.33	1.00	0.50	1.00	1.00	1.33	1.46	2.00	0.90
	Urgency	2.33	1.67	1.00	0.00	1.59	1.00	1.00	2.00	2.00	2.00	1.67	2.00	1.89	1.85	2.00	1.60
	Legitimacy	2.00	1.67	3.00	2.00	1.65	1.00	1.50	2.00	1.00	2.00	2.67	1.67	2.11	2.08	2.50	1.92
Academic	Power	0.67	0.67	0.00	1.00	1.20	1.00	1.50	1.33	1.00	0.75	1.67	1.67	1.78	1.62	1.50	1.16
	Urgency	1.67	2.67	3.00	1.00	2.41	2.00	2.50	1.83	2.00	2.50	2.67	1.67	2.33	2.31	1.50	2.14
	Legitimacy	2.00	1.67	2.00	2.00	1.71	1.00	2.00	1.83	2.00	2.25	2.67	2.00	1.89	2.15	2.50	1.98
Private sector	Power	1.33	1.33	0.00	1.00	1.65	0.00	1.50	1.00	1.00	1.50	0.67	2.00	1.22	1.46	1.00	1.11
	Urgency	1.33	1.67	1.00	2.00	2.00	1.00	1.50	1.33	2.00	1.75	2.33	1.33	1.33	1.85	2.00	1.63
	Legitimacy	1.67	2.00	1.00	2.00	1.88	1.00	2.00	1.67	2.00	1.50	2.33	1.67	1.67	1.77	2.50	1.78
Waste picker	Power	0.33	0.33	0.00	0.00	0.88	0.00	1.00	0.67	1.00	0.25	0.00	0.33	0.56	0.77	0.00	0.41
	Urgency	0.33	0.67	0.00	0.00	0.94	1.00	1.00	0.83	0.00	0.25	0.67	0.33	0.67	0.96	0.50	0.54
	Legitimacy	1.00	1.67	1.00	1.00	1.65	0.00	1.50	1.50	1.00	0.75	1.00	1.33	1.44	1.62	3.00	1.30
RES_DS	Power	0.00	1.67	0.00	2.00	1.53	0.00	1.50	1.33	1.00	0.50	1.67	2.00	1.56	1.46	2.00	1.21
	Urgency	1.67	1.67	1.00	2.00	1.47	0.00	1.50	1.67	3.00	1.75	2.00	2.00	1.78	1.69	2.50	1.71
	Legitimacy	2.33	2.33	1.00	3.00	1.88	0.00	3.00	2.00	3.00	3.00	3.00	1.67	2.33	2.15	2.50	2.21
RES_ waste	Power	0.67	1.00	0.00	2.00	1.35	1.00	1.00	1.33	1.00	0.75	1.33	2.00	1.67	1.54	2.00	1.24
	Urgency	2.33	1.00	1.00	2.00	1.88	1.00	1.50	2.00	3.00	2.00	2.33	2.33	2.33	1.92	2.00	1.91
	Legitimacy	3.00	2.00	3.00	3.00	1.94	1.00	2.00	2.50	3.00	3.00	2.33	1.67	2.56	2.38	2.00	2.36
Media	Power	0.67	0.33	0.00	2.00	1.47	1.00	1.00	1.17	1.00	0.75	0.67	0.33	1.33	1.54	0.50	0.92
	Urgency	1.33	2.00	1.00	2.00	2.06	1.00	1.00	1.33	1.00	1.25	2.67	0.67	1.78	1.85	2.33	1.55
	Legitimacy	2.00	1.33	1.00	3.00	2.18	1.00	2.50	1.67	2.00	2.75	2.67	2.00	2.22	2.15	1.00	1.96

Note: Si, I = 1-15 represent are type of stakeholders for waste management

Table 4.8 Profile score of stakeholder for waste management.

Stakeholders	Attributes	Profile score			Defuzzied profile score
		Lower range	Mean	Upper range	
EOR 3	Power	1.00	1.96	2.75	1.92
	Urgency	1.50	2.59	3.00	2.42
	Legitimacy	1.67	2.31	3.00	2.32
PNRE	Power	1.00	2.16	3.00	2.08
	Urgency	1.50	2.66	3.00	2.46
	Legitimacy	1.67	2.36	3.00	2.35
Health	Power	1.00	2.10	2.50	1.92
	Urgency	1.50	2.46	3.00	2.35
	Legitimacy	1.50	2.30	3.00	2.28
RTA	Power	1.00	2.41	3.00	2.20
	Urgency	0.50	1.95	3.00	1.85
	Legitimacy	0.50	1.97	3.00	1.86
LAO	Power	2.00	2.83	3.00	2.66
	Urgency	2.00	2.68	3.00	2.59
	Legitimacy	1.00	2.30	3.00	2.15
POLA	Power	1.00	2.17	3.00	2.08
	Urgency	2.00	2.55	3.00	2.52
	Legitimacy	2.00	2.55	3.00	2.53
NGOs	Power	0.00	0.54	1.38	0.62
	Urgency	0.00	1.64	2.50	1.44
	Legitimacy	1.00	1.92	2.75	1.90
CO	Power	0.00	1.33	2.33	1.25
	Urgency	1.00	2.02	3.00	2.01
	Legitimacy	1.00	2.29	3.00	2.14
Volunteer	Power	0.00	0.90	2.00	0.95
	Urgency	0.00	1.60	2.33	1.38
	Legitimacy	1.00	1.92	3.00	1.96
Academic	Power	0.00	1.16	1.78	1.02
	Urgency	1.00	2.14	3.00	2.07
	Legitimacy	1.00	1.98	2.67	1.91
Private sector	Power	0.00	1.11	2.00	1.06
	Urgency	1.00	1.63	2.33	1.65
	Legitimacy	1.00	1.78	2.50	1.76
Waste picker	Power	0.00	0.41	1.00	0.45
	Urgency	0.00	0.54	1.00	0.52
	Legitimacy	0.00	1.30	3.00	1.40
RES_DS	Power	0.00	1.21	2.00	1.11
	Urgency	0.00	1.71	3.00	1.61
	Legitimacy	0.00	2.21	3.00	1.86
RES_waste	Power	0.00	1.24	2.00	1.12
	Urgency	1.00	1.91	3.00	1.95
	Legitimacy	1.00	2.36	3.00	2.18
Media	Power	0.00	0.92	2.00	0.96
	Urgency	0.67	1.55	2.67	1.61
	Legitimacy	1.00	1.96	3.00	1.98

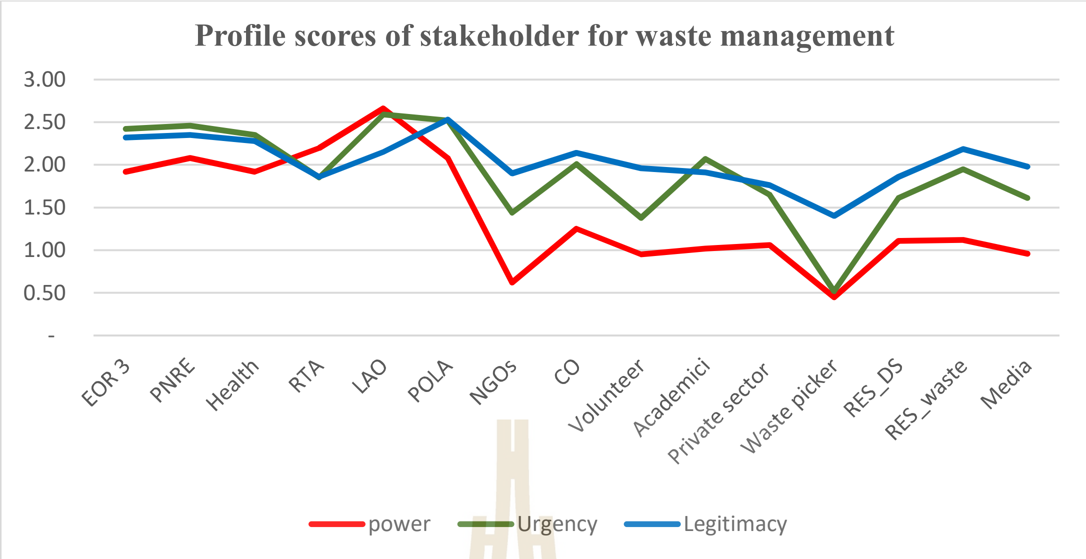


Figure 4.4 Profile scores of stakeholder for waste management.

4.2.3 Stakeholder priority leveling using Salience and Mamdani fuzzy models

Profile scores of each stakeholder were turned to be linguistic fuzzy classes using membership functions in Figure 4.4. These classes were aggregated according to fuzzy rules suggested by Poplawska et al. (2015). Following Mamdani fuzzy logic, the aggregation based on rule(s) of each combination of 3 attributes was operated using fuzzy Min while aggregation of salience classes was operated using fuzzy Max. Only some rules were active depending on available combinations of linguistic fuzzy classes of stakeholders. The results of aggregation of salience classes were finally defuzzified to be crisp values by COG method. These values represent stakeholder preferences.

The abovementioned steps were performed through the function of Mamdani FIS in Matlab. Active rules and defuzzied results of stakeholder groups were displayed in Table 4.9. From active rules, characteristic groups of stakeholders were identified, which in turn their priority levels were provided as summarized in Table 4.10. Figures 4.5 and 4.6 illustrate preferences and characteristic groups of stakeholders based on attributes of Salience model, respectively.

The group with higher priority level has higher preference or influence on decision making of the activity. The groups of high priority level was identified to be definitive characteristic (EOR 3, PNRE, RTA, CO, LAO, POLA, and Health). They should have the opportunity to provide input to major decisions and feedback on current progress.

The group with medium and high priority of dependent /definitive characteristic are RES_DS, private sector, academic, RES_waste, Media, and volunteer. This group requires increased responsiveness from the organization toward their interests or views and/or gives an advice/information to other groups.

The group with medium priority of dependent characteristic is NGOs who play roles of urgent claims and legitimate views but often rely on other stakeholders to carry out their will to compensate for a lack of power to influence the organization.

The group with low priority of discretionary characteristic is waste picker. This stakeholder possess legitimacy, but lack the power and urgent claim to influence the organization.

Table 4.9 Stakeholder analysis using Mamdani fuzzy if-then rules.

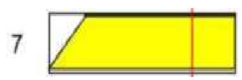
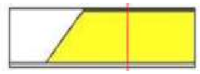
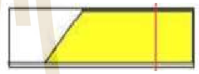
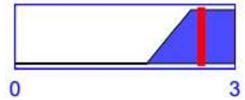
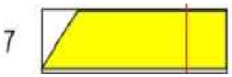
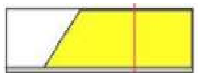
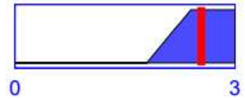
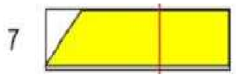
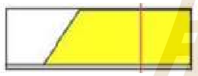
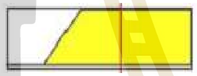
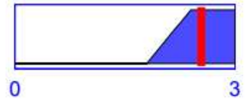
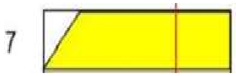
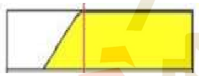
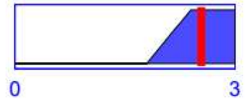
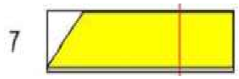
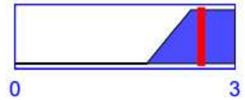
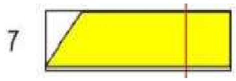
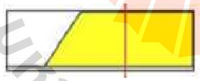
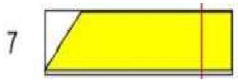
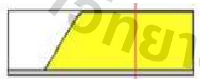
Stakeholders	If-then rules				Output
	Legitimacy	Power	Urgency	Stakeholder importance	
EOR 3					
PNRE					
RTA					
CO					
LAO					
Health					
POLA					

Table 4.9 Stakeholder analysis using Mamdani fuzzy if-then rules (Continued).

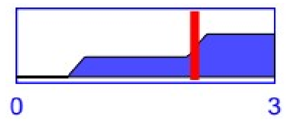
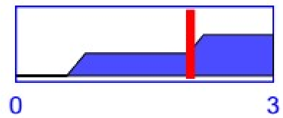
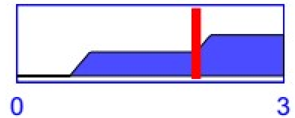
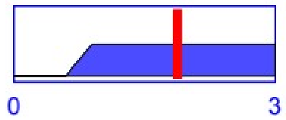
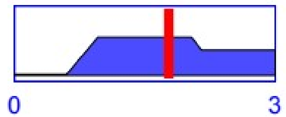
Stakeholders	If-then rules: Legitimacy, Power, Urgency, Stakeholder importance	Output
RES_DS		
Private sector		
Academic		
RES_waste		
Media		
Volunteer		

Table 4.9 Stakeholder analysis using Mamdani fuzzy if-then rules (Continued).

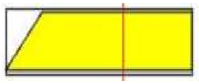
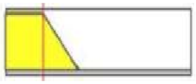
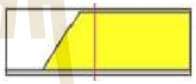
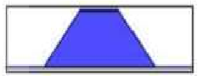
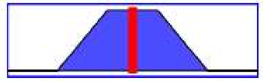
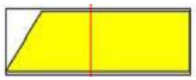
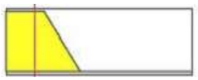
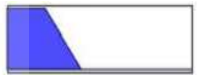
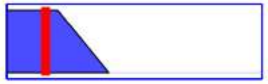
Stakeholders		If-then rules				Output
		Legitimacy	Power	Urgency	Stakeholder importance	
NGOs	6					
Waste picker	2					

Table 4.10 Summary of stakeholder characteristic groups, priority levels, and preferences.

No.	Stakeholders	Preference	Priority level	Characteristic groups
1	EOR 3	2.54	High priority	Definitive
2	PNRE	2.54	High priority	Definitive
3	RTA	2.54	High priority	Definitive
4	CO	2.54	High priority	Definitive
5	LAO	2.54	High priority	Definitive
6	Health	2.54	High priority	Definitive
7	POLA	2.52	High priority	Definitive
8	RES_DS	2.29	Medium and high priority	Dependent /definitive
9	Private sector	1.79	Medium and high priority	Dependent /definitive
10	Academic	2.09	Medium and high priority	Dependent /definitive
11	RES_waste	2.32	Medium and high priority	Dependent /definitive
12	Media	2.16	Medium and high priority	Dependent /definitive
13	Volunteer	1.96	Medium and high priority	Dependent /definitive
14	NGOs	1.50	Medium priority	Dependent
15	Waste picker	0.495	Low priority	Discretionary

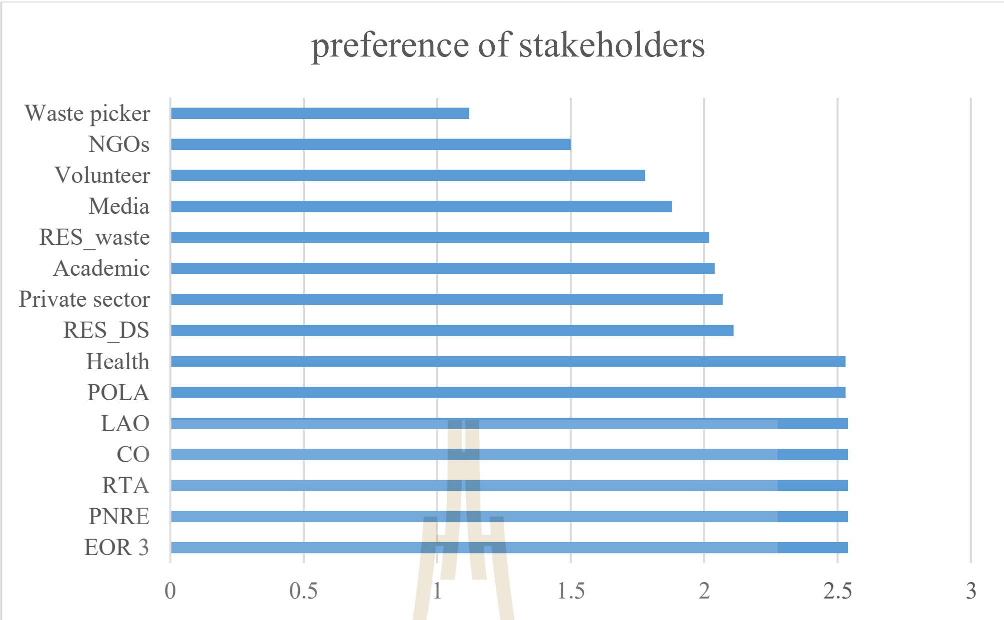


Figure 4.5 Stakeholder group and preferences.

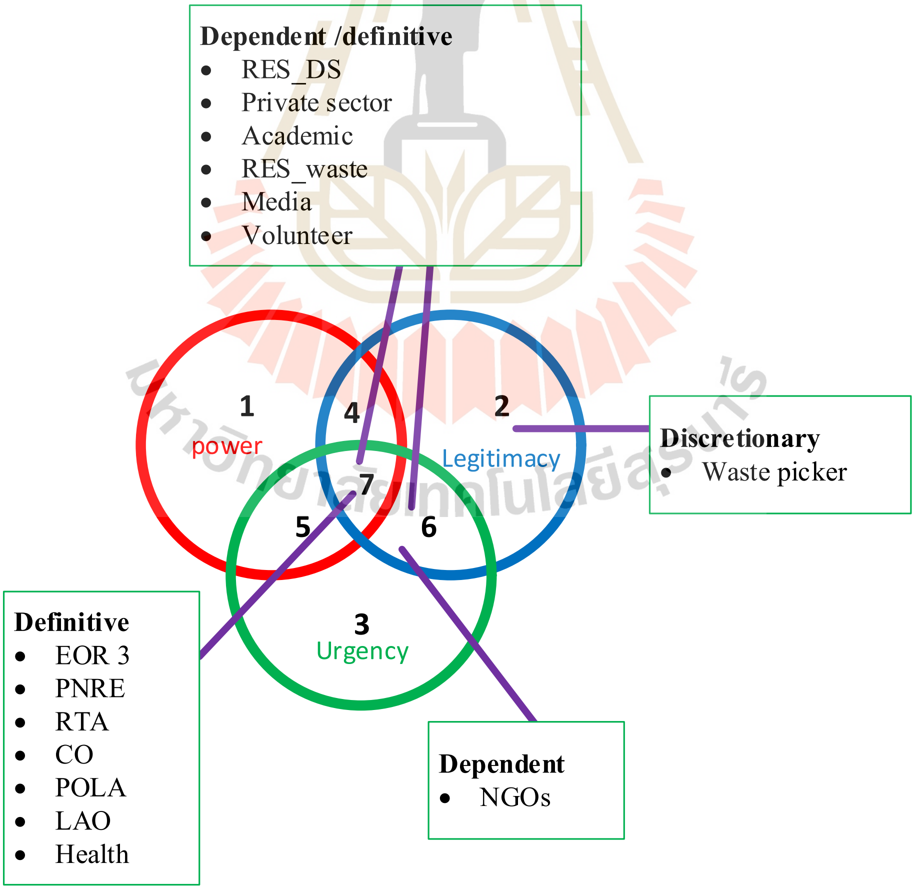


Figure 4.6 Characteristic groups of stakeholders for waste management.

4.3 Optimum paths of OD set using network analysis

Optimum paths between each TS to all DSs were analyzed. This resulted in 99 optimum routes of 9 TSs and 11 DSs. Maps of routes from each TS to all DSs are displayed in Figure 4.7. Optimum distance of each TS to each DS is listed in Table B1 of Appendix B. They were normalized and displayed as matrix in Table 4.11. The pair of Phaikhodon and Bankrang TS-Nuenkum DS shows the longest-distance optimum path. The matrix was input for all objective functions of the LP.

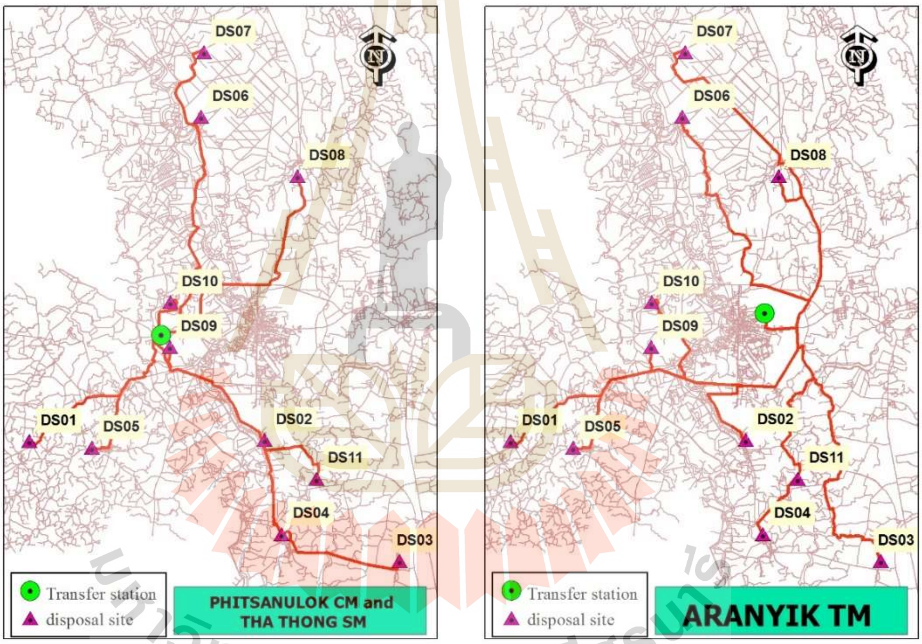


Figure 4.7 The 99 shortest paths of each TS to all DSs.

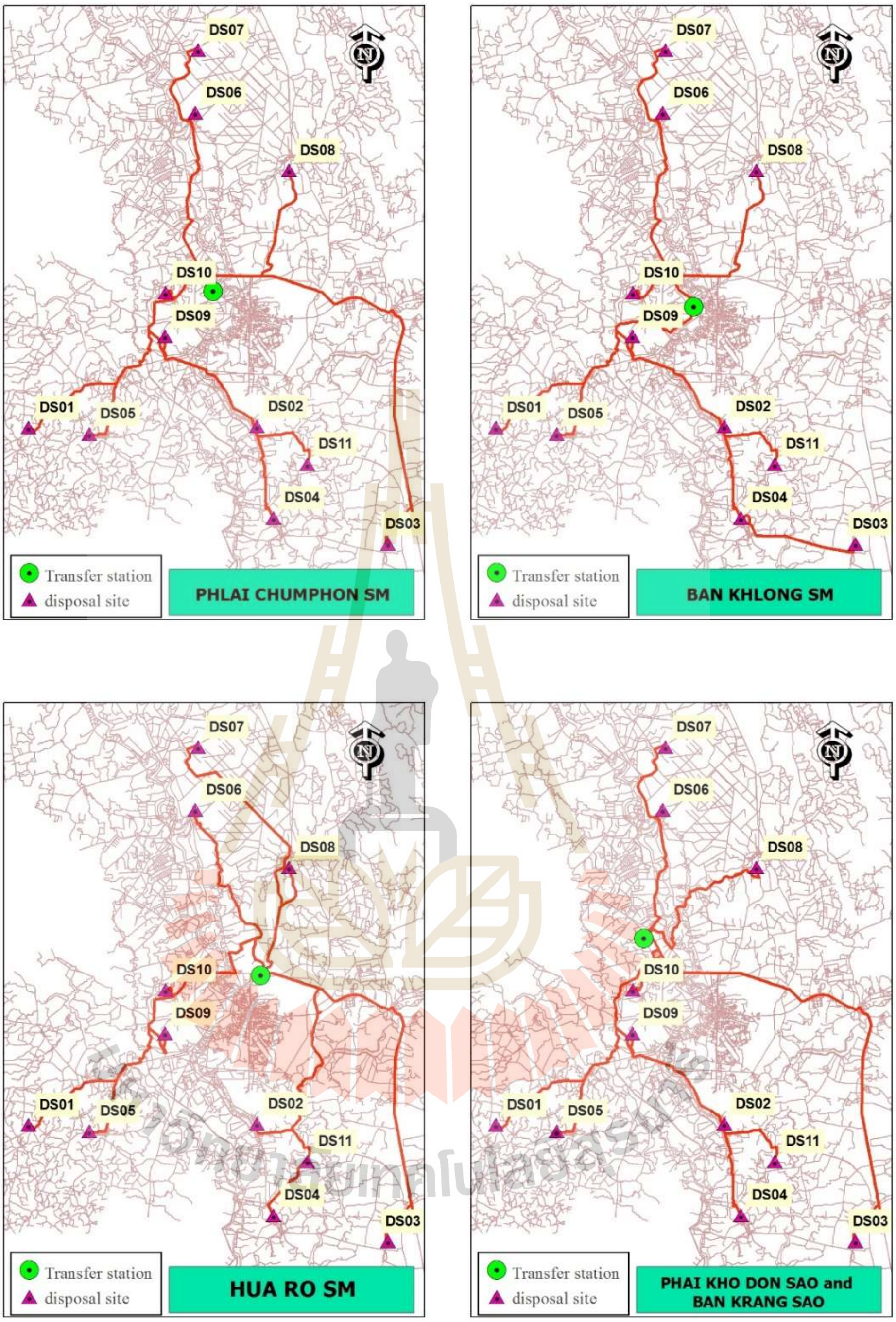


Figure 4.7 The 99 shortest paths of each TS to all DSs (Continued).

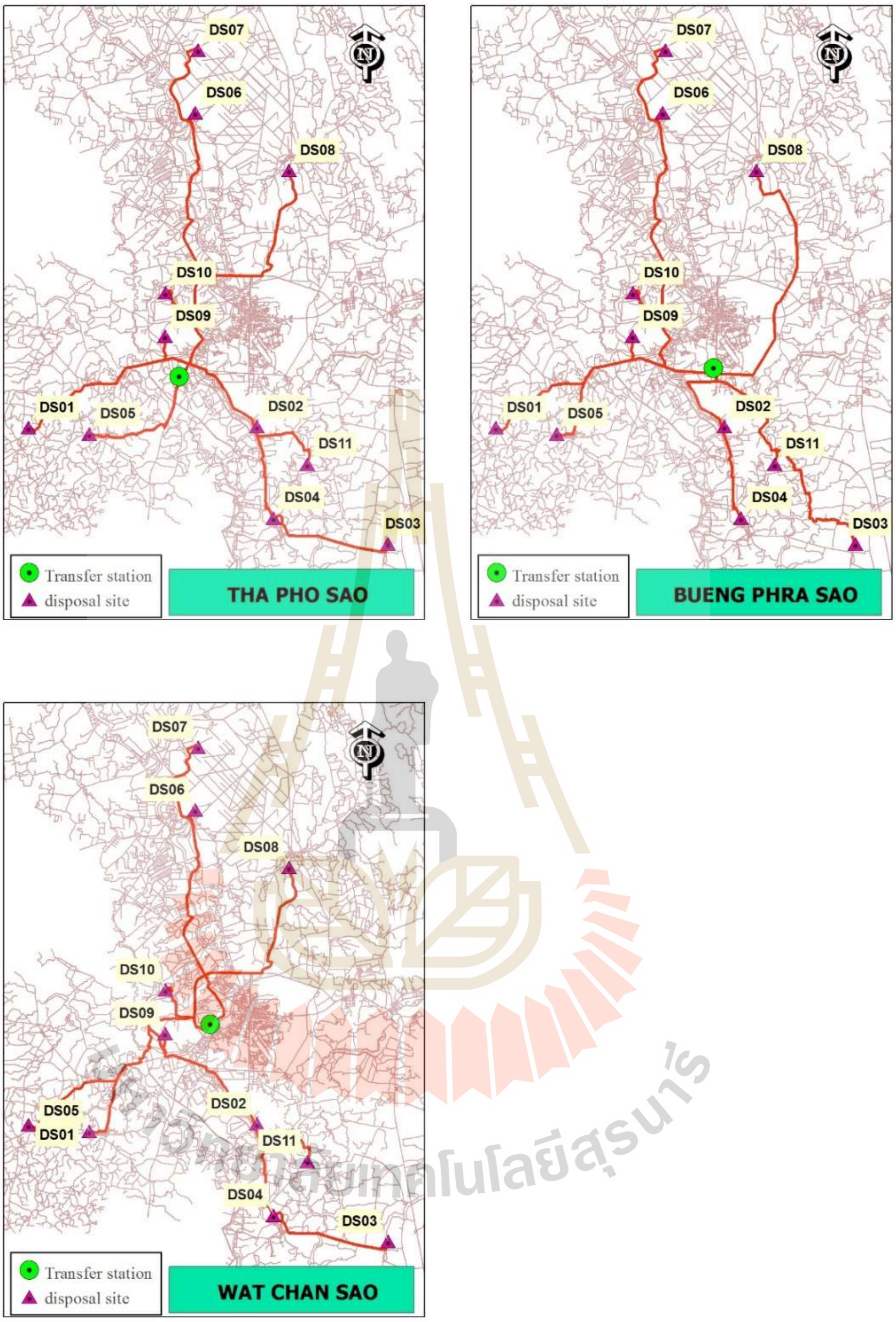


Figure 4.7 The 99 shortest paths of each TS to all DSs (Continued).

Table 4.11 Matrix of normalized distances of pairs of TS and DS.

		Temporary transfer stations (TSs)								
		Phitsanulok and Thathong (TS01)	Aranyik (TS02)	Phlaichumphon (TS03)	Bankhlong (TS04)	Hua Ro (TS05)	Phaikhodon and Bankrang (TS06)	Watchan (TS07)	Thapho (TS08)	Beungphra (TS09)
Disposal sites (DSs)	Phitsanulok (DS01)	0.38	0.77	0.60	0.57	0.82	0.62	0.51	0.40	0.50
	Banmai (DS02)	0.33	0.47	0.54	0.51	0.54	0.56	0.45	0.22	0.20
	Nuenkum (DS03)	0.77	0.71	0.97	0.96	0.78	1.00	0.90	0.66	0.57
	Bangkrathum (DS04)	0.51	0.60	0.73	0.70	0.68	0.75	0.64	0.41	0.39
	Plakrad (DS05)	0.30	0.69	0.52	0.48	0.73	0.53	0.43	0.30	0.41
	Phromphiram (DS06)	0.49	0.68	0.41	0.44	0.42	0.29	0.48	0.57	0.66
	Wongkong (DS07)	0.66	0.78	0.58	0.61	0.60	0.46	0.65	0.74	0.83
	Watbot (DS08)	0.51	0.44	0.43	0.45	0.24	0.41	0.49	0.56	0.54
	Thapho (DS09)	0.10	0.47	0.32	0.28	0.53	0.33	0.23	0.10	0.20
	Bankrang (DS10)	0.11	0.60	0.18	0.20	0.39	0.18	0.16	0.23	0.32
	Thatan (DS11)	0.49	0.47	0.70	0.67	0.54	0.72	0.61	0.38	0.27

4.4 Environmental impact evaluation of TSs and DSs

Results from this analysis was the matrix of EI of pairs of TSs and DSs and used as input in the LP process.

4.4.1 Environmental impact of TSs

Due to the fact that locations of TSs were temporarily assigned as original points of transportation. Therefore, only waste amounts generated in the administrative units (Table 1.2) were considered as their impact to environment. They were normalized to be in the range of 0-1 by making ratios with maximum waste amount as listed in Table 4.12.

Table 4.12 Normalized evaluated EI of TSs.

TS No.	Name of administrative organization	Normalized waste amount generated (EI of TSs)
TS01	Phitsanulok municipality and Thathong municipality	1.00
TS02	Aranyik municipality	0.24
TS03	Phlaichumphon municipality	0.05
TS04	Bankhlong municipality	0.09
TS05	Huaro municipality	0.16
TS06	Phaikhodon SAO and Bankrang SAO	0.10
TS07	Watchan SAO	0.05
TS08	Thapho SAO	0.14
TS09	Beungphra SAO	0.11

4.4.2 Environmental impact of DSs

EI of these DSs was studied by Phinyoyang (2017) as results displayed in Table 4.13.

Table 4.13 The result of EI evaluation of DSs.

DS No.	Organization of site	Normalized EI (EI of DSs)
DS01	Phitsanulok municipality	0.58
DS02	Banmai municipality	0.86
DS03	Nuenkum municipality	0.88
DS04	Bangkrathum municipality	0.86
DS05	Plakrad municipality	0.87
DS06	Phromphiram municipality	1.00
DS07	Wongkong municipality	0.86
DS08	Watbot municipality	0.79
DS09	Thapho SAO	0.68
DS10	Bankrang SAO	0.77
DS11	Thatan SAO	0.74

EI index of every pair of TS and DS was obtained from the summation of their EI indexes. EI indexes of all pairs are displayed as matrix in Table 4.14. Obviously, the pair of Phitsanulok and Thathong TS- Phromphiram DS shows the highest EI due to having the highest generated waste and highest impact scores from all 3 groups of criteria used in the evaluation. The matrix was input data for LP analysis.

Table 4.14 Matrix of normalized EI indexes of pairs of TS and DS.

		Temporary transfer stations (TSs)								
		Phitsanulok and Thathong (TS01)	Aranyik (TS02)	Phlaichumphon (TS03)	Bankhlong (TS04)	Hua Ro (TS05)	Phaikhodon and Bankrang (TS06)	Watchan (TS07)	Thapho (TS08)	Beungphra (TS09)
Disposal sites (DSs)	Phitsanulok (DS01)	0.79	0.40	0.31	0.33	0.36	0.34	0.31	0.36	0.34
	Banmai (DS02)	0.93	0.54	0.45	0.47	0.51	0.48	0.46	0.50	0.48
	Nuenkum (DS03)	0.94	0.55	0.46	0.48	0.52	0.49	0.46	0.51	0.49
	Bangkrathum (DS04)	0.93	0.54	0.45	0.47	0.50	0.48	0.45	0.50	0.48
	Plakrad (DS05)	0.93	0.55	0.46	0.48	0.51	0.48	0.46	0.50	0.49
	Phromphiram (DS06)	1.00	0.61	0.52	0.54	0.58	0.55	0.52	0.57	0.55
	Wongkong (DS07)	0.93	0.54	0.45	0.47	0.51	0.48	0.46	0.50	0.48
	Watbot (DS08)	0.90	0.51	0.42	0.44	0.47	0.45	0.42	0.47	0.45
	Thapho (DS09)	0.84	0.45	0.36	0.38	0.41	0.39	0.36	0.41	0.39
	Bankrang (DS10)	0.88	0.50	0.41	0.43	0.46	0.43	0.41	0.45	0.44
	Bantan (DS11)	0.87	0.48	0.39	0.41	0.44	0.42	0.39	0.44	0.42

4.5 Relative vulnerability assessment of facilities on optimum paths

According to equation (2) as described in section 2.1.5, relative vulnerability of facilities in buffered radiuses of 0.5, 1, 5, and 10 km. was assessed as results shown in Table 4.15. Figure 4.8 is a map showing optimum paths between TSs and DSs intersecting with buffered areas of different radiuses. Any route having more intersecting with shorter-distance buffered area has more vulnerability. Vulnerability as attributes of areas intersecting to each optimum route were summed up to represent VI of each route. VIs of optimum routes were normalized to be between 0-1 and are displayed as matrix in Table 4.16. Obviously, the pair of Phaikhodon and Bankrang TS-Nuenkum DS shows the highest VI along the path due to passing many facilities with high number of servicing people. The matrix was input for the LP analysis of waste transportation allotment.

Table 4.15 Relative vulnerability of facilities of distance and population.

No.	Facility	Population	Vulnerability in buffered radius.			
			0.5km.	1km.	5km.	10km.
1	Rajamangala University of Technology Lanna Phitsanulok	1,254	2.51	1.25	0.25	0.13
2	Bankrangwittayakom school	500	1.00	0.50	0.10	0.05
3	Wat Phra Sri Rattanamahatat Woramahawihan	2,484	4.97	2.48	0.50	0.25
4	Jakarnboon school	1,863	3.73	1.86	0.37	0.19
5	Janokrong school	2,155	4.31	2.16	0.43	0.22
6	Chalermkwansatree school	3,210	6.42	3.21	0.64	0.32
7	Saint Nicholas school	1,400	2.80	1.40	0.28	0.14
8	Naresuan university secondary demonstration school	1,000	2.00	1.00	0.20	0.10
9	Phisanulok university	1,500	3.00	1.50	0.30	0.15
10	Naresuan university hospital	1,488	2.98	1.49	0.30	0.15
11	Naresuan university	6,715	13.43	6.72	1.34	0.67

Table 4.15 Relative vulnerability of facilities of distance and population (Continued).

No.	Facility	Population	Vulnerability in buffered radius.			
			0.5km.	1km.	5km.	10km.
12	Triamudom Suksa School of the North	1,289	2.58	1.29	0.26	0.13
13	Anuban Phitsanulok school	2,500	5.00	2.50	0.50	0.25
14	Buddhachinnarajpittaya school	2,171	4.34	2.17	0.43	0.22
15	Phadungpanya school	1,700	3.40	1.70	0.34	0.17
16	Buddhachinnaraj hospital	1,480	2.96	1.48	0.30	0.15
17	Pitsanuej hospital	1,200	2.40	1.20	0.24	0.12
18	Phromphiramwittaya school	1,197	2.39	1.20	0.24	0.12
19	watbot school	589	1.18	0.59	0.12	0.06
20	watbot hospital	1,200	2.40	1.20	0.24	0.12
21	watbotsuksa school	551	1.10	0.55	0.11	0.06
22	Phitsanulok pittayakom school	3,310	6.62	3.31	0.66	0.33
23	Nongtomsuksa school	500	1.00	0.50	0.10	0.05
24	Phitsanulok technical college	550	1.10	0.55	0.11	0.06
25	Phitsanulok vocational college	3,577	7.15	3.58	0.72	0.36
26	Bungphra Phitsanulok commercial college	1,450	2.90	1.45	0.29	0.15
27	Watsriwisuttharam school	851	1.70	0.85	0.17	0.09
28	Piramutid school	798	1.60	0.80	0.16	0.08
29	Bangrakamwittayasuksa School	795	1.59	0.80	0.16	0.08
30	Princess Chulabhorn's College Phisanulok	791.00	1.58	0.79	0.16	0.08
31	Bangkrathumpithayakom school	829	1.66	0.83	0.17	0.08
32	Prachasongkroe school	1,039	2.08	1.04	0.21	0.10
33	Tesco Lotus phitsanulok	12,060	24.12	12.06	2.41	1.21
34	Big C supper center	10,080	20.16	10.08	2.02	1.01
35	Makro	3,420	6.84	3.42	0.68	0.34
36	Index living mall	2,213	4.43	2.21	0.44	0.22
37	Lotus extra	12,450	24.90	12.45	2.49	1.25
38	Central Plaza	15,708	31.42	15.71	3.14	1.57

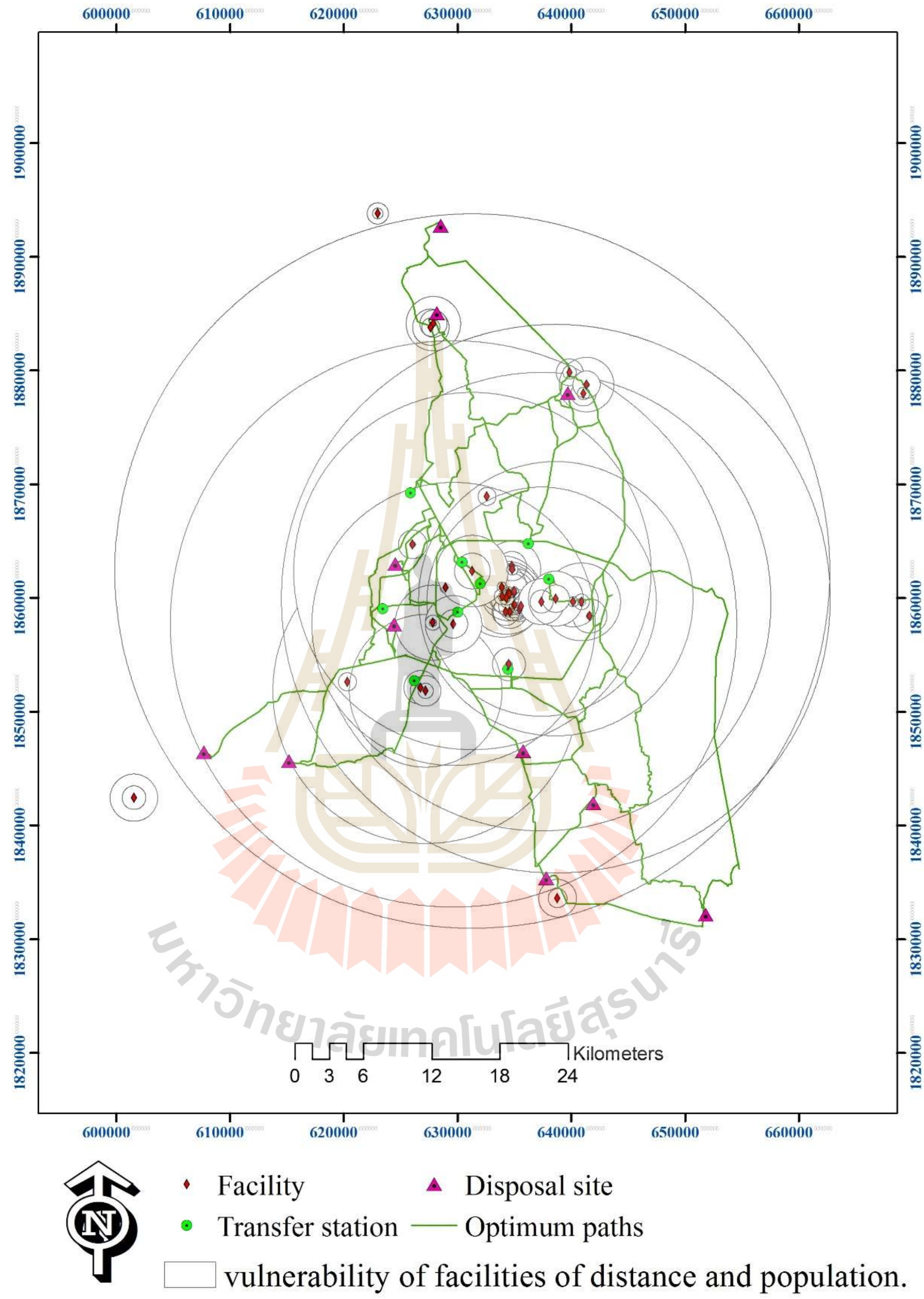


Figure 4.8 Vulnerability assessment of facilities on optimum paths.

Table 4.16 Matrix of VI indexes of pairs of TS and DS.

		Temporary transfer stations (TSs)								
		Phitsanulok and Thathong (TS01)	Aranyik (TS02)	Phlaichumphon (TS03)	Bankhlong (TS04)	Hua Ro (TS05)	Phaikhodon and Bankrang (TS06)	Watchan (TS07)	Thapho (TS08)	Beungphra (TS09)
Disposal sites (DSs)	Phitsanulok (DS01)	0.43	0.78	0.55	0.49	0.76	0.57	0.49	0.44	0.57
	Banmai (DS02)	0.29	0.41	0.40	0.35	0.66	0.43	0.34	0.20	0.21
	Nuenkum (DS03)	0.77	0.74	0.96	0.83	0.87	1.00	0.82	0.68	0.68
	Bangkrathum (DS04)	0.69	0.74	0.80	0.75	0.89	0.83	0.75	0.60	0.61
	Plakrad (DS05)	0.35	0.70	0.47	0.41	0.68	0.49	0.41	0.33	0.50
	Phromphiram (DS06)	0.34	0.52	0.26	0.26	0.35	0.20	0.26	0.40	0.53
	Wongkong (DS07)	0.46	0.68	0.39	0.39	0.54	0.33	0.39	0.53	0.66
	Watbot (DS08)	0.45	0.50	0.34	0.34	0.25	0.32	0.40	0.44	0.72
	Thapho (DS09)	0.09	0.43	0.21	0.15	0.42	0.23	0.15	0.09	0.22
	Bankrang (DS10)	0.07	0.47	0.09	0.09	0.31	0.11	0.08	0.12	0.26
	Bantan (DS11)	0.67	0.48	0.78	0.73	0.63	0.81	0.72	0.58	0.42

VI index of every pair of TS and DS is obtained from summation of their VI indexes. VI indexes of all pairs are displayed as matrix in Table 4.16. The matrix is input data of an objective function of MODA-LP.

4.6 LP analysis for waste transportation management

The results from this analysis are solid waste allotment transport from temporary TS to DSs based on different minimization of criteria or objectives. The analysis was performed with separated objectives as minimized TC, minimized EI, minimized VI, minimized TC and EI, minimized EI and VI and minimized all TC, EI, and VI. The constraint of waste supply from each TS is subject to waste amount generated in each administrative unit. Constraint on capacity of each DS was considered based on service lives of a site. In this study case, daily capacities of 3- and 5-year service lives were input as constraints so that alternative transportation allotments could be performed through LP analysis and fitted them to actual capacity of sites for optimum benefit. The result also included maps showing optimum routes of active pairs of each TS to DSs. These maps are GIS datasets able to be plotted in any working scales.

4.6.1 Minimization of TC

According to equation (14) as described in section 3.6.1 for minimization of TC, the results of the process are shown in Table 4.17, including allotments of solid waste from each temporary TS to DSs in service, TC, EI, and VI of each active pair of TS and DS. Optimum paths of active pairs of TS and DS are displayed in Figure C1 of Appendix D. The minimized total TC is 49,852.55 baht for 3-year daily capacity and 59,099.33 baht for 5-year daily capacity while total EI is 189.42 for 3-year daily capacity and 181.04 for 5-year daily capacity and total VI is 87.36 for 3-year daily capacity and 105.89 for 5-year daily capacity.

Table 4.17 Summary of waste transportation allocation and allotments from TSs to DSs based on minimization of TC for 3- and 5- year daily capacity of DSs.

Temporary TS	Optimal DS	Distance of paths (km)	3 year capacity				5 year capacity			
			Waste amount (Ton)	TC (Baht)	EI	VI	Waste amount (Ton)	TC (Baht)	EI	VI
TS01	DS01	49.91	77.97	17,473.14	61.50	33.38	145.52	32,613.39	114.78	62.57
	DS05	39.19	25.75	4,530.96	24.05	9.03	-	-	-	-
	DS09	12.84	33.39	1,924.96	28.00	2.97	-	-	-	-
	DS10	14.26	8.42	539.05	7.45	0.58	-	-	-	-
	Total		**145.52**	**24,468.11**	**121.00**	**45.95**	**145.52**	**32,613.39**	**114.78**	**62.57**
TS02	DS02	61.43	-	-	-	-	0.09	25.20	0.05	0.04
	DS03	93.31	-	-	-	-	4.62	1,936.30	2.58	3.42
	DS04	78.96	-	-	-	-	3.78	1,338.45	2.06	2.79
	DS08	56.93	31.72	8,108.64	16.35	15.90	18.54	4,737.63	9.55	9.27
	DS11	61.00	2.57	705.14	1.25	1.24	7.28	1,992.47	3.54	3.49
	Total		**34.30**	**8,813.78**	**17.60**	**17.14**	**34.30**	**10,030.05**	**17.77**	**19.01**
TS03	DS06	54.04	7.25	1,759.32	3.81	1.89	-	-	-	-
	DS10	23.43	-	-	-	-	7.25	762.89	2.97	0.65
	Total		**7.25**	**1,759.32**	**3.81**	**1.89**	**7.25**	**762.89**	**2.97**	**0.65**
TS04	DS05	63.20	-	-	-	-	11.02	3,126.00	5.28	4.52
	DS06	57.12	13.22	3,390.95	7.21	3.46	-	-	-	-
	DS10	26.51	-	-	-	-	2.21	262.62	0.95	0.20
	Total		**13.22**	**3,390.95**	7.21	**3.46**	**13.22**	**3,388.62**	**6.23**	**4.72**

Table 4.17 Summary of waste transportation allocation and allotments from TSs to DSs based on minimization of TC for 3- and 5- year daily capacity of DSs (Continued).

Temporary TS	Optimal DS	Distance of paths (km)	3 year capacity				5 year capacity			
			Waste amount (Ton)	**TC (Baht)**	**EI**	**VI**	**Waste amount (Ton)**	**TC (Baht)**	**EI**	**VI**
TS06	DS06	37.46	14.75	2,480.46	8.12	2.97	14.75	2,480.46	8.12	2.95
	Total		**14.75**	**2,480.46**	**8.12**	**2.97**	**14.75**	**2,480.46**	**8.12**	**2.95**
	DS01	66.74	-	-	-	-	5.77	1,728.14	1.81	2.83
TS07	DS05	56.01	-	-	-	-	1.57	395.79	0.72	0.65
	DS10	21.32	7.34	702.60	3.01	0.59	-	-	-	-
	Total		**7.34**	**702.60**	**3.01**	**0.59**	**7.34**	**2,123.93**	**2.53**	**3.47**
	DS02	28.31	20.62	2,620.84	10.36	4.15	-	-	-	-
TS08	DS05	38.99	-	-	-	-	1.34	235.05	0.68	0.44
	DS09	12.63	0.10	5.85	0.04	0.01	19.38	1,098.95	7.95	1.74
	Total		**20.72**	**2,626.69**	**10.40**	**4.15**	**20.72**	**1,334.00**	**8.62**	**2.19**
	DS02	26.02	5.76	672.99	2.80	1.19	15.26	1,782.90	7.42	3.20
TS09	DS09	25.75	-	-	-	-	0.72	82.78	0.28	0.16
	DS11	35.84	10.22	1,644.07	4.32	4.25	-	-	-	-
	Total		**15.98**	**2,317.06**	**7.12**	**5.44**	**15.98**	**1,865.68**	**7.70**	**3.36**
	Grand total 3-year and 5- year		**282.43**	**49,852.55**	**189.42**	**87.36**	**282.43**	**59,099.33**	**181.04**	**105.89**

4.6.2 Minimization of EI

According to equation (19) as described in section 3.6.2 for minimization of EI, the results of the process are shown in Table 4.18, including allotments of solid waste from each temporary TS to DSs in service, TC, EI, and VI of each active pair of TS and DS. Optimum paths of active pairs of TS and DS are displayed in Figure C2 of Appendix C. The total TC is 69,782.09 baht for 3-year daily capacity and 72,514.91 baht for 5-year daily capacity while total minimized EI is 170.13 for 3-year daily capacity and 171.46 for 5-year daily capacity and the total VI is 123.54 for 3-year daily capacity 128.29 for 5-year daily capacity.

Table 4.18 Summary of waste transportation allocation and allotments from TSs to DSs based on minimization of EI for 3- and 5- year daily capacity of DSs.

Temporary TS	Optimal DS	Distance of paths (km)	3 year capacity				5 year capacity			
			Waste amount (Ton)	TC (Baht)	EI	VI	Waste amount (Ton)	TC (Baht)	EI	VI
TS01	DS01	49.91	91.92	20,601.22	72.51	39.35	97.63	21,879.26	77.01	41.98
	DS04	67.12	-	-	-	-	3.78	1,137.79	3.50	2.60
	DS08	66.67	4.35	1,301.74	3.90	1.98	14.57	4,360.65	13.07	6.55
	DS09	12.84	33.49	1,930.90	28.09	2.98	20.10	1,158.71	16.86	1.81
	DS10	14.26	15.76	1,009.08	13.94	1.08	9.46	605.53	8.37	0.66
	Total		**145.52**	**24,842.94**	**118.44**	**45.39**	**145.52**	**29,141.94**	**118.80**	**53.61**
TS02	DS01	100.38	34.30	15,459.15	13.95	26.79	34.30	15,459.15	13.95	26.75
	Total		**34.30**	**15,459.15**	**13.95**	**26.79**	**34.30**	**15,459.15**	**13.95**	**26.75**
TS03	DS01	78.50	7.25	2,555.81	2.27	3.96	7.25	2,555.81	2.27	3.99
	Total		**7.25**	**2,555.81**	**2.27**	**3.96**	**7.25**	**2,555.81**	**2.27**	**3.99**
TS04	DS01	73.92	13.22	4,388.75	4.42	6.48	13.22	4,388.75	4.42	6.48
	Total		**13.22**	**4,388.75**	**4.42**	**6.48**	**13.22**	**4,388.75**	**4.42**	**6.48**
TS05	DS08	31.41	10.57	1,489.98	5.05	2.61	16.08	2,267.66	7.68	4.02
	DS11	70.41	12.79	4,043.26	5.74	8.05	7.28	2,299.88	3.26	4.58
	Total		**23.36**	**5,533.24**	**10.78**	**10.66**	**23.36**	**4,567.54**	**10.94**	**8.60**
TS06	DS01	80.55	14.75	5,332.84	5.01	8.42	14.75	5,332.84	5.01	8.41
	Total		**14.75**	**5,332.84**	**5.01**	**8.42**	**14.75**	**5,332.84**	**5.01**	**8.41**

Table 4.18 Summary of waste transportation allocation and allotments from TSs to DSs based on minimization of EI for 3- and 5- year daily capacity of DSs (Continued).

No.	Temporary TS	Optimal DS	Distance of paths (km)	3 year capacity				5 year capacity			
				Waste amount (Ton)	TC (Baht)	EI	VI	Waste amount (Ton)	TC (Baht)	EI	VI
	TS07	DS01	66.74	7.34	2,199.71	2.31	3.57	7.34	2,199.71	2.31	3.60
		Total		**7.34**	**2,199.71**	**2.31**	**3.57**	**7.34**	**2,199.71**	**2.31**	**3.60**
	TS08	DS01	51.76	20.72	4,816.09	7.46	9.11	15.02	3,490.81	5.41	6.61
		DS02	28.31	-	-	-	-	5.70	724.81	2.87	1.14
		Total		**20.72**	**4,816.09**	**7.46**	**9.11**	**20.72**	**4,215.61**	**8.27**	**7.75**
	TS09	DS01	64.88	15.98	4,653.55	5.49	9.17	15.98	4,653.55	5.49	9.11
		Total		**15.98**	**4,653.55**	**5.49**	**9.17**	**15.98**	**4,653.55**	**5.49**	**9.11**
	Grand total 3-year and 5- year			**282.43**	**69,782.09**	**170.13**	**123.54**	**282.43**	**72,514.91**	**171.46**	**128.29**

4.6.3 Minimization of VI

According to equation (20) as described in section 3.6.3 for minimization of VI, the results of the process are shown in Table 4.19, including allotments of solid waste from each temporary TS to DSs in service, TC, EI, and VI of each active pair of TS and DS. Optimum paths of active pairs of TS and DS are displayed in Figure C3 of Appendix C. The total TC is 51,608.72 baht for 3-year daily capacity and 59,767.31 baht for 5-year daily capacity, while total EI is 191.30 for 3-year daily capacity, and 182.04 for 5-year daily capacity, and the minimum VI is 85.54 for 3-year daily capacity 103.96 for 5-year daily capacity.

Table 4.19 Summary of waste transportation allocation and allotments from TSs to DSs based on minimization of VI for 3- and 5- year daily capacity of DSs.

Temporary TS	Optimal DS	Distance of paths (km)	3 year capacity				5 year capacity			
			Waste amount (Ton)	TC (Baht)	EI	VI	Waste amount (Ton)	TC (Baht)	EI	VI
TS01	DS01	49.91	69.06	15,478.32	54.48	29.57	132.84	29,771.34	104.78	57.12
	DS05	39.19	15.43	2,715.32	14.41	5.41	-	-	-	-
	DS06	64.49	11.78	3,409.70	11.78	3.95	-	-	-	-
	DS09	12.84	33.49	1,930.90	28.09	2.98	12.68	731.15	10.64	1.14
	DS10	14.26	15.76	1,009.08	13.94	1.08	-	-	-	-
	Total		**145.52**	**24,543.33**	**122.70**	**42.99**	**145.52**	**30,502.49**	**115.42**	**58.26**
TS02	DS03	93.31	-	-	-	-	4.62	1,936.30	2.58	3.42
	DS04	78.96	-	-	-	-	3.78	1,338.45	2.06	2.79
	DS06	89.30	-	-	-	-	11.34	4,545.23	7.00	5.89
	DS08	56.93	21.51	5,497.62	11.08	10.78	7.29	1,863.63	3.76	3.65
	DS11	61.00	12.79	3,502.83	6.22	6.16	7.28	1,992.47	3.54	3.49
	Total		**34.30**	**9,000.45**	**17.30**	**16.94**	**34.30**	**11,676.07**	**18.93**	**19.25**
TS03	DS06	54.04	-	-	-	-	6.93	1,681.47	3.64	1.80
	DS08	56.03	7.25	1,824.19	3.06	2.45	-	-	-	-
	DS10	23.43	-	-	-	-	0.32	33.76	0.13	0.03
	Total		**7.25**	**1,824.19**	**3.06**	**2.45**	**7.25**	**1,715.23**	**3.77**	**1.83**

Table 4.19 Summary of waste transportation allocation and allotments from TSs to DSs based on minimization of VI for 3 and 5 year capacity of DSs (Continued).

Temporary TS	Optimal DS	Distance of paths (km)	3 year capacity				5 year capacity			
			Waste amount (Ton)	TC (Baht)	EI	VI	Waste amount (Ton)	TC (Baht)	EI	VI
TS04	DS01	73.92	-	-	-	-	11.43	3,792.78	3.82	5.60
	DS06	57.12	10.26	2,630.78	5.60	2.68	-	-	-	-
	DS08	59.11	2.96	786.69	1.31	1.00	-	-	-	-
	DS10	26.51	-	-	-	-	1.80	213.74	0.77	0.16
	Total		**13.22**	**3,417.47**	**6.91**	**3.69**	**13.22**	**4,006.52**	**4.59**	**5.76**
TS05	DS08	31.41	23.36	3,293.58	11.16	5.76	23.36	3,293.58	11.16	5.84
	Total		**23.36**	**3,293.58**	**11.16**	**5.76**	**23.36**	**3,293.58**	**11.16**	**5.84**
TS06	DS06	37.46	14.75	2,480.46	8.12	2.97	7.72	1,299.30	4.25	1.54
	DS07	59.68	-	-	-	-	7.02	1,881.57	3.38	2.32
	Total		**14.75**	**2,480.46**	**8.12**	**2.97**	**14.75**	**3,180.86**	**7.64**	**3.86**
TS07	DS06	62.31	7.34	2,053.81	3.86	1.94	-	-	-	-
	DS10	21.32	-	-	-	-	7.34	702.60	3.01	0.59
	Total		**7.34**	**2,053.81**	**3.86**	**1.94**	**7.34**	**702.60**	**3.01**	**0.59**

Table 4.19 Summary of waste transportation allocation and allotments from TSs to DSs based on minimization of VI for 3 and 5 year capacity of DSs (Continued).

Temporary TS	Optimal DS	Distance of paths (km)	3 year capacity				5 year capacity			
			Waste amount (Ton)	TC (Baht)	EI	VI	Waste amount (Ton)	TC (Baht)	EI	VI
TS08	DS02	28.31	10.40	1,322.47	5.23	2.09	-	-	-	-
	DS05	38.99	10.32	1,806.40	5.21	3.39	13.93	2,439.08	7.04	4.60
	DS09	12.63	-	-	-	-	6.79	385.07	2.78	0.61
	Total		**20.72**	**3,128.87**	**10.44**	**5.49**	**20.72**	**2,824.15**	**9.82**	**5.21**
TS09	DS02	26.02	15.98	1,866.57	7.77	3.31	15.35	1,793.58	7.46	3.22
	DS09	25.75	-	-	-	-	0.62	72.22	0.25	0.14
	Total		**15.98**	**1,866.57**	**7.77**	**3.31**	**15.98**	**1,865.80**	**7.71**	**3.36**
Grand total 3-year and 5-year			**282.43**	**51,608.72**	**191.30**	**85.54**	**282.43**	**59,767.31**	**182.04**	**103.96**

4.6.4 Minimization of TC and EI

According to equation (21) as described in section 3.6.4 for minimization of TC and EI, the results of the process are shown in Table 4.20, including allotments of solid waste from each temporary TS to DSs in service, TC, EI, and VI of each active pair of TS and DS. Optimum paths of active pairs of TS and DS are displayed in Figure C4 of Appendix C. The total TC is 52,127.44 baht for 3-year daily capacity and 59,767.31 baht for 5-year daily capacity while total EI is 181.36 for 3-year daily capacity and 182.04 for 5-year daily capacity and total VI is 93.79 for 3-year daily capacity 103.96 for 5-year daily capacity.

Table 4.20 Summary of waste transportation allocation and allotments from TSs to DSs based on minimization of TC and EI for 3- and 5- year daily capacity of DSs.

Temporary TS	Optimal DS	Distance of paths (km)	3 year capacity				5 year capacity			
			Waste amount (Ton)	TC (Baht)	EI	VI	Waste amount (Ton)	TC (Baht)	EI	VI
TS01	DS01	49.91	119.48	26,776.14	94.24	51.15	132.84	29,771.34	104.78	57.12
	DS09	12.84	26.05	1,501.70	21.85	2.32	12.68	731.15	10.64	1.14
	Total		**145.52**	**28,277.84**	**116.09**	**53.46**	**145.52**	**30,502.49**	**115.42**	**58.26**
TS02	DS03	93.31	-	-	-	-	4.62	1,936.30	2.58	3.42
	DS04	78.96	-	-	-	-	3.78	1,338.45	2.06	2.79
	DS06	89.30	-	-	-	-	11.34	4,545.23	7.00	5.89
	DS08	56.93	31.72	8,108.64	16.35	15.90	7.29	1,863.63	3.76	3.65
	DS11	61.00	2.57	705.14	1.25	1.24	7.28	1,992.47	3.54	3.49
	Total		**34.30**	**8,813.78**	**17.60**	**17.14**	**34.30**	**11,676.07**	**18.93**	**19.25**
TS03	DS06	54.04	-	-	-	-	6.93	1,681.47	3.64	1.80
	DS10	23.43	7.25	762.89	2.97	0.67	0.32	33.76	0.13	0.03
	Total		**7.25**	**762.89**	**2.97**	**0.67**	**7.25**	**1,715.23**	**3.77**	**1.83**
TS04	DS01	73.92	4.71	1,564.49	1.58	2.31	11.43	3,792.78	3.82	5.60
	DS10	26.51	8.51	1,012.90	3.66	0.79	1.80	213.74	0.77	0.16
	Total		**13.22**	**2,577.39**	**5.24**	**3.10**	**13.22**	**4,006.52**	**4.59**	**5.76**
TS05	DS08	31.41	23.36	**3,293.58**	11.16	5.76	23.36	3,293.58	11.16	5.84
	Total		**23.36**	**3,293.58**	**11.16**	**5.76**	**23.36**	**3,293.58**	**11.16**	**5.84**

Table 4.20 Summary of waste transportation allocation and allotments from TSs to DSs based on minimization of TC and EI for 3- and 5- year daily capacity of DSs (continue).

Temporary TS	Optimal DS	Distance of paths (km)	3 year capacity				5 year capacity			
			Waste amount (Ton)	TC (Baht)	EI	VI	Waste amount (Ton)	TC (Baht)	EI	VI
TS06	DS06	37.46	14.75	**2,480.46**	8.12	2.97	7.72	1,299.30	4.25	1.54
	DS07	59.68	-	**-**	-	-	7.02	1,881.57	3.38	2.32
	Total		**14.75**	**2,480.46**	**8.12**	**2.97**	**14.75**	**3,180.86**	**7.64**	**3.86**
TS07	DS09	29.66	7.34	**977.75**	2.67	1.08	-	-	-	-
	DS10	21.32	-	**-**	-	-	7.34	702.60	3.01	0.59
	Total		**7.34**	**977.75**	**2.67**	**1.08**	**7.34**	**702.60**	**3.01**	**0.59**
TS08	DS02	28.31	20.62	**2,620.84**	**10.36**	**4.15**	**-**	-	**-**	**-**
	DS05	38.99	-	**-**	-	-	13.93	2,439.08	7.04	4.60
	DS09	12.63	0.10	**5.85**	0.04	0.01	6.79	385.07	2.78	0.61
	Total		**20.72**	**2,626.69**	**10.40**	**4.15**	**20.72**	**2,824.15**	**9.82**	**5.21**
TS09	DS02	26.02	5.76	**672.99**	**2.80**	**1.19**	**15.35**	1,793.58	**7.46**	**3.22**
	DS09	25.75	-	**-**	-	-	0.62	72.22	0.25	0.14
	DS11	35.84	10.22	**1,644.07**	4.32	4.25	-	-	-	-
	Total		**15.98**	**2,317.06**	**7.12**	**5.44**	**15.98**	**1,865.80**	**7.71**	**3.36**
	Grand total 3-year		**282.43**	**52,127.44**	**181.36**	**93.79**	**282.43**	**59,767.31**	**182.04**	**103.96**

4.6.5 Minimization of EI and VI

According to equation (22) as described in section 3.6.5 for minimization of EI and VI, the results of the process are shown in Table 4.21, including allotments of solid waste from each temporary TS to DSs in service, EI and VI, and TC of each active pair of TS and DS. Optimum paths of active pairs of TS and DS are displayed in Figure C5 of Appendix C. The total TC is 52,092.26 baht for 3-year daily capacity and 60,736.35 baht for 5-year daily capacity while total EI is 181.75 for 3-year daily capacity and 177.80 for 5-year daily capacity and total VI is 91.73 for 3-year daily capacity 106.37 for 5-year daily capacity.

Table 4.21 Summary of waste transportation allocation and allotments from TSs to DSs based on minimization of EI and VI for 3- and 5- year daily capacity of DSs.

Temporary TS	Optimal DS	Distance of paths (km)	3 year capacity				5 year capacity			
			Waste amount (Ton)	TC (Baht)	EI	VI	Waste amount (Ton)	TC (Baht)	EI	VI
TS01	DS01	49.91	122.35	27,420.31	96.51	52.38	145.52	32,613.39	114.78	62.57
	DS09	12.84	23.17	1,335.98	19.44	2.06	-	-	-	-
	Total		**145.52**	**28,756.30**	**115.94**	**54.44**	**145.52**	**32,613.39**	**114.78**	**62.57**
TS02	DS02	61.43	-	-	-	-	8.49	2,341.24	4.66	3.48
	DS06	89.30	-	-	-	-	11.24	4,508.60	6.95	5.85
	DS08	56.93	21.51	5,497.62	11.08	10.78	7.29	1,863.63	3.76	3.65
	DS11	61.00	12.79	3,502.83	6.22	6.16	7.28	1,992.47	3.54	3.49
	Total		**34.30**	**9,000.45**	**17.30**	**16.94**	**34.30**	**10,705.93**	**18.90**	**16.46**
TS03	DS06	54.04	1.84	446.22	0.97	0.48	-	-	-	-
	DS08	56.03	5.41	1,361.52	2.29	1.83	-	-	-	-
	DS10	23.43	-	-	-	-	7.25	762.89	2.97	0.65
	Total		**7.25**	**1,807.74**	**3.25**	**2.31**	**7.25**	**762.89**	**2.97**	**0.65**
TS04	DS01	73.92	-	-	-	-	13.22	4,388.75	4.42	6.48
	DS08	59.11	4.80	1,274.80	2.13	1.63	-	-	-	-
	DS10	26.51	8.42	1,002.21	3.62	0.79	-	-	-	-
	Total		**13.22**	**2,277.01**	**5.75**	**2.41**	**13.22**	**4,388.75**	**4.42**	**6.48**
TS05	DS08	31.41	23.36	3,293.58	11.16	5.76	23.36	3,293.58	11.16	5.84
	Total		**23.36**	**3,293.58**	**11.16**	**5.76**	**23.36**	**3,293.58**	**11.16**	**5.84**

Table 4.21 Summary of waste transportation allocation and allotments from TSs to DSs based on minimization of EI and VI for 3 and 5 year capacity of DSs (Continued).

Temporary TS	**Optimal DS**	**Distance of paths (km)**	**3 year capacity**				**5 year capacity**			
			Waste amount (Ton)	**TC (Baht)**	**EI**	**VI**	**Waste amount (Ton)**	**TC (Baht)**	**EI**	**VI**
TS05	DS08	31.41	23.36	3,293.58	11.16	5.76	23.36	3,293.58	11.16	5.84
	Total		**23.36**	**3,293.58**	**11.16**	**5.76**	**23.36**	**3,293.58**	**11.16**	**5.84**
TS06	DS06	37.46	14.75	2,480.46	8.12	2.97	14.75	2,480.46	8.12	2.95
	Total		**14.75**	**2,480.46**	**8.12**	**2.97**	**14.75**	**2,480.46**	**8.12**	**2.95**
TS07	DS01	66.74	-	-	-	-	**5.13**	1,538.64	**1.61**	**2.52**
	DS10	21.32	7.34	702.60	3.01	0.59	2.21	211.15	0.90	0.18
	Total		**7.34**	**702.60**	**3.01**	**0.59**	**7.34**	**1,749.79**	**2.52**	**2.69**
TS08	DS01	51.76	-	-	-	-	**0.63**	145.62	**0.23**	**0.28**
	DS02	28.31	10.40	1,322.47	**5.23**	**2.09**	-	-	-	-
	DS09	12.63	10.32	585.09	4.23	0.90	20.10	1,139.55	8.24	1.81
	Total		**20.72**	**1,907.56**	**9.46**	**2.99**	**20.72**	**1,285.17**	**8.46**	**2.08**
TS09	DS01	64.88	-	-	-	-	**9.11**	2,654.59	**3.13**	**5.19**
	DS02	26.02	15.98	1,866.57	7.77	**3.31**	**6.86**	801.80	**3.34**	**1.44**
	Total		**15.98**	**1,866.57**	**7.77**	**3.31**	**15.98**	**3,456.38**	**6.47**	**6.64**
Grand total 3-year and 5- year			**282.43**	**52,092.26**	**181.75**	**91.73**	**282.43**	**60,736.35**	**177.80**	**106.37**

4.6.6 Minimization of TC, EI and VI

According to equation (23) as described in section 3.6.6 for minimization of TC, EI and VI. The results of the process are shown in Table 4.22, including allotments of solid waste from each temporary TS to DSs in service, TC, EI and VI of each active pair of TS and DS. Optimum paths of active pairs of TS and DS are displayed in Figure C6 of Appendix C. The total TC is 51,283.40 baht for 3-year daily capacity and 59,264.62 baht for 5-year daily capacity while total EI is 183.91 for 3-year daily capacity and 180.35 for 5-year daily capacity and total VI is 90.97 for 3-year daily capacity 104.98 for 5-year daily capacity.

Table 4.22 Summary of waste transportation allocation and allotments from TSs to DSs based on minimization of TC, EI and VI for 3- and 5- year daily capacity of DSs.

Temporary TS	Optimal DS	Distance of paths (km)	3 year capacity				5 year capacity			
			Waste amount (Ton)	TC (Baht)	EI	VI	Waste amount (Ton)	TC (Baht)	EI	VI
TS01	DS01	49.91	112.13	25,130.92	88.45	48.00	145.52	32,613.39	114.78	**62.57**
	DS09	12.84	33.39	1,924.96	28.00	2.97	-	-	-	-
	Total		**145.52**	**27,055.87**	**116.45**	**50.97**	**145.52**	**32,613.39**	**114.78**	**62.57**
TS02	DS02	61.43	-	-	-	-	15.35	4,233.99	8.43	6.29
	DS04	78.96	-	-	-	-	3.78	1,338.45	2.06	2.79
	DS08	56.93	31.72	8,108.64	16.35	15.90	7.29	1,863.63	3.76	3.65
	DS09	61.25	-	-	-	-	0.61	166.90	0.28	0.26
	DS11	61.00	2.57	705.14	1.25	1.24	7.28	1,992.47	3.54	3.49
	Total		**34.30**	**8,813.78**	**17.60**	**17.14**	**34.30**	**9,595.43**	**18.06**	**16.49**
TS03	DS06	54.04	7.25	1,759.32	3.81	1.89	-	-	-	-
	DS10	23.43	-	-	-	-	7.25	762.89	2.97	0.65
	Total		**7.25**	**1,759.32**	**3.81**	**1.89**	**7.25**	**762.89**	**2.97**	**0.65**
TS04	DS06	57.12	4.80	1,231.82	2.62	1.26	11.24	2,883.66	6.13	2.92
	DS10	26.51	8.42	1,002.21	3.62	0.79	1.98	235.47	0.85	0.18
	Total		**13.22**	**2,234.04**	**6.24**	**2.04**	**13.22**	**3,119.13**	**6.98**	**3.10**
TS05	DS08	31.41	23.36	3,293.58	11.16	5.76	23.36	3,293.58	11.16	5.84
	Total		**23.36**	**3,293.58**	**11.16**	**5.76**	**23.36**	**3,293.58**	**11.16**	**5.84**

Table 4.22 Summary of waste transportation allocation and allotments from TSs to DSs based on minimization of TC, EI and VI for 3- and 5- year capacity of DSs (Continued).

Temporary TS	Optimal DS	Distance of paths (km)	3 year capacity				5 year capacity			
			Waste amount (Ton)	TC (Baht)	EI	VI	Waste amount (Ton)	TC (Baht)	EI	VI
TS06	DS06	37.46	14.75	2,480.46	8.12	2.97	14.75	2,480.46	8.12	2.95
	Total		**14.75**	**2,480.46**	**8.12**	**2.97**	**14.75**	**2,480.46**	**8.12**	**2.95**
TS07	DS01	66.74	**-**	-	**-**	**-**	7.11	2,131.37	2.23	3.49
	DS10	21.32	7.34	702.60	3.01	0.59	0.23	21.83	0.09	0.02
	Total		**7.34**	**702.60**	**3.01**	**0.59**	**7.34**	**2,153.20**	**2.33**	**3.50**
TS08	DS02	28.31	20.62	2,620.84	10.36	4.15	-	-	-	-
	DS05	38.99	-	-	-	-	13.93	2,439.08	7.04	4.60
	DS09	12.63	0.10	5.85	0.04	0.01	6.79	385.07	2.78	0.61
	Total		**20.72**	**2,626.69**	**10.40**	**4.15**	**20.72**	**2,824.15**	**9.82**	**5.21**
TS09	DS01	64.88	-	-	-	-	3.28	954.30	1.13	1.87
	DS02	26.02	5.76	672.99	2.80	1.19	-	-	-	-
	DS09	25.75	-	-	-	-	12.70	1,468.09	5.00	2.79
	DS11	35.84	10.22	1,644.07	4.32	4.25	-	-	-	-
	Total		**15.98**	**2,317.06**	**7.12**	**5.44**	**15.98**	**2,422.39**	**6.12**	**4.66**
	Grand total 3-year and 5 year		**282.43**	**51,283.40**	**183.91**	**90.97**	**282.43**	**59,264.62**	**180.35**	**104.98**

4.7 MODA result comparison and validation

4.7.1 MODA result comparison

With different objectives in the LP analysis, waste transportation management in the area provides different patterns of path and allotment including sets of active DSs. Results of the process in terms of waste allotment, total TC, EI, and VI with respect to specific objectives separated by service life of sites are summarized and displayed in Tables 4.23, 4.24, and 4.25.

Table 4.23 The summary of results of daily transportation cost (TC, Baht) and waste amount allotted (in parenthesis) based on specific objective functions, under the daily capacity constraints of 3- and 5- year service life of DSs.

Temporary TS	Optimal DS	Min TC	Min EI	Min VI	Min TC and EI	Min EI and VI	Min TC, EI, and VI
3- year	DS01 (49.91)	17,473.14 (77.97)	20,601.22 (91.92)	15,478.32 (69.06)	26,776.14 (119.48)	27,420.31 (122.35)	25,130.92 (112.13)
	DS05 (39.19)	4,530.96 (25.75)	-	2,715.32 (15.43)	-	-	-
	DS06 (64.49)	-	-	3,409.70 (11.78)	-	-	-
TS01	DS08 (66.67)	-	1,301.74 (4.35)	-	-	-	-
	DS09 (12.84)	1,924.96 (33.39)	1,930.90 (33.49)	1,930.90 (33.49)	1,501.70 (26.05)	1,335.98 (23.17)	1,924.96 (33.39)
	DS10 (14.26)	539.05 (8.42)	1,009.08 (15.76)	1,009.08 (15.76)	-	-	-
	Total	**24,468.11**	**24,842.94**	**24,543.33**	**28,277.84**	**28,756.30**	**27,055.87**
5- year	DS01 (49.91)	32,613.39 (145.52)	21,879.26 (97.63)	29,771.34 (132.84)	29,771.34 (132.84)	32,613.39 (145.52)	32,613.39 (145.52)
	DS04 (67.12)	-	1,137.79 (3.78)	-	-	-	-
TS01	DS08 (66.67)	-	4,360.65 (14.57)	-	-	-	-
	DS09 (12.84)	-	1,158.71 (20.10)	731.15 (12.68)	731.15 (12.68)	-	-
	DS10 (14.26)	-	605.53 (9.46)	-	-	-	-
	Total	**32,613.39**	**29,141.94**	**30,502.49**	**30,502.49**	**32,613.39**	**32,613.39**

Table 4.23 The summary of results of daily transportation cost (TC, Baht) and waste amount allotted (in parenthesis) based on specific objective functions, under the daily capacity constraints of 3- and 5- year service life of DSs (Continued).

Temporary TS	Optimal DS	Min TC	Min EI	Min VI	Min TC and EI	Min EI and VI	Min TC, EI, and VI
3- year	DS01 (100.38)	-	15,459.15 (34.30)	-	-	-	-
	DS08 (56.93)	8,108.64 (31.72)	-	5,497.62 (21.51)	8,108.64 (31.72)	5,497.62 (21.51)	8,108.64 (31.72)
TS02	DS11 (61.00)	705.14 (2.57)	-	3,502.83 (12.79)	705.14 (2.57)	3,502.83 (12.79)	705.14 (2.57)
	Total	**8,813.78**	**15,459.15**	**9,000.45**	**8,813.78**	**9,000.45**	**8,813.78**
5- year	DS01 (100.38)	-	15,459.15 (34.30)	-	-	-	-
	DS02 (61.43)	25.20 (0.09)	-	-	-	2,341.24 (8.49)	4,233.99 (15.35)
	DS03 (93.31)	1,936.30 (4.62)	-	1,936.30 (4.62)	1,936.30 (4.62)	-	-
TS02	DS04 (78.96)	1,338.45 (3.78)	-	1,338.45 (3.78)	1,338.45 (3.78)	-	1,338.45 (3.78)
	DS06 (89.30)	-	-	4,545.23 (11.34)	4,545.23 (11.34)	4,508.60 (11.24)	-
	DS08 (56.93)	4,737.63 (18354)	-	1,863.63 (7.29)	1,863.63 (7.29)	1,863.63 (7.29)	1,863.63 (7.29)
	DS09 (61.25)	-	-	-	-	-	166.90
	DS11 (61.00)	1,992.47 (7.28)	-	1,992.47 (7.28)	1,992.47 (7.28)	1,992.47 (7.28)	1,992.47 (7.28)
	Total	**10,030.05**	**15,459.15**	**11,676.07**	**11,676.07**	**10,705.93**	**9,595.43**
3- year	DS01 (78.50)	-	2,555.81 (7.25)	-	-	-	-
	DS06 (54.04)	1,759.32 (7.25)	-	-	-	446.22 (1.84)	1,759.32 (7.25)
TS03	DS08 (56.03)	-	-	1,824.19 (7.25)	-	1,361.52 (5.41)	-
	DS10 (23.43)	-	-	-	762.89 (7.25)	-	-
	Total	**1,759.32**	**2,555.81**	**1,824.19**	**762.89**	**1,807.74**	**1,759.32**
5- year	DS01 (78.50)	-	2,555.81 (7.25)	-	-	-	-
TS03	DS06 (54.04)	-	-	1,681.47 (6.93)	1,681.47 (6.93)	-	-
	DS10 (23.43)	762.89 (7.25)	-	33.76 (0.32)	33.76 (0.32)	762.89 (7.25)	762.89 (7.25)
	Total	**762.89**	**2,555.81**	**1,715.23**	**1,715.23**	**762.89**	**762.89**
3- year	DS01 (73.92)	-	4,388.75 (13.22)	-	1,564.49 (4.71)	-	-
TS04	DS06 (57.12)	3,390.95 (13.22)	-	2,630.78 (10.26)	-	-	1,231.82 (4.80)
	DS08 (59.11)	-	-	786.69 (2.96)	-	1,274.80 (4.80)	-
	DS10 (26.51)	-	-	-	1,012.90 (8.51)	1,002.21 (8.42)	1,002.21 (8.42)
	Total	**3,390.95**	**4,388.75**	**3,417.47**	**2,577.39**	**2,277.01**	**2,234.04**

Table 4.23 The summary of results of daily transportation cost (TC, Baht) and waste amount allotted (in parenthesis) based on specific objective functions, under the daily capacity constraints of 3- and 5- year service life of DSs (Continued).

Temporary TS	Optimal DS	Min TC	Min EI	Min VI	Min TC and EI	Min EI and VI	Min TC, EI, and VI
5- year TS04	DS01 (73.92)	-	4,388.75 (13.22)	3,792.78 (11.43)	3,792.78 (11.43)	4,388.75 (13.22)	-
	DS05 (63.20)	3,126.00 (11.02)	-	-	-	-	-
	DS06 (57.12)	-	-	-	-	-	2,883.66 (11.24)
	DS10 (26.51)	262.62 (2.21)	-	213.74 (1.80)	213.74 (1.80)	-	235.47 (1.98)
	Total	**3,388.62**	**4,388.75**	**4,006.52**	**4,006.52**	**4,388.75**	**3,119.13**
3- year **TS05**	DS08 (31.41)	3,293.58 (23.36)	1,489.98 (10.57)	3,293.58 (23.36)	3,293.58 (23.36)	3,293.58 (23.36)	3,293.58 (23.36)
	DS11 (70.41)	-	4,043.26 (12.79)	-	-	-	-
	Total	**3,293.58**	**5,533.24**	**3,293.58**	**3,293.58**	**3,293.58**	**3,293.58**
5- year TS05	DS06 (55.31)	2,792.35 (11.24)	-	-	-	-	-
	DS08 (31.41)	1,707.96 (12.11)	2,267.66 (16.08)	3,293.58 (23.36)	3,293.58 (23.36)	3,293.58 (23.36)	3,293.58 (23.36)
	DS11 (70.41)	-	2,299.88 (7.28)	-	-	-	-
	Total	**4,500.31**	**4,567.54**	**3,293.58**	**3,293.58**	**3,293.58**	**3,293.58**
3- year **TS06**	DS01 (80.55)	-	5,332.84 (14.75)	-	-	-	-
	DS06 (37.46)	2,480.46 (14.75)	-	2,480.46 (14.75)	2,480.46 (14.75)	2,480.46 (14.75)	2,480.46 (14.75)
	Total	**2,480.46**	**5,332.84**	**2,480.46**	**2,480.46**	**2,480.46**	**2,480.46**
5- year TS06	DS01 (80.55)	-	5,332.84 (14.75)	-	-	-	-
	DS06 (37.46)	2,480.46 (14.75)	-	1,299.30 (7.72)	1,299.30 (7.72)	2,480.46 (14.75)	2,480.46 (14.75)
	DS07 (59.68)	-	-	1,881.57 (7.02)	1,881.57 (7.02)	-	-
	Total	**2,480.46**	**5,332.84**	**3,180.86**	**3,180.86**	**2,480.46**	**2,480.46**
3- year **TS07**	DS01 (66.74)	-	2,199.71 (7.34)	-	-	-	-
	DS06 (62.31)	-	-	2,053.81 (7.34)	-	-	-
	DS09 (29.66)	-	-	-	977.75 (7.34)	-	-
	DS10 (21.32)	702.60 (7.34)	-	-	-	702.60 (7.34)	702.60 (7.34)
	Total	**702.60**	**2,199.71**	**2,053.81**	**977.75**	**702.60**	**702.60**
5- year TS07	DS01 (66.74)	1,728.14 (5.77)	2,199.71 (7.34)	-	-	1,538.64 (5.13)	2,131.37 (7.11)
	DS05 (56.01)	395.79 (1.57)	-	-	-	-	-
	DS10 (21.32)	-	-	702.60 (7.34)	702.60 (7.34)	211.15 (2.21)	21.83 (0.23)
	Total	**2,123.93**	**2,199.71**	**702.60**	**702.60**	**1,749.79**	**2,153.20**

Table 4.23 The summary of results of daily transportation cost (TC, Baht) and waste amount allotted (in parenthesis) based on specific objective functions, under the daily capacity constraints of 3- and 5- year service life of DSs (Continued).

Temporary TS	Optimal DS	Min TC	Min EI	Min VI	Min TC and EI	Min EI and VI	Min TC, EI, and VI
3- year **TS08**	DS01 (51.76)	-	4,816.09 (20.72)	-	-	-	-
	DS02 (28.31)	2,620.84 (20.62)	-	1,322.47 (10.40)	2,620.84 (20.62)	1,322.47 (10.40)	2,620.84 (20.62)
	DS05 (38.99)	-	-	1,806.40 (10.32)	-	-	-
	DS09 (12.63)	5.85 (0.10)	-	-	5.85 (0.10)	585.09 (10.32)	5.85 (0.10)
	Total	**2,626.69**	**4,816.09**	**3,128.87**	**2,626.69**	**1,907.56**	**2,626.69**
5- year TS08	DS01 (51.76)	-	3,490.81 (15.02)	-	-	145.62 (0.63)	-
	DS02 (28.31)	-	724.81 (5.70)	-	-	-	-
	DS05 (38.99)	235.05 (1.34)	-	2,439.08 (13.93)	2,439.08 (13.93)	-	2,439.08 (13.93)
	DS09 (12.63)	1,098.95 (19.38)	-	385.07 (6.79)	385.07 (6.79)	1,139.55 (20.10)	385.07 (6.79)
	Total	**1,334.00**	**4,215.61**	**2,824.15**	**2,824.15**	**1,285.17**	**2,824.15**
3- year **TS09**	DS01 (64.88)	-	4,653.55 (15.95)	-	-	-	-
	DS02 (26.02)	672.99 (5.76)	-	1,866.57 (15.98)	672.99 (5.76)	1,866.57 (15.98)	672.99 (5.76)
	DS11 (35.84)	1,644.07 (10.22)	-	-	1,644.07 (10.22)	-	1,644.07 (10.22)
	Total	**2,317.06**	**4,653.55**	**1,866.57**	**2,317.06**	**1,866.57**	**2,317.06**
5- year TS09	DS01 (64.88)	-	4,653.55 (15.98)	-	-	2,654.59 (9.11)	954.30 (3.28)
	DS02 (26.02)	1,782.90 (15.26)	-	1,793.58 (15.35)	1,793.58 (15.35)	801.80 (6.86)	-
	DS09 (25.75)	82.78 (0.72)	-	72.22 (0.62)	72.22 (0.62)	-	1,468.09 (12.70)
	Total	**1,865.68**	**4,653.55**	**1,865.80**	**1,865.80**	**3,456.38**	**2,422.39**
Total 3- year		**49,852.55**	**69,782.09**	**51,608.72**	**52,127.44**	**52,092.26**	**51,283.40**
Total 5- year		**59,099.33**	**72,514.91**	**59,767.31**	**59,767.31**	**60,736.35**	**59,264.62**

Table 4.24 The summary of results of daily EI and waste amount allotted (in parenthesis) based on specific objective functions, under the daily capacity constraints of 3- and 5- year service life of DSs.

Temporary TS	Optimal DS	Min TC	Min EI	Min VI	Min TC and EI	Min EI and VI	Min TC, EI, and VI
3- year TS01	DS01 (49.91)	61.50 (77.97)	72.51 (91.92)	54.48 (69.06)	94.24 (119.48)	96.51 (122.35)	88.45 (112.13)
	DS05 (39.19)	24.05 (25.75)	-	14.41 (15.43)	-	-	-
	DS06 (64.49)	-	-	11.78 (11.78)	-	-	-
	DS08 (66.67)	-	3.90 (4.35)	-	-	-	-
	DS09 (12.84)	28.00 (33.39)	28.09 (33.49)	28.09 (33.49)	21.85 (26.05)	19.44 (23.17)	28.00 (33.39)
	DS10 (14.26)	7.45 (8.42)	13.94 (15.76)	13.94 (15.76)	-	-	-
	Total	**121.00**	**118.44**	**122.70**	**116.09**	**115.94**	**115.94**
5- year TS01	DS01 (49.91)	114.78 (145.52)	77.01 (97.63)	104.78 (132.84)	104.78 (132.84)	114.78 (145.52)	114.78 (145.52)
	DS04 (67.12)	-	3.50 (3.78)	-	-	-	-
	DS08 (66.67)	-	13.07 (14.57)	-	-	-	-
	DS09 (12.84)	-	16.86 (20.10)	10.64 (12.68)	10.64 (12.68)	-	-
	DS10 (14.26)	-	8.37 (9.46)	-	-	-	-
	Total	**114.78**	**118.80**	**115.42**	**115.42**	**114.78**	**114.78**
3- year TS02	DS01 (100.38)	-	13.95 (34.30)	-	-	-	-
	DS08 (56.93)	16.35 (31.72)	-	11.08 (21.51)	16.35 (31.72)	11.08 (21.51)	16.35 (31.72)
	DS11 (61.00)	1.25 (2.57)	-	6.22 (12.79)	1.25 (2.57)	6.22 (12.79)	1.25 (2.57)
	Total	**17.60**	**13.95**	**17.30**	**17.60**	**17.30**	**17.60**
5- year TS02	DS01 (100.38)	-	13.95 (34.30)	-	-	-	-
	DS02 (61.43)	0.05 (0.09)	-	-	-	4.66 (8.49)	8.43 (15.35)
	DS03 (93.31)	2.58 (4.62)	-	2.58 (4.62)	2.58 (4.62)	-	-
	DS04 (78.96)	2.06 (3.78)	-	2.06 (3.78)	2.06 (3.78)	-	2.06 (3.78)
	DS06 (89.30)	-	-	7.00 (11.34)	7.00 (11.34)	6.95 (11.24)	-
	DS08 (56.93)	9.55 (18.54)	-	3.76 (7.29)	3.76 (7.29)	3.76 (7.29)	3.76 (7.29)
	DS09 (61.25)	-	-	-	-	-	0.28 (0.61)
	DS11 (61.00)	3.54 (7.28)	-	3.54 (7.28)	3.54 (7.28)	3.54 (7.28)	3.54 (7.28)
	Total	**17.77**	**13.95**	**18.93**	**18.93**	**18.90**	**18.06**

Table 4.24 The summary of results of daily EI and waste amount allotted (in parenthesis) based on specific objective functions, under the daily capacity constraints of 3- and 5- year service life of DSs (Continued).

Temporary TS	Optimal DS	Min TC	Min EI	Min VI	Min TC and EI	Min EI and VI	Min TC, EI, and VI
3- year TS03	DS01 (78.50)	-	2.27 (7.25)	-	-	-	-
	DS06 (54.04)	3.81 (7.25)	-	-	-	0.97 (1.84)	3.81 (7.25)
	DS08 (56.03)	-	-	3.06 (7.25)	-	2.29 (5.41)	
	DS10 (23.43)	-	-	-	2.97 (7.25)	-	-
	Total	**3.81**	**2.27**	**3.06**	**2.97**	**3.25**	**3.81**
5- year TS03	DS01 (78.50)	-	2.27 (7.25)	-	-	-	-
	DS06 (54.04)	-	-	3.64 (6.93)	3.64 (6.93)	-	-
	DS10 (23.43)	2.97 (7.25)	-	0.13 (0.32)	0.13 (0.32)	2.97 (7.25)	2.97 (7.25)
	Total	**2.97**	**2.27**	**3.77**	**3.77**	**2.97**	**2.97**
3- year TS04	DS01 (73.92)	-	4.42 (13.22)	-	1.58 (4.71)	-	-
	DS06 (57.12)	7.21 (13.22)	-	5.60 (10.26)	-	-	2.62 (4.80)
	DS08 (59.11)	-	-	1.31 (2.96)	-	2.13 (4.80)	
	DS10 (26.51)	-	-	-	3.66 (8.51)	3.62 (8.42)	3.62 (8.42)
	Total	**7.21**	**4.42**	**6.91**	**5.24**	**5.75**	**6.24**
5- year TS04	DS01 (73.92)	-	4.42 (13.22)	3.82 (11.43)	3.82 (11.43)	4.42 (13.22)	-
	DS05 (63.20)	5.28 (11.02)	-	-	-	-	-
	DS06 (57.12)	-	-	-	-	-	6.13 (11.24)
	DS10 (26.51)	0.95 (2.21)	-	0.77 (1.80)	0.77 (1.80)	-	0.85 (1.98)
	Total	**6.23**	**4.42**	**4.59**	**4.59**	**4.42**	**6.98**
3- year TS05	DS08 (31.41)	11.16 (23.36)	5.05 (10.57)	11.16 (23.36)	11.16 (23.36)	11.16 (23.36)	11.16 (23.36)
	DS11 (70.41)	-	5.74 (12.79)	-	-	-	-
	Total	**11.16**	**10.78**	**11.16**	**11.16**	**11.16**	**11.16**
5- year TS05	DS06 (55.31)	6.52 (11.24)	-	-	-	-	-
	DS08 (31.41)	5.79 (12.11)	7.68 (16.08)	11.16 (23.36)	11.16 (23.36)	11.16 (23.36)	11.16 (23.36)
	DS11 (70.41)	-	3.26 (7.28)	-	-	-	-
	Total	**12.31**	**10.94**	**11.16**	**11.16**	**11.16**	**11.16**

Table 4.24 The summary of results of daily EI and waste amount allotted (in parenthesis) based on specific objective functions, under the daily capacity constraints of 3- and 5- year service life of DSs (Continued).

Temporary TS	Optimal DS	Min TC	Min EI	Min VI	Min TC and EI	Min EI and VI	Min TC, EI, and VI
3- year TS06	DS01 (80.55)	-	5.01 (14.75)	-	-	-	-
	DS06 (37.46)	8.12 (14.75)	-	8.12 (14.75)	8.12 (14.75)	8.12 (14.75)	8.12 (14.75)
	Total	**8.12**	**5.01**	**8.12**	**8.12**	**8.12**	**8.12**
5- year TS06	DS01 (80.55)	-	5.01 (14.75)	-	-	-	-
	DS06 (37.46)	8.12 (14.75)	-	4.25 (7.72)	4.25 (7.72)	8.12 (14.75)	8.12 (14.75)
	DS07 (59.68)	-	-	3.38 (7.02)	3.38 (7.02)	-	-
	Total	**8.12**	**5.01**	**7.64**	**7.64**	**8.12**	**8.12**
3- year TS07	DS01 (66.74)	-	2.31 (7.34)	-	-	-	-
	DS06 (62.31)	-	-	3.86 (7.34)	-	-	-
	DS09 (29.66)	-	-	-	2.67 (7.34)	-	-
	DS10 (21.32)	3.01 (7.34)	-	-	-	3.01 (7.34)	3.01 (7.34)
	Total	**3.01**	**2.31**	**3.86**	**2.67**	**3.01**	**3.01**
5- year TS07	DS01 (66.74)	1.81 (5.77)	2.31 (7.34)	-	-	1.61 (5.13)	2.23 (7.11)
	DS05 (56.01)	0.72 (1.57)	-	-	-	-	-
	DS10 (21.32)	-	-	3.01 (7.34)	3.01 (7.34)	0.90 (2.21)	0.09 (0.23)
	Total	**2.53**	**2.31**	**3.01**	**3.01**	**2.52**	**2.33**
3- year TS08	DS01 (51.76)	-	7.46 (20.72)	-	-	-	-
	DS02 (28.31)	10.36 (20.62)	-	5.23 (10.40)	10.36 (20.62)	5.23 (10.40)	10.36 (20.62)
	DS05 (38.99)	-	-	5.21 (10.32)	-	-	-
	DS09 (12.63)	0.04 (0.10)	-	-	0.04 (0.10)	4.23 (10.32)	0.04 (0.10)
	Total	**10.40**	**7.46**	**10.44**	**10.40**	**9.46**	**10.40**
5- year TS08	DS01 (51.76)	-	5.41 (15.02)	-	-	0.23 (0.63)	-
	DS02 (28.31)	-	2.87 (5.70)	-	-	-	-
	DS05 (38.99)	0.68 (1.34)	-	7.04 (13.93)	7.04 (13.93)	-	7.04 (13.93)
	DS09 (12.63)	7.95 (19.38)	-	2.78 (6.79)	2.78 (6.79)	8.24 (20.10)	2.78 (6.79)
	Total	**8.62**	**8.27**	**9.82**	**9.82**	**8.46**	**9.82**

Table 4.24 The summary of results of daily EI and waste amount allotted (in parenthesis) based on specific objective functions, under the daily capacity constraints of 3- and 5- year service life of DSs (Continued).

Temporary TS	Optimal DS	Min TC	Min EI	Min VI	Min TC and EI	Min EI and VI	Min TC, EI, and VI
3- year	DS01 (64.88)	-	5.49 (15.98)	-	-	-	-
TS09	DS02 (26.02)	2.80 (5.76)	-	7.77 (15.98)	2.80 (5.76)	7.77 (15.98)	2.80 (5.76)
	DS11 (35.84)	4.32 (10.22)	-	-	4.32 (10.22)	-	4.32 (10.22)
	Total	**7.12**	**5.49**	**7.77**	**7.12**	**7.77**	**7.12**
5- year	DS01 (64.88)	-	5.49 (15.98)	-	-	3.13 (9.11)	1.13 (3.28)
TS09	DS02 (26.02)	7.42 (15.26)	-	7.46 (15.35)	7.46 (15.35)	3.34 (6.86)	-
	DS09 (25.75)	0.28 (0.72)	-	0.25 (0.62)	0.25 (0.62)	-	5.00 (12.70)
	Total	**7.70**	**5.49**	**7.71**	**7.71**	**6.47**	**6.12**
Total 3- year		**189.42**	**170.13**	**191.30**	**181.36**	**181.75**	**183.91**
Total 5- year		**181.04**	**171.46**	**182.04**	**182.04**	**177.80**	**180.35**

Table 4.25 The summary of results of daily VI and waste amount allotted (in parenthesis) based on specific objective functions, under the daily capacity constraints of 3- and 5- year service life of DSs.

Temporary TS	Optimal DS	Min TC	Min EI	Min VI	Min TC and EI	Min EI and VI	Min TC, EI, and VI
3- year	DS01 (49.91)	33.38 (77.97)	39.35 (91.92)	29.57 (69.06)	51.15 (119.48)	52.38 (122.35)	48.00 (112.13)
TS01	DS05 (39.19)	9.03 (25.75)	-	5.41 (15.43)	-	-	-
	DS06 (64.49)	-	-	3.95 (11.78)	-	-	-
	DS08 (66.67)	-	1.98 (66.67)	-	-	-	-
	DS09 (12.84)	2.97 (33.39)	2.98 (12.84)	2.98 (33.49)	2.32 (26.05)	2.06 (23.17)	2.97 (33.39)
	DS10 (14.26)	0.58 (8.42)	1.08 (14.26)	1.08 (15.76)	-	-	-
	Total	**45.95**	**45.39**	**42.99**	**53.46**	**54.44**	**50.97**

Table 4.25 The summary of results of daily VI and waste amount allotted (in parenthesis) based on specific objective functions, under the daily capacity constraints of 3- and 5- year service life of DSs (Continued).

Temporary TS	**Optimal DS**	**Min TC**	**Min EI**	**Min VI**	**Min TC and EI**	**Min EI and VI**	**Min TC, EI, and VI**
5- year TS01	DS01 (49.91)	62.57 (145.52)	41.98 (97.63)	57.12 (132.84)	57.12 (132.84)	62.57 (145.52)	62.57 (145.52)
	DS04 (67.12)	-	2.60 (3.78)	-	-	-	-
	DS08 (66.67)	-	6.55 (14.57)	-	-	-	-
	DS09 (12.84)	-	1.81 (20.10)	1.14 (12.68)	1.14 (12.68)	-	-
	DS10 (14.26)	-	0.66 (946)	-	-	-	-
	Total	**62.57**	**53.61**	**58.26**	**58.26**	**62.57**	**62.57**
3- year TS02	DS01 (100.38)	-	26.75 (34.30)	-	-	-	-
	DS08 (56.93)	15.90 (31.72)	-	10.78 (21.51)	15.90 (31.72)	10.78 (21.51)	15.90 (31.72)
	DS11 (61.00)	1.24 (2.57)	-	6.16 (12.79)	1.24 (2.57)	6.16 (12.79)	1.24 (2.57)
	Total	**17.14**	**26.79**	**16.94**	**17.14**	**16.94**	**17.14**
5- year TS02	DS01 (100.38)	-	26.75 (34.30)	-	-	-	-
	DS02 (61.43)	0.04 (0.09)	-	-	-	3.48 (8.49)	6.29 (15.35)
	DS03 (93.31)	3.42 (4.62)	-	3.42 (4.62)	3.42 (4.62)	-	-
	DS04 (78.96)	2.79 (3.78)	-	2.79 (3.78)	2.79 (3.78)	-	2.79 (3.78)
	DS06 (89.30)	-	-	5.89 (11.34)	5.89 (11.34)	5.89 (11.34)	-
	DS08 (56.93)	9.27 (18.54)	-	3.65 (7.29)	3.65 (7.29)	3.65 (7.29)	3.65 (7.29)
	DS09 (61.25)	-	-	-	-	-	-
	DS11 (61.00)	3.49 (7.28)	-	3.49 (7.28)	3.49 (7.28)	3.49 (7.28)	3.49 (7.28)
	Total	**19.01**	**26.75**	**19.25**	**19.25**	**16.46**	**16.49**
3- year TS03	DS01 (78.50)	-	3.96 (7.25)	-	-	-	-
	DS06 (54.04)	1.89 (7.25)	-	-	-	0.48 (1.84)	1.89 (7.25)
	DS08 (56.03)	-	-	2.45 (7.25)	-	1.83 (5.41)	-
	DS10 (23.43)	-	-	-	0.67 (7.25)	-	-
	Total	**1.89**	**3.96**	**2.45**	**0.67**	**2.31**	**1.89**

Table 4.25 The summary of results of daily VI and waste amount allotted (in parenthesis) based on specific objective functions, under the daily capacity constraints of 3- and 5- year service life of DSs (Continued).

Temporary TS	Optimal DS	Min TC	Min EI	Min VI	Min TC and EI	Min EI and VI	Min TC, EI, and VI
5- year TS03	DS01 (78.50)	-	3.99 (7.25)	-	-	-	-
	DS06 (54.04)	-	-	1.80 (6.93)	1.80 (6.93)	-	-
	DS10 (23.43)	0.65 (7.25)	-	0.03 (0.32)	0.03 (0.32)	0.65 (7.25)	0.65 (7.25)
	Total	**0.65**	**3.99**	**1.83**	**1.83**	**0.65**	**0.65**
3- year TS04	DS01 (73.92)	-	6.48 (13.22)	-	2.31 (4.71)	-	-
	DS06 (57.12)	3.46 (13.22)	-	2.68 (10.26)	-	-	1.26 (4.80)
	DS08 (59.11)	-	-	1.00 (2.96)	-	1.63 (4.80)	-
	DS10 (26.51)	-	-	-	0.79 (8.51)	0.79 (8.42)	0.79 (8.42)
	Total	**3.46**	**6.48**	**3.69**	**3.10**	**2.41**	**2.04**
5- year TS04	DS01 (73.92)	-	6.48 (13.22)	5.60 (11.43)	5.60 (11.43)	6.48 (13.22)	-
	DS05 (63.20)	4.52 (11.02)	-	-	-	-	-
	DS06 (57.12)	-	-	-	-	-	2.92 (11.24)
	DS10 (26.51)	0.20 (2.21)	-	0.16 (1.80)	0.16 (1.80)	-	0.18 (1.98)
	Total	**4.72**	**6.48**	**5.76**	**5.76**	**6.48**	**3.10**
3- year TS05	DS08 (31.41)	5.76 (23.36)	2.61 (10.57)	5.76 (23.36)	5.76 (23.36)	5.76 (23.36)	5.76 (23.36)
	DS11 (70.41)	-	8.05 (12.79)	-	-	-	-
	Total	**5.76**	**10.66**	**5.76**	**5.76**	**5.76**	**5.76**
5- year TS05	DS06 (55.31)	3.94 (11.24)	-	-	-	-	-
	DS08 (31.41)	3.03 (12.11)	4.02 (16.08)	5.84 (23.36)	5.84 (23.36)	5.84 (23.36)	5.84 (23.36)
	DS11 (70.41)	-	4.58 (7.28)	-	-	-	-
	Total	**6.96**	**8.60**	**5.84**	**5.84**	**5.84**	**5.84**
3- year TS06	DS01 (80.55)	-	8.42 (14.75)	-	-	-	-
	DS06 (37.46)	2.97 (14.75)	-	2.97 (14.75)	2.97 (14.75)	2.97 (14.75)	2.97 (14.75)
	Total	**2.97**	**8.42**	**2.97**	**2.97**	**2.97**	**2.97**

Table 4.25 The summary of results of daily VI and waste amount allotted (in parenthesis) based on specific objective functions, under the daily capacity constraints of 3- and 5- year service life of DSs (Continued).

Temporary TS	Optimal DS	Min TC	Min EI	Min VI	Min TC and EI	Min EI and VI	Min TC, EI, and VI
5- year TS06	DS01 (80.55)	-	8.41 (14.75)	-	-	-	-
	DS06 (37.46)	2.95 (14.75)	-	1.54 (7.72)	1.54 (7.72)	2.95 (14.75)	2.95 (14.75)
	DS07 (59.68)	-	-	2.32 (7.02)	2.32 (7.02)	-	-
	Total	**2.95**	**8.41**	**3.86**	**3.86**	**2.95**	**2.95**
3- year TS07	DS01 (66.74)	-	3.57 (7.34)	-	-	-	-
	DS06 (62.31)	-	-	1.94 (7.34)	-	-	-
	DS09 (29.66)	-	-	-	1.08 (7.34)	-	-
	DS10 (21.32)	0.59 (7.34)	-	-	-	0.59 (7.34)	0.59 (7.34)
	Total	**0.59**	**3.57**	**1.94**	**1.08**	**0.59**	**0.59**
5- year TS07	DS01 (66.74)	2.83 (5.77)	3.60 (7.34)	-	-	2.52 (5.13)	3.49 (7.11)
	DS05 (56.01)	0.65 (1.57)	-	-	-	-	-
	DS10 (21.32)	-	-	0.59 (7.34)	0.59 (7.34)	0.18 (2.21)	0.02 (0.23)
	Total	**3.47**	**3.60**	**0.59**	**0.59**	**2.69**	**3.50**
3- year TS08	DS01 (51.76)	-	9.11 (20.72)	-	-	-	-
	DS02 (28.31)	4.14 (20.62)	-	2.09 (10.40)	4.14 (20.62)	2.09 (10.40)	4.14 (20.62)
	DS05 (38.99)	-	-	3.39 (10.32)	-	-	-
	DS09 (12.63)	0.01 (0.10)	-	-	0.01 (0.10)	0.90 (10.32)	0.01 (0.10)
	Total	**4.15**	**9.11**	**5.49**	**4.15**	**2.99**	**4.15**
5- year TS08	DS01 (51.76)	-	6.61 (15.02)	-	-	0.28 (0.63)	-
	DS02 (28.31)	-	1.14 (5.70)	-	-	-	-
	DS05 (38.99)	0.44 (1.34)	-	4.60 (13.93)	4.60 (13.93)	-	4.60 (13.93)
	DS09 (12.63)	1.74 (19.38)	-	0.61 (6.79)	0.61 (6.79)	1.81 (2.21)	0.61 (6.79)
	Total	**2.19**	**7.75**	**5.21**	**5.21**	**2.08**	**5.21**

Table 4.25 The summary of results of daily VI and waste amount allotted (in parenthesis) based on specific objective functions, under the daily capacity constraints of 3- and 5- year service life of DSs (Continued).

Temporary TS	Optimal DS	Min TC	Min EI	Min VI	Min TC and EI	Min EI and VI	Min TC, EI, and VI
3- year	DS01 (64.88)	-	9.17 (15.98)	-	-	-	-
TS09	DS02 (26.02)	1.19 (5.76)	-	3.31 (15.98)	1.19 (5.76)	3.31 (15.98)	1.19 (5.76)
	DS11 (35.84)	4.25 (10.22)	-	-	4.25 (10.22)	-	4.25 (10.22)
	Total	**5.44**	**9.17**	**3.31**	**5.44**	**3.31**	**5.44**
5- year	DS01 (64.88)	-	9.11 (15.98)	-	-	5.19 (9.11)	1.87 (3.28)
TS09	DS02 (26.02)	3.20 (15.26)	-	3.22 (15.35)	3.22 (15.35)	1.44 (6.86)	-
	DS09 (25.75)	0.16 (0.72)	-	0.14 (0.62)	0.14 (0.62)	-	2.79 (12.70)
	Total	**3.36**	**9.11**	**3.36**	**3.36**	**6.64**	**4.66**
Total 3-year		**87.36**	**123.54**	**85.54**	**93.79**	**91.73**	**90.97**
Total 5-year		**105.89**	**128.29**	**103.96**	**103.96**	**106.37**	**104.98**

The summarized results (Table 4.26) express valid and reasonable TC, EI, and VI for different objectives. For example total TC of minimized TC objective provides comparatively minimum value while total EI and VI do the same for minimized EI and minimized VI objectives. Based on minimized TC and EI, minimized EI and VI, and minimized TC, EI, and VI objectives, the results shows compromised total TC, EI, and VI falling in the middle of results from minimized TC, EI and VI objectives.

Comparison between 3-year and 5-year service lives of DSs of each criterion in every objectives, 3-year option of total TC and VI show less values which indicate the better benefit. Oppositely, 5-year option values of total EI show a little better benefit, except total EI of minimized EI, and minimized TC and EI objective shows that 3-year option are a bit better than 5-year option. Because 3-year option provides more daily capacities of DSs and allows more chance of waste allotment to less-EI DS(s). However, this can cause higher TC and VI due to increasing transportation distance.

The percentage of difference ((5-year value – 3-year value)*100/5-year value) in each criterion was also compared. The results were the same as discussed above. For every objective but minimized EI, total TC and VI provide information that 3-year option is significant better than 5-year option as shown by different percentage between 17.71 and 13.34% Obviously, 5-year option of total EI of every objective but minimized EI and minimized TC and EI shows a bit better benefit than 3-year option (between 1.97 and 5.09%). However, 3-year option of total EI of minimized EI, and TC and EI objective provides 0.78%, 0.37% more benefit. The sum of these criteria percentages revealed that 3-year option of minimized TC objective provides the highest benefit (28.51%) while of minimized EI shows the lowest benefit (8.25%). Because the difference of total TC and VI between these 2 options were quite low. For cross criteria comparison, the result were compared based on percentage of the difference between the maximum and minimum values of 3-year or 5-year option of each criterion divided by the maximum value. The higher percentage indicates the better response criterion when using different objective functions. Total TC and VI shows very high percentage of 3-year option (28.56 and 30.75%) and total EI shows the lowest percentages for 5-year options (4.93%). Therefore, it can be concluded that total VI and TC of 3-year service life show the most significant response when varying objective function.

The results of 3-year service life seem to be better than results of 5-year service life. The 3-year service life option provides higher daily capacity of DSs. Therefore, there are more chances to transport waste to the DSs which are closer and have less EI and VI. However, shortening service life of DSs requires new DS sooner which is a difficult task that can cause significant conflicts on economic and environment to stakeholders. In other case, if the distribution of low EI- DSs is far away from each other, for minimized EI, TC and EI objective, the waste could be allotted to those DSs and cause longer and bigger transportation distance and cost.

Table 4.26 The summarized comparison results of MODA (LP).

Objectives	Total TC		% TC	Total EI		% EI	Total VI		% VI	Sum %
	3 year	5 year	difference	3 year	5 year	difference	3 year	5 year	difference	difference
Min TC	49,852.55	59,099.33	15.65	189.42	181.04	-4.63	87.36	105.89	17.50	28.51
Min EI	69,782.09	72,514.91	3.77	170.13	171.46	0.78	123.54	128.29	3.70	8.25
Min VI	51,608.72	59,767.31	13.65	191.30	182.04	-5.09	85.54	103.96	17.71	26.28
Min TC and EI	52,127.44	59,767.31	12.78	181.36	182.04	0.37	93.79	103.96	9.78	22.94
Min EI and VI	52,092.26	60,736.35	14.23	181.75	177.80	-2.22	91.73	106.37	13.76	25.77
Min TC, EI and VI	51,283.40	59,264.62	13.47	183.91	180.35	-1.97	90.97	104.98	13.34	24.84
Objective difference (%)	28.56	18.50		11.07	4.93		30.75	18.97		

4.7.2 Result of validation

The validation of LP results to serve minimized TC, EI and VI objectives were performed by method of validation (a) using a list of a TS to all DSs (9 pairs) and validation (b) using a list of all pairs of all TSs and DSs (99 pairs) as suggested in 3.6.2. The validation is separated based on each objective and on 3-year and 5-year daily capacities of DSs. For minimized TC objective, Table 4.27 shows daily waste allotment of active TS-DS pairs and total TC from LP and both validation methods for 3-year and 5-year daily capacities. Similar to Tables 4.28 and 4.29 display respectively corresponding criteria outcomes resulted from minimized EI and VI of LP and both validation methods for 3- and 5-year daily capacities. These results were summarized and are displayed in Table 4.30.

Table 4.27 Validation results of minimized TC objective under the constraints of 3- and 5-year daily capacities.

No.	Temporary TS	Optimal DS	Distance of paths (km)	3-year daily capacities						5-year daily capacities					
				LP		Validation (a)		Validation (b)		LP		Validation (a)		Validation (b)	
				Waste amount (Ton)	TC (Baht)	Waste amount (Ton)	TC (Baht)	Waste amount (Ton)	TC (Baht)	Waste amount (Ton)	TC (Baht)	Waste amount (Ton)	TC (Baht)	Waste amount (Ton)	TC (Baht)
1	TS01	DS01	49.91	77.97	17,473.14	64.86	14,536.07	80.84	18,117.42	145.52	32,613.39	86.68	19,426.25	102.03	22,866.41
		DS02	42.48	-	-	26.38	5,031.59	-	-	-	-	15.35	2,927.78	-	-
		DS05	39.19	25.75	4,530.96	25.75	4,530.96	15.43	2,715.06	-	-	13.93	2,451.12	13.93	2,451.12
		DS09	12.84	33.39	1,924.96	12.77	736.27	33.49	1,930.90	-	-	20.10	1,158.89	20.10	1,158.89
		DS10	14.26	8.42	539.05	15.76	1,009.08	15.76	1,009.08	-	-	9.46	605.70	9.46	605.70
		Total		**145.52**	**24,468.11**	**145.52**	**25,843.97**	**145.52**	**23,772.46**	**145.52**	**32,613.39**	**145.52**	**26,569.74**	**145.52**	**27,082.12**
2	TS02	DS01	100.38	-	-	-	-	-	-	-	-	22.39	10,091.63	18.61	8,387.91
		DS02	61.43	-	-	-	-	-	-	0.09	25.20	-	-	-	-
		DS03	93.31	-	-	-	-	-	-	4.62	1,936.30	4.62	1,935.60	4.62	1,935.60
		DS04	78.96	-	-	2.58	914.71	-	-	3.78	1,338.45	-	-	3.78	1,340.16
		DS08	56.93	31.72	8,108.64	31.72	8,107.61	31.72	8,107.61	18.54	4,737.63	7.29	1,863.32	7.29	1,863.32
		DS11	61.00	2.57	705.14	-	-	2.58	706.59	7.28	1,992.47	-	-	-	-
		Total		**34.30**	**8,813.78**	**34.30**	**9,022.32**	**34.30**	**8,814.20**	**34.30**	**10,030.05**	**34.30**	**13,890.56**	**34.30**	**13,526.99**
3	TS03	DS06	54.04	7.25	1,759.32	7.25	1,759.03	7.25	1,759.03	-	-	7.25	1,759.03	7.25	1,759.03
		DS10	23.43	-	-	-	-	-	-	7.25	762.89	-	-	-	-
		Total		**7.25**	**1,759.32**	**7.25**	**1,759.03**	**7.25**	**1,759.03**	**7.25**	**762.89**	**7.25**	**1,759.03**	**7.25**	**1,759.03**
4	TS04	DS01	73.92	-	-	-	-	-	-	-	-	9.23	3,063.63	9.23	3,063.63
		DS05	63.20	-	-	-	-	-	-	11.02	3,126.00	-	-	-	-
		DS06	57.12	13.22	3,390.95	13.22	3,390.37	13.22	3,390.37	-	-	3.99	1,023.27	3.99	1,023.27
		DS10	26.51	-	-	-	-	-	-	2.21	262.62	-	-	-	-
		Total		**13.22**	**3,390.95**	**13.22**	**3,390.37**	**13.22**	**3,390.37**	**13.22**	**3,388.62**	**13.22**	**4,086.90**	**13.22**	**4,086.90**

Table 4.27 Validation results of minimized TC objective under the constraints of 3- and 5-year daily capacities (Continued).

No.	Temporary TS	Optimal DS	Distance of paths (km)	3-year daily capacities						5-year daily capacities					
				LP		Validation (a)		Validation (b)		LP		Validation (a)		Validation (b)	
				Waste amount (Ton)	TC (Baht)	Waste amount (Ton)	TC (Baht)	Waste amount (Ton)	TC (Baht)	Waste amount (Ton)	TC (Baht)	Waste amount (Ton)	TC (Baht)	Waste amount (Ton)	TC (Baht)
5	TS05	DS06	55.31	-	-	-	-	-	-	11.24	2,792.35	-	-	-	-
		DS08	31.41	23.36	3,293.58	23.36	3,294.15	23.36	3,294.15	12.11	1,707.96	23.36	3,294.15	23.36	3,294.15
		Total		**23.36**	**3,293.58**	**23.36**	**3,294.15**	**23.36**	**3,294.15**	**23.36**	**4,500.31**	**23.36**	**3,294.15**	**23.36**	**3,294.15**
6	TS06	DS06	37.46	14.75	2,480.46	14.75	2,481.19	14.75	2,481.19	14.75	2,480.46	14.75	2,481.19	14.75	2,481.19
		Total		**14.75**	**2,480.46**	**14.75**	**2,481.19**	**14.75**	**2,481.19**	**14.75**	**2,480.46**	**14.75**	**2,481.19**	**14.75**	**2,481.19**
7	TS07	DS01	66.74	-	-	-	-	-	-	5.77	1,728.14	7.34	2,199.42	7.34	2,199.42
		DS05	56.01	-	-	-	-	-	-	1.57	395.79	-	-	-	-
		DS06	62.31	-	-	7.34	2,053.53	7.34	2,053.53	-	-	-	-	-	-
		DS10	21.32	7.34	702.60	-	-	-	-	-	-	-	-	-	-
		Total		**7.34**	**702.60**	**7.34**	**2,053.53**	**7.34**	**2,053.53**	**7.34**	**2,123.93**	**7.34**	**2,199.42**	**7.34**	**2,199.42**
8	TS08	DS01	51.76	-	-	-	-	-	-	-	-	20.72	4,815.29	14.07	3,269.84
		DS02	28.31	20.62	2,620.84	-	-	10.40	1,321.84	-	-	-	-	-	-
		DS05	38.99	-	-	-	-	10.32	1,806.66	1.34	235.05	-	-	-	-
		DS09	12.63	0.10	5.85	20.72	1,174.89	-	-	19.38	1,098.95	-	-	-	-
		DS11	49.34	-	-	-	-	-	-	-	-	-	-	6.65	1,473.07
		Total		**20.72**	**2,626.69**	**20.72**	**1,174.89**	**20.72**	**3,128.51**	**20.72**	**1,334.00**	**20.72**	**4,815.29**	**20.72**	**4,742.91**
9	TS09	DS01	64.88	-	-	-	-	-	-	-	-	4.92	1,433.20	-	-
		DS02	26.02	5.76	672.99	-	-	15.98	1,867.15	15.26	1,782.90	-	-	15.35	1,793.54
		DS03	73.89	-	-	-	-	-	-	-	-	-	-	-	-
		DS04	50.67	-	-	3.19	725.71	-	-	-	-	3.78	859.93	-	-
		DS09	25.75	-	-	-	-	-	-	0.72	82.78	-	-	-	-
		DS11	35.84	10.22	1,644.07	12.79	2,058.45	-	-	-	-	7.28	1,171.66	0.63	101.39
		Total		**15.98**	**2,317.06**	**15.98**	**2,784.16**	**15.98**	**1,867.15**	**15.98**	**1,865.68**	**15.98**	**3,464.79**	**15.98**	**1,894.93**
Grand total				**282.43**	**49,852.55**	**282.44**	**51,803.62**	**282.44**	**50,560.59**	**51,803.62**	**282.44**	**282.44**	**62,561.08**	**282.44**	**61,067.65**

Table 4.28 Validation results of minimized EI objective under the constraints of 3- and 5-year daily capacities.

No.	Temporary TS	Optimal DS	Distance of paths (km)	3-year						5-year					
				LP		Validation (a)		Validation (b)		LP		Validation (a)		Validation (b)	
				Waste amount (Ton)	EI	Waste amount (Ton)	EI	Waste amount (Ton)	EI	Waste amount (Ton)	EI	Waste amount (Ton)	EI	Waste amount (Ton)	EI
1	TS01	DS01	49.91	91.92	72.51	68.56	54.08	68.56	54.08	97.63	77.01	68.56	54.08	68.56	54.08
		DS02	42.48	-	-	-	-	-	-	-	-	-	-	9.47	8.82
		DS04	67.12	-	-	-	-	-	-	3.78	3.50	-	-	-	-
		DS06	64.49	-	-	-	-	-	-	-	-	2.45	2.45	-	-
		DS07	86.71	-	-	-	-	-	-	-	-	7.02	6.54	-	-
		DS08	66.67	4.35	3.90	14.92	13.39	14.92	13.39	14.57	13.07	30.65	27.51	30.65	27.51
		DS09	12.84	33.49	28.09	33.49	28.09	33.49	28.09	20.10	16.86	20.10	16.86	20.10	16.86
		DS10	14.26	15.76	13.94	15.76	13.94	15.76	13.94	9.46	8.37	9.46	8.37	9.46	8.37
		DS11	63.51	-	-	12.79	11.11	12.79	11.11	-	-	7.28	6.32	7.28	6.32
		Total		**145.52**	**118.44**	**145.52**	**120.61**	**145.52**	**120.61**	**145.52**	**118.80**	**145.52**	**122.12**	**145.52**	**121.95**
2	TS02	DS01	100.38	34.30	13.95	34.30	13.95	34.30	13.95	34.30	13.95	34.30	13.95	34.30	13.95
		Total		**34.30**	**13.95**	**34.30**	**13.95**	**34.30**	**13.95**	**34.30**	**13.95**	**34.30**	**13.95**	**34.30**	**13.95**
3		DS01	78.50	7.25	2.27	7.25	2.27	7.25	2.27	7.25	2.27	7.25	2.27	7.25	2.27
		Total		**7.25**	**2.27**	**7.25**	**2.27**	**7.25**	**2.27**	**7.25**	**2.27**	**7.25**	**2.27**	**7.25**	**2.27**
4	TS04	DS01	73.92	13.22	4.42	13.22	4.42	13.22	4.42	13.22	4.42	13.22	4.42	13.22	4.42
		Total		**13.22**	**4.42**	**13.22**	**4.42**	**13.22**	**4.42**	**13.22**	**4.42**	**13.22**	**4.42**	**13.22**	**4.42**
5	TS05	DS01	106.52	-	-	23.36	8.62	23.36	8.62	-	-	23.36	8.62	23.36	8.62
		DS08	31.41	10.57	5.05	-	-	-	-	16.08	7.68	-	-	-	-
		DS11	70.41	12.79	5.74	-	-	-	-	7.28	3.26	-	-	-	-
		Total		**23.36**	**10.78**	**23.36**	**8.62**	**23.36**	**8.62**	**23.36**	**10.94**	**23.36**	**8.62**	**23.36**	**8.62**

Table 4.28 Validation results of minimized EI objective under the constraints of 3- and 5-year daily capacities (Continued).

No.	Temporary TS	Optimal DS	Distance of paths (km)	3-year						5-year					
				LP		Validation (a)		Validation (b)		LP		Validation (a)		Validation (b)	
				Waste amount (Ton)	EI	Waste amount (Ton)	EI	Waste amount (Ton)	EI	Waste amount (Ton)	EI	Waste amount (Ton)	EI	Waste amount (Ton)	EI
6	TS06	DS01	80.55	14.75	5.01	14.75	5.01	14.75	5.01	14.75	5.01	14.75	5.01	14.75	5.01
		Total		**14.75**	**5.01**	**14.75**	**5.01**	**14.75**	**5.01**	**14.75**	**5.01**	**14.75**	**5.01**	**14.75**	**5.01**
7	TS07	DS01	66.74	7.34	2.31	7.34	2.30	7.34	2.30	7.34	2.31	7.34	2.30	7.34	2.30
		Total		**7.34**	**2.31**	**7.34**	**2.30**	**7.34**	**2.30**	**7.34**	**2.31**	**7.34**	**2.30**	**7.34**	**2.30**
8	TS08	DS01	51.76	20.72	7.46	20.72	7.46	20.72	7.46	15.02	5.41	20.72	7.46	20.72	7.46
		DS02	28.31	-	-	-	-	-	-	5.70	2.87	-	-	-	-
		Total		**20.72**	**7.46**	**20.72**	**7.46**	**20.72**	**7.46**	**20.72**	**8.27**	**20.72**	**7.46**	**20.72**	**7.46**
9	TS09	DS01	64.88	15.98	5.49	15.98	5.49	15.98	5.49	15.98	5.49	15.98	5.49	15.98	5.49
		Total		**15.98**	**5.49**	**15.98**	**5.49**	**15.98**	**5.49**	**15.98**	**5.49**	**15.98**	**5.49**	**15.98**	**5.49**
Grand total				**282.43**	**170.13**	**282.44**	**170.13**	**282.44**	**170.13**	**282.43**	**171.46**	**282.44**	**171.48**	**282.44**	**171.64**

Table 4.29 Validation results of minimized VI objective under the constraints of 3- and 5-year daily capacities.

No.	Temporary TS	Optimal DS	Distance of paths (km)	3-year						5-year					
				LP		Validation (a)		Validation (b)		LP		Validation (a)		Validation (b)	
				Waste amount (Ton)	VI	Waste amount (Ton)	VI	Waste amount (Ton)	VI	Waste amount (Ton)	VI	Waste amount (Ton)	VI	Waste amount (Ton)	VI
1	TS01	DS01	49.91	69.06	29.57	-	-	68.96	29.52	132.84	57.12	60.69	25.98	107.40	45.98
		DS02	42.48	-	-	26.38	7.53	-	-	-	-	15.35	4.38	-	-
		DS03	101.02	-	-	12.50	9.57	-	-	-	-	-	-	-	-
		DS05	39.19	15.43	5.41	13.27	4.65	25.75	9.03	-	-	13.93	4.89	8.56	3.00
		DS06	64.49	11.78	3.95	44.12	14.81	1.56	0.52	-	-	25.99	8.73	-	-
		DS09	12.84	33.49	2.98	33.49	2.98	33.49	2.98	12.68	1.14	20.10	1.79	20.10	1.79
		DS10	14.26	15.76	1.08	15.76	1.08	15.76	1.08	-	-	9.46	0.65	9.46	0.65
		Total		**145.52**	**42.99**	**145.52**	**40.63**	**145.52**	**43.13**	**145.52**	**58.26**	**145.52**	**46.41**	**145.52**	**51.41**
2	TS02	DS01	100.38	-	-	20.95	16.36	-	-	-	-	25.90	20.23	25.90	20.23
		DS03	93.31	-	-	-	-	-	-	4.62	3.42	4.62	3.40	4.62	3.40
		DS04	78.96	-	-	9.29	6.91	-	-	3.78	2.79	3.78	2.81	3.78	2.81
		DS06	89.30	-	-	-	-	-	-	11.34	5.89	-	-	-	-
		DS07	101.44	-	-	4.06	2.74	0.11	0.07	-	-	-	-	-	-
		DS08	56.93	21.51	10.78	-	-	31.72	15.90	7.29	3.65	-	-	-	-
		DS11	61.00	12.79	6.16	-	-	2.47	1.19	7.28	3.49	-	-	-	-
		Total		**34.30**	**16.94**	**34.30**	**26.02**	**34.30**	**17.16**	**34.30**	**19.25**	**34.30**	**26.44**	**34.30**	**26.44**
3		DS01	78.50	-	-	-	-	-	-	-	-	7.25	3.95	1.94	1.06
		DS06	54.04	-	-	-	-	7.25	1.89	6.93	1.80	-	-	-	-
		DS08	56.03	7.25	2.45	7.25	2.45	-	-	-	-	-	-	5.31	1.79
		DS10	23.43	-	-	-	-	-	-	0.32	0.03	-	-	-	-
		Total		**7.25**	**2.45**	**7.25**	**2.45**	**7.25**	**1.89**	**7.25**	**1.83**	**7.25**	**3.95**	**7.25**	**2.85**

Table 4.29 Validation results of minimized VI objective under the constraints of 3- and 5-year daily capacities (Continued).

No.	Temporary TS	Optimal DS	Distance of paths (km)	3-year						5-year					
				LP		Validation (a)		Validation (b)		LP		Validation (a)		Validation (b)	
				Waste amount (Ton)	VI	Waste amount (Ton)	VI	Waste amount (Ton)	VI	Waste amount (Ton)	VI	Waste amount (Ton)	VI	Waste amount (Ton)	VI
4	TS04	DS01	73.92	-	-	-	-	-	-	11.43	5.60	13.22	6.48	-	-
		DS06	57.12	10.26	2.68	-	-	13.22	3.46	-	-	-	-	11.24	2.94
		DS07	79.33	-	-	3.50	1.37	-	-	-	-	-	-	-	-
		DS08	59.11	2.96	1.00	9.72	3.29	-	-	-	-	-	-	1.98	0.67
		DS10	26.51	-	-	-	-	-	-	1.80	0.16	-	-	-	-
		Total		**13.22**	**3.69**	**13.22**	**4.66**	**13.22**	**3.46**	**13.22**	**5.76**	**13.22**	**6.48**	**13.22**	**3.61**
5	TS05	DS08	31.41	23.36	5.76	23.36	5.76	23.36	5.76	23.36	5.84	23.36	5.76	23.36	5.76
		Total		**23.36**	**5.76**	**23.36**	**5.76**	**23.36**	**5.76**	**23.36**	**5.84**	**23.36**	**5.76**	**23.36**	**5.76**
6	TS06	DS06	37.46	14.75	2.97	-	-	14.75	2.98	7.72	1.54	-	-	14.75	2.98
		DS07	59.68	-	-	-	-	-	-	7.02	2.32	7.02	2.32	-	-
		DS08	53.59	-	-	14.75	4.74	-	-	-	-	7.29	2.34	-	-
		Total		**14.75**	**2.97**	**14.75**	**4.74**	**14.75**	**2.98**	**14.75**	**3.86**	**14.75**	**4.91**	**14.75**	**2.98**
7	TS07	DS01	66.74	-	-	-	-	-	-	-	-	7.34	3.57	0.32	0.16
		DS06	62.31	7.34	1.94	-	-	7.34	1.94	-	-	-	-	-	-
		DS07	84.53	-	-	7.34	2.89	-	-	-	-	-	-	7.02	2.76
		DS10	21.32	-	-	-	-	-	-	7.34	0.59	-	-	-	-
		DS11	80.33	-	-	-	-	-	-	-	-	-	-	-	-
		Total		**7.34**	**1.94**	**7.34**	**2.89**	**7.34**	**1.94**	**7.34**	**0.59**	**7.34**	**3.57**	**7.34**	**2.92**

Table 4.29 Validation results of minimized VI objective under the constraints of 3- and 5-year daily capacities (Continued).

No.	Temporary TS	Optimal DS	Distance of paths (km)	3-year						5-year					
				LP		Validation (a)		Validation (b)		LP		Validation (a)		Validation (b)	
				Waste amount (Ton)	VI	Waste amount (Ton)	VI	Waste amount (Ton)	VI	Waste amount (Ton)	VI	Waste amount (Ton)	VI	Waste amount (Ton)	VI
8	TS08	DS01	51.76	-	-	20.72	9.11	-	-	-	-	20.72	9.11	-	-
		DS02	28.31	10.40	2.09	-	-	20.72	4.17	-	-	-	-	15.35	3.09
		DS05	38.99	10.32	3.39	-	-	-	-	13.93	4.60	-	-	5.37	1.77
		DS06	74.25	-	-	-	-	-	-	-	-	-	-	-	-
		DS09	12.63	-	-	-	-	-	-	6.79	0.61	-	-	-	-
		Total		**20.72**	**5.49**	**20.72**	**9.11**	**20.72**	**4.17**	**20.72**	**5.21**	**20.72**	**9.11**	**20.72**	**4.85**
9	TS09	DS01	64.88	-	-	3.19	1.83	-	-	-	-	8.70	4.99	8.70	4.99
		DS02	26.02	15.98	3.31	-	-	5.66	1.17	15.35	3.22	-	-	-	-
		DS09	25.75	-	-	-	-	-	-	0.62	0.14	-	-	-	-
		DS11	35.84	-	-	12.79	5.32	10.32	4.29	-	-	7.28	3.03	7.28	3.03
		Total		**15.98**	**3.31**	**15.98**	**7.15**	**15.98**	**5.47**	**15.98**	**3.36**	**15.98**	**8.02**	**15.98**	**8.02**
Grand total				**282.43**	**85.54**	**282.44**	**103.41**	**282.44**	**85.96**	**282.43**	**103.96**	**282.44**	**114.66**		**108.85**

Table 4.30 Summarized results from LP and validation methods.

Result from	Total TC (Baht) From Min TC		Total EI from Min EI		Total VI from Min VI	
	3-year	5-year	3-year	5-year	3-year	5-year
LP	49,852.55	59,099.33	170.13	171.46	85.54	103.96
Validation (a)	51,803.62	62,561.08	170.13	171.64	103.41	114.66
Validation (b)	50,560.59	61,067.65	170.13	171.48	85.96	108.85

From Tables 4.27- 4.29, they show that active pairs, waste allotment and allocation, and results from LP and validation methods are different when using different objective functions.

From Table 4.30, with corresponding objective functions of both 3-year and 5-year daily capacities, total TC and VI outcomes from validation methods are obviously higher than outcomes from LP. Total EI outcomes from validation methods are the same or almost the same with outcomes from LP, but not less than. These results confirm that the analytical results using LP are valid and trustable as useful information for further outranking analysis.

It is interesting to note that results from validation (b) are very close to results from the LP. This could be because of better ordering in waste allotment from a TS to meet constraints of DS capacities when comparing to validation (a). The total TC and VI outcomes shows much more difference in methods while very little can be noted from the total EI outcomes. The difference in total TC and VI outcomes are relied on big difference of total distance of active pairs in difference methods. The total EI outcomes from methods show the same results or very small difference because the difference of EI of all DSs are not obvious or very small while EI of TSs are constant for all methods.

4.8 PROMETHEE outranking results

The purpose of PROMETHEE outranking analysis is to rank transportation patterns or alternatives based on objective functions and select the most satisfied one by whole groups of stakeholder in waste transportation management. In fact, a transportation pattern provides information on optimum paths of active TS-DS pairs and waste allocation and allotment of the study area which reflect results in terms of TC, EI, and VI. Therefore, total TC, EI, and VI were employed as criteria outcomes to rank alternatives or transportation patterns in the process. The accomplished results were sets of transportation pattern ranks of 3- and 5-year DS service lives.

Weights of criteria outcomes from interviewing of stakeholder groups were multiplied by stakeholder preferences from stakeholder analysis, normalized, and averaged to be stakeholder-criteria weights as shown in Table 4.31.

The result indicated that stakeholders essentially care more about environment (EI and VI) than transportation cost (TC). The budget of TC fell into the acceptable level therefore more weight was applied to environmental concern. Only POLA which is in charge of considering the whole aspects of budget planning of the province still pay somewhat more interest to TC.

Table 4.31 Stakeholder-criteria weights of all groups and their average.

Stakeholders	TC	EI	VI
EOR 3	0.76	0.81	0.82
PNRE	0.64	0.68	0.71
Health	0.35	0.68	0.68
RTA	0.51	0.85	0.76
LAO	0.59	0.68	0.68
POLA	0.72	0.67	0.63
NGOs	0.32	0.44	0.44
CO	0.58	0.75	0.77
Volunteer	0.42	0.53	0.50

Table 4.31 Stakeholder-criteria weights of all groups and their average (Continued).

Stakeholders	TC	EI	VI
Academic	0.38	0.59	0.57
Private sector	0.46	0.62	0.63
Waste picker	0.21	0.31	0.28
RES_DS	0.43	0.62	0.58
RES_waste	0.46	0.57	0.55
Media	0.40	0.58	0.53
Stakeholder-criteria weight	**0.48**	**0.63**	**0.61**

As input for PROMETHEE process, transportation patterns in terms of TC, EI, and VI of all alternatives or objectives including stakeholder-criteria weights and considering conditions of criteria outcomes were concluded and are listed in Table 4.32

Table 4.32 List of criteria outcomes of all objectives in 3- and 5-year service lives including their stakeholder-criteria weights for PROMETHEE analysis.

Objective	TC 3-year	EI 3-year	VI 3-year	TC 5-year	EI 5-year	VI 5-year
Min TC	49,852.55	189.42	87.36	59,099.33	181.04	105.89
Min EI	69,782.09	170.13	123.54	72,514.91	171.46	128.29
Min VI	51,608.72	191.3	85.54	59,767.31	182.04	103.96
Min TC and EI	52,127.44	181.36	93.79	59,767.31	182.04	103.96
Min EI and VI	52,092.26	181.75	91.73	60,736.35	177.8	106.37
Min all	51,283.40	183.91	90.97	59,264.62	180.35	104.98
weights	0.48	0.63	0.61	0.48	0.63	0.61
min or max	min	min	min	min	min	min

The method firstly performed comparison in form of matrix of alternatives based on each criteria outcome. The minimum was considered the better and scored as 1, 0 otherwise. The comparison results of criteria outcomes are shown in Tables 4.33. This comparison is performed binary consideration or merely based on the minimum but does not care about how much less. The process shows no compensatory consideration among criteria scores.

The results were incorporated with stakeholder-criteria weights by multiplication as results shown in Table 4.34. By applying stakeholder-criteria weights to comparison scores, the process performed compensatory consideration among alternatives.

Table 4.33 Comparison matrix of alternatives based on each criteria outcome of 3- and 5- year DS service life.

(a) 3-year DS service life.

C1: TC 3-year	min TC	min EI	min VI	min TC+EI	min EI+VI	min all
min TC	-	1	1	1	1	1
min EI	0	-	0	0	0	0
min VI	0	1	-	1	1	0
minTC+EI	0	1	0	-	0	0
minEI+VI	0	1	0	1	-	0
min all	0	1	1	1	1	-

C2: EI 3-year	min TC	min EI	min VI	min TC+EI	min EI+VI	min all
min TC	-	0	1	0	0	0
min EI	1	-	1	1	1	1
min VI	0	0	-	0	0	0
minTC+EI	1	0	1	-	1	1
minEI+VI	1	0	1	0	-	1
min all	1	0	1	0	0	-

C3: VI 3-year	min TC	min EI	min VI	min TC+EI	min EI+VI	min all
min TC	-	1	0	1	1	1
min EI	0	-	0	0	0	0
min VI	1	1	-	1	1	1
minTC+EI	0	1	0	-	0	0
minEI+VI	0	1	0	1	-	0
min all	0	1	0	1	1	-

(b) 5-year DS service life.

C1: TC 5-year	min TC	min EI	min VI	min TC+EI	min EI+VI	min all
min TC	-	1	1	1	1	1
min EI	0	-	0	0	0	0
min VI	0	1	-	1	1	0
minTC+EI	0	1	1	-	1	0
minEI+VI	0	1	0	0	-	0
min all	0	1	1	1	1	-

C2: EI 5-year	min TC	min EI	min VI	min TC+EI	min EI+VI	min all
min TC	-	0	1	1	0	0
min EI	1	-	1	1	1	1
min VI	0	0	-	1	0	0
minTC+EI	0	0	1	-	0	0
minEI+VI	1	0	1	1	-	1
min all	0	1	1	1	1	-

C3: VI 5-year	min TC	min EI	min VI	min TC+EI	min EI+VI	min all
min TC	-	1	0	0	1	0
min EI	0	-	0	0	0	0
min VI	1	1	-	1	1	1
minTC+EI	1	1	1	-	1	1
minEI+VI	0	1	0	0	-	0
min all	0	1	1	1	1	-

Table 4.34 Incorporating results of comparison matrix and stakeholder-criteria weights.

(a) 3-year DS service life.

C1: TC 3-year						
	min TC	min EI	min VI	min TC+EI	min EI+VI	min all
min TC	-	0.48	0.48	0.48	0.48	0.48
min EI	0	-	0	0	0	0
min VI	0	0.48	-	0.48	0.48	0
minTC+EI	0	0.48	0	-	0	0
minEI+VI	0	0.48	0	0.48	-	0
min all	0	0.48	0.48	0.48	0.48	-

C2: EI 3-year						
	min TC	min EI	min VI	min TC+EI	min EI+VI	min all
min TC	-	0	0.63	0	0	0
min EI	0.63	-	0.63	0.63	0.63	0.63
min VI	0	0	-	0	0	0
minTC+EI	0.63	0	0.63	-	0.63	0.63
minEI+VI	0.63	0	0.63	0	-	0.63
min all	0.63	0	0.63	0	0	-

C3: VI 3-year						
	min TC	min EI	min VI	min TC+EI	min EI+VI	min all
min TC	-	0.61	0	0.61	0.61	0.61
min EI	0	-	0	0	0	0
min VI	0.61	0.61	-	0.61	0.61	0.61
minTC+EI	0	0.61	0	-	0	0
minEI+VI	0	0.61	0	0.61	-	0
min all	0	0.61	0	0.61	0.61	-

(b) 5-year DS service life.

C1: TC 5-year						
	min TC	min EI	min VI	min TC+EI	min EI+VI	min all
min TC	-	0.48	0.48	0.48	0.48	0.48
min EI	0	-	0	0	0	0
min VI	0	0.48	-	0.48	0.48	0
minTC+EI	0	0.48	0.48	-	0.48	0
minEI+VI	0	0.48	0	0	-	0
min all	0	0.48	0.48	0.48	0.48	-

C2: EI 5-year						
	min TC	min EI	min VI	min TC+EI	min EI+VI	min all
min TC	-	-	0.63	0.63	0	0
min EI	0.63	-	0.63	0.63	0.63	0.63
min VI	0	0	-	0.63	0	0
minTC+EI	0	0	0.63	-	0	0
minEI+VI	0.63	0	0.63	0.63	-	0.63
min all	0.63	0	0.63	0.63	0	-

C3: VI 5-year						
	min TC	min EI	min VI	min TC+EI	min EI+VI	min all
min TC	-	0.61	0	0	0.61	0
min EI	0	-	0	0	0	0
min VI	0.61	0.61	-	0.61	0.61	0.61
minTC+EI	0.61	0.61	0.61	-	0.61	0.61
minEI+VI	0	0.61	0	0	-	0
min all	0.61	0.61	0	0	0	-

The preference values, leaving flow, $F^{+}(A_i)$, entering flow, $F^{-}(A_i)$, and net flow, F (A_i) were calculated and ranking of alternatives was performed as results shown in Table4.35. The preference values of comparison cells were estimated by aggregating values in the same cell locations of all criteria matrixes. For example, the preference value in the cell of min TC compared to min EI of 3-year DS service life is 1.09 which is obtained from (0.48+0+0.61). The leaving flow, $F^{+}(A_i)$, entering flow, $F^{-}(A_i)$, and net flow, F (A_i) of min TC were calculated as results are 0.97, 0.74, and 0.23. They are obtained from ((1.09 + 1.11 + 1.11+1.09+0.48)/5), ((0.63 + 0.61 + 0.61+0.63+1.23)/5), and (0.97 – 0.74), respectively. The ranking was finally performed from the difference of leaving and entering flows or net flow ($F^{+}(A_i) - F^{-}(A_i)$). The more difference indicates the higher rank.

$F^{+}(A_i)$ indicates how a given alternative is more advantage than others while $F^{-}(A_i)$ indicates how the other alternatives are more advantage than a given one. With respect to every alternative, the higher difference of them ($F^{+}(A_i) - F^{-}(A_i)$) indicates the higher rank.

For both DS service lives, the PROMETHEE procedure provided the same results in the complete ordering of the alternatives: min all > min TC > min VI and min TC+EI > min EI+VI > min EI.

For implementation to achieve the objective of min all or minimized TC, EI, and VI which is the highest rank of transportation pattern, active DSs including waste allocation and allotment are also provided in Table 4.22. Optimum paths between TSs and active DSs are provided as well in Figure 6C in Appendix C.

Table 4.35 Aggregated preference values of all criteria outcomes in the comparison matrix.

(a) 3-year service life

	min TC	**min EI**	**min VI**	**Min TC+EI**	**Min EI+VI**	**Min all**	$F^+(A_i)$	**F(A$_i$)**	**Rank**
min TC	-	1.09	1.11	1.11	1.09	0.48	**0.97**	0.23	**2**
min EI	0.63	-	0.63	0.63	0.63	0.63	**0.63**	-0.46	**6**
min VI	0.61	1.09	-	1.72	1.09	0.61	**1.02**	-0.01	**3**
minTC+EI	0.61	1.09	1.72	-	1.09	0.61	**1.02**	-0.01	**3**
minEI+VI	0.63	1.09	0.63	0.63	-	0.63	**0.72**	-0.16	**5**
min all	1.23	1.09	1.11	1.11	0.48	-	**1.00**	0.41	**1**
$F^-(A_i)$	**0.74**	**1.09**	**1.04**	**1.04**	**0.88**	**0.59**			

(b) 5-year service life

	min TC	**min EI**	**min VI**	**Min TC+EI**	**Min EI+VI**	**Min all**	**$F^+(A_i)$**	**F(A$_i$)**	**Rank**
min TC	-	1.09	1.11	1.11	1.09	0.48	**0.97**	0.23	**2**
min EI	0.63	-	0.63	0.63	0.63	0.63	**0.63**	-0.46	**6**
min VI	0.61	1.09	-	1.72	1.09	0.61	**1.02**	-0.01	**3**
minTC+EI	0.61	1.09	1.72	-	1.09	0.61	**1.02**	-0.01	**3**
minEI+VI	0.63	1.09	0.63	0.63	-	0.63	**0.72**	-0.16	**5**
min all	1.23	1.09	1.11	1.11	0.48	-	**1.00**	0.41	**1**
F-(Ai)	**0.74**	**1.09**	**1.04**	**1.04**	**0.88**	**0.59**			

4.9 Preferred DS service life

From the stakeholder interview to choose which service life was preferred, the score of each stakeholder group incorporating with stakeholder preference was normalized to be preference score as shown in Table 4.36. All stakeholder groups has agreement in common that 5-year DS service life which has higher preference score was better. However, the average preference scores of 3- and 5-year DS service lives were 0.40 and 0.48, respectively, which did not show much difference.

Table 4.36 Normalized preference scores of 3- and 5-year DS service lives from stakeholder groups.

Stakeholders	**3-year**	**5-year**
EOR 3	0.55	0.60
PNRE	0.45	0.57
Health	0.29	0.54
RTA	0.48	0.57
LAO	0.55	0.59
POLA	0.51	0.54
NGOs	0.30	0.32
CO	0.48	0.53
Volunteer	0.34	0.37
Academic	0.30	0.45
Private sector	0.38	0.41
Waste picker	0.24	0.26
RES_DS	0.47	0.49
RES_waste	0.40	0.47
Media	0.31	0.41
Average	**0.40**	**0.48**

CHAPTER V

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The main goal of this study is to properly manage waste transportation or to select the optimum transportation pattern in local administrative units, having full service function on this matter, of Phitsanulok province of Thailand. Transportation cost, environmental impact of TSs and DSs, and vulnerability along transportation routes were considered as criteria for decision making by stakeholders.

Efficient waste transportation management requires information extracted from a series of analyses. The information include identified stakeholder groups and their preferences, locations of TS, optimum paths from TSs to available DSs, EI evaluation of TSs and DSs, VI along optimum paths, waste allocation and allotment from TSs to active DSs based on 6 objective functions, and ranking of transportation patterns. Input data, analytical processes, and results of information extraction can be concluded as follows:

1) Stakeholder analysis was operated to obtain a list of relevant stakeholders, their opinions and preferences required for decision making in the management. By in-depth interview, 15 groups of relevant stakeholders were identifield. Their opinions on characteristics of other stakeholders based on 3 attributes of power, legitimacy, and urgency organized in linguistic terms were aggregated by

rule-based Mamdani fuzzy operation and defuzzied to be the group preference and priorty class of fuzzy salience model. The higher class has higher preference and more important role on decision making in the management.

Seven stakeholder groups of high priority class (Environmental Office Region 3, Provincial Offices for Natural Resources and Environment Phitsanulok, 4th Infantry Division (Royal Thai Army), Community-Based Organizations, Local Administrative Organization, Province Office for Local Administration, and Phitsanulok Health Provincial Office), 6 groups of medium and high priority class (residents of nearby disposal site and optimum route, Private Sector Companies, Academicians/ Researcher, Residential waste generators, Media, and Volunteers Natural Resources and Environment), medium priority class (Non-Governmental Organization), and low priority class (Waste picker) have preferences 2.52-2.54, 1.79-2.32, 1.5, and 0.495, respectively. The results of the analysis completely served the first objective of the study.

2) To serve the second objective of the study, temporary transfer station (TS) of each local administrative unit was located using GIS weighted centering. According to the policy and existing land use examination, Phitsanulok-Thatong and Phai kho don-Ban Krang were grouped to be 2 TSs. They were relocated to the optimum positions under the supervision of officers of administrative units. They were used as origin of waste transportation in optimum path analysis.

3) Optimum paths from TSs to available DSs of waste transportation management of the study area were performed using network analysis of Arc GIS and resulted in 99 routes. The impedance of links in road network for the analysis is the length (distance). According to comments of stakeholders, barrier links were set as

removed links of the road network before input into the analysis. The distances of optimum paths from each TS to each DS were prepared in form of a matrix. This matrix was further employed in LP analysis. The result already served the third study objective.

4) EI evaluation was performed for both TSs and DSs. Waste amounts generated in the administrative units indicated EI of TSs. EI of DSs was adopted from the study of Phinyoyang (2017) of which 3 groups of criteria namely, PCD criteria, specific environmental characteristics, and disposal methods were evaluated. The matrix of normalized EI of pairs of TSs and DSs were prepared to further use in waste allocation and allotment by LP process.

5) VI along optimum paths from TSs to DSs was evaluated based on locations of facilities and their servicing population. The higher vulnerability on paths indicates more chance that waste transportation can cause adverse impact on people both sides of them. Vulnerability as attributes of areas intersecting to each optimum route were summed up to represent VI of each route. The matrix of normalized VI along optimum path of each pair of TS and DS was prepared and used as input for the LP analysis of waste transportation allocation and allotment. The result of the analysis served the third study objective.

6) Waste allocation and allotment from TSs to active DSs based on 6 objective functions and 3- and 5-year service lives of DSs were performed using LP analysis. The objective functions include minimized TC, EI, VI, and their combinations with varying constraints of DS capacity of different service lives and waste amount generated at TS. The results in terms of TC, EI, and VI of each objective function were validated and proved that the results were valid. The results of 3-year service life was better than results of 5-year service life due to providing higher daily capacity of DSs.

However, shortening service life of DSs requires new DS sooner which is a difficult task that can cause significant conflicts on economic and environment to stakeholders.

7) Transportation patterns resulted from 6 objective functions in terms of TC, EI, and VI, incorporated with stakeholder-criteria weights, were ranked using PROMETHEE method. The procedure provided the same results for both DS service lives and the complete ordering of the alternatives are: min all > min TC > min VI and min TC+EI > min EI+VI > min EI. The transportation pattern resulted from minimized TC, EI, and VI objective function was identified as the highest rank which in turn, for implementation, providing active DSs, relevant optimum paths, waste allocation and allotment from TSs to DSs, which were obtained from a series of analyses mentioned above. Finally, all study objectives are achieved fruitfully as reported in this section.

8) Preferred DS service life between 3 and 5 years was additionally analyzed using criteria scores from stakeholder interview incorporating with stakeholder preferences. All stakeholder groups has agreement in common that 5-year DS service life was better. However, the average preference scores of both service lives did not show much difference.

5.2 Recommendation

For further study, some suggestions could be recommended as the followings:

1) For ultimate application of the analyses to efficient transportation management, spatial decision support system (SDSS) should be developed. The system should allow interactive action to users when generated waste amount, a number of available DSs, and DS service life are varied and return possible results for efficient implementation.

2) The result could be more practical if budget for DS management is included. Such a case is necessary when a given DS is constructed to serve a certain local administrative unit and has to be open for waste generated from others. Additionally, the budget for using DS service should be applied to any local administrative unit of which waste is generated.

3) More number of DSs is finally and strongly required. Site suitability analysis of new DSs should be operated from time to time or other disposal methods should be set in seeking schedule.

4) For vulnerability assessment, it could be worth trying on applying VI as one of impedances to road network for optimum path analysis.

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APPENDICES

APPENDIX A

QUESTIONNAIRE FOR STAKEHOLDER ANALYSIS

Questionnaire A1

<u>แบบสอบถามสำหรับการวิจัย</u>

เรื่อง การบูรณาการการวิเคราะห์เชิงพื้นที่และผู้มีส่วนได้ส่วนเสียสำหรับการจัดการขยะ

<u>คำชี้แจงในการตอบแบบสอบถาม</u>

1. แบบสอบถามนี้ต้องการวิเคราะห์หาผู้มีส่วนได้ส่วนเสียในการจัดการขยะจากสถานีขนถ่ายขยะไปจนถึงแหล่งกำจัด ในเขตพื้นที่องค์กรปกครองส่วนท้องถิ่นในจังหวัดพิษณุโลก ซึ่งเป็นวัตถุประสงค์หนึ่งสำหรับการทำวิทยานิพนธ์เรื่องการบูรณาการของการวิเคราะห์และปัจจัยเชิงพื้นที่สำหรับการจัดการขยะ เพื่อให้ได้รูปแบบในการจัดสรรค์ขยะที่เหมาะสมกับความต้องการของผู้มีส่วนได้ส่วนเสีย

2. แบบสอบถามแบ่งออกเป็น 2 ตอน

ตอนที่ 1 ข้อมูลทั่วไปของผู้ตอบแบบสอบถาม

ตอนที่ 2 การศึกษาผู้มีส่วนได้ส่วนเสีย แบ่งออกเป็น 2 ส่วน

ส่วนที่ 1 ความคิดเห็นด้านบทบาทและความสำคัญในระหว่างกลุ่มของผู้มีส่วนได้ส่วนเสีย

ส่วนที่ 2 ความคิดเห็นบนพื้นฐาน อำนาจ ความชอบธรรม และความเร่งด่วนอันเป็นคุณลักษณะประจำของกลุ่มผู้มีส่วนได้ส่วนเสียทุกกลุ่ม

3. ขอความกรุณาท่านได้ตอบแบบสอบถาม ตามสภาพความเป็นจริง โดยคำตอบของท่านจะนำไปสรุปผลการศึกษาค้นคว้าในลักษณะภาพรวม ไม่มีผลกระทบหรือเกิดความเสียหายต่อท่านหรือผู้อื่น ทั้งทางตรงและทางอ้อมแต่ประการใด หากแต่จะเป็นประโยชน์ต่อการจัดการขยะในหน่วยงานของท่านให้ดียิ่งขึ้นต่อไปในอนาคต

ขอขอบคุณในการอนุเคราะห์ในการให้ความร่วมมือของท่าน

พิมประไพ พิพัฒน์นวกุล

นักศึกษาระดับดุษฎีบัณฑิต มหาวิทยาลัยเทคโนโลยีสุรนารี

ตอนที่ 1 ข้อมูลทั่วไปของผู้ตอบแบบสอบถาม

<u>คำชี้แจง</u> โปรดกรอกข้อมูลลงในช่องว่าง ที่ท่านเห็นว่าตรงกับสภาพความเป็นจริงของท่าน

1. หน่วยงาน/ที่อยู่ (เทศบาล/ตำบล) ของผู้ตอบแบบสอบถาม..

2. ตำแหน่งของผู้ตอบแบบสอบถาม..

3. ท่านคิดว่าตนเองมีส่วนเกี่ยวข้องกับการจัดการขยะในพื้นที่ของท่านอย่างไร. ....

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ส่วนที่ 2 ความคิดเห็นด้านบทบาทและความสำคัญในระหว่างกลุ่มของผู้มีส่วนได้ส่วนเสีย ให้เรียงลำดับ 5 อันดับแรกที่มีส่วนเกี่ยวข้องมากที่สุด

ลำดับที่	คำถาม	1. สสภ.3	2. ทสจ.	3. อาสาสมัครกรมส่งเสริมคุณภาพ	4. สธ.	5. ทหาร	6. อปท.	7. NGO	8. องค์กรชาวบ้าน	9. ประชาชนที่ใช้	10. สถาบันการศึกษา	11. เอกชนที่เกี่ยวข้องกับการกำจัดขยะ	12. คนคัดแยกที่site	13. ปชช.ใกล้ site	14. นักข่าว	15. ท้องถิ่นจังหวัด	16. บริษัทที่ปรึกษาด้านสิ่งแวดล้อม
1.	ใครเป็นผู้ได้รับประโยชน์จากการจัดการขยะที่มีประสิทธิภาพ																
2.	ใครเป็นผู้ได้รับผลกระทบทางด้านลบ																
3.	ใครเป็นผู้มีอำนาจหน้าที่ตามกฎหมายสำหรับการจัดการขยะ																
4.	ใครเป็นผู้มีความชอบธรรมในการเข้าร่วมแสดงความคิดในการจัดการขยะ																
5.	ใครที่อาจจะเป็นผู้สนับสนุนการต่อต้านการดำเนินการจัดการขยะ																
6.	ใครเป็นผู้ริเริ่มในการให้ความสำคัญด้านการจัดการขยะอย่างเป็นรูปธรรม																
7.	ใครคือผู้ที่มีทักษะ/ความรู้ในการจัดการขยะ (ทางเทคนิคและสิ่งแวดล้อม)																
8.	ใครควรให้การสนับสนุนด้านงบประมาณ																

No.	Questionnaires	1. EOR 3	2. PNRE	3. Health	4. RTA	5. LAO	6. POLA	7. NGO	8. CO	9. Volunteer	10. Academic	11. Waste picker	12. Private sector	13. RES_DS	14. RES_waste	15. Media	16. Consulting
1.	Who are potential beneficiaries from good waste management?																
2.	Who might be adversely affected?																
3.	Who is the legal authority for waste management?																
4.	Who has existing rights?																
5.	Who may be a supporter of anti-waste management operations?																
6.	Who is responsible for the intended plans?																
7.	Who has skills or key information?																
8.	Who should provide budget support?																

ส่วนที่ 3 ความคิดเห็นบนพื้นฐาน อำนาจ ความชอบธรรม และความเร่งด่วนอันเป็นคุณลักษณะประจำของกลุ่มผู้มีส่วนได้ส่วนเสียทุกกลุ่ม

โดยพิจารณาจากคุณลักษณะ 3 ประการ คือ

1 อำนาจ (Power) หมายถึง ความสามารถที่เป็นตามอำนาจหน้าที่ตามกฎหมาย, ตามระเบียบข้อบังคับ, มาตราการการควบคุมและสอดส่งดูแล การสนับสนุนงบประมาณ, และกำลังคนเพื่อให้เกิดผลประโยชน์ต่อคนส่วนใหญ่

2 ความชอบธรรม (Legitimacy) หมายถึง การรับรู้โดยทั่วกันว่าเป็นการกระทำที่เหมาะสมตามบรรทัดฐาน หรือแนวปฏิบัติที่เคยมีมาก่อน ความน่าเชื่อถือ หรือคำจำกัดความของสังคม

3 ความเร่งด่วน (Urgency) หมายถึง ระดับของผู้มีส่วนได้ส่วนเสียที่ทำการเรียกร้องให้ได้รับความสนใจอันเนื่องมาจากวิกฤตของปัญหา ซึ่งควรได้รับการขจัดหรือบรรเทาอย่างเร่งด่วน

Power is to influence the organization or project deliverables (coercive, financial or material, brand or image).

Legitimacy indicates the relationship and actions in terms of desirability, properness or appropriateness.

Urgency informs the requirements in terms of criticality and time sensitivity for the stakeholder.

แบบสอบถามชุดนี้มีความต้องการข้อมูลค่าคะแนนของค่าน้ำหนักประจำกลุ่มผู้มีส่วนได้ส่วนเสีย 0-3 โดยมีรายละเอียดดังนี้

0 คือ ไม่มีค่า

1 หมายถึง มีค่าในระดับต่ำ

2 หมายถึง มีค่าในระดับปานกลาง

3 หมายถึง มีค่าในระดับสูง

คำชี้แจง ให้คะแนนในแต่ละกลุ่มผู้มีส่วนได้ส่วนเสีย 0-3 คะแนน

กลุ่มผู้มีส่วนได้ส่วนเสีย	**อำนาจ**	**ความชอบธรรม**	**ความเร่งด่วน**
1. สำนักงานสิ่งแวดล้อมภาคที่ 3			
2. สำนักงานทรัพยากรธรรมชาติและสิ่งแวดล้อม จังหวัดพิษณุโลก			
3. อาสาสมัครกรมส่งเสริมคุณภาพสิ่งแวดล้อม			
4. สำนักงานสาธารณสุข			
5. กองพลทหารราบที่ 4			
6. องค์กรปกครองส่วนท้องถิ่น (เทศบาล,อบต.,อบจ.)			
7. องค์กรพัฒนาเอกชน (ด้านสิ่งแวดล้อม) (NGO)			
8. องค์กรชาวบ้าน จ.พิษณุโลก			
9. สถาบันการศึกษา			
10. เอกชนที่เกี่ยวข้องกับการกำจัดขยะ			
11. คนคัดแยกตามแหล่งกำจัด			
12. ประชาชนที่อยู่ใกล้แหล่งกำจัด			
13. ประชาชนที่ใช้บริการ			
14. นักข่าว			
15. ท้องถิ่นจังหวัด			

Stakeholder	POWER	Urgency	Legitimacy
1. EOR 3			
2. PNRE			
3. Health			
4. RTA			
5. LAO			
6. POLA			
7. NGO			
8. CO			
9. Volunteer			
10. Academic			
11. Waste picker			
12. Private sector			
13. RES_DS			
14. RES_waste			
15. Media			

APPENDIX B

OPTIMUM DISTANCE OF EACH TS TO EACH DS

Table B-1 Optimum distance (back and forth) of each TS to each DS.

No.	Paths of TSs to DSs	Distance of paths (km)
1	Phitsanulok municipality and Thathong municipality (TS01) to Phitsanulok municipality (DS01)	49.91
2	Phitsanulok municipality and Thathong municipality (TS01) to Banmai municipality (DS02)	42.48
3	Phitsanulok municipality and Thathong municipality (TS01) to Nuenkum municipality (DS03)	101.02
4	Phitsanulok municipality and Thathong municipality (TS01) to Bangkrathum municipality (DS04)	67.12
5	Phitsanulok municipality and Thathong municipality (TS01) to Plakrad municipality (DS05)	39.19
6	Phitsanulok municipality and Thathong municipality (TS01) to Phromphiram municipality (DS06)	64.49
7	Phitsanulok municipality and Thathong municipality (TS01) to Wongkong municipality (DS07)	86.71
8	Phitsanulok municipality and Thathong municipality (TS01) to Watbot municipality (DS08)	66.67
9	Phitsanulok municipality and Thathong municipality (TS01) to Thapho SAO (DS09)	12.84
10	Phitsanulok municipality and Thathong municipality (TS01) to Bankrang SAO (DS10)	14.26
11	Phitsanulok municipality and Thathong municipality (TS01) to Bantan SAO (DS11)	63.51
12	Aranyik municipality (TS02) to Phitsanulok municipality (DS01)	100.38
13	Aranyik municipality (TS02) to Banmai municipality (DS02)	61.43
14	Aranyik municipality (TS02) to Nuenkum municipality (DS03)	93.31
15	Aranyik municipality (TS02) to Bangkrathum municipality (DS04)	78.96
16	Aranyik municipality (TS02) to Plakrad municipality (DS05)	89.66
17	Aranyik municipality (TS02) to Phromphiram municipality (DS06)	89.30
18	Aranyik municipality (TS02) to Wongkong municipality (DS07)	101.44
19	Aranyik municipality (TS02) to Watbot municipality (DS08)	56.93
20	Aranyik municipality (TS02) to Thapho SAO (DS09)	61.25
21	Aranyik municipality (TS02) to Bankrang SAO (DS10)	77.75
22	Aranyik municipality (TS02) to Bantan SAO (DS11)	61.00
23	Phlaichumphon municipality (TS03) to Phitsanulok municipality (DS01)	78.50

Table B-1 Optimum distance (back and forth) of each TS to each DS (Continued).

No.	Paths of TSs to DSs	Distance of paths (km)
24	Phlaichumphon municipality (TS03) to Banmai municipality (DS02)	71.07
25	Phlaichumphon municipality (TS03) to Nuenkum municipality (DS03)	126.93
26	Phlaichumphon municipality (TS03) to Bangkrathum municipality (DS04)	95.71
27	Phlaichumphon municipality (TS03) to Plakrad municipality (DS05)	67.78
28	Phlaichumphon municipality (TS03) to Phromphiram municipality (DS06)	54.04
29	Phlaichumphon municipality (TS03) to Wongkong municipality (DS07)	76.25
30	Phlaichumphon municipality (TS03) to Watbot municipality (DS08)	56.03
31	Phlaichumphon municipality (TS03) to Thapho SAO (DS09)	41.43
32	Phlaichumphon municipality (TS03) to Bankrang SAO (DS10)	23.43
33	Phlaichumphon municipality (TS03) to Bantan SAO (DS11)	92.09
34	Bankhlong municipality (TS04) to Phitsanulok municipality (DS01)	73.92
35	Bankhlong municipality (TS04) to Banmai municipality (DS02)	66.49
36	Bankhlong municipality (TS04) to Nuenkum municipality (DS03)	125.03
37	Bankhlong municipality (TS04) to Bangkrathum municipality (DS04)	91.13
38	Bankhlong municipality (TS04) to Plakrad municipality (DS05)	63.20
39	Bankhlong municipality (TS04) to Phromphiram municipality (DS06)	57.12
40	Bankhlong municipality (TS04) to Wongkong municipality (DS07)	79.33
41	Bankhlong municipality (TS04) to Watbot municipality (DS08)	59.11
42	Bankhlong municipality (TS04) to Thapho SAO (DS09)	36.85
43	Bankhlong municipality (TS04) to Bankrang SAO (DS10)	26.51
44	Bankhlong municipality (TS04) to Bantan SAO (DS11)	87.52
45	Huaro municipality (TS06) to Phitsanulok municipality (DS01)	106.52
46	Huaro municipality (TS06) to Banmai municipality (DS02)	70.89
47	Huaro municipality (TS06) to Nuenkum municipality (DS03)	102.31
48	Huaro municipality (TS06) to Bangkrathum municipality (DS04)	88.37

Table B-1 Optimum distance (back and forth) of each TS to each DS (Continued).

No.	Paths of TSs to DSs	Distance of paths (km)
49	Huaro municipality (TS06) to Plakrad municipality (DS05)	95.80
50	Huaro municipality (TS06) to Phromphiram municipality (DS06)	55.31
51	Huaro municipality (TS06) to Wongkong municipality (DS07)	78.00
52	Huaro municipality (TS06) to Watbot municipality (DS08)	31.41
53	Huaro municipality (TS06) to Thapho SAO (DS09)	69.45
54	Huaro municipality (TS06) to Bankrang SAO (DS10)	51.46
55	Huaro municipality (TS06) to Bantan SAO (DS11)	70.41
56	Phaikhodon SAO and Bankrang SAO (TS07) to Phitsanulok municipality (DS01)	80.55
57	Phaikhodon SAO and Bankrang SAO (TS07) to Banmai municipality (DS02)	73.11
58	Phaikhodon SAO and Bankrang SAO (TS07) to Nuenkum municipality (DS03)	130.66
59	Phaikhodon SAO and Bankrang SAO (TS07) to Bangkrathum municipality (DS04)	97.76
60	Phaikhodon SAO and Bankrang SAO (TS07) to Plakrad municipality (DS05)	69.82
61	Phaikhodon SAO and Bankrang SAO (TS07) to Phromphiram municipality (DS06)	37.46
62	Phaikhodon SAO and Bankrang SAO (TS07) to Wongkong municipality (DS07)	59.68
63	Phaikhodon SAO and Bankrang SAO (TS07) to Watbot municipality (DS08)	53.59
64	Phaikhodon SAO and Bankrang SAO (TS07) to Thapho SAO (DS09)	43.47
65	Phaikhodon SAO and Bankrang SAO (TS07) to Bankrang SAO (DS10)	23.38
66	Phaikhodon SAO and Bankrang SAO (TS07) to Bantan SAO (DS11)	94.14
67	Watchan SAO (TS08) to Phitsanulok municipality (DS01)	66.74
68	Watchan SAO (TS08) to Banmai municipality (DS02)	59.30
69	Watchan SAO (TS08) to Nuenkum municipality (DS03)	117.84
70	Watchan SAO (TS08) to Bangkrathum municipality (DS04)	83.95
71	Watchan SAO (TS08) to Plakrad municipality (DS05)	56.01
72	Watchan SAO (TS08) to Phromphiram municipality (DS06)	62.31
73	Watchan SAO (TS08) to Wongkong municipality (DS07)	84.53

Table B-1 Optimum distance (back and forth) of each TS to each DS (Continued).

No.	Paths of TSs to DSs	Distance of paths (km)
74	Watchan SAO (TS08) to Watbot municipality (DS08)	64.20
75	Watchan SAO (TS08) to Thapho SAO (DS09)	29.66
76	Watchan SAO (TS08) to Bankrang SAO (DS10)	21.32
77	Watchan SAO (TS08) to Bantan SAO (DS11)	80.33
78	Thapho SAO (TS09) to Phitsanulok municipality (DS01)	51.76
79	Thapho SAO (TS09) to Banmai municipality (DS02)	28.31
80	Thapho SAO (TS09) to Nuenkum municipality (DS03)	86.85
81	Thapho SAO (TS09) to Bangkrathum municipality (DS04)	52.95
82	Thapho SAO (TS09) to Plakrad municipality (DS05)	38.99
83	Thapho SAO (TS09) to Phromphiram municipality (DS06)	74.25
84	Thapho SAO (TS09) to Wongkong municipality (DS07)	96.47
85	Thapho SAO (TS09) to Watbot municipality (DS08)	72.55
86	Thapho SAO (TS09) to Thapho SAO (DS09)	12.63
87	Thapho SAO (TS09) to Bankrang SAO (DS10)	29.67
88	Thapho SAO (TS09) to Bantan SAO (DS11)	49.34
89	Beungphra SAO (TS10) to Phitsanulok municipality (DS01)	64.88
90	Beungphra SAO (TS10) to Banmai municipality (DS02)	26.02
91	Beungphra SAO (TS10) to Nuenkum municipality (DS03)	73.89
92	Beungphra SAO (TS10) to Bangkrathum municipality (DS04)	50.67
93	Beungphra SAO (TS10) to Plakrad municipality (DS05)	54.15
94	Beungphra SAO (TS10) to Phromphiram municipality (DS06)	86.83
95	Beungphra SAO (TS10) to Wongkong municipality (DS07)	109.05
96	Beungphra SAO (TS10) to Watbot municipality (DS08)	70.63
97	Beungphra SAO (TS10) to Thapho SAO (DS09)	25.75
98	Beungphra SAO (TS10) to Bankrang SAO (DS10)	42.25
99	Beungphra SAO (TS10) to Thatan SAO (DS11)	35.84

APPENDIX C

OPTIMUM PATHS OF ACTIVE PAIRS OF TS AND DS

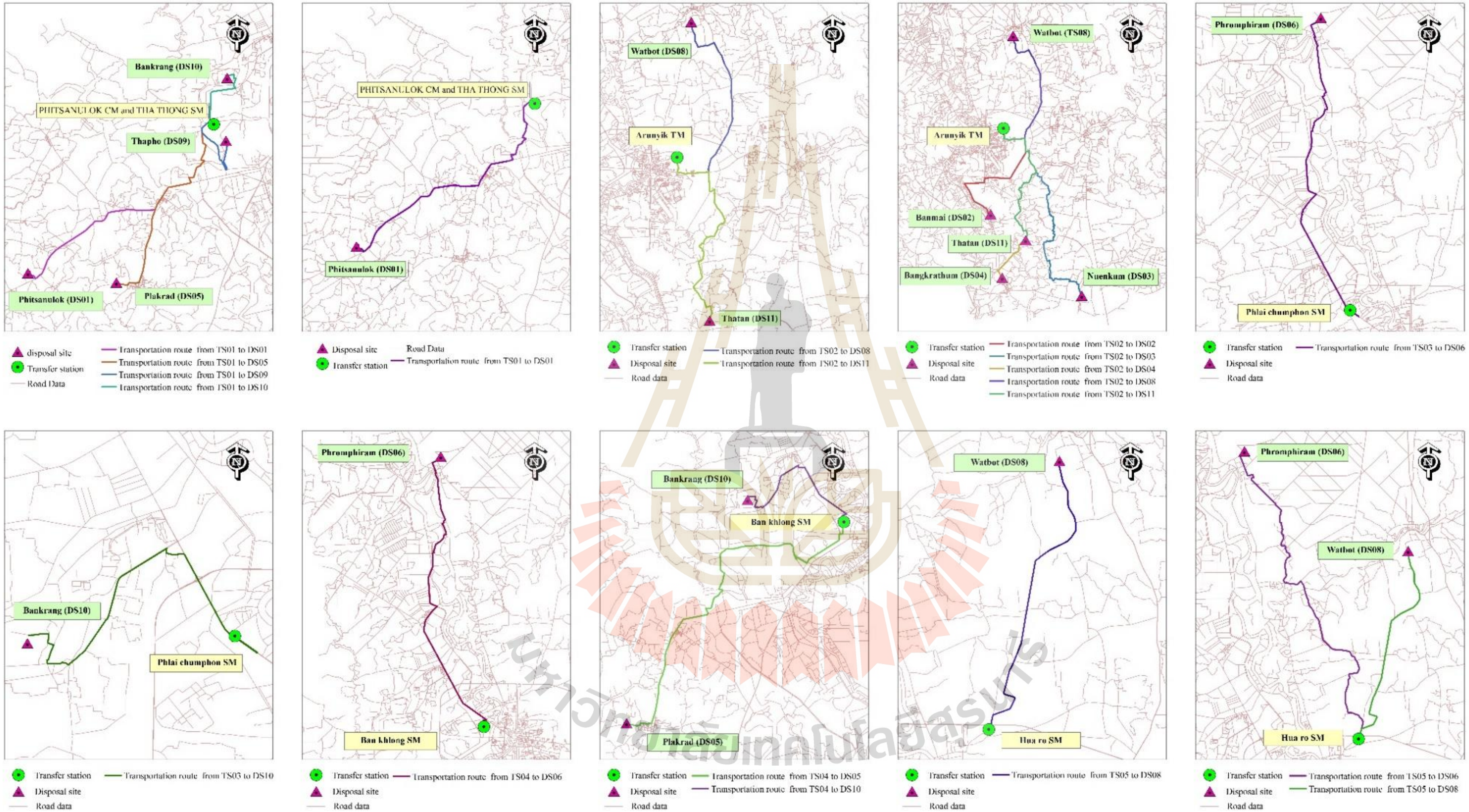

Figure C-1 Optimum paths of active pairs of TS and DS for minimized TC.

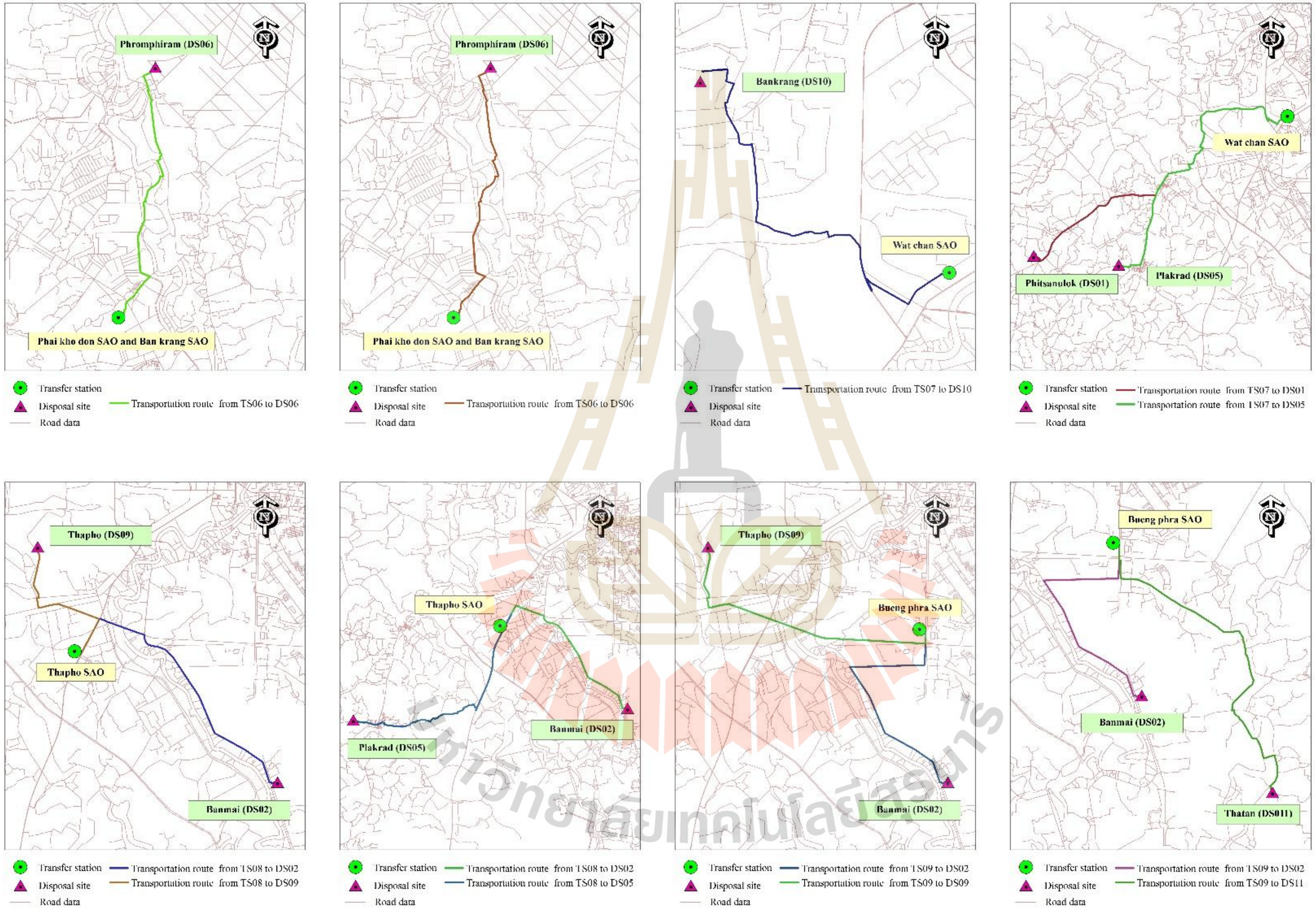

Figure C-1 Optimum paths of active pairs of TS and DS for minimized TC (Continued).

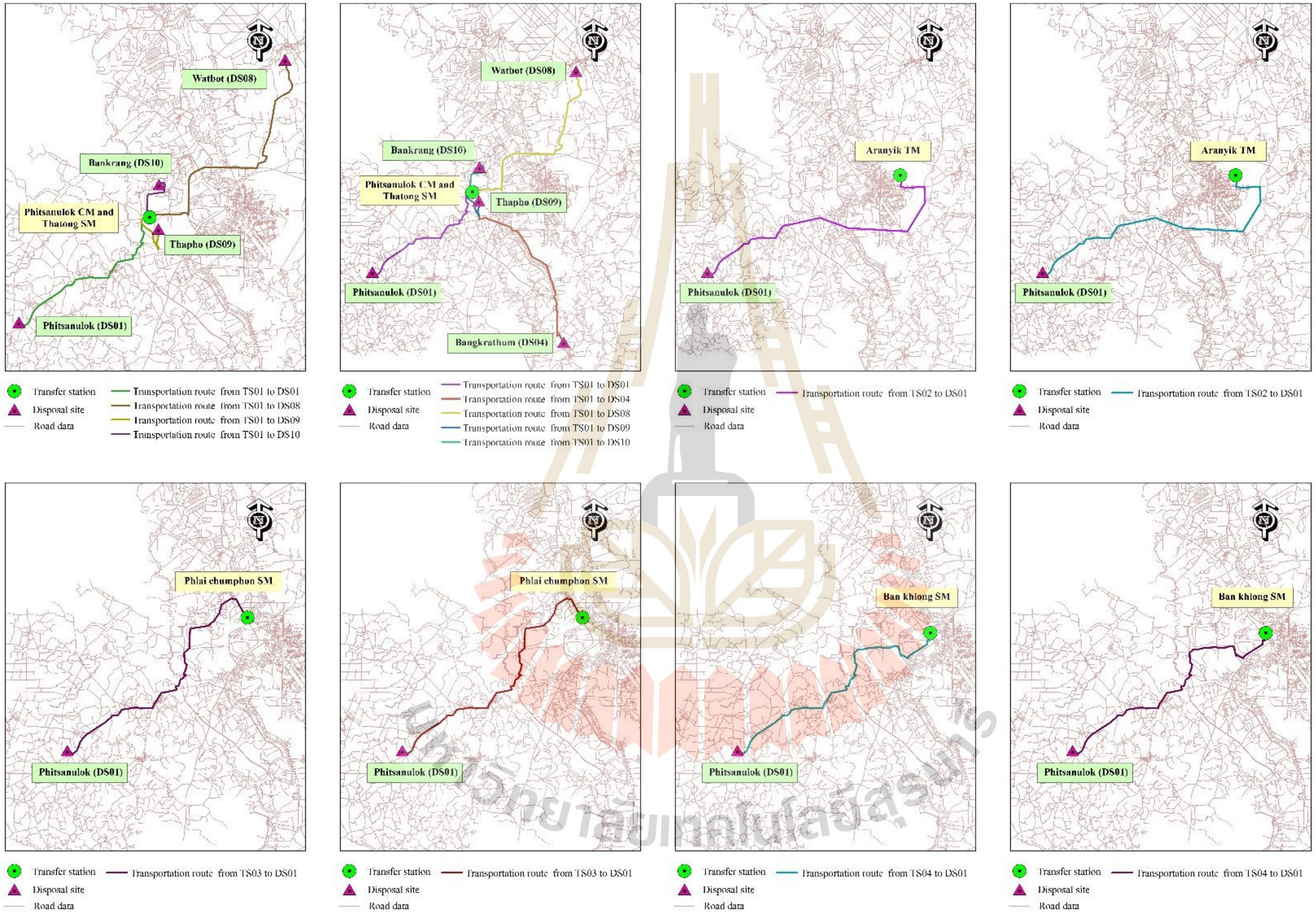

Figure C-2 Optimum paths of active pairs of TS and DS for minimized EI.

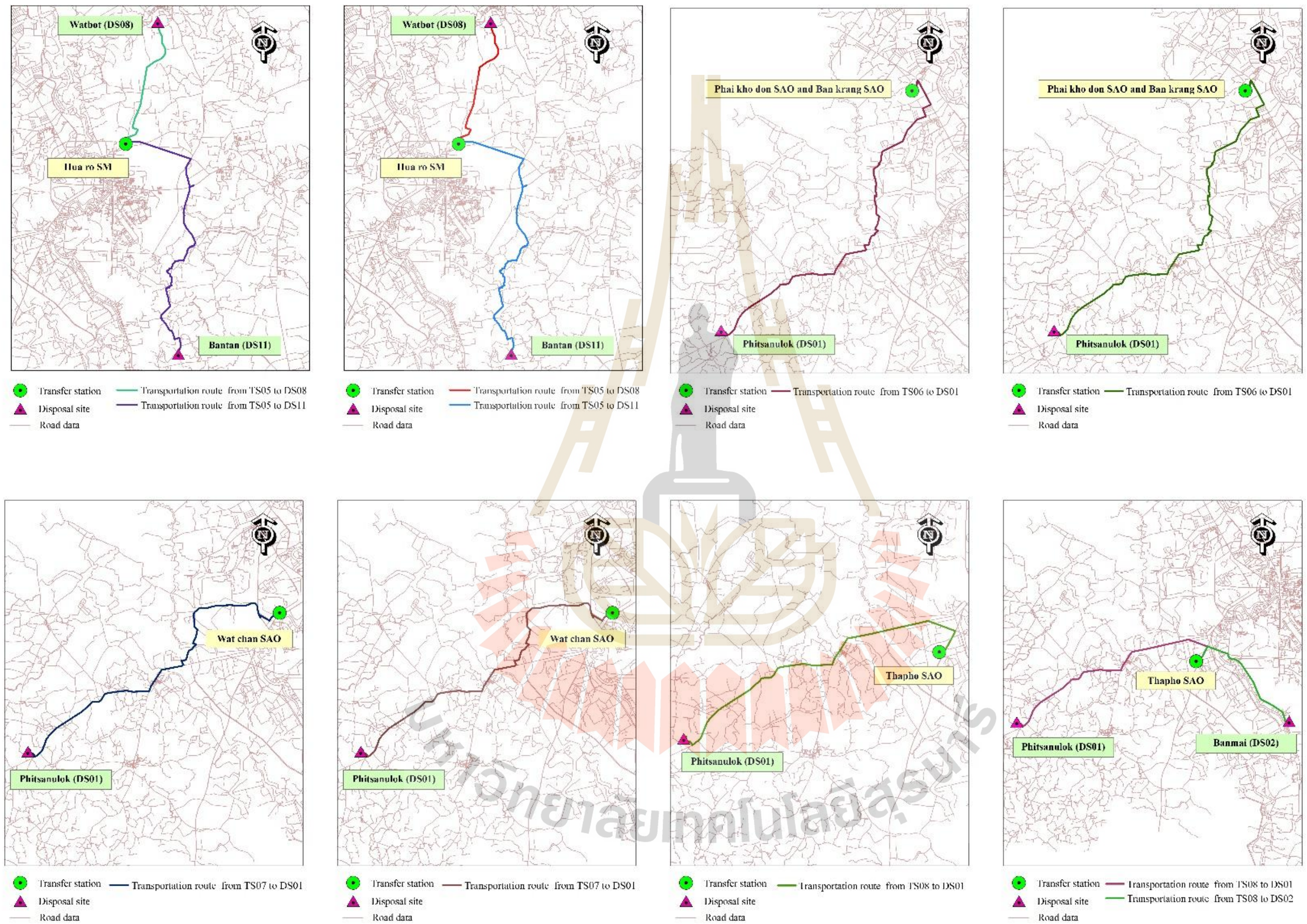

Figure C-2 Optimum paths of active pairs of TS and DS for minimized EI (Continued).

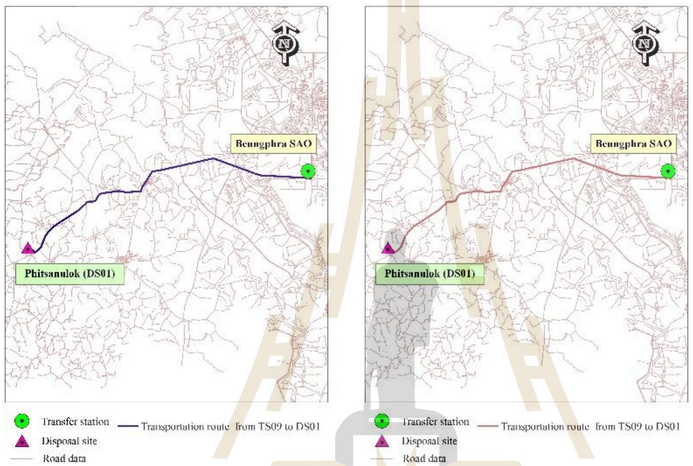

Figure C-2 Optimum paths of active pairs of TS and DS for minimized EI (Continued).

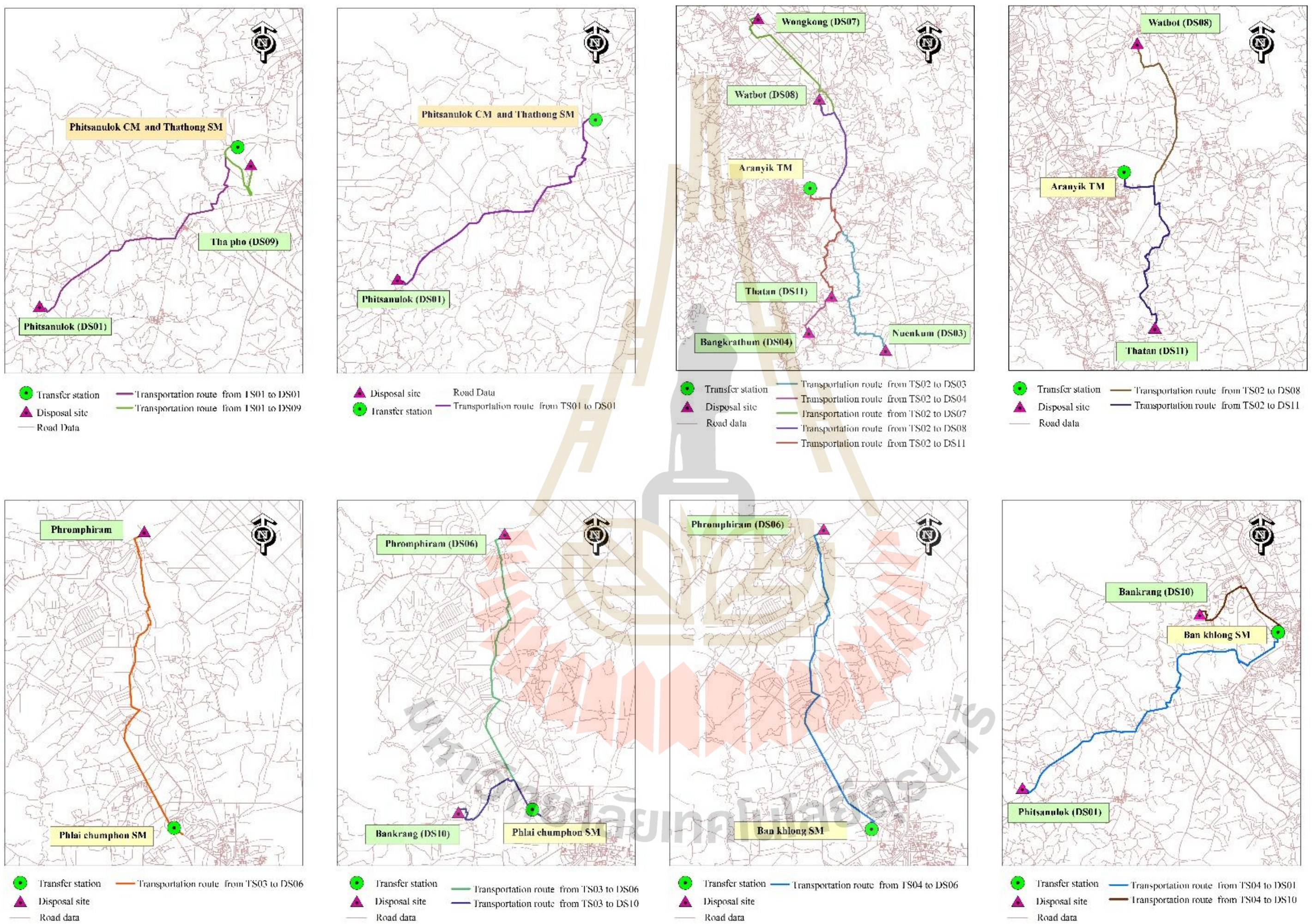

Figure C-3 Optimum paths of active pairs of TS and DS for minimized VI.

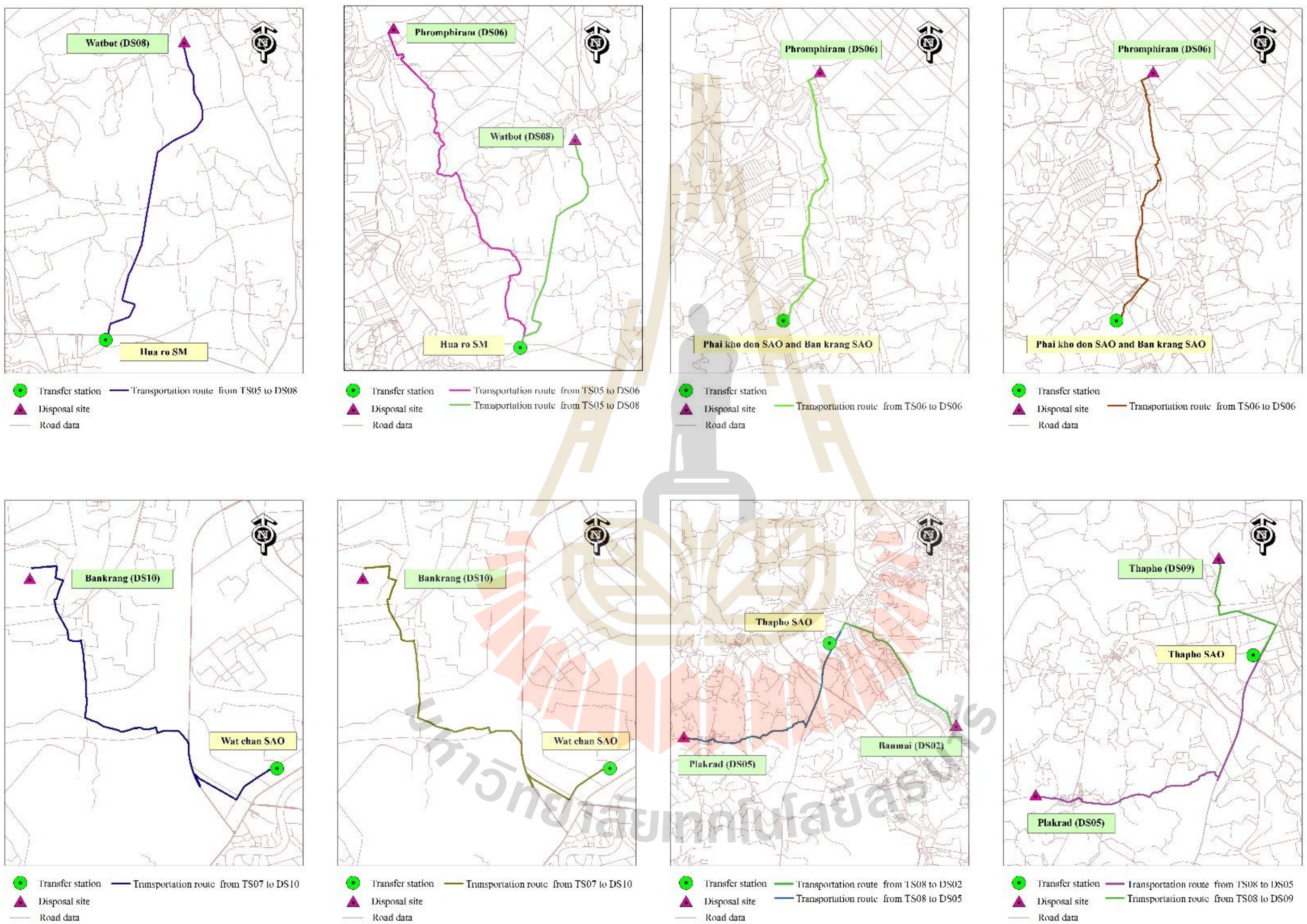

Figure C-3 Optimum paths of active pairs of TS and DS for minimized VI (Continued.).

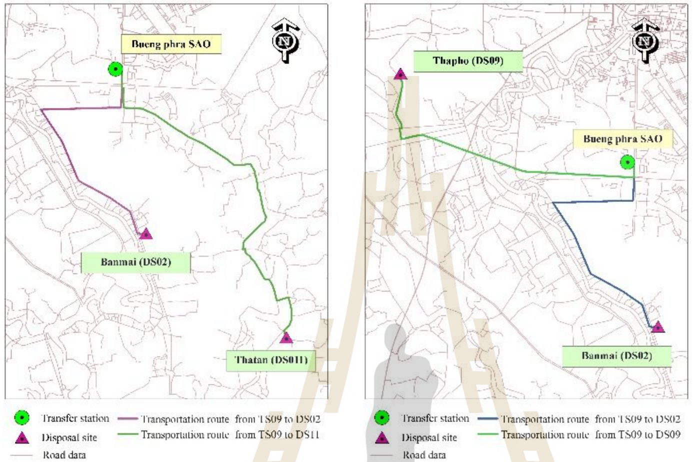

Figure C-3 Optimum paths of active pairs of TS and DS for minimized VI (Continued.).

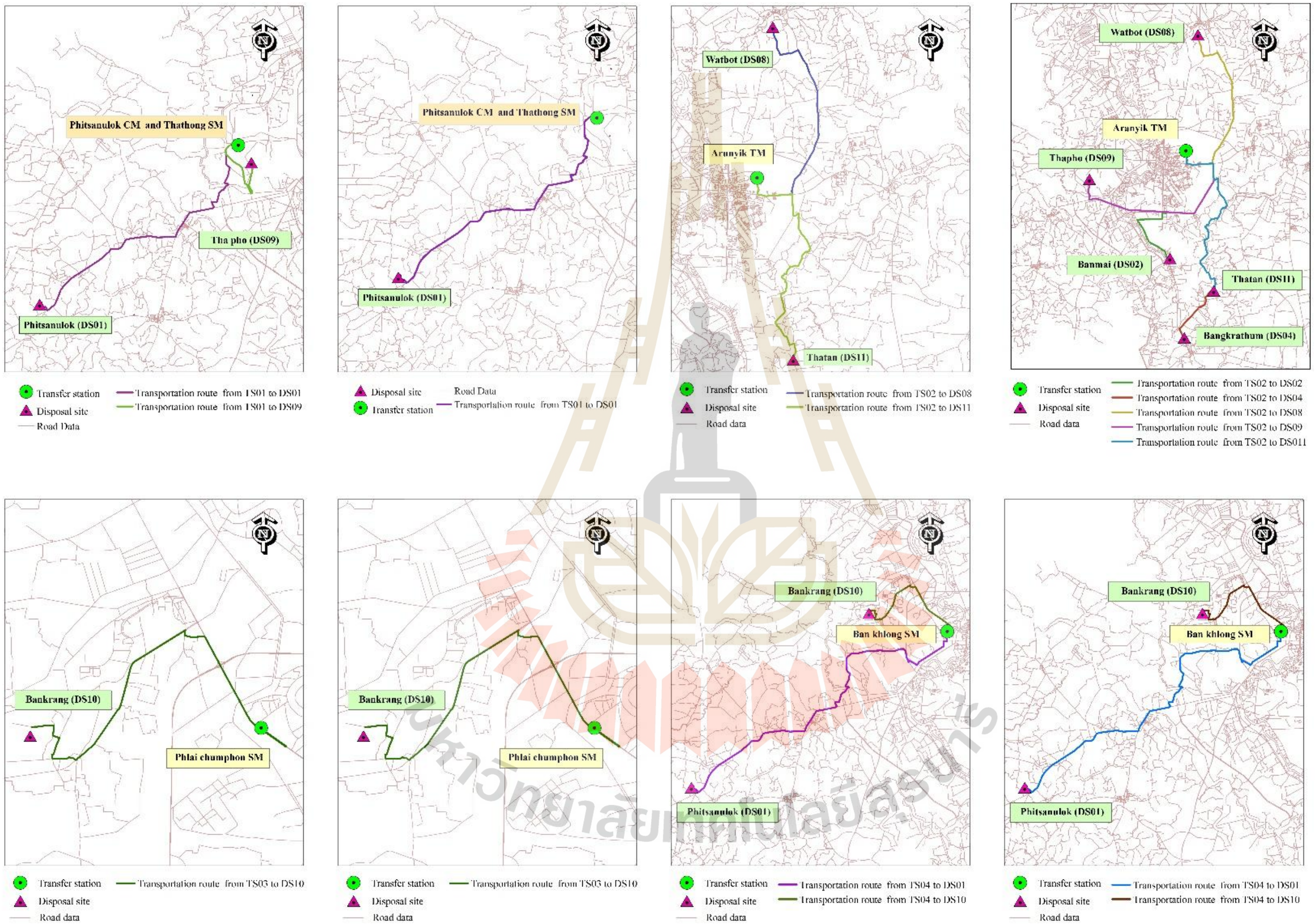

Figure C-4 Optimum paths of active pairs of TS and DS for minimized TC and EI.

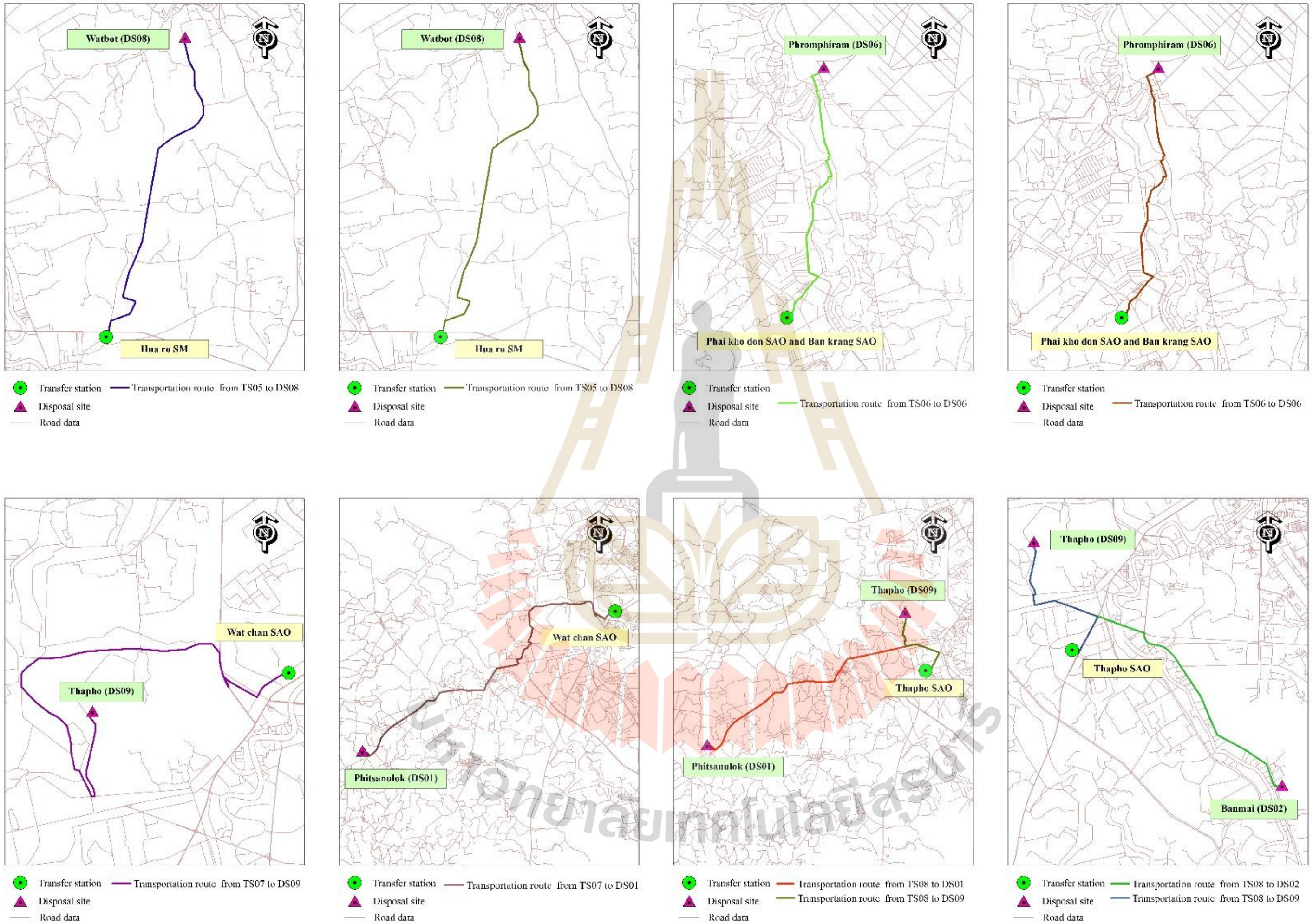

Figure C-4 Optimum paths of active pairs of TS and DS for minimized TC and EI (Continued.).

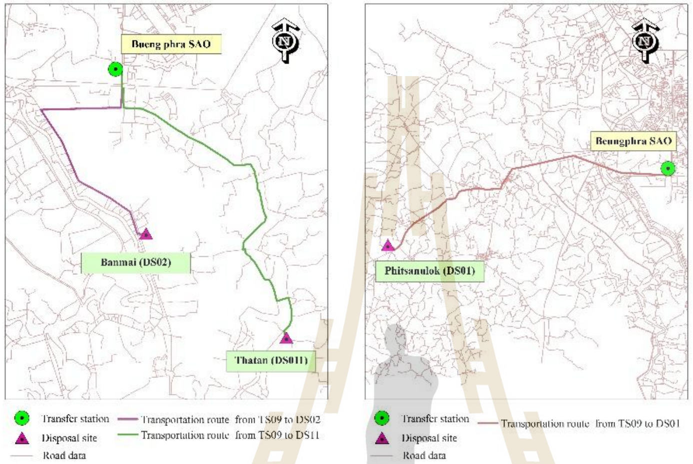

Figure C-4 Optimum paths of active pairs of TS and DS for minimized TC and EI (Continued.).

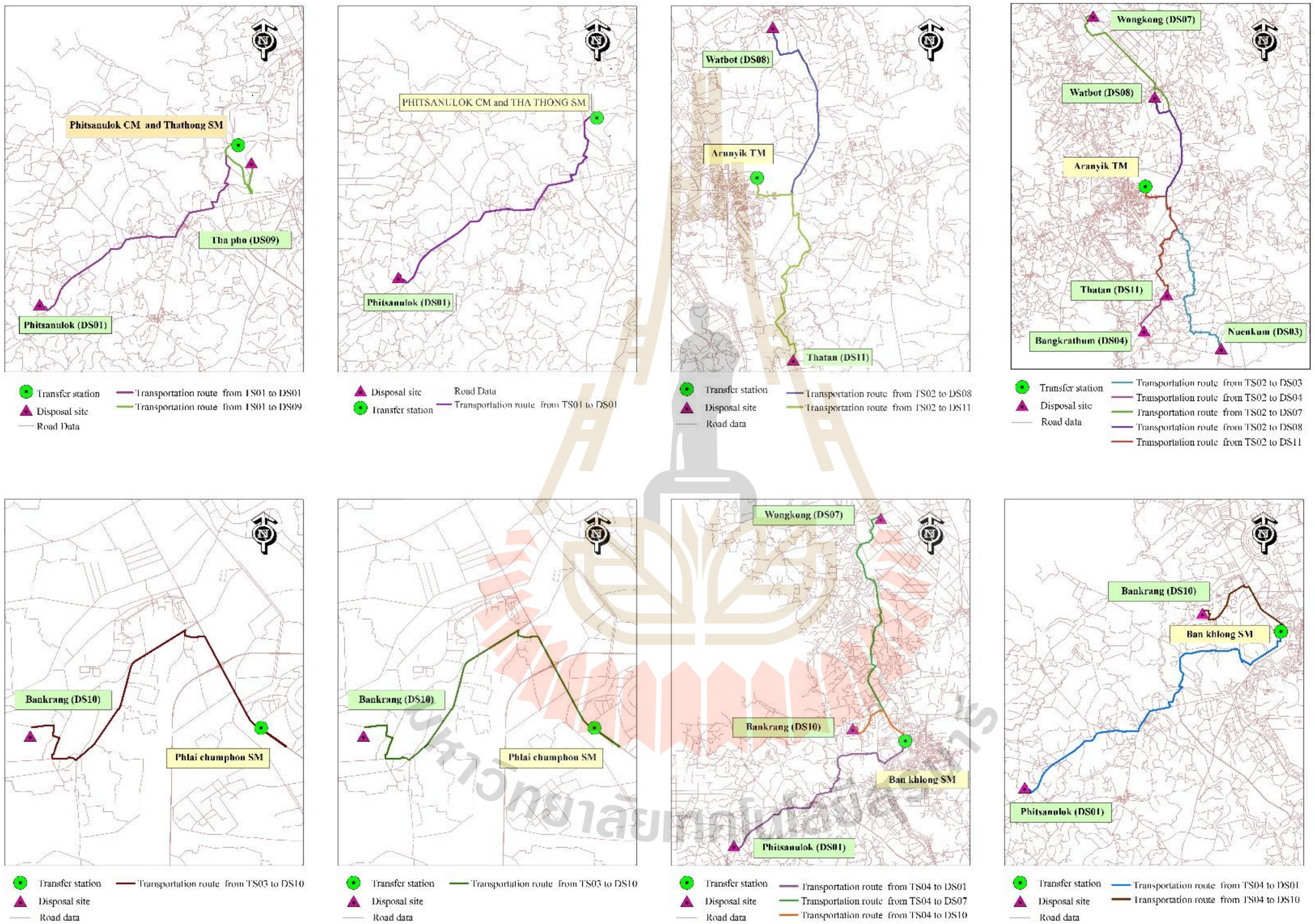

Figure C-5 Optimum paths of active pairs of TS and DS for minimized EI and VI.

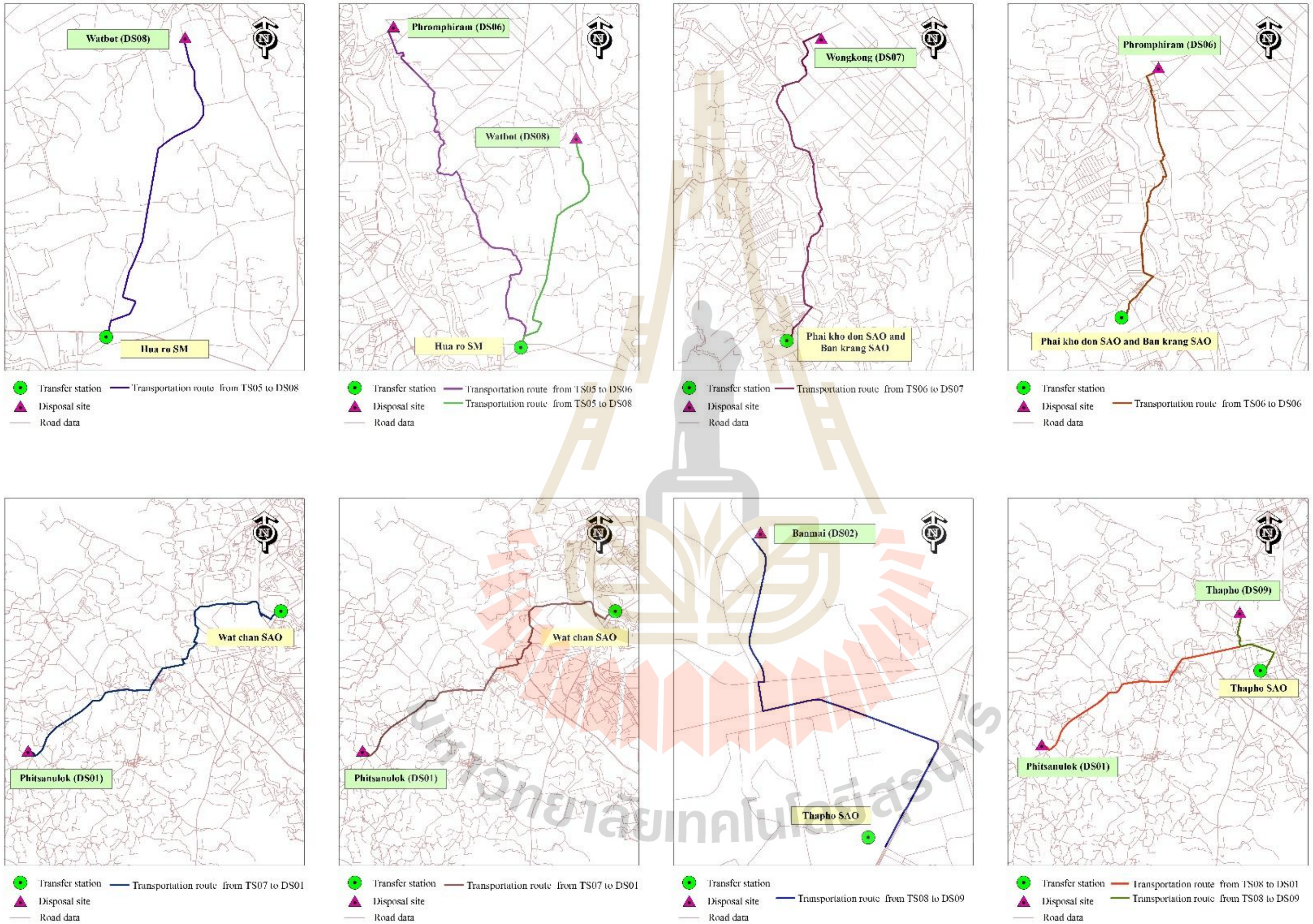

Figure C-5 Optimum paths of active pairs of TS and DS for minimized EI and VI (Continued.).

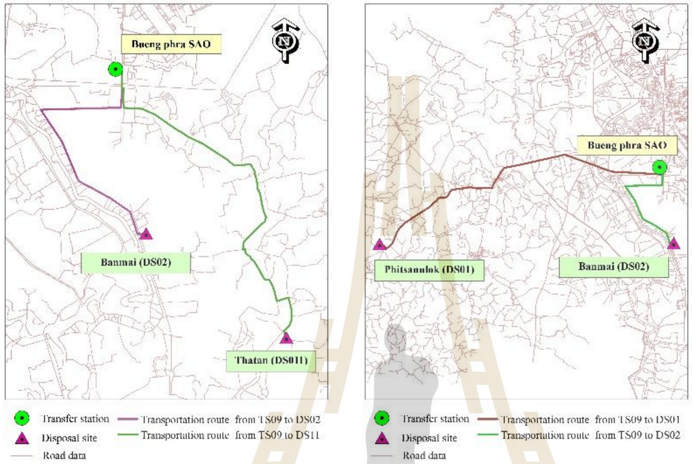

Figure C-5 Optimum paths of active pairs of TS and DS for minimized EI and VI (Continued.).

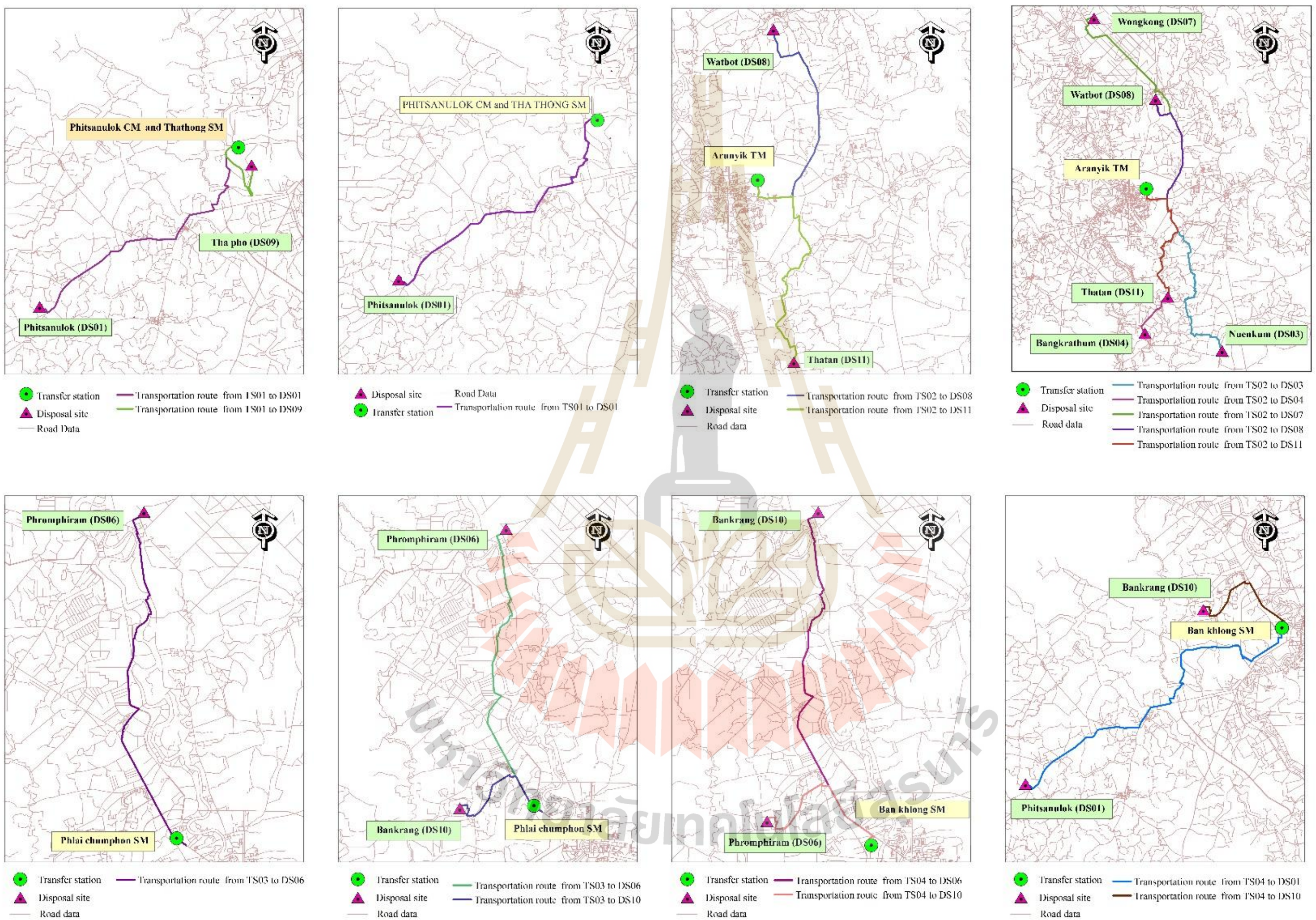

Figure C-6 Optimum paths of active pairs of TS and DS for minimized TC, EI, and VI.

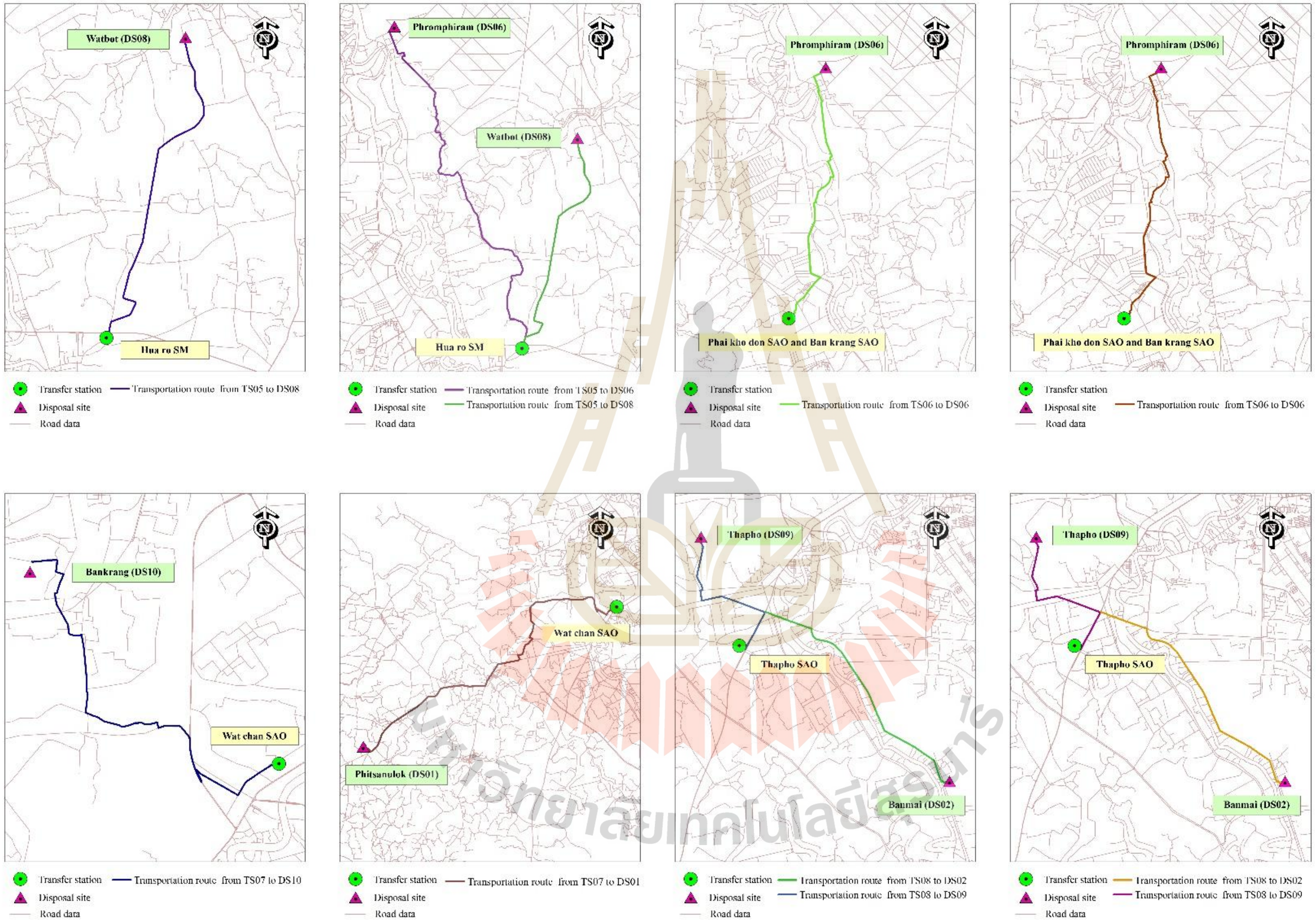

Figure C-6 Optimum paths of active pairs of TS and DS for minimized TC, EI, and VI (Continued.).

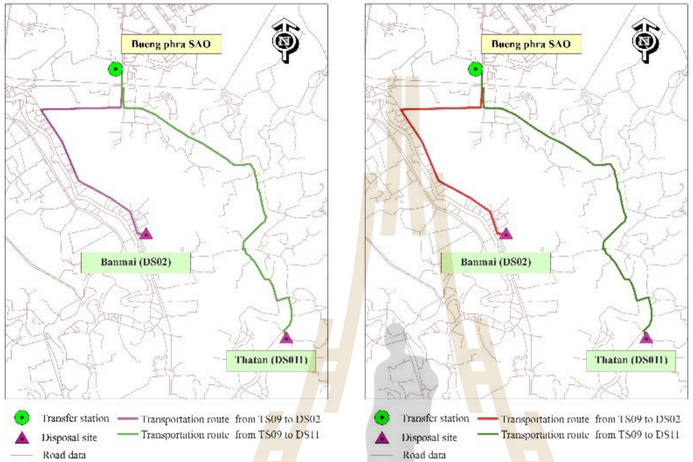

Figure C-6 Optimum paths of active pairs of TS and DS for minimized TC, EI, and VI (continued.).

APPENDIX D

QUESTIONNAIRE FOR OUTRANKING TRANSPORTATION PATTERNS

<u>แบบสอบถามสำหรับการวิจัย</u>

เรื่อง การบูรณาการการวิเคราะห์เชิงพื้นที่และผู้มีส่วนได้ส่วนเสียสำหรับการจัดการขยะ

<u>คำชี้แจงในการตอบแบบสอบถาม</u>

1. แบบสอบถามนี้ต้องการวิเคราะห์หารูปแบบที่เหมาะสมในการจัดสรรขยะจากที่พักขยะไปยังแหล่งกำจัดขยะ ในเขตพื้นที่องค์กรปกครองส่วนท้องถิ่นในจังหวัดพิษณุโลก ซึ่งเป็นวัตถุประสงค์หนึ่งสำหรับการทำวิทยานิพนธ์เรื่องการบูรณาการของการวิเคราะห์และปัจจัยเชิงพื้นที่สำหรับการจัดการขยะ เพื่อให้ได้รูปแบบในการจัดสรรค์ขยะที่เหมาะสมกับความต้องการของผู้มีส่วนได้ส่วนเสีย

2. ขอความกรุณาท่านได้ตอบแบบสอบถาม ตามสภาพความเป็นจริง โดยคำตอบของท่านจะนำไปสรุปผลการศึกษาค้นคว้าในลักษณะภาพรวมไม่มีผลกระทบหรือเกิดความเสียหายต่อท่านหรือผู้อื่น ทั้งทางตรงและทางอ้อมแต่ประการใด หากแต่จะเป็นประโยชน์ต่อการจัดการขยะในหน่วยงานของท่านให้ดียิ่งขึ้นต่อไปในอนาคต

ขอขอบคุณในการอนุเคราะห์ในการให้ความร่วมมือของท่าน

พิมประไพ พิพัฒน์นวกุล

นักศึกษาระดับดุษฎีบัณฑิต มหาวิทยาลัยเทคโนโลยีสุรนารี

ตอนที่ 1 การให้ค่าคะแนนสำหรับการเลือกความเหมาะสมของอายุการใช้งานแหล่งกำจัดขยะ

โดยการให้ค่าคะแนน 0-100 ตามความเหมาะสม โดยค่าความเหมาะสมมากที่สุดจะต้องมีค่าคะแนนมากที่สุด ตามช่วงคะแนนโดยประมาณต่อไปนี้

0 – 20 มีค่าเท่ากับ น้อยมาก 21 - 40 มีค่าเท่ากับ น้อย

41 - 60 มีค่าเท่ากับ ปานกลาง 61 - 80 มีค่าเท่ากับ มาก

81 -100 มีค่าเท่ากับ มากที่สุด

เกณฑ์	**อายุการใช้งาน 3 ปี**	**อายุการใช้งาน 5 ปี**
1. ค่าขนส่งรายวัน	น้อยกว่า	มากกว่า
ค่าคะแนน		
2. อายุการใช้งานแหล่งกำจัดขยะ	สั้นกว่า	ยาวนานกว่า
ค่าคะแนน		
3. มีแหล่งกำจัดขยะที่ใช้บริการมากขึ้นเพื่อประกันความเสี่ยง	มีแหล่งน้อยกว่า	มีแหล่งมากกว่า
ค่าคะแนน		
4. การวางแผนหาแหล่งกำจัดใหม่มีเวลาในการตัดสินใจมากขึ้น หาทางเลือกในการกำจัดได้มากขึ้น	มีเวลาน้อยกว่า	มีเวลามากกว่า
ค่าคะแนน		
5. ผลกระทบทางด้านสิ่งแวดล้อมที่มีต่อเส้นทางขนส่งและแหล่งกำจัด	ผลกระทบสูงกว่า	ผลกระทบต่ำกว่าเนื่องจากมีการกระจายตัวมากกว่า
ค่าคะแนน		
6. การรับมือกับปัญหาฉุกเฉิน (เช่น แหล่งกำจัดปิดตัวลงกระทันหัน)	รับมือได้ยากกว่า	รับมือได้ง่ายกว่า
ค่าคะแนน		

Very Low = 0 - 20 Low = 21 - 40

Medium = 41 - 60 High = 61 - 80

Very High = 81 - 100

Considered criteria	**3-year service life**	**5-year service life**
Daily transportation cost	less	more
SCORE		
Service life	shorter	longer
SCORE		
Number of DS in service for risk warranty	less	more
SCORE		
Available time for new DSs searching and selection	less	more
SCORE		
EI of DS and VI along transportation route	more	less
SCORE		
Emergency case handling (e.g. DS is suddenly shut down due to acute EI)	harder to handle	easier to handle
SCORE		

ตอนที่ 2 พิจารณาเกณฑ์ที่ใช้ในการขนส่งขยะ

การให้ค่าคะแนน 0-100 ตามความเหมาะสม โดยค่าความเหมาะสมมากที่สุดจะต้องมีค่าคะแนนมากที่สุด ตามช่วงคะแนนโดยประมาณต่อไปนี้

0 – 20 มีค่าเท่ากับน้อยมาก 21 - 40 มีค่าเท่ากับ น้อย

41 - 60 มีค่าเท่ากับ ปานกลาง 61 - 80 มีค่าเท่ากับ มาก

81 -100 มีค่าเท่ากับ มากที่สุด

1. ค่าใช้จ่ายที่เกิดจากการขนส่ง
   ค่าคะแนน............................
2. ค่าดัชนีผลกระทบด้านสิ่งแวดล้อมจากสถานีพักขยะและแหล่งกำจัดขยะ
   ค่าคะแนน............................
3. ค่าดัชนีความอ่อนไหวของประชาชนที่อยู่ในสถานที่ที่มีจำนวนมากกว่า 500 คนขึ้นไป เช่น โรงเรียน สถานที่ท่องเที่ยว ห้างสรรพสินค้า เป็นต้น ที่ได้รับผลกระทบจากการขนส่งขยะ
   ค่าคะแนน............................

Very Low = 0 - 20 Low = 21 - 40

Medium = 41 - 60 High = 61 - 80

Very High = 81 - 100

1. Transportation cost

   Score ....

2. Environmental Index

   Score ....

3. Vulnerability Index

   Score ....

APPENDIX E

PHOTO FROM FIELD SURVEY

E-1 Disposal site and Transfer station

Figure E-1.1 Disposal site

Figure E-1.2 Transfer station and facility.

E-2 Interviewing and questionnaire

Figure E-2.1 Interview stakeholder in the field survey

Figure E-2.1 Interview stakeholder in the field survey (continued).

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