Sustainable Hazardous Waste Transport: Multi Criteria Decision Making and Geographic Information System approach.

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Abstract

The transport of chemical waste from industrial site to disposal site is an aspect of the waste life cycle, which is composed of production, storage, transport and recycling or final disposal activities. Traditionally, majority of waste life cycle researches were focus on locating treatment and disp osal facilities and limited attention has paid to risk during transport phase. An accident during waste transport can cause relatively high impact to stakeholders involve; government, businesses and society in term of risk posed by the toxic nature of hazardous waste. Building a comprehensive decision making framework is therefore a main goal of hazardous waste transport problem. The concept of sustainability can broader a goal of hazardous waste transport that economic should not be solely considered as a major factor in hazardous waste transport, social welfare in term of safety of and environmental risk should be concerned and incorporated into every stages of decision making process. Currently, Thailand does not have a comprehensive framework for sustain able hazardous waste transport. Decision making based on sustainability paradigm can provide an integrated framework to solve the problems. To achieve sustainable hazardous waste transport's decision making, an efficient analytical tool is needed to conduct the analysis of the problem. The main purpose of this paper is to propose a framework of applying Multi criteria decision analysis (MCDA) via Geographic information system (GIS) approach that can create a holistic insight during the three stages of hazardous waste decision making; data manipulation, transport planning and route selection, which can lead to a broader understanding from all stakeholders.

Key word: *Sustainability: Geographic Information System (GIS): Risk analysis: Hazardous waste transport: Multi-criteria decision analysis (MCDA).*

1. INTRODUCTION

Hazardous waste is growing rapidly with an increasing trend due to strong economy and industrial development policy of Thailand. Transporting hazardous waste along routes is certainly risky. Historical evidences show that the risks associated with hazardous waste transportation can be of the same magnitude of the risk due to fixed installations [1,2]. Hazardous waste is generally toxic by itself. It can cause adverse health effect if over-standard dose of chemical substance is exposed to the population. In a mean time, transport activities carry other types of risk in case of accidental event on its shipment route.. In most case, risk and safety interests of hazardous waste transport conflict with economic interests, rendering the decision making process a complex task. In Thailand, the management of hazardous waste transport is often left in the hands of the stakeholders directly involved in the transportation activities, which can lead to routing decision for hazardous waste transport based mostly on economic factors.

To minimize hazardous waste transportation problems, various models have been developed based on optimization method. Some model have been developed by the formulation of the regional hazardous waste management system (RHWMS) as a vehicle routing analysis for the purpose of accomplishing the goal of both minimum cost and minimum risk [3]. Risk analysis for hazardous waste transport is mostly modeled by the product of total prob ability of release-causing accident during transportation or accidental rate (in case no statistical of relea se-causing accident is available). As can be seen from previous research, cost and risk are the key factors that needed to be modeled in optimization method. A limit number of research applications have paid attention to other relate issues like a security or safety [4]. Therefore, securing lowest cost should not be the only purpose of the routing analysis, but to integrate environment and society ri sk to the analysis can propose a holistic framework for better decision making process.

2. HAZARDOUS WASTE TRANSPORT AND SUSTAINABILITY

Conventional focus of hazardous waste transport was concentrated on cost and risk as criteria and using optimization method to derive the best shipment route among shortest path, shortest time and minimum risk in term of probabilistic risk assessment as an important factors and criteria. However, from a broader view of sustainability, the consideration of only cost and risks is not enough to provide a comprehensive perspective for making decision on hazardous waste transport problems.

Three components that are crucially considered in the sustainability approach are econ omic, environment and society. The e conomic dimension refers to benefit gain in monetary terms during hazardous waste transport such as shortest path and/or shortest time of truck movement. The environment is concerned with risk from hazardous waste transport that can affect the surroundings environment. Risk can be defined in term of the probability of the occurrence of accident on the shipment route. The impact can be huge if there are a numbers of sensitive environmental place i.e. river, stream or agricultural area located along the shipment route. The society dimension refers to the chance of people being posed a risk from hazardous waste transport, the concept has usually been defined in term of “safety” concern. To minimize risk from hazardous waste transport, the concept of sustainability should be incorporated in all stages of routing decision making process. This decision making process should be redesigned to allow all stakeholders involved, especially in Thailand, not to leave hazardous waste transport decision only to transportation related auth orities..

Generally, there are three main stages in hazardous waste transport decision making process: data manipulation stage, the transport planning stage and the route selection stage. The data manipulation stage involves the activity of gathering all data needed in database; quantitative and/or qualitative, spatial and/or non-spatial data. The transport planning stage relates to the selection of analytical method and the definition of associated factors and criteria. The route selection stage is the last stage of decision making process that concerns about the selection of the best alternative route by decision makers.

To effectively conduct sustainable hazardous waste transport decision making process, an efficient tool is needed to allow an accurate analysis, based on a vast amount of data, factors and criteria involved.

Geographic information system (GIS) is widely used to manage spatial data and is heavily depended on the availability of suitable data. Some GIS techniques can be applied for hazardous waste transport problem such as defining the buffer zone along either side of the road, measuring nearby population, including the probability of accident on road network. Many researches have tried to provide accurate impact of exposed populations by modeling the dispersion of toxic gas plume [5, 6], including ground water vulnerability [7].

The next approach in the analysis is focused on the route determination between origin and destinations that fit certain criteria. The combination of mathematical algorithm and GIS can be employed to find the best path between origin and destination on the network that is in line with the specified constraint. Objectives that are usually used to derive the best route are shortest path or travel time, minimum population exposure, smallest number of accidental risk. From this kinds of analysis, the optimum route will vary depending on the criteria used and the relative importance of such criteria. The last approach of GIS application to hazardous waste transport deals with emergency management and evacuation planning. GIS has been used to estimate the number of people that are at risk and need to be evacuated after an incident. More sophisticate approach is to consider the capacity of road network and use GIS to plan for optimum site for emergency response unit, and the identification of existing buildings that can be served as temporary shelter sites for displaced population [8].

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 preferable to the least preferable 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. For hazardous waste transport problem, shortest path is the best objective in economic sense, but it is very more likely to pose some risk to population nearby because it is often located in urban area. MCDA is an approach to understand complex issues that might be characterized by any mixture of monetary and non-monetary objectives. By dividing the problem into more manageable pieces to allow data and judgments to be brought to bear on the pieces, and then reassembling the pieces to present a comprehensive overall picture to decision makers.

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) “Weighing” 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.

3. THE ROLE OF GIS AND MCDA IN SUSTAINABILITY

The major aim of GIS is to support decision making process. Nowadays, GIS system have been focused on supporting the first stage of the decision making process. It offers a unique opportunity to effectively solve problems with the powerful data analysis capability. GIS can play a major role at the initial stage of the development of sustainable hazardous waste decision making by storing and managing large amount of spatial data and related information. Therefore, it can lay a strong base for following stages of analysis. In case of hazardous waste transport, some factors and criteria cannot be suitably perform in monetary form such as sensitive place like a stream or conservation area that shipments have been routed through. This creates a difficult task for optimization problem. Nevertheless, MCDA is an interesting approach to deal with this complexity of problems. To effectively perform analysis in planning and selecting stages of hazardous waste transport, the MCDA paradigm can be employed to create a comprehensive framework for hazardous waste transportation problems as depicted in figure 1.

To apply MCDA for hazardous waste transport, the mentioned framework in figure 1 is illustrated hereunder. The question still arises about how to identify factors and criteria to be used in MCDA analysis, cost versus risk? In this sense, MCDA can design a broader factors and criteria approaching a sustainability viewpoint from stakeholders. Economic factor can be shortest path between origin and destination point, social factors is about risk from accidental release of chemical substance to nearby population, environment factors concern natural areas that are at risk such as stream, agricultural area, etc. After the determination of sustainable factors and criteria, GIS can be an efficient tool in managing the analysis of factors and criteria to derive score and weight in each alternative route.

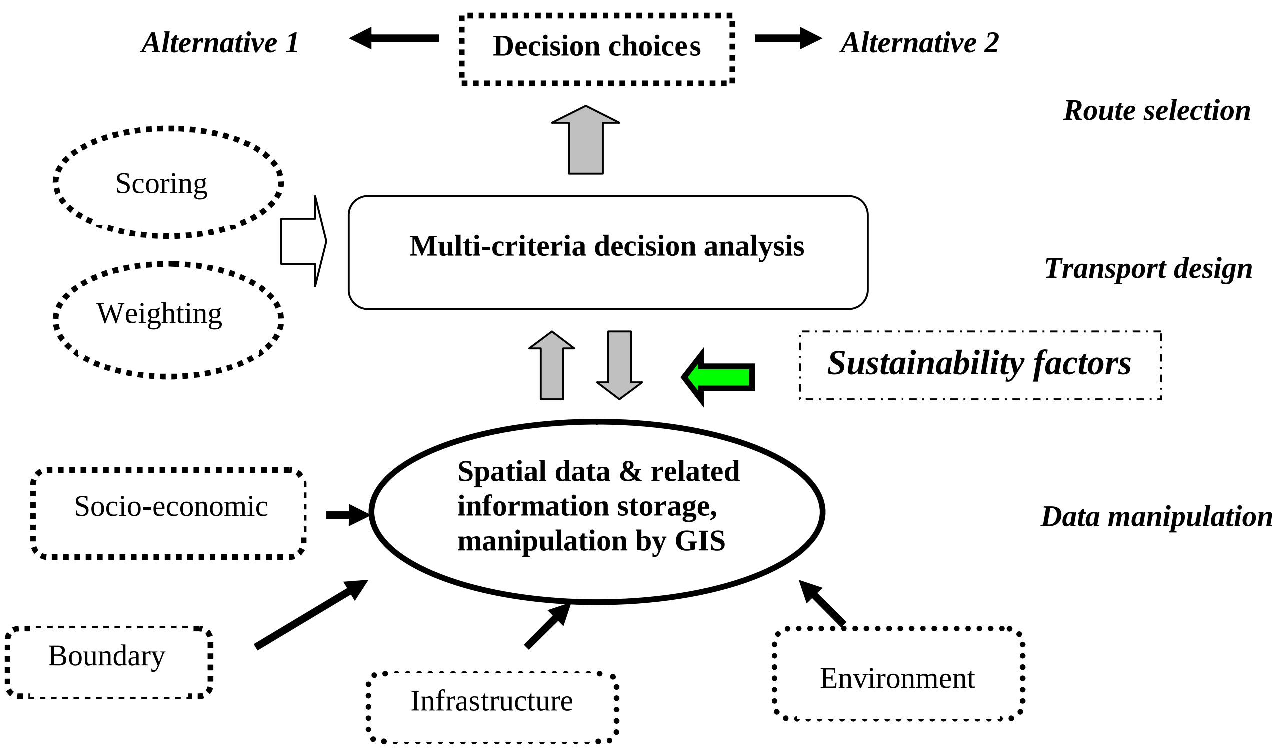

Figure 1. Proposed framework for the integration of GIS and multi-criteria decision analysis

4. SUSTAINABLE HAZARDOUS WASTE TRANSPORT IN THAILAND

Currently, there is no national legislation regulating hazardous waste transport in Thailand that can be used to assign specific road section for hazardous waste movement. Furthermore, transport contractors are generally reluctant to provide operational details on the basis of commercial secrecy. In Eastern part of Thailand, especially at Rayong province, there are many heavy industries such as petrochemical, plastic, pulp and paper located in this region. Hazardous wastes are then generated inevitably. Much of hazardous waste is sent to disposal site or recovery unit in order to get some

value back. From the statistic of the Pollution control department, a total of 490 000 tons of liquid hazardous waste, which represents 74.80 % of the country's total liquid hazardous waste, was sent to incinerators that are operated by the cement industry, located at Saraburi province, in the Central part of Thailand. Most of the liquid wastes have been shipped from the Eastern part as or igin site to the central part as destination which is a long distance for burning purpose.
Thailand has initiated many programs that tried to involve sustainability issues. The National Council for Sustainable Development (NCSD) was established with the purpose of establishing national sustainable development strategies. It is essentially there to lay the groundwork for sustainability approach in all future development plans in any areas of development. Hazardous waste transport can be one focal point in linking transport activities and environment issues.

The paradigm of sustainability is extremely valuable when applying the three phases of hazardous waste transport decision making. Factors and criteria using in MCDA need to be in line with sustainability core concepts. Some examples of how to define factors and criteria (each of criteria can be separated out to sub-criteria) are shown in Table 1.

Table 1 Example of sustainable factors and criteria

Economic	Environment	Society
Distance	Sensitive place such as stream, conservation area, agricultural area	Imposed chemical risk by hazardous waste
Traffic condition	Hazardous waste dispersion	Location of rescue unit
Delay cost		Proximity of fire station
Travel time		

Stakeholders can greatly influence the route selection process for the transport of hazardous waste. Stakeholders can be preliminary defined to three main groups: *the transport companies* in charge of transporting hazardous waste to disposal or recycling site, *the government or policy-makers both national and local*, and the *community* in general. The transportation companies in charge of transporting hazardous waste materials are interested in maximizing their profits. One of the factors that help achieve this purpose is to reduce operational costs. If the shortest path (length or time) between origin and destination is used, then the operational cost can be minimiz ed, therefore maximizing profit. There are two main issues that are under the jurisdiction of "government". They are responsible for the functionality of the transport network at all times and they have to maintain a safe urban and rural environment. If an accident occurs in the process of hazardous waste shipment, the transport network and the surrounding environment can be affected negatively. The last construct "community" refers to the people living in or nearby area where the hazardous waste is being transported. This becomes even more relevant when the shipment of hazardous waste takes place in an urban area.

However, the different interest of each stakeholder may prone to be conflicted with the interest of each other. For the transport of hazardous waste, the risk perception of the stakeholders involved strongly affects the way decisions need to be taken. Risk perception of a transport company may differ from the one of the government. What may be perceived as unacceptable risk by the government may be acceptable in the view of transport companies, due to the revenue or profit received from the actual transport activity. A GIS integrated with MCDA approach based on sustainability can be applied to hazardous waste transport decision making to provide a broader picture of related issues and to try balance a common agreement among stakeholders.

5. CONCLUSION

The increase of the hazardous waste transport, both in industrialized and non-industrialized sectors, has initiated concern about risk involved in the transportation of hazardous waste**.** Traditional approach such as shortest-path model cannot be fully effective to model hazardous waste transport problems, which in reality, dealing with both quantitative and qualitative information and poses a great risk to society. The focusing on sustainability is a vital role to rethink about the traditional decision making process of hazardous waste transport. Sustainability is widely accepted as the science of development that creates a balance between economic, environment and society related factors. To achieve sustainable hazardous waste transport, not only factors and criteria that are covered in the three stages of decision making process, but also the reliability of the analysis method for managing and analyzing of large amount of complex information for making the most reliable choice that can lead to the proper decision.

Multi criteria decision analysis (MCDA) using in combination with GIS is an integrated approach to can help solve a complicate problem of hazardous waste transport pertaining to spatial and non-spatial data that impacts various factors and criteria. Applying MCDA via GIS to solve hazardous waste transport problem has a high potential to manage complex information and to establish sustainability thinking through the three stages for decision making process: data manipulation, transport planning and route selection stages. Decision based on a comprehensive framework of analysis can then be made by decision makers in accordance with the one key goal of sustainability, which is aiming at balancing the economic, environment and society conditions for the benefit of sustainable future.

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