กรอบความคิดของการวางแผนเส้นทางการขนส่งของเสียอันตรายด้วยการบูรณาการกระบวนการตัดสินใจหลายตัวแปรและเทคโนโลยีสารสนเทศภูมิศาสตร์

นายสถาพร มนต์ประภัสสร

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรดุษฎีบัณฑิต

สาขาวิชาการจัดการสิ่งแวดล้อม (สหสาขาวิชา)

บัณฑิตวิทยาลัย จุฬาลงกรณ์มหาวิทยาลัย

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INTEGRATED MULTI CRITERIA DECISION ANALYSIS AND GEOGRAPHIC INFORMATION SYSTEM FRAMEWORK FOR HAZARDOUS WASTE ROUTE PLANNING

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A Dissertation Submitted in Partial Fulfillment of the Requirements
for the Degree of Doctor of Philosophy Program in Environmental Management
(Interdisciplinary Program)
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Thesis Title	Integrated Multi Criteria Decision Analysis and Geographic Information System Framework for Hazardous Waste Route Planning
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วิทยานิพนธ์ฉบับนี้ได้บูรณาการกระบวนการตัดสินใจหลายตัวแปร (Multi criteria decision analysis) และระบบสารสนเทศภูมิศาสตร์ (Geographic information system) เพื่อช่วยวางแผนการตัดสินใจการเลือกเส้นทางการขนส่งของเสียอันตราย การขนส่งของเสียอันตรายประกอบไปด้วยความเสี่ยงอันเกิดจากการเกิดอุบัติเหตุระหว่างการขนส่ง ซึ่งความรุนแรงจากอุบัติเหตุนั้นขึ้นกับปัจจัยหลายปัจจัย เช่นความหนาแน่นของประชากร, จำนวนสถานที่ที่มีความเสี่ยงในการได้รับผลกระทบรุนแรง เช่น โรงพยาบาลและ โรงเรียน, ระยะห่างจาก สถานีดับเพลิง, สถานีตำรวจ ฯลฯ โดยไม่ได้ขึ้นอยู่กับปัจจัยทางด้านเศรษฐศาสตร์ เช่น ระยะทางหรือเวลาเพียงอย่างเดียว ดังนั้น การพิจารณาปัจจัยหลัก และ/หรือเกณฑ์ที่เกี่ยวข้องพร้อมๆกันเป็นสิ่งที่สำคัญก่อนที่จะมีการตัดสินใจวางแผนเลือกเส้นทางการขนส่ง อย่างไรก็ตามการขาดกฎหมายและการควบคุมที่ชัดเจนสำหรับการวางแผนการเลือกเส้นทางในการขนส่งวัตถุอันตรายที่ผู้ประกอบการขนส่งสามารถนำมาใช้เพื่อประกอบการตัดสินใจเลือกเส้นทางในการขนส่งนับเป็นประเด็นที่กำลังได้รับความสนใจมากขึ้น

วิทยานิพนธ์นี้มีวัตถุประสงค์เพื่อทำการพัฒนากรอบความคิดและนำไปใช้ประกอบการตัดสินใจในการเลือกเส้นทางการขนส่งของเสียอันตรายโดยการทำการพิจารณาปัจจัยหลักใน 4 หมวดหมู่ได้แก่ เศรษฐศาสตร์, สิ่งแวดล้อม, สังคม(ด้านผลกระทบ) และสังคม(ด้านการตอบสนองต่อเหตุฉุกเฉิน) ซึ่งการเลือกปัจจัยหลักนี้เป็นไปตามกรอบแนวคิดของการพัฒนาที่ยั่งยืน โดยได้นำกรอบแนวคิดนี้มาประยุกต์ใช้ในการขนส่งของเสียอันตรายจากนิคมอุตสาหกรรมมาบตาพุด จังหวัดระยองไปยังโรงงานกำจัดวัสดุที่ไม่ใช้แล้วที่เป็นและไม่เป็นของเสียอันตรายด้วยวิธีเผาในเตาเผาปูนซีเมนต์ จังหวัดสระบุรี โดยได้แบ่งวิธีการวิเคราะห์ออกเป็น 2 วิธี โดยในวิธีแรกเป็นการหาเส้นทางที่เหมาะสม โดยพิจารณาเฉพาะปัจจัยหลักทีละปัจจัย โดยใช้ โมเดลสมการเชิงเส้น ซึ่งจะทำให้สามารถหาเส้นทางที่เหมาะสมจากจุดเริ่มต้นไปยังจุดสิ้นสุดโดยการพิจารณาในแต่ละปัจจัยหลักเท่านั้น ส่วนวิธีที่สองเป็นการหาเส้นทางที่เหมาะสม โดยพิจารณาในสี่ปัจจัยหลักไปพร้อมๆกันจากกลุ่มของเส้นทางที่กำหนดไว้แล้วจากจุดเริ่มต้นไปยังจุดปลายทาง กรอบแนวคิดที่นำเสนอนี้สามารถที่จะเป็นประโยชน์ต่อผู้มีอำนาจในการตัดสินใจและผู้มีส่วนได้ส่วนเสียในด้านการขนส่งวัตถุอันตราย และ/หรือของเสียอันตราย เช่น รัฐบาล และ บริษัทขนส่งวัตถุอันตราย และ/หรือบริษัทรับกำจัดของเสียอันตราย เพื่อใช้เป็นกรอบในประเมินการเลือกเส้นทางการขนส่งวัตถุอันตรายที่ส่งผลกระทบน้อยที่สุด

สาขาวิชาการจัดการสิ่งแวดล้อม ลายมือชื่อนิสิต..

ปีการศึกษา 2551 ลายมือชื่ออ.ที่ปรึกษาวิทยานิพนธ์หลัก..

ลายมือชื่ออ.ที่ปรึกษาวิทยานิพนธ์ร่วม..

ลายมือชื่ออ.ที่ปรึกษาวิทยานิพนธ์ร่วม..

##4689714920: MAJOR ENVIRONMENTAL MANAGEMENT
KEY WORD: RISK ANALYSIS/ HAZARDOUS MATERIALS TRANSPORT / MULTI CRITERIA DECISION MAKING / ROUTE PLANNING

SATHAPORN MONPRAPUSSORN: INTEGRATED MULTI CRITERIA DECISION ANALYSIS AND GEOGRAPHIC INFORMATION SYSTEM FRAMEWORK FOR HAZARDOUS WASTE ROUTE PLANNING. THESIS PRINCIPAL ADVISOR: DANAI THAITAKOO, Ph.D, THESIS COADVISOR: ASSOC. PROF. RUTH BANOMYONG, Ph.D, DANIEL J. WATTS, Ph.D 142 pp.

This dissertation introduces an integrated Multi criteria decision analysis (MCDA) and Geographic Information System (GIS) approaches to the hazardous waste transport issue. There are risks associated with a truck being involved in an accident during shipment of Hazardous materials (HAZMAT). The severity of impact posed to surroundings depends on many factors such as population density, number of sensitive locations, proximity to rescue units, and security, not only distance and/or time alone. It is essential that all of the related factors and criteria involved be considered prior to making route planning decision. In Thailand, a lack of a comprehensive framework for the selection of HAZMAT route planning that the transporter can use for aiding their decisions is a major concern.

The purpose of this dissertation is to develop a framework for making optimum hazardous waste transport route planning choices by considering multiple factors and criteria. Factors and criteria are divided into three main categories: economic, environmental and societal (exposure and emergency response) issues to approach the sustainability paradigm. A framework has been tested to a regional hazardous waste transport from Map Ta Phut Industrial Estate, Rayong province, Thailand to five incinerator plants, located in Saraburi province. A framework is divided to two different methods. The method 1 tried to calculate total final value (Ri) based on single objectives and multiple objectives. Method 2 is applied for the finite sets of alternative routes between origin-destination. The results show that preferred routes (minimum Ri value) are depended on different objectives (single and multiple). The proposed framework can contribute to the planning processes of governmental policy-makers and carriers when they plan and evaluate possible routes and are making their decision in order to minimize damage from transporting hazardous waste.

Field of study Environmental Management Student's signature...Sathaporn Monprapussorn...

Academic year 2008 Principal Advisor's signature:...Danai Thaitakoo...

Co-advisor's signature:..........................

Co-advisor's signature:..........................

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CHAPTER I

INTRODUCTION

1.1 Hazardous Materials (HAZMAT) Transport Perspectives: An Overview

Our society benefits from the chemical, nuclear, electrical and petroleum industries, which require hazardous materials in their production and also produce hazardous wastes. Industrial growth accelerates an increasing demand for hazardous materials (HAZMAT) to be used as raw materials for the production of various commercial goods. As a consequence of growing numbers of industrial operations, an increasing quantity of hazardous waste is a major concern as well. Although the probability of an accidental release while transporting HAZMAT is very low, there is concern that HAZMAT be transported in the safest manner as possible, since a release can catastrophic for a community and the environment.

1.1.1 *HAZMAT transportation and risk*

The transportation of HAZMAT is an important strategic and tactical decision problem. They include explosives, gases, flammable, liquids and solids, oxidizing substances, poisonous and infectious substances, corrosive substances, and hazardous wastes. Although rare, accidental releases of HAZMAT do occur during transportation, and these events often have very damaging consequences, including fatalities. Historical evidence has shown that the risks related to HAZMAT transportation can be of the same magnitude as those due to fixed installations (Leonelli *et al.*, 1999). Glickman *et al.* (1992) compares the percentage of accidents due to the transportation of hazardous material and those at fixed installation on worldwide basis between 1945 and 1986 as shown in Figure 1.1

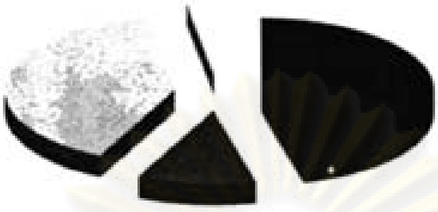

Figure 1.1 Comparison of types of major technological accidents world wide between 1945 and 1986

Source: Glickman *et al.* (1992)

Research in the United States during the early 1990s estimated that there were some 500,000 shipments of HAZMAT every day (Turnquist and List, 1993). While in the UK, it is currently estimated that each year approximately 80,000 different organizations are involved in carrying around 100,000 tons of dangerous goods by road and rail (Briggs *et al.*, 2002). While accidents usually result in some form of inconvenience at the very least, or in the worst cases in injury or death, public concern has started to rise about how and when these shipments are planned and routed through specific geographical areas. The main issue derives from the population potentially at risk in the impact area (the routes may cross or pass by towns and villages) rather than from the scale of any accident itself (Fabiano, *et al.* 2005). Therefore, mitigation of the public and environmental risk is an essential component of HAZMAT transportation planning.

1.1.2 *HAZMAT transport impact*

When considering a problem of HAZMAT transport, possible impacts of the problem can be categorized into two types depending on duration; *immediate effects* such as a loss from the accident, hazard from chemical exposure and *long term effects* such as a spill of a toxic chemical in the environment. The degree of the problem consists of various factors involves such as population density, the number of sensitive places such as elementary schools, the proximity to sensitive environments and rescue units, etc. However, it is rare for a carrier to consider all the related factors and criteria when planning and selecting a shipment route for HAZMAT in real situations. A few critical factors and criteria are generally chosen and reasonable routes are planned. Considering only cost is not comprehensive enough to advance hazardous waste transport. Transportation routes based on cost-only criteria can potentially pose many risks to human beings and the surroundings. These dangers can lead to huge immediate effects, while some other outcomes can cause chronic or long-term effects. For example, the consequences of hazardous waste transport accidents involve a high damage potential in terms of economical losses. The economic impact can be quantified by calculating the value of money needed to re-establish the transportation network, as one example. The reconstruction cost of roads and other infrastructures can be seen as a case where the government or local authorities are responsible for the expense. In addition, the consequence can result in economic loss to the private transportation company. Medical treatment for injured employee and others due to exposure to toxic chemicals, replacement of the transport unit, and delays in the supply of hazardous waste to recovery or disposal units are clear examples.

1.1.3 *HAZMAT transport risk management*

The goal of transportation risk management is to reduce the risk of transporting HAZMAT. It is an ongoing process for continuing improvement. The activity involved in transportation risk management focus on identifying of hazard, assessment of the risk associated with the identified hazard, and reduction of risk where necessary. Effective distribution of risk management is a continuing process. Many of the factors involved in the risk management are dynamic and changing, and the process needs to be repeated periodically. To response with dynamic data, a comprehensive risk management framework should be established first. In addition, as more data and information become available, a framework can be used to understand the risks better, and to manage those risks more effectively.

1.1.4 *HAZMAT transport and sustainability*

The word sustainable, according to the Encarta World English Dictionary, means "able to be maintained". This definition can be applied to various subject matters, including societal as the whole, industries, agriculture, transport etc.

Sustainability is related to the quality of life in a community -- whether the economic, social and environmental systems that make up the community are providing a healthy, productive, meaningful life for all community residents, present and future. While a meaning of sustainable mentioned in Brundtland report is "the development that meets the needs of the present without compromising the ability of future generations to meet their own needs.

To push HAZMAT transport toward sustainability approach, issues of economic, environmental and societal system must be concerned before making the decision for route planning. This means that a decision must lead to risk reduction posed to surroundings from HAZMAT transport operation. A benefit thinking of HAZMAT transport and sustainability is depicted in figure 1.1 below.

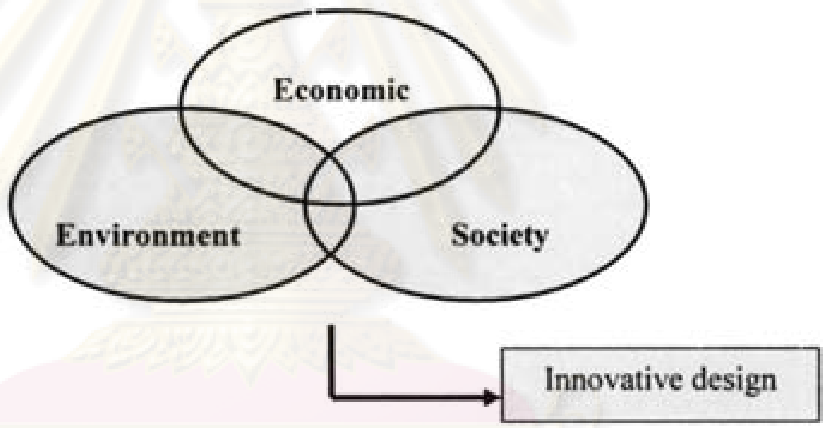

Figure 1.2 Benefit of sustainability thinking

1.2 Rationale

Hazardous waste is a sub-category of HAZMAT. Hazardous waste has to be transported from one or more origins to the destination. The origin is a fixed facility where the hazardous wastes are commonly generated. It is then transported to storage, treatment and disposal or recovery sites where the hazardous waste is required to be sent.

1.2.1 *Risks from hazardous waste transport*

Risk is often defined as the probability of a damaging event to occur and of its consequences (Berdica, 2002; Fabiano *et. al*., 2002). It is clear that the shipment of hazardous waste will carry some risks to the public along the route, as well as to the surrounding environment. The problem that arises when transporting hazardous waste is how to select a suitable route for theirs shipment. First, hazardous waste transport has to be economically feasible for the stakeholders directly involved. On the other hand, hazardous waste transport must be safe transport by minimizing the real and potential impacts from any incident throughout the whole transportation process. Determination of economic factors is a straightforward task. However, identifying other risks factors such as environmental and societal factors is far more complex.

Accidents may happen, and loads carried by truck can be released in a serious accident. An accident can be quite costly in different ways to all parties involved. There are many uncertainties along with the hazardous waste transportation system such as the waste generation rate, environmental impact, and other associated parameters. The selection of a hazardous waste route frequently has been cited as an important topic in the last two decades. The earliest objective was to optimize the costs associated with the reverse flow of hazardous waste collection and storage, transportation, treatment and disposal. However, the most complete solution to the hazardous waste management problem must respond to several different perspectives in order to manage the problem in a safe and cost-effective manner. For the example, from the point of view of the hazardous waste treatment company, the best solution for routing would be the route that leads to the least operational cost. While for the government, the best solution would be the route with the least impact to the surroundings. With increasing environmental awareness, however, environmental and societal issues are now considered as more important equally to cost issues, especially in many developed countries such as the United States and European countries.

1.2.2 *Hazardous waste routing*

Decision making tools such as route models are widely applied in transportation research, especially for HAZMAT route selection, which allow decision makers to determine the best route for the transport of HAZMAT. The simplest example of such a model is one that looks for the best route based on the economic factors related to the transport phase. The economic factors can be related to the operation costs based on distance and/or time. The main purpose of route model is to reduce a risk involved in routing. However, better route selection models would be those where risk related factors and criteria are fully considered. The factors and criteria for the route selection problem for HAZMAT or hazardous waste transport may vary from one organization to another or from one country to another as shown in Figure 1.3

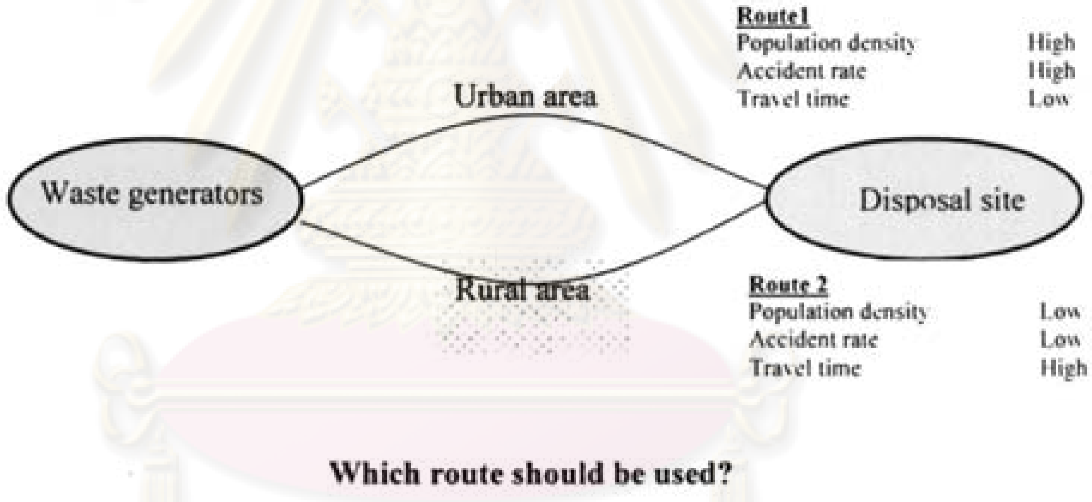

Figure 1.3 Example of HAZMAT transportation routing problem

In most cases, risk and safety interests conflict with economic interests, making decision process a complex task. For example, the results of the considerations may vary in different countries because of differences in the perception of risk and economic interests that may exist, based upon their development level. It has long been known that in developed countries, there will likely be a greater awareness of the dangers of HAZMAT transport when compared with the level of awareness in other developing countries. This leads to the creation of more protective policies and regulatory frameworks with regard to HAZMAT transport in many developed countries. The opposite of this attitude is reflected in the way HAZMAT related issues are managed in developing countries, where economic factors may play a bigger role than other factors. This attitude contributes to the lack of interest and awareness in developing countries towards HAZMAT transport.

1.2.3 *Comprehensive planning framework*

In order to be able to select economical and safe routes for the transport of hazardous waste, it is necessary to use a tool that allows policy and decision makers to evaluate all alternative routes based on economic, environmental as well as societal considerations to create different scenarios, and to assist in searching for a solution to the particular problem. This research is oriented towards the development of "a conceptual framework" for the selection of reasonable routes for hazardous waste transport planning to achieve sustainability goal by equal considering of economic, environment and societal (in term of exposure and emergency response) factors. The goal is to develop a framework that is able to evaluate and find optimal routes among all candidate routes in the transport network between origin and destination.

A comprehensive framework is therefore required to achieve the desired level of safety standards for any activity involved in the hazardous waste transport planning, paying attention to more than the cost issue alone. It is critical to realize that good planning and decision making framework must be initiated and developed to manage and support the process models operation involved in hazardous waste shipments. Furthermore, this framework must lead to route planning that can mitigate the impact to surroundings.

1.3 Research Questions and Objectives

The research questions, main objectives, sub objectives, and are presented in the following three sections.

1.3.1 *Research questions*

- What is the factor affecting routing pertaining to sustainability framework in the research study?
- What is the procedure to define factors, methods, tools for optimum hazardous waste transport route planning to achieve sustainability goal?

1.3.2 *Main objective*

- To construct a hazardous waste route planning framework that can be used as a decision support system in the assessment of possible routes by taking into account all economic, environmental and societal (in term of exposure and emergency response) factors.

1.3.3 *Sub Objectives*

- To propose the process of defining factors, methodology, and tool for creating hazardous waste transport framework.
- To establish integrated Multi criteria decision analysis (MCDA) and Geographic Information System (GIS) framework for route selection of hazardous waste transport.
- To propose route planning framework and apply for the case study.
- To compare a key component of the proposed route planning framework in the different management scenarios as a way for improving hazardous waste transport leading to more sustainable manner.

1.4 Conceptual framework

In order to achieve the main objective and every sub-objective presented, the following conceptual framework is proposed. The beginning point of the framework is to identify the factors and criteria related to the phenomenon of transporting hazardous waste that should be considered for the development of a routing framework. Once these factors have been determined, the process for the development of routing cost model for the transport of hazardous waste will be initiated. The literature review chapter will provide useful insight about the findings of previous research studies on route optimization models for HAZMAT transport based on different factors and methodologies and will help to set a conceptual framework for the research study presented in this document. In the literature review chapter, the question of what are the factors affecting routing pertaining needed to be consider in the route optimization model will be answered, including a limitation

The process of developing a route planning framework for hazardous waste transport will take place in a stepwise manner. Prior to the development of the framework, the necessary tool needs will be described, e.g. MCDA and GIS, as well as the factors and criteria that will be taken into account to derive the optimal routes. In each of the phases of the framework development, a consideration of the different factors will be input into the model.

Figure 1.4 below simplifies the conceptual framework of the study presented in this document. The dashed arrow indicates the factors to be proposed in the routing framework that can be directly or indirectly involved in hazardous waste transportation. The solid arrows indicate the sequence followed by the proposed method: first defining what factors will be considered in the framework, and then how the factors will be incorporated into a framework.

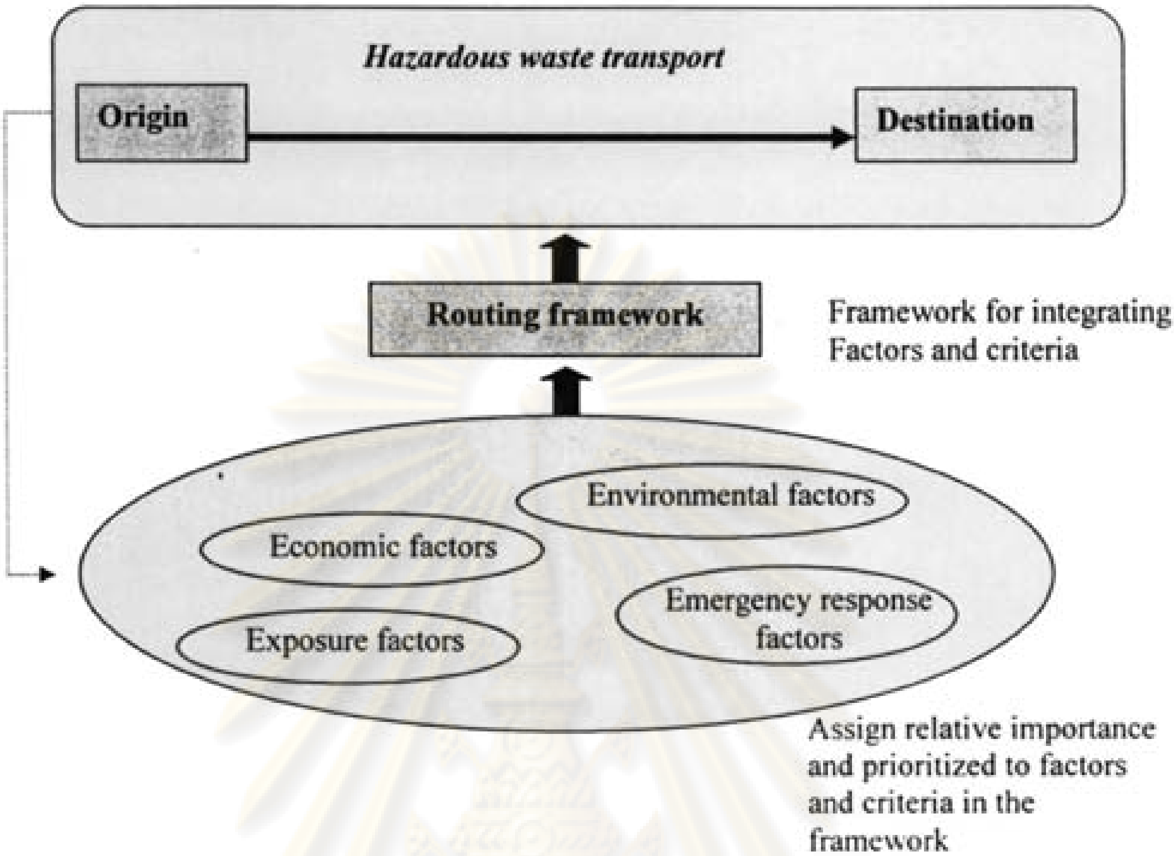

Figure 1.4 Basic conceptual model of the research strategy

1.5 Contributions

This dissertation makes several contributions to the field of HAZMAT transportation. Hazardous waste can cause high risk and lead to potential harm to the environment and society if there is no proper way to handle and manage it during the transport phase. An underlying concept of sustainability has been studied and proposed and the idea of what factors and criteria that should be considered in HAZMAT route planning has been presented.

After identifying factors and criteria, a next critical step is to develop a method that can input an idea of multiple factor and criteria into consideration. An integrated method based Multi criteria decision analysis (MCDA) and Geographic Information System (GIS) tool is an emerging critical framework for efficient management of conflicting objectives that consist of multiple factors and criteria involved. The proposed framework can be incorporated with the cost model with the purpose of generating various scenario results for planning and analyzing hazardous waste management transport.

The availability of the framework can provide additional benefit as well. For example, the framework can input multiple factors and criteria to achieve sustainability goal. Similarly, the selection of possible routes for hazardous waste transport may benefit from application of the framework to real situation of decision making process. In both cases, the framework is capable of providing a guideline in such situations that allows an optimal balance decision between economic, environmental and societal considerations.

This research is expected to accelerate the idea of defining factors and criteria to build a framework for sustainability goal and to develop a method for creating a comprehensive framework based on integrated Multi criteria decision analysis (MCDA) and a Geographic information system (GIS). The last one is to applying a proposed framework into practice for promoting a win-win situation among stakeholders and to minimize the potential impact to surroundings of negative outcomes of transportation incidents.

1.6 A brief diagram to this dissertation

The research diagram is depicted in Figure 1.5 below.

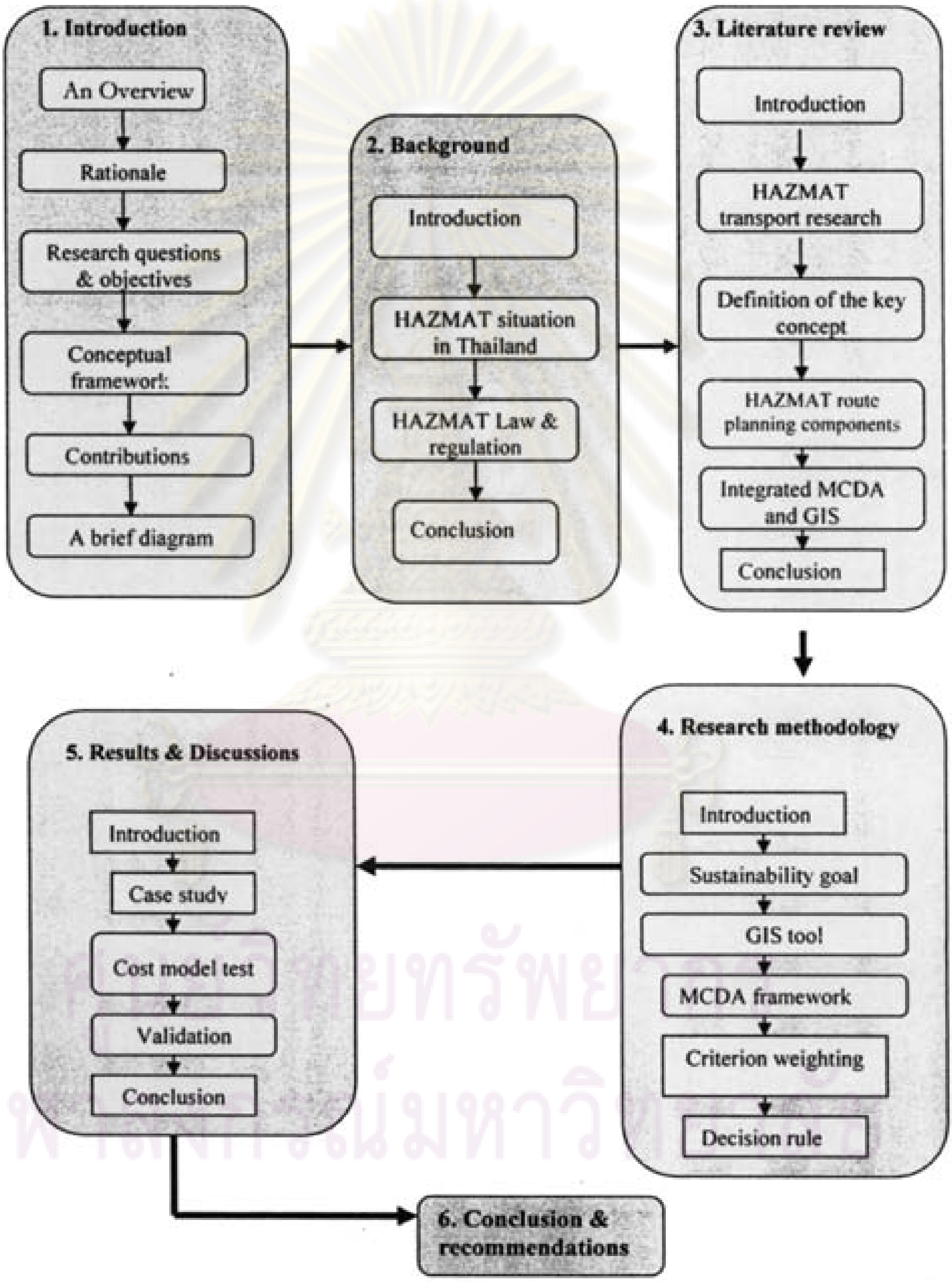

Figure 1.5 A brief diagram to this dissertation

CHAPTER II
BACKGROUND

2.1 Introduction

During 1980s, Thailand has gradually progressed toward industrialized economic country. The country's GDP in the second half of 1980s exceeded 10 % per year, and range among the fastest growing economy in the world. The rapid economic development caused problems on the environment and quality of life at alarming rate. In addition, the growth of industrial and service sector and urbanization without efficient management and planning system as well as the lack of environmental awareness are the key factors lead to environmental deterioration through air, land and water resources.

Hazardous waste has become one of the most serious problem and need to be solved urgently. In Thailand, there are more than 1 million tons of hazardous waste generated each year, as a result of activities in both industrial and community sector. Such a practice is, however, ineffective in preventing the potential migration of hazardous contaminants off-site and the results could pose a variety of harms to human health and the environment. In addition, Thailand had ever faced the damage caused by an incident of illegal transboundary dumping of hazardous waste. Even though a lot of money was spent for the recovery from these issues of the 1980's, some long run effects have still remained.

2.2 HAZMAT and hazardous waste situation in Thailand

In 2004, it was estimated that the total of hazardous waste generated in Thailand was approximately 1.4 million tons. It is clearly point out from this estimate that the activities of industrial/manufacturing sector generate a significant amount of hazardous waste in the country as shown in Figure 2.1

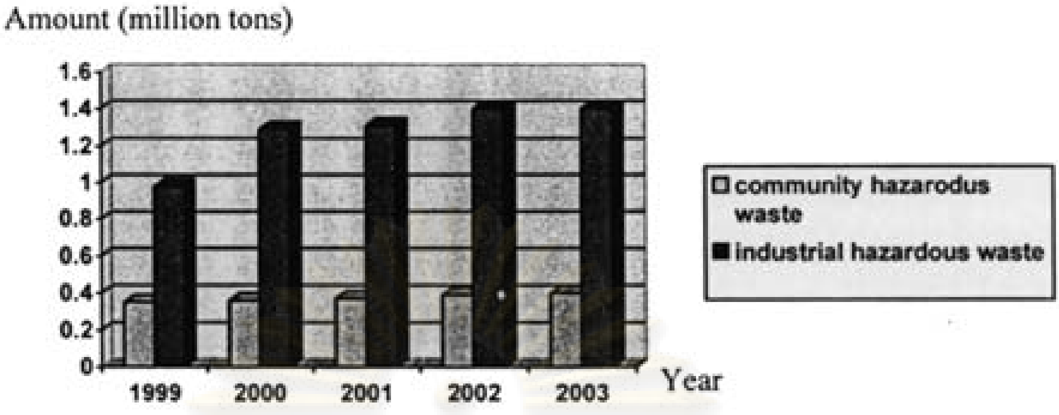

Figure 2.1 The generation amount of hazardous waste between 1999 - 2003

.The quantity of hazardous waste is likely to grow rapidly with an increasingly strong economy in Thailand. In the late 1980s and early 1990s, industrial waste generation grew dramatically. As reported by Pollution Control Department (2006), hazardous waste quantities are increased from 531,154 tons/year in 1986 to 1,808,104 tons/year 2003. This is a result from an average annual growth in manufacturing of about 10 percent. Although there was a dip in manufacturing production during the financial crisis, yet since then the manufacturing sector has recovered, growing an average of 4 percent over the last several years as the population and economy continue to grow (World Bank, 2003). Recent evidence has shown an increasing demand for HAZMAT as a result of the industrial growth in Thailand. From statistics of Pollution Control Department (PCD), the total imports of HAZMAT has increased from 3.11 to 5.22 million tons, while the total amount of HAZMAT production within the country has also been increased from 9.80 to 28.81 million tones during the period 1998-2005 (PCD, 2006). The three highest imported hazardous materials include: flammable liquids (82.08 percent), flammable gases (15.49 percent) and corrosive substances (1.28 percent) respectively (Office of Permanent Secretary, Ministry of Transport, 2004). The rising level of industrial production correlates strongly with the hazardous waste quantity increase.

From a report by Pollution Control Department (PCD) in 2006, only 276,687 tons or about 20 percent of the industrial hazardous waste is sent to disposal sites (not including reuse or recycling at the production site). Nearly 70 percent of the total treated amount of hazardous waste has been directed to incinerator plants as raw materials for fuel blending as part of cement factory operations (PCD, 2006). As in the 9th National plan of Thailand (2002-2006), hazardous waste is one of the major concerns to impede Thailand in moving to sustainable development on the environment. The state of waste and hazardous waste disposal is critical and need serious improvement. Further, the proportion of appropriate hazardous waste treatment and disposal is small.

2.2.1 *HAZMAT and hazardous waste incident*

From statistic reported by PCD, a trend of dangerous good incident in Thailand is increasingly during year 1999-2004. Most incidents have occurred within fix facilities and transport of chemical substances. In 2001, there are 14 HAZMAT transport incidents out of total 24 incidents. A characteristic of incidents are mostly occurred by a leak of chemical substance and explosion. This can cause a huge impact to surrounding environment. Nevertheless, it should be noticed that HAZMAT incident statistic reported has been underestimated because a lot of HAZMAT incident events have not been reported. A lack of complete information can play a major role in attempting to prevent and solve this problem effectively, including a lack of comprehensive planning to the problem as well. HAZMAT incident reported is shown in Table 2.1 below.

Table 2.1 A number of HAZMAT incident classified by source and/or cost of incident during 1999-2005

Year	Source or cause of incidents					
	In factory	In chemical warehouse	Transportation	Illegal dumping	Others (natural incident)	Total
1999	2	2	1	0	1	6
2000	10	1	7	3	1	22
2001	6	1	14	3	0	24
2002	10	6	5	6	0	27
2003	4	2	6	15	1	28
2004	13	6	5	4	1	29
2005	2	0	3	1	0	6

2.3 HAZMAT transport laws and regulations

2.3.1 *International status*

Laws and regulations on the use and handling of hazardous materials may differ depending on the activity and status of the material. For example, one set of requirements may apply to their use in the workplace while a different requirement may apply to spill response, sale for consumer use, or transportation activity. The most widely applied regulatory scheme is that for the transportation of dangerous goods. The Committee of Experts on the Transport of Dangerous Goods of the United Nations Economic and Social Council issues Model Regulations on the Transportation of Dangerous Goods. These model regulations provide a labeling system for HAZMAT classes, packing and tank provisions, consignment procedures and requirements for standards for construction and testing of packaging and containers. Most regional and national regulatory schemes for hazardous materials are harmonized to a greater or lesser degree with the UN Model Regulations. Many individual nations have also structured their dangerous goods transportation regulations to harmonize with the UN Model in organization as well as in specific requirements. However, some developed countries like the United States have issued further routing criteria for HAZMAT transport and many factors are considered in the route designation process. Unfortunately, a major concern in most developing countries is the lack of comprehensive framework for route selection of HAZMAT that transporters can use for aiding their decisions

2.3.2 *Thailand status*

Thailand has inconsistent legal definition of toxic or hazardous waste. In practice, hazardous waste is solid, semi-solid, liquid or gaseous material which exhibit or which is contaminated with substances exhibiting one or more of the hazardous substances.

2.3.2.1 *Hazardous Substance Act of B.E. 2535 (1992)*

The hazardous substances act has been effective since April. 7 1992. It includes explosive substances; flammable substances; oxidizing agents and peroxides; toxic substances; infectious substances; radioactive substances; mutant causing substances; corrosive substances; irritating substances; and other substances which may cause injury to persons, animals, plants, properties of the environment. For the efficient hazardous waste control and management. the specific lists of hazardous waste are defined by the national legislation as the following:

Four items of hazardous wastes from industries are defined and listed in the Notification of the Ministry of Industry No.6 B.E. 2540 (1997) on Disposal of Wastes or Unusable Materials issued under the Factory Act B.E. 2535 (1992) as follows:

Item 1: Hazardous wastes: ignitable, corrosive, reactive, toxic and leachable substances.

Item 2: Hazardous wastes from non-specific and specific sources.

Item 3: Hazardous waste: Discarded commercial chemical products, off-specification species, container residues, and spill residues (Acute hazardous and toxic hazardous chemicals), and

Item 4: Hazardous wastes: Chemical wastes.

13 items of chemical wastes are defined and listed in the Notification of the Ministry of Industry B.E. 2548 (2005) on List of Hazardous Substances issued under the Hazardous Substance Act B.E. 2535 (1992), This list is defined in accordance with the wastes listed in Annex I of the Basel Convention (Y1-Y44) for control of export, import and transit within Thailand. Therefore, a comprehensive legal framework exists to control operations in a fixed installation facility, but there are no clear national standards that can be used as a guideline for route selection for HAZMAT and/or hazardous waste transport. Only a few laws and regulations have been released from various government agencies as the followings:

2.3.2.2 *Laws and regulations related HAZMAT transport*

A law and regulation in Thailand related to handling and storage of HAZMAT in the building, during transportation, and safety are regarded to United Nations (UN) standard. However, highway routing for HAZMAT law and regulation is a major issue that Thailand still lacks when comparing with the United States as shown in Table 2.2

Table 2.2 A comparative of HAZMAT issue between the United States and Thailand

Issue	U.S.A	Thailand
Handling and storage in building	●	●
Safety	●	●
Handling and storage during transportation	●	●
Highway routing	●	-

There are a few laws and regulation with regard to the issue of HAZMAT transport in Thailand as summarized in Table 2.3

Table 2.3 Summary of laws and regulations with regard to HAZMAT transport in Thailand

Law and regulation	Detail
Restriction of HAZMAT truck transporting in urban area of BMA	A regulation that restricts HAZMAT and/or hazardous wastes truck transporting within a radius of 113 kilometers around the center of the Bangkok Metropolitan Area (BMA) during the day time.
Restriction of HAZMAT truck transporting on expressway (2006)	A restriction of HAZMAT truck route on some express ways (2006) (with the exception for some types of HAZMAT class and the exception will be granted in case that transporter fill up documents stating the details of express way used, type and time for their shipments and inform responsible government office before transporting those materials).
Hazardous waste manifest (2004)	Based on self-declaration by which every party concerned follows the official rules by filing documents stating the hazardous waste origin and destination.
Hazardous materials transport insurance act (2006)	Declare a criteria and condition related to pay liability cost from HAZMAT transport incident (leak, explosion and flammable) that cause the following damage; physical injury of people, damage to surrounding properties and recovery cost. The maximum liability cost is not exceed 30 million bath

Contrary, the framework and guidelines for HAZMAT transport in the United States, Canada and European countries establish the factors and criteria that need to be considered during planning for shipment of those materials. There are major problem in a lack of framework when considering the factors and criteria related to routing planning for HAZMAT in Thailand. The system of hazardous waste transportation in European countries, United States and Thailand are compared in Table2.1

Table 2.4 A comparison of hazardous waste transportation system in United States, European Union and Thailand

Issues	U.S.A	E.U	THAILAND
Transportation mode	All modes	All modes	Mode unspecified
Waste tracking	Manifest system used	Manifest system used	Manifest system used
Competence of drivers and action in emergencies	Drivers and other personnel trained	Drivers and other personnel trained	Drivers and other personnel trained
Highway Routing	Required by Federal Law and varies in States	Mostly required by Law and varies by countries	No Law directly concerned

2.4 Conclusion

Hazardous Substance Act of B.E. 2535 (1992) is a well established law and regulation concerning Hazardous materials in Thailand and many notifications are released by Ministry of Industry and Department of Industrial Works under this act. However, Thailand has currently no law and regulation that can be used as a guideline or framework for assisting HAZMAT transport route planning. However, appropriate routing for hazardous waste shipment is considered as essential element in the future development plan of Thailand, but public hearing need to be conducted first. Moreover, factors and criteria consideration in HAZMAT transport is also another critical issue. If a framework is developed with a lack of comprehensive insight in risk factors and criteria, it can lead decision making based on some risk factors alone such as economic while other critical risk factors are not taken into account in the HAZMAT route planning framework.

Hence, it is very crucial that the issues of the lack of HAZMAT route planning framework, with integration of multiple risk factors and criteria needed to be considered in the framework and it should be well organized and understood manner. Moreover, a method to development a framework and a tool required to construct a framework is also another important issue as well. In the next chapter, a review of these issues has been conducted. How previous and existing HAZMAT route planning frameworks were developed? What risk factors to be used in those frameworks? What is a necessary method and tool to aid the framework development? All these questions will be answered in the next chapter.

CHAPTER III
LITERATURE REVIEW

3.1 Introduction

This chapter consists of five topics. The first topic explains about a major consideration in HAZMAT transport. The second topic dedicates to the definition of key concept in HAZMAT transport, both definition of risk and sustainability. The next topic of the chapter discusses a previous HAZMAT route planning component with regard to risk framework used, methodology development by applying NCDA framework and tool. An integrated MCDA with GIS in HAZMAT transport research is described in fourth topic. Finally, the chapter ends with a conclusion with the point of view, strengths and weakness derived from previous literatures. A review diagram of this chapter is shown in Figure 3.1

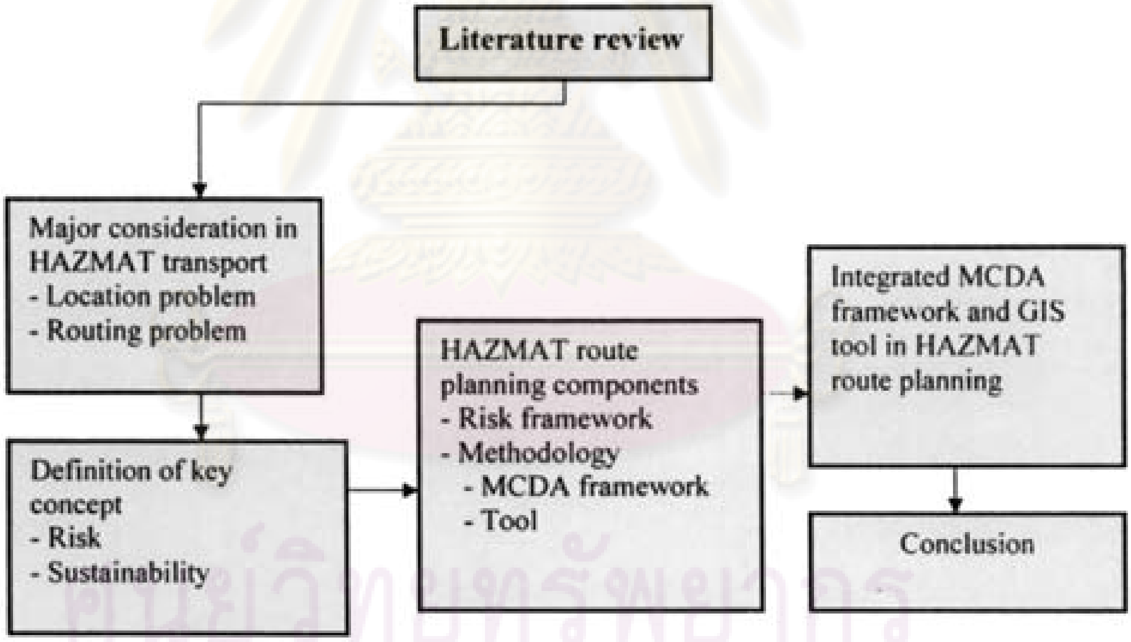

Figure 3.1 A review diagram for chapter 3

3.2 Major consideration in HAZMAT transportation research

A traditional consideration in HAZMAT transportation research is consisted of two main topics; location problem and routing problem. However, this dissertation pays much of attention to HAZMAT routing problem.

3.2.1 *HAZMAT location problem*

The HAZMAT routing problem was first proposed to find a location for treatment and disposal facilities. An early example is the study by Pierce and Davidson (1982) that utilizes a linear programming method to solve and formulate the optimum transportation routing among many transfer stations, disposal facilities, and long term storage impoundments such as landfill sites. However, the model was based only on consideration of factors that would lead to the most cost-effective solution. The most recent review published on this topic can be found in Erkut and Neuman (1989). A major goal for locating these facilities is to reduce the potential adverse effects of the facilities on the surroundings, especially on nearby populations. Although the cost of using these facilities will increase according to the magnitude of the distance they are located from cities or population center, greater distances would seem to be reasonable in terms of risk minimization.

3.2.2 *HAZMAT routing problem*

Concerning with risk in HAZMAT transport was first taken into consideration by Jenning and Scolars (1984). They formulated a regional hazardous waste management system (RHWMS) as simply a vehicle routing problem in an attempt to accomplish the goal of achieving either minimum cost and/or minimum risk. Routing of HAZMATs has been considered as a crucial aspect in many literature reports. Although the scale of HAZMAT transportation is still limited, the risks associated with such transport to nature and to human environment can be enormous. Because accidents usually result in some form of inconvenience at the very least, or even worse in injury or death, public concern has started to rise about how and when these shipments are planned and routed through specific geographical areas. The main issue is derived from the size of the population that is potentially at risk in the impact area (the routes may cross or pass by towns and villages) rather than from the scale of any accident itself (Fabiano *et al*., 2005). When considering a problem of HAZMAT transport, the impact of the problem can be categorized into two types depending on duration; *immediate effect* such as a loss from the accident or the hazard from chemical exposure and *long term effect* such as a spill of a toxic chemical in the environment. The main purpose of considering the problem is to seek the optimum route for HAZMAT by minimizing the risk for moving the materials between the point of origin and the destination point or the origin-destination pairs (OD pairs). However to accomplish risk minimization, an idea of risk measurement must be formed and applied. Generally, only two common risk measures are used: societal risk and population exposure. Societal risk is the product of the probability of an accident involving a truck carrying hazardous waste and the consequences of that accident. While the population exposure measures the number of people exposed to HAZMAT as a result of such an accident.

Cost and risk are critical factors of concern in both the location and routing problems. However, during the transportation phase, inevitably one must deal with a number of potential consequences from a truck accident that may result in environmental risk by the dispersion of toxic chemicals spreading to environmental media such as air, land and water. The degree of the accident consists of various factors involved such as the population density, the number of sensitive places such as the number of schools, the number of heritage and cultural places, the proximity to sensitive environmental sites such as ponds and lakes and the proximity to rescue units including fire stations, police stations and hospitals. Therefore, it is rare for a carrier to consider all of the related factors and criteria when they have to plan and select a shipment route for HAZMAT in a real situation. Usually, only a few critical risk factors in HAZMAT transport are understood and chosen by transporter. This leads to HAZMAT route selection decision without reasonable planning.

3.3 Definition of the key concept

To make a reasonable decision about HAZMAT route planning, a truly understand with the definition of key concept should be met first. This section will provide the definition of the terms related to risk, hazard and vulnerability.

3.3.1 *Risk*

Risk is often defined as the probability of a damaging event occurrence, and the consequences produced by this event once it has occurred. Some researchers have defined risk as the interaction between hazard and vulnerability factors (Blaikie *et al.*, 1994). Risk can be viewed as a warning signal telling about certain events that could take place sometime in the future. If the event does take place, it is expected that damage can occur to both living things and property. Based on the definition presented by the United Nations Disaster Relief Office (1991), risk is the expected number of lives lost, persons injured, damage to property and disruption of economic activity due to a particular hazard, and consequently the product of the specific risk and the element at risk.

3.3.2 *Hazard*

Hazard represents a potential damaging event that can affect a vulnerable population, production site or infrastructure: and the vulnerability factors represent the status of a given population that might be susceptible to damage if the hazardous events occur. Hazards can be divided into different types: Natural, socio-natural, man-made or technological, and social hazards. Lavell (2000) specified that natural hazards are those related to natural phenomena such as meteorological, geo-technical, geological, or oceanographic hazards; socio-natural hazards are those related to social processes that transform the natural environment and resources in such a way that new hazard types are created. A clear example of a socio-natural hazard is slope mining at the base of hills, which may lead to increased probability of landslide events. Another example is the cutting of many trees that can increase the probability of flooding in a subsequent rainy season.

A human induced hazard related to HAZMAT transport is the probability of an accident occurring in a certain section of a transport network, a number that is generally known as the accident rate. To estimate the accident rate for a particular area, historical records of the accidents in that area can be used. However, when there is not enough statistical data to derive the accident rate, data from countries with similar traffic conditions can be used. In the case that no data is available, assumptions are often made. Nicolet-Monnier and Gheorghe (1996) proposed a typical rate value of 3.0×10^{-6} accidents/vehicle-km. However, the accident rate can be derived from the physical conditions of the transport network, such as the average traffic volume. It is important to realize that the accident rate does not depend solely on the level of congestion of the network. Other factors need to be considered, especially, human errors such as driving at excessive speed, not leaving enough space between vehicles, over fatigue of drivers, and failure to observe traffic warning signs. Regardless of how the accident rate is estimated, it must take into account that there are spatial components related to it such as road slope or grade. The accident rate is not the same in every section of a transport network. However, a major problem is that accident rate data in developing countries are mostly incomplete or unavailable (Huang, et al., 2004). It would be useful therefore in such situations to develop other factors as surrogates for the accidental rate.

3.3.3 *Vulnerability*

The vulnerability of an element at risk depends on its characteristics and on the type of hazard being considered. Vulnerability is mostly measured on a scale ranging from zero to one (UNDRO; 1991), where zero represents the situation where there is no damage inflicted to the elements at risk in case of exposure to the hazard, and one represents total damage of the elements at risk when exposed to the hazard. UNDRO (1991) also suggested that the vulnerability of a certain element at risk exposed to a given hazard can be determined by using vulnerability curves. Frank et al. (2000), Zagrafos and Androutsopoulos (2004)) have proposed the term potential impact area, which is defined by a radial distance (λ) measured from the center of the accident, and further have assigned a value of one to every element at risk located within the impact area, and zero to every element outside of the impact area range.

3.3.4 *Risk indicators*

It is essential to use risk indicators to measure risk. The risk indicator can tell us how much risk there is for a particular element at risk exposed to a given hazard. The remaining question is what units do we use to express risk? The answer depends on how specifically we need to express risk. The specific risk is derived by multiplying the probability of a hazard by the vulnerability of an element at risk. The specific risk has no unit, but it still can indicate what percentage is expected to be lost from an element at risk if a hazardous event occurs. The total risk is used to quantify the specific risk, expressing the total risk in measurable units: numbers of persons, number of cubic meters, number of linear meters of road, number of millions of euros, or other examples of measurable units.

Other risk indices are individual and societal risk. Bohnenblust and Slovic (1998) define individual risk as the annual probability of being harmed by a hazardous situation and societal risk as the probability of a group of individuals, companies or institutions being affected by exposure to a hazardous situation. Individual and societal risk indices are commonly used in risk analysis of fixed facilities. However, these risk indices can also be calculated as linear risk indices for a case such as the transport of HAZMAT. The route can be seen as a line formed by a continuous set of points, where every point represents a risk source, allowing evaluation of the contribution of these risk sources to the total risk over the route. According to Leonelli *et al*. (1999), to quantify these risk indices, it is necessary to access a great amount of data, such as the characteristics of the particular HAZMAT being transported, the meteorological conditions and the properties of the element at risk.

3.3.5 *Sustainability*

Sustainability is a term that has varying definitions but generally means providing the means for economic development for the current generation without compromising the needs of future generations. It is often described as the 'capacity for continuance' and is associated with terms such as 'development' and 'environment'. Sustainability issue has been taken into account in many developed countries. In the United States, the transportation community has shown an increasing interest in sustainable transportation and its linkages to land use and urban development patterns, economic growth, environmental impacts, and social equity. In addressing this interest, many U.S. transportation agencies are re-examining their policies, planning approaches, and evaluation methods and are considering changes to every aspect of practices, from the materials and designs used in construction to the kinds of alternatives considered for implementation. Federal, State, and local agencies as well as private organizations are working to translate the broad goals of sustainability into specific transportation policies, objectives, and programs. Hence, sustainability issue can be translated to HAZMAT transportation to identify a specific policy (FHWA, 1994). In previous reviewed literature, sustainability and/or sustainable HAZMAT transport have been mentioned a very few. Most common factors and criteria that have been selected to create a model and/or framework are distance, time and population at risk. Security is a popular factor that takes into account in HAZMAT transport after 9-11 events in 2001. To push HAZMAT transport issue toward sustainability approach, economic, environmental and societal issues should be incorporated as a factor and criteria to be considered in decision making process.

3.4 HAZMAT route planning components

3.4.1 *Risk framework*

The previous research studies related to HAZMAT transport have been involved with risk framework. A typical objective of risk framework has tried to minimize the total incident probability and/or the total population exposure to toxic chemical substances from HAZMAT transport incidents (Kara, *et al*., 2003). Leonelli, *et al.* (2000) introduced a methodology based on the quantification of individual and societal risk indices for the selection of an optimal route for the transport of HAZMAT. The hazard considered is the accident probability of a HAZMAT transport unit, and the population is considered as the element at risk, those being affected in the case of an accident. The population value results from aggregating the population traveling on the transport network and the population located adjacent to the transport network. Leonelli, *et al.* (2000) mentioned that the use of individual and societal risk can give an accurate indication of risk, however to calculate these value, a great quantity of data and programming effort is required. Because of this, a number of other simplified quantification techniques have been adopted in other research studies.

A simplified approach has been proposed by Frank, *et al*. (2000) to quantify risk. This research study focused on the development of a spatial decision support system for the selection of routes for the transport of HAZMAT within the United States. The element at risk considered in this research study is the population located in the impact area of the accident. The impact area is located alongside the route and it extends to both sides of the route up to a predefined bandwidth. The hazard is the probability of the HAZMAT transport unit getting into an accident while traveling between the origin and destination points. For this research, historical data was available to estimate the accident rate based on the visibility conditions over the network and the time of the day. The risk for the population was calculated by multiplying the accident probability by the number of persons located in the impact area.

Table 3.1 Accident rates derived from historical data in the United States

Road type and condition	**Truck accident rate**
Dry urban expressway with **unrestricted** visibility	2.379×10^{-6} accidents per mile
Dry urban expressway with **restricted** visibility	4.054×10^{-6} accidents per mile
Highway with good weather, **day** time	1.440×10^{-6} accidents per mile
Highway with good weather, **night** time	1.470×10^{-6} accidents per mile

Source: Frank *et al.* (2000)

Karkazis and Boffey (1995) also focus on the damage induced to the population in case of an accident. However, this research study pays attention to the dispersion of HAZMAT through air. Therefore the impact area is not defined by a given bandwidth, but it is a function dependent on the type of material transported and the meteorological conditions at the moment of the accident. Zografos and Androutsopoulos (2004) also considered the population as the element at risk. In this study, the population located inside the impact area is assumed to have the same vulnerability value, namely one. The risk for the population is defined as the product of individual risk and the total population located in the impact area of the accident. The equation used by Zografos and Androutsopoulos (2004), calculates that the risk for the population for a particular section of the transport network will be proportional to the probability of the HAZMAT accident for the network section, the probability of release of the material in a given HAZMAT accident, the probability of a consequence (e.g. fire and explosion) in a certain release event and the population within the impact area. The total risk for the population over the whole route will be calculated by the summation of the risk values of every section in the route. The new model by redefining the decision problem as one of satisfying demand at the destination has been presented (Erkut and Ingolfsson, 2005).

3.4.2 *A complexity of risk factors*

In a research study conducted by Brainard, *et al.* (1997), three aspects of risk were examined. The first of these concerned the threat to nearby residents and was assessed by calculating the number of people living within 500 m of identified routes. Utilizing a standard distance band was somewhat simplistic, because the zone affected by a spillage will vary according to factors such as wind speed and direction, but these considerations could not be readily incorporated given the regional scale of analysis. They also evaluated the hazard posed to groundwater supplies. The overall accident risk for the routing scenarios is calculated from the details of the predicted level of tanker traffic on each class of road and the frequency of travel.

Environmental Science Division, under Argonne National Laboratory in United States of America proposed integrate cumulative risk framework that can lead to stronger policies for achieving a healthy and sustainable environment. An initial technical focus is on human health risks, with an emphasis on mixtures as in Figure 3.2

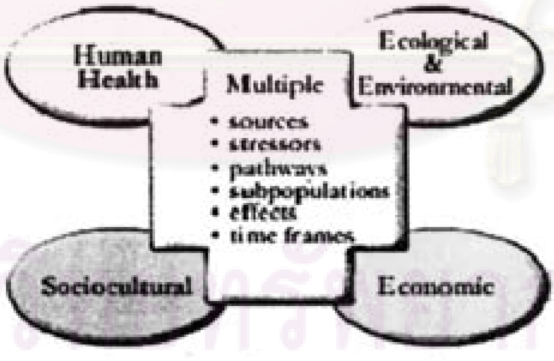

Figure 3.2 Showing integrated cumulative risk

Different functions employed to quantify risk factors and risk values have been proposed in previous research studies. Some of these functions aim to estimate the risk value as accurately as possible. There are other functions which give a simplified, but still useful risk value. Risk that is quantified in terms of individual and societal risk gives a good measure of risk. However, such quantification also requires a great quantity of data, such as data related to historical records of accidents, meteorological factors, and the chemical properties of the materials. It is a fact that these data can be accessed and retrieved much easier in developed countries, while in developing countries, historical records and meteorological data may be incomplete or unavailable. In most developing countries, the lack of data is a fact that cannot be avoided and has to be dealt with when trying to plan a HAZMAT route transportation framework. As the risk framework that will be created in the course of this research is intended for use in developing countries, a risk approach that can be quantified in a simplified and acceptable manner is proposed.

Clearly, there are many factors involve in risk framework for HAZMAT transport. Dealing with all of these factors is very complex and it makes a risk framework is too complicate. However, it is very essential that all factors and criteria should be realized and incorporated into the HAZMAT risk framework when making decision on HAZMAT transport. A comprehensive method that can take all essential factors and criteria into consideration is required.

3.4.3 *HAZMAT route planning methodology*

To deal with complexity nature of HAZMAT transport. A transport route framework that considers different factors for the selection of a HAZMAT route can serve as an integrated risk management tool. The importance of being concerned with different risk factors lies in the fact that we cannot avoid being exposed to many risk sources. We can avoid certain risks sometime, but we are exposed ourselves to even more risks of other types. The government of any country cannot assure protection of the population against every risk source, nor can pursuing the reduction of every risk be achieved due to economic reasons. Perhaps not all risk can be managed, but the decision about what risk should be managed or not should be based on the incorporation of the multi criteria decision analysis approach is better than single factor consideration and is very useful for HAZMAT transport decision making.

3.4.3.1 Multi Criteria Decision Analysis (MCDA)

Decision-makers are typically required to consider multiple, often conflicting, objectives in making their choices about various types of problem such as engineering, business, science, and policy. Multi criteria decision analysis (MCDA) is a discipline aimed at supporting decision makers who are faced with making numerous and conflicting evaluations. MCDA aims at highlighting these conflicts and deriving a way to come to a compromise in a transparent process. Broadly speaking, Multi-criteria Decision Making (MCDM) problems involve a set of alternatives that are evaluated on the basis of often conflicting and incommensurate criteria. [Note: the term multi criteria decision making (MCDM) and multi criteria decision analysis (MCDA) are used interchangeably] Typically, MCDM consists of two related paradigms: Multiple Attribute Decision Making (MADM) and Multiple Objective Decision Making (MODM) (Malczewski, 1999). The MADM approach requires that the choice be made among decision alternatives described by their attributes (i.e. criteria). MADM problems are assumed to have a predetermined, limited number of decision alternatives. Solving an MADM problem involves sorting and ranking the decision alternatives. In the MODM approach, unlike the MADM approach, the decision alternatives are not given. Instead, the set of decision alternatives is explicitly defined by constraints using Multiple Objective Programming. Each alternative, once identified, is judged by how closely it satisfies a single objective or multiple objectives. The number of potential decision alternatives may be large for the MODM approach.

A generic framework for discussing the principal steps in the application of MCDM models, and the concepts and procedures involved, has been identified in the following sequence of steps in a typical application;

1. Establish the decision context, the decision objectives (goals), and identify the decision maker(s).

2. Identify the alternatives (here, the set of routes to be considered from origin to destination for hazardous waste shipment).

3. Identify the criteria (attributes) and/or sub-criteria that are relevant to the decision problem.

4. For each of the criteria, assign scores to measure the performance of the alternatives against each of these and construct an evaluation matrix (often called an options matrix or a decision table).

5. Standardize the raw scores to generate a priority scores matrix or decision table.

6. Determine a weight for each criterion to reflect how important it is to the overall decision.

7. Use aggregate functions (also called decision rules) to compute an overall assessment measure for each decision alternative by combining the weights and priority scores. This provides a measure of how well an alternative performs over all the criteria and forms the basis of a preference ranking.

8. Perform a sensitivity analysis to assess the robustness of the preference ranking to changes in the criteria scores and/or the assigned weight.

9. Examine the preference ranking, and make a provisional decision on the subset of alternatives that might be considered as candidates for a problem.

Multi criteria decision analysis (MCDA) is capable of handling and managing the HAZMAT transport problem, especially in performing an analysis based on multiple factors and criteria. There are two general types of analyses in MCDA; Prescriptive and Evaluation of past decisions. Prescriptive analysis involves multi criteria scoring that can be separated based upon the set of alternatives. For finite sets of alternatives for the problems, the Analytical Hierarchy Process (AHP) and the Simple Multi-attribute Rating Technique (SMART) are examples of widely used techniques, while Multi-Objective Linear Programming (MOLP) and Linear Programming (LP) are techniques generally applied to the problems with large alternative sets.

3.4.3.1.1 *Single and multi objective decision making* another critical aspect is how to develop a methodology to analyze and solve HAZMAT transport routing problem. The typical route determination method applies the shortest path problem or Dijkstra's algorithm that is widely applied in path selection for much transportation research. However, additional risk analysis methodologies for HAZMAT transport have been proposed. An optimization technique based on multi objective decision making has been cited for the HAZMAT transport routing in the recent literature for use in finding out the best route by single objective with a limited set of constraints (Kara, *et al*. 2003 and Erkut & Ingolfsson, 2000), Turnquist and List (1993). List *et al*. (1991) introduced an integrated multi-objective model for routing and storing HAZMAT wastes. In addition to risk and cost, they also considered risk equity, which is measured as the maximum risk per unit population. Total risk, however, is the sum of all zonal risks from transportation or from treatment facilities. Erkut and Verter (1995) explored the different models of risk. The traditional definition of risk is the product of both the probability and the consequence of the undesirable event. They cited unit road segment risk, edge risk and path risk as models of risk using the traditional definition. They also cited alternative risk models involving perceived risk, the disutility of risk and conditional risk. They also suggested that the risk-minimization problem is a bi-criterion optimization problem: one of minimizing incident probability and population exposure. The consideration of other criteria is also possible. As long as each criterion is additive to its edge attributes, a weighting method can be used to generate a subset of efficient points.

Leonelli, *et al*. (2000) developed a route optimization model using mathematical programming to calculate the optimal routes. The optimization problem is presented as a single objective minimum cost flow problem, where the objective is to minimize the total cost over the route. The total cost over the route is the summation of the cost values assigned to every transport network section that is part of the route. The term cost in this case is not only "out-of-pocket" costs or operational cost, but also includes "risk-related" costs that are related to the expected number of persons affected in case of the occurrence of an accident involving a HAZMAT transport unit. It is important to express operational cost and risk related cost in same monetary unit. The Human Life Value (HLV) is used to express the risk related costs in monetary term. For their research, the operational costs are 0.86 Canadian$ km^{-1} vehicle-1 and the HLV is 617,190 Canadian$ $fatality^{-1}$. However, Castillo (2004) stated that the use of HLV to represent the risk related cost for a route optimization model is not appropriate for a developing country. Using HLV requires constant updating, especially in those countries where an unstable economy leads to the devaluation of currency exchange rates. He also comments that if HLV is not regularly updated, the value will not longer reflect the actual current reality. Furthermore the use of HLV may lead to the misuse of public funds when funds intended for use in communities affected by a hazardous event end up in the pockets of corrupt politician and authorities.

Zografos and Androutsopoulos (2004) developed a model that seeks to achieve the lowest level of operational costs and the highest level of safety while transporting HAZMAT. The optimization problem is presented as a bi-objective routing and scheduling problem. The two objectives are the minimization of operational costs and the minimization of the risk for the population. To solve the bi-objective optimization challenge, a weighting method is proposed. By using a weighting scheme, the bi-objective formulation can be transformed into a set of single objective problems. This research is focused on the development of a new heuristic algorithm to calculate the optimal route. The heuristic algorithm is an insertion algorithm that builds the route stepwise by inserting a new demand point in the already existing routes calculated on previous iterations, until the optimal route is found.

Zografos and Davis (1989) present in their research study the development of a route optimization model that differs from those of the other research studies. The purpose of their study is to develop a multi objective decision making model. The four objectives proposed to be considered in the model are: minimization of risk for the population, minimization of risk imposed to special population groups, minimization of travel time, and minimization of risk for properties located alongside the route. To solve this multi objective optimization problem, the authors proposed using goal programming for the following reasons: it offers considerable flexibility to the decision maker and allows the creation of many scenarios, it does not require a conversion of all objectives to a single monetary value when evaluating different scenarios and, most important: it requires only a limited amount of information on the part of the decision maker.

The problem of designing road network for HAZMAT shipments is proposed by Erkut and Alp (2005). They formulate a tree design problem as an integer programming problem with the objective of minimizing total transport risk. With a similar one, the problem of network design for HAZMAT transportation where the government designates a network and carrier choose the routes on the network is solved by heuristic solution method that always finds a stable solution (Erkut and Gzara, 2007). With regard to designing emergency response networks for HAZMAT transportation, Berman, *et al.* (2005) proposed a novel methodology to determine the optimum design of a specialized team network so as to maximize its stability to respond to such incidents in a region.

As mentioned above, a traditional purpose was dedicated to single objective that attempted to minimize total cost for HAZMAT transport. Later development was based on multi objective decision with the optimization technique that tries to minimize the risk posed to the population and to maximize the profit for the operation in terms of shortest paths and/or shortest time simultaneously. This technique is applied for large alternative sets (linear programming based) of the problem. Multi-objective linear programming (MOLP) and goal programming (GP) are examples of optimization techniques that have been used in many HAZMAT transport research studies.

3.4.3.1.2 *Multi attribute decision making* In contrast with Multi objective decision making, multi attribute decision making (MADM) is another approach toward multi criteria decision making that is based on finite sets of alternatives. A few researchers have used this approach to deal with qualitative criteria. Huang *et al.* (2004) attempted to identify and evaluate criteria that may be used to route HAZMAT vehicles. The criteria considered were related to safety, costs and more importantly, to security. The application of Geographic Information System (GIS) approach to quantify the factors on each link of the network that contribute to each of the evaluation criteria for a possible route was also proposed by Brainard, *et al.* (1997) and Huang *et al.* (2004). The Analytical Hierarchy Process (AHP) was used to assign weights to the factors, depending on their perceived relative importance. Security consideration is given a greater emphasis, as it has been previously neglected. Four identified criteria are: exposure, socio-economic considerations, risk of hijack and traffic conditions. Based on those factors and criteria, each route can be quantified by a cost function and the suitability of the routes for HAZMAT transportation can be compared. The resulting costs from the two methods will then be compared. The proposed route evaluation method was demonstrated on the portion of the road network in Singapore. However, sensitive environmental factors were not considered and input into their framework.

Goh *et al*. (1995) introduced a methodology for the risk analysis of hazardous chemical transportation in Singapore. A case study involving the transportation of Liquefied Petroleum Gas (LPG) addressed the modeling of three hazard scenarios: instantaneous release, medium spill and small spill. Risk assessment was also done for the off-road population as well as the road users. A similar idea has proposed the use of a GIS function as part of a risk assessment methodology by determining a score for related factors and criteria for routing hazardous materials transport, including such factors as location of schools, hospitals, police stations and fire stations in the United States (Schubert, 2005).

From previous researches, MCDA has been paid attention in some degrees. However, there are no rules that what factors and criteria should take into account in risk framework. This can lead HAZMAT transport decision making solely based on some factors such as accidental rate, distance, population exposure. While a factor like emergency response, proximity to environmental sensitive area that are critical factors as well, did not take into account in previous research. With regard to many factors and criteria consideration, HAZMAT transport framework can be complex. It is essential that an efficient tool is required to integrate with MCDA framework to manipulate this complexity.

3.4.4 *Tool*

The process of developing a framework for HAZMAT transport can be viewed as a two stage process. The first stage is where the planning part of framework takes place, whereas in the second stage, the framework for use by the decision makers or end users is produced. The planning stage focuses on the "What is going to be planned" part of the process, and the second stage focuses on the "how the things are going to be planned" part. In this section, attention is paid to how such a plan has been developed in previous research. The purpose of this section is to provide an overview of the available fundamental tool that can be used to develop the routing framework proposed in this research. To do this, some of the framework developed in previous studies will be reviewed, as well as what tool was used in the route planning.

3.4.4.1 *Geographic Information System (GIS)*

Geographic Information System (GIS) is a geo-database system that uses computers to collect, store, manipulate, analyze and display geographic information as depicted in Figure 1. GIS technology integrates common database operations such as query and statistical analysis with unique visualization and geographic analysis capabilities. These functional attributes distinguish GIS from other information systems and make it valuable to several public and private enterprises for explaining events, predicting outcomes and planning strategies. Geographic information is an indispensable source to provide a comprehensive link between spatial location and activities (Panwhar, *et al.*, 2000). Geographic information can be divided into two classes: *location or spatial data*, which records the location of a given object (point, line, or polygon), and *attribute or nonspatial data*, which describes characteristics of the object. GIS has been used as a tool in this research for handling and manipulating both spatial data and nonspatial data such as road networks, political boundaries, streams, location of sensitive places (schools, petrol/gas stations, cultural &heritage sites), population density, intersections, traffic density and location of emergency response units (hospitals, police stations and fire stations), and for identifying alternative routes for hazardous waste transport purposes.

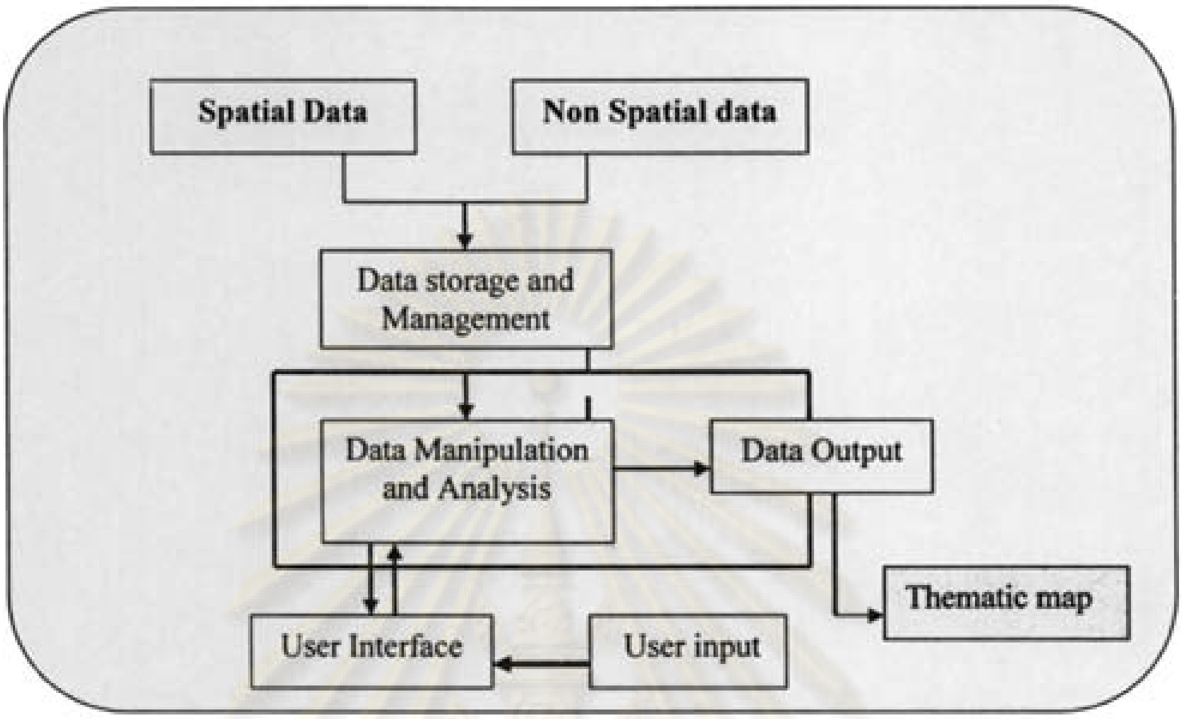

Figure 3.3 Structure of a GIS

In the last few decades, there has been a greatly increasing interest in the development of tools for transportation management. GIS developers have included in their systems extensions for the analysis of transport-oriented problems. The GIS packages provided with this extension or capability is called GIS for transportation (GIS-T) (Mainguenaud, 2000). Private and government stakeholders are nowadays more than ever interested in the use of GIS-T for their planning and decision making (Lepofsky, 1996). With the use of GIS-T, it is possible to find the shortest route between an origin and a destination point, which can be seen as one objective for the optimization problem. Alternatively, the objective can be selected to represent time, or distance, or population exposed, or other factors. Therefore, the optimal route can be found when minimizing either time, or distance, or population exposed individually. In the case where the combination of different criteria is of interest, the units of each criterion must be converted into a single common unit, such as a monetary currency unit for example. Some applications of GIS-T are devoted to scheduling problems, using the same principle of finding the shortest route, being based on a single objective optimization and incorporating a temporal decision into the problem, with the purpose of finding the best route to use and the best time for using/traveling the route.

However, the usefulness of the application of GIS-T for transportation problems, especially in route optimization problems, falls short when the problem is complex and requires more analytical framework than the capability supported by GIS-T (in the present stage of development). Depending on the model being developed, the amount and complexity of calculations required for finding the optimal route will differ from other models. In a case where the GIS-T cannot cope with the model's analytical requirements, it is possible to use external software that can cope with complex calculations. In this case, the GIS-T is used to manage the data and visualize the model output in the best way possible, and specialized software for multi-criteria decision making methods such as simple and complex mathematical programming codes can be used to perform the calculations required for the route optimization model process.

3.4.4.2 *HAZMAT route planning with GIS*

Existing literature shows that the use of GIS to aid HAZMAT route planning is not new. Lepofsky and Abkowitz (1993) demonstrated that GIS can be used to integrate plume representation with population data and transport maps to estimate consequences more effectively. Using combinations of routing criteria (e.g. population exposure, accident likelihood and sensitive places such as schools.) in a single analysis with varying weights on their importance, one can examine the trade-offs between various alternatives. Souletrette and Sathisan (1994) applied GIS to routing for the transportation of radioactive materials. Key inputs included demographics, environmental features and transportation system characteristics. They identified three methodologies namely; comparative studies, worst-case assessment and probabilistic risk assessment. Lovett *et al.* (1997) developed a GIS-based route optimization model for liquid hazardous waste transportation. Four routing scenarios namely; minimizing travel time; encouraging use of trunk roads; avoiding densely populated areas and minimizing accident rates were implemented to identify sections of road that consistently saw heavy traffic. The first two scenarios were used to identify the most probable routes used by tanker drivers to deliver their consignments.

The next two methods were risk reduction scenarios. Groundwater vulnerability was also considered in their study. Frank *et al.* (2000) developed a spatial decision support system for the route selection for HAZMAT transport. A user interface for the model was developed through a GIS environment for the visualization of the optimal routes. The optimization problem is defined as single objective temporal constraint shortest path using Dijkstra's algorithm. The model aims at minimizing the travel time between the origin and the destination point, but the objective is subject to a set of constraints--the distance traveled, the accident probability on the route, and the population exposed. The model allows the user to input the upper bounds of the constraint *i.e.* maximum travel distance allowed, maximum accident probability value allowed, maximum number of persons located in and alongside the route that are being exposed to the hazard, and maximum risk for the population value. The risk for the population is defined as the accident probability for the network section multiplied by the number of persons who populate the same network section.

3.5 Integrated MCDA framework and GIS tool in hazardous waste route planning

A very few previous literature have mentioned about the integrated of MCDA and GIS with the full scale of factors and criteria consideration in HAZMAT route planning. A research conducted by Huang *et al.* (2004) tried to make a comparative study for alternative routes by using GIS to manage a complex data and using MCDA approach to determine weight. However, it is still a lack of environmental factor consideration in their framework. Therefore, a good framework for HAZMAT transport must be composed of two criteria. A former is to consider all factors that are truly involved HAZMAT transport. As mentioned earlier, sustainability framework can be used as a goal to determine a number of factors and criteria in HAZMAT transport route planning. A consideration of economic, environmental and societal issues can be taken into account in form of factors and criteria in the framework to achieve the sustainability goal. A latter is a selection of a suitable framework and tool to manage complex information (both spatial and non-spatial) in the framework. MCDA framework integrated with GIS tool can serve as effective method to manipulate a complexity of factors and criteria and display a result in thematic context, which is easily to understand by decision makers. A relationship among sustainability, MCDA and GIS is shown in Figure 3.4

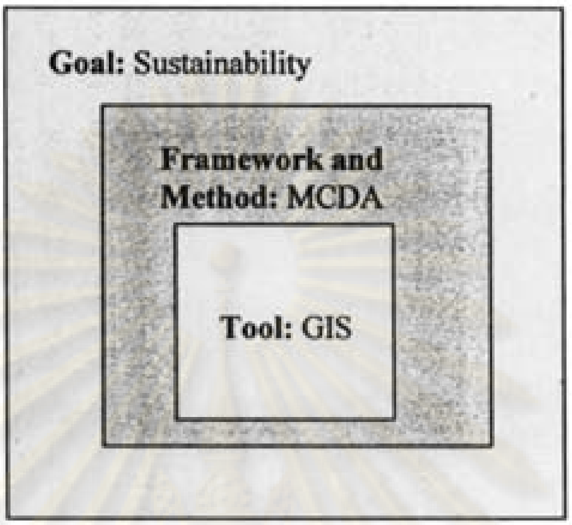

Figure 3.4 Integrated among sustainability, MCDA and GIS in HAZMAT transport

As depicted in Figure 3.4, a purpose of the framework is to generate factors, method and tool development with integrative approach. Sustainability thinking has been integrated into the framework through factors and criteria related to HAZMAT transport for achieving the goal of sustaining economic, environmental and societal simultaneously. If multiple factors and criteria consideration are perceived in leading to sustainability goal, MCDA is the framework and method that can be used to weight factors and criteria involve with theirs relative importance and then combine with a score that is determined by GIS tool. Various cost models can be run under integrated MCDA and GIS framework and provide a results in different scenarios depending on different objectives. This strategy can potentially lead HAZMAT route planning decision to achieve sustainability goal in comprehensive manner.

3.6 Conclusion

In the last few decades, HAZMAT has been of increasing interest among researchers. Several routing planning models have been developed and proposed in many literatures. Minimizing cost plays as an important single objective in traditional HAZMAT routing. Cost can be minimized through distance and time factors of the model. Later HAZMAT routing research paid much concern to risk that was usually defined in term of population exposure or population at risk. This is an initial movement from single factors to multiple factors consideration in HAZMAT transport. Until recently, more factors and criteria have been taken into account and lead to the complexity problem that requires effective framework and/or method to handle with. To comprehensively identify factors and criteria in HAZMAT route planning problem, sustainability can be served as a goal by determining factors and criteria in achieving economic, environmental and societal sustainable simultaneously. The framework that is proposed in this research will be shaped in such a way as to deal with the issue of integrating different risk factors and criteria by incorporating economic, environmental and societal issues (in terms of exposure and emergency response) to derive a holistic framework. The integration of different factors and criteria that influence or are influenced by the phenomenon of transporting HAZMAT is a crucial part necessary to push forward a routing model to the development of a comprehensive route planning. In order to transport hazardous waste, a mode of transportation must be used; in this research study the mode of transport will be limited to the road mode only.

Integrated multi criteria decision analysis (MCDA) framework with geographic information system tool (GIS) demonstrates a good approach by assigning score and weight to factors and criteria involved. It is also flexible for the incorporation of different cost models into the framework. Using GIS is without a doubt the most suitable tool for the management of geo referenced data and for performing spatial analysis for aiding the definition of a comparative finale value. Moreover, GIS can help in deriving a score calculation and in visualizing the output of the route model in various scenarios. With regard to the MCDA framework, GIS can serve as tool to store and manipulate all information which is related to factors directly and/or indirectly. Moreover, GIS can allow input of different cost model. In some cases, it can be applied as a platform for running a cost model as well.

There still a need for adding a value on further research as the following issue; firstly, most previous research created an analysis framework based on tradition risk assessment approach which relies on a probability of accident and total consequence (population data). The strength of this framework is to require a few data in analysis and it can provide a result based on many constraints such as distance and time.

However, most researches have been conducted in developed countries that HAZMAT related data are available and easily retrievable. In contrast with developed countries, most HAZMAT transport related data is unavailable and/or incomplete such as accidental, etc. that it can potentially lead to the level of accuracy problem.

Secondly, a variety of factors, criteria and method related to HAZMAT transport is still existed. There is no common agreement in defining a factor and criteria concerned by HAZMAT transport framework. A selection of factors and criteria based on sustainability goal was not mentioned earlier and was clearly seen by a lack of the consideration of environmental and emergency response factors in many previous researches. Identifying factors and criteria to achieve sustainability goal in HAZMAT transport framework could add more strength and value in previous research studied.

After reviewing all available literature for this research study. it is possible to conclude that there certainly is in fact a scope for improvement in the approaches to development of HAZMAT route planning framework with. The research presented in this document aims at developing a route planning framework by incorporating multiple factors and criteria to achieve economic, environmental and societal issues. The integration of sustainability goal, multi-criteria decision analysis (MCDA) framework and geographic information system (GIS) tool can readily allow running of different cost model in the framework. Defining factors and criteria, method and tool developed in this dissertation can lead to comprehensive framework that tries to fulfill the gaps that were presented in previous literatures with the following issues;

- Integration of different types of factors to achieve sustainability goal; economic, environmental, and societal issues
- Extension of the focus to other factors and criteria than just cost and population, environmental factors and criteria has been taken into consideration
- Apply a simplified cost model, in order to create a comprehensive hazardous waste route planning framework oriented toward using in the developing countries.

- Demonstrate a comprehensive integrative framework between MCDA and GIS by using Thailand as a case study (regional level).

CHAPTER IV
RESEARCH METHODOLOGY

4.1 Introduction

A purpose of this chapter is to present the development stage of the integration framework of sustainability, MCDA and GIS for hazardous waste transport route planning. This chapter starts with sustainability framework, GIS tool, MCDA framework and the integrated MCDA and GIS framework that allow the application of different cost models. A chapter ends with the application of created framework to a case study. The analysis framework for this chapter is shown in Figure 4.1.

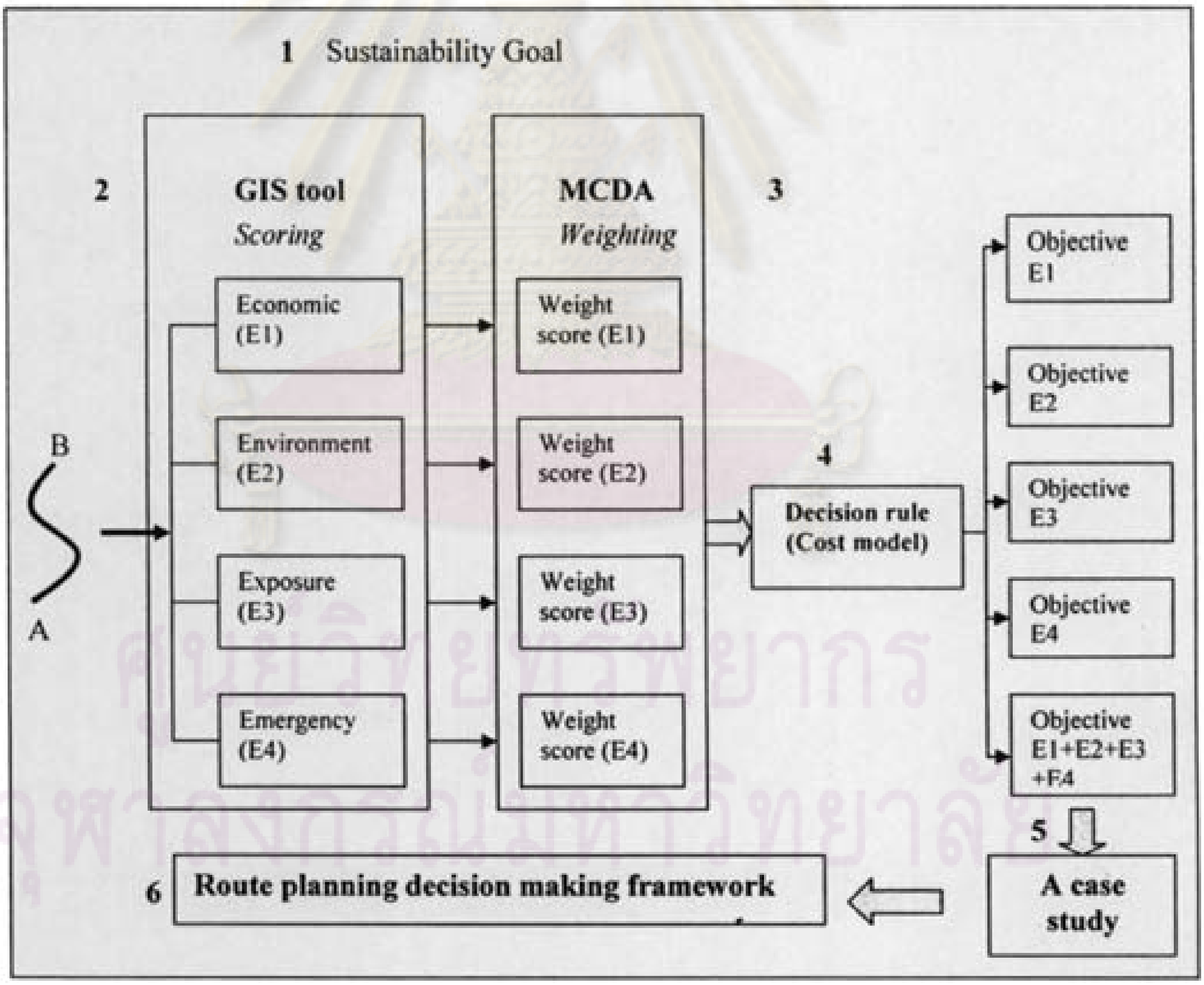

Figure 4.1 A methodology of analysis framework

As seen in Figure 4.1, there are sixth important steps for the analysis framework in proposed methodology. More detail in each step is also shown in Figure 4.2

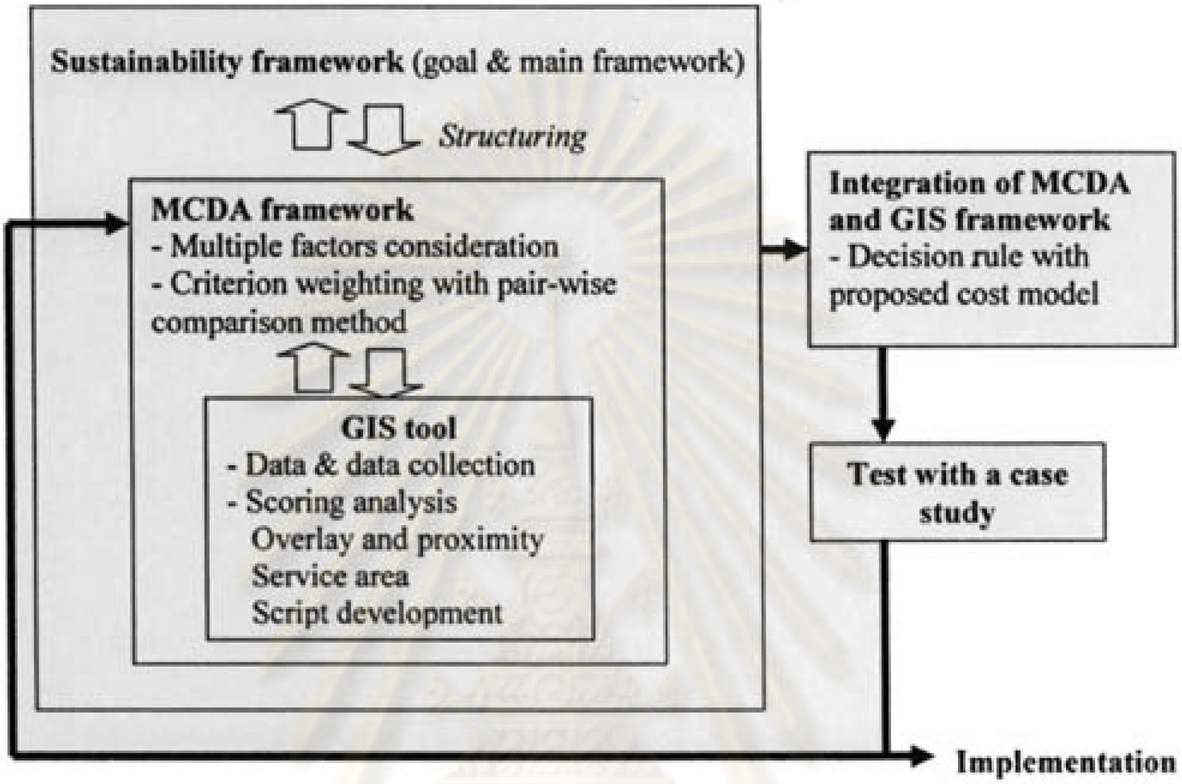

Figure 4.2 A detail diagram in Chapter 4

4.2 Sustainability Goal

In 1987 the Brundtland commission report, also known as "Our Common Future", alerted the world to the urgency of making progress toward economic development that could be sustained without depleting natural resources or harming the environment. The report also suggested that economic, environment and social priorities should be developed simultaneously to ensure a sustainable future.

Focusing on the sustainability issue is a vital contribution to reformulation of the ideas included in the traditional decision making process for HAZMAT transport. Sustainability is widely accepted as the practice of development that creates a balance between economics, environment and society. Moving toward sustainable HAZMAT transport, require that consideration of factors and criteria in line with economic, environmental and societal priorities should be incorporated into every step of the decision making process. The three pillars of sustainability is presented in Figure 4.3

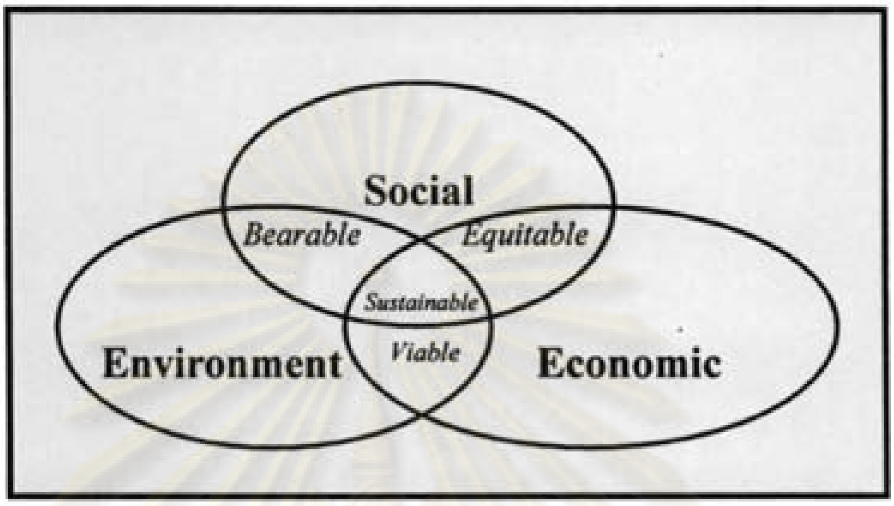

Figure 4.3 Scheme of sustainability: at the confluence of three constitute parts

4.3 Geographic Information System Tool (GIS Tool)

4.3.1 *Data and Data Collection*

Data in this research are divided into two main types based on the following considerations.

4.3.1.1 *Spatial data*

Spatial data include political boundaries, transportation networks, water resources, infrastructure & public facilities, forestry and terrain

4.3.1.2 *Non-spatial data*

Non-spatial data include population density and traffic density

4.3.2 *Data sources*

Because Map Ta Phut Industrial Estate (MTPIE) and incinerator plants has been selected as origin and destination for hazardous waste routing, spatial and non-spatial data collection is then covered in 11 provinces; Bangkok, Samut Prakarn, Chonburi, Nakhon Nayok, Pathum Thani, Saraburi, Phra Nakhon Si Ayutthaya, Rayong, Prachin Buri, Nontaburi, Nakhon Ratchasima, Chachoengsao. The sources of data included three main government offices as follow:

4.3.2.1 *Ministry of Transport (MOT)*

MOT Transport FDGS data is a recently updated version of transport infrastructure data in Thailand. These data were digitized from 1: 20000 scale maps. Four out of eleven categories have been used in this research as below;

- *Political boundary*; province, amphoe, *tambon* (smallest level used in this research)
- *Transportation network*; including main road and rural road
- *Water resources* (main streams)
- *Infrastructure and public facilities*; including schools, police stations, petrol and gas stations, tourism & heritage places, hospitals, fire stations, Map Ta Phut Industrial Estates, and Incinerator plants).

4.3.2.2 *Department of Environmental Quality Promotion (DEQP), Ministry of Natural Resources and Environment*

Department of Environmental Quality Promotion (DEQP) is responsible for building databases within 75 provinces in Thailand (except Bangkok). These data were digitized from 1: 50000 scale maps. In this research, two categories are used as derived by DEQP including the following;

- *Terrain such as slope*
- *Forest data; including conservation areas and parks*

4.3.2.3 *Department of Highways (DOH)*

Traffic density is non-spatial including that derived by the Department of Highways. It is used as a one of the critical factors to account for economic criteria in this research.

The Default projected coordination system in this research is known as Indian_1975_UTM_Zone47N and the Transverse Mercator is used as the default projection. Data from MOT Transport FDGS is already in the default coordinate system and there is no need to make a conversion. However, slope and forestry data, which are derived by Department of Environmental Quality Promotion, have been converted from WGS_1984_UTM_Zone47N to the default projected coordinate system.

4.3.3 *Database Preparation*

After collecting data both spatial and non spatial data from various sources, creating the database is the next critical step. A purpose of creating database is to systematically prepare data so that they are readily usable in the analysis phase. Database preparation is then reclassified with regard to multiple factors and criteria determination, which is designed to approach sustainability goal by taking economic, environment, and societal into account.

4.3.3.1 *Transport network data*

From FDGS data, the transportation network from 12 provinces has been selected from a whole road country database as shown in Figure 4.4

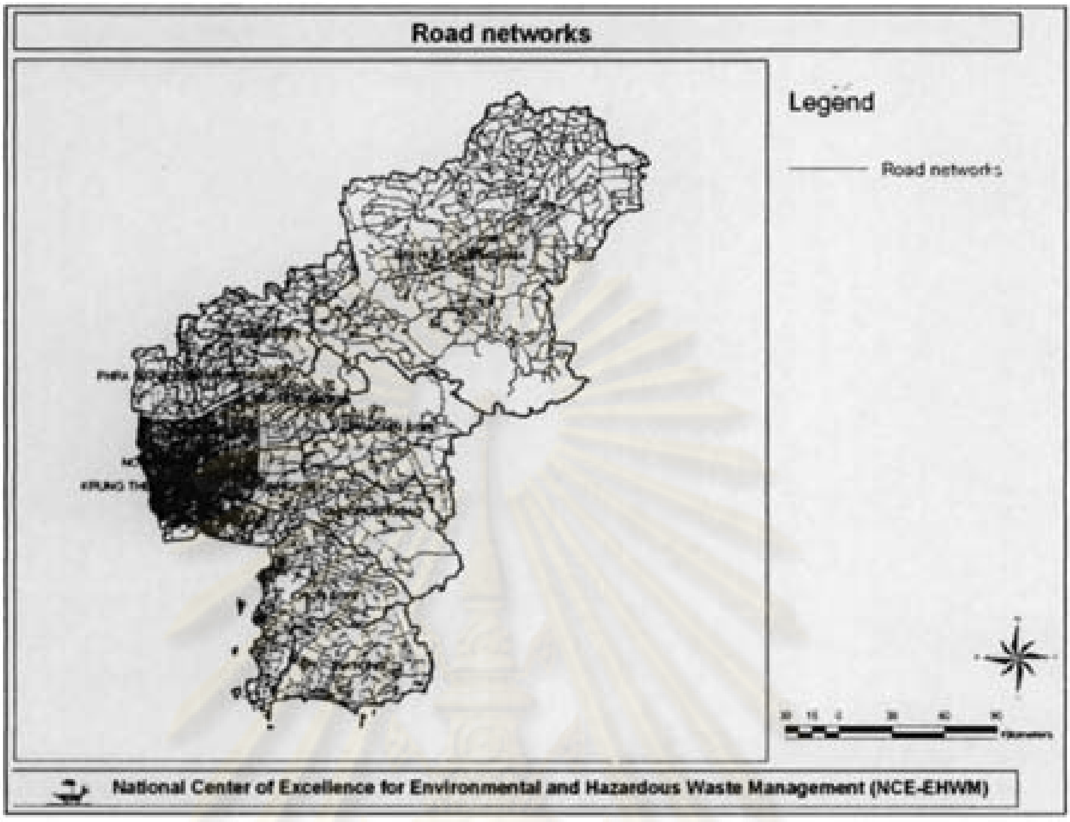

Figure 4.4 Show all road network databases in 12 provinces

From all road networks, only road type number 1 (highway that is a responsibility of Department of Highways or DOH) and road type number 2 (rural roads that are the responsibility of Department of Rural Roads or DOR) are the main roads to be considered. The initial size of the network (more than 20000 distinct road sections) was reduced further by eliminating minor roads, except those in the vicinity of the production or disposal sites, to approximately 5000 segments with concretes and asphalts road surface. Moreover, checking of topology to ensure connectivity of all the roads is a very critical task for the preparation of a good road network database. Topological errors were detected in the road network database and were fixed by the topology tool in ArcGIS 9.2 as depicted in Figure 4.5

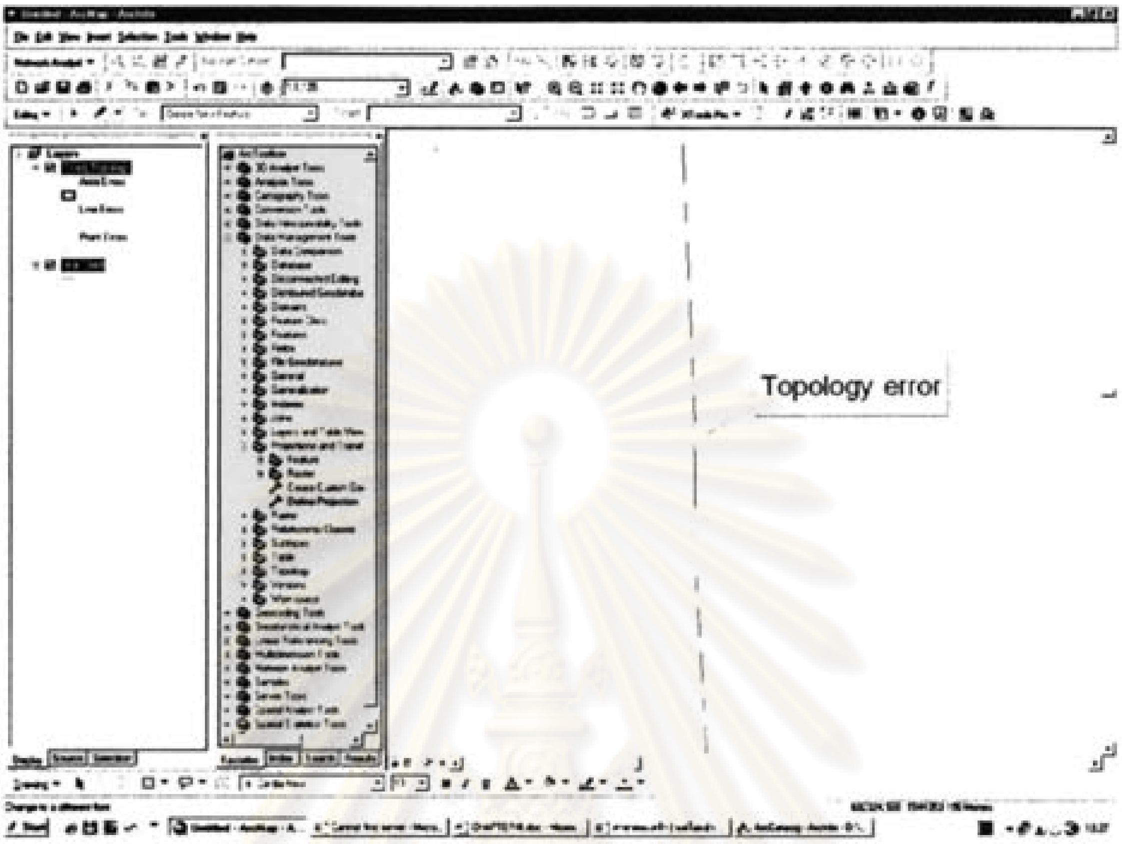

Figure 4.5 Show some topological errors on road network

Moreover, routing of trucks within the urban area of Bangkok (radius of 113 kilometers from the center of Bangkok Metropolitan Area or BMA) has been legally restricted. It is then reasonable that the road networks that are located within the inner city of Bangkok will be eliminated from the database. Moreover, this research directs to road transportation system only, express ways were also eliminated from road network preparation. The resulting baseline road network database for hazardous waste routing in this research is shown in Figure 4.6 below. A preparation of road network database is very important because each transportation link in road networks will be added with the value of other criteria through scoring method defined in Appendix 1

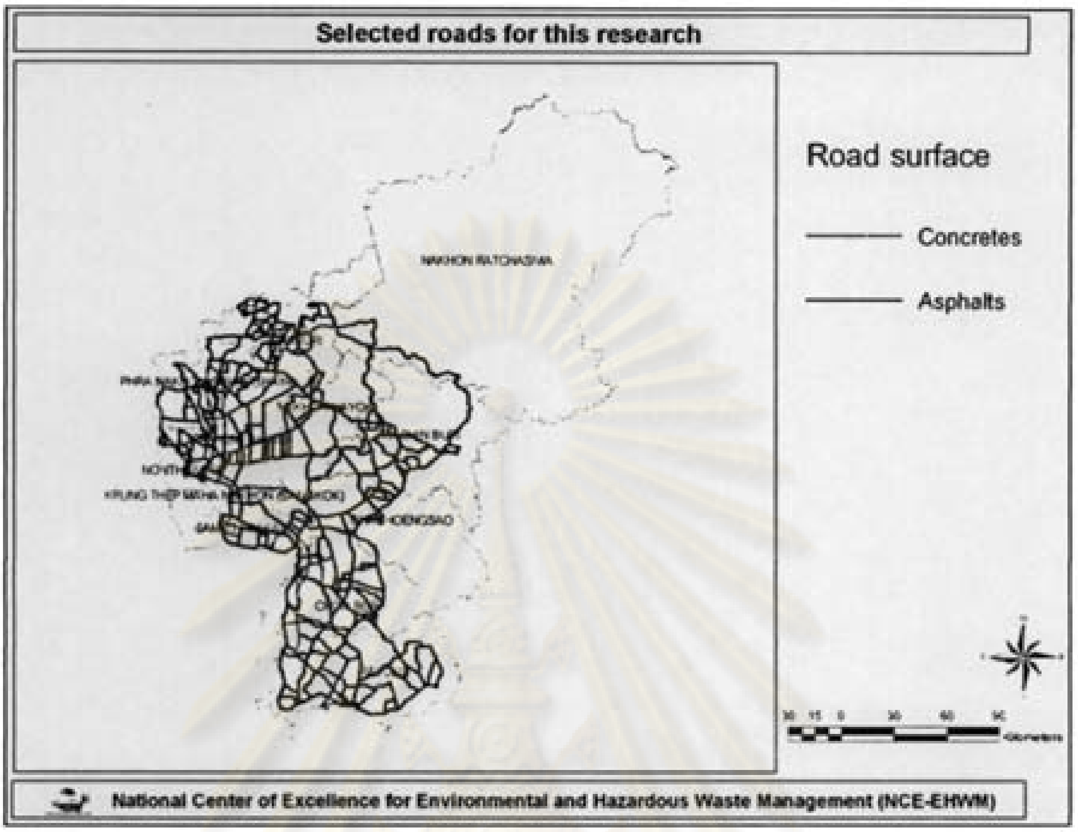

Figure 4.6 Main road with concretes and asphalts surface used in this research

4.3.3.2 *Political Boundary*

The smallest scale of administrative boundary is the district. Three new fields, namely population, pop_den and pop_score have been added to the existing table with the purpose of calculating population density (pop_den field) and then derive population score (pop_score field) for each road section that would be used in the exposure scenario as shown in Figure 4.7 and 4.8

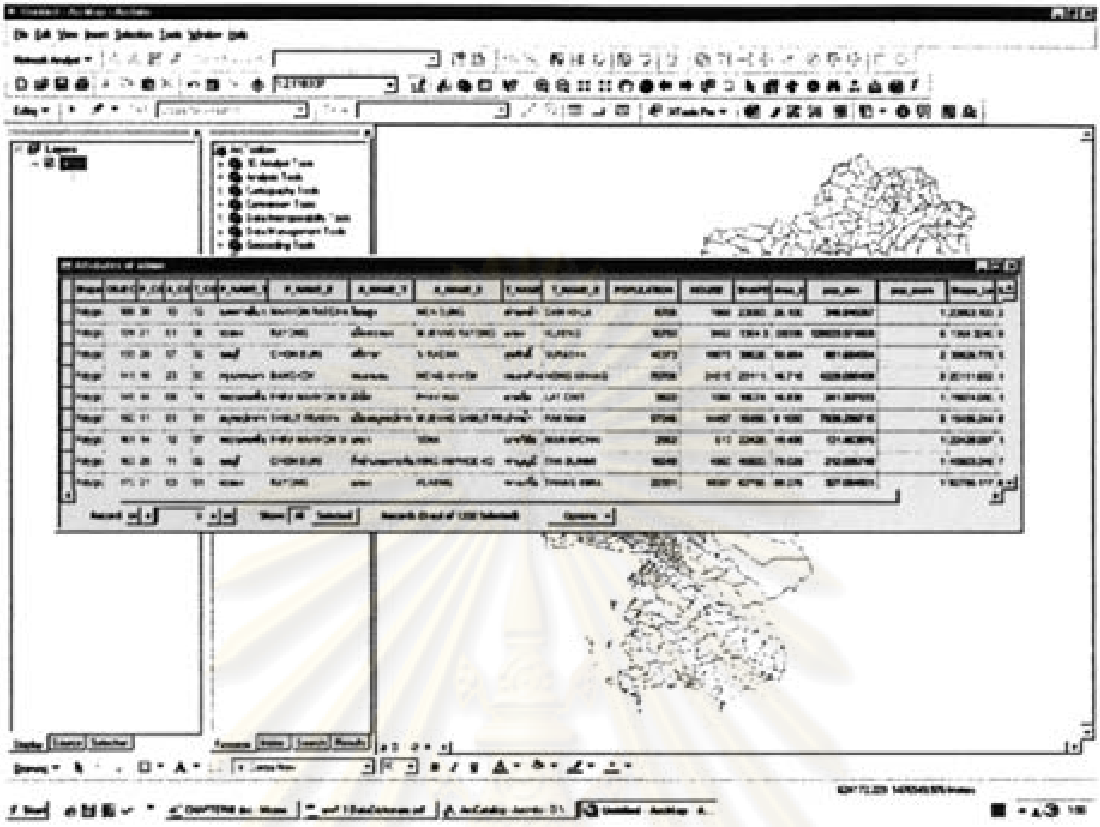

Figure 4.7 Adding three new fields in the administrative boundary.

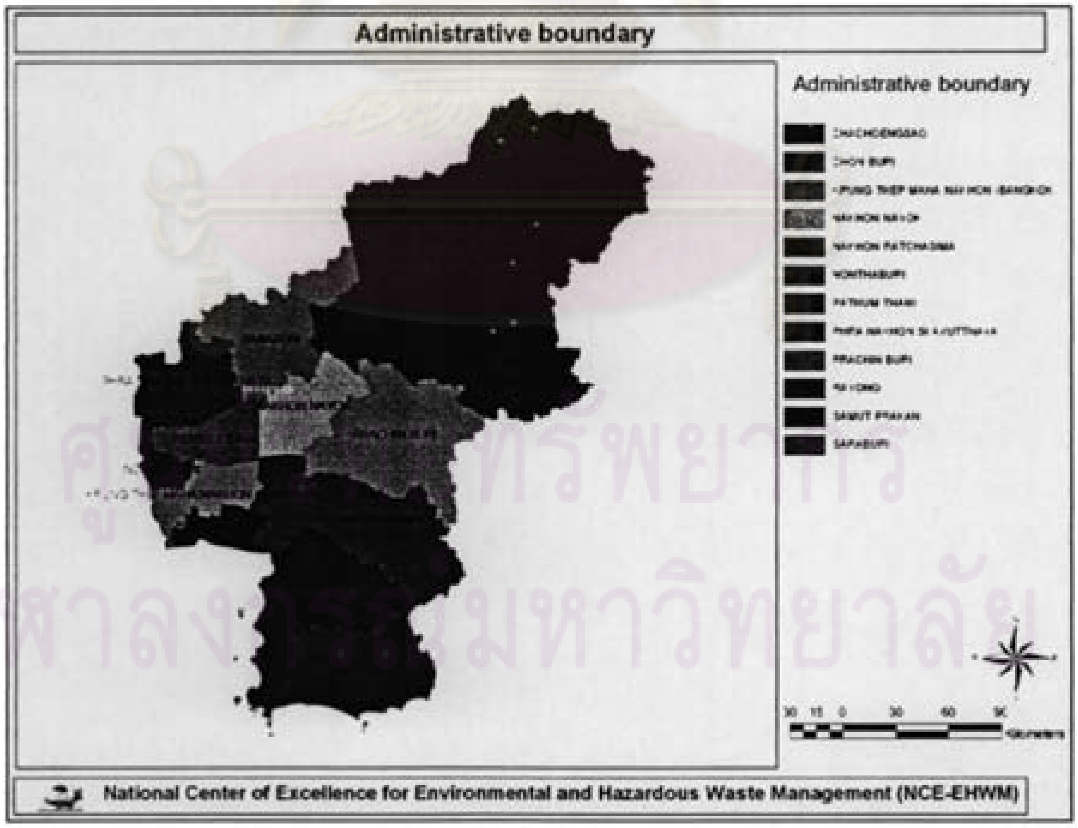

Figure 4.8 Political boundaries in the study area

4.3.3.3 *Infrastructure and public facilities*

There are seven type of infrastructures considered; schools, hospitals, petrol and gas stations, police stations, fire stations, Map Ta Phut industrial estate (which served as origin) and five incinerator plants (which served as destination). All infrastructure data format is point. In some cases, a query operation has been used to extract more useful data such as a query of main hospitals while disregarding local health care unit because main hospitals have more potential to respond to HAZMAT incidents. The location of Map Ta Phut industrial estate, incinerator plants, main hospital and schools are the examples shown in Figure 4.9

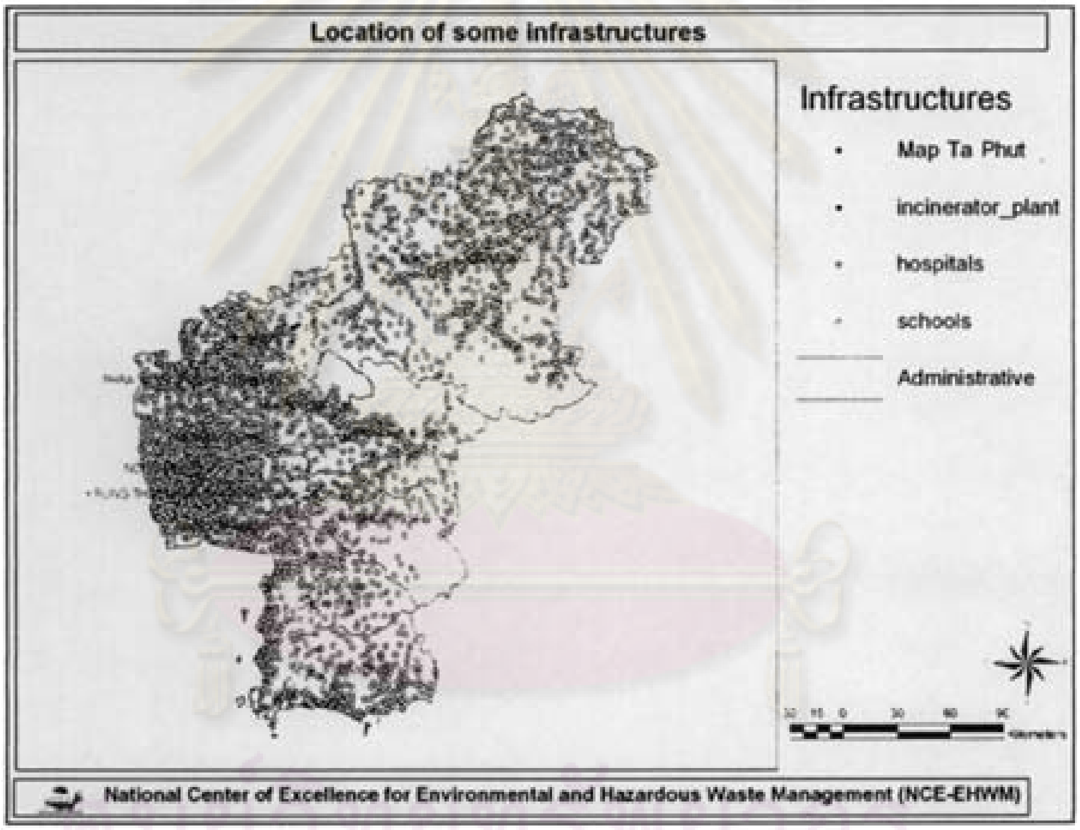

Figure 4.9 Show the location of some infrastructures in the study area

4.3.3.4 *Water resources (main streams and ponds and lakes)*

Water resources are seen as sensitive natural and environmental resources that can be potentially affected by a hazardous waste transport incident (FHWA, 1994). Two categories of water resources, namely main streams (rivers and canals) and ponds and lakes, have been selected as sensitive environmental places and will be input as environmental criteria in the research as shown in the Figure 4.10 below;

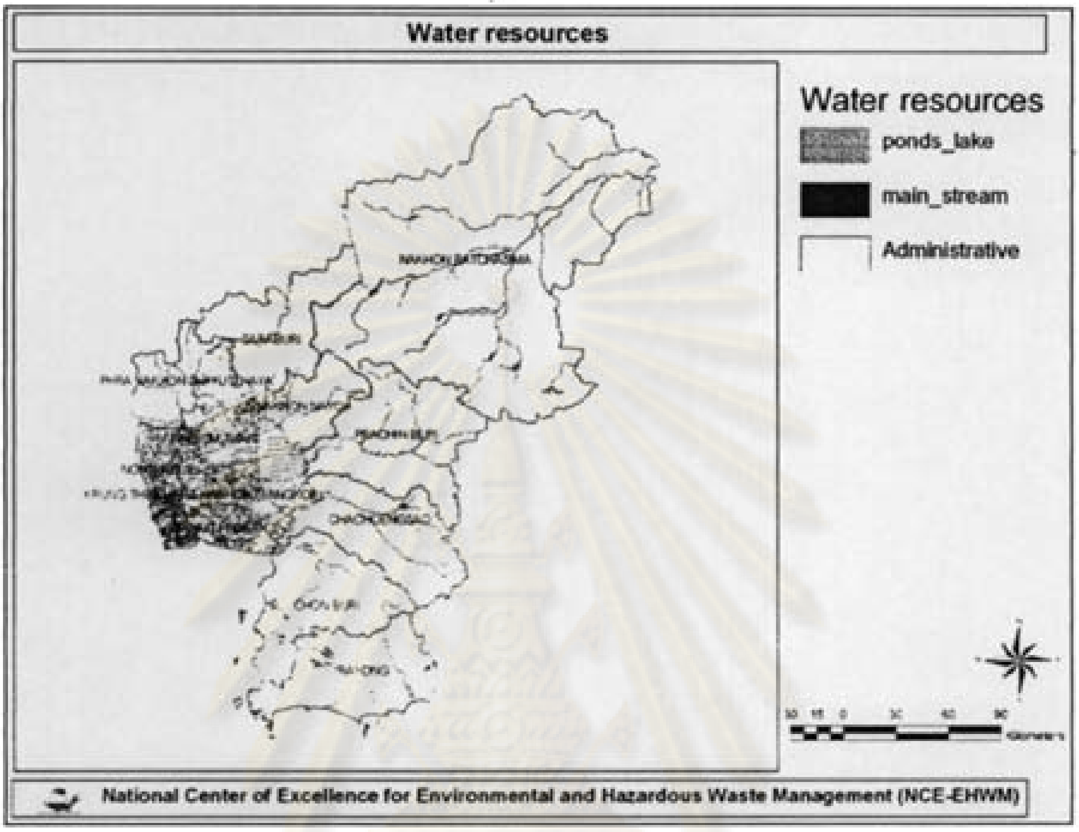

Figure 4.10 Map of two types of water resources

4.3.3.5 *Forestry data*

Conservation areas and parks are the two main types of forest data to be considered as one of the sensitive environment areas (FHWA, 1994) to be input as environmental criteria in the research. Figure 4.11 below shows the location of forest data in the study area.

4.3.3.6 *Slope*

Road slope is prepared from a slope map which is categorized by percent slope class and depicted in Figure 4.12

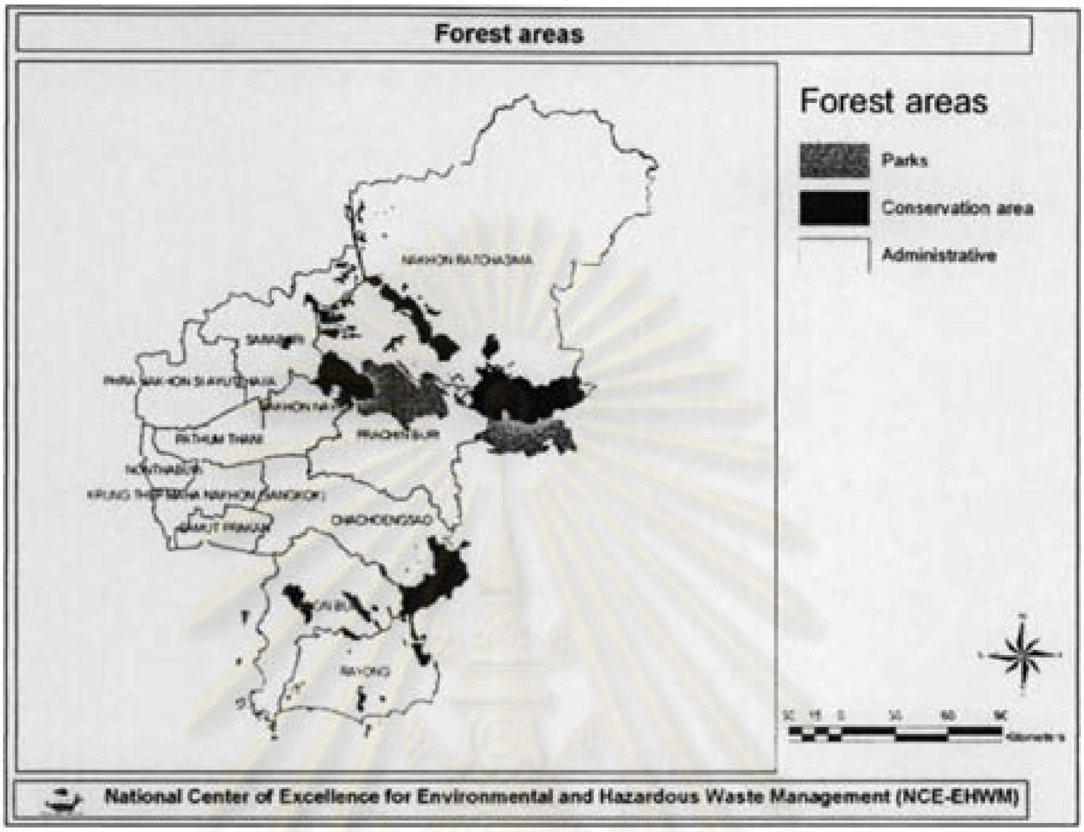

Figure 4.11 Shows parks and conservation areas

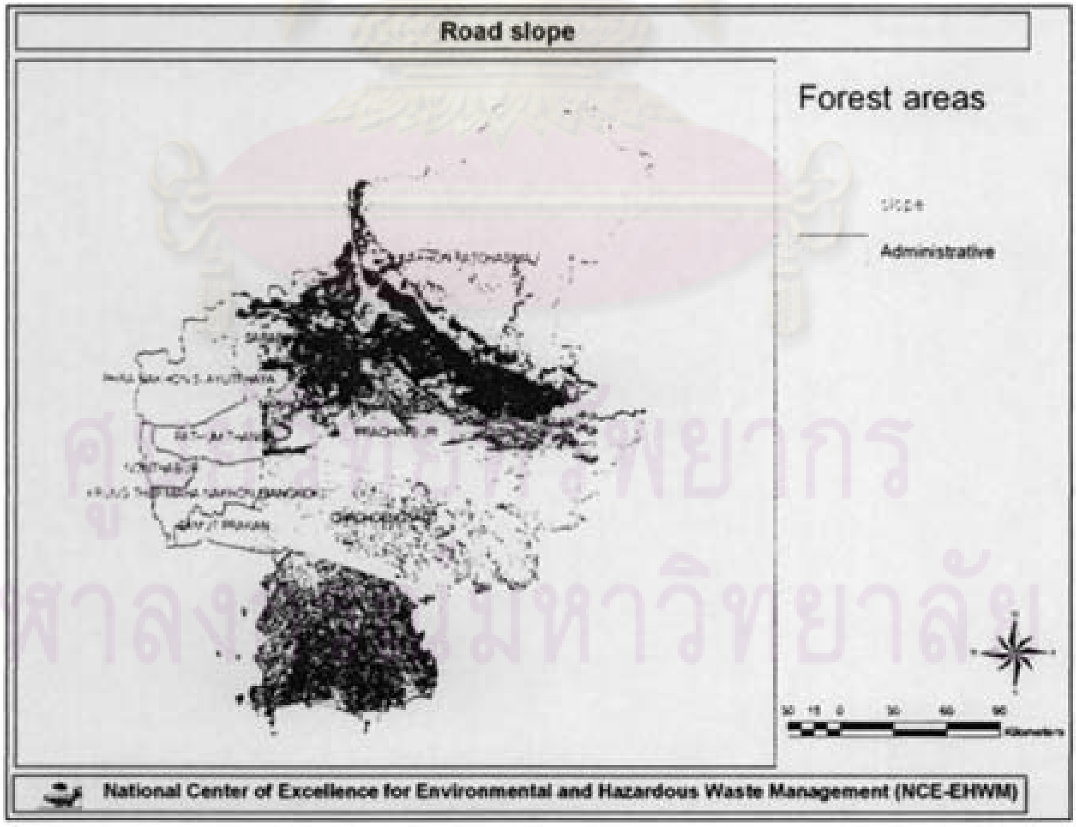

Figure 4.12 Show road slope

4.3.4 *Scoring method*

The hazardous waste transport framework will be created incorporating three scenarios; economic, environmental and societal scenarios (with societal separated into "exposure" and "emergency response" issues). In this research, a major economic scenario is based on the shortest route between the origin and the destination point. Other related economic factors such as traffic density and road slope are taken into account as well. The environmental and societal scenarios are based on the various factors as described in Table 4.1 Score is a measurable quantity that expresses the physical relationship in meaningful value. The scoring system for the exposure risk and security factors was adapted from a system recommended by the United States Federal Highway Administration or FHWA (1994) and Huang, *et al.* (2004). Some factors and criteria were added or adapted to account for environmental issues. A scoring system was devised by classifying the identified factors with each being given a score ranging from 1 to 5. The scores can be considered as substitutes for accident probabilities required in a traditional risk analysis. It represents a better surrogate to actual accident probabilities, which require accident-rate data that are often insufficient or unavailable, especially in most developing countries. Relevant data is then gathered and input into the GIS database. Table 4.1 below shows the example of the scoring system of environment factors (the full scale of the scoring system for all factors and sub-factors is shown in Appendix 1).

Table 4.1 Scoring system of environmental factors

Criteria & factors	Score				
	1	2	3	4	5
Environment					
Distance to ponds & lakes	>2	1.5-2	1-1.5	0.5-1	0-0.5
Distance to conservation areas	>2	1.5-2	1-1.5	0.5-1	0-0.5
Number of streams crossed	0-3	4-6	7-9	10-12	>12

A determination of the score is accomplished by GIS capabilities. There are two main GIS functions that were used to derive a score for each of criteria as described in the next section.

4.3.4.1 *Deriving score in societal (exposure objective)*

Proximity analysis has been done through the buffer and/or the multiple ring buffer command. This function was used to identify the score for the criteria in the societal factor (exposure issue). Because the potential impact zone for flammable or combustible HAZMAT is taken as 0.8 km in all directions (Nicolett-Monnier and Gheorghe, 1996), a buffer of 0.8 km width is generated for each road section in the road network database case study. A purpose of this operation is to count the total number of interested features (such as schools, petrol stations, hospitals, heritage and cultural places and population) and then classify the number to be scored with regarding to scoring system in Appendix A. However, counting the total number of interested features for about 5000 road sections is a very time consuming task. Visual basic script (VB scripts) was therefore utilized to make this task easier and to reduce the time as compared to the traditional approach. A new interface button has been created in the ArcGIS toolbar that was attached with VB script included. After the selection of a road section (select only one section for each click) in the road attribute table, clicking at the new interface button results in a total number of features located within an 0.8 km width of road section and automatically inputs a value to the new added field of selected road sections. A demonstration screen and scripts are shown in Figure 4.13

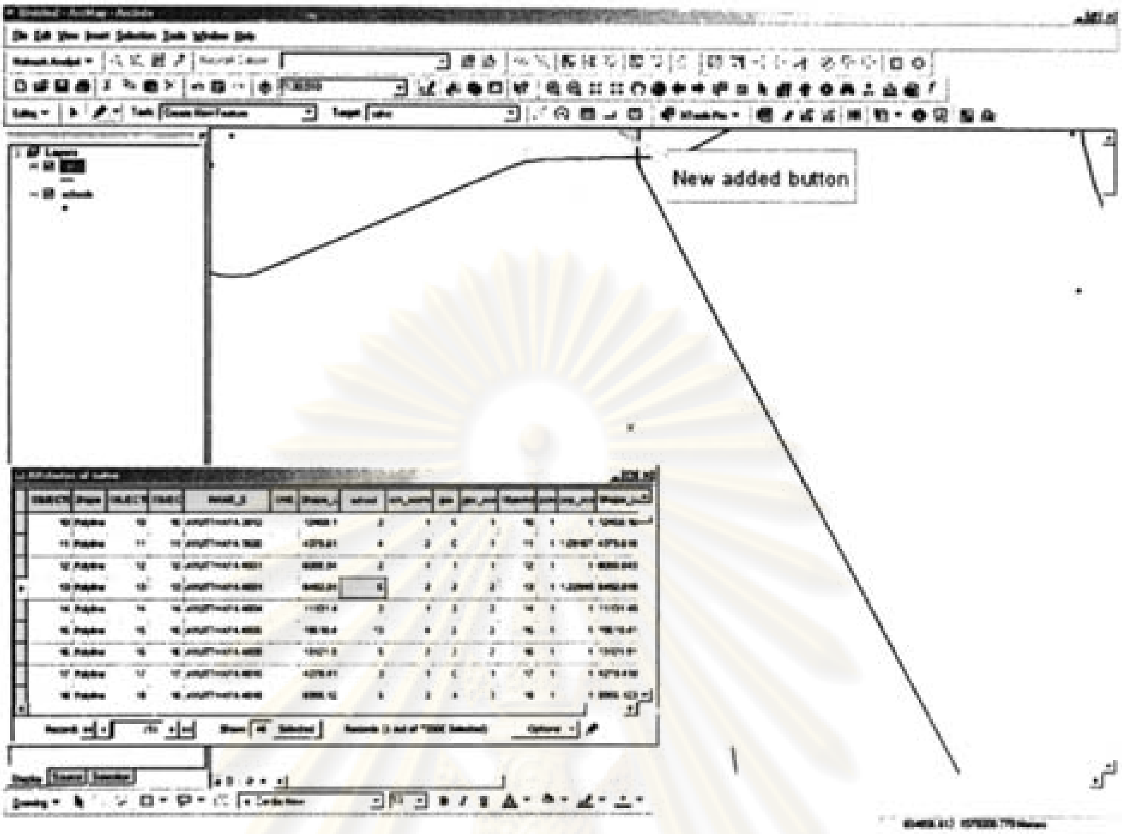

Figure 4.13 A demonstration screen of working VB script to count a school feature within a buffer of 0.8 km width of road section.

With regard to above method, we can use the same approach to work with different features of interests as well such as hospitals, petrol stations, and heritage place as well. A process to derive population density score for each road section is depicted in Figure 4.14

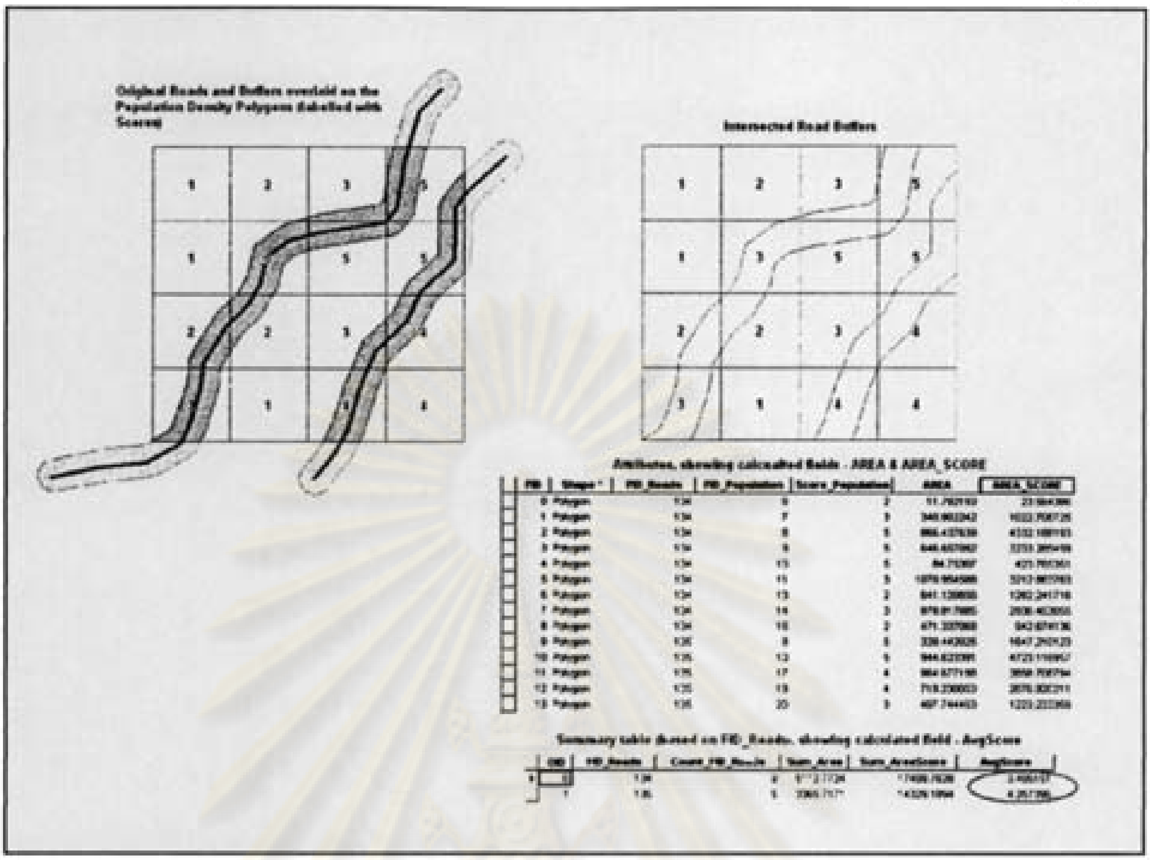

Figure 4.14 Captured screen of a process to derive population score in GIS

4.3.4.2 *Deriving score in Societal (emergency response)*

In emergency response, accessibility refers to how easy it is to get to a site. In ArcGIS Network Analyst, accessibility can be measured in terms of travel time, distance, or any other impedance on the network. One simple way to evaluate accessibility is by a buffer distance around a point. For example, find out how many customers live within a 5-kilometer radius of a site using a simple circle buffer. However, considering people travel by road, this method won't reflect the actual accessibility to the site. Service networks computed by ArcGIS Network Analyst can overcome this limitation by identifying the accessible streets within five kilometers of a site via the road network. Once created, you can use service networks to see what is alongside the accessible streets, for example, find competing businesses within a 5-kilometer drive.

For emergency response factors, a realization of the actual accessibility to the road network and/or accidental location from rescue units such as police stations, fire stations and hospitals is very important. The actual distance of accessible streets can be measured by identifying impedances distance such as 0.5, 1, 1.5, 2 kilometer. This will result in an accessible road within an assigned distance from rescue units. A captured screen of a 1.5 kilometer default breaks for service road lines from fire stations are depicted in Figure 4.15 below.

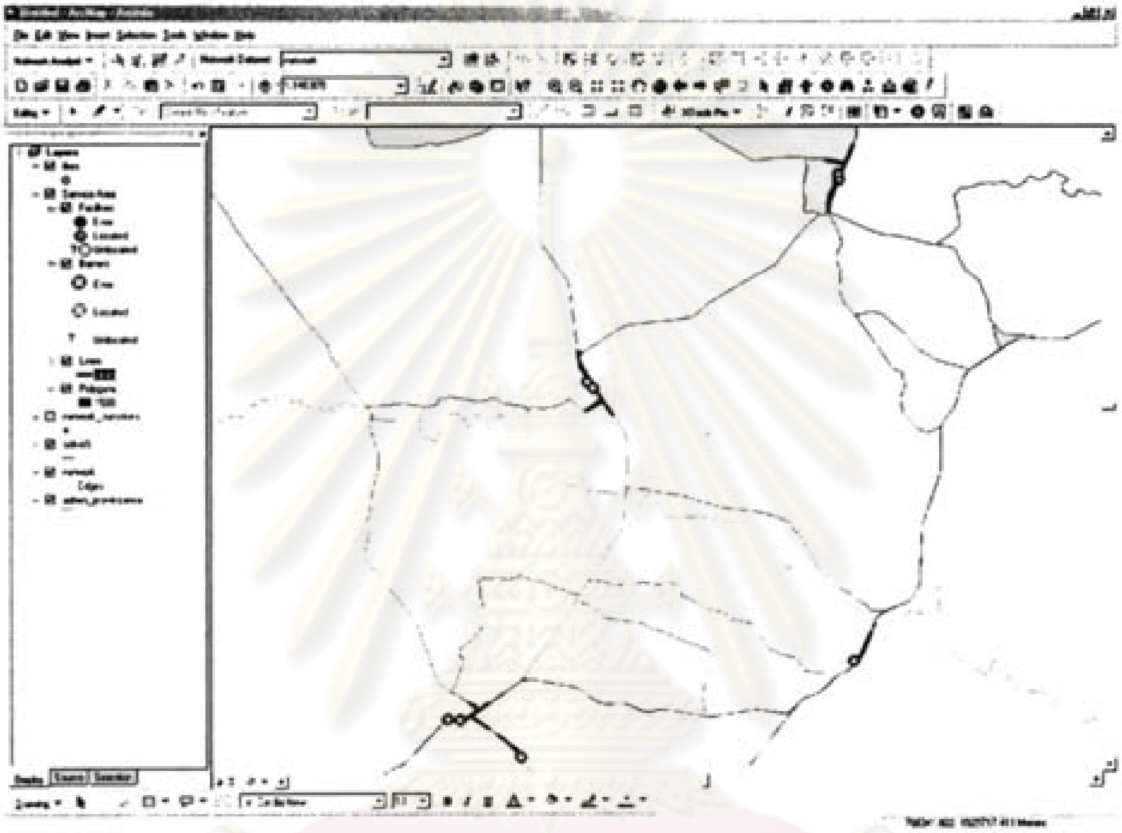

Figure 4.15 Showing service line by assigning distance by 1.5 kilometer from each fire station

However, service line varies with the defined distance. To derive a score of fire stations for each road section, the following steps are explained in Figure 4.16 below;

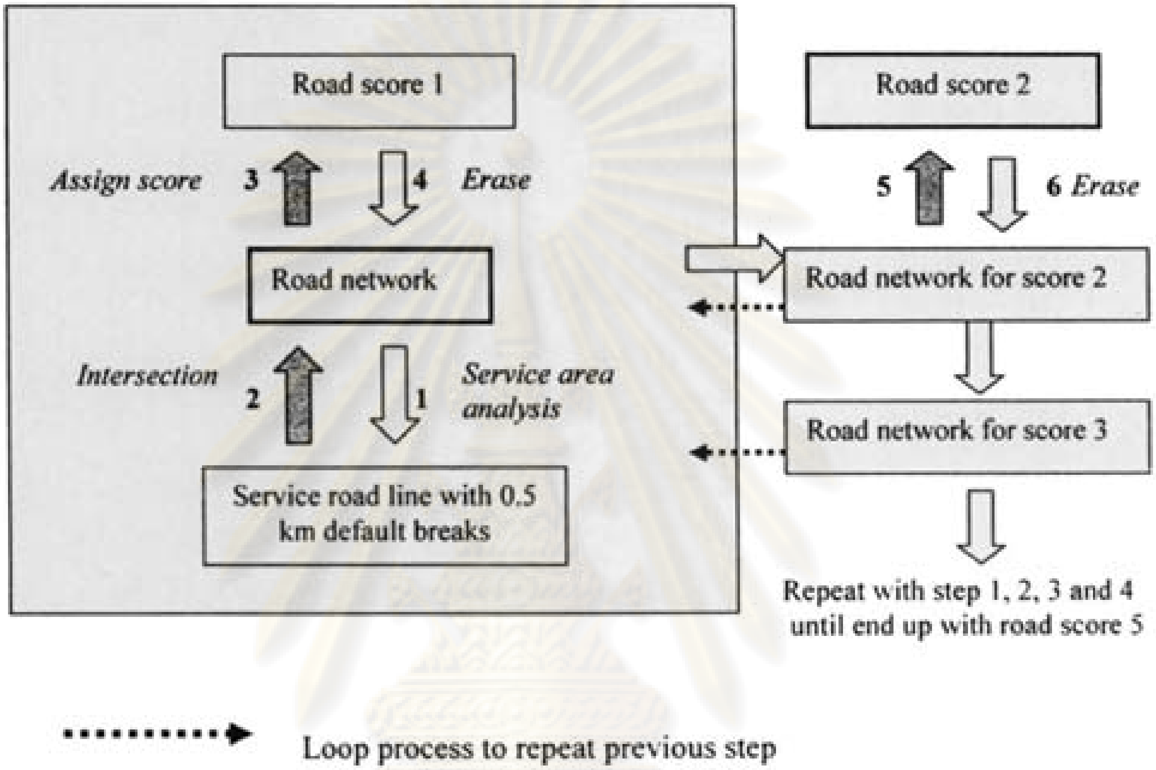

Figure 4.16 A stepwise approach to derive score for each road section in emergency response factors

From figure 4.16, the road network of the case study has been analyzed by service area analysis. Road service lines were generated in accordance with the default breaks value of distance impedance; 0.5, 1, 1.5, 2 and more than 2 kilometer. For the example, a default break value of distance is set to 0.5 kilometer when running the service area analysis (step 1). As a result, service road lines are generated and then intersected with original road networks and are assigned the score "1" (step 2 and step 3). A road score "1" feature has been used to erase the original road network again (step 4). As a consequence, an original road network with the removal of lines that intersect with road score 1 is created (also called road network for score 2). This road was sent back to repeat step 1, 2, 3 and 4 again following the direction of the dashed arrow line (change default break value to 1 kilometer and assign a score "2"). The same step is then looped with the change only "default break value" and "score" until stopped at road score 5. Hence, all of road score features (score 1 to 5) have been merged to produce new single road network with assigned scores based on service line of fire station.

It is possible that each road section will be designated with more than one score. It is reasonable to aggregate scores for each road section. A normalization method is proposed by a adding new field name "length_score" which is a value derived by the product of shape length and score. A summary table has been created based on road object id with the sum of the "shape length" field and the "length_score" field. The last step is to add a new field in the summary table and derive a value in the new field by dividing the length_score value in the length value. This will result in the average score of proximity to fire stations for each road section as shown in Figure 4.17

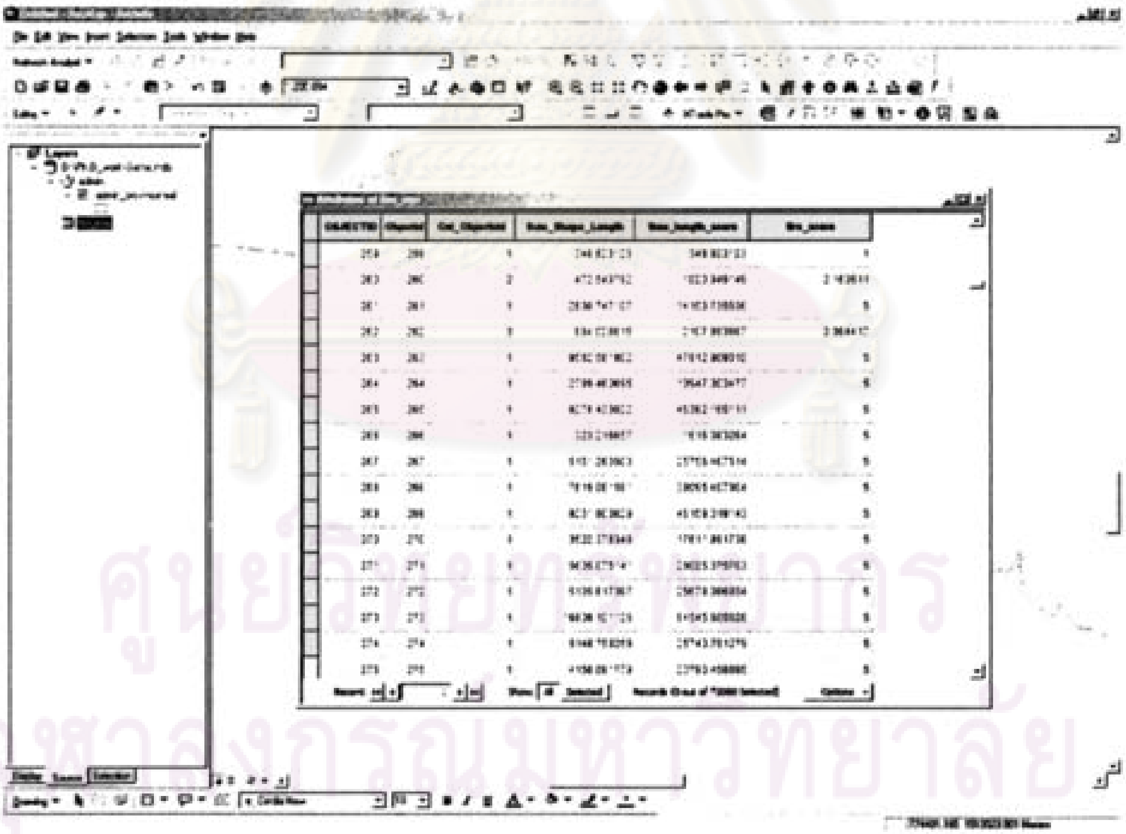

Figure 4.17 The average score of the proximity to fire station for each road section

The service area approach as mentioned above was also used for assigning an average score for proximity to hospitals and proximity to police stations in a similar manner.

4.3.4.3 *Deriving score in environmental factor*

To determine a score for environmental criteria in environment category, an idea of the combining of the proximity and overlay analyses in ArcGIS has proven to be useful. Unlike the accessibility issue, the potential impact zone for flammable or combustible materials to environmentally sensitive places such as ponds and lakes can be defined by dispersion in all directions. Buffer analysis has become a useful tool to create buffer distance with regard to distance criteria set by the scoring system. Figure 4.18, which is similar to Figure 4.16, depicts a diagram of analysis processes for proximity to environmentally sensitive places.

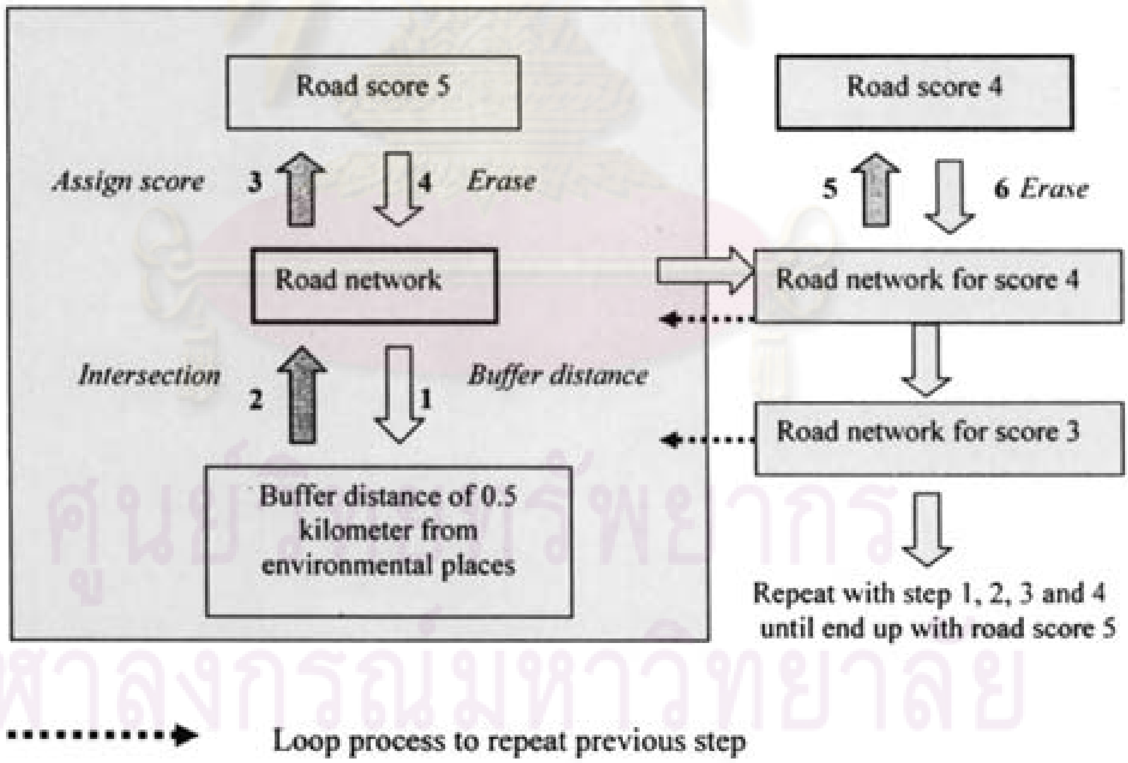

Figure 4.18 A stepwise approach to derive scores for each road section in environmental factors

A flow process in Figure 4.18 is particularly similar to the one in Figure 4.16 except for using the buffer function instead of the service area function and an inverse of the score from 5 to 1 based on buffer distance. The closer a hazardous waste transport route is to an environmental sensitive place implies a greater of risk for that location, and definitely is assigned a higher score.

As shown in Figure 4.19, the example of using certain buffer distances and intersect functions to aid the assigning of score is proposed. The process used to derive average score is the same as that mentioned in emergency response and has been skipped here. The same process can be used in determining proximity score to conservation area and number of river crossed criteria as well.

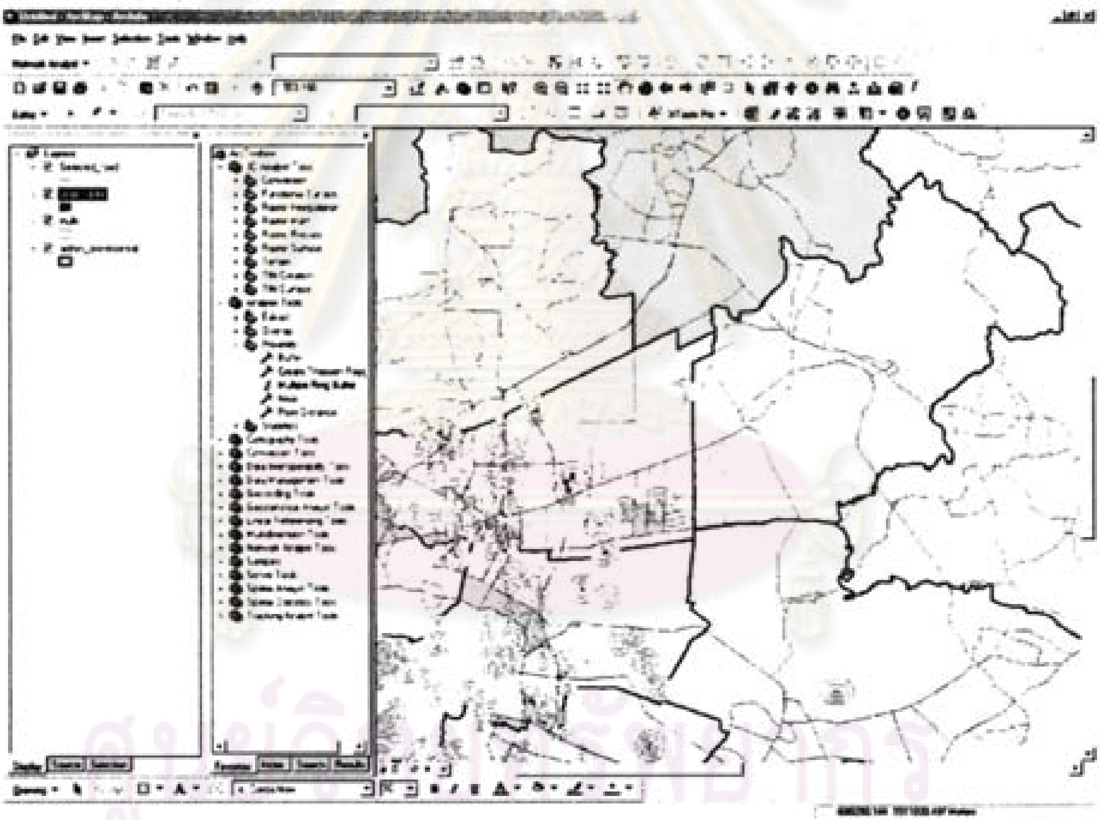

Figure 4.19 Proximity analysis of each road section to identify distance away from ponds & lakes in each link of road network

4.3.4.4 *Deriving score in others economic factor*

To derive score of traffic density for each link of transportation network, average traffic density data (ADT) will be used to determine a score of each road link. However, ADT data availability for all transportation links in this research is not possible because ADT has been collected only in some roads. The best way to tackle this problem is to calculate unknown ADT data in each transport link by using average ADT from neighbor transport link. Then, from ADT raw data, a final score for traffic density criteria can be determined.

To derive score of road slope, overlay function with identity command can be used to derive an average score for each transport link. The process is similar to what has been done in deriving environmental criteria score, then a process will be skipped here.

4.4 Multi criteria decision analysis framework

4.4.1 *Multiple factors consideration*

For the HAZMAT transport problem, thinking about economic, environmental and societal issues plays a vital role in moving toward sustainability as part of decision making. All of these issues have been taken into account in this dissertation as well.

4.4.1.1 *Economic factors*

The economic issues for Hazardous waste transport in this research are concerned with how to reduce the cost of transport as much as possible. Distance is a vital factor because if a HAZMAT truck travels a shorter distance, it means lower consumption of fuel as well. Moreover, high traffic density leads to a longer travel time and therefore increased freight cost. Road slope (or grade) considerations may affect the potential severity of an accident and then lead to higher costs as well (FHWA, 1994).

4.4.1.2 *Environmental factors*

To deal with the environment issues related to HAZMAT transport, consideration should be given to the sensitive environmental sites that could be affected by an accident. The proximity of the routes to a particular location such as ponds and/or lakes, parks and wildlife conservation areas leads to a higher potential risk for living things if a HAZMAT truck is involved in an accident. Moreover, the number of rivers and inland waters crossed are criteria that should be minimized during HAZMAT transport (D.J. Briggs *et al*., 2002).

4.4.1.3 *Societal factors*

There are two main societal issues related to HAZMAT transport. One concern is the exposure of populations to hazardous substances in case a HAZMAT truck is involved in an accident. Population density, school children, and hospital patients are seen as special populations and should be considered when determining the potential risk to populations along a highway routing (FHWA, 1994). Petrol stations can be affected by flammable substances and can stimulate a greater consequence to nearby populations. The second major concern relates to the maximum capacity for emergency response with regard to the availability of rescue units. The proximity of the routes from a particular location or transport link to a fire station or other emergency responder and/or a hospital improves the incident response time in the rescue operations. Nearby police stations may also respond to any chaos and extend further assistance (Huang, *et al*., 2004)

Multi-criteria decision analysis (MCDA) is used to initialize consideration of multiple factors and criteria involved in the HAZMAT transport problem and then are used further to determine the relative weight of factors and criteria. In this research, factors and criteria are categorized to comply sustainable goal that takes economics, environmental and societal (exposure and emergency response) issue into consideration as shown in Table 4.2 Several GIS functions are utilized to calculate spatially and derive a score for each link of the road network as described in previous section. The weighting process is a very crucial step for HAZMAT transport decision making. This task should be carried out by participation of potential stakeholders or experts. However, the government and/or policy-makers are solely viewed as major stakeholders that currently influence HAZMAT transport decision making in Thailand.

Table 4.2 Factors and criteria for hazardous waste transport

Economic	**Environment**	**Society (exposure)**	**Society (emergency response)**
Distance	Distance to ponds and lakes	Population density	Proximity to police stations
Traffic density	Distance to parks and conservation areas	Proximity to schools	Proximity to fire stations
Slope	Number of rivers crossed	Proximity to heritage & cultural places	Proximity to hospitals
		Number of petrol stations	
		Proximity to hospitals	

4.5 Criterion weighting with Pair-wise comparison

The relative importance of respective criteria together with their factors was determined using a Multi criteria evaluation technique in order to combine a score into meaningful usable value. Weights must be assigned to factors and criteria. Developing priorities can be accomplished by a pair-wise comparison method. The output is a set of weights representing their relative importance. The advantage of the pair-wise comparison method when compared with other criterion weighting methods is shown in Table 4.3

Table 4.3 Summary of method for assessing criterion weight

Feature	Method			
	Ranking	**Rating**	**Pair-wise comparison**	**Trade-off analysis**
Number of judgments	n	n	n(n-1)/2	<n
Response scale	Ordinal	Interval	Ratio	Interval
Hierarchical	Possible	Possible	Yes	Yes
Underlying theory	None	None	Statistical/heuristic	Axiomatic/deductive
Ease of use	Very easy	Very easy	Easy	Difficult
Trustworthiness	Low	High	High	Medium
Precision	Approximations	Not precise	Quite precise	Quite precise

Sources: Adapted from Malczewski (1999)

4.5.1 *Development of pair-wise comparison matrix*

The pair-wise comparison method was developed by Saaty (1980) in the context of the analytical hierarchy process (AHP). This method involves use of pair-wise comparison to create a ratio matrix. It takes as an input the pair-wise comparisons and produces the relative weights as output. Specifically, the weights are determined by normalizing the eigenvector associated with the maximum eigenvector of the (reciprocal) matrix. The method employs an underlying scale with values from 1 to 9 to rate the relative preferences for two criteria (see table 4.4)

Table 4.4 Scale for pair-wise comparison

Intensity of importance	Definition	Explanation
1	Equally preferred	Two activities contribute equally to the objective
2	Equally to moderately preferred	Represent compromise between scale 1 and 3
3	Moderately preferred	Experience and judgment slightly favor one activity over the other
4	Moderately to strongly preferred	Represent compromise between scale 3 and 5
5	Strongly preferred	Experience and judgment strongly or essentially favor one activity over the other
6	Strongly to very strongly preferred	Represent compromise between scale 5 and 7
7	Very strongly preferred	An activity is strongly favored over another and its dominance demonstrated in practice.
8	Very strongly to extremely preferred	Represent compromise between scale 7 and 9
9	Extremely preferred	The evidence favoring one activity over another is of the highest degree possible of affirmation
Reciprocals	Reciprocals for inverse comparison	

Source: Saaty (1980)

Suppose that proximity to fire stations is moderately to strongly preferred over the proximity to police stations attribute; that is, the comparison results in a value of 4. Further, suppose that proximity to fire stations is very strongly preferred to proximity to hospitals. This is a numerical score of 7. Finally, consider the only other pair-wise comparison, which is the proximity to police stations attribute compared to proximity to hospitals and suppose that the former is strongly preferred to the latter, a score of 5. These score are placed in the upper right corner of the pair-wise comparison matrix (Table 4.5). From this information, we can determine the remaining entries in such a table. First, we make the assumption that the comparison matrix is reciprocal; that is, if criterion A is twice as preferred to criterion B, we can conclude that criterion B is preferred only one-half as much as criterion A. Thus, if criterion A receives a score of 2 relative to criterion B, criterion B should receive a score of ½ when compared to criterion A. We can use the same logic to complete the lower left side of the matrix of pair-wise comparisons. For this matrix, all that remains is to enter scores down the diagonal from the upper left corner to the lower right corner. To this end, we make the observation that when comparing anything to itself, the evaluation scale must be 1, representing equally preferred criteria. Thus we can place 1 in the main diagonal of the matrix

Table 4.5 Pair-wise comparison of the evaluation criteria

Criterion	Proximity to fire stations	Proximity to police stations	Proximity to hospitals
Proximity to fire stations	1	4	7
Proximity to police stations	1/4	1	5
Proximity to hospitals	1/7	1/5	1
	1.393	**5.200**	**13.0**

4.5.2 *Computation of the criterion weights*

The computation of the criterion weights involves the following operations: (a) sum the values in each column of the pair-wise comparison matrix; (b) divide each element in the matrix by its column total (the resulting matrix is referred to as the normalized pair-wise comparison matrix); and (c) compute the average of the elements in each row of the normalized matrix, that is, divide the sum of normalized scores for each row by 3 (the number of criteria). These averages provide an estimate of the relative weights of the criteria being compared (Table 4.6)

Table 4.6 A determination of the relative criterion weights

Criterion	Proximity to fire stations	Proximity to police stations	Proximity to hospitals	Weight
Proximity to fire stations	1 / 1.393 = 0.718	4 / 5.200 = 0.769	7 / 13 = 0.538	(0.718 + 0.769 + 0.538) / 3 = 0.675
Proximity to police stations	¼ / 1.393 = 0.179	1 / 5.200 = 0.192	5 / 13 = 0.385	(0.179 + 0.192 + 0.385) / 3 = 0.252
Proximity to hospitals	1/7 / 1.393 = 0.102	1/5 / 5.200 = 0.039	1 / 13 = 0.077	(0.102 + 0.039 + 0.077) / 3 = 0.073
	1.000	**1.000**	**1.000**	**1.000**

Using this method, the weights are interpreted as the average of all possible ways of comparing the criteria. As we can see, the criterion weights are 0.675, 0.252 and 0.073 for proximity to fire stations, proximity to police stations and proximity to hospitals respectively. This means that proximity to fire stations is the most important criterion, followed by proximity to police stations and proximity to hospitals.

4.5.3 *Estimation of the consistency ratio*

In this step it determines if a result of comparisons are consistent. It involves the following operations: (a) determine the weighted sum vector by multiplying the weight for the first criterion (proximity to fire station) times the first column of the original pair-wise comparison matrix, then multiply the second weight (proximity to police station) times the second column, the third criterion times the third column of the original matrix, finally, sum these values over the rows; and (b) determine the consistency vector by dividing the weighted sum vector by the criterion weights determined previously. A process to determine the consistency vector is shown in Table 4.7

Table 4.7 Determining the consistency ratio

Criterion	Step 1	Step 2
Proximity to fire stations	(0.675)(1) + (0.252)(4) + (0.073)(7) = 2.194	2.194 / 0.675 = 3.250
Proximity to police stations	(0.675)(0.25) + (0.252)(1) + (0.073)(5) = 0.786	0.786 / 0.252 = 3.119
Proximity to hospitals	(0.675)(0.143) + (0.252)(0.2) + (0.073)(1) = 0.220	0.220 / 0.073 = 3.014

After the calculation of consistency vector, it needs to compute values for two more terms, lambda (λ) and the consistency index (CI). The value for lambda is simply the average value of the consistency vector:

$$\lambda = 3.250 + 3.119 + 3.014 / 3 = 3.128$$

The calculation of CI is based on the observation that λ is always greater than or equal to the number of criteria under consideration (n) for positive. reciprocal matrixes, and $\lambda = n$ if the pair-wise comparison matrix is a consistent matrix. Accordingly, λ-n can be considered as a measure of the degree of inconsistency. This measure can be normalized as follows:

$$CI = \lambda\text{-}n / n\text{-}1 = 3.128\text{-}3 / 3\text{-}1 = 0.064$$

The CI term, referred to as consistency index, provides a measure of departure from consistency. Further, it can calculate the consistency ratio (CR), which is defined as follows:

$$CR = CI / RI = 0.064 / 0.58 = 0.110$$

Where RI is the random index, the consistency index of a randomly generated pair-wise comparison matrix. It can be shown that RI depends on the number of elements being compared (see Table 4.8). The consistency ratio (CR) is designed in such a way that if CR < 0.10, the ratio indicates a reasonable level of consistency in the pair-wise comparisons; if, however, CR >= 0.10, the values of the ratio are indicative of inconsistent judgments. In such cases one should reconsider and revise the original values in the pair-wise comparison matrix.

Table 4.8 Random inconsistency indices (RI) for n = 1, 2,........, 15

n	RI	n	RI	n	RI
1	0.00	6	1.24	11	1.51
2	0.00	7	1.32	12	1.48
3	0.58	8	1.41	13	1.56
4	0.90	9	1.45	14	1.57
5	1.12	10	1.49	15	1.59

Source: Adapted from Saaty (1980)

4.5.4 *Multiple expert opinions*

To derive weight for factors and criteria, in-depth interviews have been conducted. A reason behind the use of the in-depth interview method is that it would be easier in obtaining points of view with respondents for whom questionnaire alone cannot fulfill a task. Twelve people from six government offices that are related to HAZMAT transport operation were chosen and appointments were made to conduct an in-depth interview. It is clearly that the laws and regulations concerning the HAZMAT transport issue are in the hands of government offices. Therefore it was decided to select government officials as expert opinion in this research to reflect the currently reality. The list of government offices and a number of respondents are shown in Table 4.9 More detail of a result weight by each respondent and CR value calculation can be found in Appendix 4.

Table 4.9 List of government offices and a corresponding number of respondents

Government offices	No. of respondents
Hazardous waste management division *Department of Industrial works (DIW)*	2
Disaster control division *Department of Disaster Prevention and Mitigation*	2
Highway safety division *Department of Highway (DOH)*	2
Engineering and safety division *Department of Land Transport (DOL)*	2
Hazardous materials and hazardous waste management division *Pollution Control Department (PCD)*	1
Safety and occupational health division *Industrial Estate Authority of Thailand (IEAT)*	3

However, the procedures discussed in the section above address the problem of assigning weights to evaluation factors by a single decision maker. With regard to many decision makers in this research, overall weight can be derived based on group input. A technique called multiple comparisons has been applied to derive a single weight for each factor and criteria. For example, if 11 of 12 decision makers considered "traffic density" to be more important than "slope", this implies that 1 of 12 decision makers assigned more importance to "slope" than to "traffic density". If we designate the number of criteria by k and the number of decision maker by n, then n = 12 and k = 2 (Table 4.7), and the range nk – n = 12. Given the range, we can compute the weights of importance for 2 criteria. First each rank is divided by the range and the results are added. The weights are obtained by dividing each (rank/range) by the total of 1. The example of this comparison is given in Table 4.9. Because evaluation factors are weighted by 12 experts, a set of the values resulting from such comparison is given in table 4.10, 4.11, 4.12, 4.13 and 4.14

Table 4.10 Final weight value by multiple experts for economic objective

Consideration	Traffic density	Slope	Rank/Range	Weight
Traffic density	-	11	(11/12) = 0.916	**0.916**
Slope	1	-	(1/12) = 0.083	**0.084**
			1	1

Table 4.11 Final weight value by multiple experts for environmental objective

Consideration	Proximity to ponds and lakes	Proximity to conservation areas (national park, wildlife area)	Number of stream crossed	Rank/ Range	Weight
Proximity to ponds and lakes	-	6	8	0.583	**0.388**
Proximity to conservation area (national parks, wildlife area)	6	-	6	0.5	**0.333**
Number of stream crossed	4	6	-	0.416	**0.278**
				1.499	1

Table 4.12 Final weight value by multiple experts for societal (exposure) objective

Consideration	Population density	No. of schools	No. of heritage and cultural places	No. of petrol stations	No. of hospitals	Rank/ Range	Weight
Population density	-	11	11	12	9	0.895	**0.361**
No. of schools	1	-	11	10	5	0.562	**0.226**
No. of heritage and cultural places	1	1	-	7	2	0.229	**0.092**
No. of petrol/gas stations	0	2	4	-	2	0.166	**0.067**
No. of hospitals	3	7	10	10	-	0.625	**0.253**
						2.477	1

Table 4.13 Final weight value by multiple experts for societal (emergency response) objective

Consideration	Proximity to police stations	Proximity to fire stations	Proximity to hospitals	Rank/Range	Weight
Proximity to police stations	-	1	5	0.250	**0.172**
Proximity to fire stations	10	-	9	0.791	**0.542**
Proximity to hospitals	7	3	-	0.416	**0.285**
				1.457	1

Table 4.14 Final weight value by multiple experts for multiple objectives

Consideration	Economics	Environment	Society (exposure from incident)	Society (emergency response)	Rank/ Range	Weight
Economics	-	4	3	1	0.222	**0.112**
Environment	8	-	1	1	0.277	**0.140**
Society (exposure from incident)	9	10	-	5	0.666	**0.338**
Society (emergency response)	11	11	7	-	0.805	**0.409**
					1.97	1

4.6 Decision rule

After deriving weight, score and combining of weight and score, the cumulative weights and scores that represent a final value of each route are given by the following cost model;

$$R_i = \sum_{c=1}^{nc} [Wc \sum_{cf=1}^{ncf} WcfScf] \qquad (1)$$

Where R_i = the overall final value of link ith

c = criteria

n_c = number of criteria c

W_c = weight of criteria c

n_{cf} = number of factors under criteria c

W_{cf} = weight of factors

S_{cf} = score of factors

4.6.1 *Algorithm application to cost model*

4.6.1.1 *Dijkstra's algorithm*

The classic Dijkstra's algorithm solves the single-source, shortest-path problem on a weighted graph. To find a shortest path from a starting location ***s*** to a destination location ***d*** , Dijkstra's algorithm maintains a set of junctions, ***S*** , whose final shortest path from ***s*** has already been computed. The algorithm repeatedly finds a junction in the set of junctions that has the minimum shortest-path estimate, adds it to the set of junctions ***S***, and updates the shortest-path estimates of all neighbors of this junction that are not in ***S*** . The algorithm continues until the destination junction is added to ***S***.

4.6.1.2 *Hierarchical routing*

Finding the exact shortest path on a nationwide network dataset is time consuming due to the large number of edges that need to be searched. To improve performance, network datasets can model the natural hierarchy in a transportation system where driving on an interstate highway is preferable to driving on local roads. Up to three levels of hierarchy can be supported by the network dataset. Once a hierarchical network has been created, a modification of the bidirectional Dijkstra is used to compute a route between an origin and a destination.

The overall objective here is to minimize the impedance while favoring the higher-order hierarchies present in the network. It does this by simultaneously searching from both origin and destination locations as well as connection or entry points into higher-level roads, then searching the higher-level roads until segments from both origin and destination meet. As the search is restricted to the upper hierarchy, a smaller number of edges are searched, resulting in faster performance. Note that this is a heuristic algorithm; its goal is fast performance and good solutions, but it does not guarantee that the shortest path will be found. For this heuristic to be successful, the top-level hierarchy must be connected, as it will not descend to a lower level if a dead end is reached.

4.6.2 *Method 1: Optimization method*

Method 1 is to find the best single route based on the least final value for entire routes from origin to destination with regard to different objectives (shown in Table 4.14). A proposed method 1 framework for the integration of MCDA and GIS framework for the hazardous waste transport problem is depicted in Figure 4.20

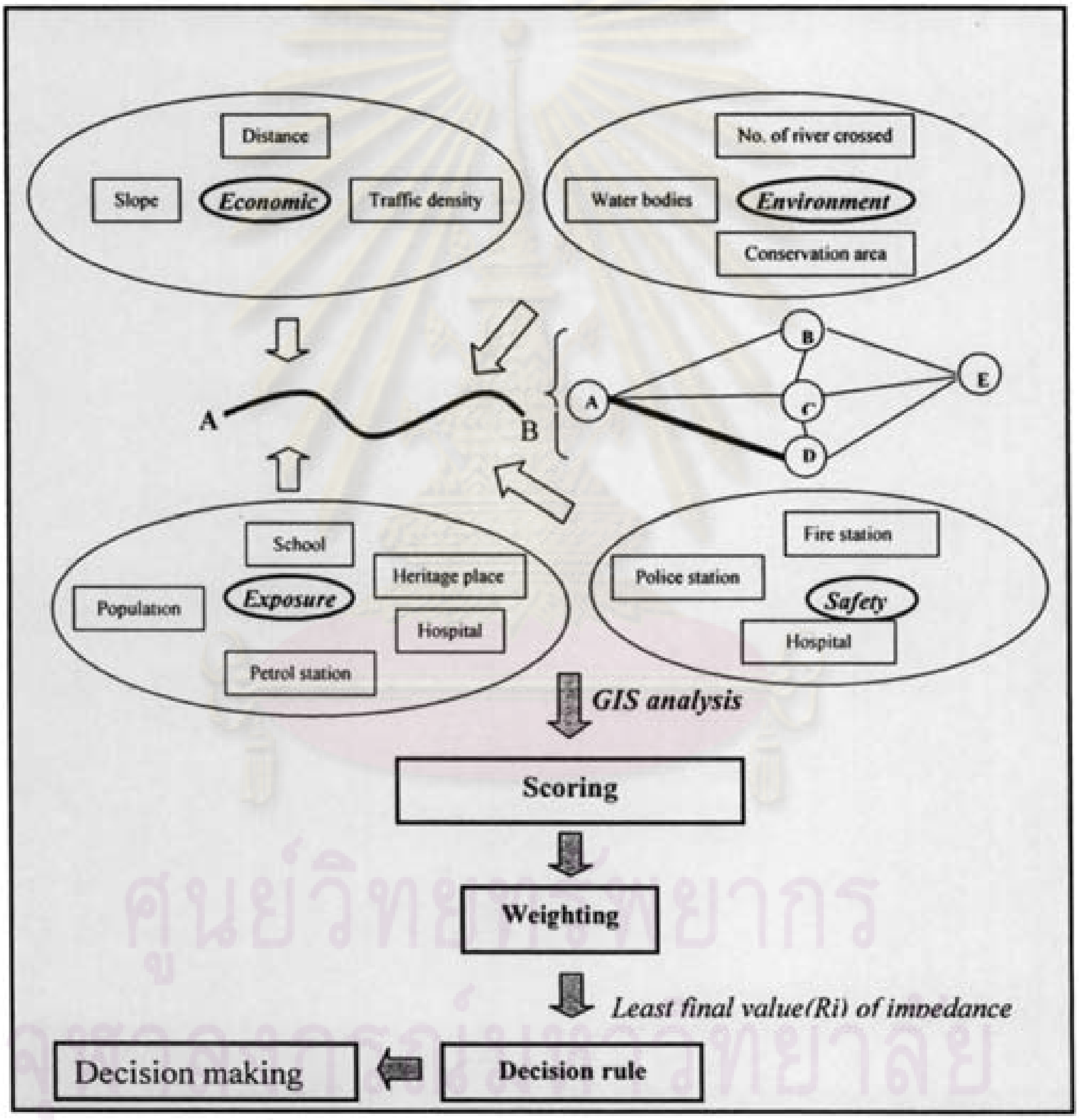

Figure 4.20 Proposed framework for the integration of MCDA and GIS for hazardous waste transport problem (method 1)

As mentioned above, economic, environment, social (exposure) and social (emergency response) are four main factors to be considered in this research. Each of main factors is consist of criteria (described in appendix 1). In this research, finding the best route is to derive the least final value (Ri) with regard to different objectives as shown in Table 4.15;

Table 4.15 Different objectives of finding routes

Factors and criteria	**Objective**
Economic - Distance, road slope and traffic density	Shortest distance between OD pair (traditional objectives) and Least final value (Ri) for economic factors
Environment - Distance to ponds & lakes, distance to parks & conservation area and no. of river crossed	Least final value (Ri) for environment factors
Social (exposure) - Population density, no. of schools, no. of petrol station, no of hospital and no. of heritage and cultural places.	Least final value (Ri) for social factors (exposure)
Social (emergency response) - Proximity to fire stations, police stations and hospitals	Least final value (Ri) for social (emergency response)
A combination of above factors	Least final value (Ri) for all factors and criteria

4.6.2.1 *Cost modeling*

From the formula mentioned in previous chapter, the relative preference of one path to another path of cost model is resulted from the quantitative result of Ri. In other word, paths are selected after running cost model analysis with the lowest value (multiply of weight and score) in all studies path of road networks.

The length of the route and Ri function have a direct relationship with each other. A general formula for each objective only is presented as the general cost model adapted from equation (1);

$$R_i = Li\,(W_1F_1 + W_2F_2 + W_3F_3 + \ldots\ldots\ldots W_nF_n) \qquad (2)$$

When W_1 and F_1 equal to weight and score of sub-factors 1 in link i

W_2 and F_2 equal to weight and score of sub-factors 2 in link i

W_n and F_n equal to weight and score of sub-factors 3 in link i

Li is the length of each link,

Hence, the best path between origin and destination is calculated by deriving a minimum value of R_i based on each objective as the following equation;

$$R_i = \sum_{cf=1}^{ncf} WcfScfLi \qquad (3)$$

Cost model for economic factor

$$R_{econ} = \sum \; Li\,(W_{td}F_{td} + W_{sl}F_{sl}) \qquad (4)$$

When W_{td} and F_{td} equal to weight and score of traffic density

W_{sl} and F_{sl} equal to weight and score of road slope in

Li is the length of each link

Cost model for environmental factor

$$R_{envi} = \sum \; Li\,(W_{ptp}F_{ptp} + W_{ptc}F_{ptc} + W_{rc}F_{rc}) \qquad (5)$$

When W_{ptp} and F_{ptp} equal to weight and score of proximity to ponds and lakes

W_{ptc} and F_{ptc} equal to weight and score of proximity to conservation areas

W_{rc} and F_{rc} equal to weight and score of a number of rivers crossed

Li is the length of each link

Cost model for exposure factor

$$R_{expo} = \sum Li\,(W_{sch}F_{sch} + W_{pet}F_{pet} + W_{heri}F_{heri} + W_{hos}F_{hos} + W_{pop}F_{pop}) \quad (6)$$

When W_{sch} and F_{sch} equal to weight and score of proximity to schools

W_{pet} and F_{pet} equal to weight and score of proximity to petrol stations

W_{heri} and F_{heri} equal to weight and score of proximity to heritage & cultural places

W_{hos} and F_{hos} equal to weight and score of proximity to hospitals

W_{pop} and F_{pop} equal to weight and score of population

Li is the length of each link

Cost model for emergency response factor

$$R_{emer} = \sum Li\,(W_{fs}F_{fs} + W_{ps}F_{ps} + W_{hos}F_{hos}) \quad (7)$$

When $W_{fs}F_{fs}$ equal to weight and score of proximity to fire stations

$W_{ps}F_{ps}$ equal to weight and score of proximity to police stations

$W_{hos}F_{hos}$ equal to weight and score of proximity to hospitals

Li is the length of each link

Cost model for all factors and criteria

$$R_i = \sum [(W_{eco}R_{eco}) + (W_{envi}R_{envi}) + (W_{expo}R_{expo}) + (W_{emer}R_{emer})] \quad (8)$$

When Ri equals final cost value for all factors and criteria

W_{eco} equals weight for economic factor

W_{envi} equals weight for environmental factor

W_{expo} equals weight for societal (exposure) factor

W_{emer} equals weight for societal (emergency response) factor

4.6.3 *Method 2: Analytical Hierarchy Process (AHP)*

Another method is to compare alternative routes between origin and destination and to calculate overall final value (Ri) based on factors and criteria and to derive the best single route among alternative routes. Analytical Hierarchy Process or AHP, developed by Saaty (1980), is based on three principle: decomposition, comparative judgement, and synthesis of priorities. The decomposition principle requires that the decision problem be decomposed into a hierarchy that captures the essential elements of the problem. The principle of comparative judgment requires assessment of pair-wise comparisons of the elements within a given level of the hierarchical structure, with respect to their parent in the next higher level. The synthesis principle takes each of the derived ratio-scale local priorities in the various level of the hierarchy and constructs a composite (global) set of priorities for the elements at the lowest level of the hierarchy (i.e., alternatives)

In contrast with method 1, AHP method is preferable in case that decision makers already have their limit sets of alternative. A proposed framework for the integration of MCDA and GIS for the hazardous waste transport problem for method 2 is depicted in Figure 4.21

4.6.3.1 *Cost modeling*

A general formula for each alternative is presented as the general cost model

$$Ri = \sum_{c=1}^{nc} [Wc \sum_{cf=1}^{ncf} WcfScf] \quad (9)$$

Where R_i = the overall final value of link i[th]

c = criteria

n_c = number of criteria c

W_c = weight of criteria c

n_{cf} = number of factors under criteria c

W_{cf} = weight of factors

S_{cf} = score of factors

A reason behind the selection of Analytical Hierarchy Process (AHP) as the cost model is that AHP supports pair-wise comparison method for criterion weighting. Decision making interaction via AHP is high and the assumption is moderately restrictive. A comparison between AHP and other methods is shown in Table 4.16

Table 4.16 A comparison between AHP and other methods

Method	Method				
	input	**output**	**Decision type**	**Decision making interaction**	**Assumption**
scoring	Attribute, score, weight	Ordinal ranking	Individual, deterministic	Moderate	Nonrestrictive
Multi attribute value	Value, functions, weight	Cardinal ranking	Individual and group, deterministic, fuzzy	High	Very restrictive
Multi attribute utility	Utility, functions, weights	Cardinal ranking	Individual and group, deterministic, fuzzy	High	Very restrictive
AHP	Attribute, score, pair-wise comparison	Cardinal ranking (ratio scale)	Individual and group, deterministic, probabilistic fuzzy	High	Moderately restrictive
Ideal point	Attribute, score, weight, ideal-point	Cardinal ranking	Individual and group, deterministic, probabilistic fuzzy	Moderate	Nonrestrictive

Cost model by AHP method has been tested with five alternative routes with the combination of all objectives with the purpose of providing least Ri value in equation (9).

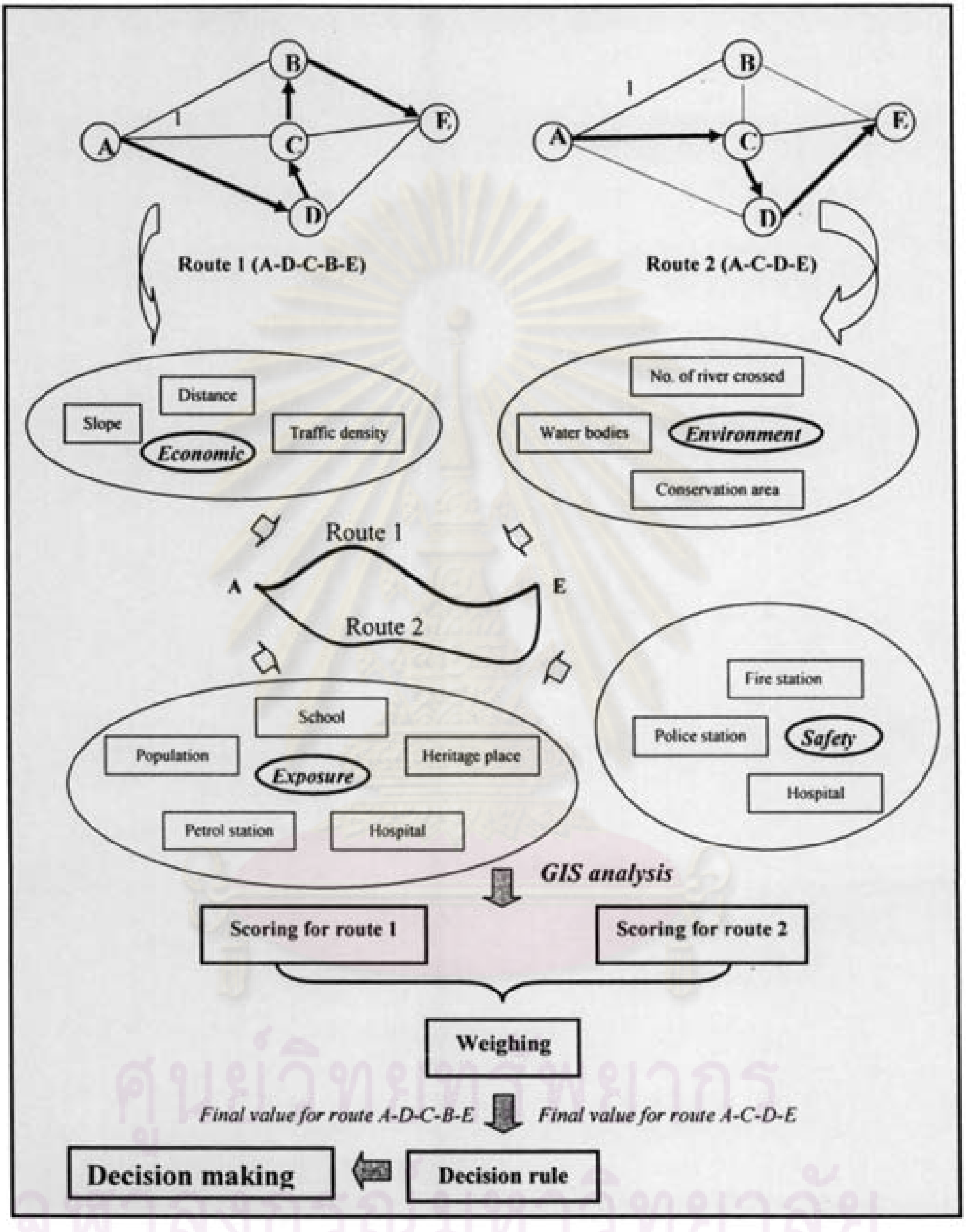

Figure 4.21 Proposed framework for the integration of GIS and MCDA for hazardous waste transport problem applied by AHP method (method 2)

CHAPTER V
RESULTS AND DISCUSSION

5.1 Introduction

In this chapter, many routing scenarios with different objectives have been proposed. As mentioned in previous chapter, economic, environmental, societal (exposure and emergency response) are considered as four main factors. A method 1, which tries to find route between origin-destination with minimum value (Ri), is proposed first and is then compared with shortest rout While a comparison of final value (Ri) for predetermined route and/or alternative routes (method 2) is then presented in the next topic.

5.2 A Case Study

There are many heavy industries such as petrochemical, plastic, pulp and paper production located in the area of Rayong province. From a total amount of 1,558,743 tons of hazardous waste in the country, the eastern part of Thailand generated 1,092,672 tons (70 percent of the total amount of hazardous waste), while Rayong province is responsible for 618,115 tons (40 percent of the country's hazardous waste and 57 percent of the region's hazardous waste) (DIW, 2006). Furthermore, from a 2006 report by PCD, only 276,687 tons or about 20 percent of industrial hazardous waste is sent to disposal sites (not including reuse or recycle at the production site itself). Approximately 70 percent of the total treated amount of hazardous waste has been directed to incinerator plants as raw materials for fuel blending to support the energy needs for operation of cement factories (PCD, 2006).

From a recent data of Department of Industrial Works (DIW), total hazardous industrial wastes amount that are permitted to ship out from the estate to incinerate at incinerator plant in Saraburi province is 96806.20 tons in 2006. However, they only categorized the amount of hazardous waste into 43 groups, not go into detail about a specific name of those wastes. Information related to which type and amount of hazardous waste that sent to each incinerator plant is also secrecy as well due to the release of information law in Thailand since 2007. Author decided to select liquid hazardous waste transport from MTPIE to incinerator plants because these wastes can potentially cause an adverse affect more than solid hazardous waste. As a consequence, Map Ta Phut Industrial Estate, located in Rayong province and five incinerator plants which are located in Saraburi province have been selected as origin and destinations in this research. The road network used for the case study is shown in Figure 5.1

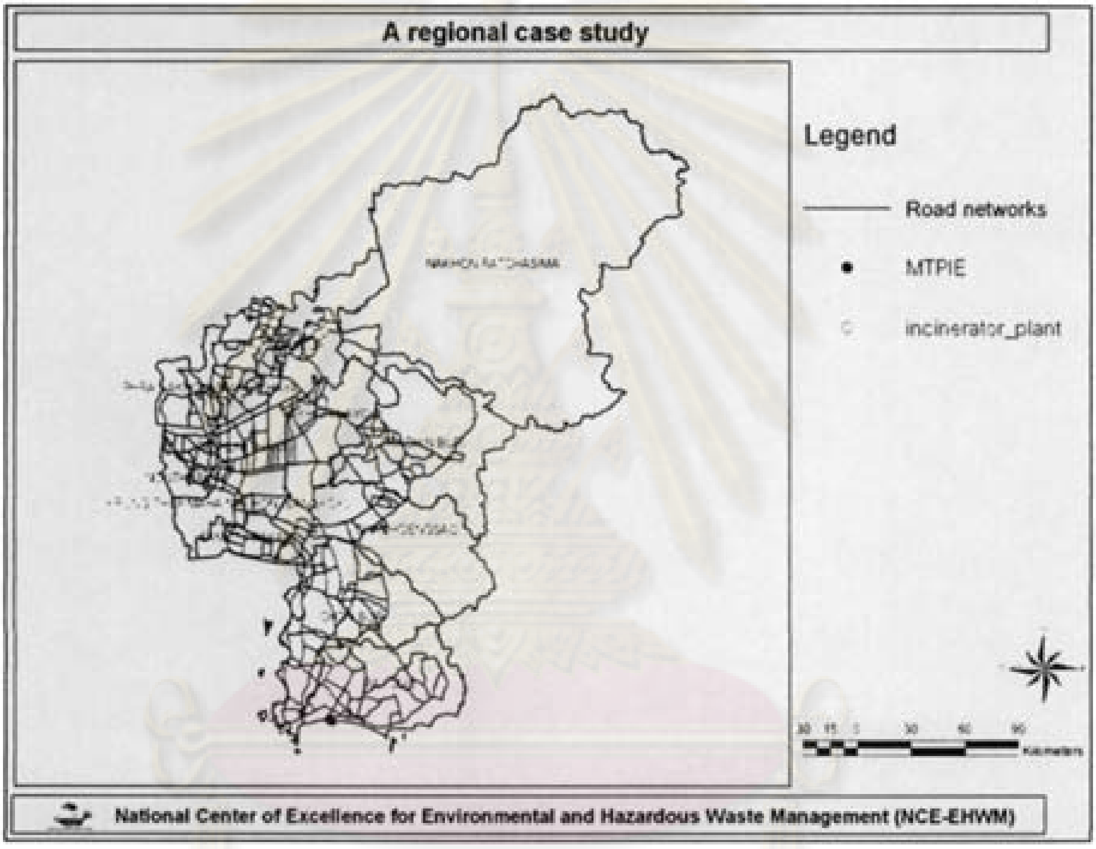

Figure 5.1 Showing the origin (MTPIE) – destination (Incinerator plants) study area for hazardous waste transport

5.3 Cost Model Test

The developed cost model is tested with two different methods; optimization and analytical hierarchy process to find the optimum route. Map Ta Phut Industrial Estate (MTPIE) has been selected as an origin of liquid hazardous waste generation. The purpose of transport these liquid wastes are to dispose at incinerator plants located in

Saraburi province. A main purpose of this research is to propose the integrated MCDA framework with GIS tool by proposing the general cost model for hazardous waste route planning. Therefore, a shipment of liquid hazardous waste to one incinerator plants have been chosen and tested with a cost model with six different objectives; distance, environment, exposure, emergency response, other economic factors and the combination of previous objectives.

5.3.1 *Method 1: Optimization method*

5.3.1.1 *Routing by distance objective*

There are five incinerator plants (called plant 1, plant 2, plant 3, plant 4 and plant 5 in this research respectively) located in Saraburi province and definitely served as destination for incineration purpose. Incinerator plant 1, located in Bankrua district, Amphoe Banmhor, Saraburi province, has been chosen as the destination for the shipment. The first objective is to find a minimum distance from MTPIE to incinerator plant 1 and followed with the rest objectives as mentioned above by weighting factors and criteria (by pair-wise comparison). With distance objective, a result route is illustrated in Figure 5.1 A screenshot of distance matrix based on different objectives is compared with the shortest route. A shortest distance is 278.687, while other objectives have a bit longer routes as shown in Table 5.1

Table 5.1 Total distance from MTPIE – Incinerator plant 1 with different objectives

Origin-destination	Distance (km)
Distance objective	278.687
Environmental objective	284.079
Exposure objective	310.555
Emergency response objective	281.887
Other economics objective	309.175
Combined objective	284.094

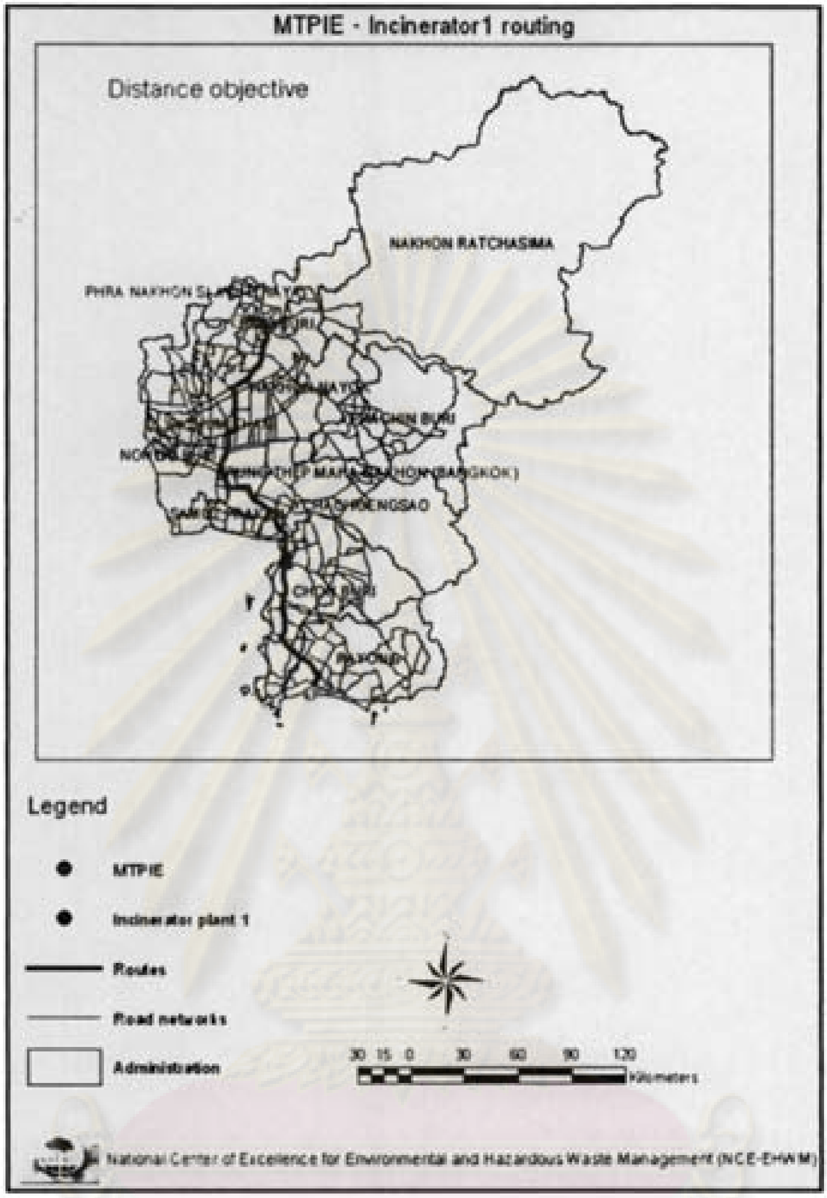

Figure 5.2 Routing from MTPIE to incinerator plant 1 by distance objective

Figure 5.2 shows a route based on distance objective. To make a comparative between with other different objectives, Table 5.2 shows a total score of other objectives if shortest route has been chosen for transport hazardous waste.

Table 5.2 Total score of other objectives with routing by distance objective

Routing by distance objective	Total score
Total environmental score	355.153
Total economic score	793.745
Total societal (exposure) score	404.889
Total societal (emergency response) score	397.152

5.3.1.2 *Routing by environmental objective*

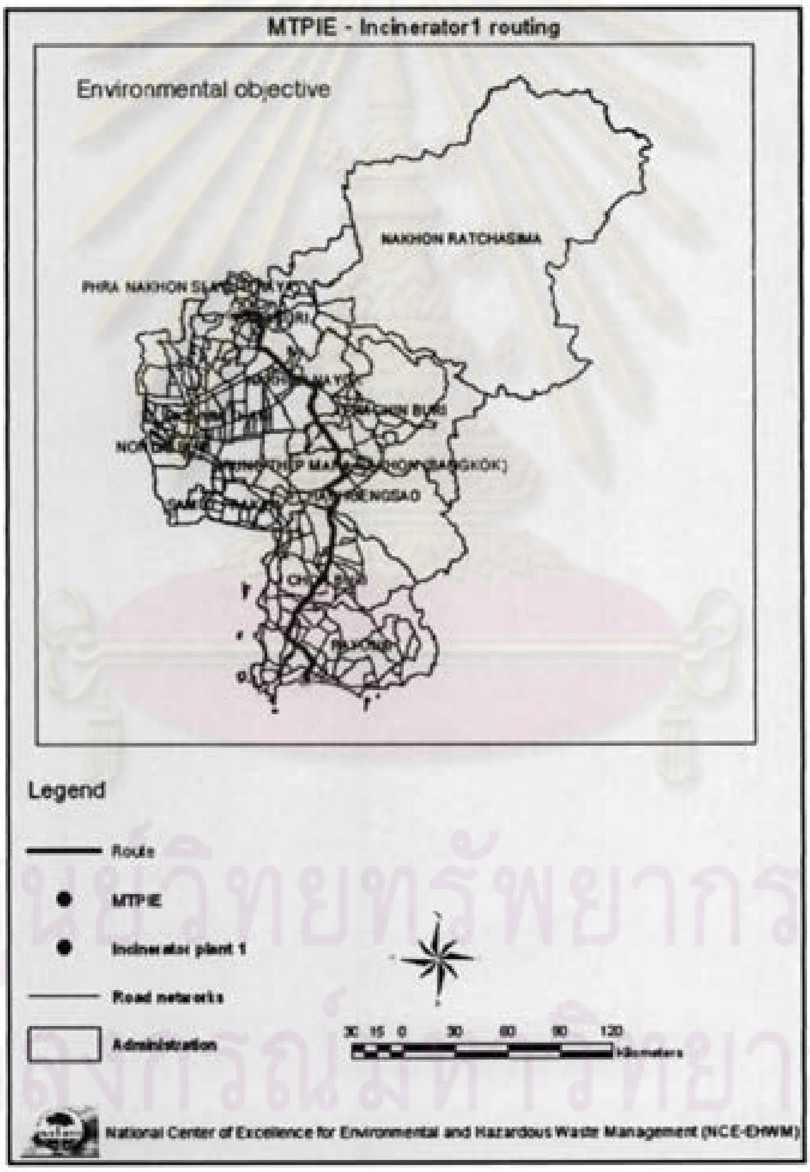

Figure 5.3 Routing from MTPIE to incinerator plant 1 by environmental objective

Table 5.3 Total score of other objectives with routing by environmental objective

Routing by distance objective	Total score
Total environmental score	*301.550*
Total economic score	548.444
Total societal (exposure) score	352.820
Total societal (emergency response) score	383.447

Figure 5.3 shows a result of route based on environmental objective. From Table 5.3, routing by environmental objective has the least score of 301.550. A different of distance from shortest route is increased by 1.93 %.

5.3.1.3 *Routing by societal (exposure) objective*

Figure 5.4 shows a result of route based on societal (exposure) objective. Table 5.4 also indicates the total score of other objectives as well.

Table 5.4 Total score of other objectives with routing by societal (exposure) objective

Routing by distance objective	Total score
Total environmental score	341.259
Total economic score	530.731
Total societal (exposure) score	*349.102*
Total societal (emergency response) score	509.163

Routing by societal (exposure) objective has the least score of 349.142, while a distance is increased by 11.43 % from shortest route.

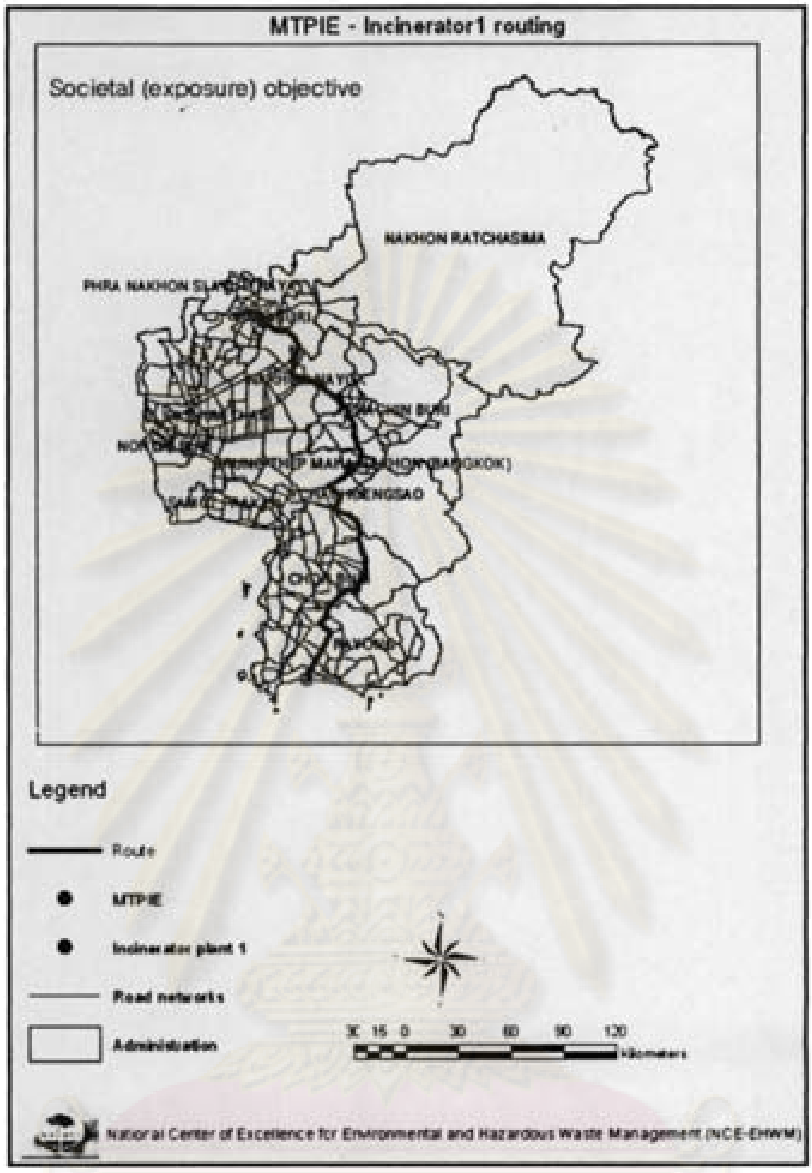

Figure 5.4 Routing from MTPIE to incinerator plant 1 by societal (exposure) objective

5.3.1.4 *Routing by societal (emergency response objective)*

Figure 5.5 shows a result of route based on societal (emergency response) objective. A total score of other objectives is also shown in Table 5.5.

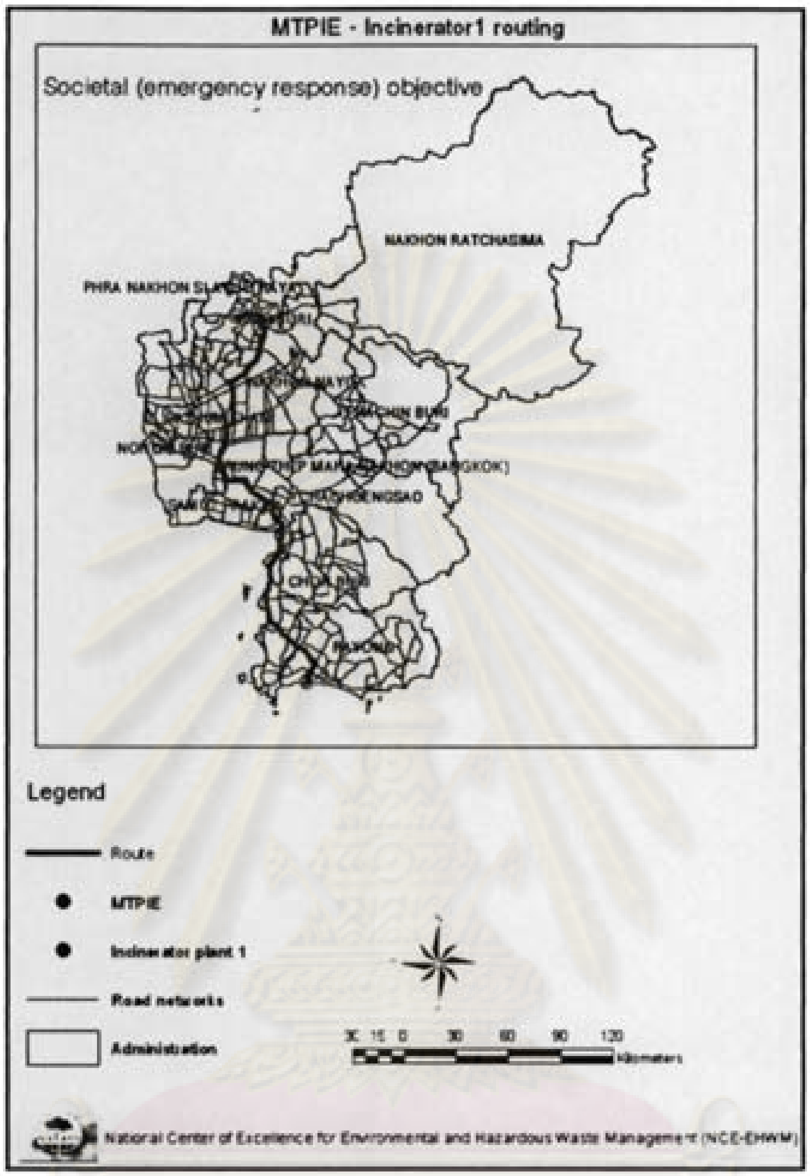

Figure 5.5 Routing from MTPIE to incinerator plant 1 by societal (emergency response) objective

Table 5.5 Total score of other objectives with routing by societal (emergency response) objective

Routing by emergency response objective	Total score
Total environmental score	348.481
Total economic score	802.002
Total societal (exposure) score	466.931
Total societal (emergency response) score	*382.498*

Routing by societal (emergency response) objective has the least score of 382.498, while a distance is increased by 1.11 % from shortest route.

5.3.1.5 *Routing by economic objective*

Figure 5.6 shows a result of route based on societal economic objective. A total score of other objectives is also shown in Table 5.6

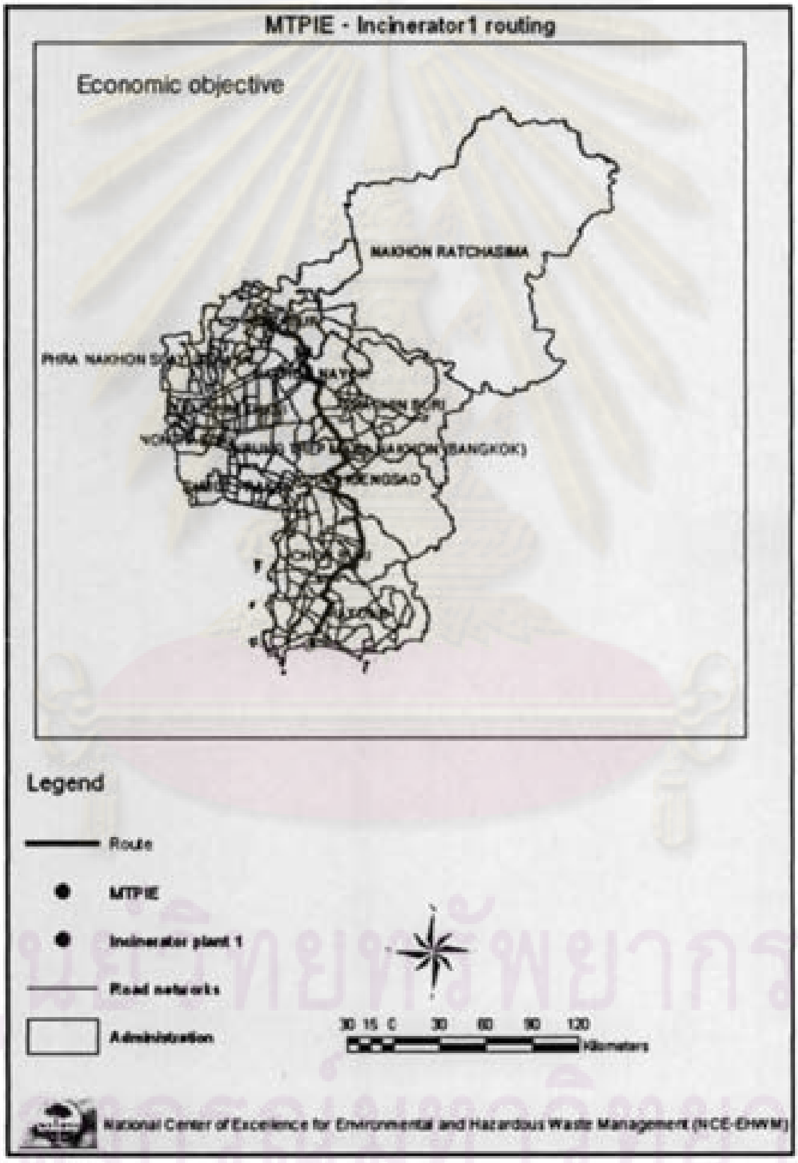

Figure 5.6 Routing from MTPIE to incinerator plant 1 by economic objective

Table 5.6 Total score of other objectives with routing by economic objective

Routing by economic objective	Total score
Total environmental score	339.880
Total economic score	*438.980*
Total societal (exposure) score	369.163
Total societal (emergency response) score	522.661

Routing by economic objective has the least score of 438.980, while a distance is increased by 1.93 % from shortest route.

5.3.1.6 *Routing by multiple objective*

Figure 5.7 shows a result of route based on multiple objectives. A total score of other objectives is also shown in Table 5.7

Table 5.7 Total score of other objectives with routing by multiple objectives

Routing by multiple objective	Total score
Total environmental score	308.692
Total economic score	488.172
Total societal (exposure) score	401.860
Total societal (emergency response) score	398.568
Total multiple objective score	*734.969*

Routing by multiple objectives has the least score of 734.969, while a distance is increased by 3 % from shortest route.

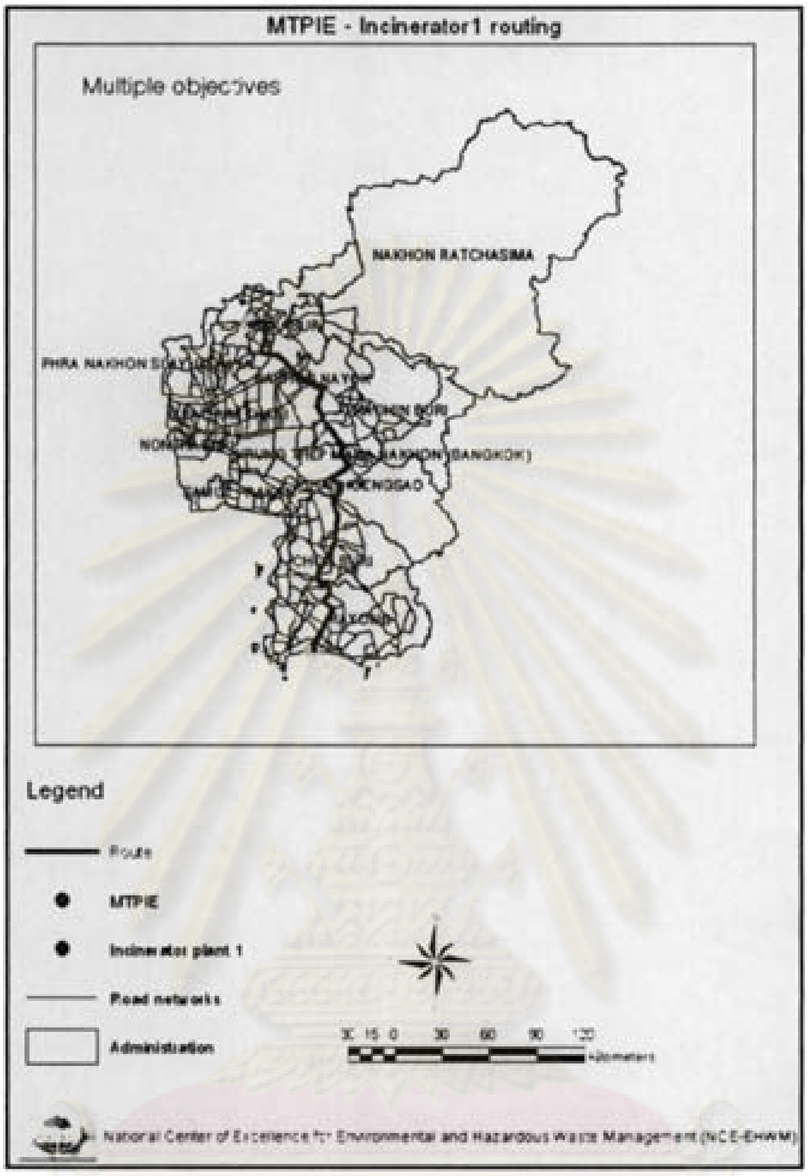

Figure 5.7 Routing from MTPIE to incinerator plant 1 by multiple objectives

5.3.2 *Method 2: Analytical Hierarchy Process*

This method is similar to method 1 but the purpose of finding route is somewhat difference. With this method, assuming that there are exact set of routes that are predefined origin destination pair. This means that a cost model in equation (9) will be used to calculate the final value (Ri) of predefined origin destination routes and then take into account the multiple objectives and the priority weight assigned to each objective. Assuming there is six alternatives route in transporting hazardous waste from MTPIE to incinerator plant 1. The question is which alternative should be used? To answer this question the cost model can be extended in order to assess from all alternative routes available, which one is the best one.

Let consider routing hazardous waste from MTPIE to incinerator plant 1, a first step is to use the database that already prepared as described in chapter 4. The next step is to use a proposed cost model calculate total final value (Ri) as shown in equation (9) for each alternative route and then make a comparison of final value (Ri) among alternative routes. The lowest final value (Ri) indicates the most proper route to transport hazardous waste. Figure 5.8 shows six alternative routes for hazardous waste transport. After the calculation of Ri value for five different objectives route and one multiple objective route, Table 5.8 shows a comparative between final value (Ri) and objective score in six alternative routes

Table 5.8 A comparative between final value (Ri) and objective score in six alternative routes

Alternative routes	Final value (Ri)	Economic score	Environment score	Exposure score	emergency response score
Route 1 (distance)	776.458	793.745	355.153	404.889	397.152
Route 2 (emergency)	796.871	802.002	348.481	466.931	**382.498**
Route 3 (environment)	748.422	518.441	**301.550**	352.820	389.447
Route 4 (exposure)	760.098	530.731	341.259	**349.102**	509.163
Route 5 (economic)	804.341	**438.980**	339.123	369.613	522.661
Route 5 (multiple objectives)	**734.969**	488.172	308.692	401.860	398.568

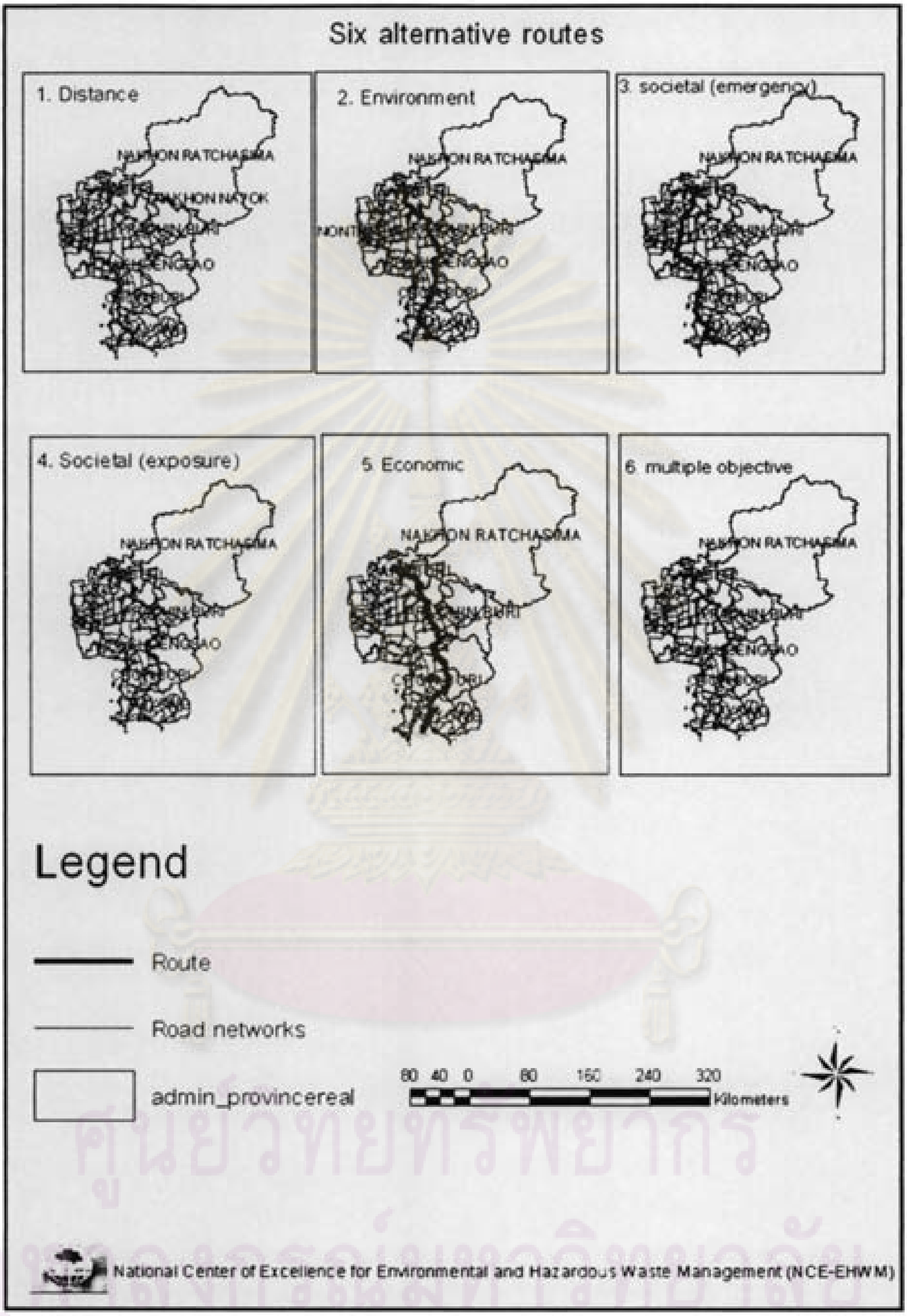

Figure 5.8 Six alternative routes from MTPIE to Incinerator plant for hazardous waste transport

After calculating total final value (Ri) in six alternative routes, the results show that route 6, which consideration of multiple objectives, has the lowest total final value (Ri = 734.969), followed with route 3 (Ri = 748.422), and route 4 (Ri = 760.098) respectively. Decision makers and/or hazardous waste transporter can make a judgment based on the consideration of final value (Ri) as useful indicator to help them make decision making to reduce risk posed to surroundings in case of truck incident. Table 5.9 shows a comparison between route (based on multiple objectives) and traditional route (based on distance objective) for number of school passes, distance used, population within 800 meters, including summation of score for traffic density, proximity to fire stations and proximity to ponds/lakes area criteria.

Table 5.9 Show a comparison between route 6 (multiple objectives) and route 1 (traditional distance objective) with various criteria

Alternative routes	No of school	Distance (km)	Population (ppl)	Traffic density (sum score)	Fire station (sum score)	Ponds/lakes (sum score)
Route 1 (distance)	346	278.687	318,994	541	779	246
Route 2 (emergency)	368	281.887	384,972	506	810	229
Route 3 (environment)	249	284.079	115,162	291	590	108
Route 4 (exposure)	146	310.555	112,464	237	473	123
Route 5 (economic)	184	309.175	105,486	155	571	112
Route 6 (multiple objectives)	215	287.021	89,120	217	481	116

5.4 Validation of the proposed framework with expert opinions

The last stage of the analysis is to validate the route planning result with potential stakeholders. The objective of this process is to show the route planning results and receive a comment from potential stakeholders. A selected number of respondents, who given a weight in the criterion weighting process, have been chosen as potential stakeholders and made an interview person by person to get a valuable comment about route planning result in this dissertation. Two respondents from department of industrial works (DIW) and one respondent from department of highway (DOH) have been chosen as potential stakeholders. The following issues are the comment from respondents.

5.4.1 The application of the proposed framework in Thailand

In the opinion of respondents, a proposed framework is better than the existing practice for hazardous waste transport in Thailand. Existing hazardous waste transport practice depends on how to reduce operation cost only. This leads the existing practice solely based on distance and/or time. To compare the existing practice with a framework presented in this dissertation, it would be useful to start thinking about multiple factors and criteria for hazardous waste transport issue. Environmental and societal thinking must be thought as important as economic thinking.

Until recently, a proposed framework is a new in the area of HAZMAT transport issue in Thailand. A flexibility of the framework is flexible enough for further improvement because a cost model used in the framework is not static. The input of new cost model to the framework is possible due to an independent between the framework and cost model. A proposed framework is very useful for the application in Thailand. Hazardous waste transport companies can apply this framework to route planning before transporting hazardous waste to disposal site. Moreover, a proposed framework is also useful for other type of materials such as hazardous materials (HAZMAT) and it can be applied in any area from local area to regional area. It should also notice that it is very hard to raise awareness with a proposed framework to understand risk from hazardous waste transport issue to hazardous waste transporter. Most of them are currently use a route that they familiar with and it is certainly the shortest route.

Another limitation of the framework is how to bring this framework into practice in operation level. A proposed framework is understandable in policy maker level, especially a people who have a rich of knowledge in MCDA and GIS. However, applying this framework into practice may be obstacle in the operation level. The best way to tackle this obstacle is to create a general platform of the model that can interface with user by readily and comprehensively.

5.4.2 Law and regulation development related to a proposed framework

Until now, there is no law and regulation related to route planning for hazardous waste transport, especially in the region outside the Bangkok Metropolitan Area. Although waste manifest system was release since 2004, but the route used for transport hazardous waste is not enforced to report in manifest paper. The selection of route for transporting HAZMAT or hazardous waste is a plan for the near future of Thailand by a collaboration of Ministry of Transport, Ministry of Industry and Ministry of Natural Resources and Environment. Nevertheless, law and regulation related to this issue needs to be carefully developed because many stakeholders are being involved such as governments, policy makers, waste generator, transporter and people. Public hearing is really important process to be conducted before the consideration of the issue. A proposed framework can be use as a framework and tool in the near future when considering laws and regulations concerning hazardous waste transport.

5.5 Conclusion

Two type of method has been tested by the selection of hazardous waste transport from MTPIE to incinerator plant in Saraburi province as a case study. From the optimization method (method 1), the choice of routes are calculated by equation (4), (5), (6), (7) and (8) and are differed for each objective. It can be noticed that routing with environmental, societal (exposure), societal (emergency response), economic criteria and multiple objectives will increase a length of route when comparing with shortest route (distance objective alone). For Analytical Hierarchy Process (method 2), a proposed cost model in equation (9) can use for calculate Ri to find out which routes have the least Ri vaule in case that decision maker has a limited set of alternative routes. The objective is certainly set to be the combined score in four objectives; economic, environmental, societal (exposure) and societal (emergency response). With regard to this approach, decision maker can plan their hazardous waste route to reduce risk to surroundings in case of truck's incident.

A main different between two methods is the purpose of route planning and a number of factor and criteria involve in the process. Table 5.10 summarized the different between optimization method (method1) and analytical hierarchy process (method 2) for hazardous waste route planning

Table 5.10 Summary of the different between method 1 and method 2

Item	Method 1	Method 2
Purpose	To find out a route from a large road networks with different objectives	To find out a route from a limited set of alternative routes
Algorithm build in	- Dijstra's algorithm - Hierarchy algorithm	- Dijstra's algorithm - Hierarchy algorithm
Number of factors	Vary	Vary
Number of criteria	Vary	Vary
Database complex	Very complex	Not complex
Cost model	Various form of cost model used	Single form of cost model used

Moreover, Table 5.11 shows a simplify summary about factor and criteria used in each objective under method 1 and method 2

Table 5.11 Summary of factors and criteria applied in method 1 and method 2

Method	Factor	Criteria
Method 1		
Distance objective	distance	distance
Environmental objective	environment	-Proximity to ponds/lakes -Proximity to conservation area -Number of river crossed
Exposure objective	societal	-Number of school -Number of petrol station -Number of heritage and cultural place -Number of hospital -Population density
Emergency response	societal	-Proximity to fire stations -Proximity to police stations -Proximity to hospitals
Economic objective	economic	-Traffic density -Road slope
Multiple objective	Environment, societal (exposure), societal (emergency response), economic and multiple objectives	All criteria mentioned above
Method 2		
Multiple objective	Environment, societal (exposure), societal (emergency response), economic and multiple objectives	All criteria mentioned above

CHAPTER VI
CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

A shipment of hazardous waste can carry some risks to the public along the route, as well as to the environment. Accidents can happen, and the content of the truck will be leaked in a serious accident. Risk cannot be avoided, but they can in fact be managed. Any risk factor that is managed properly can contribute to the reduction of risk. One of the primary goals of this thesis was to assess and to create a framework for HAZMAT transport to achieve multiple factors and criteria considerations. By the application of Multi Criteria Decision Analysis (MCDA) and a Geographic Information System (GIS) approach, a conceptual framework for HAZMAT transport has been formulated using the transport of hazardous waste from Map Ta Phut industrial estate to one of the five incinerator plants in Thailand as a case study. The integrated MCDA framework with GIS tools can provide a framework for the input of cost model to solve and manage complex hazardous waste transport problems. There are many factors and criteria that can affect the selection of routes for the transport of HAZMAT, and at the same time there are other processes that influence these factors and criteria. As a consequence, there will be no fixed answer to what risk factors should be considered when developing the route planning framework. Since this will depend to the characteristics of each case study. Nevertheless, it was the aim of this research study to consider the integration of different factors and criteria that comply with sustainability framework (economic, environmental and societal issues) when developing the routing framework. Factors and criteria are defined with the goal of sustainability first and are then taken into account through analysis by the integrated MCDA framework with GIS tool.

The methodology proposed in chapter IV was developed in pursue of considering different risk factors other than single factor and criteria consideration. In a presented framework, the objectives may conflict with each other. The conflict among the objectives is present also among the units in which each objective function is measured. In order to be able to evaluate the route, especially multiple factors and criteria consideration, it would be useful to transform the unit of objective into a common one by the development of scoring system. The method proposed in this research suggested in two ways. A former is to routing based on finding route with different objectives and the multiple objectives. While the latter intends to apply for the evaluation of finite set of alternative routes, however, two approaches were also based on the minimum total final value of each transportation link.

To determine the different risk factors based on economic, environment and societal objectives that influence outcomes directly and indirectly within the hazardous waste transport system. This research has considered sustainability goal at the first glance. Economic, environmental and societal factors and criteria are taken into account. Multi criteria decision making (MCDA) is then a framework that integrates multiple factors and criteria into hazardous waste transport problem. Geographic Information System (GIS) serve as a working tool to transform and quantify spatial related information of factors and criteria to score. This can ensure that the framework is developed by incorporating all necessaries factors and criteria as described in chapter III and chapter IV (see all lists of factors and sub factors in appendix 1), including cost model that use these factors and criteria as an input parameters in chapter V

To integrate Multi criteria decision analysis (MCDA) and Geographic information system (GIS) based frameworks for hazardous waste route planning, GIS serve as a working tool to quantify a score in each road section while MCDA performs a criterion weighting for factors and criteria to achieve sustainability goal. The integrated MCDA framework with GIS tool has been proposed by the generation of cost model, underlying with algorithm build in. A proposed cost model can combine weight and score in simplify and meaningful manner and provide a numerical value (Ri) that can be used to aid route planning decision making. With regard to cost model presented in this dissertation, the minimum numerical value (Ri) of multiple objectives consideration is desired when making a route planning for hazardous waste transport. Moreover, a presented cost model also facilitates decision making process by making a comparative study of alternative routes between origin and destination with proposed method 2. A test of integrated MCDA framework with GIS tool, including a proposed cost model is conducted by using a regional hazardous waste transport system (MTPIE to incinerator plants) as a case study. As a result, different routes have been created with different single objectives and have been compared by the route with multiple objectives.

The proposed framework is designed and created to allow the flexibility for the application in the future. Other areas of study can be applied by adding new spatial database into GIS. However, a method for quantifying score and weight is also the same as presented in the proposed framework. This brings framework flexible enough for application in other areas. Nevertheless, a selection of the cost model used in the framework is independent with the proposed framework. There would be no problem if a new development of cost model will be input to the proposed framework because the framework is designed in a flexible platform. A proposed analytical framework can be very useful for hazardous waste route planning to achieve sustainability goal based on the multiple factors and criteria, especially environmental and societal factors and criteria that are rarely take into consideration in most previous literatures. The integrated MCDA framework with GIS tool can be used as planning procedure that will aid decision maker to plan and to select appropriate route for HAZMAT transport. This proposed framework can be proposed as a base for policy makers move their current practices of decision making toward HAZMAT transport sustainability in the near future.

The framework development in this dissertation can be customized and used to other case studies and not just the one presented in this document is of great relevance when considering the application of proposed framework in the developing countries. It is essential to aware that a reality in developing countries can be so much different and complex than in the developed countries. The level in which risk factors are perceived by the government in developing countries may be diminished by the need to satisfy the basic services to the population. In case where there is awareness of the need to manage risk, the access to framework that can aid to the risk management may not be available. Another case could be one where frameworks are available but the lacking of information required by the frameworks can represent a drawback in the management process of risk. For this reason, the integrated MCDA framework with GIS tool to achieve sustainability goal serves as a framework and tool simultaneously that can be easily adapted and flexible to fit the reality of a given case study. This flexibility aspect of the proposed framework is the main component in this research.

6.2 Limitation and Recommendations

There are the areas from the research study presented in this document that can be improved. These areas represent an opportunity for further research to be carried out. There are improvements that can be made to the framework if more accurate and reliable data are acquired. The following lists are data needed to be collected or revised;

6.2.1 *Data*

- The completeness of data related to traffic condition of transport network is needed. Some Traffic data such as Average Daily Traffic (ADT) is not available at some transportation links. The estimation method by the average of known ADT data that are connected with that link is conducted in this research.
- An up to date spatial data in some categories would be beneficial such as environmental data (ponds, lakes and forestry data). It can lead to the higher accuracy level in the analysis result.
- Topological error in road networks and rivers should be eliminated prior to the dissemination of data. This can introduce an easier way for further analysis, especially in such a case large road network such as regional road network that has been presented in this document.

6.2.2 *Methodology*

- Other different cost models are possible to input in the proposed framework. However, weighing is a very critical issue in MCDA. Weighting by truly involved stakeholders would be beneficial to the decision making process for hazardous waste transport problem. A pair-wise comparison is weighting method that has been selected in the proposed framework to receive weight through a view of policy maker perspective. However, public hearing is very important in weighting process to get involve many stakeholders such as transport companies and people.

After public hearing process, the development of weighting manual with different method of weighting would be useful for operation level. Moreover, a results of public hearing that is derived by expert in each stakeholder will be useful for developing Delphi method that should be more rigorous than pair-wise comparison method.

- A devised scoring system in this research is adapted from previous literatures that were conducted in developed countries. A scoring system based on the development in developing countries would be beneficial. However, this is very time consuming task and need to be cooperative with various organizations in national level.

6.2.3 *Tools*

- An accuracy level of analysis performed by GIS is depended on data precision. Hence, more precision of data will reflect the increase in accuracy of GIS analysis.

6.2.4 *Framework*

- A proposed framework is based on the integrated MCDA framework with GIS tool to achieve sustainability goal. Other frameworks may be developed with a different factors and criteria.

- The proposed framework can be potentially developed in advance from static to dynamic framework. To make a framework dynamic, real time information system should be established and coordinated among various organizations such as Ministry of Transport, Ministry of Industry, Ministry of Natural Resources and Environment, Ministry of Interior and Ministry of Information and Communication Technology. The example of real time data are meteorological data (temperature, humidity, weather condition), type of waste, nearest location of rescue units, including an exact location of incident derived by Global Positioning System (GPS) built in the HAZMAT truck. The coordination of these dynamic data is necessary for knowing the exact surroundings condition and accelerating response time. Dynamic framework also requires a rich of resources, including well organized and developed information system, up to date data, high machine performance and people.

6.3 Future works

There are the areas for expanding an idea the scope for this research which is still rare in Thailand. A result in this study can be used as solid base data for the development of real time vehicle routing system by input real time incident data during transport phase to the system and predict an impact result to surroundings. However, an accuracy of the system depends on many things such as real time data accuracy (such as meteorology data, comprehensive link and cooperation among government officials would be very critical issue.

This result can be extending to a comprehensive HAZMAT emergency response research, although author has develop a simple emergency response scheme with the assumption of truck getting involve accident. However, in depth study of HAZMAT emergency response can be expanded to another one research topic such as a development of chemical database and link with plume modeling to predict response time to rescue operation by using algorithm.

Multi modal transport can be modeling with the application of MCDA framework and GIS function by considering the possibility of performing a link among various transport modes such as road, rail and waterways are possible. Comparative studies for HAZMAT transport can be made between inter modal transport and road transport. An impact can be quantified in a similar way with a framework presented in this research and will be beneficial in the future.

6.4 Final remarks

As a final remark, I would like to emphasize in the fact that the route planning framework is a decision support tools, it does not give a solution to the problem related with economic and safe transport of HAZMAT transport, but it simplifies the decision making process with the information generated by the integrated MCDA framework with GIS tool. Even more important is the fact that the framework deals with the integration of different factors and criteria that is complied with sustainability goal, which certainly contribute to perform the integrated economic, environmental and societal issues.

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APPENDICES

APPENDIX A
SCORING SYSTEM

Scoring System

Factors and sub-factors	Score				
	1	2	3	4	5
Economic					
Traffic density	0-200 Veh/hr	201-1000 veh/hr	1001-3000 Veh/hr	3001-5000 Veh/hr	> 5000 Veh/hr
Distance	shortest	0-5 km away	6-10 km away	11 – 15 km away	> 15 km away
Slope	0-5 %	5-15 %	15-25 %	25-35 %	>35 %
Environment					
Distance to water bodies	>2	1.5-2	1-1.5	0.5-1	0-0.5
Distance to conservation area	>2	1.5-2	1-1.5	0.5-1	0-0.5
Number of streams crossed	0-3	4-6	7-9	10-12	>12
Society (exposure)					
Population density	0-500 ppl/km^2	501-3000 ppl/km^2	3001-10000 ppl/km^2	10001-20000 ppl/km^2	> 20000 ppl/km^2
No. of schools	0-3	4-6	7-9	10-12	>12
No. of heritage & cultural place	0-3	4-6	7-9	10-12	>12
No. of petrol/gas station	0-1	2-3	4-5	6-7	>7
No. of hospital	0-1	2-3	4-5	6-7	>7
Society (safety)					
Proximity to police station	0-0.5	0.5-1	1-1.5	1.5-2	>2
Proximity to fire station	0-0.5	0.5-1	1-1.5	1.5-2	>2
Proximity to hospital	0-1.5	1.5-3	3-4.5	4.5-6	>6

APPENDIX B

VBA SCRIPT DEVELOPMENT

This visual basic application script is developed by author. A purpose of this script is to create a button on ArcGIS 9.2 and count a feature of interest within 0.8 km buffer for each road section. After counting a feature of interest, the script will automatically update that value to attribute table of road network. A script can immensely reduce a time consuming, especially a road networks that consists of many road sections

```
Private Sub UIButtonControl1_Click()
Test
UpdateSelectedFeatures
GetFeatureCount
End Sub

Sub Test()
Dim dDistance As Double
dDistance = 800

Dim pMxDoc As IMxDocument
Set pMxDoc = ThisDocument
Dim pBag As IGeometryBag
Set pBag = GetBuffers(pMxDoc.FocusMap.Layer(0), dDistance)
SpatiallyIndex pBag

Dim pSF As ISpatialFilter
'Dim pSpatialFeat As IFeature
Set pSF = New SpatialFilter
Set pSF.Geometry = pBag
pSF.SpatialRel = esriSpatialRelIntersects

Dim pFSel As IFeatureSelection
Set pFSel = pMxDoc.FocusMap.Layer(1)
pFSel.SelectFeatures pSF, esriSelectionResultNew, False
'
Dim pAV As IActiveView
Set pAV = pMxDoc.FocusMap
pAV.ScreenDisplay.Invalidate Nothing, True, _
```

```
pAV.ScreenCacheID(esriViewGeoSelection, Nothing)

End Sub

Sub SpatiallyIndex(pSI As ISpatialIndex)
pSI.AllowIndexing = True
pSI.Invalidate
End Sub

Function GetBuffers(pFLayer As IFeatureLayer, dDistance As Double) As IGeometryBag
Dim pMxDoc As IMxDocument
Set pMxDoc = Application.Document
Dim pGeomColl As IGeometryCollection
Set pGeomColl = New GeometryBag

Dim pFSelection As IFeatureSelection
Set pFSelection = pFLayer

Dim pFCur As IFeatureCursor

Dim pEnumFeature As IEnumFeature
Set pEnumFeature = pMxDoc.FocusMap.FeatureSelection

Dim pFeat As IFeature
Set pFeat = pEnumFeature.Next
Do Until pFeat Is Nothing
Dim pTopoOp As ITopologicalOperator
Set pTopoOp = pFeat.ShapeCopy
If TypeOf pFeat.Shape Is ITopologicalOperator2 Then
Simplify pTopoOp
End If
pGeomColl.AddGeometry pTopoOp.Buffer(dDistance)

Set pFeat = pEnumFeature.Next
Loop
Set GetBuffers = pGeomColl
```

```
End Function

Sub Simplify(pTopoOp As ITopologicalOperator2)
pTopoOp.IsKnownSimple = False
pTopoOp.Simplify
End Sub
Sub UpdateSelectedFeatures()

Dim pMxDoc As IMxDocument
Set pMxDoc = ThisDocument
Dim pMap As IMap
Set pMap = pMxDoc.FocusMap
Dim pActiveView As IActiveView
Set pActiveView = pMap
Dim pFLayer As IFeatureLayer
Dim pFeat As IFeature
Dim pCur As IFeatureCursor

'Select the parcels layer
Set pFLayer = pMap.Layer(0)

'Get a cursor from the selected features

Dim pFeatureSelection As IFeatureSelection
Dim pSelectionSet As ISelectionSet

Set pFeatureSelection = pFLayer
Set pSelectionSet = pFeatureSelection.SelectionSet
pSelectionSet.Search Nothing, False, pCur

Set pFeat = pCur.NextFeature

'Loop through the features using the cursor
Do While Not pFeat Is Nothing
pFeat.Value(pFeat.Fields.FindField("school")) = GetFeatureCount
pFeat.Store
```

```
Set pFeat = pCur.NextFeature
Loop

End Sub

Function GetFeatureCount() As Long
Dim pMxDoc As IMxDocument
   Set pMxDoc = ThisDocument
   Dim pMap As IMap
   Set pMap = pMxDoc.FocusMap
   Dim pLayer As IFeatureLayer
   Set pLayer = pMap.Layer(1)

   Dim pFS As IFeatureSelection
   Set pFS = pLayer

   GetFeatureCount = pFS.SelectionSet.Count
End Function
```

APPENDIX C
A STRUCTURE OF QUESTION FOR CRITERION WEIGHTING

Hazardous waste transportation interview form

A purpose of this interview form is to receive information from potential respondent for doing Ph.D. dissertation in the topic of "Appropriate road transportation for hazardous waste: A case study of Map Ta Phut Industrial Estate, Rayong Province, THAILAND". International Postgraduate Programs in Environmental Management (Hazardous Waste Management), Graduate school, Chulalongkorn University, THAILAND

1.General information

Name..

Position..

Organization..

Phone...

Date of interview..

Time...

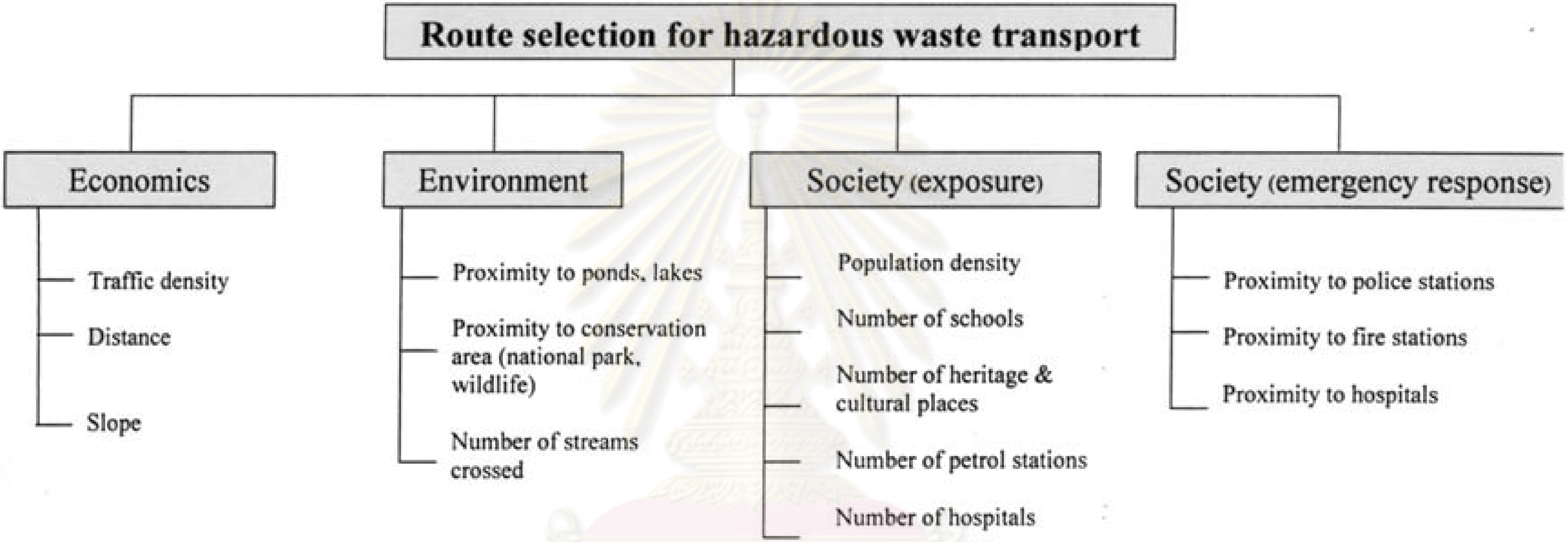

Figure 1 Hierarchy tree of route selection for hazardous waste transport problem

Sources Adapted from Federal Highway Administration (FHWA, 1994) และ Huang (2000)

<u>Scale of Preference between two elements (Saaty, 1980)</u>

Level of importance	Definition	Explanation
1	Equally preferred	Two activities contribute equally to the objective
2	Equally to moderately preferred	Represent compromise between scale 1 and 3
3	Moderately preferred	Experience and judgment slightly favor one activity over the other
4	Moderately to strongly preferred	Represent compromise between scale 3 and 5
5	Strongly preferred	Experience and judgment strongly or essentially favor one activity over the other
6	Strongly to very strongly preferred	Represent compromise between scale 5 and 7
7	Very strongly preferred	An activity is strongly favored over another and its dominance demonstrated in practice.
8	Very strongly to extremely preferred	Represent compromise between scale 7 and 9
9	Extremely preferred	The evidence favoring one activity over another is of the highest degree possible of affirmation
Reciprocals	Reciprocals for inverse comparison	

In the comparison table, if element in row has more important than element in column, a normal scale is then put in a cell. But if element in column has more important than element in row, a reciprocal of scale is then put in a cell

<u>Example</u> For economic consideration, a comparison has been made between traffic density and distance. If respondent viewpoint agrees that distance is more important than traffic density with a scale of preference 5. In this case, element in column (distance) is more important than element in row (traffic density). Then, respondent put a reciprocal of scale 1/5.

Consideration	Traffic density	Distance	Intersections	Slope	
Traffic density	1	1/5			

If respondent viewpoint agrees that traffic density (in row) is more important than distance (column) with a scale of preference 2. In this case, element in row (traffic density) is more important than element in column (distance). Then, respondent puts a normal scale 2.

Consideration	Traffic density	Distance	Intersections	Slope	
Traffic density	1	[illegible]			

1 = Same element has been met in a cell

X = Respondent has no need to put a scale of preference

<u>2. Pair-wise comparison</u>

2.1 Criteria level

2.1.1 Other Economics consideration

Consideration	Traffic density	Slope	
Traffic density	1		
Slope	x	1	

2.1.2 Environmental consideration

Consideration	Proximity to ponds, lakes	Proximity to conservation area (national park, wildlife area)	Number of stream crossed	
Proximity to ponds and lakes	**1**			
Proximity to conservation area (national parks, wildlife area)	**x**	**1**		
Number of stream crossed	**x**	**x**	**1**	

2.1.3 Society consideration (Exposure from incident)

Consideration	Population density	Number of schools	Number of heritage & cultural places	Number of petrol/gas stations	Number of hospitals	
Population density	1					
Number of schools	x	1				
Number of heritage & cultural places	x	x	1			
Number of petrol stations	x	x	x	1		
Number of hospitals	x	x	x	x	1	

2.1.4 Society (emergency response)

Consideration	Proximity to police stations	Proximity to fire stations	Proximity to hospitals	
Proximity to police stations	1			
Proximity to fire stations	x	1		
Proximity to hospitals	x	x	1	

2.2 Factor level

Consideration	Economics	Environment	Society (exposure from incident)	Society (emergency response)	
Economics	**1**				
Environment	**x**	**1**			
Society (exposure from incident)	**x**	**x**	**1**		
Society (emergency response)	**x**	**x**	**x**	**1**	

Thank you for your kind cooperative

APPENDIX D
IN-DEPTH INTERVIEW RESULT

A result of factors and criterion weighting derived by in-depth interview is summarized in table below

1. Summary table of position and workplace of respondents

Position	Government offices	No. of respondents
One scientist One engineer	Hazardous waste management division *Department of Industrial works (DIW)*	2
Two scientists	Disaster control division *Department of Disaster Prevention and Mitigation*	2
One Head of traffic information system One engineer	Highway safety division *Department of Highway (DOH)*	2
One Head of specialized and HAZMAT truck One engineer	Engineering and safety division *Department of Land Transport (DOL)*	2
One researcher	Hazardous materials and hazardous waste management division *Pollution Control Department (PCD)*	1
One Director of safety and occupational health division Two scientists	Safety and occupational health division *Industrial Estate Authority of Thailand (IEAT)*	3

2. Two respondents from Department of Highway (DOH)

Factors/Criteria	Respondent 1 weight	Respondent 2 weight
Factors		
Economic	0.040	0.120
Environment	0.113	0.073
Societal (exposure)	0.392	0.265
Societal (emergency response)	0.453	0.541
Consistency ratio (CR)	**0.077**	**0.078**
Criteria		
Traffic density	0.8	0.75
Road slope	0.2	0.25
Consistency ratio (CR)	**0.054**	**0.058**
Proximity to police stations	0.093	0.104
Proximity to fire stations	0.279	0.258
Proximity to hospitals	0.626	0.636
Consistency ratio (CR)	**0.072**	**0.03**
No. of schools	0.076	0.25
No. of petrol stations	0.060	0.10
No. of heritage & cultural places	0.072	0.05
No. of hospitals	0.205	0.12
Population density	0.584	0.42
Consistency ratio (CR)	**0.066**	**0.085**
Proximity to ponds/lakes	0.171	0.77
Proximity to conservation areas	0.750	0.08
No. of river crossed	0.078	0.139
Consistency ratio (CR)	**0.084**	**0.044**

3. Two respondents from Department of Disaster Prevention and Mitigation, Ministry of Interior

Factors/Criteria	Respondent 1 weight	Respondent 2 weight
Factors		
Economic	0.043	0.033
Environment	0.198	0.162
Societal (exposure)	0.354	0.371
Societal (emergency response)	0.403	0.487
Consistency ratio (CR)	**0.043**	**0.088**
Criteria		
Traffic density	0.5	0.875
Road slope	0.5	0.125
Consistency ratio (CR)	**0.050**	**0.069**
Proximity to police stations	0.353	0.054
Proximity to fire stations	0.586	0.655
Proximity to hospitals	0.060	0.289
Consistency ratio (CR)	**0.029**	**0.068**
No. of schools	0.119	0.045
No. of petrol stations	0.038	0.070
No. of heritage & cultural places	0.086	0.041
No. of hospitals	0.438	0.210
Population density	0.317	0.631
Consistency ratio (CR)	**0.071**	**0.079**
Proximity to ponds/lakes	0.458	0.069
Proximity to conservation areas	0.062	0.348
No. of river crossed	0.479	0.582
Consistency ratio (CR)	**0.0017**	**0.027**

4. One respondent from Pollution Control Department (PCD)

Factors/Criteria	**Respondent 1 weight**
Factors	
Economic	0.036
Environment	0.27
Societal (exposure)	0.374
Societal (emergency response)	0.317
Consistency ratio (CR)	**0.022**
Criteria	
Traffic density	0.833
Road slope	0.166
Consistency ratio (CR)	**0.074**
Proximity to police stations	0.4
Proximity to fire stations	0.4
Proximity to hospitals	0.2
Consistency ratio (CR)	**0.0015**
No. of schools	0.076
No. of petrol stations	0.229
No. of heritage & cultural places	0.063
No. of hospitals	0.253
Population density	0.376
Consistency ratio (CR)	**0.064**
Proximity to ponds/lakes	0.773
Proximity to conservation areas	0.139
No. of river crossed	0.087
Consistency ratio (CR)	**0.044**

5. Two respondents from Department of Land Transport (DOL)

Factors/Criteria	Respondent 1 weight	Respondent 2 weight
Factors		
Economic	0.719	0.039
Environment	0.059	0.124
Societal (exposure)	0.080	0.427
Societal (emergency response)	0.140	0.409
Consistency ratio (CR)	**0.066**	**0.086**
Criteria		
Traffic density	0.875	0.75
Road slope	0.125	0.25
Consistency ratio (CR)	**0.069**	**0.058**
Proximity to police stations	0.131	0.065
Proximity to fire stations	0.792	0.573
Proximity to hospitals	0.076	0.361
Consistency ratio (CR)	**0.017**	**0.044**
No. of schools	0.233	0.069
No. of petrol stations	0.121	0.037
No. of heritage & cultural places	0.158	0.078
No. of hospitals	0.062	0.219
Population density	0.421	0.594
Consistency ratio (CR)	**0.08**	**0.091**
Proximity to ponds/lakes	0.366	0.704
Proximity to conservation areas	0.497	0.084
No. of river crossed	0.135	0.210
Consistency ratio (CR)	**0.081**	**0.027**

6. Two respondents from Department of Industrial works

Factors/Criteria	Respondent 1 weight	Respondent 2 weight
Factors		
Economic	0.118	0.041
Environment	0.349	0.322
Societal (exposure)	0.043	0.322
Societal (emergency response)	0.488	0.312
Consistency ratio (CR)	**0.098**	**0.0082**
Criteria		
Traffic density	0.857	0.9
Road slope	0.142	0.1
Consistency ratio (CR)	**0.051**	**0.072**
Proximity to police stations	0.745	0.058
Proximity to fire stations	0.156	0.278
Proximity to hospitals	0.098	0.663
Consistency ratio (CR)	**0.044**	**0.044**
No. of schools	0.267	0.308
No. of petrol stations	0.037	0.024
No. of heritage & cultural places	0.194	0.068
No. of hospitals	0.420	0.265
Population density	0.079	0.332
Consistency ratio (CR)	**0.095**	**0.099**
Proximity to ponds/lakes	0.156	0.242
Proximity to conservation areas	0.745	0.056
No. of river crossed	0.098	0.702
Consistency ratio (CR)	**0.044**	**0.091**

7. Three respondents from Industrial Estate Authority of Thailand (IEAT)

Factors/Criteria	**Respondent 1 weight**	**Respondent 2 weight**	**Respondent 3 weight**
Factors			
Economic	0.137	0.196	0.123
Environment	0.113	0.065	0.140
Societal (exposure)	0.410	0.186	0.414
Societal (emergency response)	0.339	0.551	0.320
Consistency ratio (CR)	**0.055**	**0.099**	**0.043**
Criteria			
Traffic density	0.666	0.875	0.8
Road slope	0.333	0.125	0.2
Consistency ratio (CR)	**0.052**	**0.069**	**0.054**
Proximity to police stations	0.109	0.125	0.093
Proximity to fire stations	0.581	0.795	0.626
Proximity to hospitals	0.308	0.078	0.279
Consistency ratio (CR)	**0.0031**	**0.044**	**0.072**
No. of schools	0.252	0.054	0.175
No. of petrol stations	0.052	0.114	0.068
No. of heritage & cultural places	0.087	0.041	0.059
No. of hospitals	0.208	0.573	0.170
Population density	0.398	0.215	0.526
Consistency ratio (CR)	**0.0059**	**0.076**	**0.065**
Proximity to ponds/lakes	0.416	0.35	0.285
Proximity to conservation areas	0.457	0.58	0.062
No. of river crossed	0.126	0.06	0.652
Consistency ratio (CR)	**0.0079**	**0.030**	**0.062**

8. Summary table of the weight (criteria level) derived by experts

Consideration (criteria level)	Multiple weight
Proximity to police stations	0.172
Proximity to fire stations	***0.542***
Proximity to hospitals	0.285
No. of schools	0.226
No. of petrol stations	0.067
No. of heritage and cultural places	0.092
No. of hospitals	0.253
Population density	***0.361***
Proximity to ponds/lakes	***0.388***
Proximity to conservation areas	0.333
No. of river crossed	0.278
Traffic density	***0.916***
Slope	0.084

9. Summary table of the weight (factors level) derived by experts

Consideration (factors level)	Multiple weight
Economics	0.112
Environment	0.140
Societal (exposure)	***0.409***
Societal (emergency response)	0.338

BIOGRAPHY

Sathaporn Monprapussorn was born in Bangkok, Thailand on November 4, 1975. He received his Bachelor of Science (Biology) from Mahidol University in 1996. He graduated with Master of Science (Environmental science) from Chulalongkorn University in 1999. He worked as Researcher at Thammasat Unversity during 2000 – 2002. He begins his Ph.D. study in November 2003