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Multi Criteria Decision Analysis and Geographic Information System Framework for Hazardous Waste Transport Sustainability

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Abstract: This study introduces a combination of Multi Criteria Decision Analysis (MCDA) and Geographic Information System (GIS) approaches to the hazardous waste transport problem. There are risks associated with a truck being involved in an accident during shipment of hazardous materials (HAZMAT) and/or hazardous wastes. The level of impact posed to surroundings depends on many factors such as population density, No. of sensitive locations, proximity to rescue units and security. It is essential that all of the related factors and criteria involved be considered prior to making decisions about route selection. Certain routing criteria and standards for HAZMAT transport have been developed in many developed countries such as the United States, Canada and European countries with the purpose of risk avoidance during shipment of these materials. However, a lack of a comprehensive framework for the selection of HAZMAT and/or hazardous waste routes that the transporter can use for aiding their decisions is a major concern in most developing countries. The purpose of this study is to develop a framework for making optimum hazardous waste transport routing choices by incorporating multiple factors and sub-factors. Factors and sub-factors are divided into three main categories; economic, environmental and societal (exposure and emergency response) issues that are in line with the sustainability paradigm. The proposed framework can contribute to the thought processes of governmental policy-makers and carriers when they evaluate possible routes and are making their decision in order to minimize damage from transporting hazardous waste.

Key words: Risk analysis, hazardous material transport, multi-criteria decision making, route planning

INTRODUCTION

Recent evidence has shown a rising need for HAZMAT in Thailand. From statistics of the Pollution Control Department (PCD), the total import amount of HAZMAT has increased from 3.11 to 5.22 million tonnes, while the total amount of HAZMAT production within the country has also increased from 9.80 to 28.81 million tonnes during the years 1998-2005. The three highest imported hazardous materials include: flammable liquids (82.08%), flammable gases (15.49%) and corrosive substances (1.28%) (Survey and Study on Transport Routs for Dangerous Goods, 2004). The increasing level of industrial production strongly correlates with an increasing amount of hazardous waste. The Pollution Control Department (PCD) estimated that hazardous waste generation quantities in Thailand have increased from 1.38 to 1.81 million tonnes during the years 1998-2005 and more than 70% of that is produced by industrial sectors. From a report by PCD in 2006, only 276,687 tonnes or approximately 20% of the industrial hazardous waste is sent to disposal sites (not including reuse or recycle at the production site itself). Approximately 70% of the total treated amount of hazardous waste has been directed to incinerator plants, which are operated by cement factories, to serve as raw materials for fuel blending.

Laws and regulations on the use and handling of hazardous materials may differ depending on the activity and status of the material. 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 countries like United States have issued routing criteria for HAZMAT transport and have considered multiple factors in the route designation process.

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Unfortunately, a lack of a comprehensive standard and/or framework for route selection of HAZMAT and/or hazardous wastes that a transporter can use for aiding in their decisions is a major problem in most developing countries.

In Thailand, a comprehensive legal framework exists to control HAZMAT related operations in fixed installation facilities. Moreover, Thailand currently is applying a system based on self-declaration so that every party concerned follows the official rules by filing documents stating the hazardous waste origin and destination-an approach also known as a hazardous waste manifest system. There are no clear national Thai standards that can be used as a guideline for route selection of HAZMAT and/or hazardous wastes transport. Only a few laws and regulations have been released from various government agencies such as a restriction on HAZMAT and/or hazardous waste truck routing within the urban area of the Bangkok Metropolitan Area (BMA) during daytime and on some certain express ways. It is clear that there is still a lack of framework that deals with multiple factors thinking when considering all of the related factors and criteria for route selection of hazardous waste in Thailand.

Although the scale of HAZMAT and/or hazardous waste transportation is still limited, the risks to nature and the human environment associated with such transport are quite enormous. Because accidents usually result in some form of inconvenience at the very least, or worse in injury or death, public concern has started to rise on how and when these shipments are planned and routed through specific geographical areas. The main issue is derived 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 the accident itself (Fabiano *et al*., 2005). The degree of the problem reflects various factors involved such as the population density, the number of sensitive places such as elementary schools potentially affected, the proximity to sensitive environmental areas and to rescue units. However, it is rare for a carrier to consider all of the related factors and criteria when planning and selecting a shipment route for HAZMAT and/or hazardous wastes in real situations. A few critical factors and criteria are generally chosen and reasonable routes are planned.

A typical risk factor framework tries to minimize probability of any type of incident and/or the total exposure of populations to toxic chemical substances from any HAZMAT transport incidents (Kara *et al*., 2003). Some research has suggested that using maximum population exposure at any point along a route is the best way to reduce the risk from a catastrophic incident (Erkut and Ingolfsson, 2000). Others have been concerned about avoidance of catastrophes when considering new security factors such as the risk of HAZMAT being used as a weapon of mass destruction by terrorists (Huang *et al*., 2004). When considering catastrophic events, it is often most useful to examine a potential risk to the population by evaluating the airborne emission pathway. It is very crucial to model the dispersion plume and the probability of an undesirable consequence as a function of the contaminant concentration (Zhang *et al*., 2000). Many researchers have also tried to provide an accurate estimate of the impact to exposed populations by modeling the dispersion of the toxic gas plume for emergency preparedness (Jarup, 2001; Abkowitz, 1993). Consideration of the potential broader impact of hazardous wastes transport to groundwater vulnerability has been proposed in the UK by using risk assessment and a GIS method (Lovett *et al*., 1997).

Another critical aspect is how to develop a methodology to analyze and solve HAZMAT and/or hazardous waste transport problems. The typical route determination method applies the shortest path problem or Dijkstra's algorithm that is widely used in route selection for much transportation research. However, other risk analysis methodologies for HAZMAT and/or hazardous waste transport have been proposed subsequently. Optimization techniques have been used often for HAZMAT transport problem in the literature to find the best route within a set of constraints (Kara *et al*., 2003; Erkut and Ingolfsson, 2000). A main purpose of optimization techniques is to try to minimize the risk posed to a population and to maximize the profit for the operation in terms of the shortest path and/or the shortest time for the transport operation. This technique is based on a Multi Objectives Decision Making (MODM) approach with large alternative sets (linear programming based) within the problem. Multi-objective Linear Programming (MOLP) and Goal Programming (GP) are examples of the techniques that have been used often in HAZMAT transport research. Multi attribute decision making (MADM) is another approach based on finite sets of alternatives. This technique has been applied to HAZMAT transport planning in Singapore by using the Analytical Hierarchy Process (AHP) to specify weights for route selection (Huang *et al*., 2004). While a similar idea in the United States has proposed the use of a GIS function for risk assessment methodology by determining a score from related factors and criteria for routing hazardous material transport such as locations of schools, hospitals, police stations and fire stations (Schubert, 2005).

The purpose of this study is to develop a framework for choosing optimum routes for hazardous waste transport through the combination of Multi Criteria Decision Analysis (MCDA) and Geographic Information System (GIS) approaches by incorporating multiple factors and criteria considerations that align with the sustainability paradigm-economic, environmental and societal (exposure and emergency response) issues. The proposed framework can contribute to the thought processes of governmental policy-makers and of carriers when attempting to evaluate alternative routes and to make their decisions that minimize the impact from an incident during transportation of hazardous waste.

MATERIALS AND METHODS

A framework for hazardous waste transport: It is crucial that the development of a framework must be flexible enough to incorporate multiple factors. Multi Criteria Decision Analysis (MCDA) can serve as an effective tool to create a framework for HAZMAT and/or hazardous waste transport with the following advantages: (1) it provides a formal and often quantitative, approach, (2) it responds to the presence of multiple factors and/or criteria and (3) it facilitates decision making by either individuals or groups. However, transporting HAZMAT and/or hazardous waste always is influenced by many factors and criteria that relate to the location structure such as distance, proximity of emergency response units, sensitive places and highway slope or grade. It is clear that these kinds of data must be linked to spatial maps (roads, rivers, boundaries, agricultural lands and landmarks). The link between spatial and non-spatial data and the analysis capability can be effectively handled by a Geographic Information System (GIS). To develop a HAZMAT and/or hazardous waste transport framework, the consideration of multiple factors and criteria should be mandated and incorporated into all stages of the routing decision making process through the application of combinations of Multi Criteria Decision Analysis (MCDA) and Geographic Information System (GIS).

Geographic information system: A Geographic Information System (GIS) is a geo database system that uses computers to collect, store, manipulate, analyze and display geographic information as depicted in Fig. 1. GIS technology integrates common database operations such as query and statistical analysis with unique visualization and geographic analysis capabilities. These functions 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 resource 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 and heritage sites), population density, intersections, traffic density and locations of emergency response units (hospitals, police stations and fire stations) and identifying alternatives routes for hazardous waste transport purpose.

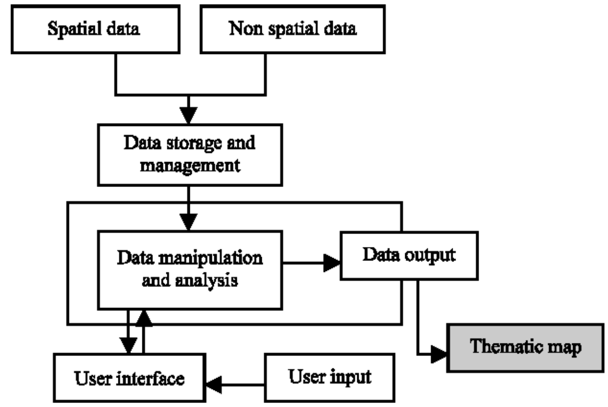

Fig. 1: Structure of a GIS

A major aim of the GIS application is to support comprehensive decision making. GIS models help in quantifying the risk and provide better accuracy in analyzing a risk when dealing with many of parameters. A GIS-based approach can perform an accurate and fast transportation risk analysis for road and rail transport of dangerous goods, as well as for their combination (so-called intermodal transport), giving rise to a tool capable of performing all the steps from initial route selection to final risk assessment (Bubbico *et al*., 2004). GIS can play a major role at the initial stage of the development of HAZMAT and/or hazardous wastes transport decision making approaches by storing and manipulating large amounts of spatial and nonspatial data and can easily perform the analysis task during transportation analysis. However, GIS can be utilized further as a tool for real time vehicle routing by linking real time data with a global positioning system (GPS). It can provide planning capability based on real time data such as the linkage of GPS and GIS to real time vehicle routing.

However, real time vehicle routing requires a high level of data accuracy and this need may raise many obstacles for the application of the approach in developing countries.

Multi Criteria Decision Analysis (MCDA): Multi-criteria Decision Analysis (MCDA), involves a set of alternatives that are evaluated on the basis of conflicting and incommensurate criteria. Criterion is considered a generic term that includes both the concepts of attribute and objective, MCDA is both an approach and a set of techniques, with the goal of providing an overall ordering of options, from the most preferred to the least preferred option. The options may differ due to the extent and differences of objectives and not a single option will be able to achieve all objectives. In addition, some conflict or trade-off is usually evident amongst the objectives (Monprapussorn *et al*., 2007). There are 8 significant stages in MCDA; (1) Establish the decision context: (2) Identify the options to be appraised: (3) Identify objectives, factors and criteria: (4) Scoring for the assessment of the expected performance of each option against the criteria and then assess the value associated with the consequences of each option for each criterion: (5) Weighting by assigning weights for each of the criterion to reflect their relative importance to the decision: (6) Combine the weights and scores for each option to derive an overall value.: (7) Examine the results and (8) Conduct a sensitivity analysis.

Multi Criteria Decision Analysis (MCDA) is capable of handling and managing the HAZMAT and/or hazardous waste transport problem, especially in performing an analysis based on multiple factors and criteria. There are two general types of analysis in MCDA; prescriptive and evaluation of a past decision. Prescriptive analysis involves multi criteria scoring that can be separated by following 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 problem with large alternative sets. In this study, using MCDA through AHP based on multi attribute decision analysis has been used because finite sets of selected routes between origins and destination points for HAZMAT and/or hazardous wastes transport have been applied.

Risk factors framework: In 1987 the Brundtland 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, environmental and social perspectives should be developed simultaneously as much as possible to ensure a sustainable future. Therefore, consideration of economic, environmental and societal factors plays a vital role in developing sustainable HAZMAT and/or hazardous waste transport routes.

The economic issues for HAZMAT and/or hazardous waste transport are concerned largely with how to provide least cost of transport. Distance plays a key role because if a HAZMAT truck travels a shorter distance, it means lower fuel consumption. A high traffic density leads to a longer travel time and therefore increasing freight cost. Slope or grade considerations may affect the potential severity of an accident and then lead to higher cost (FHWA, 1994). A higher number of signalized intersections translates to a longer time taken for the journey and hence, higher cost (Huang *et al*., 2004).

To deal with environmental issues, consideration should be given to sensitive environmental places that could be affected by a HAZMAT truck incident. The proximity of the routes to particular types of locations such as ponds and/or lakes, natural 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 (Briggs *et al*., 2002).

There are two main societal issues related to HAZMAT transport. One issue is concerned with the exposure of the population to hazardous substances in case a HAZMAT truck is involved in an accident. Population density, schools and hospitals are then seen as special population issues and should be considered when determining the potential risk to population along a highway routing (FHWA, 1994). Petrol and/or gas stations can be affected by flammable substances and can stimulate a greater consequence to nearby populations. Another issue involves emergency response by considering the maximum response capacity of available rescue units. The proximity of the routes to a particular emergency response location or links to a fire station 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)

MCDA considers multiple factors and sub-factors involved in the HAZMAT and/or hazardous wastes transportation problem. It can determine the relative weight of factors and sub-factors. In this research, factors and sub-factors are categorized in line with the

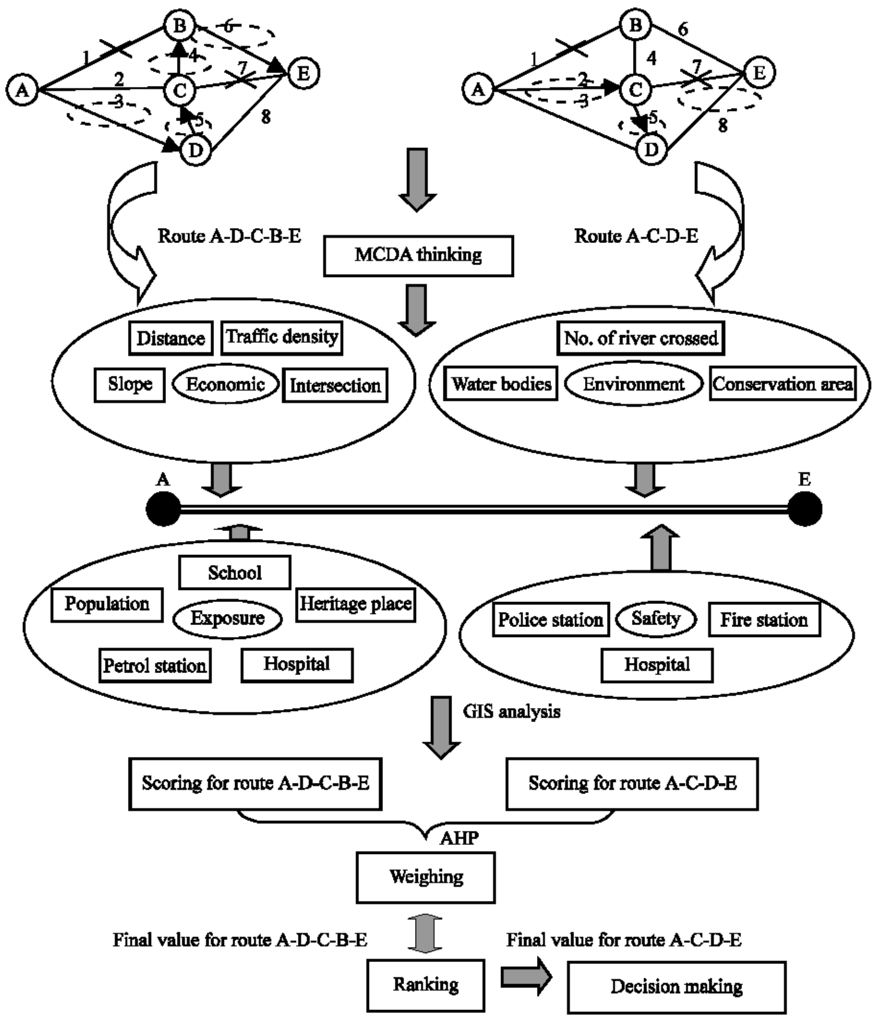

Fig. 2: Proposed framework for the integration of GIS and MCDA for hazardous waste transport problem

Table 1: Factors and sub-factors for hazardous waste transport

Economic	Environment	Society (exposure)	Society (emergency response)
Distance	Distance to ponds and/or lakes	Population density	Proximity to police stations
Traffic density	Distance to national park, wildlife area	Proximity to school	Proximity to fire stations
No. of intersection	No. of river crossed	Proximity to heritage and cultural place	Proximity to hospitals
Slope		No. of petrol and/or gas stations	
		Proximity to hospital	

sustainability paradigm that takes economic, environmental exposure and emergency response issues into consideration as shown in Table 1. Several GIS functions are utilized to calculate spatially and to derive a score for each link of the road network. It is important to note that weighting process is a very crucial step for HAZMAT and/or hazardous waste transport decision making. This task should be participated in by potential stakeholders or experts. The government and/or policy-makers and waste management businesses are currently viewed as two major stakeholders that influence HAZMAT and/or hazardous waste transport decision making in Thailand.

A proposed framework for the integration of GIS and MCDA for addressing the hazardous waste transport problem is depicted in Fig. 2.

As shown in Fig. 2, there are many arcs and nodes between the origin and the destination point (A to E). The arc or link is represented by a line between two nodes, while some nodes can be connected with more than one arc. Some routes might be restricted for truck transport such as roads with loose surfaces and/or road that route through an urban area such as arc No. 1 and 7 in Fig. 2 and will be not included in the analysis. The analysis framework is to identify first a number of alternative routes between Origin-Destination pair (OD) and then to incorporate GIS and MCDA analysis to derive a score for each link. Finally, a final score for each link is then obtained by a linear additive weighting method.

The first task is to identify the alternative routes between the OD pair and to calculate the score for each link. There are two different approaches for determining routes. One can be done by using an algorithm, which would be appropriate for an infinite set of alternative routes such as a large scale road network. The other approach can be done through the selection of a finite set of alternative routes between the OD pair, which can be conducted by using statistical or survey data. The latter approach has been used in this research. For the example, two alternative routes between the OD pair have been selected, i.e., such as route No. 3-5-4-6 and route No. 2-5-8. To identify a relative priority between the two routes, a score for each link will be calculated first by GIS. A final score is simply derived by multiplying the score for each of arc No. 3, 5, 4 and 6 and arc No. 2, 5 and 8 with the weight and then conducting a linear additive method. As a result, a final score for both alternative routes can be computed and compared.

To derive risk factors and sub-factors for each link, a scoring system was adapted from Federal Highway Administration (FHWA), (1994) and Huang *et al.* (2004) that is provided in Table 3 and weights are derived by AHP as described in more detail in the next section. Each link is evaluated based on multiple factors taking economic, environmental and social factors into consideration; some factors will be added to the environmental category such as number of streams crossed, distance to heritage and cultural places as mentioned earlier in Table 1. After the calculation of the final score for all possible links between the OD pair, a ranking decision can be made by decision makers.

The proposed framework in Fig. 2 explores an integration of GIS and MCDA to address the hazardous waste transport problem. A critical aspect of this framework is to link and combine different tools to more efficiently handle and solve the problem.

Data preparation: To prepare the data for using in the analysis, all required data files were requested and/or downloaded from various government agencies such as Ministry of Transport (MOT), Department of Environmental Quality Promotion (DEQP), Department of Land Development (DLD) and Ministry of Interior (MOI) in year 2007. Data was then converted, if necessary, to shape files platform for use with ArcGIS. The initial size of the network (more than 20000 distinct road sections) was further reduced by eliminating minor roads, except in the vicinity of producer or disposal sites, to approximately 5000 segments. Spatial and non-spatial data that will be used in this study are categorized by following factors and sub-factors that are determined in accordance with the sustainability paradigm as mentioned earlier in Table 1.

Conceptual framework definition: The scoring system for factors and sub-factors was adapted from a system by FHWA (1994) and Huang *et al.* (2004). The scoring system for factors is shown in Table 3. In order to combine a score into a meaningful entity, weights must be assigned to the factors and sub-factors. Therefore, AHP was used to determine their weights. Developing priorities can be conducted by AHP based on a pair-wise comparison method. The advantage of the pair-wise comparison method when making a comparison with other criterion weight methods (Malczewski, 1999) is shown in Table 2.

Table 2: Summary of method for assessing criterion weight

	Method			
Feature	Ranking	Rating	Pairwise comparison	Trade-off analysis
No. 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)

Table 3: Scoring system (adapted from FHWA, 1994 and Huang *et al.*, 2004)

	Score				
Factors and sub-factors	1	2	3	4	5
Economic					
Traffic density	0-200 veh h^{-1}	201-1000 veh h^{-1}	1001-3000 Veh h^{-1}	3001-5000 Veh h^{-1}	> 5000 Veh h^{-1}
Distance	shortest	0-10 km away	11-20 km away	21 – 30 km away	> 30 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
No. 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 and 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

To judge a weight of factors and sub-factors, the final value (Ri) is calculated following with below equation:

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

Where:

- R_i = The overall value of ith alternatives
- c = Criteria
- n_c = No. of criteria c
- W_c = Weight of criteria c
- n_{cf} = No. of factors under criteria c
- W_{cf} = Weight of factors
- S_{cf} = Score of factors

A conceptual framework was developed using the ESRI ArcGIS 9. That system offers the analytical potential for database storage and manipulation, including spatial and network analysis function. Spatial and attribute data gathering from various sources has been put into the GIS database management system such as geo database or network dataset for the purpose of furthering the analysis task.

RESULTS AND DISCUSSION

A case study: There are many heavy industries such as petrochemical, plastic, pulp and study manufacturers located in the area of Rayong Province. From a total amount of 1,558,743 tonnes of hazardous waste in the country, the eastern part of Thailand generated 1,092,672 tonnes (70% of the total amount of hazardous waste), while Rayong province is responsible for 618,115 tonnes (40% of the country's hazardous waste and 57% of the eastern region's hazardous waste). A road network used for the case study is shown in Fig. 3.

As mentioned earlier, a possible route is then evaluated using each scenario factor set; economic, environmental and societal (exposure and emergency response). The most preferred alternative is selected by identifying the one with the minimum value of R_i. The picture below shows the example in a case where truck operators have three alternative routes from Map Ta Phut Industrial estate, Rayong province, to one incinerator plants that are located in Banmhor District, Saraburi province. Routing is designated to be on highway roads. route 1 is routed from highway No. 36 to highway No. 7 and to highway No. 3 (by pass) and meet with highway 3 again while route 2 continue to route on highway No. 36 until the end and it changes the direction to route on highway No. 3 and so on. In contrast with route 1 and route 2, route 3 is totally different in direction as shown in Fig. 4. A route that is normally used by trucks is route 1 (Fig. 4) because it is the shortest route.

For three alternative routes, weighting of factors and sub-factors has been assumed to be equal for a simple demonstration reason (i.e., weighting 0.20 in each of five sub-factors under exposure factor and weighting 0.25 in economic, environmental, societal (exposure) and societal (emergency response) factors). After the calculation of score and weight following equation (1), the total scores (R_i) of route 1, route 2 and route 3 are 9.860, 10.066 and 9.057, respectively. A smaller final value indicates a proper route for transporting HAZMAT and/or hazardous waste when taking all factors and sub-factors into consideration. It implies that transporting hazardous waste on route 3 is more suitable than route 1 and route 2, respectively because it provides the least final value (R_i). A final value

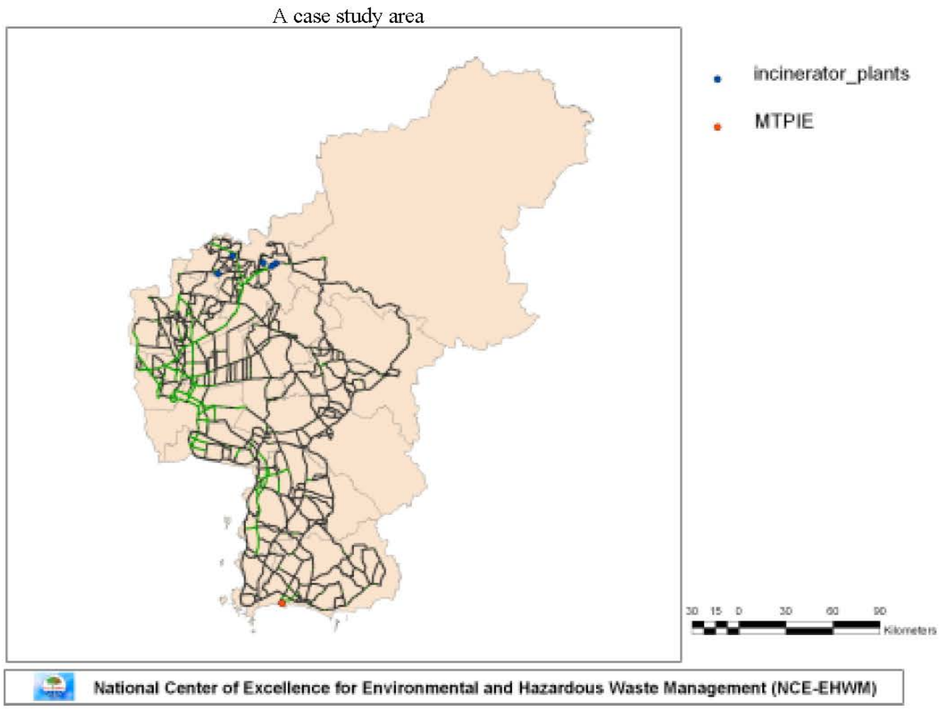

Fig. 3: The origin (MTPIE)-destination (Incinerator plants) study area for the hazardous waste transport problem

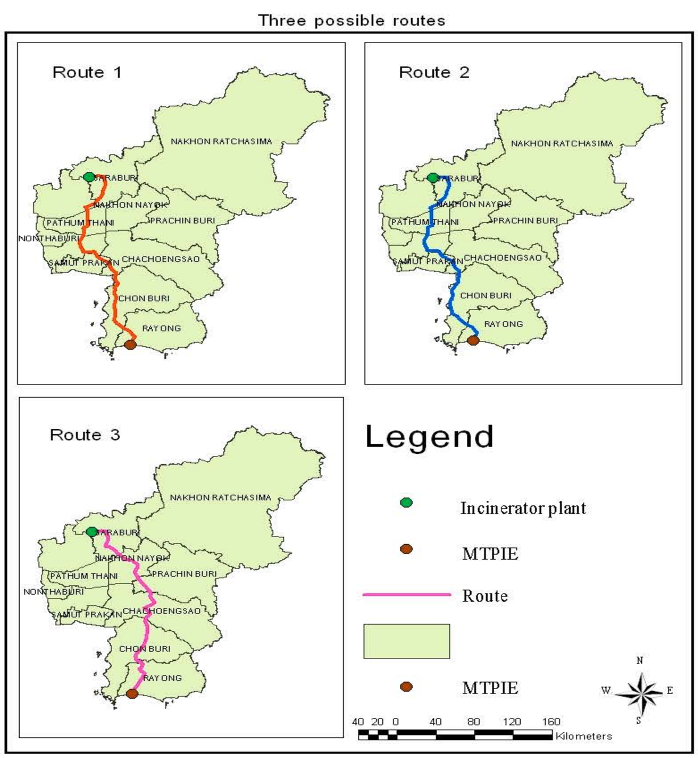

Fig. 4: Comparative studies of three alternative paths from origin to destination

can be used as an indicator to the treat effect in term of economic, environmental and societal consideration if the HAZMAT and/or hazardous waste trucks involve an accident during its shipment.

Focusing on the sustainability issue is a vital contribution to the reformulation of the ideas included in the traditional decision making process for HAZMAT and/or hazardous waste transport. Sustainability is widely accepted as a practice of development that creates a balance between economics, environmental and societal concerns. In order to move toward sustainable HAZMAT and/or hazardous waste transport, consideration of factors and sub-factors in line with economic, environmental and societal priorities should be incorporated into every step of the decision making process.

A proposed analytical framework can be very useful for the planning task of HAZMAT and/or hazardous waste transport based on the incorporation of multiple factors and sub-factors, especially environmental and societal factors and sub-factors that are rarely taken into consideration in most previous studies. A framework can provide the reasonable results that can assist decision maker to plan and to select an appropriate route with a comprehensive approach. This proposed framework can be brought forward as a base for policy makers to move their current practices of decision making toward sustainable hazardous waste transport.

CONCLUSION

One of the primary goals of this study was to assess and to create a framework for hazardous waste transport based on consideration of multiple factors and sub-factors. By the combination of Multi Criteria Decision Analysis (MCDA) and a Geographic Information System (GIS), a conceptual framework for hazardous waste transport has been formulated using Thailand as a case study. The integration of MCDA and GIS methodologies can provide a quantitative approach to solve and manage complex hazardous waste transport problems.

A shortest-route model alone is not capable of dealing with the broader problems of HAZMAT and/or hazardous waste transport. Routings with the shortest path may involve moving through urban areas thereby posing a greater risk to nearby populations resulting in a disaster with serious consequences. It is very crucial to realize that least cost decisions based on the shortest route is not sufficient. In this research, a consideration of incorporating environmental and societal factors (in terms of exposure and emergency response) has been conducted through adding sub-factors and has been analyzed by MCDA. It must be of significant concern to decision making framework that decision making based on this framework can make a contribution in terms of risk prevention and can be used as a guideline to strengthen relevant HAZMAT laws and regulations. Above all, the proposed framework can contribute to the decision-making processes for HAZMAT and/or hazardous waste transporters in accordance with the key goal of sustainability, which is aimed at balancing the economic, environmental and societal dimensions for the benefit of the sustainable future.

REFERENCES

Abkowitz, M., 1993. Working Together to Build a Safer Future. In: Transportation of Hazardous Materials: Issues in Law Social Science and Engineering, Moses, L.N. and D. Lindstrom (Eds.). Kluwer Academic Publishers, Kluwer, ISBN: 9780792393405, pp: 85-101.

Briggs, D.J., Forer, P. L. Jarup and R. Stern, 2002. GIS for Emergency Preparedness and Health Risk Reduction. 1st Edn., Kluwer Academic Publishers, Kluwer, ISBN: 101402007981.

Bubbico, R., S.D. Cave and B. Mazzarotta, 2004. Risk analysis for road and rail transport of hazardous materials: A GIS approach. J. Loss Prevention Process Indus., 17: 483-488.

Erkut, E. and A. Ingolfsson, 2000. Catastrophe avoidance models for hazardous materials route planning. Transportation Sci., 34: 165-179.

Fabiano, B., F. Curro, A.P. Reveberi and R. Pastorino, 2005. Dangerous goods transportation by road: From risk analysis to emergency planning. J. Loss Prevention Process Indus., 18: 403-413.

FHWA, 1994. Guidelines for applying criteria to designated routes for transporting hazardous materials. Report FHWA- SA-94-083. Federal Highway Administrations, United States of America.

Jarup, L., 2001. The Role of Geographical Studies in Risk Assessment. In: Spatial Epidemiology: Methods and Applications, Elliott, P., J.C. Wakefield, N.G. Best and D.J. Briggs (Eds.). Oxford University Press, Oxford, pp: 415-433.

Kara, B.Y., E. Erkut and V. Verter, 2003. Accurate calculation of hazardous materials transport risks. Operations Res. Lett., 31: 285-292.

Lovett, A.A., J.P. Parfitt and J.S. Brainard, 1997. Using GIS in risk analysis: A case study of hazardous waste transport. Int. J. Geographical Inform. Syst., 10: 831-849.

Malczewski, J., 1999. GIS and Multicriteria Decision Making. 1st Edn., John Wiley and Sons, Inc., Wiley, ISBN: 0-471-32944-4.

Monprapussorn, S., D.J. Watts, D. Thaitakoo and R. Banomyong, 2007. Sustainable hazardous waste transport: Multi criteria decision making and geographic information system approach. Proceeding of SECOTOX Conference and the Int. Conf. on Environ. Management, Engin., Planning and Economic, June 24-28, Skiathos Island, Greece, pp: 2127-2132.

Panwhar, S.T., R. Pitt and M.D. Anderson, 2000. Development of a GIS-based hazardous materials transportation management system. UTCA Report 99244, A publication of the University Transportation Center for Alabama, Tuscaloosa, Alabama.

Schubert, J., 2005. Routing hazardous material shipments: A risk assessment methodology. M.Sc Thesis, University of Texas at Dallas, United States.

Survey and Study on Transport Routes for Dangerous Goods, 2004. Office of Permanent Secretary. Ministry of Transport, Thailand.

Zhang, J., J. Hodgson and E. Erkut, 2000. Using GIS to assess the risks of hazardous materials transport in networks. Eur. J. Operat. Res., 121: 316-329.