WASTE TRANSPORTATION MANAGEMENT BASED ON TRANSPORTATION COST AND ENVIRONMENTAL IMPACT OF SITES

Athiwat Phinyoyang

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มหาวิทยาลัยเทคโนโลยีสุรนารี

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Thesis Examining Committee

(Assoc. Prof. Dr. Songkot Dasananda)

Chairperson

(Asst. Prof. Dr. Sunya Sarapirome)

Member (Thesis Advisor)

(Asst. Prof. Dr. Jiradech Majandang)

Member

(Assoc. Prof. Dr. Suwit Ongsomwang)

Member

(Dr. Pantip Piyatadsananon)

Member

(Prof. Dr. Sukit Limpijumnong)

Vice Rector for Academic Affairs and Innovation

(Prof. Dr. Santi Maensiri)

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ระบบจัดการขยะมูลฝอยชุมชนในการศึกษาครั้งนี้เกี่ยวข้องกับการเลือกเส้นทางขนส่งที่เหมาะสมจากสถานีขนส่งขยะไปยังแหล่งกำจัดขยะที่มีอยู่แล้ว และการจัดแบ่งปริมาณขยะอย่างมีประสิทธิภาพเพื่อให้มีต้นทุนในการขนส่งและมีผลกระทบทางสิ่งแวดล้อมที่น้อยที่สุด รวมถึงเป็นการยืดอายุการใช้งานของแหล่งกำจัดขยะ วัตถุประสงค์หลักคือการจัดการการขนส่งขยะในองค์กรปกครองส่วนท้องถิ่นของจังหวัดพิษณุโลก ประเทศไทย องค์กรปกครองส่วนท้องถิ่นจำเป็นต้องมีสถานีขนส่งขยะแบบชั่วคราวซึ่งได้จากการวิเคราะห์การกำหนดศูนย์กลางเฉลี่ยโดยมีน้ำหนักจากจำนวนประชากร เส้นทางขนส่งที่เหมาะสมจากสถานีขนส่งขยะไปยังแหล่งกำจัดขยะแต่ละคู่ถูกกำหนดโดยการวิเคราะห์โครงข่าย ผลกระทบทางสิ่งแวดของแหล่งกำจัดขยะได้รับการประเมินโดยใช้วิธีการรวมเกณฑ์แบบถ่วงน้ำหนักซึ่งครอบคลุมเกณฑ์ของกรมควบคุมมลพิษ คุณลักษณะด้านสิ่งแวดล้อมเฉพาะทาง และวิธีการกำจัดของแหล่งกำจัดขยะ ทั้งหมดนี้จะถูกใช้เป็นข้อมูลนำเข้าในกระบวนการของการโปรแกรมเชิงเส้นเพื่อการจัดแบ่งปริมาณขยะมูลฝอยชุมชนจากสถานีขนส่งขยะไปยังแหล่งกำจัดขยะเพื่อให้บรรลุฟังก์ชันวัตถุประสงค์ของกระบวนการซึ่งครอบคลุมการทำให้ค่าขนส่งโดยรวม ผลกระทบทางสิ่งแวดล้อม และทั้งสองอย่างมีค่าน้อยที่สุดโดยเป็นไปตามข้อบังคับของกระบวนการที่มีการลำเลียงขยะจากสถานีขนส่งได้หมดสิ้นและแปรผันตามความจุรายวันเพื่อให้แหล่งกำจัดขยะมีอายุการใช้งาน 3 ปี และ 5 ปี

การตรวจสอบเส้นทางขนส่งและการจัดแบ่งปริมาณขยะที่เหมาะสมของแต่ละฟังก์ชันวัตถุประสงค์มีผลลัพธ์ในทางบวก การจัดแบ่งปริมาณขยะที่เหมาะสมที่ได้รับส่งผลให้ค่าขนส่งและผลกระทบทางสิ่งแวดล้อมโดยรวมมีค่าน้อยที่สุดหรือเหมาะสมตามเงื่อนไขของฟังก์ชันวัตถุประสงค์ทั้ง 3 แบบ

ค่าขนส่งและผลกระทบทางสิ่งแวดล้อมโดยรวมตามเงื่อนไขของฟังก์ชันวัตถุประสงค์ทั้ง 3 แบบภายใต้อายุการใช้บริการของแหล่งกำจัดขยะแบบเดียวกัน ได้รับการเปรียบเทียบโดยใช้สัดส่วนระหว่างความแตกต่างของค่าสูงสุดและต่ำสุดกับค่าสูงสุด การกำหนดให้อายุการใช้บริการของแหล่งกำจัดขยะแบบ 3 ปี ให้ผลลัพธ์ดีกว่าแบบ 5 ปี ค่าความแตกต่างของค่าขนส่งและผลกระทบทางสิ่งแวดล้อมโดยรวมในแบบ 3 ปี มีค่าร้อยละ 23.26 และร้อยละ 11.88 ในขณะที่ของ

5 ปี มีค่าร้อยละ 11.55 และร้อยละ 4.94 ตามลำดับ ค่าสัดส่วนแสดงความแตกต่างที่สูงกว่าแสดงว่าผลที่ได้รับเป็นไปตามเป้าหมายของฟังก์ชันวัตถุประสงค์มากกว่า

สาขาวิชาการรับรู้จากระยะไกล	ลายมือชื่อนักศึกษา_______
ปีการศึกษา 2559	ลายมือชื่ออาจารย์ที่ปรึกษา_______
	ลายมือชื่ออาจารย์ที่ปรึกษาร่วม_______

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WASTE TRANSPORTATION MANAGEMENT/ ENVIRONMENTAL IMPACT OF DISPOSAL SITE/ NETWORK ANALYSIS/ LINEAR PROGRAMMING

Municipal solid waste (MSW) management system of the study deals with selecting optimum paths from transfer stations (TS) to available disposal sites (DS) and efficient allotment to minimize total transportation cost (TC) and environmental impact (EI) including prolonging service life of sites. The main objective of the study is waste transportation management of local administrative units of Phitsanulok province of Thailand. Required temporary TS of local administrative units were obtained by GIS mean centering analysis weighting by population. Optimum paths of TS-DS pairs were determined by Network Analysis (NA). Simple Additive Weighting (SAW) was used to evaluate EI of exiting DSs, covering criteria of Pollution Control Department (PCD), specific environmental characteristics and disposal methods of DSs. They are input data of Linear Programming (LP) to allot MSW from TSs to DSs to serve objective functions of minimizing TC, EI, and both. Constraints of the LP were waste amount of TS and 3-year and 5-year daily capacities of DSs.

Optimum paths and waste allotments of different objective functions of the analyses show positive validation. Waste allotment resulting from LP proved to have minimized total TC and EI based on corresponding objective functions.

Total TC and EI resulting from 3 objective functions were compared using percentage of the ratio between the maximum-minimum difference and the maximum value of TC and EI of the same site service life. The 3-year service life of active DSs provides better results compared to 5-year service life. The difference of total TC and EI are 23.26% and 11.88% of 3-year service life, while 11.55% and 4.94% of 5-year service life, respectively. The more difference indicates the better valid results.

School of Remote Sensing

Academic Year 2016

Student's Signature A. Phinyoyang.

Advisor's Signature ______

Co-advisor's Signature ______

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LIST OF ABBREVIATIONS

CM	=	City Municipality
DEQP	=	Department of Environmental Quality Promotion
DGR	=	Department of Groundwater Resources
DMR	=	Department of Mineral Resources
DS	=	Disposal site
DWR	=	Department of Water Resources
EOR 3	=	Environmental Office Region 3
EA	=	Environmental Assessment
EI	=	Environmental Impact
EIA	=	Environmental Impact Assessment
GIS	=	Geographic Information System
kg	=	Kilogram
km	=	Kilometer
LDD	=	Land Development Department
LP	=	Linear Programming
m	=	Meter
MADA	=	Multi-attribute Decision Analysis
MCDA	=	Multi-criteria Decision Analysis
MODA	=	Multi-objective Decision Analysis
MSW	=	Municipal Solid Waste

LIST OF ABBREVIATIONS (Continued)

MSWMS	=	Municipal Solid Waste Management System
NA	=	Network Analysis
ONEP	=	Office of Natural Resources and Environmental Policy and Planning
PCD	=	Pollution Control Department
RFD	=	Royal Forest Department
RHD	=	Royal Highway Department
RID	=	Royal Irrigation Department
STRM	=	Shuttle Radar Topography Mission
RTSD	=	Royal Thai Survey Department
SAO	=	Subdistrict Administrative Organization
SAW	=	Simple Additive Weighting
SM	=	Subdistrict Municipality
TC	=	Transportation Cost
TDS	=	Total Dissolved Solids
TM	=	Town Municipality
TMD	=	Thai Meteorological Department
TS	=	Transfer station
UNEP	=	United Nations Environment Programme
USEPA	=	United States Environment Protection Agency

CHAPTER I

INTRODUCTION

1.1 Background problems and significance of the study

Waste is a major problem in many countries around the world. Thailand, as a developing country, is also facing the problem of solid waste management, due to the fast population growth. The fast growth of urban population is the main cause of tremendous increase in solid waste (Dadras, Ahmad, and Farjad, 2010; Chinda, Leewattana, and Leeamnuayjaroen, 2012). They have been produced daily and enormously, however they cannot be disposed timely. Therefore, the proper waste transportation management is considered very important, particularly when dealing with transportation cost and environmental impact at both sites, transfer station and disposal site.

The process of solid waste management 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). One of the main goals of the municipal solid waste management system is to determine the type, location, and capacity of facilities that will be used for disposal and/or treatment of the waste, based on environmental, economic, social, and health considerations. Suitable locations of transfer station and disposal facilities are a major issue in waste management. Most studies have focused on location of the landfill alone, with limited attention given to site selection for transfer stations (Kontos, Komilis, and Halvadakis, 2005; Al-Jarrah and Abu-Qdais, 2006, quoted in Rafiee et al., 2011).

A transfer station is a facility located close to residential areas that is used to receive and hold waste temporarily until it is transported to remote landfills, processing centers, or composing facilities (USEPA, 2004). Waste transfer stations are an important component of an integrated waste management system, serving as the link between community solid waste collection and a remote disposal site. A transfer station's basic function is the transfer and consolidation of waste from multiple collection vehicles into larger, high-volume transfer vehicles for more economical transportation to a distant disposal site.

The transportation of solid waste is an important issue in waste management. It is related to a substantial amount of total expenditures spent on the collection and transport of solid waste by city authorities. Optimization of the routing system for collection and transport of solid waste thus constitutes an important component of an effective solid waste management system (Ghose, Dikshit, and Sharma, 2006).

The collection/transport component is the showcase for any solid waste management system whose implications are straightforward to evaluate the success of the system and its costs. The operation involves the removal and transfer of waste from production or assembly points to transfer station or from transfer station to processing or to final disposal site. It is therefore the most influential and most costly component as it absorbs the biggest fraction of the budget for solid waste management (Khan and Samadder, 2014; Arribas, Blazquez, and Lamas, 2009).

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, 2556). In fact, only 11 local administrations are having the full service function while the rests still have random household burning or too little amount of total solid waste to allow service functioning. 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 mainly focuses on the use of GIS technique for waste transportation management which involves in allocation and transport of solid waste from transfer station to disposal site. Transportation pattern through optimum route operated by Network Analysis (NA) can certainly provide the minimum cost. Unavoidably, transfer stations (TSs) and disposal sites (DSs) have their own characteristics related to environmental impact. This impact can be evaluated using multi-criteria evaluation as input are in form of attributes or called Multi-attribute Decision Analysis (MADA). The bigger amount of waste allocated to poor sites can create or stimulate more environmental impact. Minimization on objectives of transportation cost and environmental impact of sites can be effectively performed using Linear Programming of Multi-objective Decision Analysis (MODA) and results in optimum allocation management of waste amount from TSs to DSs.

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 minimizing of TC and EI. Three objectives of this study are set as follows:

1.2.1 To locate temporary waste transfer stations of local administrative units using GIS weighted mean centering;

1.2.2 To evaluate environmental impact of waste transfer stations and existing disposal sites using multi-attribute decision analysis (MADA); and

1.2.3 To manage waste transportation using network analysis (NA) and multi-objective decision analysis (MODA) on minimization of transportation cost and environmental impact under varying constraints.

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 to record and is disposed by random burning.

1.3.2 Due to self-managing waste collection of each SAO or municipality, many of them do not need TS because of low amount of waste generated. However, because of lacking of household positions and waste generation plus to allow waste transportation analysis possible, temporary or imaginary TS is required for every administrative unit. This TS site will be located based on its own waste generated from villages in the unit.

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

1.3.4 Transportation management as well as environmental impact will be considered merely among TSs to DSs. The impact along transportation route will not be included.

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 km away from the study area and listed by EOR 3.

1.3.7 GIS data on road of the study area is adopted from Royal Thai Survey Department (RTSD) and Royal Highway Department (RHD) which was digitized by Department of Environmental Quality Promotion (DEQP) (2003). The distance of links in road network will be applied as an impedance to NA.

1.3.8 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.

1.3.9 Actual daily transportation cost of each admin unit has never been officially recorded and has no actual data source to estimate. Therefore, there is no comparison to the study result.

1.3.10 Results from LP objective functions in terms of TC and EI are not in the same unit and so far there is no reference in converting EI index to be monetary value. Therefore, cross comparison between TC and EI cannot be perfectly performed.

1.4 Study area

1.4.1 Geographic location

The study area is located at some part of Meuang Phitsanulok district in Phitsanulok province, Thailand (Figure 1.1). It consists of 11 SAOs and municipalities which include Phaikhodon, Phlaichumphon, Watchan, Beungphra, Thathong, Aranyik, Thapho, Bankhlong, Phitsanulok, Huaro, and Bankrang. 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.

According to the record of EOR 3 (สำนักงานสิ่งแวดล้อมภาคที่ 3, 2556), there have been 22 DSs available in the province. There are only 11 DSs chosen for the study as shown in 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 are sanitary landfill while others are currently developed from open dump to be controlled dump which has more measures for environmental protection.

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 for analysis in this study. The road network and distribution of the selected DSs are displayed in Figure 1.2.

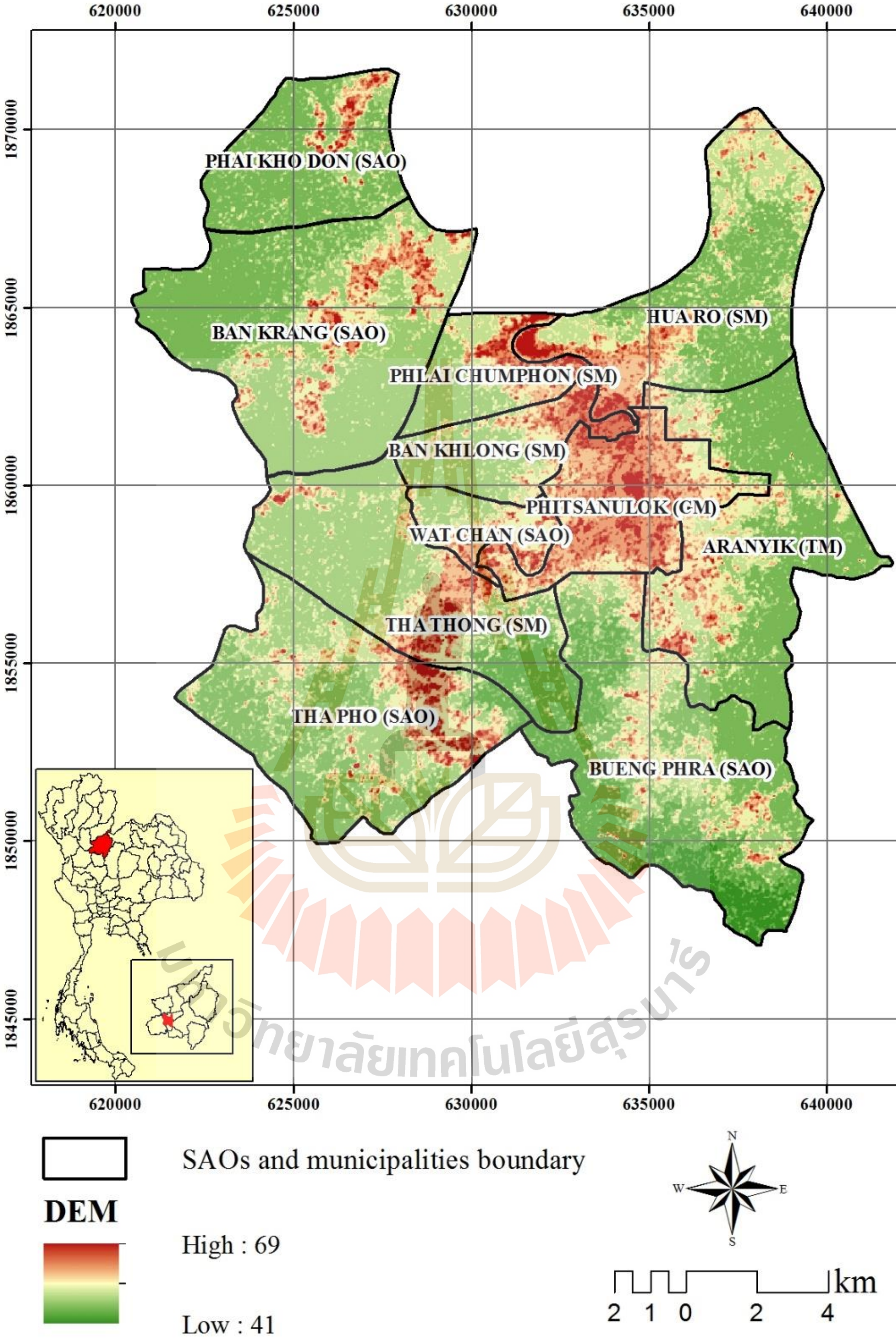


Figure 1.1 SAOs and municipalities of the study area.

Table 1.1 The existing DSs within 30 km of the study area.

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

1.4.2 Population and waste generation

According to the report of EOR 3 (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 shows the list of population, waste generation rate and amount, and type of organization within the study area.

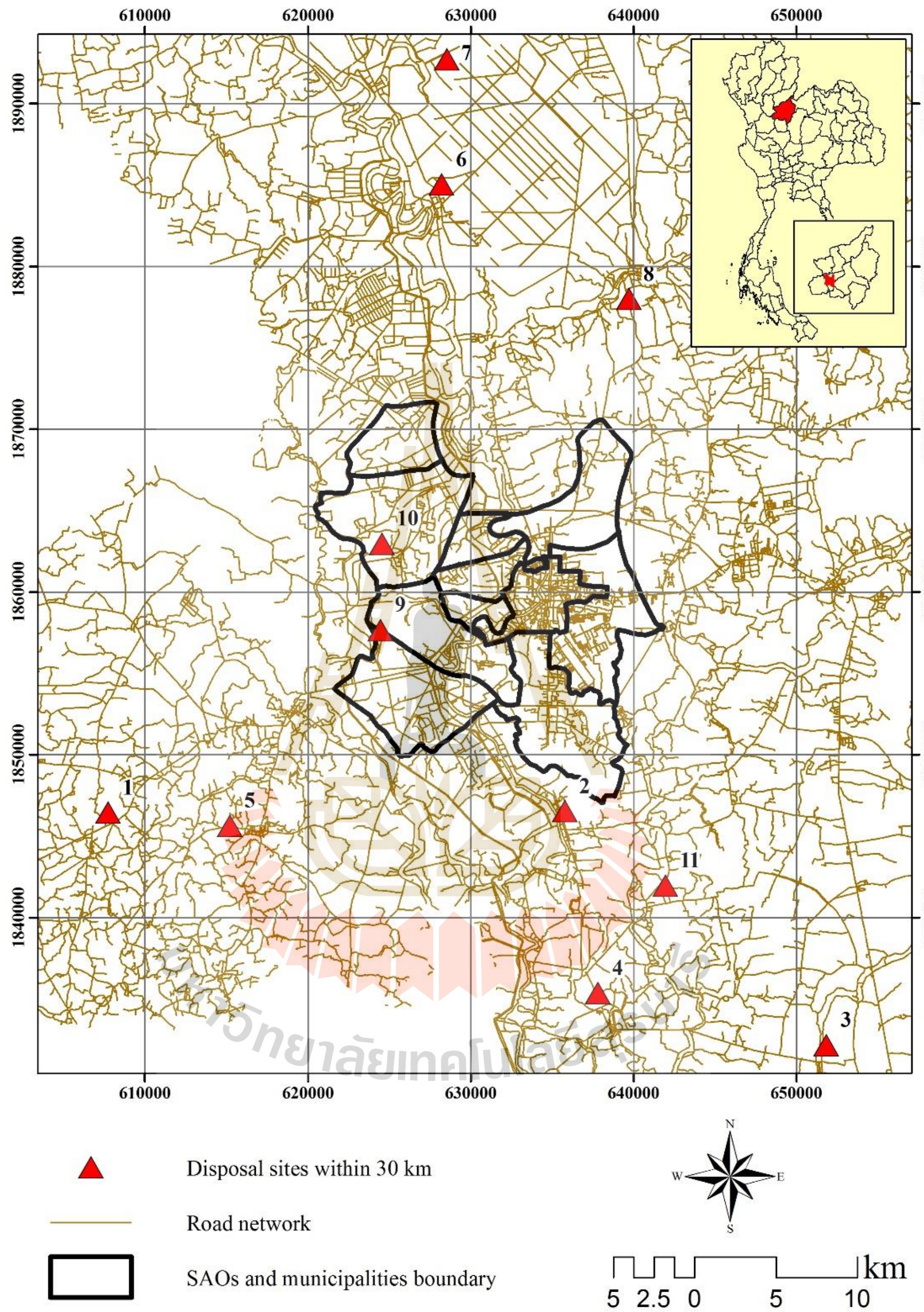


Figure 1.2 Road network and distribution of DSs within 30 km of the study area.

Table 1.2 Population, waste generation rate and amount, and type of organization within the study area.

Name of administrative organization	Administrative organization type	Population	Waste generation (Kg/person/day)	Waste amount (Tons)
Phitsanulok	CM	70,000	1.89	132.30
Aranyik	TM	29,825	1.15	34.33
Phlaichumphon	SM	7,109	1.02	7.25
Bankhlong	SM	13,194	1.02	13.46
Thathong	SM	13,136	1.02	13.40
Huaro	SM	22,898	1.02	23.36
Phaikhodon	SAO	4,096	0.91	3.73
Watchan	SAO	8,067	0.91	7.34
Thapho	SAO	23,773	0.91	21.63
Beungphra	SAO	17,555	0.91	15.98
Bankrang	SAO	12,152	0.91	11.06

Population source: Department of Provincial Administration, Ministry of Interior (December, 2015).

1.5 Benefits of the study

Useful outcomes serving study objectives can be achieved as in the following list:

1.5.1 Location of temporary TS of each SAO/municipality.

1.5.2 Optimum paths of pairs of TS and DS based on distance impedance.

1.5.3 Matrixes of EI indexes and TC of pairs of TS and DS.

1.5.4 Allotment of waste transportation based on minimization of TC and EI under varying constraints.

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 disposal, and waste transfer station, and methods for environmental impact evaluation, network analysis, and MODA for waste allotment management. Previous studies are also gathered and discussed.

2.1 Solid waste disposal

The most fundamental step in waste management is quantifying and qualifying the different types of waste being generated. It is important to have a system for the collection and analysis of basic information about wastes. Among the data needed are: the sources of wastes, the quantities of waste generated, their composition and characteristics, and future trends of generation. Such information forms the basis for the development of appropriate waste management strategies. In fact, data collection and management should be an on-going exercise for monitoring purposes and to enable future and long-term planning and decision-making (UNEP, 2004).

2.1.1 Types of solid waste

According to UNEP (2004) type of solid waste in South East Asia can be summarized to be 6 types, i.e. municipal solid waste, industrial solid waste, hazardous waste, municipal wastewater, industrial wastewater, and storm water. This study will focus to deal only with municipal solid waste.

Municipal solid waste

Municipal solid waste (MSW) is thus seen as primarily coming from households but also includes wastes from offices, hotels, shopping complexes/shops, schools, institutions, and from municipal services such as street cleaning and maintenance of recreational areas. The major types of MSW are food wastes, paper, plastic, rags, metal and glass, with some hazardous household wastes such as electric light bulbs, batteries, discarded medicines and automotive parts. Table 2.1 highlights the main sources of MSW, the waste generators, and types of solid waste generated (UNEP, 2004).

Table 2.1 Source and types of municipal solid waste (UNEP, 2004).

Sources	Typical waste generators	Types of solid waste
Residential	Single and multifamily dwellings	Food wastes, paper, cardboard, plastics, textiles, glass, metals, ashes, special wastes (bulky items, consumer electronics, batteries, oil, tires) and household hazardous wastes
Commercial	Stores, hotels, restaurants, markets, office buildings	Paper, cardboard, plastics, wood, food wastes, glass, metals, special wastes, hazardous wastes
Institutional	Schools, government center, hospitals, prisons	Paper, cardboard, plastics, wood, food wastes, glass, metals, special wastes, hazardous waste
Municipal services	Street cleaning, landscaping, parks, beaches, recreational areas	Street sweepings, landscape and tree trimmings, general wastes from parks, beaches, and other recreational areas

2.1.2 Solid waste disposal method

Solid waste disposal methods may be defined as the discipline associated with the control of generation, storage, collection, transfer and transport, processing and disposal of solid wastes. Integrated solid waste management includes the selection and application of suitable techniques, technologies and management programs to achieve specific waste management objectives and goals (Tchobanoglous and Kreith, 2002). According to Hoornweg and Bhada-Tata (2012) current solid waste disposal method can be summarized as source reduction, recycle and recovery, composing, incineration, landfill, and controlled dump.

All methods for solid waste disposal are described briefly as follows:

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) 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 greenhouse gas 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 greenhouse gas emissions, except for processing the materials for sale or reuse, which can be relatively high if improperly burned, e.g. metal recovery from e-waste (Hoornweg and Bhada-Tata, 2012).

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).

4) 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).

5) 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 (landfill gas), produced from the anaerobic decomposition of organic matter, can be recovered and the methane (about 50% of landfill gas) burned with or without energy recovery to reduce greenhouse gas emissions. Proper landfilling is often lacking, especially in developing countries. Landfilling usually progresses from open-dumping, controlled dumping, controlled landfilling, to sanitary landfilling. In conclusion, landfill is one of the most common solid waste management methods used in many countries (Kabite and Suryabhagavan 2012).

6) Controlled dump

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).

2.1.3 Solid waste disposal sites

Solid waste disposal site means land or water where deliberately discarded solid waste, as defined above, is discharged, deposited, injected, dumped, spilled, leaked, or placed so that such solid waste or a constituent thereof may enter the environment or be emitted into the air or discharged into water, including ground waters. Solid waste disposal sites include facilities for the incineration of solid waste and transfer stations. (National Archives and Record Administration, 2009).

2.2 Waste transfer station

2.2.1 Definition of transfer station

Waste transfer stations, according to United States Environmental Protection Agency (USEPA, 2016), are facilities where municipal solid waste is unloaded and held for a while and reloaded onto larger long-distance travelling trucks to landfills or other treatment or disposal facilities. Communities can save money on cost of labour and transporting since waste taken to distant disposal sites are brought together from several individual waste collection trucks into a single shipment. The total number of vehicular trips to and from the disposal site is also reduced. Although waste transfer stations help reduce the impacts of trucks travelling to and from the disposal site, they can cause an increase in traffic in the immediate area where they are located. The siting, designing and operation of a transfer station, if not properly done, can cause problems for residents living closer.

Bovea, Powell, Gallardo, and Capuz-Rizo (2007) also described that waste transfer stations are an integral part of present-day in municipal solid waste management systems. Suitably locating transfer station can reduce transport costs, since it is cheaper to haul great volumes of waste over long distances in large trucks than in smaller ones. By bulking up the waste at the transfer station, a larger truck can be used to transport them to the disposal site with more saving cost.

2.2.2 Type of transfer station

The USEPA’s decision maker's guide to solid waste management (USEPA, 1995) handbook, describes the feasibility of community’s transfer station as being dependent on the design variables such as capacity required and volume of waste storage needed, the types of wastes received, processes required for recovery of material from wastes before haulage, types of collection vehicles that use the facility, types of transfer vehicles that can be accommodated at the disposal facilities, and topography and access of the site. Waste transfer station types usually used are described under three categories, namely small capacity (less than 100 tons/day), medium capacity (100 to 500 tons/day), and large capacity (more than 500 tons/day).

1) Small to medium transfer stations

Small to medium transfer stations are direct-discharge stations that provide no intermediate waste storage area. These stations usually have drop-off areas for use by the general public to accompany the principal operating areas dedicated to municipal and private refuse collection trucks. Depending on weather, site aesthetics, and environmental concerns, transfer operations of this size may be located either indoors or outdoors.

More complex small transfer stations are usually attended during hours of operation and may include some simple waste and materials processing facilities. For example, the station might include a recyclable materials separation and processing center. Usually, direct-discharge stations have two operating floors. On the lower level, a compactor or open-top container is located. Station users dump wastes into hoppers connected to these containers from the top level.

Smaller transfer stations used in rural areas often have a simple design and are often left unattended. These stations, used with the drop-off collection method, consist of a series of open-top containers that are filled by station users. These containers are then emptied into a larger vehicle at the station or hauled to the disposal site and emptied. The required overall station capacity (i.e., number and size of containers) depends on the size and population density of the area served and the frequency of collection. For ease of loading, a simple retaining wall will allow containers to be at a lower level so that the tops of the containers are at or slightly above ground level in the loading area (USEPA, 1995).

2) Larger transfer stations

Larger transfer stations are mostly designed for heavy commercial use by private and municipal collection trucks. The public, in some instances, has access to sections of the station (USEPA, 1995). According to the United Nations Environment Programme (UNEP, 2013, quoted in Christian, 2014), large-scale transfer station design in industrialized countries generally includes a floor for tipping the waste, after which bulldozers are used to push the waste into transfer trucks or a compacting chamber for packing the waste into trucks or compacting the waste into a high-density bale that is mostly wrapped in wire mesh. Recyclables and special wastes are increasingly being sorted and processed at transfer stations. It further describes three common types of transfer station that represent sound practice and they are open tipping floor, open pit design and Direct dumping transfer stations.

It is recommended that, larger-scale transfer stations, be located at farther distance from places designated for residential use due to noise, odours, leachate from waste, and vehicular traffic; but closer to the generation points that collection trucks can quickly do a return journey to and from the area; at locations that are planned and zoned for industrial or commercial use; where there is ease in accessing a major road; on the location of landfill which has served its lifetime, since the road network land use existing around the landfill are deemed suitable for siting transfer stations; and where road restrictions (weight, noise, speed, surface, axle weight, truck length) do not vary with the usage terms related to transfer (UNEP, 2013).

More than one transfer station may be needed to service large or heavily populated areas, especially in regions where the population centers are separated by relatively sparsely populated areas. To know the appropriate number of transfer stations for an area, will depend primarily on the number and size of service areas covered by the Municipal Solid Waste Management System (MSWMS), the distance between the areas, the volume of MSW generated, the distance to disposal site, the types of vehicles used in primary collection, and the size and type of transfer stations selected (UNEP, 2013).

2.3 Waste transfer station selection

The selection of a site for any waste-related facility can be a sensitive issue, particularly for those living nearby. In principle, most people realize that such facilities are needed and will be needed in the future. In some cases, however, concern arises about a specific location for a waste transfer station and whether the facility will be properly managed (USEPA, 2002). General site selection for most facility establishment will consider factors such as accessibility, image/visual quality, visibility, demographic patterns, site capacity, neighborhood compatibility, legal matters, utilities availability, physiography (Anon, 2013).

For Thailand, there is no criteria for transfer station selection issued by any government agency. If necessary, criteria used to select suitable landfill site of the Pollution Control Department (กรมควบคุมมลพิษ, 2552) should presumably be fit for transfer station selection.

2.3.1 GIS weighted mean centering

To maximize waste collection efficiency, transfer stations should be located centrally to waste collection routes and service area (administrative unit in this study case). As a rule of thumb in urban and suburban areas, transfer stations should be no more than 10 miles away from the end of all collection routes. Beyond that distance, collection routes might need to be altered to enable refuse to be collected and deposited at the transfer station within one operating shift (USEPA, 2002).

1) Mean center

ESRI (2014) describes in detail the mean center is the average x and y coordinate of all the features in the study area. It is sometimes called a center of gravity in that it represents the point in a distribution where all other points are balanced if they existed on a plane and the mean center was a fulcrum.

The mean center can be explained as a point where both the sum of all differences between the mean X coordinate and all other X coordinates is zero and the sum of all differences between the mean Y coordinate and all other Y coordinates is zero (Levine, 2008).

The formula for the mean center is:

$$\bar{X} = \sum_{i=1}^{N} \frac{X_i}{N} \tag{1}$$

$$\bar{Y} = \sum_{i=1}^{N} \frac{Y_i}{N} \tag{2}$$

where X_i and Y_i are the coordinates of individual locations and N is the total number of points.

2) Weighted mean center

A weighted mean center is produced by weighting each coordinate by another variable, W_i. For example, if the coordinates are villages that produce solid waste, then the weight could be waste amount of the villages. The weights have to be a positive number greater than or equal to 1. The numerator is the sum of the product of the variable and the weight while the denominator is the sum of weights.

$$\bar{X} = \frac{\sum_{i=1}^{N} W_i X_i}{\sum_{i=1}^{N} W_i} \tag{3}$$

$$\bar{Y} = \frac{\sum_{i=1}^{N} W_i Y_i}{\sum_{i=1}^{N} W_i} \tag{4}$$

where W_i is the weight of observation and X_i and Y_i are as defined in Equations (3) and (4).

2.4 General concept of environmental impact evaluation of TSs and DSs

Environmental impact (EI) means the possible adverse effects caused by a development, industrial, or infrastructural project or by the release of a substance in the environment (Business Dictionary, 2016).

Solid waste disposal method and management causes all types of pollution: air in form of odour, soil toxification, and leachate to surface and groundwater (Singh, 2013; Senior, 1990). The most obvious environmental effect of inadequate solid waste management is the aesthetic deterioration of both urban and rural landscapes. The degradation of the natural landscape caused by uncontrolled waste disposal is increasing. Open dumps and piles of garbage have become an increasingly common sight (Jaramillo, 2003). As the aim of solid waste management, a part from removing waste from urban areas, is to reduce or avoid the impacts of solid waste management on the natural environment and human habitat, the environmental impacts of an entire solid waste management system must be considered when evaluating an existing system and its alternatives (Kirkeby, Birgisdottir, Bhander, Hauschild, and Christensen, 2007).

Environmental impact assessment (EIA) or simply environmental assessment (EA) is an important technique for ensuring that the likely impacts on the environment of proposed development are fully understood and taken into account before such development is allowed to go ahead or not.

In general, land use, geology, groundwater, surface water, ecology, visibility, traffic and topography are important in environmental siting criteria. This criteria gives guidance to the user on how to reduce environmental impacts during the development of transfer station (USEPA, 2002).

In 2009, the PCD issued the government gazette on criteria for selecting landfill site. The criteria include the site should not be in wetland, landslide and flood prone area, not close to airport, and archeological sites. They also should not be located in areas of conservation, community, water consumption source, and water body, or closer than a certain distance announced by departments of government. Sound foundation is required, including not interfered by active fault and sink hole, and having low permeability.

These criteria attributes should be able to score so that quantitative environmental impact of stations and sites can be assessed, for example when dealing with groundwater depth and quality, the suitability and score can be assigned as shown in Table 2.2 and Table 2.3. The higher score assigned can indicate the higher suitability. For example, the high, moderate, and low suitability can be scored to be 3, 2, and 1, respectively.

Table 2.2 Groundwater depth and landfill suitability (Bolton and Stewart, 2002).

Depth to Groundwater	**Suitability**
Over 60 meters (200 ft)	High
15 to 60 meters	Moderate
Under 15 meters (50 ft)	Low

Table 2.3 Groundwater quality and landfill suitability (Bagchi, 1994).

Groundwater Quality (TDS in mg/l)	**Suitability**
Over 10,000	High
1,000 to 10,000	Moderate
Under 1,000	Low

The total scores of suitability of stations and sites can be operated using weighted linear combination analysis as expressed in Equation (5). Weight and score of each criterion can be obtained from available scientific and practical specifications including expert opinion through questionnaire.

$$A_i = \sum_j w_i x_{ij} \tag{5}$$

where A_i is overall score of the ith alternative, x_{ij} is score of the ith alternative with respect to the jth attribute, and w_i is normalized weight (Malczewski, 1999).

The inversion of suitability scores indicates the probable intensity of environmental impact of stations and sites. This character is an intrinsic property of the location on land. The impact of the location can be increased and more affected according to its service activity. The impact will be increased with increasing amount of solid waste involving as a service of the location.

2.5 Network analysis

A network is a line coverage, which is topology-based and has the appropriate attributes for the flow of objects such as traffic (Chang, 2002). The network model is essentially adaptation of the vector data model composed of line segments and node elements with addition attributes using for specific analysis, e.g. impedance which can be time, distance, fuel used, traffic volume, etc. (Heywood, Cornelius, and Carver, 2002).

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, 2006).

NA is a special type of line analysis involving a set of interconnected lines. NA can be used to answer types of questions, namely address geocoding, optimum routing, finding closest facilities, traveling salesman problem service area, and location-allocation (Verbyla, 2002; Chang, 2014).

In this study, the NA deals only with closest facility function of ArcGIS 10.x using the shortest path analysis through Dijkstra's algorithm.

2.5.1 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 (Chang, 2014). Shortest path analysis typically deals with an impedance matrix in which a value represent the impedance of a direct link between two nodes on a network. The problem is to find the shortest distance (least cost) from a node (facility) to all other nodes (incident) (Zhan and Noon, 1998; Zeng and Church, 2009). A tool using Dijkstra's algorithm will be utilized in the study.

2.5.2 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 and Minieka, 1992, quoted in Aunphoklang, 2012). Dijkstra's algorithm is a label-setting 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.

2.5.3 Closest facility analysis

Chang (2014) describes in detail that 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 selected location to all candidate facilities, and then chooses the closest facility among the candidates.

Closest facility function allows to involve all or selected incidents and facilities and results in a matrix of cumulative impedance between each incident to each facility. Additionally, the direction of shortest path connecting each incident to each facility is also the result.

2.6 MODA for waste allotment management

The generic classification of Multi-criteria Decision Analysis (MCDA) is organized into two sections dealing with multi-attribute and multi-objective spatial decision problem. The aim of Multi-attribute Decision Analysis (MADA) is to rank the alternatives in descending order of preference. In MADA methods the attributes serve as both decision variables and decision criteria, where as in the Multi-objective Decision Analysis (MODA) approaches, decision criteria (objective functions) and decision variables are different. The MODA decision rules define and rank the set of alternatives using decision model operating on a set of objective functions and a set of constraints imposed on the decision variables (Malczewski, 1999).

The expected processes of objective decision analyses in this research is minimized optimization using LP. The objectives analysis should cover transportation cost and environmental impact caused by pattern of transportation management. Amount and allotment of solid waste transported to stations and sites will be managed to achieve optimum transportation cost and environmental impact.

2.6.1 Linear programming

Bazaraa, Jarvis, and Sherali (1990) explained the general concept of the LP, which is concerned with the optimization (minimization or maximization) of a linear function while satisfying a set of linear equality and/or inequality of constraints or restrictions. The concept explanation begins by formulating a particular type of a LP problem. 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:

$$z = \min(c_1x_1 + c_2x_2 + ... + c_nx_n); \tag{6}$$

subject to:

$$\left.\begin{aligned} a_{11}x_1 + a_{12}x_2 + ... + a_{1n}x_n &\geq b_1; \\ a_{21}x_1 + a_{22}x_2 + ... + a_{2n}x_n &\geq b_2; \\ &. \\ &. \\ &. \\ a_{m1}x_1 + a_{m2}x_2 + ... + a_{mn}x_n &\geq b_m; \end{aligned}\right\} \tag{7}$$

and:

$$x_1, x_2, ..., x_n \geq 0. \tag{8}$$

LP consists of the following three parts.

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

2.7 Previous studies

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.

Chen, Wang, and Lin (2008) developed a multi-objectives GIS with ESRI ArcView GIS 3.x interface to finding an optimal route between Institute of Nuclear Energy Research and the harbors with multiple objectives using road network. The three model objectives were minimizing travel time, minimizing transportation risk, and minimizing the exposed population. This research Dijkstra's algorithm was applied to resolve the shortest route problem in the multi-objectives linear model using Avenue of ArcView 3.x. The result of optimal route with minimal travel time is 106.44 min by mainly using the freeway and the expressway for transportation rather than local roads. Optimal route with minimal transportation risk could have 720 vehicles per hour and taking multiple turns so as to be evacuated from the congested traffic area as soon as possible. The optimal route with minimal exposed population is 12,819 residents which is very far away from the heavily populated area or the capital area.

Karadimas, Doukas, Kolokathi, and Defteraiou (2008) studied about routing optimization heuristics algorithms for urban solid waste transportation management. This research used GIS network analysis, Ant Colony System algorithm to identify an optimized route to collect 15 bulk items from different locations in Attica, Greece, one of the 30 waste collection districts within Athens, Greece. The criteria used in this research included: bulk item locations, road networks, traffic volume, and population density. Network Analyst parameter settings were configured to calculate shortest distance and nighttime collection. The limitation of NA included street directions (one-way), no U-turns except dead-ends. The current collection route was devised empirically and covered a distance of 5.7km. The newly optimized Network Analyst route covered 4.5 km, for a 20% drop in kilometers driven to collect the items.

Chalkias and Lasaridi (2009) developed GIS network analysis based on Dijkstra’s algorithm to finding the optimisation of the waste collection and transport system in municipality of Nikea, Athens, Greece. This paper two scenarios were compared with the current empirical collection scheme: S1-collection vehicle routing optimisation, and S2-reallocation of bins and routing optimisation. The results show that both scenarios provided savings compared to the current situation in terms of collection time (3.0% and 17.0% for S1 and S2 respectively) and travel distance (5.5% and 12.5% for S1 and S2 respectively). Time and distance reduction relate to similar CO_2 emissions and fuel consumption savings.

Tavares, Zsigraiova, Semiao, and Carvalho (2009) developed a model to optimize the routing of MSW collection vehicles using the fuel consumption as a core criterion and taking into account local road gradients. This paper the model was developed in the GIS environment using ESRI’s ArcGIS 9.1 software and its extensions (3D analyst and network analyst). The model was applied to two collection and transportation schemes to demonstrate its advantages over the use of both 2D models and the travelled distance as the cost function. The results of this study demonstrate the relevance of optimizing MSW collection vehicle routing for minimum fuel consumption, rather than shortest distance or time. The work also recommends the use of 3D modelling, rather than 2D, particularly where significant road gradients exist.

Galante, Aiello, Enea, and Panascia (2010) applied GIS and MODA to determine a set of values for the decision variables in order to minimize both costs and environmental impact. This research were used three models consist of goal programming, weighted sum, and fuzzy multi-objective linear programming. The model considers both initial investment and operative costs related to transportation and transfer stations. Two conflicting objectives are evaluated, the minimization of total cost and the minimization of environmental impact. The results obtained show how according to the choice of the decision maker variations in fuel use and total cost are about 45% and 32%, respectively. The attitude of the decision maker, hence, significantly influences the performance of the system on the basis of the objectives considered.

Bhambulkar and Khedikar (2011) studied about municipal solid waste (MSW) collection route for Laxmi Nagar, Maharashtra, India. This research applied GIS Network analysis based on distance and time criteria to determine the optimum route for waste collection and disposal. And compare the fuel costs between the proposed optimum route and the existing run routes for the vehicles used for disposal. The result show that optimum route was identified which found to be cost effective and less time consuming when compared with the existing run route. The route is to be obtain by Arc GIS is 5.1 km. and time are 8 Hr. 35 min. The cost for these operation are 965 rupees per day 28,950 rupees per month 352,225 rupees per year. The cost is save up to 14% per month.

Jovičić et al. (2011) applied GIS network analysis to calculate the shortest solid waste collection route for City of Kragujevac, Serbia, with the goal to reduce overall fuel costs, which has approximately 4,000 waste bins at 2,000 locations within 12 city collection districts. The research considered one day shift collection truck, with 88 pickup points containing 200 waste bins. This vehicle used a GPS tracking device, to identify the route traveled. The criteria used in this study consisted of: raster photo images of the Kragujevac city, street network data, waste bin locations, waste bin capacity, current collection routes driven, service time to collect bins, truck type, and capacity. The original collection route length was 30.9 km, while the new method produced a waste collection route of 22.2 km in length, for a 28.1% decrease in overall kilometers traveled. This created a potential savings of 2,710 km driven per year.

Malakahmad, Bakri, Mokhtar, and Khalil (2014) studied about solid waste collection routes optimization via GIS techniques in Ipoh city, Malaysia. This research applied GIS-ArcView application based on Network Analysis to minimize the current routes distance and time which will resulted in availability of existing equipment and labour to perform separate collection of recyclable waste in the city. Five routes were selected in different area of Ipoh city for pilot study and the present routes were optimized to reduce the length of the routes and consequently the time taken to complete the collection. The results indicate up to 22% length minimization in the routes and the collection duration was also reduced from 6934s to 4602s. This will reduce the reliance of city councils to disposal sites and increase disposal sites operational life.

Das and Bhattacharyya (2015) studied about optimization of municipal solid waste collection and transportation route. This paper developed heuristic solution to identify optimal waste collection and transportation routes for reduction of waste collection and transportation cost in the waste management system design. The heuristic solution included: optimal waste collection from source to collection center, from collection center to transfer station, form transfer station to processing plant, and from processing plant to landfill site. The result show that the proposed scheme is able to reduce more than 30% of the total waste collection path length.

Kallel, Serbaji, and Zairi (2016) studied about Using GIS-Based Tools f or the Optimization of Solid Waste Collection and Transport: Case Study of Sfax City, Tunisia. In this study, optimized scenarios were developed using ArcGIS Network Analyst tool in order to improve the efficiency of waste collection and transportation in the district Cite El Habib of Sfax city, Tunisia. GIS was created based on data collection and GPS tracking (collection route/bins position). The actual state (Scenario S0) was evaluated, and by modifying its particular parameters, other scenarios were generated and analyzed to identify optimal routes: S1, route optimized with the same working resources (change of stops sequencing only); S2, route optimized with change of vehicles; and S3, route optimized with change of collection method (vehicles and reallocation of bins). The results showed that the three scenarios guarantee savings compared to S0 in terms of collection time (14%, 57%, and 57% for S1, S2, and S3, resp.) and distance (13.5%, 13.5%, and 40.5% for S1, S2, and S3, resp.). Thus, a direct impact on fuel consumption can be expected with savings of 16%, 20%, and 48% for S1, S2, and S3, respectively, without mentioning the additional benefits related to carbon dioxide emissions, hours of work, vehicles wear/maintenance, and so forth.

CHAPTER III

RESEARCH PROCEDURES

The scope of this study mainly focuses on the use of GIS technique and MODA for waste transportation management. The steps involves locating TSs, evaluating environmental impact of TSs and DSs, finding optimum routes between TSs and DSs, and allocating waste amount to DSs, shown as the conceptual framework in Figure 3.1.

As mentioned above, this study contain 3 research objectives: the first is to locate optimized waste TSs using GIS weighted centering. The second is to evaluate environmental impact of waste TSs and existing DSs using MADA. The third is to manage waste transportation using NA and MODA on minimization of transportation cost and environmental impact. The research procedures in detail is described as follows:

3.1 Data collection and preparation

The input 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.

The sources of road network data layer are from DEQP and MOT. The consistency and continuity of data are examined to correspond with Google earth image and ArcGIS based map for correctness improvement. The topology of data are checked consequently.

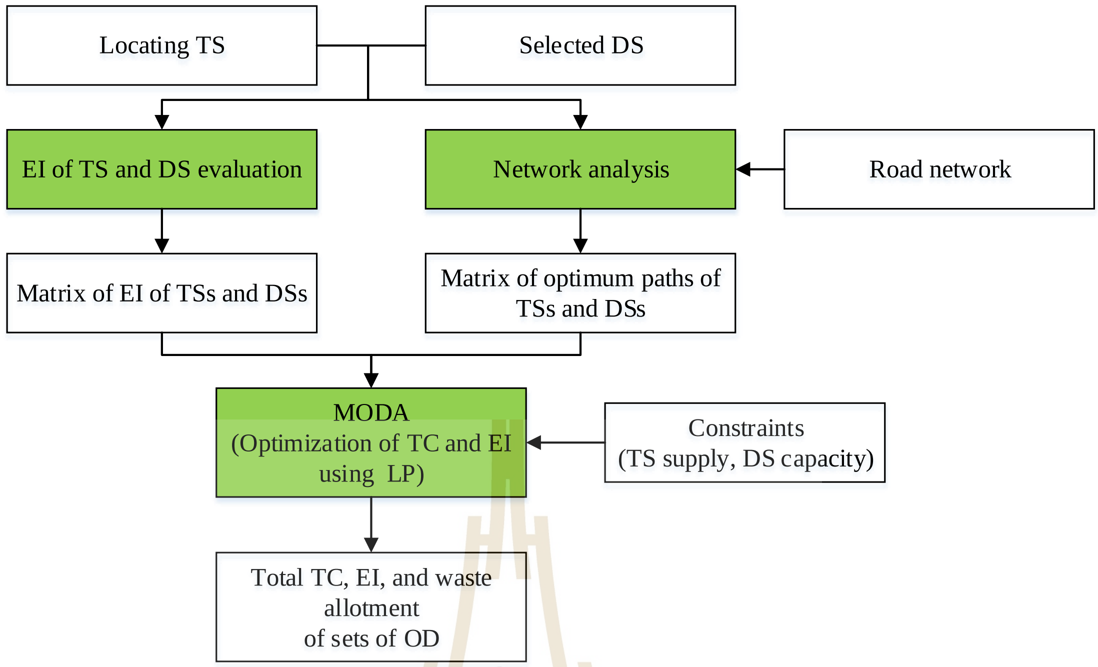


Figure 3.1 Conceptual research procedures framework of this study.

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 or touch interior", 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 or touch interior", line in one feature class (or subtype) must only touch other lines of the same feature class (or subtype) at endpoints. 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.

Table 3.1 Main required data and their sources.

No.	Data layers	Source	Year	Procedures
1	Road network	DEQP	2003	NA
2	Administrative unit boundary	RTSD	2007	Transfer station
3	Villages	RTSD	2007	Transfer station
4	DEM	STRM	2014	EI evaluation
5	Existing disposal site	EOR 3	2016	NA, EI evaluation
6	Land use / Land cover	LDD	2009	EI evaluation
7	Wetland	DWR	2010	EI evaluation
8	Flood plain	DMR	2001	EI evaluation
9	Airport location	Google earth	2016	EI evaluation
10	Archeological sites	ONEP	2010	EI evaluation
11	Watershed class	DWR	2011	EI evaluation
12	Conservation area	RFD	2009	EI evaluation
13	Natural conservation site and geopark	ONEP	2010	EI evaluation
14	Settlement/Community	LDD	2009	EI evaluation
15	Water consumption source	DWR	2011	EI evaluation
16	Water body	RID	2002	EI evaluation
17	Flow accumulation	From DEM	2014	EI evaluation
18	Water table	DGR	2009	EI evaluation
19	Prevailing wind	TMD	2016	EI evaluation
20	Drainage of surface sediments on landform	DMR	2001	EI evaluation
21	Sanitary landfill	EOR 3	2016	EI evaluation
22	Control dump	EOR 3	2016	EI evaluation

Waste amount is calculated and added to be attribute of village data layer. Population of each village existing in the study area is operated with waste generation rate per head to obtain waste amount. The rates varying on different types of administrative unit based on the report of EOR 3 (สำนักงานสิ่งแวดล้อมภาคที่ 3, 2556) is applied. Total waste amount of each administrative unit can be summarized (see Table 1.2).

Capacity of DS varies from site to site according to varying operating area in a site plan. The volume of the site for compacted waste can be estimated using Equation (9).

$$V = \frac{H}{3} * (A_1 + A_2) + (A_1 * A_{2)})^{0.5} \tag{9}$$

where V = Capacity of DS

H = Depth of pit

A_1 = Area of bottom portion

A_2 = Area of top portion

Area of top portion for site volume estimation is regarded as operating area which is 50% of a site plan area. Area of bottom portion is designed to be 90% of the top portion. The capacity of a site is total weight of compacted waste containing in a volume. The determined weight of compacted waste is 1.2 ton/m^3. Waste generated rates of local administrative units of sites locating outside waste generation area of the study are subtracted from site capacities before analysis of objective function.

3.2 Transfer station location

To locate temporary transfer station to maximize waste collection efficiency within every administrative unit, the weight centering process (see 2.3.1) is used. The center point of waste generation was determined for each of 11 SAOs and municipalities by applying village locations and their waste amounts within its own unit as the weights of the process.

The process of transfer station location in this study can be displayed as shown in Figure 3.2.

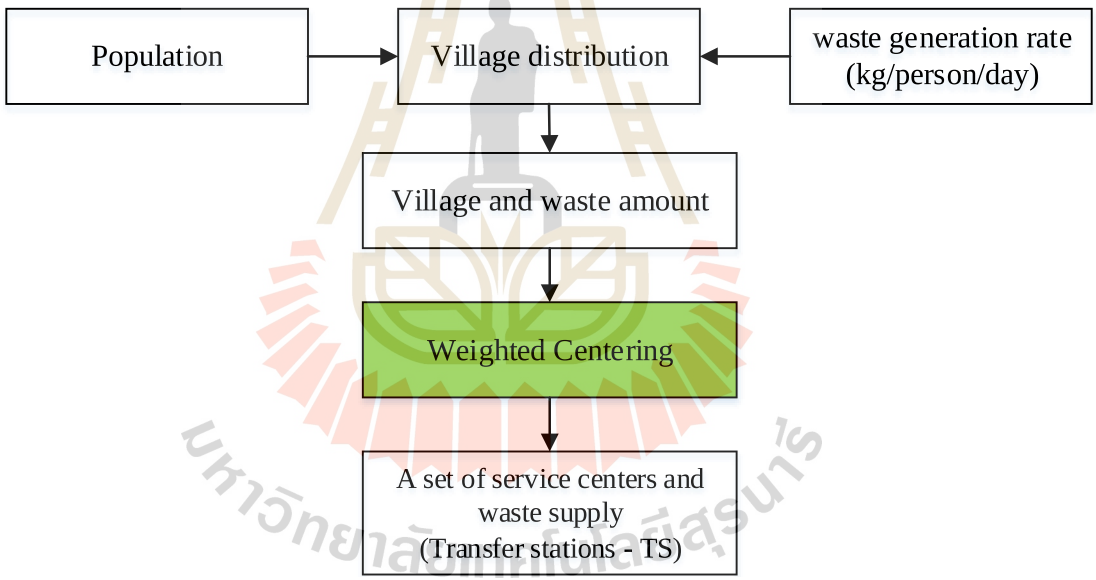


Figure 3.2 The process of transfer station location.

3.3 Environmental impact evaluation of TSs and DSs

Environmental impact of both TSs and DSs will be evaluated to be used as an input of one objective in the MODA later. As already mentioned in the scope and limitation of the study, the TS location will be temporary for transportation analysis.

Therefore, environmental impact of all TSs of all administrative units will be the same. Only waste amount generated in the units will make their impact different.

For the environmental impact evaluation of DSs, criteria considered will separated into 3 groups namely, PCD criteria, specific environmental characteristic, and disposal methods. The details of these groups and their condition for scoring are listed in Table 3.2.

Table 3.2 Criteria for environmental impact evaluation of DSs.

Criteria	Condition for scoring
PCD criteria	
- Wetland	The site should not be in wetland area.
- Landslide	The site should not be in landslide area.
- Flood plain	The site should not be in flood plain area (30 years).
- Airport	The site should not close to airport less than 5,000 m.
- Archeological sites	The site should not close to archeological sites less than 1,000 m.
- Watershed	The site should not close to watershed (class 1,2) less than 1,000 m.
- Conservation area	The site should not close to conservation area less than 1,000 m.
- Natural conservation site and geopark	The site should not close to natural conservation site and geopark less than 1,000 m.
- Settlement/Community	The site should not close to settlement/community less than 1,000 m.
- Water consumption source	The site should not close to water consumption source less than 700 m.
- Water body	The site should not close to water body less than 100 m.
- Active fault	The site should not close to active fault less than 100 m.

Table 3.2 Criteria for environmental impact evaluation of DSs (Continued).

Criteria	Condition for scoring	
Specific environmental characteristic		
- Flow accumulation	Higher score for site with more number of cell accumulation (x_1). ($x_1 \geq 20$ score = 1, $0 < x_1 < 20$ score = $(1/20)x_1$).	
- Water table	Higher score for shallower water table (x_2). ($x_2 \leq 3$ score = 1, $3 < x_2 \leq 20$ score = $1-((1/17)(x_2-3))$, $x_2 > 20$ score = 0).	
- Prevailing wind	Higher score for more impact of wind on villages and population (x_3). (x_3/maximum population)	
- Drainage of surface sediments on landform	Higher score for more drainage ability of surface sediments. (alluvial fan score = 0.7, terrace score = 0.5, and low lying plain score = 0.2)	
Disposal methods	**Sanitary landfill**	**Controlled dump**
- Contamination (leachate) to soil and surface water	Very low	Medium/Low (discriminated by slope and areal extent)
- Unpleasant odors	Low	Medium
- Methane GAS (CH_4)	Very low	Medium
- Site protected channeling runoff (inverse)	Low	High

PCD criteria (กรมควบคุมมลพิษ, 2552) are the government regulation which are considered important. Binary scoring should be fit for them. Dealing with this kind of environmental impact, it will require more conservative measures. The scoring to represent the group should be the average value based on a number of active criteria.

The specific environmental characteristics of sites provide obviously impact as a point source to air, surface water, and groundwater. Flow accumulation positively indicate impact on surface water. Flow accumulation equal or more than 20 cells (30 m

* 30 m for a cell) will be score as 1. The score will reduce proportionally to a number of accumulated cells. This is estimated from the statistical record of average maximum rainfall per hour of the study area and 50% infiltrating of the ground, on the limit of approximately 10 cm runoff on a cell at the site. From base of DS, water table shallower than or equal to 3 m will be scored as 1 while deeper than that will be proportionally reduced to 0 at depth of 30 m. For prevailing wind criteria, the scoring will be based on population of villages falling into the affected area bounded by 2,000 m downstream distance and 30^{o} of air dispersion angle of a site. The score of a site based on this criteria will be normalized using maximum total population of villages falling into the affected area. The affected area with maximum total population will be scored to be 1. Drainage of surface sediments at a site can be scored based on landform which are classified to be alluvial fan, terrace, and low lying plain as 0.7, 0.5, and 0.2, respectively. Disposal method of sanitary landfill with lower score is environmentally safer than control dump. Among sites with control dump method can be scored discriminately according to their slope and areal extent.

All scores of groups of criteria will be normalized and aggregated to indicate environmental impact of intrinsic and man-made properties of sites. Weighted linear combination (Equation (5)) is used for this aggregation. This impact will be enhanced by waste amount generated of administrative units. This will result as the matrix of EI of each pair of TS and DS which will be further used as input of one objective of MODA. Preferences of all groups of criteria are considered equal so that this objective can be synchronously operated with the objective of transportation cost.

The process of environmental impact evaluation of TSs and DSs in this study can be displayed in form of the flowchart as shown in Figure 3.3.

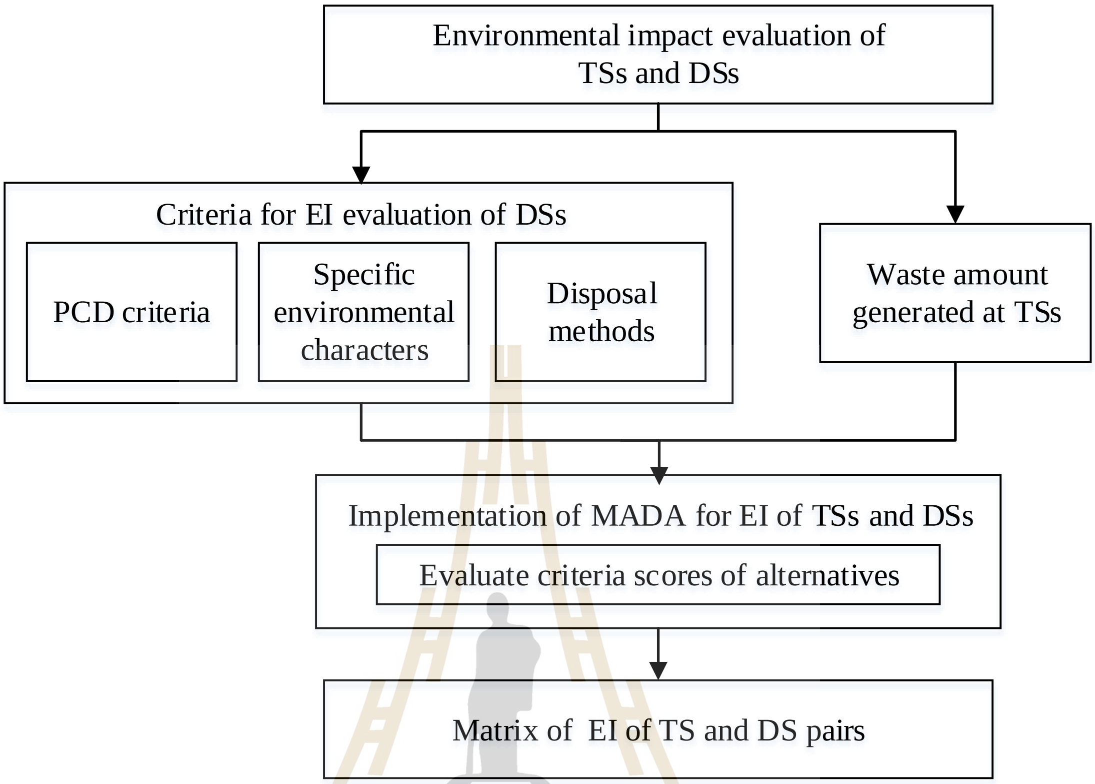


Figure 3.3 The process of environmental impact evaluation of TSs and DSs.

3.4 Optimum routes using network analysis

Closet facility function of the network analysis is performed to obtain optimum path and distance of each TS to each DS. Input data of the analysis are locations of 11 TSs and 11 DSs including edited road network covering this sites. The impedance of link between nodes of the network is considered only distance. Barrier link, if any, can be marked in the process as ignored path. Every resulting route is overlaid on Google earth image so that correctness of the route on specified road condition can be checked. This process will result in matrix of distance between TSs and DSs which will be used as an input of minimized TC objective analysis.

3.5 MODA for waste transportation management

Linear programming will be used for MODA. Objectives of the analysis will be minimization of TC and EI between TSs and DSs under certain constraints. These constraints include capacity of each DS, supply amount of each TS, and a number of active DSs which can be varied. Objective analysis can be operated either one objective or multi-objective at a time. Result of each analysis will be matrix showing 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 constraint.

The first objective (minimized TC) and the second objective (minimized EI) deal with common waste supply at TS. Therefore distance of the first and EI of the second should be normalized to between 0-1 before multiplying with waste supply. This makes them to be comparable unit while performing linear programming. Transportation cost (TC) is considered as a constant value used to multiply allotted product of waste amount and normalized distance to obtain total transportation cost.

3.5.1 Single objective function: Minimization of TC

This objective analysis is estimation for waste transportation allotment as to minimize the total transportation cost from TSs to DSs. The cost is the product of waste amount and distance of optimum path from a given pair of TS and DS. The linear programming model working as the transportation optimization function can be expressed as the following equations:

Minimize TC:

$$\min\left(\sum_{ts=1}^{n}\sum_{ds=1}^{m} WTC_{ts/ds} * D_{ts/ds} * Q_{ts/ds}\right) \tag{10}$$

Subject to constraints:

$$\sum_{ts=1}^{n} Q_{ts/ds} = S_{ts} \qquad \text{for} \forall_{ts}; \tag{11}$$

$$\sum_{ds=1}^{m} Q_{ts/ds} \leq C_{ds} \qquad \text{for} \forall_{ds}; \tag{12}$$

$$\sum_{ds=1}^{m} ds = N_{ds} \qquad \text{for} \forall_{ds}; \tag{13}$$

$$Q_{ts/ds} \geq 0 \qquad \text{for} \forall_{ts/ds}; \tag{14}$$

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.

3.5.2 Single objective function: Minimization of EI

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

Minimize EI:

$$\min\left(\sum_{ts=1}^{n}\sum_{ds=1}^{m} EI_{ts/ds} * Q_{ts/ds}\right) \quad (15)$$

where EI is total environmental impact of TSs and DSs,

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

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

3.5.3 Multi objective function: Minimization of TC and EI

This objective analysis is estimation for waste transportation allotment as to minimize both TC and EI. 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:

Minimize TC and EI:

$$\min\left(\sum_{ts=1}^{n}\sum_{ds=1}^{m} WTC_{ts/ds} * D_{ts/ds} * Q_{ts/ds} + \sum_{ts=1}^{n}\sum_{ds=1}^{m} EI_{ts/ds} * Q_{ts/ds}\right) \quad (16)$$

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

3.6 Result validation

Validation of the study results will be concerned with NA for optimum path identification between pairs of TSs and DSs and LP for waste allocation to serve minimized objectives of TC and EI.

3.6.1 NA validation

Based on a number of TSs, 11 pairs of TSs and DSs are randomly selected and assigned new paths between pairs of them. Assignment of new paths is to try to obtain the shortest distance but will not duplicate paths achieved by the NA. The NA results will be valid if assigned distance of any pairs could never been shorter than corresponding ones achieved from NA.

3.6.2 LP validation

To validate results of waste allocation by LP, methods will be designed referring to minimized TC and EI with respect to distance and EI between pairs of TSs and DSs, respectively. For allotment serving minimized TC, active pairs of TSs and DSs will be 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 will be arranged by ordering distance from the shortest to the longer in (a) a list of a TS to all DSs (11 pairs) and (b) a list of all pairs of all TSs and DSs (121 pairs). A number of active pair selection will be performed under the constraint of DS daily capacity. If a DS is selected to serve a given TS and its daily capacity is not enough for a daily waste from the TS, the next DS in the order will be selected until all amount of daily waste from the TS is disposed.

For a list of all pairs of all TSs and DSs, TSs can be alternately selected to perform according to the order of optimum paths of all pairs.

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

The total TC and EI from waste allocations using validation methods described above should not be lower than result from the LP.

CHAPTER IV

RESULT AND DISCUSSION

This Chapter presents the report and discussion of results from waste transportation management based on transportation cost and environmental impact of sites. Results from (1) input data (2) transfer stations of administrative units (3) environmental impact of TSs and DSs (4) optimum routes of TSs and DSs (5) waste transportation management using MODA (6) comparison of the results and (7) validated results 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 Road network data

The road network data layer of MOT and DEQP in the study area were edited, updated, and topology checked to be ready for NA. The result of the layer is shown in Figure 4.1.

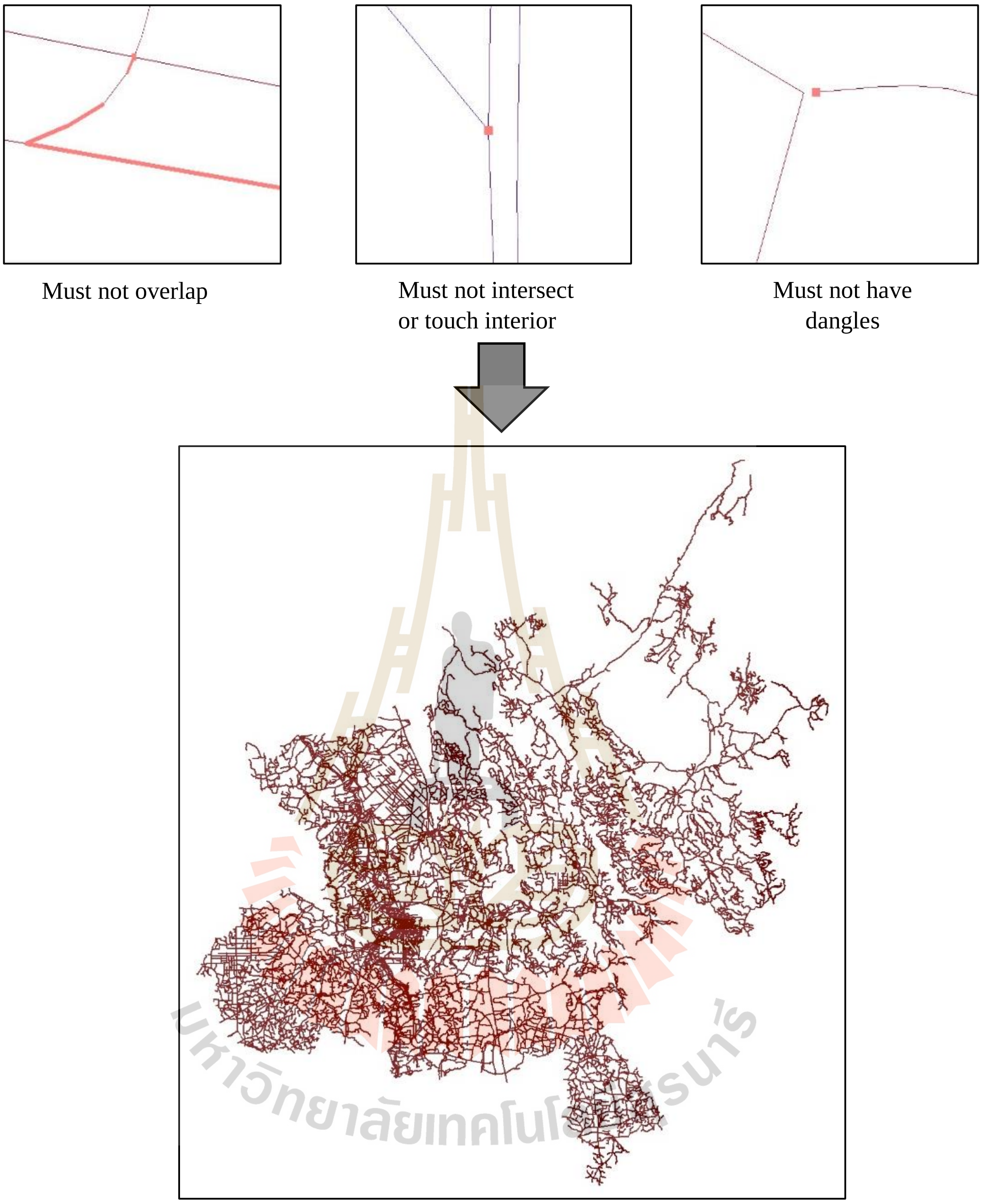


Figure 4.1 The topological checked of road network data layer.

4.1.2 Flow accumulation

The flow accumulation of the study area was obtained from ArcGIS Hydrology function using SRTM DEM as input data. Average flow accumulation of cells falling into area of each DS site was estimated and scored as result displayed in Table A1 of Appendix A.

4.1.3 Water table

From groundwater well database of the DGR, depths to water table of 2,194 wells in Phitsanulok province were extracted. They were converted to be water table surface above msl by subtracting from DEM data and then interpolating. Average water table of cells falling into area of each DS site was estimated and scored as result displayed in Table A1 of Appendix A.

4.1.4 Prevailing wind

Wind speed and direction from 7 meteorological stations located within and surrounding the study area (Table 4.1), recorded by the TMD, were interpolated using IDW function. Intersect area between buffer area of village(s) based on population and affected area based on wind speed and direction of each DS was estimated and normalized as displayed in Table A1 of Appendix A. Wedge-shape affected area based on wind speed and direction was prepared using Focal statistics function in ArcGIS Neighborhood toolbox.

Table 4.1 Meteorological station in this study.

No.	Station Name	Station Code	Easting	Northing
1	Uttaradit meteorological station	351201	616401	1948979
2	Sukhothai meteorological station	373201	585108	1891468
3	Phitsanulok meteorological station	378201	635971	1857449
4	Phetchabun meteorological station	379201	729575	1818088
5	Lomsak meteorological station	379401	739775	1855869
6	Kamphaengphet meteorological station	380201	556243	1822857
7	Phichit meteorological station	386301	646032	1806899

4.1.5 Capacity of DSs

Capacity of a DS is compacted waste (Ton/day). It is estimated from 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. Capacity of DSs are listed in Table 4.2

Table 4.2 Total capacity of DSs.

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**

*The service life of Phitsanulok DS was officially designed for 10 years long and the daily organization at the site is limited to this amount. So its daily capacity is assumed constant.

4.2 Transfer stations of administrative units

The temporary TS in each administrative unit of the waste generating area was located using GIS weighted mean centering process as described in section 3.2 of Chapter III. The result of temporary TS of each administrative unit is displayed as map in Figure 4.2.

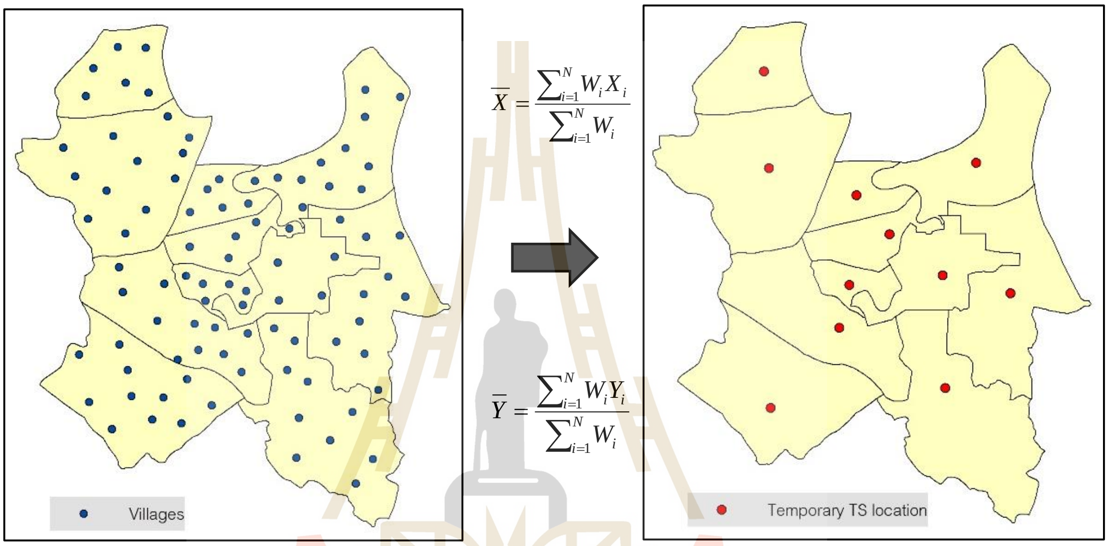


Figure 4.2 Temporary transfer station of each administrative unit.

4.3 Environmental impact of TSs and DSs

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

4.3.1 Environmental impact of TSs

Due to the fact that locations of TSs are temporarily assigned as original point of transportation. Therefore, only waste amounts generated in the administrative units (Table 1.2) and transported to DSs are considered as their impact to environment. They were normalized to be in the range of 0-1 by ratio with maximum waste amount as listed in Table 4.3.

Table 4.3 The result of EI evaluation of TSs.

TS No.	Name of administrative organization	Normalized waste amount generated (EI of TSs)
TS01	Phitsanulok municipality	1.00
TS02	Aranyik municipality	0.26
TS03	Phlaichumphon municipality	0.05
TS04	Bankhlong municipality	0.10
TS05	Thathong municipality	0.10
TS06	Huaro municipality	0.18
TS07	Phaikhodon SAO	0.03
TS08	Watchan SAO	0.06
TS09	Thapho SAO	0.16
TS10	Beungphra SAO	0.12
TS11	Bankrang SAO	0.08

4.3.2 Environmental impact of DSs

GIS data layers of criteria for EI evaluation of DSs are prepared according to conditions listed in Table 3.2. They are displayed in Figures 4.3, and 4.4 according to groups.

Normalization and summation are operated from raw scores of criteria in each group and among groups as shown in Table 4.4. They are normalized by ratio with maximum. Final results from Table 4.4 are again normalized to be EI indexes of DSs as listed in Table 4.5.

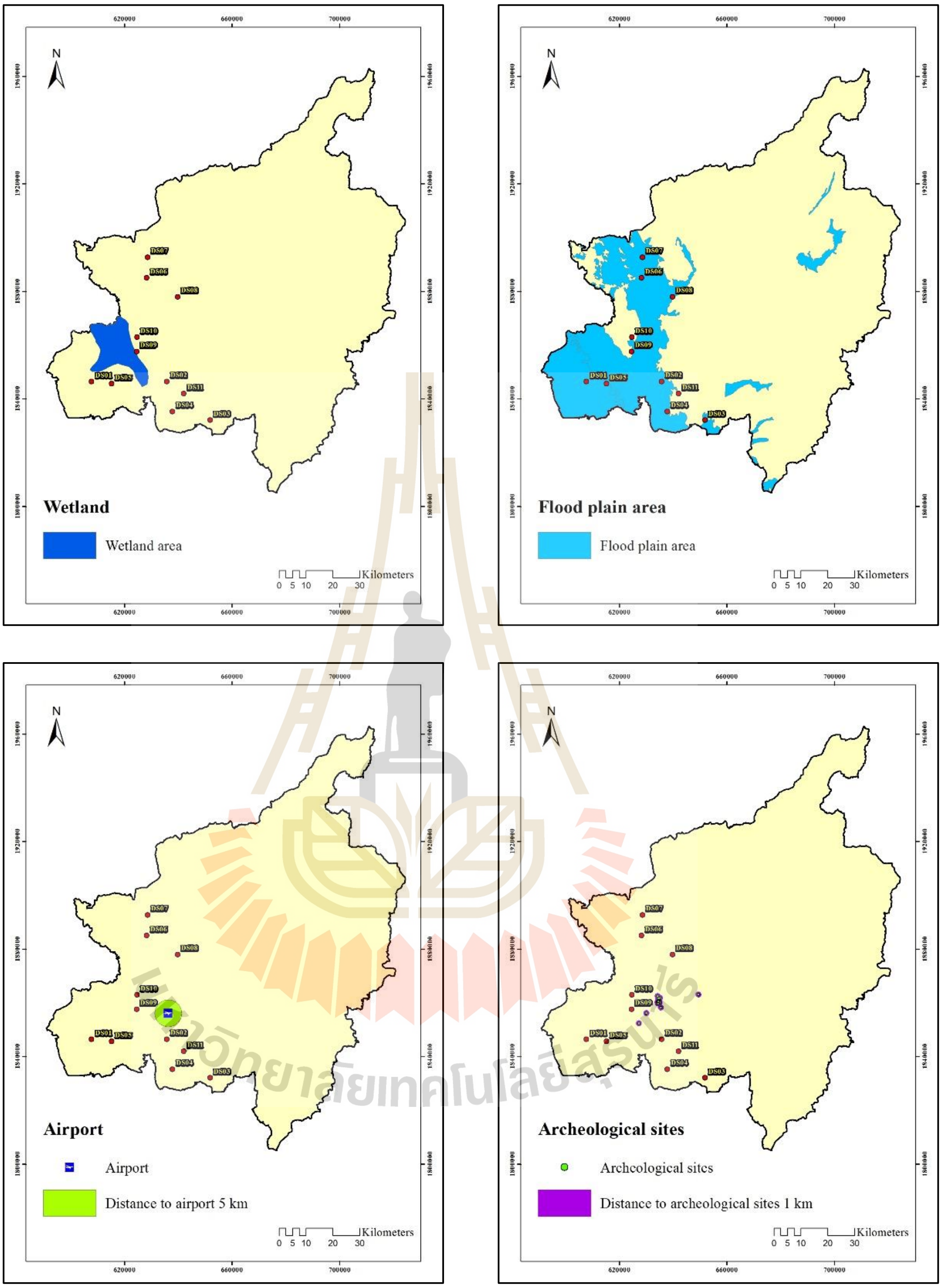


Figure 4.3 Map of PCD criteria for EI evaluation.

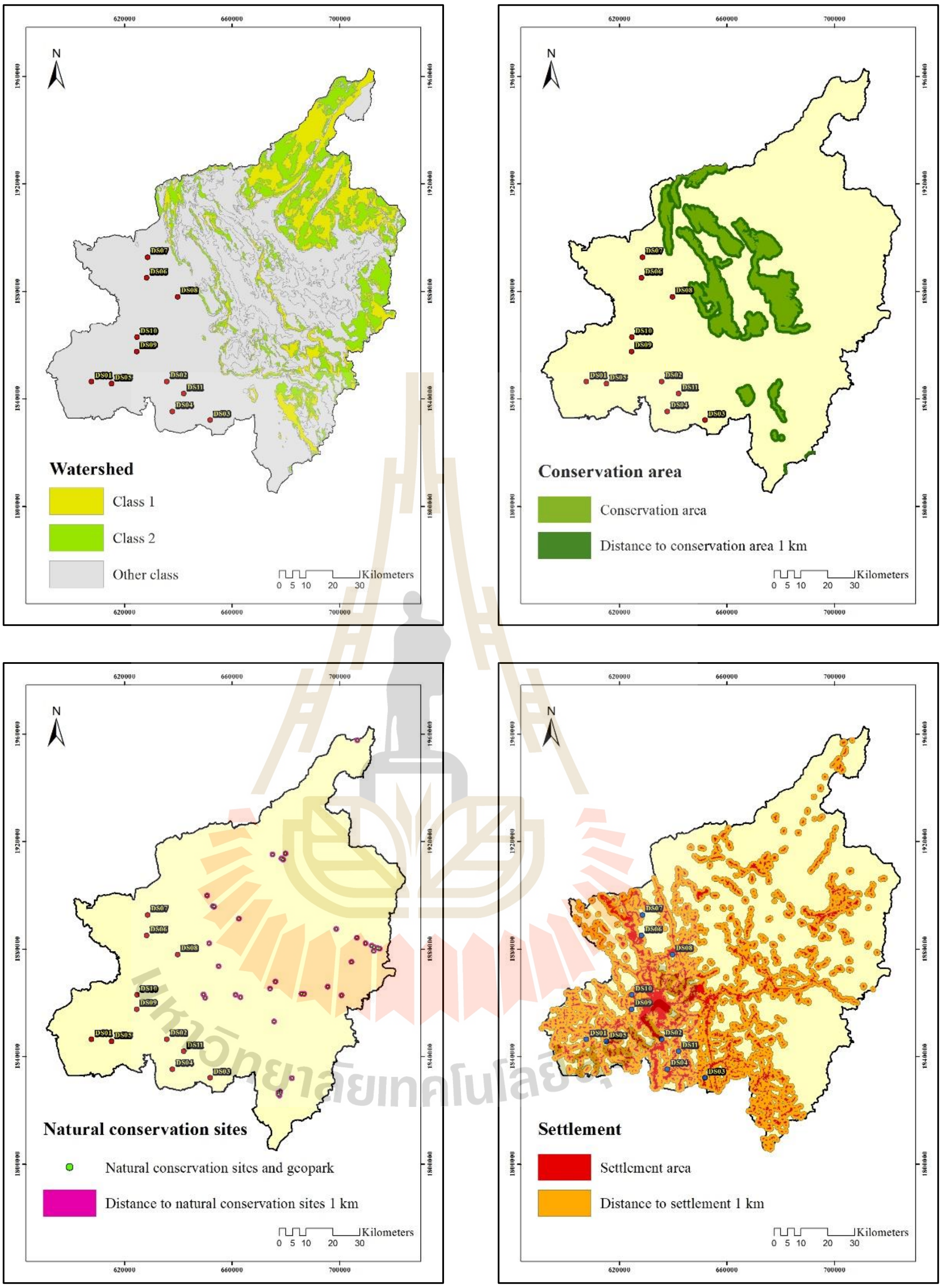


Figure 4.3 Map of PCD criteria for EI evaluation (Continued).

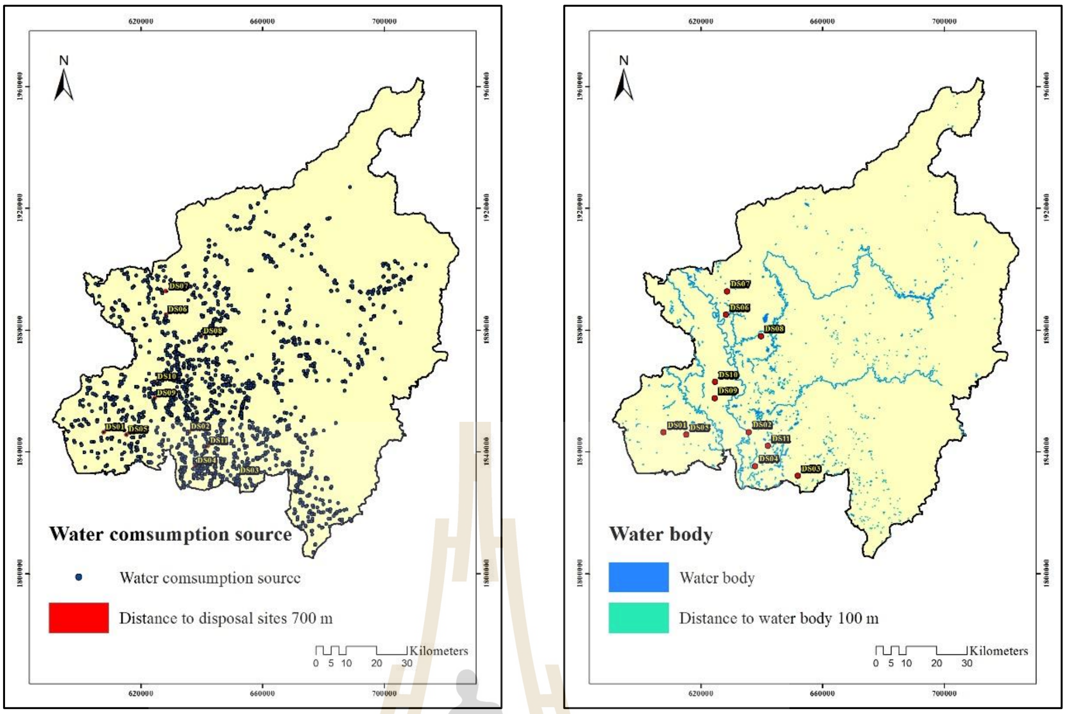


Figure 4.3 Map of PCD criteria for EI evaluation (Continued).

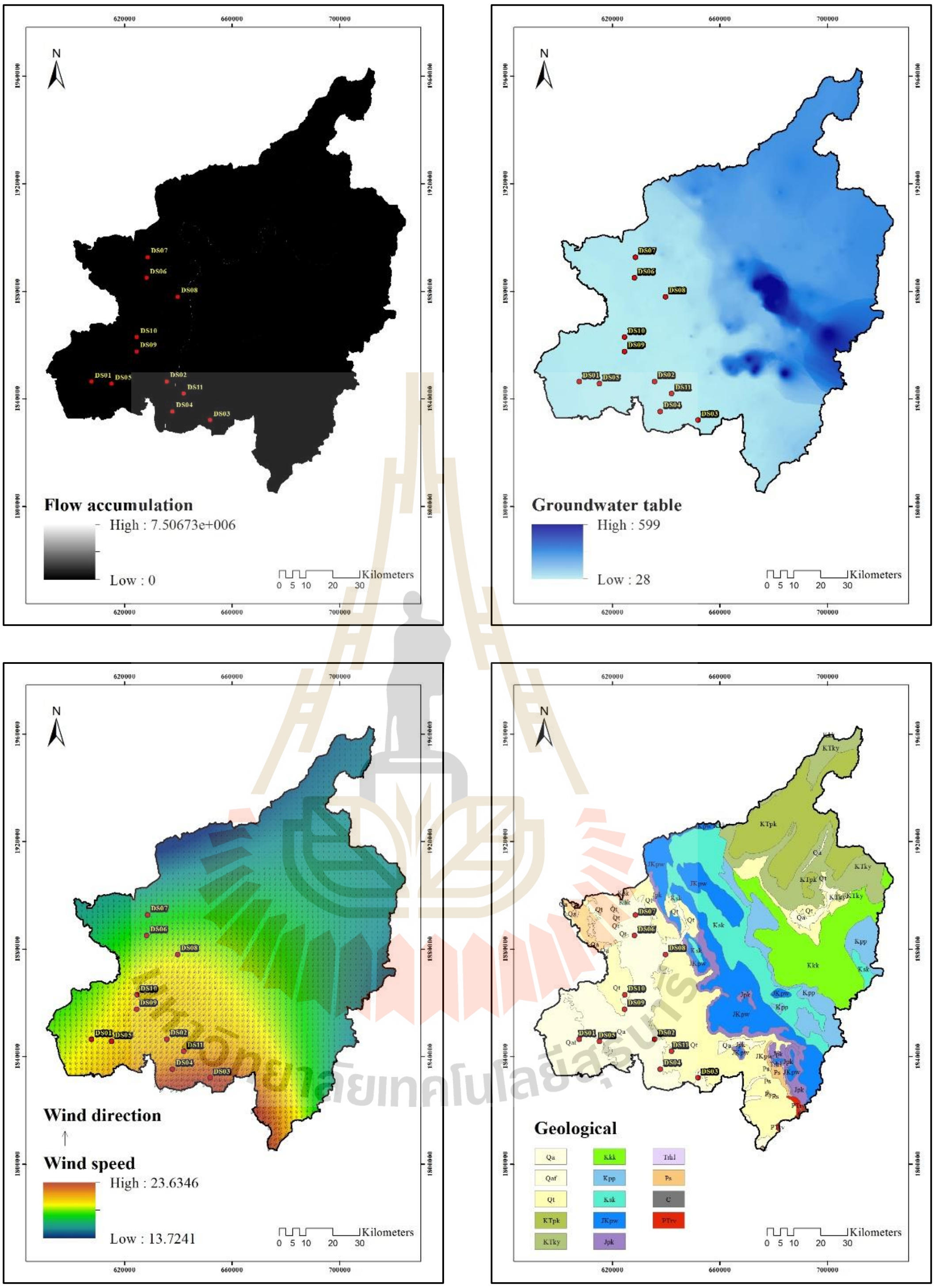


Figure 4.4 Map of specific environmental characteristic criteria for EI evaluation.

Table 4.4 Normalized EI score of criteria of DSs.

DS No.	PCD criteria										Specific envi. characteristic criteria				Disposal methods				SUM of PCD criteria	SUM of specific envi. characteristic criteria	SUM of disposal method	Norm of PCD criteria	Norm of specific envi. characteristic criteria	Norm of disposal method	SUM of Norm EI of DS
	Wetland	Flood plain	Airport	Archeological sites	Watershed	Conservation area	Natural conservation site and geopark	Settlement	Water consumption source	Water body	Flow accumulation	Water table	Prevailing wind	Drainage of surface sediment on landform	Contamination (leachate) to soil and surface water	Unpleasant odors	Methane GAS (CH_4)	Site protected channeling runoff							
DS01	0	0	0	0	0	0	0	1	1	0	0.54	0.82	0.00	0.70	1	2	1	2	2	2.06	6	0.2	0.67	0.46	1.33
DS02	0	1	0	0	0	0	0	1	1	0	1.00	1.00	0.15	0.20	2	3	3	4	3	2.35	12	0.3	0.76	0.92	1.98
DS03	0	1	0	0	0	0	0	1	1	0	1.00	0.96	0.00	0.50	2	3	3	4	3	2.46	12	0.3	0.80	0.92	2.02
DS04	0	1	0	0	0	0	0	1	1	0	1.00	0.80	0.00	0.50	2	3	3	4	3	2.30	12	0.3	0.75	0.92	1.97
DS05	0	0	0	0	0	0	0	1	1	0	1.00	0.76	0.00	0.70	3	3	3	4	2	2.46	13	0.2	0.80	1.00	2.00
DS06	0	1	0	0	0	0	0	1	1	0	1.00	0.89	1.00	0.20	3	3	3	4	3	3.09	13	0.3	1.00	1.00	2.30
DS07	0	1	0	0	0	0	0	1	1	0	1.00	0.91	0.00	0.20	3	3	3	4	3	2.11	13	0.3	0.68	1.00	1.98
DS08	0	1	0	0	0	0	0	1	1	0	0.62	0.81	0.00	0.20	3	3	3	4	3	1.63	13	0.3	0.53	1.00	1.83
DS09	0	1	0	0	0	0	0	1	1	0	1.00	0.82	0.14	0.50	1	2	1	2	3	2.46	6	0.3	0.80	0.46	1.56
DS10	0	0	0	0	0	0	0	1	1	0	0.23	0.65	0.62	0.50	2	3	3	4	2	2.00	12	0.2	0.65	0.92	1.77
DS11	0	0	0	0	0	0	0	1	1	0	0.15	0.68	0.44	0.50	2	3	3	4	2	1.76	12	0.2	0.57	0.92	1.69

Table 4.5 The result of EI evaluation of DSs.

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

EI index of every pair of TS and DS is obtained from summation of their EI indexes. EI indexes of all pairs are displayed as matrix in Table 4.6. The matrix is input data of an objective function of MODA.

4.4 Optimum routes of TSs and DSs

Optimum route between each TS to each DS is analyzed. This results in 121 optimum routes in both maps and distances. Maps of routes from TS of Phitsanulok municipality (TS01) to all DSs are displayed as an example in Figure 4.5. Optimum distance of each TS to each DS is listed in Table B1 of Appendix B. They are normalized and displayed as matrix in Table 4.7. The matrix is input for objective function of minimizing TC of the MODA.

Table 4.6 Matrix of EI indexes of pairs of TS and DS.

		Temporary transfer stations (TSs)										
		Phitsanulok (TS01)	Aranyik (TS02)	Phlaichumphon (TS03)	Bankhlong (TS04)	Thathong (TS05)	Hua Ro (TS06)	Phaikhodon (TS07)	Watchan (TS08)	Thapho (TS09)	Beungphra (TS10)	Bankrang (TS11)
Disposal sites (DSs)	Phitsanulok (DS01)	0.79	0.42	0.32	0.34	0.34	0.38	0.30	0.32	0.37	0.35	0.33
	Banmai (DS02)	0.93	0.56	0.46	0.48	0.48	0.52	0.45	0.46	0.51	0.49	0.47
	Nuenkum (DS03)	0.94	0.57	0.47	0.49	0.49	0.53	0.45	0.47	0.52	0.50	0.48
	Bangkrathum (DS04)	0.93	0.56	0.46	0.48	0.48	0.52	0.44	0.46	0.51	0.49	0.47
	Plakrad (DS05)	0.93	0.56	0.46	0.48	0.48	0.52	0.45	0.46	0.52	0.49	0.48
	Phromphiram (DS06)	1.00	0.63	0.53	0.55	0.55	0.59	0.51	0.53	0.58	0.56	0.54
	Wongkong (DS07)	0.93	0.56	0.46	0.48	0.48	0.52	0.45	0.46	0.51	0.49	0.47
	Watbot (DS08)	0.90	0.53	0.42	0.45	0.45	0.49	0.41	0.43	0.48	0.46	0.44
	Thapho (DS09)	0.84	0.47	0.37	0.39	0.39	0.43	0.35	0.37	0.42	0.40	0.38
	Bankrang (DS10)	0.88	0.51	0.41	0.44	0.44	0.47	0.40	0.41	0.47	0.45	0.43
	Bantan (DS11)	0.87	0.50	0.40	0.42	0.42	0.46	0.38	0.40	0.45	0.43	0.41

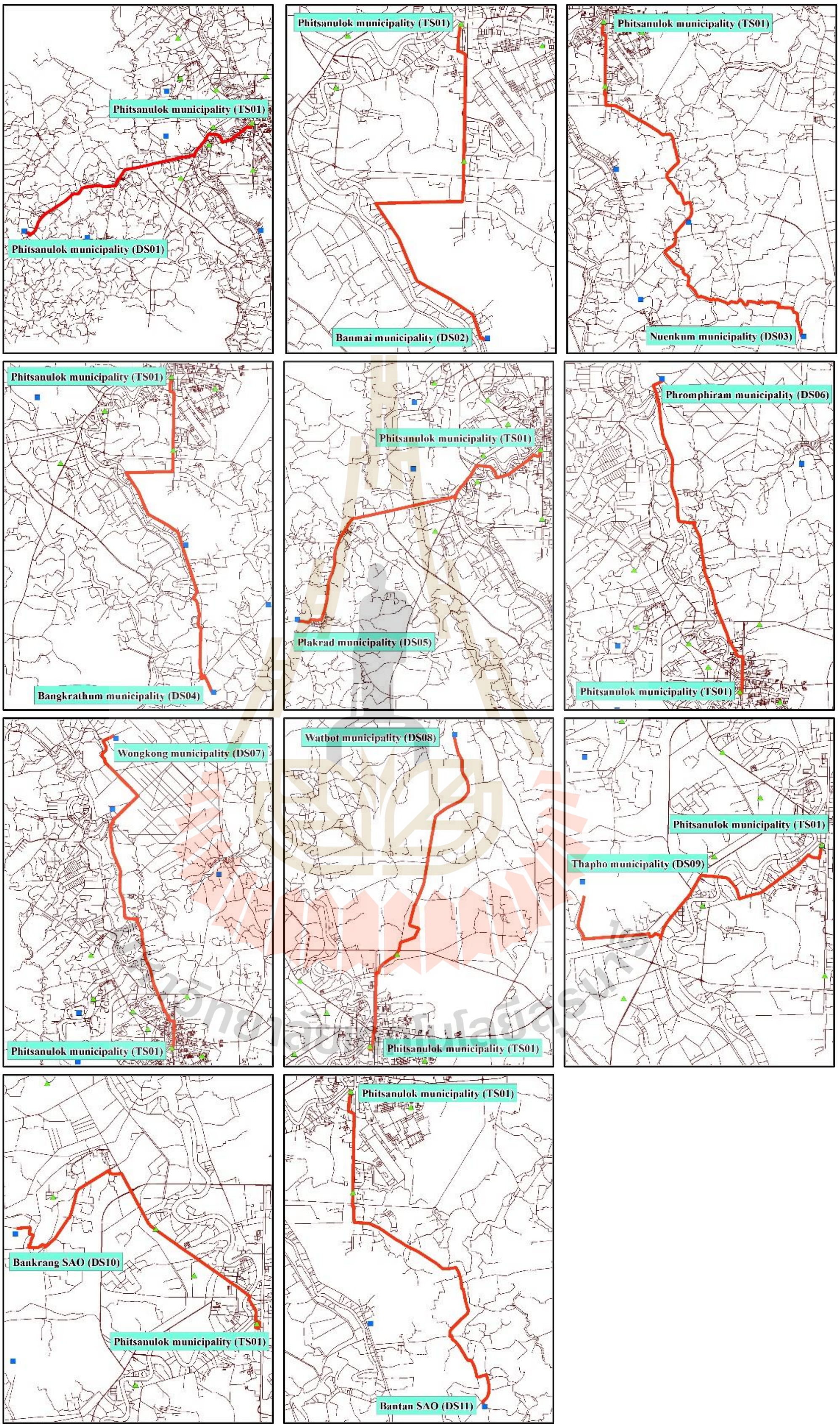


Figure 4.5 The 11 shortest paths of TS of Phitsanulok municipality to all DSs.

Table 4.7 Matrix of distances of pairs of TS and DS.

		Temporary transfer stations (TSs)										
		Phitsanulok (TS01)	Aranyik (TS02)	Phlaichumphon (TS03)	Bankhlong (TS04)	Thathong (TS05)	Hua Ro (TS06)	Phaikhodon (TS07)	Watchan (TS08)	Thapho (TS09)	Beungphra (TS10)	Bankrang (TS11)
Disposal sites (DSs)	Phitsanulok (DS01)	0.57	0.65	0.60	0.54	0.50	0.66	0.70	0.48	0.43	0.53	0.60
	Banmai (DS02)	0.31	0.34	0.38	0.34	0.23	0.41	0.54	0.29	0.23	0.21	0.49
	Nuenkum (DS03)	0.74	0.77	0.84	0.81	0.71	0.84	1.00	0.77	0.72	0.64	0.95
	Bangkrathum (DS04)	0.51	0.54	0.59	0.55	0.43	0.61	0.74	0.49	0.44	0.41	0.69
	Plakrad (DS05)	0.48	0.56	0.51	0.45	0.41	0.57	0.61	0.39	0.32	0.44	0.51
	Phromphiram (DS06)	0.50	0.55	0.45	0.47	0.60	0.43	0.39	0.52	0.64	0.59	0.42
	Wongkong (DS07)	0.69	0.74	0.64	0.66	0.79	0.62	0.59	0.71	0.83	0.78	0.62
	Watbot (DS08)	0.37	0.43	0.40	0.42	0.47	0.26	0.44	0.45	0.56	0.46	0.45
	Thapho (DS09)	0.26	0.33	0.28	0.23	0.19	0.35	0.38	0.17	0.12	0.23	0.28
	Bankrang (DS10)	0.28	0.34	0.20	0.22	0.35	0.28	0.19	0.26	0.29	0.37	0.11
	Bantan (DS11)	0.39	0.42	0.49	0.46	0.40	0.49	0.65	0.46	0.41	0.29	0.60

4.5 Waste transportation management using MODA

The results from this analysis can be used for solid waste allotment transport from temporary TS to DSs based on minimum TC and EI. The analysis was performed with separated objectives as minimum TC, minimum EI, and minimum both TC and EI. The constraint of waste supply is subjected to waste amount generated in each administrative unit. Constraint on capacity of each DS was considered based on service life of a site. In this study case, daily capacities of 3-year and 5-year service life are input as constraints so that alternative transportation allotments can be observed and fitted them to actual capacity of sites for optimum benefit.

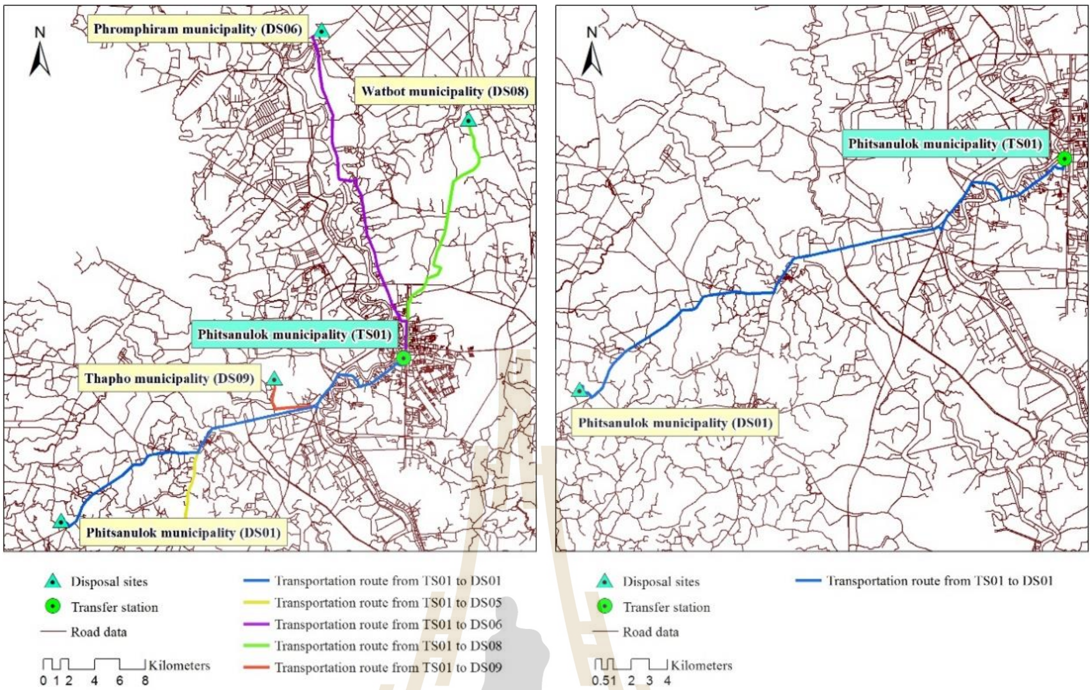
4.5.1 Minimization of TC

According to Equation (10) as described in section 3.5.1 of research procedures in Chapter III for minimization of TC. The results of the process show in Table 4.8, including allotments of solid waste from each temporary TS to DSs in service, minimum total TC, and EI of each active pair of TS and DS. Optimum paths of active pairs of TS and DS are displayed in Figure 4.6. The minimum total TC is 59,541.59 baht for 3-year capacity, and 69,223.65 baht for 5-years capacity, while total EI is for 187.94 3-year capacity, and 175.69 for 5-years capacity.

Table 4.8 Summary of waste transportation allotments from TSs to DSs based on minimization of TC and 3 and 5 year capacity of DSs.

No.	Temporary TS	Optimal DS	Distance of paths (km)	3-year capacity			5-year capacity		
				Waste amount (ton/day)	TC (Baht)	EI	Waste amount (ton/day)	TC (Baht)	EI
1	Phitsanulok	- Phitsanulok	68.85	47.77	14,765.31	37.68	132.30	40,892.82	104.36
		- Plakrad	58.12	4.12	1,075.15	3.85	-	-	-
		- Phromphiram	59.85	37.84	10,166.91	37.84	-	-	-
		- Watbot	45.05	29.88	6,042.62	26.81	-	-	-
		- Thapho	30.78	12.69	1,753.79	10.65	-	-	-
2	Aranyik	- Phitsanulok	77.92	-	-	-	3.21	1,123.05	1.35
		- Banmai	40.91	26.38	4,844.45	14.80	10.42	1,913.54	5.85
		- Bangkrathum	65.59	6.10	1,796.17	3.40	-	-	-
		- Phromphiram	66.76	-	-	-	13.41	4,019.68	8.44
		- Watbot	51.83	1.84	214.06	0.97	7.29	1,696.18	3.84
3	Phlaichumphon	- Phromphiram	54.06	2.55	618.96	1.34	7.25	1,759.79	3.82
		- Bankrang	23.65	4.70	498.87	1.94	-	-	-
4	Bankhlong	- Phitsanulok	65.28	-	-	-	0.70	205.18	0.24
		- Thapho	27.22	13.46	1,645.05	5.24	12.76	1,559.50	4.97
5	Thathong	- Phitsanulok	59.98	13.40	3,608.76	4.55	13.40	3,608.76	4.55
6	Huaro	- Watbot	31.41	23.36	3,293.43	11.35	23.36	3,293.43	11.35
7	Phaikhodon	- Phromphiram	46.94	3.73	786.14	1.92	3.73	786.14	1.92
8	Watchan	- Thapho	20.03	-	-	-	7.34	659.79	2.69
		- Bankrang	31.92	7.34	1,051.97	2.69	-	-	-
9	Thapho	- Phitsanulok	51.76	-	-	-	7.70	1,789.50	2.85
		- Plakrad	38.99	21.63	3,785.69	11.15	13.93	2,438.03	7.18
10	Beungphra	- Banmai	25.37	-	-	-	4.93	561.36	2.42
		- Bangkrathum	50.05	3.19	717.01	1.56	3.78	849.63	1.84
		- Bantan	35.23	12.79	2,022.58	5.48	7.28	1,151.24	3.12
11	Bankrang	- Phromphiram	51.24	-	-	-	1.60	368.11	0.87
		- Bankrang	13.08	11.06	640.61	4.72	9.46	547.93	4.03
		Total		**283.84**	**59,541.59**	**187.94**	**283.84**	**69,223.65**	**175.69**

(a) TS of Phitsanulok municipality (TS01)



(b) TS of Aranyik municipality (TS02)

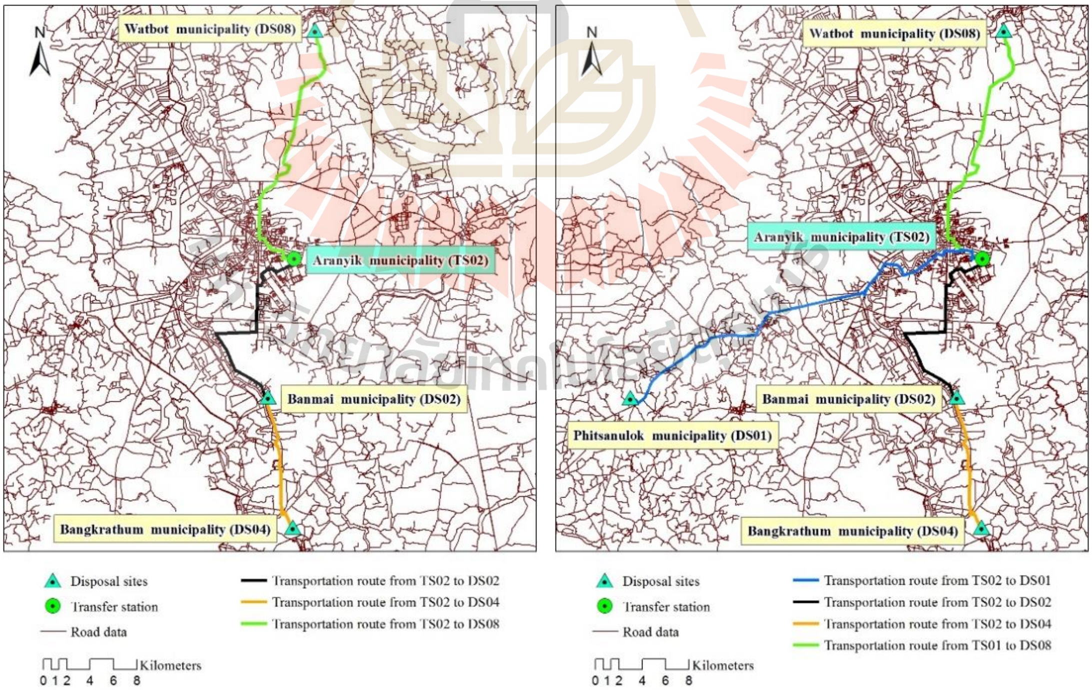
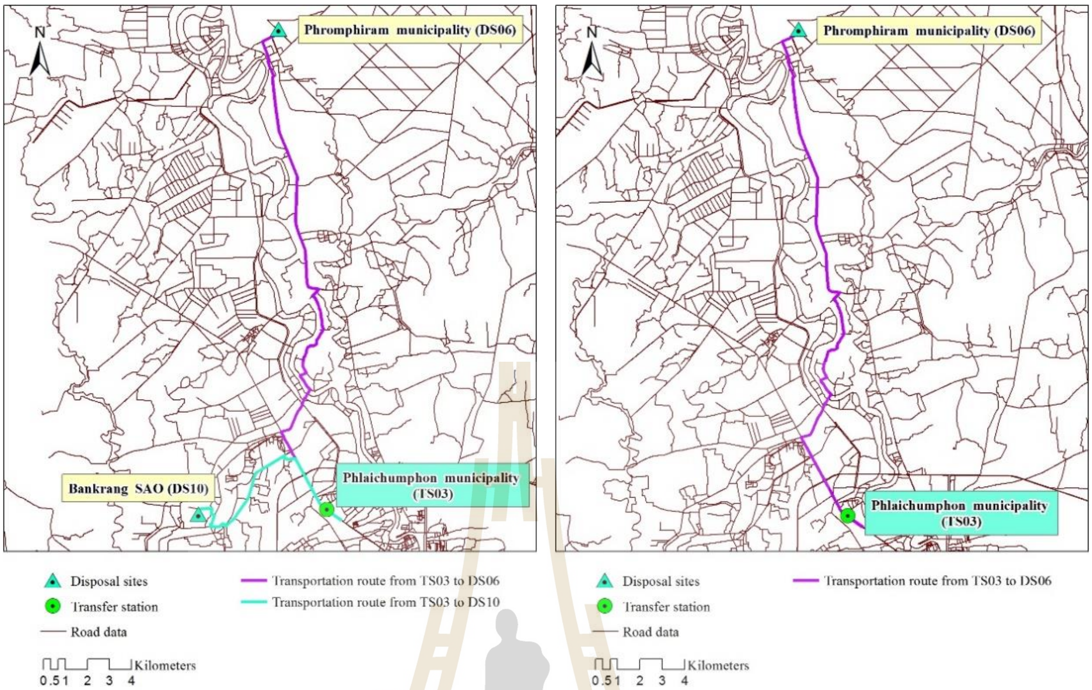


Figure 4.6 Optimum paths from each TS to DS(s) based on minimization of TC and constraints of 3 (left hand side) and 5 (right hand side) year service life of sites.

(c) TS of Phlaichumphon municipality (TS03)



(d) TS of Bankhlong municipality (TS04)

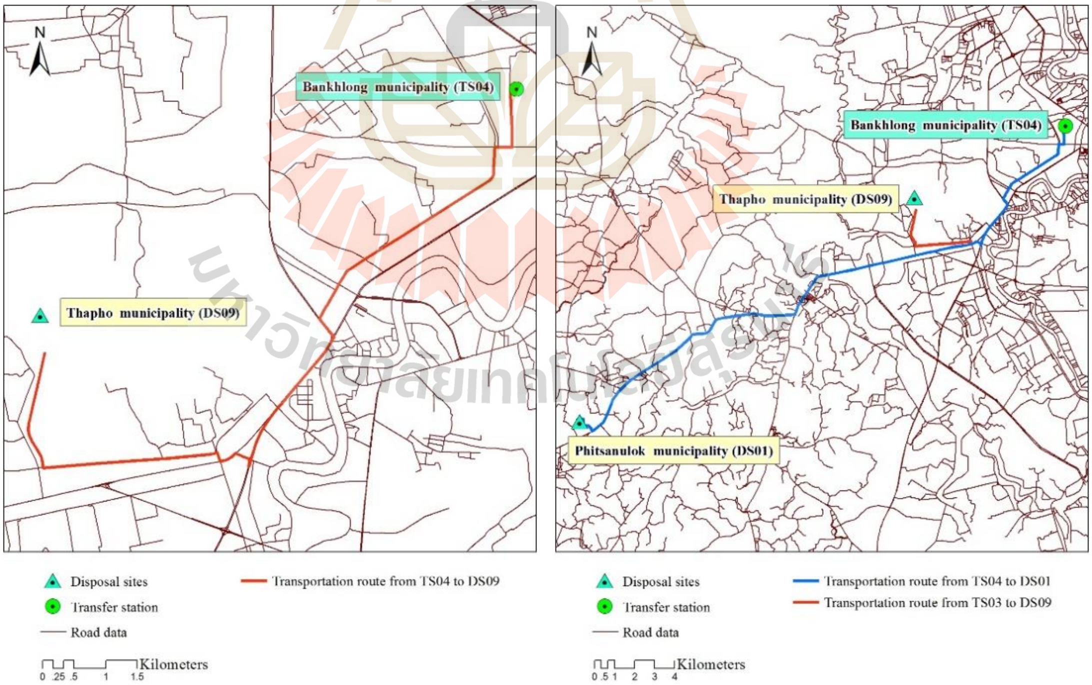
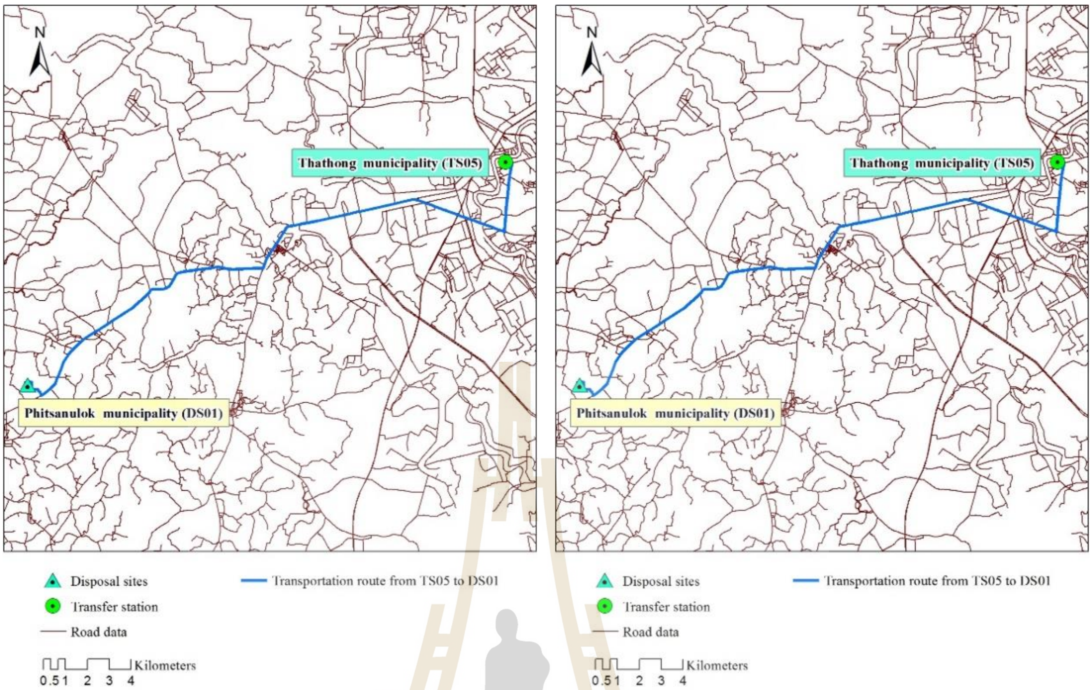


Figure 4.6 Optimum paths from each TS to DS(s) based on minimization of TC and constraints of 3 (left hand side) and 5 (right hand side) year service life of sites (Continued).

(e) TS of Thathong municipality (TS05)



(f) TS of Huaro municipality (TS06)

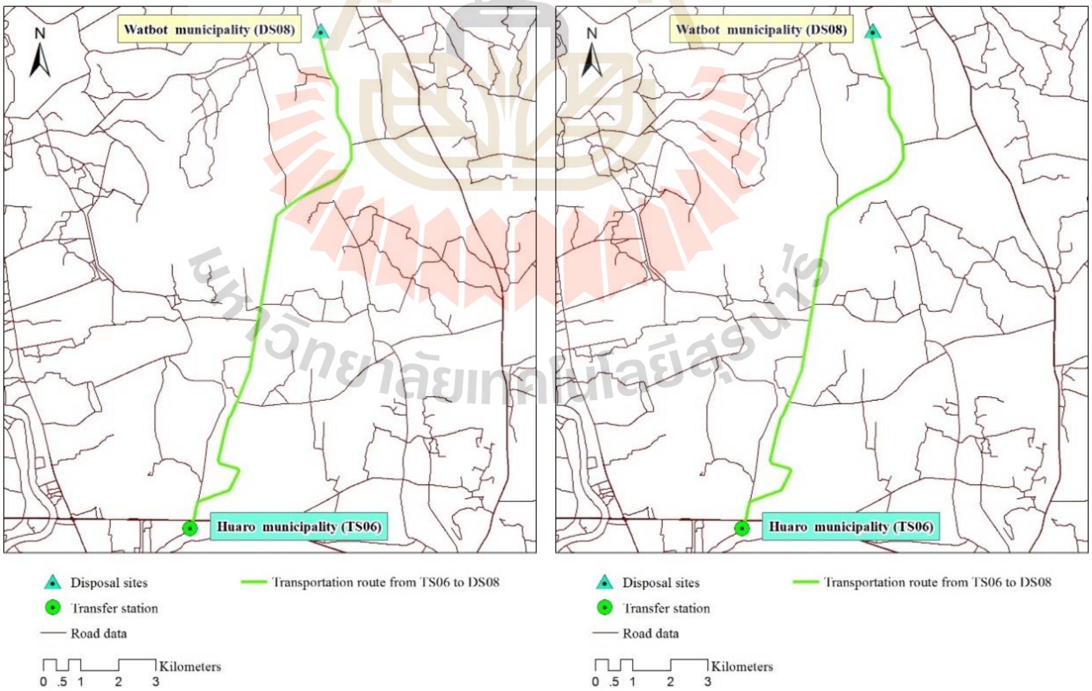
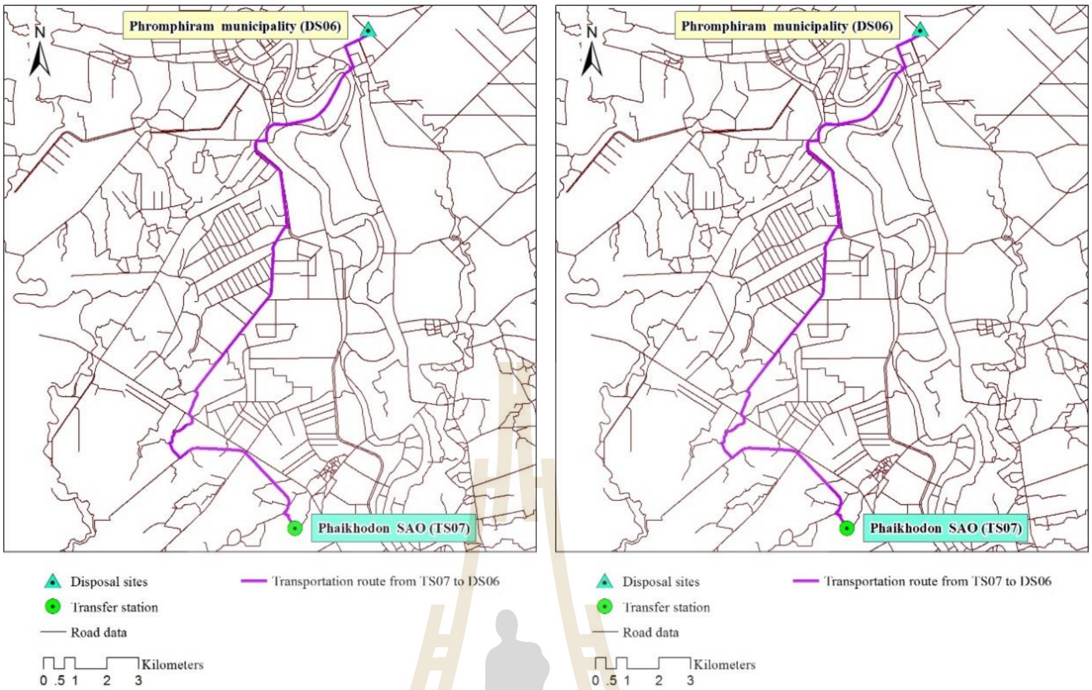


Figure 4.6 Optimum paths from each TS to DS(s) based on minimization of TC and constraints of 3 (left hand side) and 5 (right hand side) year service life of sites (Continued).

(g) TS of Phaikhodon SAO (TS07)



(h) TS of Watchan SAO (TS08)

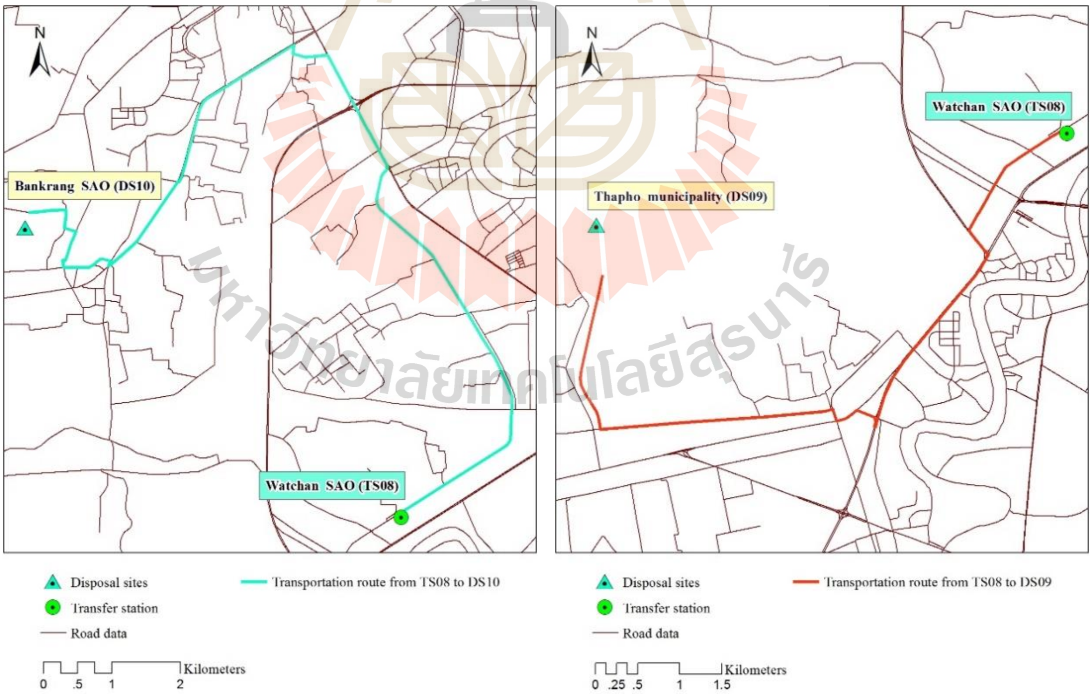
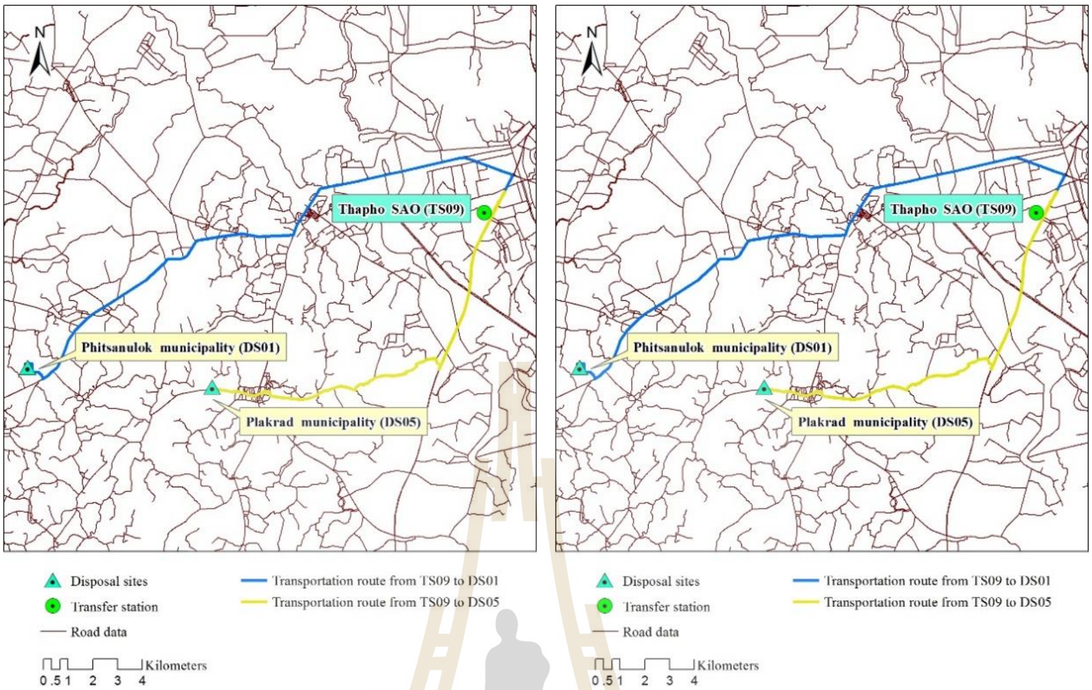


Figure 4.6 Optimum paths from each TS to DS(s) based on minimization of TC and constraints of 3 (left hand side) and 5 (right hand side) year service life of sites (Continued).

(i) TS of Thapho SAO (TS09)



(j) TS of Beungphra SAO (TS10)

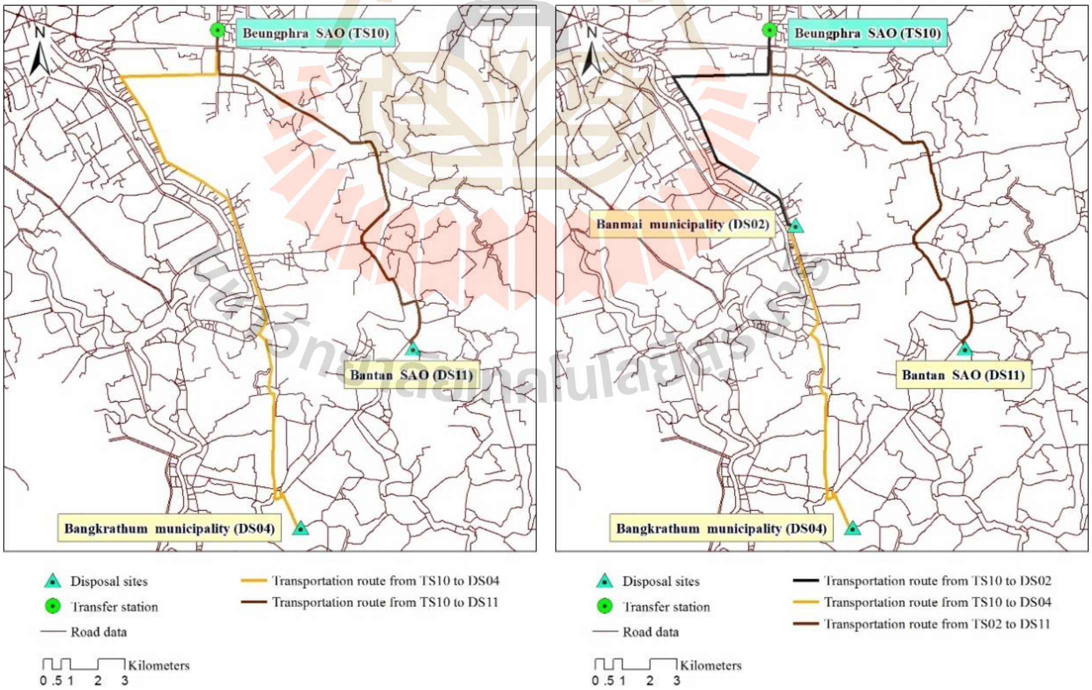


Figure 4.6 Optimum paths from each TS to DS(s) based on minimization of TC and constraints of 3 (left hand side) and 5 (right hand side) year service life of sites (Continued).

(k) TS of Bankrang SAO (TS11)

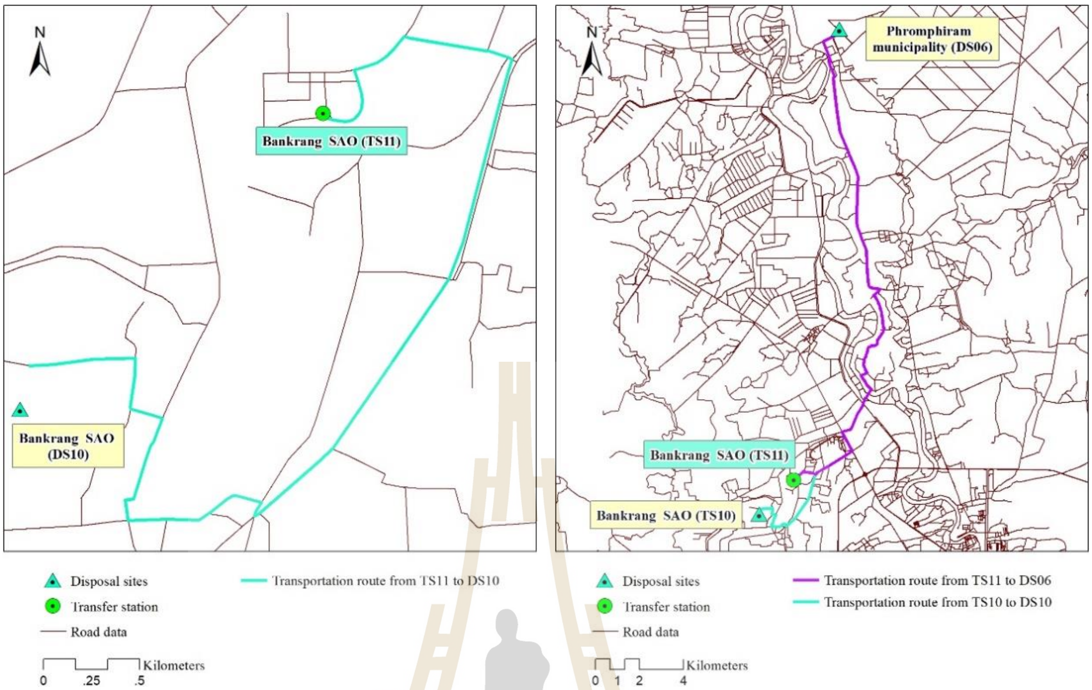


Figure 4.6 Optimum paths from each TS to DS(s) based on minimization of TC and constraints of 3 (left hand side) and 5 (right hand side) year service life of sites (Continued).

4.5.2 Minimization of EI

According to Equation (15) as described in section 3.5.2 of research procedures in Chapter III for minimization of EI. The results of the process show in Table 4.9, including allotments of solid waste from each temporary TS to DSs in service, total TC, and minimum EI of each active pair of TS and DS. Optimum paths of active pairs of TS and DS are displayed in Figure 4.7. The total TC is 77,593.08 baht for 3-year capacity, and 78,264.71 baht for 5-years capacity, while total minimum EI is 165.61 for 3-year capacity, and 167.01 for 5-years capacity.

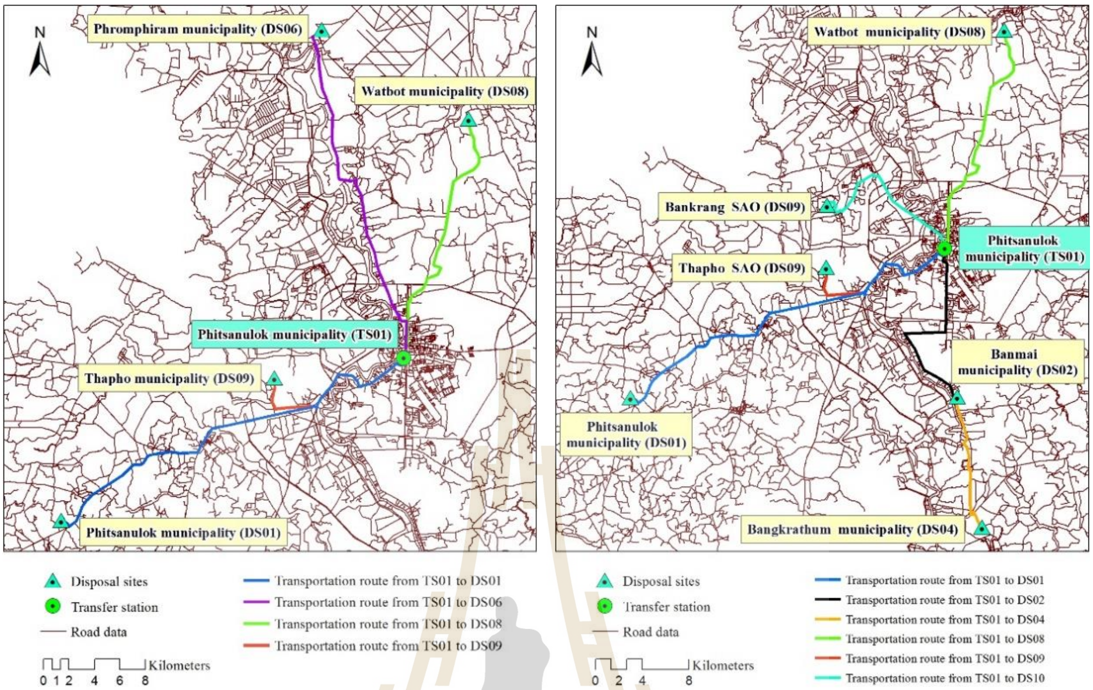
4.5.3 Minimization of TC and EI

According to Equation (16) as described in section 3.5.3 of research procedures in Chapter III for minimization of TC and EI. The results of the process show in Table 4.10, including allotments of solid waste from each temporary TS to DSs in service, total TC, and EI of each active pair of TS and DS. Optimum paths of active pairs of TS and DS are displayed in Figure 4.8. The total TC is 63,161.44 baht for 3-year capacity, and 71,647.43 baht for 5-years capacity, while total EI is 173.60 for 3-year capacity, and 168.45 for 5-years capacity.

Table 4.9 Summary of waste transportation allotments from TSs to DSs based on minimization of EI and 3 and 5 year capacity of DSs.

No.	Temporary TS	Optimal DS	Distances of paths (km)	3-year capacity			5-year capacity		
				Waste amount (ton/day)	TC (Baht)	EI	Waste amount (ton/day)	TC (Baht)	EI
1	Phitsanulok	- Phitsanulok	68.85	70.46	21,778.59	55.58	64.95	20,075.50	51.23
		- Banmai	58.12	-	-	-	7.11	1,176.08	6.62
		- Bangkrathum	61.52	-	-	-	3.78	1,044.13	3.50
		- Watbot	45.05	12.58	2,544.05	11.29	26.92	5,444.02	24.16
		- Thapho	30.78	33.49	4,628.39	28.09	20.10	2,777.86	16.86
		- Bankrang	33.80	15.76	2,391.77	13.94	9.46	1,435.67	8.37
2	Aranyik	- Phitsanulok	77.92	34.33	12,010.72	14.37	34.33	12,010.72	14.37
3	Phlaichumphon	- Phitsanulok	72.25	7.25	2,351.59	2.29	7.25	2,351.92	2.29
4	Bankhlong	- Phitsanulok	65.28	13.46	3,945.22	4.57	13.46	3,945.22	4.57
5	Thathong	- Phitsanulok	59.98	13.40	3,608.76	4.55	13.40	3,608.76	4.55
6	Huaro	- Phitsanulok	80.07	23.36	8,397.21	8.81	23.36	8,398.25	8.81
7	Phaikhodon	- Watbot	53.59	3.73	897.34	1.53	3.73	897.34	1.53
8	Watchan	- Phitsanulok	58.10	-	-	-	0.06	15.65	0.02
		- Bantan	55.92	7.34	1,842.94	2.91	7.28	1,827.87	2.88
9	Thapho	- Phitsanulok	51.76	16.18	3,760.27	5.99	21.63	5,026.86	8.01
		- Bantam	49.34	5.45	1,207.37	2.45	-	-	-
10	Beungphra	- Phitsanulok	64.26	15.98	4,610.67	5.58	15.98	4,610.67	5.58
11	Bankrang	- Phitsanulok	72.86	11.06	3,618.18	3.66	11.06	3,618.18	3.66
		Total		**283.84**	**77,593.08**	**165.61**	**283.84**	**78,264.71**	**167.01**

(a) TS of Phitsanulok municipality (TS01)



(b) TS of Aranyik municipality (TS02)

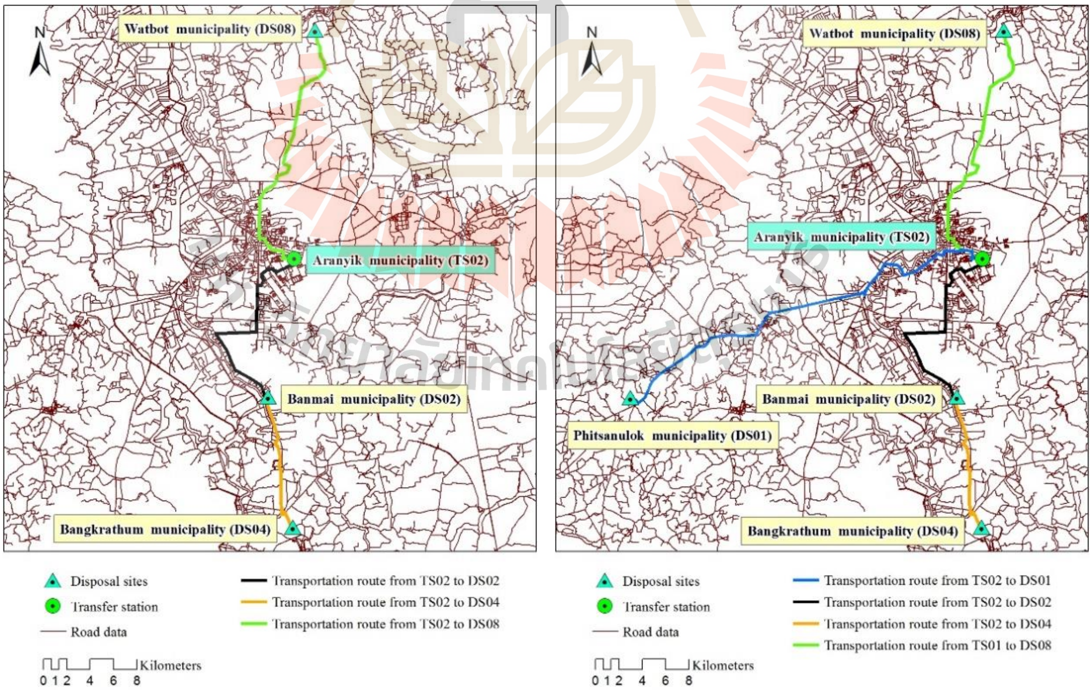
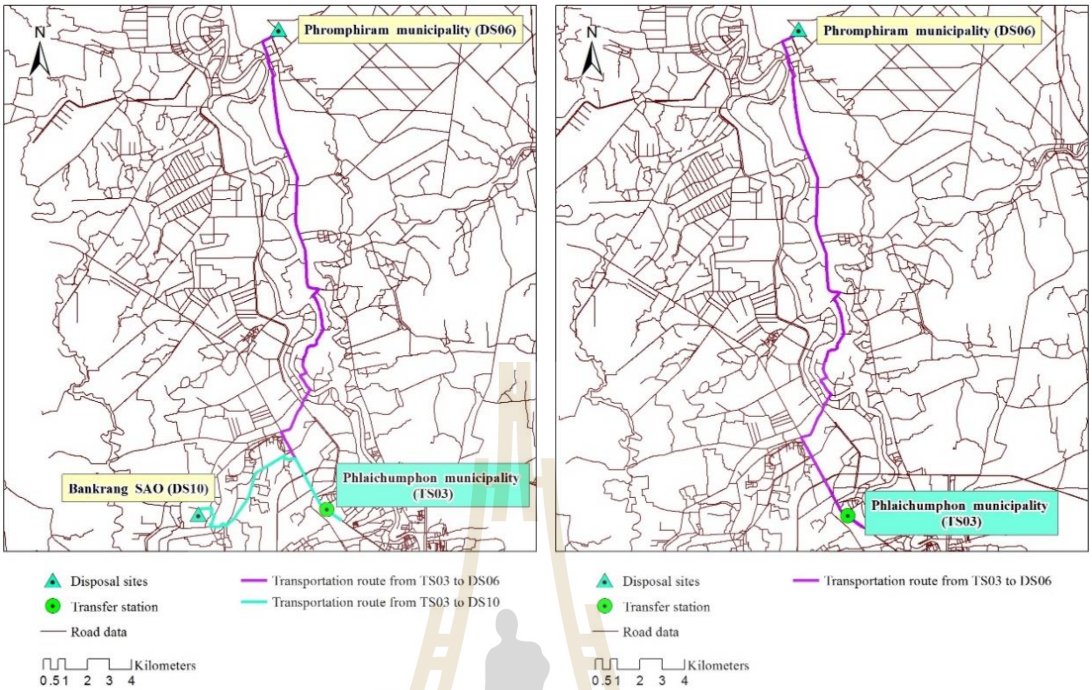


Figure 4.7 Optimum paths from each TS to DS(s) based on minimization of EI and constraints of 3 (left hand side) and 5 (right hand side) year service life of sites.

(c) TS of Phlaichumphon municipality (TS03)



(d) TS of Bankhlong municipality (TS04)

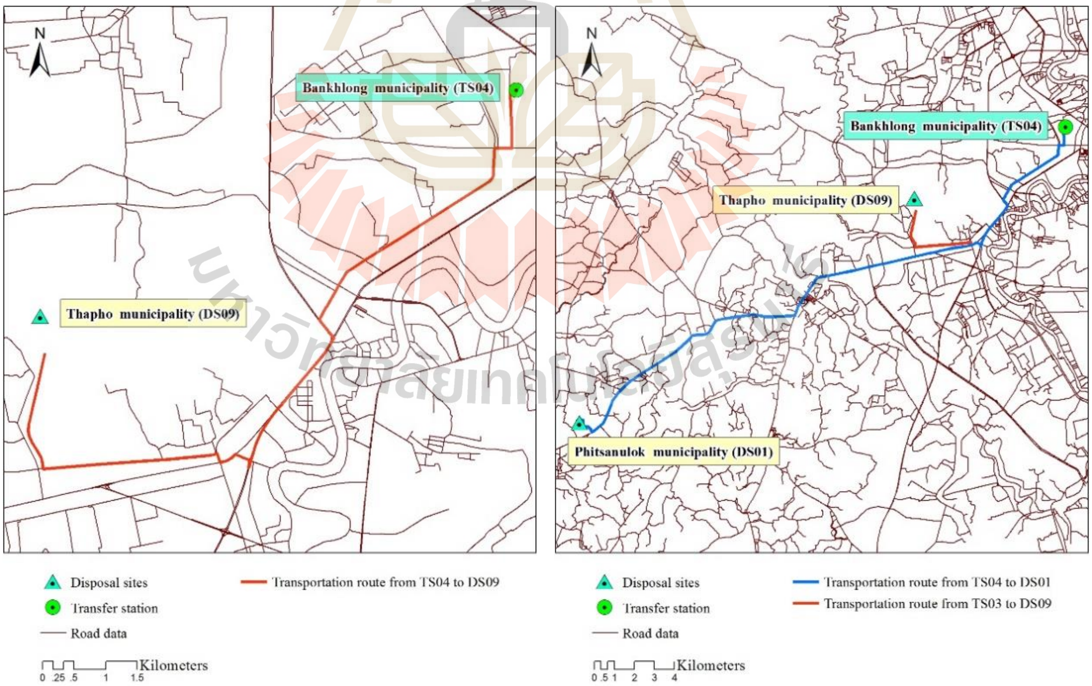
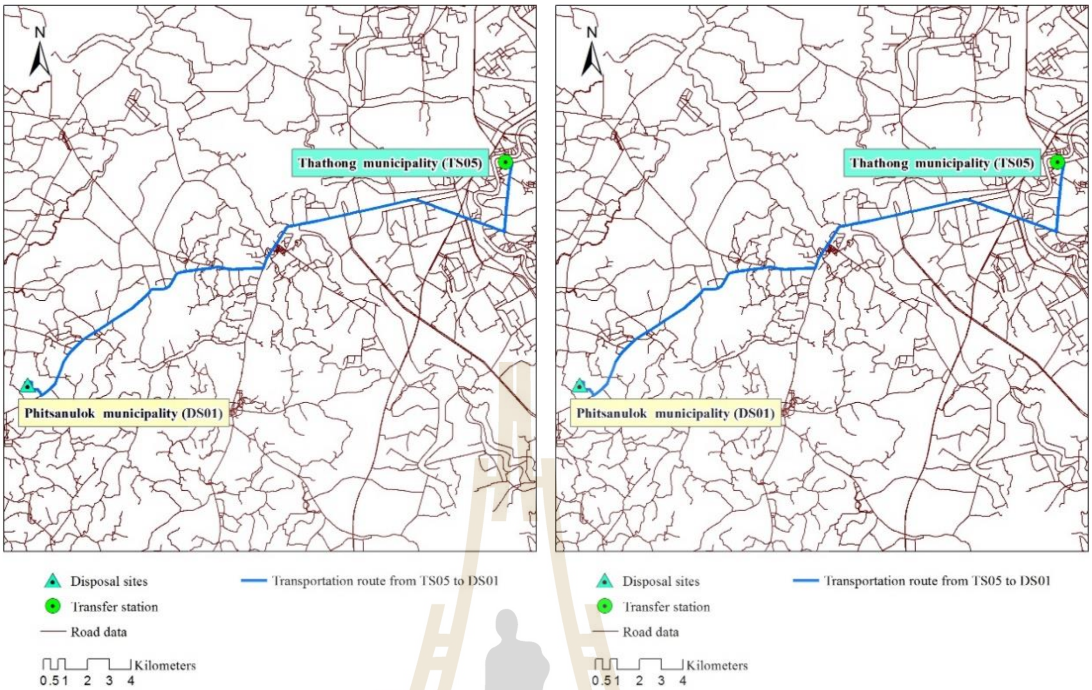


Figure 4.7 Optimum paths from each TS to DS(s) based on minimization of EI and constraints of 3 (left hand side) and 5 (right hand side) year service life of sites (Continued).

(e) TS of Thathong municipality (TS05)



(f) TS of Huaro municipality (TS06)

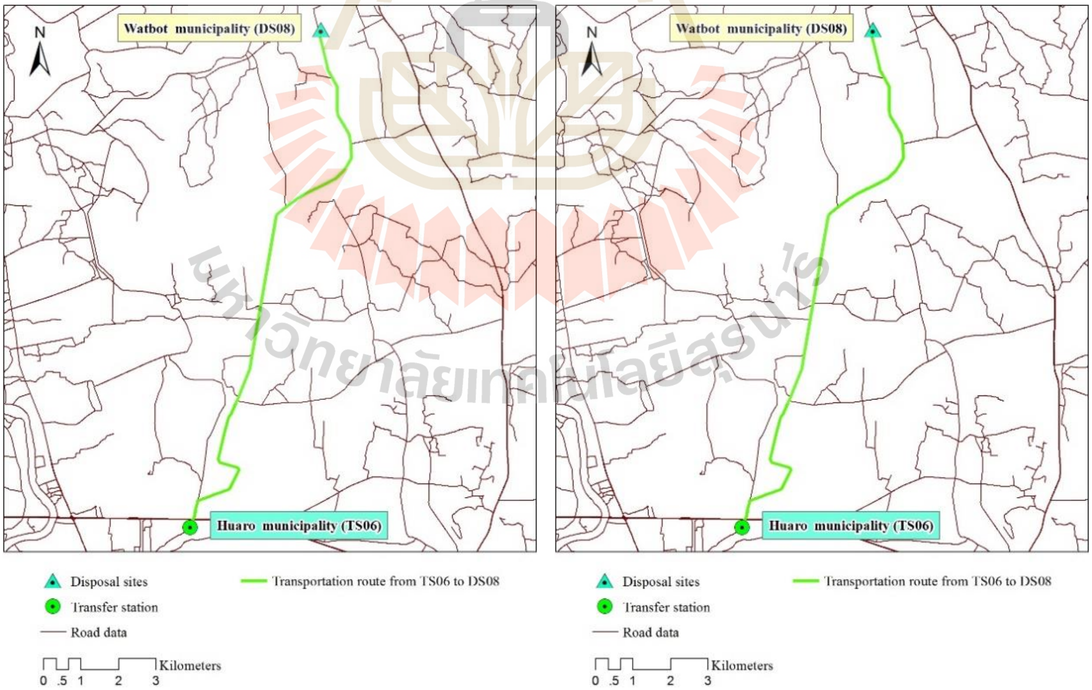
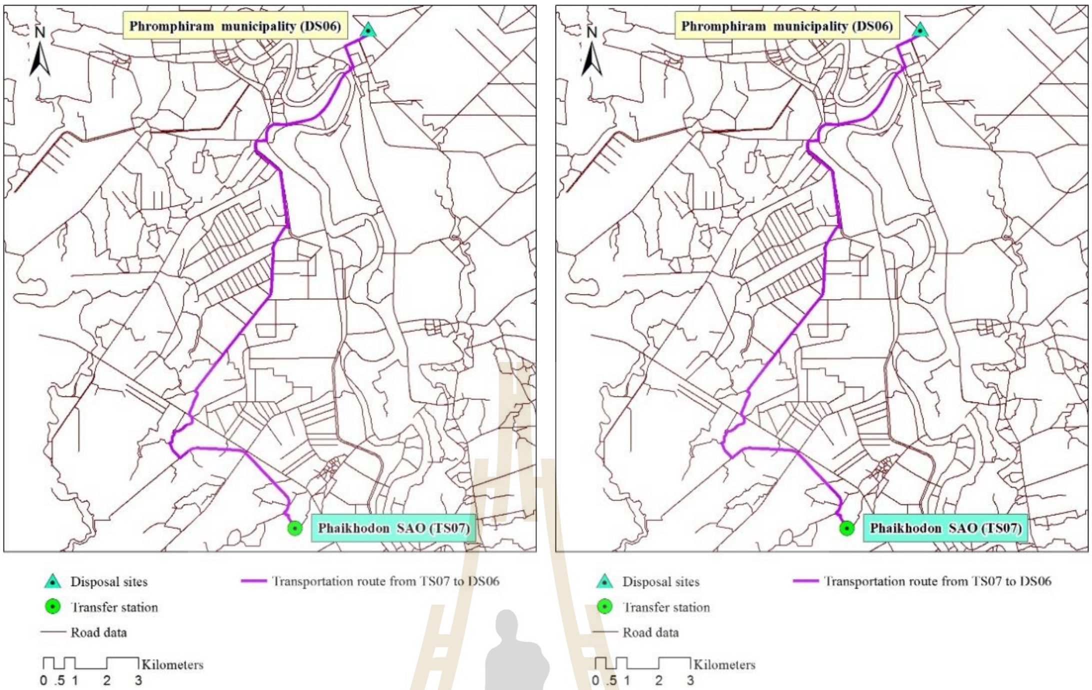


Figure 4.7 Optimum paths from each TS to DS(s) based on minimization of EI and constraints of 3 (left hand side) and 5 (right hand side) year service life of sites (Continued).

(g) TS of Phaikhodon SAO (TS07)



(h) TS of Watchan SAO (TS08)

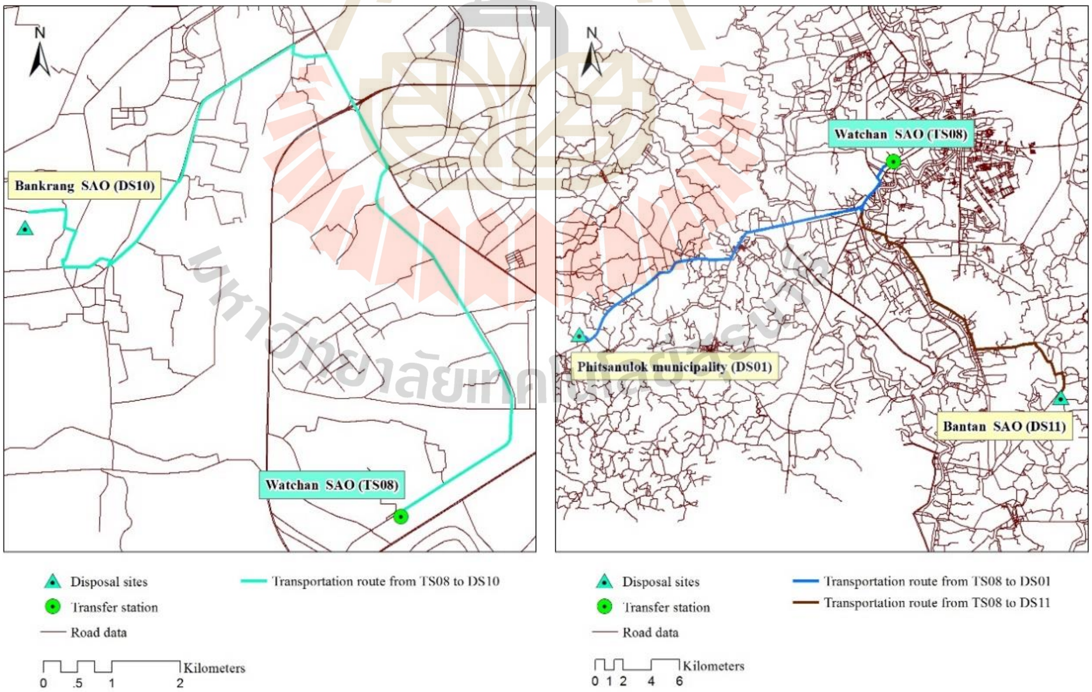
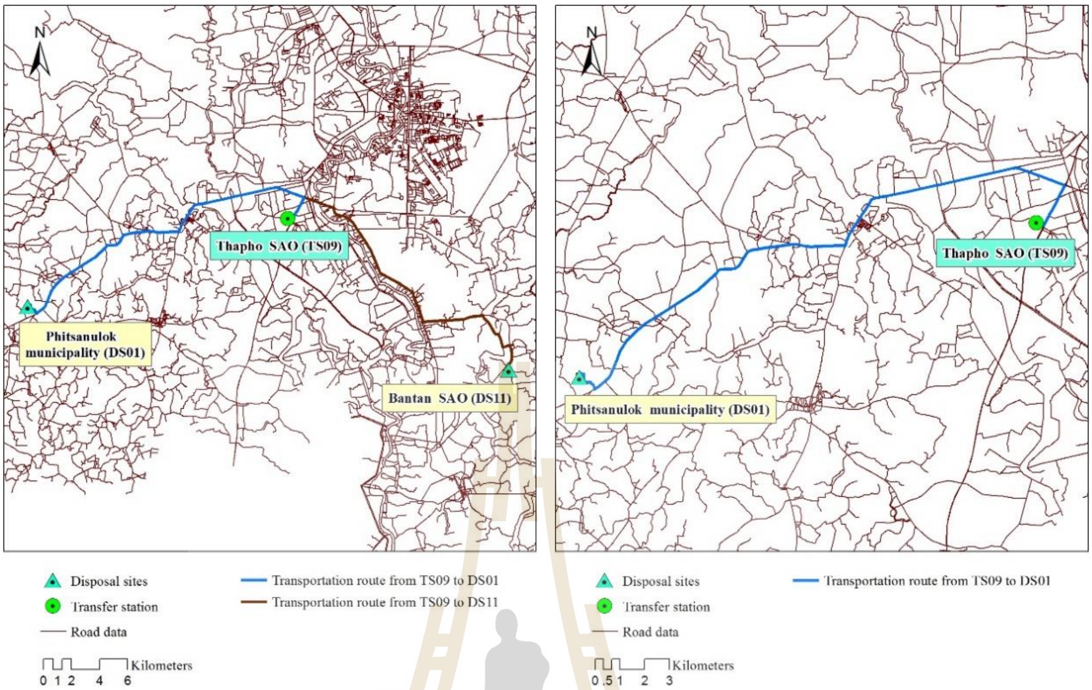


Figure 4.7 Optimum paths from each TS to DS(s) based on minimization of EI and constraints of 3 (left hand side) and 5 (right hand side) year service life of sites (Continued).

(i) TS of Thapho SAO (TS09)



(j) TS of Beungphra SAO (TS10)

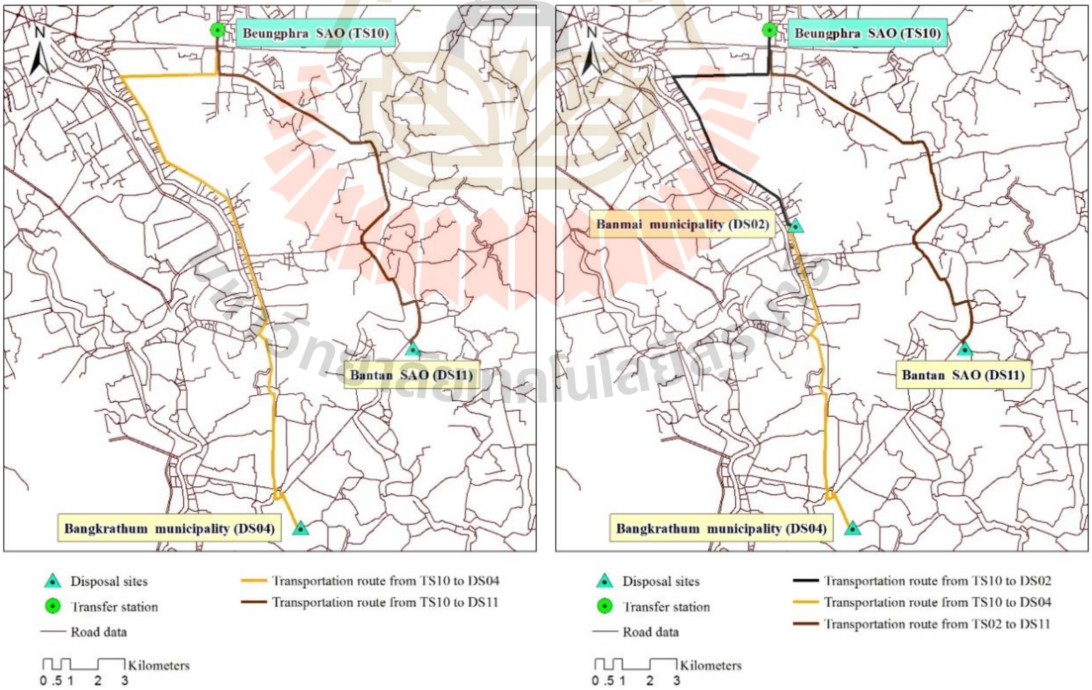


Figure 4.7 Optimum paths from each TS to DS(s) based on minimization of EI and constraints of 3 (left hand side) and 5 (right hand side) year service life of sites (Continued).

(k) TS of Bankrang SAO (TS11)

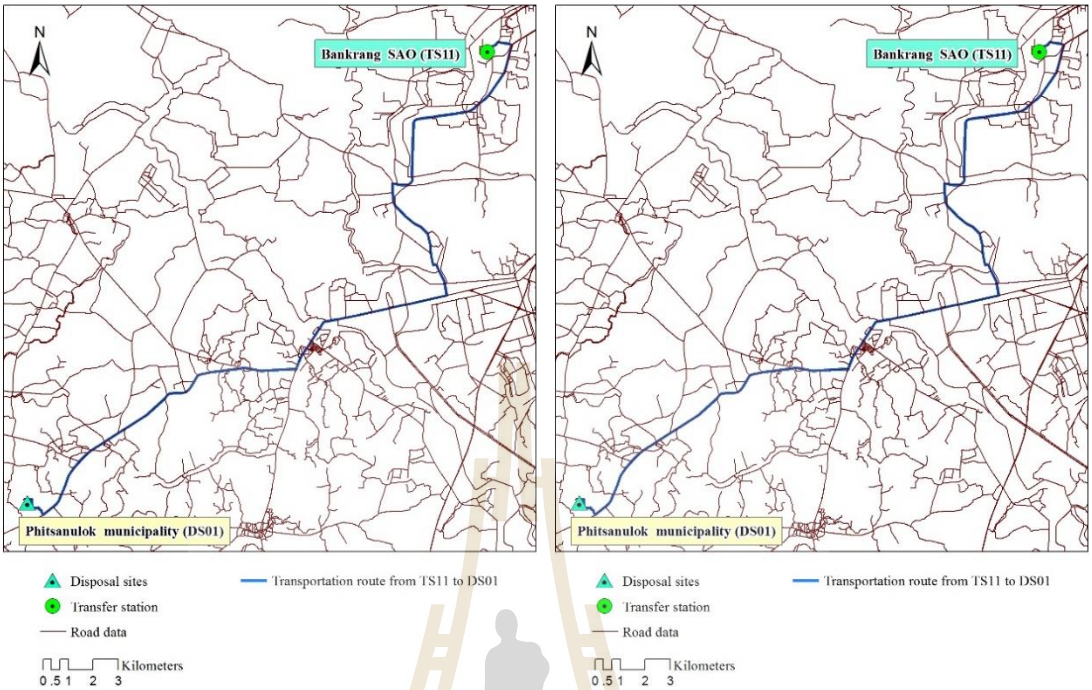
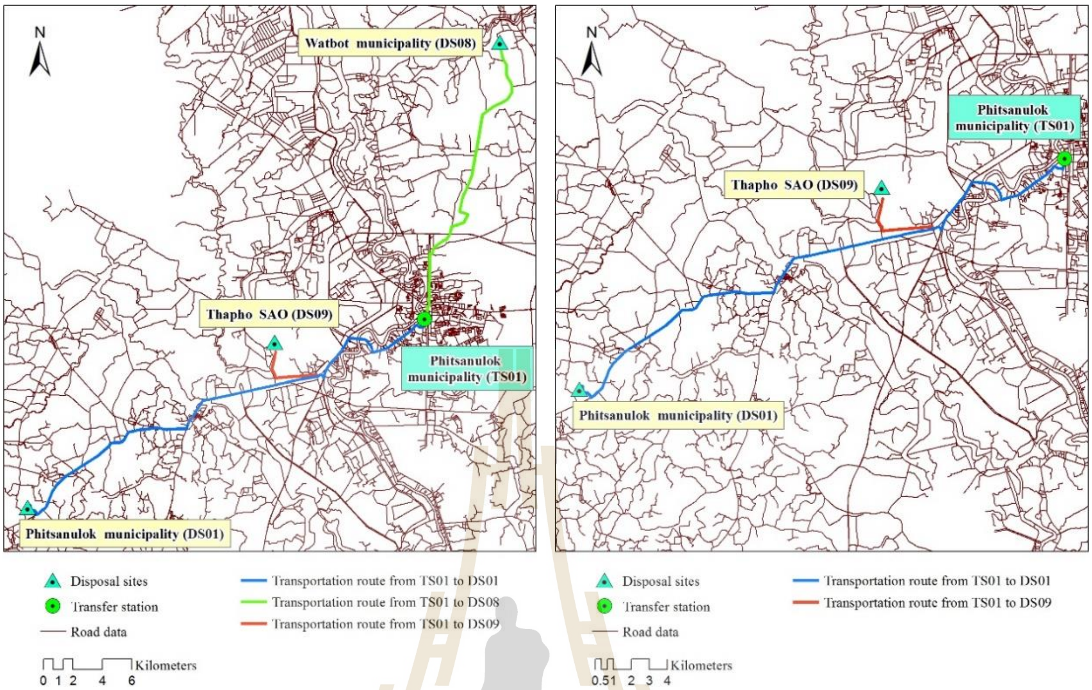


Figure 4.7 Optimum paths from each TS to DS(s) based on minimization of EI and constraints of 3 (left hand side) and 5 (right hand side) year service life of sites (Continued).

Table 4.10 Summary of waste transportation allotments from TSs to DSs based on minimization of TC and EI and 3 and 5 year capacity of DSs.

No.	Temporary TS	Optimal DS	Distances of paths (km)	3-year capacity			5-year capacity		
				Waste amount (ton/day)	TC (Baht)	EI	Waste amount (ton/day)	TC (Baht)	EI
1	Phitsanulok	- Phitsanulok	68.85	91.84	28,386.97	72.44	121.15	37,446.45	95.56
		- Watbot	45.05	14.31	2,893.91	12.84	-	-	-
		- Thapho	30.78	26.15	3,613.99	21.94	11.15	1,540.95	9.36
2	Aranyik	- Phitsanulok	77.92	-	-	-	20.40	7,137.16	8.54
		- Banmai	40.91	23.20	4,260.47	13.01	6.65	1,221.21	3.73
		- Watbot	51.83	11.13	2,589.64	5.87	7.29	1,696.18	3.84
3	Phlaichumphon	- Phitsanulok	72.25	-	-	-	7.25	2,351.92	2.29
		- Watbot	48.27	6.28	1,361.00	2.67	-	-	-
		- Bankrang	23.65	0.97	102.96	0.40	-	-	-
4	Bankhlong	- Phitsanulok	65.28	13.46	3,945.22	4.57	13.46	3,945.22	4.57
5	Thathong	- Phitsanulok	59.98	13.40	3,608.76	4.55	13.40	3,608.76	4.55
6	Huaro	- Watbot	31.41	23.36	3,293.43	11.35	23.36	3,293.43	11.35
7	Phaikhodon	- Phromphiram	46.94	-	-	-	3.73	786.14	1.92
		- Bankrang	23.38	3.73	391.61	1.49	-	-	-
8	Watchan	- Thapho	20.03	7.34	660.08	2.69	7.34	659.79	2.69
9	Thapho	- Phitsanulok	51.76	21.63	5,026.86	8.01	21.63	5,026.86	8.01
10	Beungphra	- Banmai	25.37	3.19	363.36	1.57	8.70	990.64	4.28
		- Bantan	35.23	12.79	2,022.58	5.48	7.28	1,151.24	3.12
11	Bankrang	- Thapho	33.90	-	-	-	1.60	243.54	0.61
		- Bankrang	13.08	11.06	640.61	4.72	9.46	547.93	4.03
		Total		**283.84**	**63,161.44**	**173.60**	**283.84**	**71,647.43**	**168.45**

(a) TS of Phitsanulok municipality (TS01)



(b) TS of Aranyik municipality (TS02)

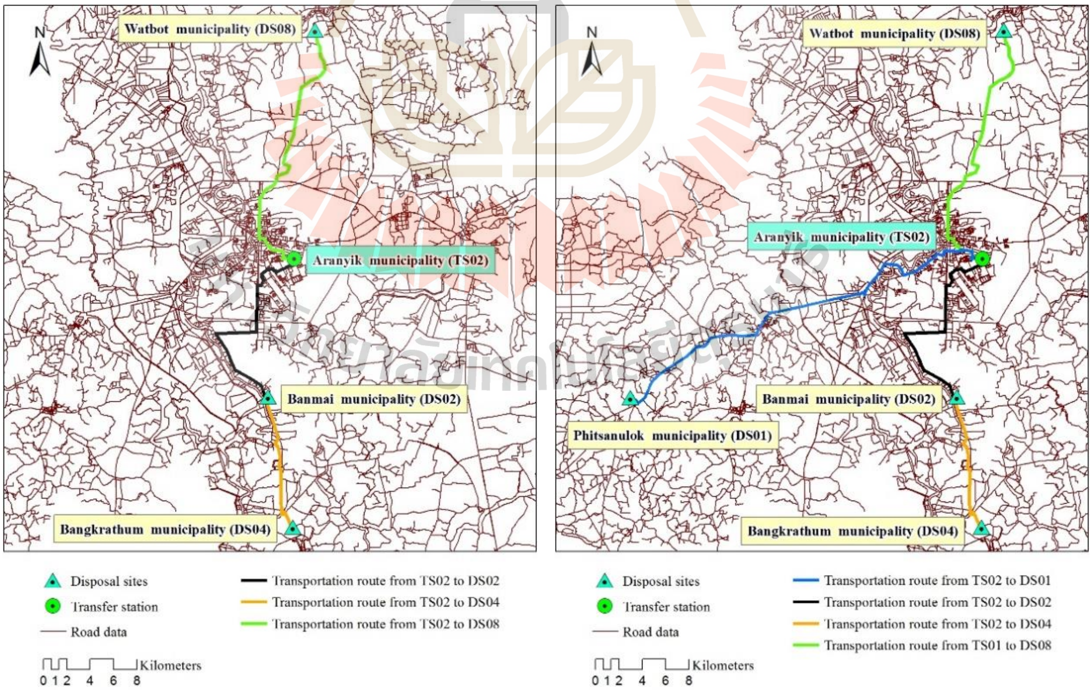
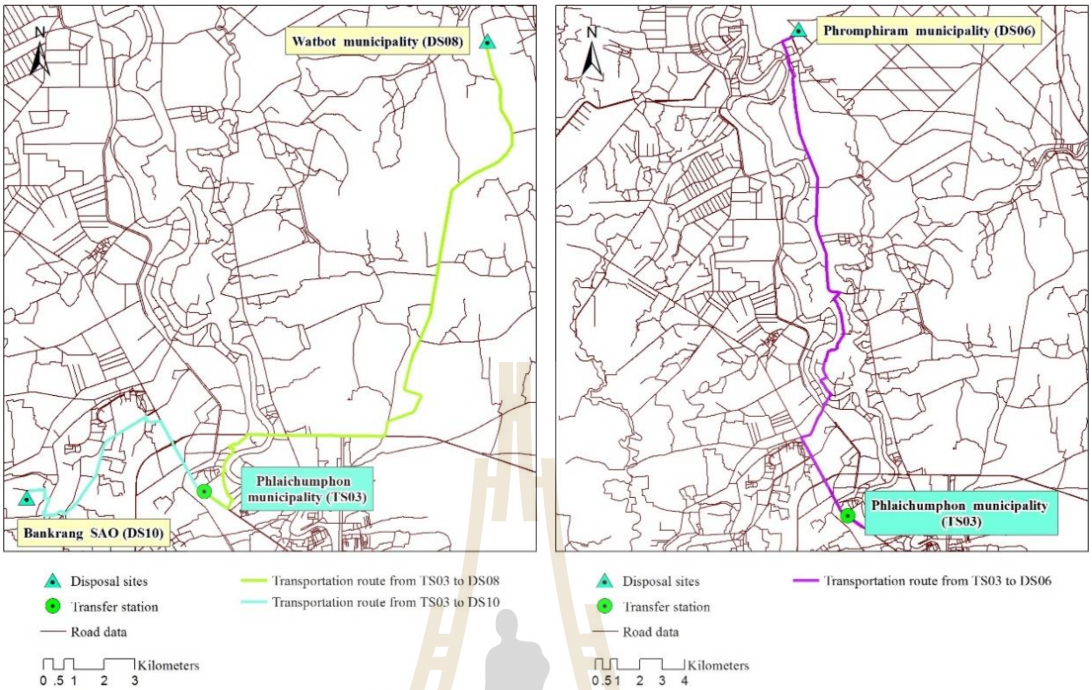


Figure 4.8 Optimum paths from each TS to DS(s) based on minimization of TC and EI and constraints of 3 (left hand side) and 5 (right hand side) year service life of sites.

(c) TS of Phlaichumphon municipality (TS03)



(d) TS of Bankhlong municipality (TS04)

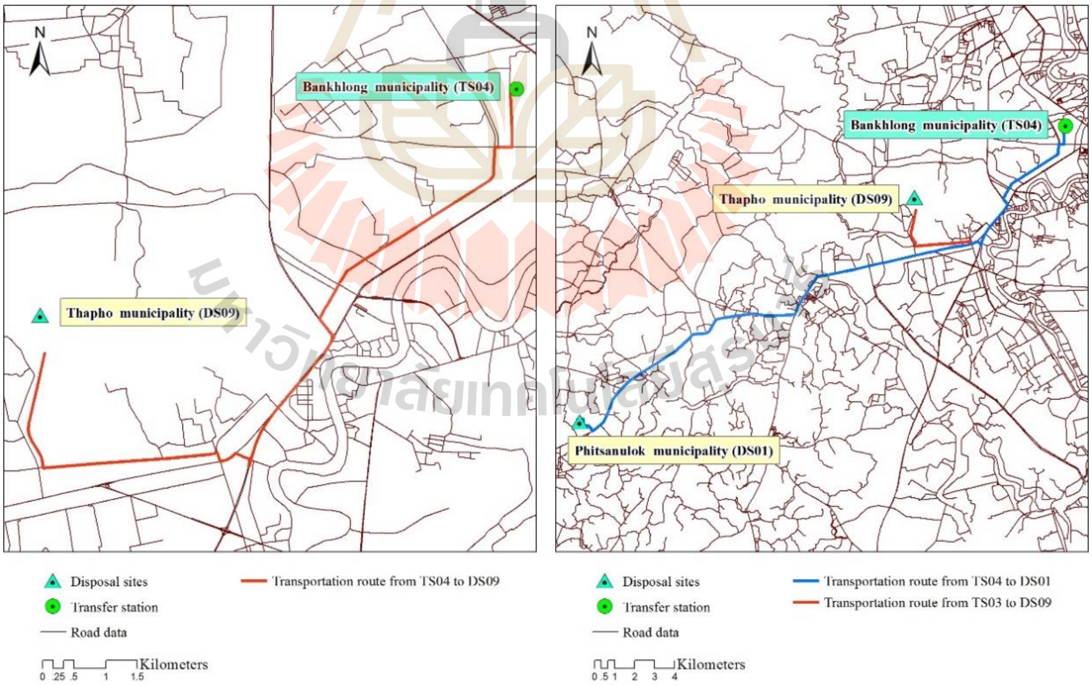
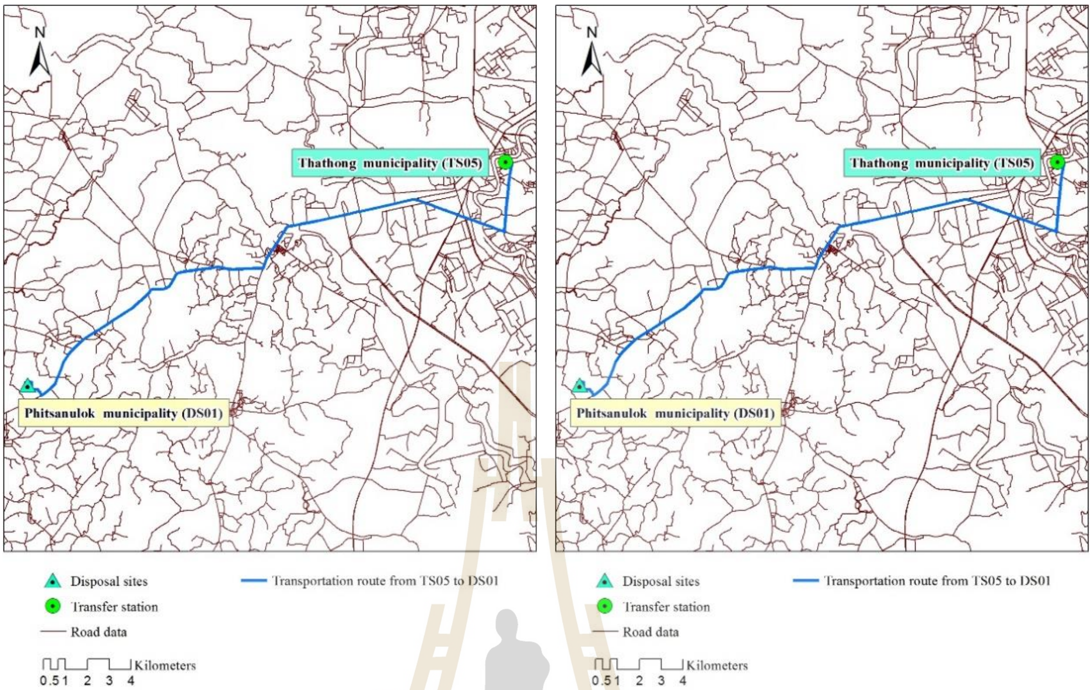


Figure 4.8 Optimum paths from each TS to DS(s) based on minimization of TC and EI and constraints of 3 (left hand side) and 5 (right hand side) year service life of sites (Continued).

(e) TS of Thathong municipality (TS05)



(f) TS of Huaro municipality (TS06)

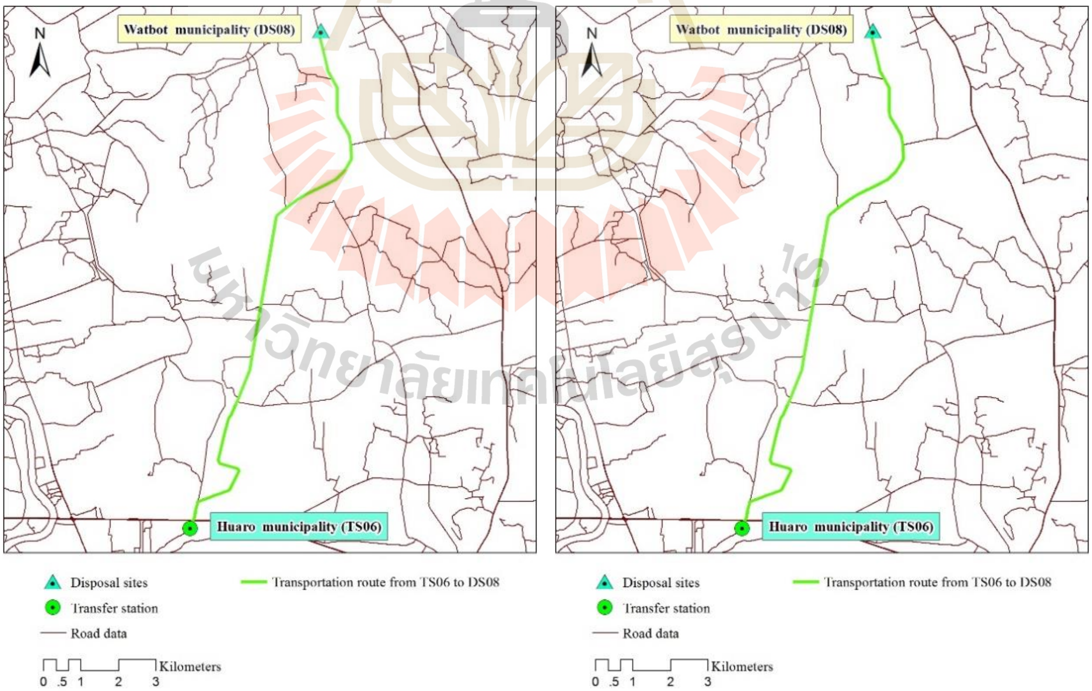
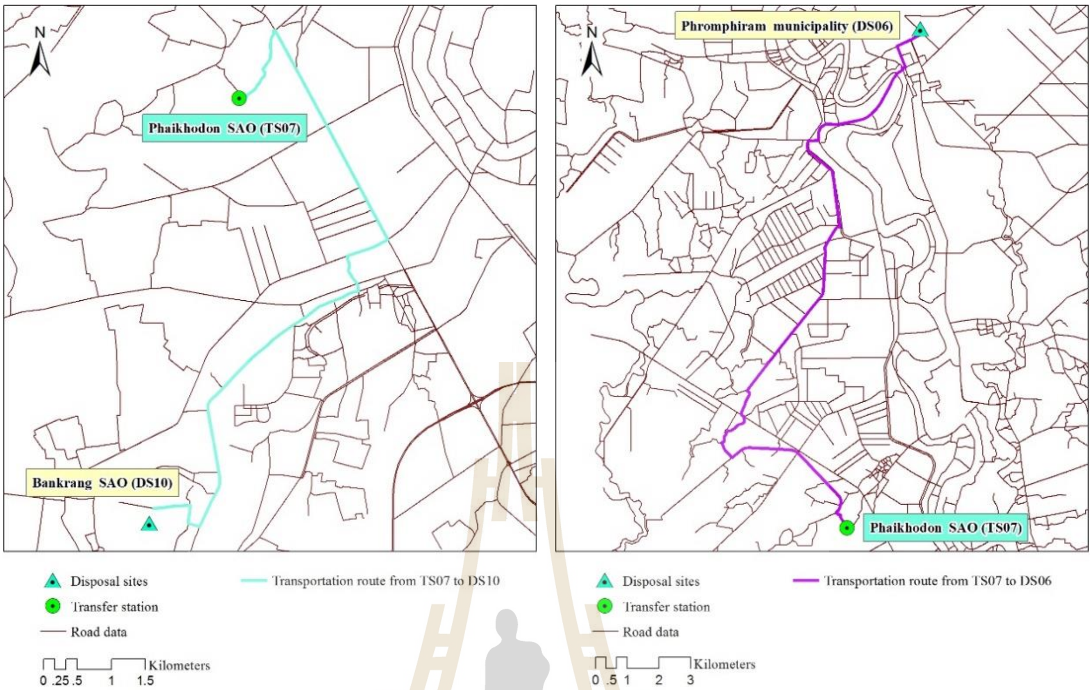


Figure 4.8 Optimum paths from each TS to DS(s) based on minimization of TC and EI and constraints of 3 (left hand side) and 5 (right hand side) year service life of sites (Continued).

(g) TS of Phaikhodon SAO (TS07)



(h) TS of Watchan SAO (TS08)

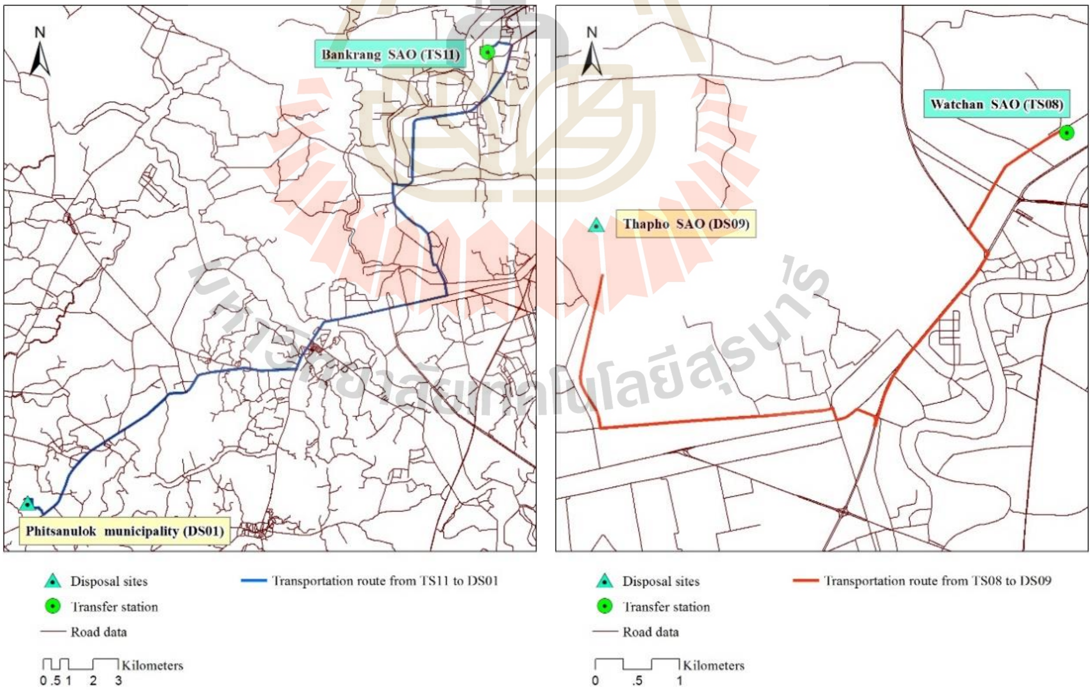
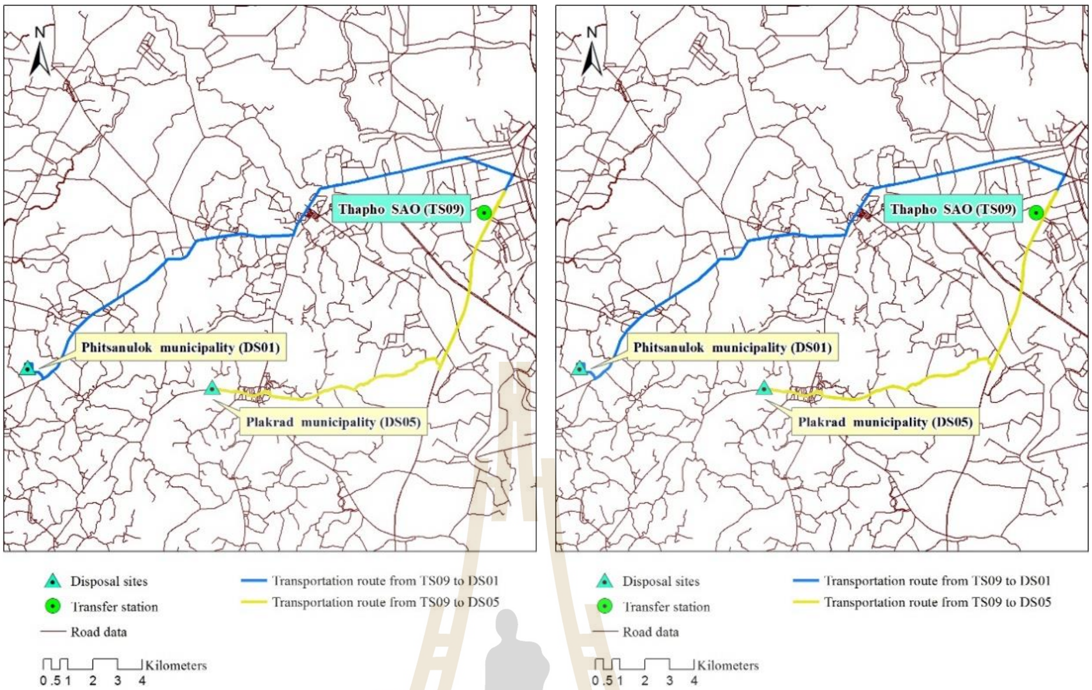


Figure 4.8 Optimum paths from each TS to DS(s) based on minimization of TC and EI and constraints of 3 (left hand side) and 5 (right hand side) year service life of sites (Continued).

(i) TS of Thapho SAO (TS09)



(j) TS of Beungphra SAO (TS10)

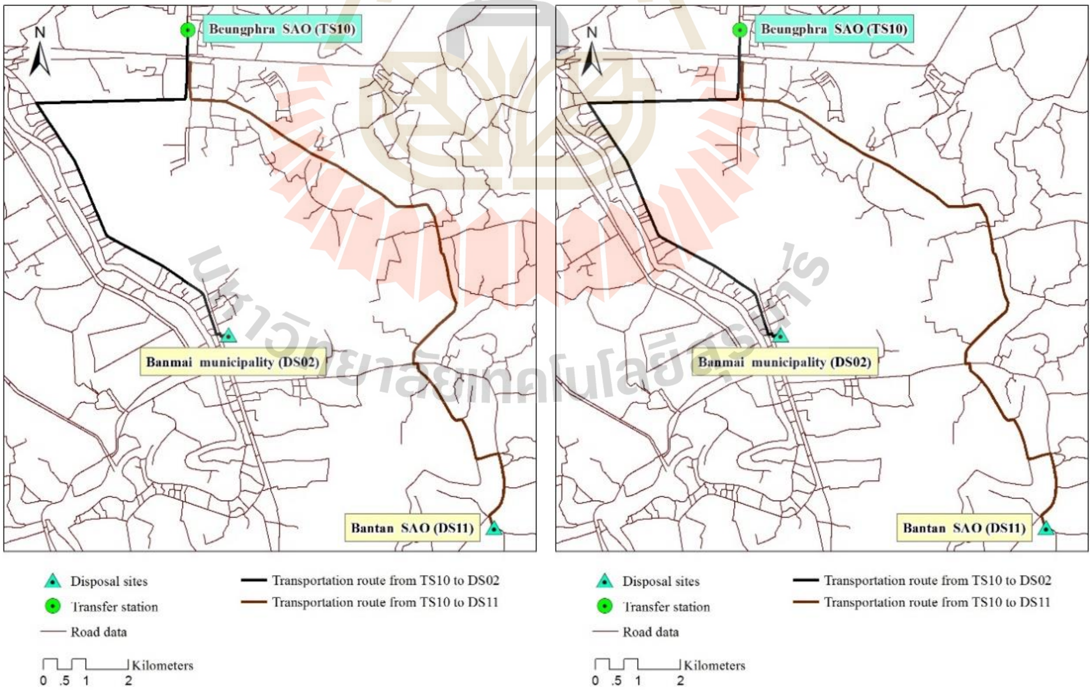


Figure 4.8 Optimum paths from each TS to DS(s) based on minimization of TC and EI and constraints of 3 (left hand side) and 5 (right hand side) year service life of sites (Continued).

(k) TS of Bankrang SAO (TS11)

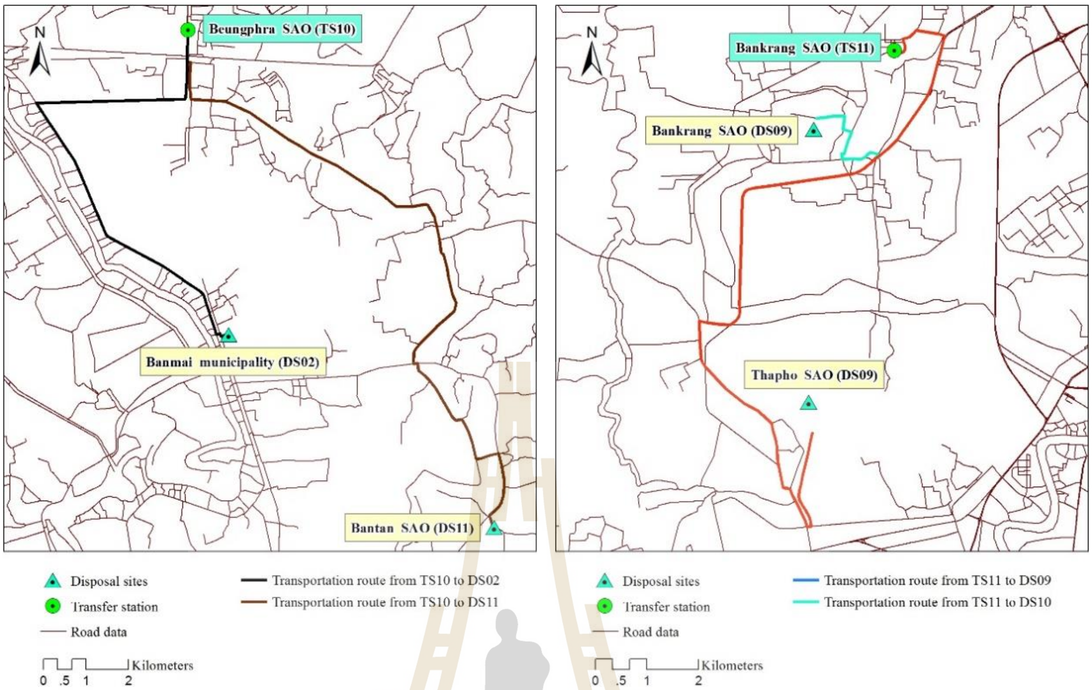


Figure 4.8 Optimum paths from each TS to DS(s) based on minimization of TC and EI and constraints of 3 (left hand side) and 5 (right hand side) year service life of sites (Continued).

Referring to Tables 4.8 - 4.10, waste allotment from each TS to active DSs based on 3-year and 5-year service life are different. For example in Table 4.8, in 3-year capacity the waste from Phitsanulok TS is allotted to DSs of Phitsanulok, Plakrad, Phromphiram, Watbot, and Thapho in amounts of 47.77, 4.12, 37.84, 29.88, and 12.69 tons/day, respectively, while 5-year capacity it is allotted to only DS of Phitsanulok with waste amount of 132.30 tons/day. For 3-year capacity, daily capacities of DSs are higher. Then allotment from this TS has more chance to the closer DSs. For 5-year capacity all waste from this TS is allotted to only DS of Phitsanulok. Because daily capacities of all DSs are decreased but the closer DSs are already taken first by waste from other TSs and filled up. Then all waste from this TS only comes to this DS.

When considering Table 4.9 of minimized EI objective, it means the distance between TS-DS pairs and TC are ignored. Therefore, wastes from many TSs with small amounts of waste can be allotted to Phitsanulok DS which has the least EI among other DSs. This makes EI of those pairs having low EI. Moreover, look in 5-year capacity, waste from Phitsanulok TS are allotted to 6 DSs because the capacity of Phitsanulok DS is filled up. Then the rest can goes to other DSs which have more EI in order.

In Table 4.10, the minimized both TC and EI objective can lead to compromise in waste allotment. The number of DSs waste allotted to are not obviously different in 3-year and 5-year capacities, like appear in Tables 4.8 - 4.9 of other objectives. It is remarkable in allotment of TSs with high waste amount such as Phitsanulok and Aranyik TSs.

4.6 Comparison of the results

With different objectives in the MODA, 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 and EI with respect to specific objectives separated by service life of sites are summarized and displayed in Tables 4.11 and 4.12.

The summarized results (Table 4.13) express valid and reasonable TC and EI for different objectives. For example total TC of minimized TC objective provides comparatively minimum value while total EI does the same for minimized EI objective. Based on minimized TC and EI objective, the results shows compromised total TC and EI falling in the middle of results from minimized TC and EI objectives. In all objectives, total TCs seem to show significantly different more than total EIs do. The significant difference is more obvious in 3-year service life of site.

The difference of total TCs and EIs based on specific objectives can be compared based on percentage of the difference between the maximum and minimum values divided by the maximum value. Of 3-year service life, the differences of total TC and EI are 23.26% and 11.88%, while they are 11.55% and 4.94% of 5-year service life, respectively. Therefore, it can be concluded that total TCs of 3-year service life show the most significant benefit. The results of 3-year service life seem to be better than results of 5-year service life. 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 environmental impact. However, shortening service life of DSs requires new DS sooner which is a difficult task that can cause significant conflicts on

Table 4.11 The summary of results of waste management based on specific objectives and 3-year service life of site.

Temporary TS	Optimal DS	Distance of paths (km)	TC minimization			EI minimization			TC and EI minimization		
			Waste amount (ton/day)	**TC (Baht)**	**EI**	**Waste amount (ton/day)**	**TC (Baht)**	**EI**	**Waste amount (ton/day)**	**TC (Baht)**	**EI**
Phitsanulok	- Phitsanulok	68.85	47.77	14,765.31	37.68	70.46	21,778.59	55.58	91.84	28,386.97	72.44
	- Plakrad	58.12	4.12	1,075.15	3.85	-	-	-	-	-	-
	- Phromphiram	59.85	37.84	10,166.91	37.84	-	-	-	-	-	-
	- Watbot	45.05	29.88	6,042.62	26.81	12.58	2,544.05	11.29	14.31	2,893.91	12.84
	- Thapho	30.78	12.69	1,753.79	10.65	33.49	4,628.39	28.09	26.15	3,613.99	21.94
	- Bankrang	33.80	-	-	-	15.76	2,391.77	13.94	-	-	-
Aranyik	- Phitsanulok	77.92	-	-	-	34.33	12,010.72	14.37	-	-	-
	- Banmai	40.91	26.38	4,844.45	14.80	-	-	-	23.20	4,260.47	13.01
	- Bangkrathum	65.59	6.10	1,796.17	3.40	-	-	-	-	-	-
	- Phromphiram	66.76	-	-	-	-	-	-	-	-	-
	- Watbot	51.83	1.84	428.12	0.97	-	-	-	11.13	2,589.64	5.87
Phlaichum-phon	- Phitsanulok	72.25	-	-	-	7.25	2,351.59	2.29	-	-	-
	- Phromphiram	54.06	2.55	618.96	1.34	-	-	-	-	-	-
	- Watbot	48.27	-	-	-	-	-	-	6.28	1,361.00	2.67
	- Bankrang	23.65	4.70	498.87	1.94	-	-	-	0.97	102.96	0.40
Bankhlong	- Phitsanulok	65.28	-	-	-	13.46	3,945.22	4.57	13.46	3,945.22	4.57
	- Thapho	27.22	13.46	1,645.05	5.24	-	-	-	-	-	-
Thathong	- Phitsanulok	59.98	13.40	3,608.76	4.55	13.40	3,608.76	4.55	13.40	3,608.76	4.55
Huaro	- Phitsanulok	80.07	-	-	-	23.36	8,397.21	8.81	-	-	-
	- Watbot	31.41	23.36	3,293.43	11.35	-	-	-	23.36	3,293.43	11.35

Table 4.11 The summary of results of waste management based on specific objectives and 3-year service life of site (Continued).

Temporary TS	Optimal DS	Distance of paths (km)	TC minimization			EI minimization			TC and EI minimization		
			Waste amount (ton/day)	TC (Baht)	EI	Waste amount (ton/day)	TC (Baht)	EI	Waste amount (ton/day)	TC (Baht)	EI
Phaikhodon	- Phromphiram	46.94	3.73	786.14	1.92	-	-	-	-	-	-
	- Watbot	53.59	-	-	-	3.73	897.34	1.53	-	-	-
	- Bankrang	23.38	-	-	-	-	-	-	3.73	391.61	1.49
Watchan	- Thapho	20.03	-	-	-	-	-	-	7.34	660.08	2.69
	- Bankrang	31.92	7.34	1,051.97	2.69	-	-	-	-	-	-
	- Bantan	55.92	-	-	-	7.34	1,842.94	2.91	-	-	-
Thapho	- Phitsanulok	51.76	-	-	-	16.18	3,760.27	5.99	21.63	5,026.86	8.01
	- Plakrad	38.99	21.63	3,785.69	11.15	-	-	-	-	-	-
	- Bantan	49.34	-	-	-	5.45	1,207.37	2.45	-	-	-
Beungphra	- Phitsanulok	64.26	-	-	-	15.98	4,610.67	5.58	-	-	-
	- Banmai	25.37	-	-	-	-	-	-	3.19	363.36	1.57
	- Bangkrathum	50.05	3.19	717.01	1.56	-	-	-	-	-	-
	- Bantan	35.23	12.79	2,022.58	5.48	-	-	-	12.79	2,022.58	5.48
Bankrang	- Phitsanulok	72.86	-	-	-	11.06	3,618.18	3.66	-	-	-
	- Bankrang	13.08	11.06	640.61	4.72	-	-	-	11.06	640.61	4.72
SUM			**283.84**	**59,541.59**	**187.94**	**283.84**	**77,593.08**	**165.61**	**283.84**	**63,161.44**	**173.6**

Table 4.12 The summary of results of waste management based on specific objectives and 5-year service life of site.

Temporary TS	Optimal DS	Distance of paths (km)	TC minimization			EI minimization			TC and EI minimization		
			Waste amount (ton/day)	TC (Baht)	EI	Waste amount (ton/day)	TC (Baht)	EI	Waste amount (ton/day)	TC (Baht)	EI
Phitsanulok	- Phitsanulok	68.85	132.30	40,892.82	104.36	64.95	20,075.50	51.23	121.15	37,446.45	95.56
	- Banmai	36.83	-	-	-	7.11	1,176.08	6.62	-	-	-
	- Bangkrathum	61.52	-	-	-	3.78	1,044.13	3.50	-	-	-
	- Watbot	45.05	-	-	-	26.92	5,444.02	24.16	-	-	-
	- Thapho	30.78	-	-	-	20.10	2,777.86	16.86	11.15	1,540.95	9.36
	- Bankrang	33.80	-	-	-	9.46	1,435.67	8.37	-	-	-
Aranyik	- Phitsanulok	77.92	3.21	1,123.05	1.35	34.33	12,010.72	14.37	20.40	7,137.16	8.54
	- Banmai	40.91	10.42	1,913.54	5.85	-	-	-	6.65	1,221.21	3.73
	- Phromphiram	66.76	13.41	4,019.68	8.44	-	-	-	-	-	-
	- Watbot	51.83	7.29	1,696.18	3.84	-	-	-	7.29	1,696.18	3.84
Phlaichum-phon	- Phitsanulok	72.25		-	-	7.25	2,351.92	2.29	7.25	2,351.92	2.29
	- Phromphiram	54.06	7.25	1,759.79	3.82	-	-	-	-	-	-
Bankhlong	- Phitsanulok	65.28	0.70	205.18	0.24	13.46	3,945.22	4.57	13.46	3,945.22	4.57
	- Thapho	27.22	12.76	1,559.50	4.97	-	-	-	-	-	-
Thathong	- Phitsanulok	59.98	13.40	3,608.76	4.55	13.40	3,608.76	4.55	13.40	3,608.76	4.55
Huaro	- Phitsanulok	80.06	-	-	-	23.36	8,398.25	8.81	-	-	-
	- Watbot	31.40	23.36	3,293.43	11.35	-	-	-	23.36	3,293.43	11.35
Phaikhodon	- Phromphiram	46.94	3.73	786.14	1.92	-	-	-	3.73	786.14	1.92
	- Watbot	53.58	-	-	-	3.73	897.34	1.53	-	-	-
Watchan	- Phitsanulok	58.10	-	-	-	0.06	15.65	0.02	-	-	-
	- Thapho	20.03	7.34	659.79	2.69	-	-	-	7.34	659.79	2.69
	- Bantan	55.92	-	-	-	7.28	1,827.87	2.88	-	-	-
Thapho	- Phitsanulok	51.76	7.70	1,789.50	2.85	21.63	5,026.86	8.01	21.63	5,026.86	8.01
	- Plakrad	38.98	13.93	2,438.03	7.18	-	-	-	-	-	-

Table 4.12 The summary of results of waste management based on specific objectives and 5-year service life of site (Continued).

Temporary TS	Optimal DS	Distance of paths (km)	TC minimization			EI minimization			TC and EI minimization		
			Waste amount (ton/day)	TC (Baht)	EI	Waste amount (ton/day)	TC (Baht)	EI	Waste amount (ton/day)	TC (Baht)	EI
Beungphra	- Phitsanulok	64.26	-	-	-	15.98	4,610.67	5.58	-	-	-
	- Banmai	25.37	4.93	561.36	2.42	-	-	-	8.70	990.64	4.28
	- Bangkrathum	50.05	3.78	849.63	1.84	-	-	-	-	-	-
	- Bantan	35.23	7.28	1,151.24	3.12	-	-	-	7.28	1,151.24	3.12
Bankrang	- Phitsanulok	72.86	-	-	-	11.06	3,618.18	3.66	-	-	-
	- Phromphiram	51.24	1.60	368.11	0.87	-	-	-	-	-	-
	- Thapho	33.90	-	-	-	-	-	-	1.60	243.54	0.61
	- Bankrang	12.90	9.46	547.93	4.03	-	-	-	9.46	547.93	4.03
SUM			**283.84**	**69,223.65**	**175.69**	**283.84**	**78,264.71**	**167.01**	**283.84**	**71,647.43**	**168.45**

Table 4.13 The summarized results of MODA.

Objectives	Total TC		Total EI	
	3 year	**5 year**	**3 year**	**5 year**
TC minimization	59,541.59	69,223.65	187.94	175.69
EI minimization	77,593.08	78,264.71	165.61	167.01
TC and EI minimization	63,161.44	71,647.43	173.60	168.45
Difference (%)	23.26	11.55	11.88	4.94

economic and environment to stakeholders. The study results provide basic and useful information for decision makers in waste transportation management of the area.

4.7 Validated results

To ensure the accuracy of the study results, validation of results from NA and LP are concerned.

4.7.1 Validation of NA results

Eleven sample paths were picked up from every TS to any DSs as suggested in 3.6.1. These path distances are compared to optimum paths from the NA as listed in Table 4.14. None of sample path distances is shorter than or equal corresponding optimum path distances. It confirms that the performance of NA provides a validated result of optimum paths of TS-DS pairs. The comparison of corresponding paths are shown in Figure 4.9 as well.

Table 4.14 The comparison of corresponding path distances from NA and sample paths to validate.

No.	Transportation routes	Distance of path from NA (km)	Distance of sample path to validate (km)
1	Temporary TS of Phitsanulok (TS01) to DS of Aranyik (DS02)	18.42	18.98
2	Temporary TS of Aranyik (TS02) to DS of Thapho (DS09)	19.93	21.78
3	Temporary TS of Phlaichumphon (TS03) to DS of Phromphiram (DS06)	27.03	30.44
4	Temporary TS of Bankhlong (TS04) to DS of Watbot (DS08)	25.14	33.23
5	Temporary TS of Thathong (TS05) to DS of Bantan (DS11)	24.18	27.35
6	Temporary TS of Huaro (TS06) to DS of Watbot (DS08)	15.70	19.53
7	Temporary TS of Phaikhodon (TS07) to DS of Bankrang (DS10)	11.69	12.03
8	Temporary TS of Watchan (TS08) to DS of Plakrad (DS05)	23.69	26.23
9	Temporary TS of Thapho (TS09) to DS of Plakrad (DS05)	19.49	20.17
10	Temporary TS of Beungphra (TS10) to DS of Nuenkum (DS03)	38.78	42.48
11	Temporary TS of Bankrang (TS11) to DS of Phitsanulok (DS01)	36.43	40.80

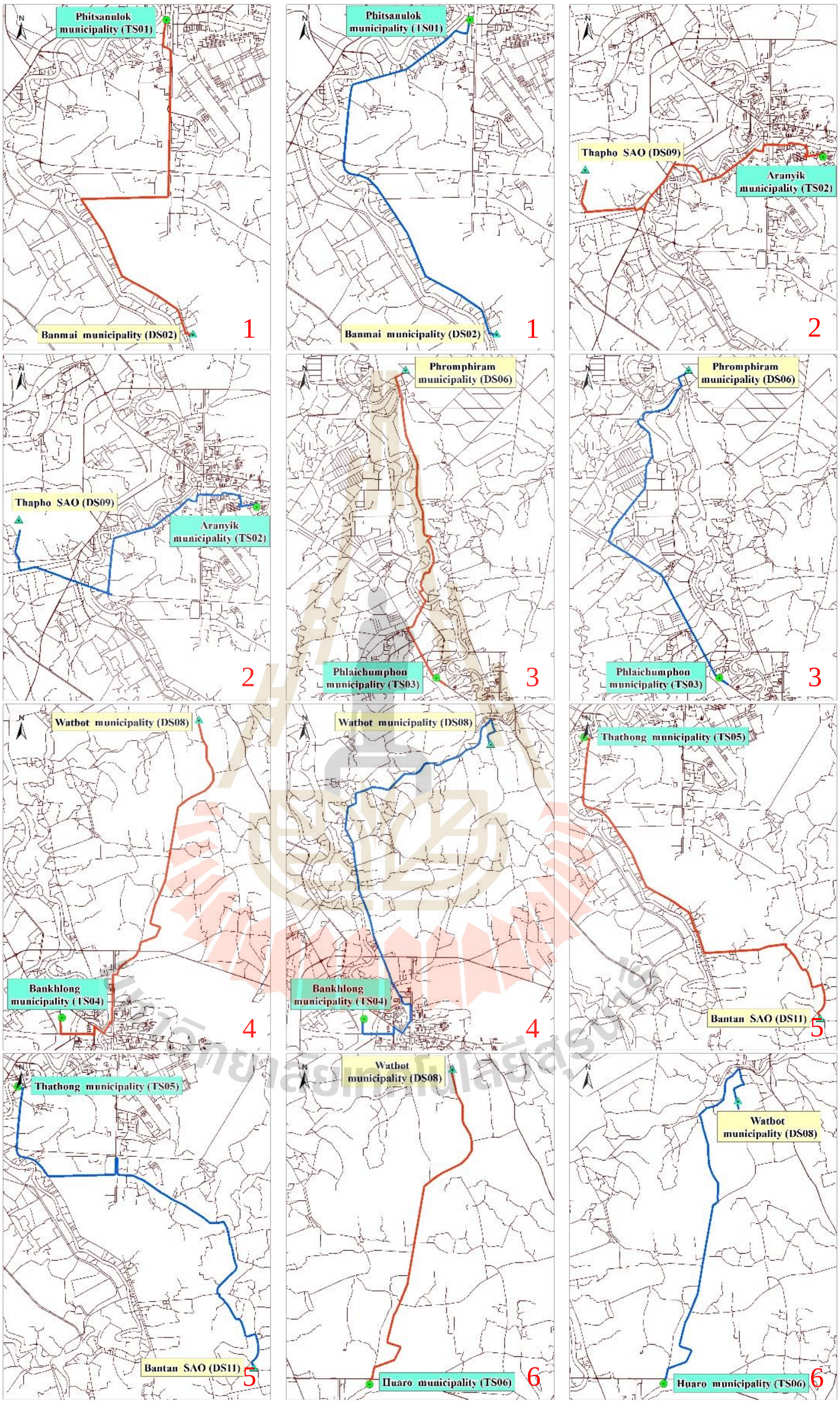


Figure 4.9 The comparison of corresponding paths from NA and sample paths to validate.

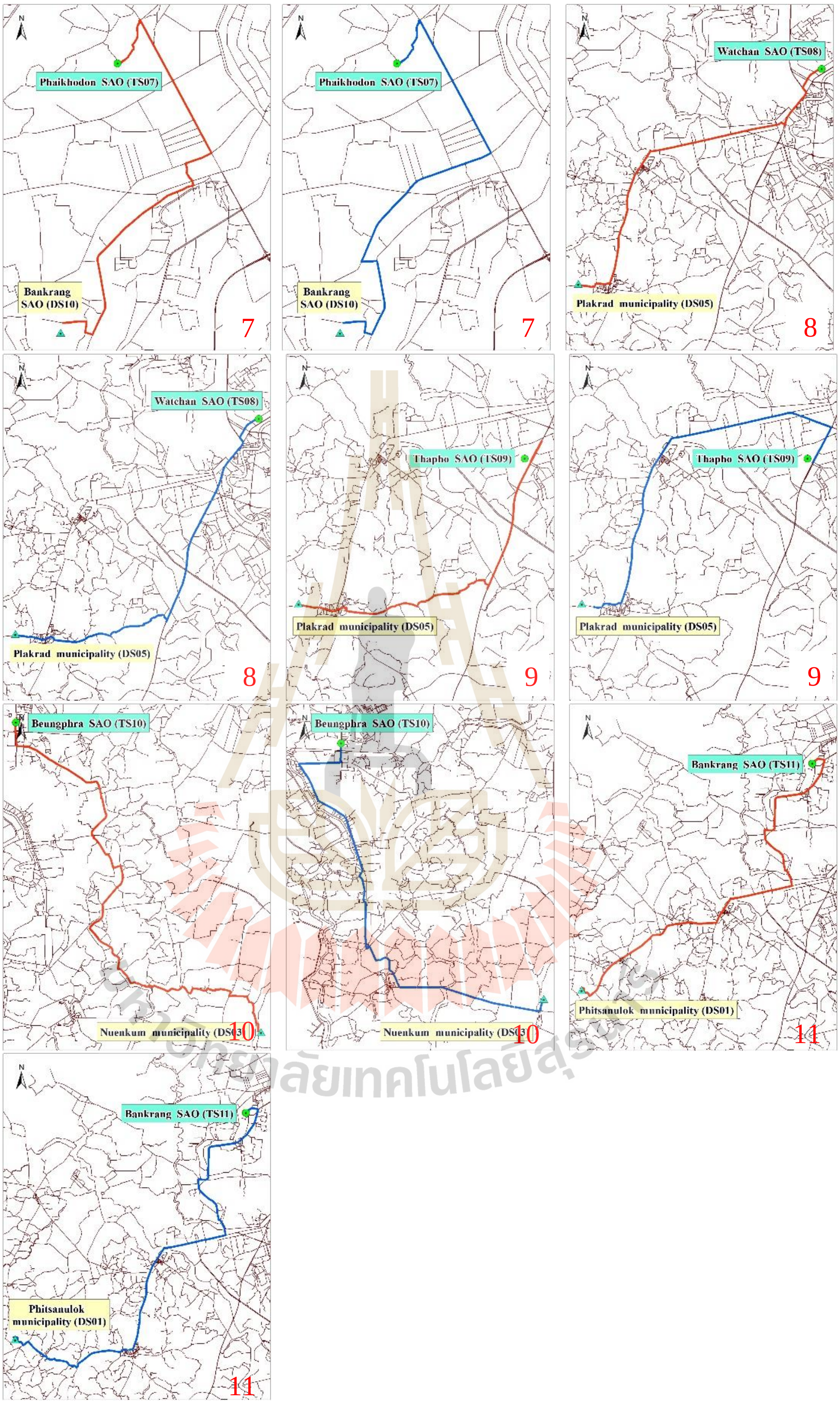


Figure 4.9 The comparison of corresponding paths from NA and sample paths to validate (Continued).

4.7.2 Validation of LP results

The validation of LP results to serve minimized TC and EI objectives were performed on (a) a list of a TS to all DSs (11 pairs) and (b) a list of all pairs of all TSs and DSs (121 pairs) as suggested in 3.6.2. The validation is separated based on each objective and on 3-year and 5-year capacity. For minimized TC objective, Table 4.15 of 3-year capacity and Table 4.16 of 5-year capacity show daily waste allotment, TC, and EI from the different lists of pairs. For minimized EI objective, Table 4.17 of 3-year capacity and Table 4.18 of 5-year capacity show daily waste allotment, TC, and EI from the different lists of pairs. Summary of TC and EI of objectives and different capacity is shown in Table 4.19.

Table 4.15 Validation results of minimized TC objective and 3-year service life of sites.

No.	Temporary TS	Optimal DS	Distance of paths (km)	LP 3-Year			List of a TS to all DSs			List of all pairs		
				Waste amount (ton/day)	TC (Baht)	EI	Waste amount (ton/day)	TC (Baht)	EI	Waste amount (ton/day)	TC (Baht)	EI
1	Phitsanulok	- Phitsanulok	68.84	47.77	14,765.31	37.68	-	-	-	33.36	10,311.30	26.31
		- Banmai	36.83	-	-	-	26.38	4,362.65	24.57	1.52	251.37	1.42
		- Bangkrathum	61.52	-	-	-	-	-	-	9.29	2,565.95	8.62
		- Plakrad	58.12	4.12	1,075.15	3.85	-	-	-	25.75	6,719.69	24.05
		- Phromphiram	59.84	37.84	10,166.91	37.84	-	-	-	30.66	8,237.78	30.66
		- Watbot	45.04	29.88	6,042.62	26.81	55.08	11,138.81	49.43	31.72	6,414.72	28.47
		- Thapho	30.78	12.69	1,753.79	10.65	33.49	4,628.39	28.09	-	-	-
		- Bankrang	33.80	-	-	-	15.76	2,391.75	13.94	-	-	-
		- Bantan	46.69	-	-	-	1.59	333.35	1.38	-	-	-
2	Aranyik	- Phitsanulok	77.92	-	-	-	-	-	-	34.33	12,010.72	14.37
		- Banmai	40.90	26.38	4,844.45	14.80	-	-	-	-	-	-
		- Bangkrathum	65.58	6.10	1,796.17	3.40	9.29	2,735.48	5.18	-	-	-
		- Wongkong	89.87	-	-	-	13.84	5,584.66	7.76	-	-	-
		- Watbot	51.82	1.84	428.12	0.97	-	-	-	-	-	-
		- Bantan	50.77	-	-	-	11.20	2,552.94	5.58	-	-	-
3	Phlaichumphon	- Phitsanulok	72.25	-	-	-	-	-	-	6.28	2,037.22	1.99
		- Phromphiram	54.06	2.55	618.96	1.34	7.25	1,759.79	3.82	-	-	-
		- Bankrang	23.64	4.70	498.87	1.94	-	-	-	0.97	102.96	0.40

Table 4.15 Validation results of minimized TC objective and 3-year service life of sites (Continued).

No.	Temporary TS	Optimal DS	Distance of paths (km)	LP 3-Year			List of a TS to all DSs			List of all pairs		
				Waste amount (ton/day)	TC (Baht)	EI	Waste amount (ton/day)	TC (Baht)	EI	Waste amount (ton/day)	TC (Baht)	EI
4	Bankhlong	- Plakrad	54.56	-	-	-	13.46	3,297.35	6.52	-	-	-
		- Phromphiram	57.14	-	-	-	-	-	-	13.46	3,453.54	7.41
		- Thapho	27.22	13.46	1,645.05	5.24	-	-	-	-	-	-
5	Thathong	- Phitsanulok	59.98	13.40	3,608.76	4.55	1.11	298.93	0.38	-	-	-
		- Banmai	27.30	-	-	-	-	-	-	8.88	1,088.55	4.28
		- Plakrad	49.26	-	-	-	12.29	2,718.18	5.95	-	-	-
		- Thapho	22.94	-	-	-	-	-	-	4.52	465.65	1.76
6	Huaro	- Phromphiram	52.12	-	-	-	23.36	5,466.46	13.74	-	-	-
		- Watbot	31.40	23.36	3,293.43	11.35	-	-	-	23.36	3,293.43	11.35
7	Phaikhodon	- Phromphiram	46.94	3.73	786.14	1.92	3.73	786.14	1.92	-	-	-
		- Bankrang	23.38	-	-	-	-	-	-	3.73	391.61	1.49
8	Watchan	- Phitsanulok	58.10	-	-	-	7.34	1,914.69	2.32	-	-	-
		- Thapho	20.02	-	-	-	-	-	-	7.34	659.79	3.69
		- Bankrang	31.92	7.34	1,051.97	2.69	-	-	-	-	-	-
9	Thapho	- Phitsanulok	51.76	-	-	-	21.63	5,026.86	8.01	-	-	-
		- Plakrad	38.98	21.63	3,785.69	11.15	-	-	-	-	-	-
		- Thapho	14.72	-	-	-	-	-	-	21.63	1,429.58	10.10

Table 4.15 Validation results of minimized TC objective and 3-year service life of sites (Continued).

No.	Temporary TS	Optimal DS	Distance of paths (km)	LP 3-Year			List of a TS to all DSs			List of all pairs		
				Waste amount (ton/day)	TC (Baht)	EI	Waste amount (ton/day)	TC (Baht)	EI	Waste amount (ton/day)	TC (Baht)	EI
10	Beungphra	- Phitsanulok	64.26	-	-	-	15.98	4,610.89	5.58	-	-	-
		- Banmai	25.36	-	-	-	-	-	-	15.98	1,819.59	8.86
		- Bangkrathum	50.06	3.19	717.01	1.56	-	-	-	-	-	-
		- Bantan	35.22	12.79	2,022.58	5.48	-	-	-	-	-	-
11	Bankrang	- Phitsanulok	72.86	-	-	-	1.28	418.77	0.42	-	-	-
		- Phromphiram	51.24	-	-	-	9.78	2,250.06	5.30	-	-	-
		- Bankrang	12.90	11.06	640.61	4.72	-	-	-	11.06	640.61	4.72
Total			**-**	**283.84**	**59,541.59**	**187.94**	**283.84**	**62,276.16**	**189.91**	**283.84**	**61,894.05**	**189.92**

Table 4.16 Validation results of minimized TC objective and 5-year service life of sites.

No.	Temporary TS	Optimal DS	Distance of paths (km)	LP 5-Year			List of a TS to all DSs			List of all pairs		
				Waste amount (ton/day)	TC (Baht)	EI	Waste amount (ton/day)	TC (Baht)	EI	Waste amount (ton/day)	TC (Baht)	EI
1	Phitsanulok	- Phitsanulok	68.84	132.30	40,892.82	104.36	5.76	1,780.37	4.54	118.36	36,584.08	93.36
		- Banmai	36.83	-	-	-	15.35	2,538.54	14.29	-	-	-
		- Bangkrathum	61.52	-	-	-	3.78	1,044.06	3.51	-	-	-
		- Plakrad	58.12	-	-	-	13.93	3,635.16	13.01	-	-	-
		- Phromphiram	59.84	-	-	-	25.99	6,983.03	25.99	-	-	-
		- Watbot	45.04	-	-	-	30.65	6,198.34	27.51	7.29	1,474.25	6.54
		- Thapho	30.78	-	-	-	20.10	2,777.86	16.86	-	-	-
		- Bankrang	33.80	-	-	-	9.46	1,435.66	8.37	-	-	-
		- Bantan	46.69	-	-	-	7.28	1,526.28	6.32	6.65	1,394.19	5.77
2	Aranyik	- Phitsanulok	77.92	3.21	1,123.05	1.35	34.33	12,010.72	14.37	34.33	12,010.72	14.37
		- Banmai	40.90	10.42	1,913.54	5.85	-	-	-	-	-	-
		- Phromphiram	66.76	13.41	4,019.68	8.44	-	-	-	-	-	-
		- Watbot	51.82	7.29	1,696.18	3.84	-	-	-	-	-	-
3	Phlaichumphon	- Phitsanulok	72.25	-	-	-	7.25	2,351.89	2.29	-	-	-
		- Phromphiram	72.24	7.25	1,759.79	3.82	-	-	-	7.25	1,759.79	3.82
4	Bankhlong	- Phitsanulok	65.28	0.70	205.18	0.24	13.46	3,945.22	4.57	0.05	14.66	0.02
		- Phromphiram	57.14	-	-	-	-	-	-	13.41	3,440.71	7.39
		- Thapho	27.22	12.76	1,559.50	4.97	-	-	-	-	-	-

Table 4.16 Validation results of minimized TC objective and 5-year service life of sites (Continued).

No.	Temporary TS	Optimal DS	Distance of paths (km)	LP 5-Year			List of a TS to all DSs			List of all pairs		
				Waste amount (ton/day)	TC (Baht)	EI	Waste amount (ton/day)	TC (Baht)	EI	Waste amount (ton/day)	TC (Baht)	EI
5	Thathong	- Phitsanulok	59.98	13.40	3,608.76	4.55	13.40	3,608.76	4.55	4.56	1,228.05	1.55
		- Bangkrathum	51.99	-	-	-	-	-	-	3.78	882.30	1.81
		- Plakrad	49.26	-	-	-	-	-	-	5.06	1,119.12	2.45
6	Huaro	- Phitsanulok	80.07	-	-	-	16.34	5,874.15	6.16	-	-	-
		- Wongkong	75.23	-	-	-	7.02	2,371.25	3.65	-	-	-
		- Watbot	31.40	23.36	3,293.43	11.35	-	-	-	23.36	3,293.43	11.35
7	Phaikhodon	- Phitsanulok	84.52	-	-	-	3.73	1,415.57	1.13	-	-	-
		- Phromphiram	46.94	3.73	786.14	1.92	-	-	-	3.73	786.14	1.92
8	Watchan	- Phitsanulok	58.10	-	-	-	7.34	1,914.69	2.32	-	-	-
		- Plakrad	47.37	-	-	-	-	-	-	7.34	1,561.23	3.39
		- Thapho	20.02	7.34	659.79	2.69	-	-	-	-	-	-
9	Thapho	- Phitsanulok	51.76	7.70	1,789.50	2.85	21.63	5,026.86	8.01	-	-	-
		- Plakrad	38.98	13.93	2,438.03	7.18	-	-	-	1.53	267.78	0.79
		- Thapho	14.72	-	-	-	-	-	-	20.10	1,328.46	8.45
10	Beungphra	- Phitsanulok	64.26	-	-	-	15.98	4,610.89	5.58	-	-	-
		- Banmai	25.36	4.93	561.36	2.42	-	-	-	15.35	1,747.85	7.55
		- Bangkrathum	50.06	3.78	849.63	1.84	-	-	-	-	-	-
		- Bantan	35.22	7.28	1,151.24	3.12	-	-	-	0.63	99.63	0.27

Table 4.16 Validation results of minimized TC objective and 5-year service life of sites (Continued).

No.	Temporary TS	Optimal DS	Distance of paths (km)	LP 5-Year			List of a TS to all DSs			List of all pairs		
				Waste amount (ton/day)	TC (Baht)	EI	Waste amount (ton/day)	TC (Baht)	EI	Waste amount (ton/day)	TC (Baht)	EI
11	Bankrang	- Phitsanulok	72.86	-	-	-	11.06	3,618.39	3.66	-	-	-
		- Phromphiram	51.24	1.60	368.11	0.87	-	-	-	1.60	368.11	0.87
		- Bankrang	12.90	9.46	547.93	4.03	-	-	-	9.46	547.93	4.03
Total			**-**	**283.84**	**69,223.65**	**175.69**	**283.84**	**74,667.70**	**176.69**	**283.84**	**69,908.44**	**175.69**

Table 4.17 Validation results of minimized EI objective and 3-year service life of sites.

No.	Temporary TS	Optimal DS	Distance of paths (km)	LP 3-Year			List of a TS to all DSs			List of all pairs		
				Waste amount (ton/day)	TC (Baht)	EI	Waste amount (ton/day)	TC (Baht)	EI	Waste amount (ton/day)	TC (Baht)	EI
1	Phitsanulok	- Phitsanulok	68.84	70.46	21,778.59	55.58	132.30	40,892.82	104.36	53.94	16,672.40	42.55
		- Watbot	45.04	12.58	2,544.05	11.29	-	-	-	32.08	6,487.53	28.79
		- Thapho	30.78	33.49	4,628.39	28.09	-	-	-	33.49	4,628.39	28.09
		- Bankrang	33.80	15.76	2,391.77	13.94	-	-	-	-	-	-
		- Bantan	46.69	-	-	-	-	-	-	12.79	2,681.47	11.11
2	Aranyik	- Phitsanulok	77.92	34.33	12,010.72	14.37	34.33	12,010.72	14.37	34.33	12,010.72	14.37
3	Phlaichumphon	- Phitsanulok	72.24	7.25	2,351.59	2.29	7.25	2,351.59	2.29	7.25	2,351.59	2.29
4	Bankhlong	- Phitsanulok	65.28	13.46	3,945.22	4.57	13.46	3,945.22	4.57	13.46	3,945.22	4.57
5	Thathong	- Phitsanulok	59.98	13.40	3,608.76	4.55	13.40	3,608.76	4.55	13.40	3,608.76	4.55
6	Huaro	- Phitsanulok	80.07	23.36	8,397.21	8.81	4.74	1,703.88	1.79	23.36	8,397.21	8.81
		- Thapho	42.00	-	-	-	18.62	3,511.13	7.95	-	-	-
7	Phaikhodon	- Phitsanulok	84.52	-	-	-	-	-	-	3.73	1,915.57	1.13
		- Watbot	53.58	3.73	897.34	1.53	-	-	-	-	-	-
		- Thapho	45.56	-	-	-	3.73	763.11	1.32	-	-	-
8	Watchan	- Phitsanulok	58.10	-	-	-	-	-	-	7.34	2,414.78	2.32
		- Thapho	20.03	-	-	-	7.34	660.08	2.69	-	-	-
		- Bantan	34.86	7.34	1,842.94	2.91	-	-	-	-	-	-

Table 4.17 Validation results of minimized EI objective and 3-year service life of sites (Continued).

No.	Temporary TS	Optimal DS	Distance of paths (km)	LP 3-Year			List of a TS to all DSs			List of all pairs		
				Waste amount (ton/day)	TC (Baht)	EI	Waste amount (ton/day)	TC (Baht)	EI	Waste amount (ton/day)	TC (Baht)	EI
9	Thapho	- Phitsanulok	51.76	16.18	3,760.27	5.99	-	-	-	21.63	5,026.86	8.01
		- Thapho	14.72	-	-	-	3.80	251.15	1.60	-	-	-
		- Bankrang	34.75	-	-	-	5.04	786.27	2.35	-	-	-
		- Bantan	49.34	5.45	1,207.37	2.45	12.79	2,833.45	5.76	-	-	-
10	Beungphra	- Phitsanulok	64.26	15.98	4,610.67	5.58	-	-	-	15.98	4,610.67	5.58
		- Watbot	55.92	-	-	-	5.26	1,320.71	2.41	-	-	-
		- Thapho	27.22	-	-	-	-	-	-	-	-	-
		- Bankrang	45.15	-	-	-	10.72	2,173.27	4.77	-	-	-
11	Bankrang	- Phitsanulok	72.86	11.06	3,618.18	3.66	-	-	-	11.06	3,618.18	3.66
		- Watbot	53.89	-	-	-	11.06	2,676.20	4.86	-	-	-
Total			**-**	**283.84**	**77,593.08**	**165.61**	**283.84**	**79,488.36**	**165.62**	**283.84**	**78,369.35**	**165.82**

Table 4.18 Validation results of minimized EI objective and 5-year service life of sites.

No.	Temporary TS	Optimal DS	Distance of paths (km)	LP 5-Year			List of a TS to all DSs			List of all pairs		
				Waste amount (ton/day)	TC (Baht)	EI	Waste amount (ton/day)	TC (Baht)	EI	Waste amount (ton/day)	TC (Baht)	EI
1	Phitsanulok	- Phitsanulok	68.84	64.95	20,075.50	51.23	132.30	40,892.82	104.36	53.94	16,672.40	42.55
		- Banmai	36.84	7.11	1,176.08	6.62	-	-	-	-	-	-
		- Bangkrathum	61.52	3.78	1,044.13	3.50	-	-	-	-	-	-
		- Plakrad	58.12	-	-	-	-	-	-	3.85	1,004.69	3.60
		- Wongkong	82.96	-	-	-	-	-	-	7.02	2,614.85	6.54
		- Watbot	45.04	26.92	5,444.02	24.16	-	-	-	30.65	6,198.34	27.51
		- Thapho	30.78	20.10	2,777.86	16.86	-	-	-	20.10	2,777.86	16.86
		- Bankrang	33.80	9.46	1,435.67	8.37	-	-	-	9.46	1,435.67	8.37
		- Bantan	46.69	-	-	-	-	-	-	7.28	1,526.28	6.32
2	Aranyik	- Phitsanulok	77.92	34.33	12,010.72	14.37	27.05	9,463.73	11.32	34.33	12,010.72	14.37
		- Bantan	50.77	-	-	-	7.28	1,659.41	3.63	-	-	-
3	Phlaichumphon	- Phitsanulok	72.25	7.25	2,351.92	2.29	7.25	2,351.92	2.29	7.25	2,351.92	2.29
4	Bankhlong	- Phitsanulok	65.28	13.46	3,945.22	4.57	13.46	3,945.22	4.57	13.46	3,945.22	4.57
5	Thathong	- Phitsanulok	59.98	13.40	3,608.76	4.55	13.40	3,608.76	4.55	13.40	3,608.76	4.55
6	Huaro	- Phitsanulok	80.07	23.36	8,398.25	8.81	12.02	4,321.36	4.53	23.36	8,398.25	8.81
		- Thapho	42.00	-	-	-	11.34	2,138.36	4.84	-	-	-
7	Phaikhodon	- Phitsanulok	84.52	-	-	-	3.73	1,415.57	1.32	3.73	1,415.57	1.13
		- Watbot	53.58	3.73	897.34	1.53	-	-	-	-	-	-

Table 4.18 Validation results of minimized EI objective and 5-year service life of sites (Continued).

No.	Temporary TS	Optimal DS	Distance of paths (km)	LP 5-Year			List of a TS to all DSs			List of all pairs		
				Waste amount (ton/day)	TC (Baht)	EI	Waste amount (ton/day)	TC (Baht)	EI	Waste amount (ton/day)	TC (Baht)	EI
8	Watchan	- Phitsanulok	58.10	0.06	15.65	0.02	-	-	-	7.34	1,914.78	2.32
		- Thapho	20.03	-	-	-	5.03	452.34	1.84	-	-	-
		- Bankrang	31.92	-	-	-	2.31	331.10	0.95	-	-	-
		- Bantan	34.86	7.28	1,827.87	2.88	-	-	-	-	-	-
9	Thapho	- Phitsanulok	51.76	21.63	5,026.86	8.01	-	-	-	21.63	5,026.86	8.01
		- Watbot	67.45	-	-	-	14.48	4,385.41	6.94	-	-	-
		- Bankrang	34.75	-	-	-	7.15	1,115.44	3.34	-	-	-
10	Beungphra	- Phitsanulok	64.26	15.98	4,610.67	5.58	-	-	-	15.98	4,610.67	5.58
		- Thapho	27.22	-	-	-	15.98	1,953.33	7.32	-	-	-
11	Bankrang	- Phitsanulok	72.86	11.06	3,618.18	3.66	-	-	-	11.06	3,618.18	3.66
		- Banmai	58.80	-	-	-	3.85	1,016.52	1.82	-	-	-
		- Wongkong	74.35	-	-	-	7.02	2,343.60	3.32	-	-	-
		- Watbot	53.89	-	-	-	0.19	45.97	0.08	-	-	-
Total			**-**	**283.84**	**78,264.71**	**167.01**	**283.84**	**81,440.87**	**167.02**	**283.84**	**79,131.04**	**167.03**

Table 4.19 Summary of LP validation results.

Obj.	Result from	Total TC (Baht)		Total EI	
		3-year	5-year	3-year	5-year
Min TC	LP	59,541.59	69,223.65	187.94	175.69
	List of a TS to all DSs	62,276.16	74,667.70	189.91	176.69
	List of all pairs	61,894.05	69,908.44	189.92	175.69
Min EI	LP	77,593.08	78,264.71	165.61	167.01
	List of a TS to all DSs	79,488.36	81,440.87	165.62	167.02
	List of all pairs	78,369.35	79,131.04	165.82	167.03

From Tables, they show that active pairs, waste allotment, total TC and EI are all different in different objectives and capacities. From the summarized Table 4.19, the total TC from LP of minimized TC objective is obviously less than the results from both validation lists and from minimized EI objective. The total cost of 3-year capacity is less than the one of 5-year capacity. The same is applied to total EI of minimized EI objective.

This comparison confirms that results from the LP is validated. It is interesting to note that results from a list of all pairs are very close to results from the LP. This could be because of better ordering in waste allotment from a TS to meet a constraint of DS capacity. The total TC shows much more difference in methods while very little can be noted from the total EI. The difference in total TC is relied on big difference of total distance of active pairs in difference methods. The total EIs from methods show very small difference because EI of TSs are constant for all methods while the difference of EI of all DSs are not obvious or very small, whether they are active or not.

CHAPTER V

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The main goal of this study is to manage solid waste transportation in 11 local administrative units of Phitsanulok province of Thailand. The objectives of the study included locating temporary TSs of local administrative units using GIS weighted mean centering, evaluating EI of TSs and existing DSs using SAW decision rule of MADA, and managing waste transportation using NA for optimum path of active TS-DS pairs and LP for waste allotment serving minimized TC and EI under varying constraints. The constraints are waste amount generated at every TS and 3-year and 5-year capacities of active DSs.

Three study objectives which are a goal of the study are achieved completely and proved by obtaining TS locations and waste amounts, EI of existing DSs, and acceptable validation on optimum path selection and waste allotment.

All obtaining TS locations fall into their own local administrative boundaries. Their waste amounts are considered as EI of them. Estimated EI of all DSs were obtained using MADA on 3 groups of criteria, i.e. PCD criteria, specific environmental characteristics, and disposal methods which are their attributes. Matrix of EI of active pairs of TSs and DSs were used for waste allotment process.

Distances of sample paths from all TSs to some DS are longer than corresponding optimum paths obtained from the NA. Waste allotment resulting from LP proved to have minimized total TC and EI based on minimized TC and EI objectives, respectively. Based on minimized both TC and EI objective, the results are reasonable and stay between results of those two objectives alone. The analyses comply with varying constraints of objectives. Allotments using ordering of a list of a TS to all DSs (11 pairs) and a list of all pairs of all TSs and DSs (121 pairs) were used to validate allotment from LP. The results reveal that allotment from LP provide less total TC and EI than those validating lists, based on corresponding LP objectives.

The 3-year service life of active DSs provide better results compared to 5-year service life. The shorter service life of DSs have higher daily capacity and can provide more chances to transport waste from TSs to DSs which are closer and have less environmental impact.

With 3 different objectives in LP operations for waste allotment, the results of TC show more obviously different than of EI. To be fair comparison within the same service life, percentage of the difference between the maximum and minimum values on the basis of the maximum were estimated. The results show that the differences of total TC and EI of 3-year service life are 23.26% and 11.88%, while they are 11.55% and 4.94% of 5-year service life, respectively. This different information is provided clearly in terms of monetary value and EI index. It can assist policy makers to decide which transportation pattern from different objective functions fit to their resources and constraints.

5.2 Recommendation

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

5.2.1 In case the waste transportation will be managed through town or city having more complicate traffic system e.g. one way system and restricted passing regulation, NA operation on back and forth from TS to DS should be performed to make results more accurate and practical.

5.2.2 If the policy on having TS is seriously implemented, the evaluation of its EI should be performed under relevant criteria systematically.

5.2.3 The study results show that shorter service life of DS provide better total TC and EI in the waste transportation management. However, shortening service life of DSs requires new DS sooner. This leads to confronting a difficult task that can cause significant conflicts on economic and environment to stakeholders. Therefore, stakeholder analysis should be included as a key activity that can effectively moderate conflicts of new site selection and choose the optimum pattern of waste transportation.

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APPENDICES

APPENDIX A

RAW SCORES OF EI EVALUATION

Table A1 Raw scores of EI evaluation.

DS No.	PCD criteria										Specific envi. characteristic criteria				Disposal method			
	Wetland	Flood plain	Airport	Archeological sites	Watershed	Conservation area	Natural conservation site and geopark	Settlement	Water consumption source	Water body	Flow accumulation	Water table	Prevailing wind	Drainage of surface Sediment on landform	Contamination (leachate) to soil and surface water	Unpleasant odors	Methane GAS (CH_4)	Site protected channeling runoff
DS01	0	0	0	0	0	0	0	1	1	0	10.73	6.03	0.00	0.70	1	2	1	2
DS02	0	1	0	0	0	0	0	1	1	0	141.77	1.03	94.13	0.20	2	3	3	4
DS03	0	1	0	0	0	0	0	1	1	0	21.31	3.62	0.00	0.50	2	3	3	4
DS04	0	1	0	0	0	0	0	1	1	0	138.22	6.38	0.00	0.50	2	3	3	4
DS05	0	0	0	0	0	0	0	1	1	0	50.81	7.16	0.00	0.70	3	3	3	4
DS06	0	1	0	0	0	0	0	1	1	0	8936.12	4.93	638.50	0.20	3	3	3	4
DS07	0	1	0	0	0	0	0	1	1	0	313.10	4.55	1.11	0.20	3	3	3	4
DS08	0	1	0	0	0	0	0	1	1	0	12.32	6.20	1.31	0.20	3	3	3	4
DS09	0	1	0	0	0	0	0	1	1	0	865.97	6.00	86.71	0.50	1	2	1	2
DS10	0	0	0	0	0	0	0	1	1	0	4.68	9.02	393.07	0.50	2	3	3	4
DS11	0	0	0	0	0	0	0	1	1	0	3.00	8.52	279.37	0.50	2	3	3	4

APPENDIX B

OPTIMUM DISTANCE OF EACH TS TO EACH DS

Table B1 Optimum distance (back and forth) of each TS to each DS.

No.	Paths of TSs to DSs	Distance of paths (km)
1	Phitsanulok municipality (TS01) to Phitsanulok municipality (DS01)	68.85
2	Phitsanulok municipality (TS01) to Banmai municipality (DS02)	36.83
3	Phitsanulok municipality (TS01) to Nuenkum municipality (DS03)	89.03
4	Phitsanulok municipality (TS01) to Bangkrathum municipality (DS04)	61.52
5	Phitsanulok municipality (TS01) to Plakrad municipality (DS05)	58.12
6	Phitsanulok municipality (TS01) to Phromphiram municipality (DS06)	59.85
7	Phitsanulok municipality (TS01) to Wongkong municipality (DS07)	82.96
8	Phitsanulok municipality (TS01) to Watbot municipality (DS08)	45.05
9	Phitsanulok municipality (TS01) to Thapho SAO (DS09)	30.78
10	Phitsanulok municipality (TS01) to Bankrang SAO (DS10)	33.80
11	Phitsanulok municipality (TS01) to Bantan SAO (DS11)	46.69
12	Aranyik municipality (TS02) to Phitsanulok municipality (DS01)	77.92
13	Aranyik municipality (TS02) to Banmai municipality (DS02)	40.91
14	Aranyik municipality (TS02) to Nuenkum municipality (DS03)	93.11
15	Aranyik municipality (TS02) to Bangkrathum municipality (DS04)	65.59
16	Aranyik municipality (TS02) to Plakrad municipality (DS05)	67.20
17	Aranyik municipality (TS02) to Phromphiram municipality (DS06)	66.76
18	Aranyik municipality (TS02) to Wongkong municipality (DS07)	89.87
19	Aranyik municipality (TS02) to Watbot municipality (DS08)	51.83
20	Aranyik municipality (TS02) to Thapho SAO (DS09)	39.85
21	Aranyik municipality (TS02) to Bankrang SAO (DS10)	41.33
22	Aranyik municipality (TS02) to Bantan SAO (DS11)	50.77
23	Phlaichumphon municipality (TS03) to Phitsanulok municipality (DS01)	72.25

Table B1 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)	46.46
25	Phlaichumphon municipality (TS03) to Nuenkum municipality (DS03)	101.86
26	Phlaichumphon municipality (TS03) to Bangkrathum municipality (DS04)	71.14
27	Phlaichumphon municipality (TS03) to Plakrad municipality (DS05)	61.52
28	Phlaichumphon municipality (TS03) to Phromphiram municipality (DS06)	54.06
29	Phlaichumphon municipality (TS03) to Wongkong municipality (DS07)	77.18
30	Phlaichumphon municipality (TS03) to Watbot municipality (DS08)	48.27
31	Phlaichumphon municipality (TS03) to Thapho SAO (DS09)	34.18
32	Phlaichumphon municipality (TS03) to Bankrang SAO (DS10)	23.65
33	Phlaichumphon municipality (TS03) to Bantan SAO (DS11)	59.52
34	Bankhlong municipality (TS04) to Phitsanulok municipality (DS01)	65.28
35	Bankhlong municipality (TS04) to Banmai municipality (DS02)	41.41
36	Bankhlong municipality (TS04) to Nuenkum municipality (DS03)	98.02
37	Bankhlong municipality (TS04) to Bangkrathum municipality (DS04)	66.10
38	Bankhlong municipality (TS04) to Plakrad municipality (DS05)	54.56
39	Bankhlong municipality (TS04) to Phromphiram municipality (DS06)	57.14
40	Bankhlong municipality (TS04) to Wongkong municipality (DS07)	80.26
41	Bankhlong municipality (TS04) to Watbot municipality (DS08)	50.29
42	Bankhlong municipality (TS04) to Thapho SAO (DS09)	27.22
43	Bankhlong municipality (TS04) to Bankrang SAO (DS10)	26.73
44	Bankhlong municipality (TS04) to Bantan SAO (DS11)	55.68
45	Thathong municipality (TS05) to Phitsanulok municipality (DS01)	59.98
46	Thathong municipality (TS05) to Banmai municipality (DS02)	27.30
47	Thathong municipality (TS05) to Nuenkum municipality (DS03)	85.88
48	Thathong municipality (TS05) to Bangkrathum municipality (DS04)	51.99

Table B1 Optimum distance (back and forth) of each TS to each DS (Continued).

No.	Paths of TSs to DSs	Distance of paths (km)
49	Thathong municipality (TS05) to Plakrad municipality (DS05)	49.26
50	Thathong municipality (TS05) to Phromphiram municipality (DS06)	71.96
51	Thathong municipality (TS05) to Wongkong municipality (DS07)	95.07
52	Thathong municipality (TS05) to Watbot municipality (DS08)	57.16
53	Thathong municipality (TS05) to Thapho SAO (DS09)	22.94
54	Thathong municipality (TS05) to Bankrang SAO (DS10)	42.67
55	Thathong municipality (TS05) to Bantan SAO (DS11)	48.37
56	Huaro municipality (TS06) to Phitsanulok municipality (DS01)	80.07
57	Huaro municipality (TS06) to Banmai municipality (DS02)	49.09
58	Huaro municipality (TS06) to Nuenkum municipality (DS03)	101.29
59	Huaro municipality (TS06) to Bangkrathum municipality (DS04)	73.78
60	Huaro municipality (TS06) to Plakrad municipality (DS05)	69.34
61	Huaro municipality (TS06) to Phromphiram municipality (DS06)	52.12
62	Huaro municipality (TS06) to Wongkong municipality (DS07)	75.23
63	Huaro municipality (TS06) to Watbot municipality (DS08)	31.41
64	Huaro municipality (TS06) to Thapho SAO (DS09)	42.00
65	Huaro municipality (TS06) to Bankrang SAO (DS10)	33.33
66	Huaro municipality (TS06) to Bantan SAO (DS11)	58.95
67	Phaikhodon SAO (TS07) to Phitsanulok municipality (DS01)	84.52
68	Phaikhodon SAO (TS07) to Banmai municipality (DS02)	64.67
69	Phaikhodon SAO (TS07) to Nuenkum municipality (DS03)	120.69
70	Phaikhodon SAO (TS07) to Bangkrathum municipality (DS04)	89.35
71	Phaikhodon SAO (TS07) to Plakrad municipality (DS05)	73.80
72	Phaikhodon SAO (TS07) to Phromphiram municipality (DS06)	46.94
73	Phaikhodon SAO (TS07) to Wongkong municipality (DS07)	70.76

Table B1 Optimum distance (back and forth) of each TS to each DS (Continued).

No.	Paths of TSs to DSs	Distance of paths (km)
74	Phaikhodon SAO (TS07) to Watbot municipality (DS08)	53.59
75	Phaikhodon SAO (TS07) to Thapho SAO (DS09)	45.56
76	Phaikhodon SAO (TS07) to Bankrang SAO (DS10)	23.38
77	Phaikhodon SAO (TS07) to Bantan SAO (DS11)	78.35
78	Watchan SAO (TS08) to Phitsanulok municipality (DS01)	58.10
79	Watchan SAO (TS08) to Banmai municipality (DS02)	34.85
80	Watchan SAO (TS08) to Nuenkum municipality (DS03)	93.43
81	Watchan SAO (TS08) to Bangkrathum municipality (DS04)	59.54
82	Watchan SAO (TS08) to Plakrad municipality (DS05)	47.37
83	Watchan SAO (TS08) to Phromphiram municipality (DS06)	62.34
84	Watchan SAO (TS08) to Wongkong municipality (DS07)	85.45
85	Watchan SAO (TS08) to Watbot municipality (DS08)	53.80
86	Watchan SAO (TS08) to Thapho SAO (DS09)	20.03
87	Watchan SAO (TS08) to Bankrang SAO (DS10)	31.92
88	Watchan SAO (TS08) to Bantan SAO (DS11)	55.92
89	Thapho SAO (TS09) to Phitsanulok municipality (DS01)	51.76
90	Thapho SAO (TS09) to Banmai municipality (DS02)	28.27
91	Thapho SAO (TS09) to Nuenkum municipality (DS03)	86.85
92	Thapho SAO (TS09) to Bangkrathum municipality (DS04)	52.95
93	Thapho SAO (TS09) to Plakrad municipality (DS05)	38.99
94	Thapho SAO (TS09) to Phromphiram municipality (DS06)	77.59
95	Thapho SAO (TS09) to Wongkong municipality (DS07)	100.70
96	Thapho SAO (TS09) to Watbot municipality (DS08)	67.45
97	Thapho SAO (TS09) to Thapho SAO (DS09)	14.72
98	Thapho SAO (TS09) to Bankrang SAO (DS10)	34.75

Table B1 Optimum distance (back and forth) of each TS to each DS (Continued).

No.	Paths of TSs to DSs	Distance of paths (km)
99	Thapho SAO (TS09) to Bantan SAO (DS11)	49.34
100	Beungphra SAO (TS10) to Phitsanulok municipality (DS01)	64.26
101	Beungphra SAO (TS10) to Banmai municipality (DS02)	25.37
102	Beungphra SAO (TS10) to Nuenkum municipality (DS03)	77.57
103	Beungphra SAO (TS10) to Bangkrathum municipality (DS04)	50.05
104	Beungphra SAO (TS10) to Plakrad municipality (DS05)	53.54
105	Beungphra SAO (TS10) to Phromphiram municipality (DS06)	70.85
106	Beungphra SAO (TS10) to Wongkong municipality (DS07)	93.96
107	Beungphra SAO (TS10) to Watbot municipality (DS08)	55.92
108	Beungphra SAO (TS10) to Thapho SAO (DS09)	27.22
109	Beungphra SAO (TS10) to Bankrang SAO (DS10)	45.15
110	Beungphra SAO (TS10) to Bantan SAO (DS11)	35.23
111	Bankrang SAO (TS11) to Phitsanulok municipality (DS01)	72.86
112	Bankrang SAO (TS11) to Banmai municipality (DS02)	58.80
113	Bankrang SAO (TS11) to Nuenkum municipality (DS03)	114.82
114	Bankrang SAO (TS11) to Bangkrathum municipality (DS04)	83.49
115	Bankrang SAO (TS11) to Plakrad municipality (DS05)	62.14
116	Bankrang SAO (TS11) to Phromphiram municipality (DS06)	51.24
117	Bankrang SAO (TS11) to Wongkong municipality (DS07)	74.35
118	Bankrang SAO (TS11) to Watbot municipality (DS08)	53.89
119	Bankrang SAO (TS11) to Thapho SAO (DS09)	33.91
120	Bankrang SAO (TS11) to Bankrang SAO (DS10)	13.08
121	Bankrang SAO (TS11) to Bantan SAO (DS11)	72.48

CURRICULUM VITAE

Name Mr. Athiwat Phinyoyang

Date of Birth April 19, 1992

Place of Birth Chaiyaphum Province, Thailand

Education 2013 Bachelor of Science in Geoinformatics (Second Class Honor), Program of Geoinformatics, Faculty of Science and Technology, Nakhon Ratchasima Rajabhat University.

Grant and Fellowships SUT outstanding academic performance scholarship, Suranaree University of Technology.