Route Optimization for Hazardous Materials Transport

Jimmy Ernesto Avendano Castillo
March, 2004

Route Optimization for Hazardous Materials Transport

by

Jimmy Ernesto Avendano Castillo

Thesis submitted to the International Institute for Geo-information Science and Earth Observation in partial fulfilment of the requirements for the degree of **Master of Science in Urban Planning and Land Administration.**

Degree Assessment Board

Prof. Dr. D. Webster (Chair)
Dr. S.C.M. Geertman (External examiner)
Dr. Ir. L.G.J. Boerboom (First Supervisor)
Ir. M.J.G. Brussel (Second Supervisor)

INTERNATIONAL INSTITUTE FOR GEO-INFORMATION SCIENCE AND EARTH OBSERVATION
ENSCHEDE, THE NETHERLANDS

I certify that although I may have conferred with others in preparing for this assignment, and drawn upon a range of sources cited in this work, the content of this thesis report is my original work.

Signed …………………….

Abstract

Hazardous materials are used in many processes in the industry all over the world. Due to the nature of hazardous materials every production, storage, and transportation activity related to the use of these materials inherits many risks for both society and environment. Despite this fact, the use of hazardous material has been justified by the economical revenue, which is generated by their use. In order to avoid the risks turning into real events it is necessary to integrate risk mitigation and prevention measures into the transport management. In the case of transporting hazardous materials the selection of routes for which economic and risk issues are dealt with, represents an example of an integrated transport and risk management. The selection of routes under economic and safety perspective is not easily achieved when considering that many stakeholders with specific and conflicting objectives may be related directly or indirectly to the transportation of hazardous materials. This research study aims to develop a decision support tool for the selection of routes for the transport of hazardous materials taking into account economic and risk factors.

This document discusses the development of a route optimization model as a decision support tool. Before the development of the model, a review and discussion on the issues related to risks in the transport of hazardous materials as well as the modelling tool available for routing problems of hazardous materials is made. Based upon the previous discussion the use of multiple objective mathematical programming is proposed for calculating optimal routes that are dependant to the criteria set of the problem. The criterion set is composed by five objective functions that are to be minimized *i.e.* optimized. These objectives are: travel time, travel distance, risk for the population, risk for the urban environment, and risk related to a natural hazard. Where the first two are used to model the economic issues and the last three are used to model the risks issues.

The criteria set given in this document is not to be considered as a ‘rule of the thumb’ when developing a decision support tool like the one developed in this research. The methodology proposed enables the modeller to develop models that are flexible enough to be customized according to the characteristics of the case study. Furthermore, the role of the stakeholders in the decision-making process and in the use of the route optimization model is discussed. At the end of this document the model is put to the test by calculating routes for the transport of petrol derivates in the city of Lalitpur, Nepal. The results of this practical application are discussed.

Acknowledgments

This document contains the research work that now I am proudly finishing; and I must say, that throughout the research period I received the cooperation and support of many people. I wish to express my gratitude to each and every one of them. Although I cannot mention by name every person that helped me one way or another, I thank you all for your valuable and highly appreciated support.

I have sincere gratitude for my first supervisor Dr. Luc Boerboom, for his constant support before and during my research period. His guidance certainly helped me to stay focus on my research study. I also thank my second supervisor Ir. Mark Brussel, for his important remarks regarding my work; remarks that greatly contributed to my work. I feel privileged for being able to count on both of my supervisors who always managed to make some space for me in their tight and busy agendas.

I would like to thank the staff members of the Urban and Regional Planning and Geo-information Management (PGM) Department, especially Dr. Lorena Montoya, Dr. Eric de Man, Ms. Petra Weber, Ing. Frans van den Bosch, Ir. Liza Groenendijk, Dr. Mike McCall, Drs. Jeroen Verplanke, for always being cooperative and willing to discuss with me. I would like to also thank Ms. Ayako Kagawa, her lectures in research methodology helped to shape my research proposal. I wish you all success in your professional life. I thank my fellow colleagues from the Urban Planning and Land Administration Programme, for sharing the 'burden' and especially 'grey-matter'. I very much enjoyed having you as my fellow mates; I also wish you success in your home countries.

Furthermore, I would like to thank the people of Nepal, their kindness certainly eased my fieldwork activities; but especially thanks to Ramesh Guragain and Ganesh Jimee from the National Society for Earthquake Technology (NSET), Niyam Maharjan from the Municipality of Lalitpur, Dinkar Sherma from the Department of Roads (DoR), Manav Shrestha from the Thankot Petrol Depot, and Saroj Pandey from the Nepal Petrol Dealers Association, for their cooperation during my fieldwork.

Jimmy Ernesto Avendano Castillo
Enschede, March 2004

To the ‘Coronel’ and my family

Thank you Father

Table of content

List of Figures

List of boxes

List of tables

List of Acronyms

ADT	Average Daily Traffic
DoR	Department of Roads
GAMS	General Algebraic Modelling System
GIS	Geographic Information System
GIS-T	GIS for Transportation problems
HazMat	Hazardous Materials
HLV	Human Life Value
ITC	International Institute for Geo-Information Science and Earth Observation
JICA	Japan International Cooperation Agency
MMI	Modified Mercalli Intensity
MOMP	Multiple Objective Mathematical Programming
NOC	Nepal Oil Corporation
NPDA	Nepal Petrol Dealers Association
SLARIM	Strengthening Local Authorities in Risk Management
SVG	Scalable Vector Graphics
UNDRO	United Nations Disaster Relief Office
UNESCAP	United Nations Economic and Social Commission for Asia and the Pacific

1. Introduction and research background

This chapter starts by giving a brief background in the phenomenon of transporting hazardous materials. Then the research problem on which this research study will focus is introduced, as well as the potential stakeholders that can be related to the research problem. The motivation for doing this research study is discussed preceding the listing of the research objectives and questions. This chapter finalizes by giving an overview on the research methodology, the case study, and the outline of this research study.

1.1 Hazardous materials transport

Nowadays, hazardous materials are used in a wide range of industrial and economic activities. Materials such as Plutonium and Ammonia for example, are used to produce energy and fertilizers respectively. The use of these type of materials certainly generates economic benefits; nevertheless the term 'hazardous' is an indicative that negative and damaging consequences can result from an accident event, which takes place in activities where hazardous materials are present. If such event occurs, the consequences can affect our society and environment. In this document materials such as explosives, flammable liquids, oxidizing substances, poisonous gases and radioactive materials are considered to be hazardous materials (Zhang, Hodgson *et al.*: 2000), and from this point onwards, the abbreviation 'HazMat' is used for the term 'Hazardous Materials'.

In most of the cases (if not all) HazMat have to be transported from a point of origin to one or more destination points. The origin points are fixed facilities where the HazMat are produced, stored, or distributed. The HazMat are then transported from a production facility to a storage, distribution, or another facility where the HazMat is required. Due to the nature of HazMat, safety measures must be considered in any process of production, storage, and distribution of HazMat. Therefore, in order to minimize any risk related to the use of HazMat, safety standards and codes are often implemented to regulate the proper use of HazMat. The purpose of these regulations and codes is to minimize the risk attached to the use of HazMat. However, the elaboration of such regulations and codes does not represent a full warranty against accidents. A good management is required to achieve the desired safety standard of any process involving the use of HazMat. Therefore, planning and decision-making tools are developed to manage processes related to HazMat.

Decision-making tools such as route models are used in the management of HazMat transport operations, which allow decision makers to determine the best route for the transport of HazMat. The simplest example of a model is one that looks for the best route based on the economical factors related with the transport operations. The economical factors can be related to the operational costs. However, better route selection models will be those where risk related factors are considered as well. What factors should be considered in a route selection process may depend on the interest of the stakeholders involved in the process of transporting HazMat. The criteria for selecting routes for HazMat transport may vary from one organization to another, from one country to another.

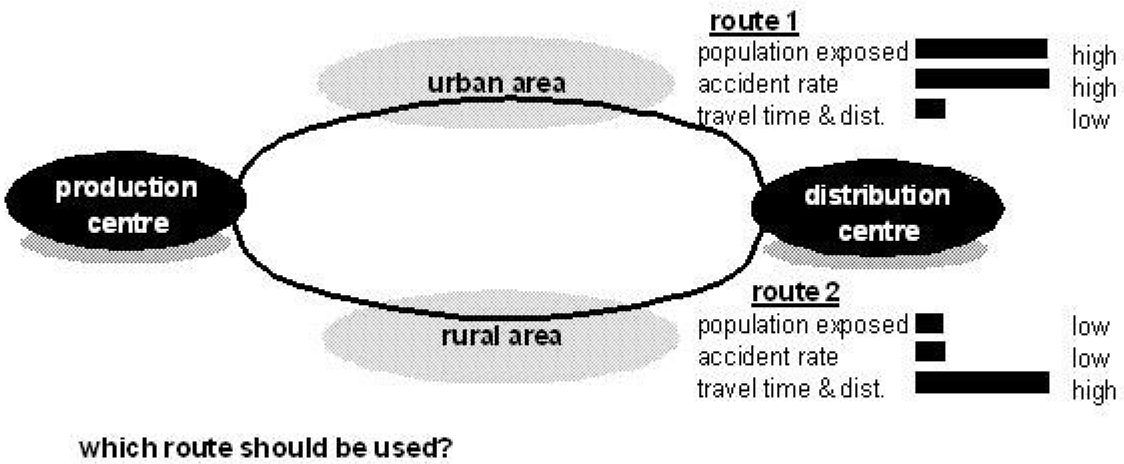


Figure 1-1 example of a HazMat transport routing problem

In most cases, risk and safety interests conflict with economic interests, rendering the decision-making process a complex task. Consider for example the differences in risk perception and economic interest that may exist in different countries, based on their development level. It has long been known that in developed countries, there will be a greater awareness of the dangers of HazMat as compared to the awareness in developing countries. Therefore, in most developed countries policies and regulations are created for managing HazMat transportation activities. The opposite of this attitude is the way HazMat related issues are managed in developing countries, where economical factors may play a bigger role than risk factors. In developing countries natural disasters are considered to be of more concern to private and public sector groups than those related with HazMat (Glickman, Golding *et al.*: 1992). This contributes to the lack of interest and awareness in developing countries towards HazMat use and transport. The management of HazMat transport in developing countries is often left in the hands of the stakeholders directly involved in the transportation activities, which can lead to the selection of routes for HazMat transport based mostly on economical factors.

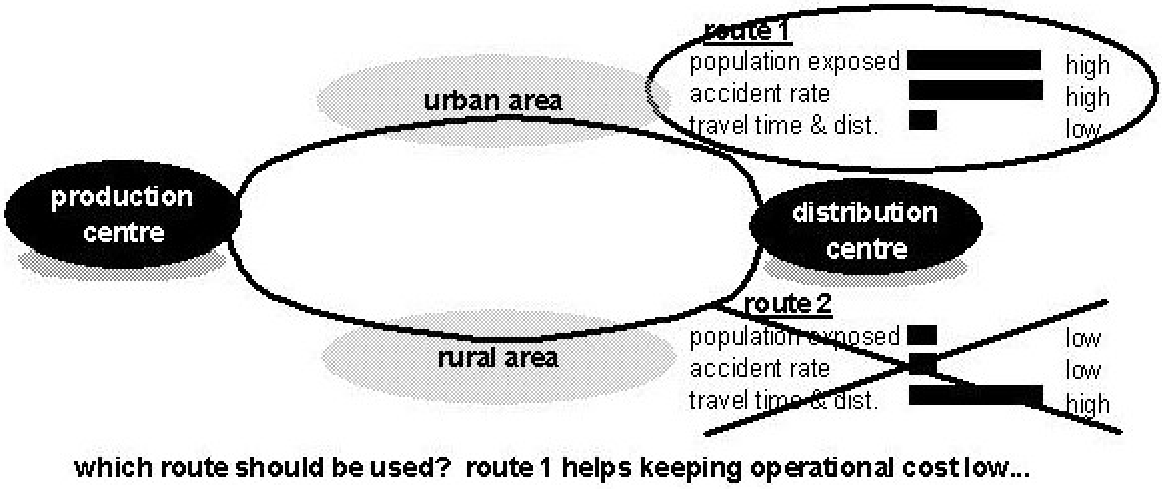


Figure 1-2 example of route selection based on economic factors

1.2 The research problem

The problem that arises when transporting HazMat is how to select a route where economic and risk issues are considered. On one hand the HazMat transport has to be economically feasible for the stakeholders directly involved in this activity. On the other hand, the HazMat transport must pursue the safe transport by minimizing the risk throughout the whole transportation process. Defining the economical factor is a straight-forward task. However, defining what determines risk is a far more complex reality. The economical feasibility of a transportation activity can be seen in terms of the operational costs. The more the operational costs involved in the transport process are kept under a certain threshold, the more economically feasible the process will be.

The term 'risk' is often defined as the probability of a damaging event to occur and its consequences (Lavell: 1996; Berdica: 2002; Fabiano, Curro *et al.*: 2002). In other words risk is the interaction of hazards and vulnerability factors of one or more elements at risk. The interaction of these factors however, can be determined and/or influenced by other external factors *e.g.* environmental, social, political, *etc*. There is a considerable amount of research on route modelling for the transport of HazMat where factors such as accident probability, explosion probability, and population vulnerability are considered when it comes to risk assessment. Some of these research studies are the ones carried by Karkazis and Boffey (1995), Bonvicini *et al.* (1998), Frank *et al.* (2000), Leonelli *et al.* (2000), and Zografos and Androutsopoulos (2004) just to name a few (a discussion related to this references is presented in the second chapter). However, the influence of other natural or socio-natural hazards, affecting elements at risk other than population, has not been considered, or at least I have not come across research studies which have considered these issues.

In order to be able to select economic and safe routes for the transport of HazMat it is necessary to use 'tools' that allow planners and decision makers to evaluate all possible routes, to create different scenarios, and to assist in finding a solution to a particular problem. This research aims at developing a 'tool' that can be used in the planning and management of HazMat transport. The research problem is oriented towards the development of a 'model' for the selection of economic and safe routes for HazMat transport. The model is developed to be able to evaluate and find 'optimal routes' among all available routes in the transport network, and by doing so contributing to the management of HazMat transport.

In any management problem there are stakeholders to be considered. In this case, the stakeholders are those individuals and/or groups that have a direct or indirect influence in the process of HazMat transport; but also those that are affected directly or indirectly when an accident occurs while transporting HazMat. Therefore, the term 'optimal routes' in its singular form means the route that best fulfils the objectives set by the stakeholders related with the process of transporting and distributing HazMat within the study area. In this document, the process of selecting an 'optimal route' for a particular case is defined as 'route optimization' process. Thus, the problem presented in this document is the route optimization for the transport of HazMat.

1.3 Who are the potential stakeholders?

In this section I will discuss the question of who are the potential and main stakeholders, which from my point of view influence the route optimization process for the transport of HazMat. The main purpose of selecting a specific route for HazMat transport is to reduce the negative effects triggered by an accident and, at the same time, maintaining the economic attractiveness of the transport operations. Among all the possible stakeholders, three main stakeholders can be preliminary identified: the transport companies in charge of transporting petrol derivates, the government, and the population in general. Later in this document I will list the stakeholders identified in the case study area of this research study.

The transport companies (private or public) in charge of transporting HazMat are interested in maximizing their profits. One of the factors that help achieve this objective is reducing operational costs, particularly their variable costs. Operational costs can be calculated considering cost per units of length travelled, or considering travel time between the source and distribution point. If the shortest route (either length or time) between origin and destination is used, then the operational cost can be minimized, therefore maximizing profit. If between origin and destination points, there are intermediary stops, reducing the travelling time of the trip can result in covering a greater number of distribution points, which in the long run can turn into a higher profit.

Depending on the case study area, the term ‘government’ refers to either central or local government. Two issues dealt with by the government are bearing for the functionality of the transport network at all times, and maintaining a safe urban environment. If an accident occurs in the process of transporting HazMat, the transport network and the surrounding environment can be affected negatively. In order to maintain the functionality of the transport network, the government must incur with economical expenses for the proper rehabilitation of the damaged infrastructure. The negative effects on the urban environment in case a damaging event occurs extent to buildings, parks, schools, *etc*. The ‘value’ of the damage to the urban environment can be expressed in economic terms, as well as in human lives.

The term ‘population in general’ refers to the people living in or nearby the area where the HazMat are being transported. This becomes even more relevant when the transport of HazMat takes place in urban areas. People are always interested in their safety, both as individuals and society. The term “not in my backyard” is used very often when people do not want to be exposed to some kind of hazard. It is understandable that people will not agree about being exposed to a hazard in their own work and/or residential area. In risk and disaster management, the population is one of the first elements at risk to be considered. Therefore, when selecting an optimal route for transporting HazMat, people expect the least amount of exposure to the risk source.

1.4 Why do a research on route optmization for HazMat transport ?

In order to determine whether doing research on route selection for HazMat transport by road is justified or not, I give the following three reasons:

The first reason for research on the topic of HazMat routing is based on the risk related to HazMat transport. Historical evidence has shown that the risks related to HazMat transportation can be of the same magnitude of those due to fixed installations (Leonelli, Bonvicini *et al.*: 1999; Leonelli, Bonvicini *et al.*: 2000). As an example I mention the research done by Glickman *et al*. (1992) where he discusses the percentage of accidents due to the transportation of HazMat and fixed installations at a worldwide level. Between 1945 and 1986 most of the accidents have occurred with HazMat (dangerous goods) being transported.

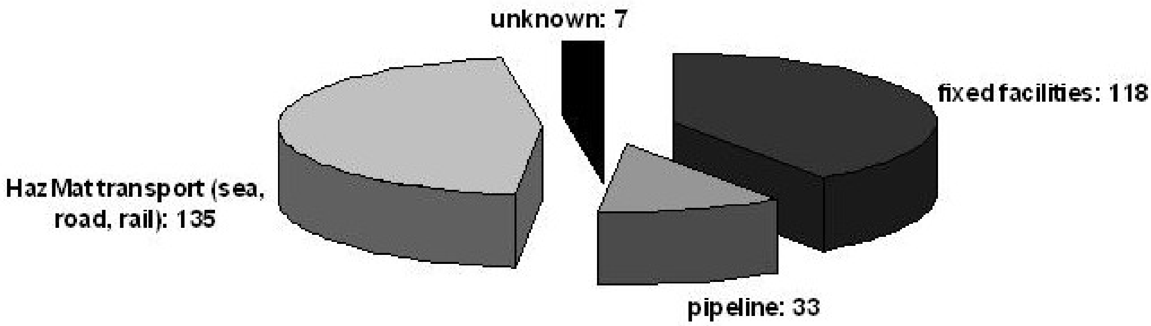


Figure 1-3 number of major technological accidents world wide between 1945 and 1986
Source Glickman *et al.* (1992)

The second reason for research on the topic of HazMat routing is based on the consequences of HazMat transport accidents: HazMat transport accidents involve a high damage potential in terms of economical losses. The economical impact can be quantified by adding the value of money needed to re-establish the transportation network to normal. The reconstruction of roads and other infrastructure can be named as some examples, where the government or the local authorities are responsible for these expenses. Furthermore, the economical losses of the private transportation company are also part of the consequences of HazMat transport accidents. Medical treatment for injured employees, replacement of the transport units, and delays in the supply of the materials are some more examples.

The third reason for research on this topic of HazMat routing is based on the impact caused to third parties. A high percentage of HazMat transport accidents involve third parties, such as the people living along or close to the transportation route, as well as the environment. This issue is given more relevance when considering that the HazMat has to be transported through populated areas such as cities. Related to the above stated is the fact that HazMat accidents receive a high profile in the media, which can lead to other types of consequences like suing demands from the society to the government. Furthermore, they affect the interest of people intending to live in the city, or can even create an unsafe image of the city (Bohnenblust and Slovic: 1998).

1.5 Research objectives and questions

The research objectives, sub objectives, and research questions are presented in the following three sections. The research questions are listed under their respective sub-objective.

1.5.1 Main Objective

- To develop a route optimization model that can be used as a decision support tool in the assessment of routes for the transport of HazMat taking into considerations economic and risk factors.

1.5.2 Sub Objectives

- To determine the different risk related factors that can influence directly and indirectly the transportation activities of HazMat and that can be considered in the route optimization model.
- To propose a methodology for the development of a route optimization model.
- To develop a GIS based model for the selection of optimal routes for the transport of HazMat based on the proposed methodology.
- To assess the influence of the stakeholders in the selection of routes for the transport of HazMat.
- To apply the route optimization model in the selected case study of this research.

1.5.3 Research Questions

Sub objective: to determine the different risk related factors that can influence directly and indirectly the transportation activities of HazMat and that can be considered in the route optimization model.

- What is labelled as risk factor?
- How is risk derived?
- What types of hazards can be considered when developing a route optimization model for HazMat transport?
- Which elements at risk are interacting with the hazards related to the HazMat transport, and what are their vulnerability values?
- What risk factors should be considered in the route optimization model to develop in this research study?

Sub objective: to propose a methodology for the development of a route optimization model.

- What are the basic elements of the transport network to be considered in the route optimization model?
- What is the approach for evaluating optimal routes?
- What is the functionality of a decision variable in the route optimization problem?
- What are the mathematical equations used to define the objectives and constraints of the route optimization model?

Sub objective: to develop a GIS based model for the selection of optimal routes for the transport of HazMat based on the proposed methodology.

- What software is suitable to use for the development of the route optimization model?
- What data of the transport network is required for the route optimization model?
- What data is available from the case study area?
- What scientific assumptions can be considered in order to overcome the lacking of data?

Sub objective: to assess the influence of the stakeholders in the selection of routes for the transport of HazMat.

- Who are the stakeholders?
- What are their interests in relation to the transport of HazMat?
- What is the role of the stakeholders in the utilization of the route optimization model?

Sub objective: to apply the route optimization model in the selected case study of this research.

- How can the route optimization model contribute to management of HazMat transport in the case study?
- What are the optimal routes calculated by the route optimization model for the case study area?
- What scenarios can be created considering the transport network data?

1.6 Research methodology

In order to answer the questions that will in fact enable the achievement of the main objective and every sub-objective proposed in this document; I proposed the following methodology. The starting point of the methodology is to determine the factor related to the phenomenon of transporting HazMat and that can be considered for the development of a route optimization model. Once these factors have been determined, the process for developing a route optimization model for the transport of HazMat will take place. The literature review chapter will provide with useful insight about the findings of previous research studies on route optimization models for HazMat transport and will help to set the horizon for the research study presented in this document. At the literature review chapter the question of what factors to consider in the route optimization model will be answered.

The process of developing the route optimization model for HazMat transport will take place in a phase-wise manner. Prior to the development of the model, the tools needed to develop the model will be stated, *e.g.* software and programming tools, as well as the criteria that will be use to calculate the optimal routes. On each of the phases of the model development one or more criteria will be input into the model, preserving the criteria already inputted to the model in previous phases. This means that the level of complexity of the route optimization model will increase as each phase of the development process is achieved.

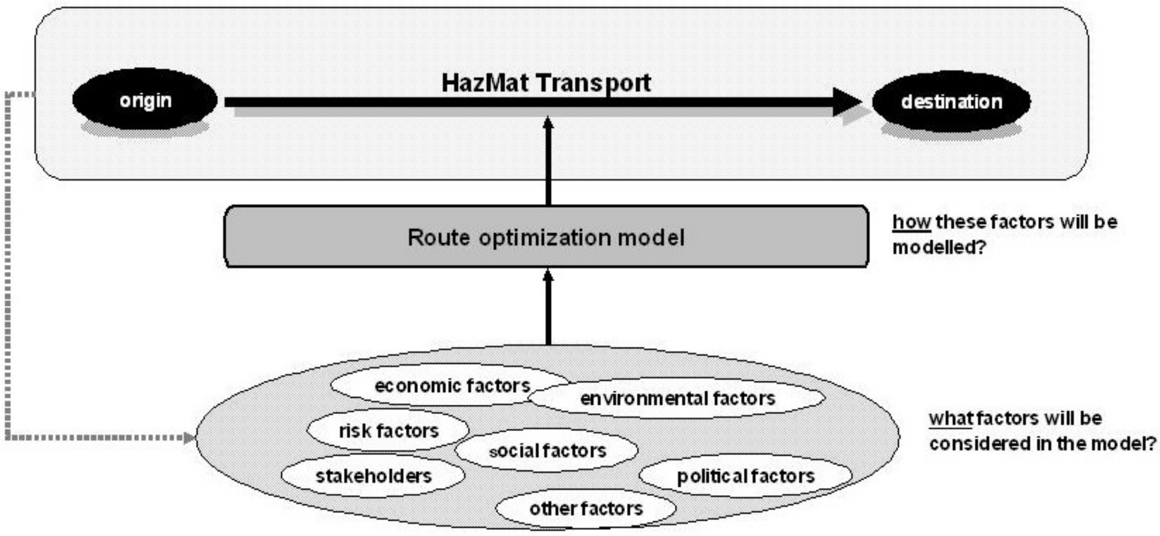


Figure 1-4 basic conceptual model of the research study

Figure *1-4* simplifies the methodology for the research study presented in this document. The dashed arrow indicates that the factors to be considered in the route optimization model can be directly or indirectly related to the phenomenon of transporting HazMat. The solid arrows indicate the sequence followed by the proposed methodology, first defining what factors will be considered in the model, and the how the factors will be in fact modelled.

1

1.7 The choice of the case study

The transport of petrol derivates in urban areas will be used as case study in this research study considering the fact that petrol derivates are a HazMat, which can be found in most urban areas around the world. Whether we consider a developed or developing country, the presence of vehicles that use petrol derivates as energy source is a fact. It is even more concerning when we look at statistics showing the growth in the number of vehicles in a given city. This increase in the number of vehicles means that the demand for petrol derivates is increasing as well. If the demand in a city is increasing, therefore the number of tankers transporting petrol derivates in the city increases as well.

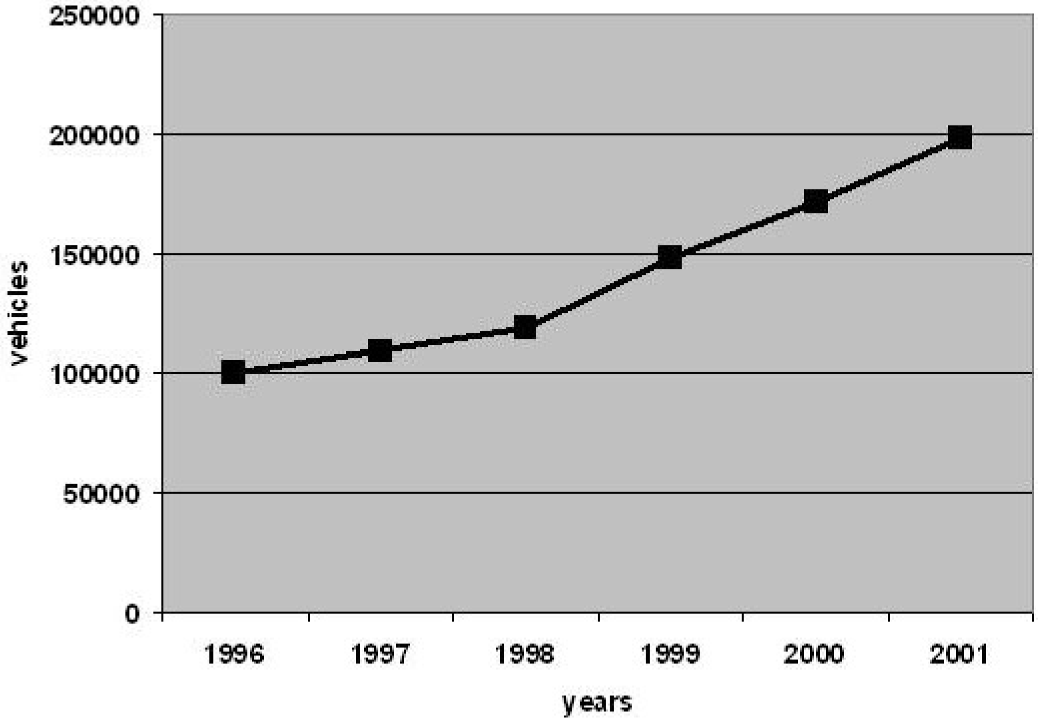


Figure 1-5 number of vehicles registered in the Kathmandu valley between the years 1996 and 2001 Source UNESCAP (2003)

In the Kathmandu Valley, Nepal, the number of vehicles increased from *100* Thousand units in 1996 to almost *200* Thousand units in the year 2001 (UNESCAP: 2003). This development means that in just six years the amount of vehicles in this specific area has increased by *100%*, which is equivalent to *16%* yearly growth. This yearly growth figure definitely calls the attention to the increasing interest in doing a research on HazMat routing.

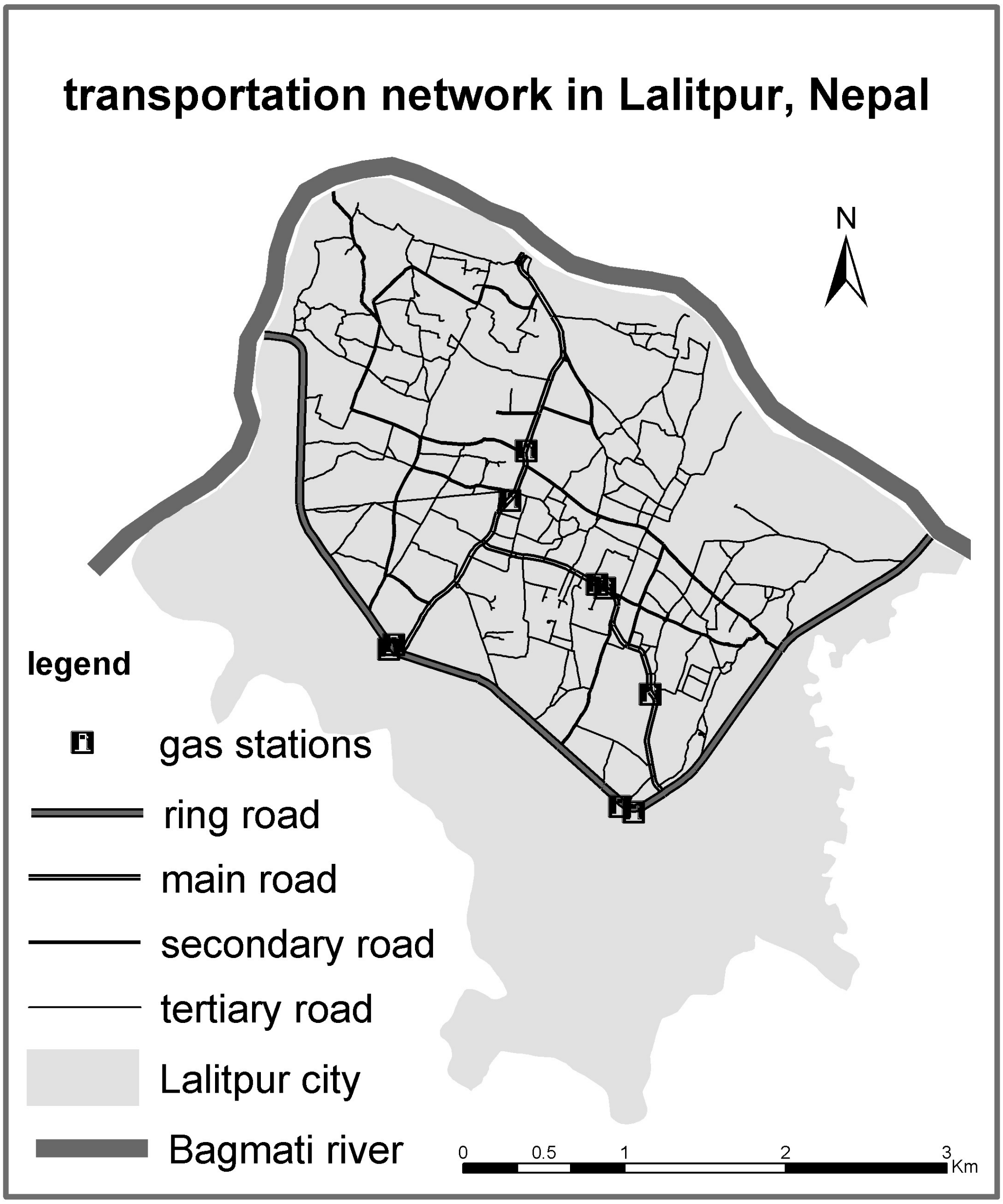


Figure 1-6 transportation network of the Lalitpur city, Nepal
Source of data JICA (2002)

In the Kathmandu valley the following three main cities occupy most of the space: Kathmandu, the capital of Nepal, Lalitpur, and Bhaktapur. From these three cities, the city of Lalitpur has been selected as case study area due to be one of the case study cities of the SLARIM project of ITC. The term ‘SLARIM’ stands for “Strengthening Local Authorities in RIsk Management”. Several research studies on population, infrastructure, and building vulnerability in case of an earthquake are being carried out simultaneously that are using the city of Lalitpur as a case study city. The outcome of the research study presented in this document in combination with the outcome of the other research studies will contribute to the strengthening of local authorities in managing risk. The city of Lalitpur is divided in *22 wards*, covering an area of *15.42 km²*. Wards are spatial sub-divisions of the geographical extension of the city. The length of the paved road network in the city of Lalitpur is more that *70 km*, with *9* gas stations located within the inner ring road boundary.

1.8 Outline of this document

The outline of this document is as follows:

Chapter One gives a brief introduction to the topic of HazMat transport. It discusses the problem definition and its justification. It introduces who are the potential stakeholders related to the transport of HazMat. It lists the research objectives, sub-objectives, and research questions, followed by a brief discussion of the research methodology. It finalizes by discussing the choice of the case study, and the research outline.

Chapter Two discusses the literature reviewed. It defines the necessary risk terminology relevant to the research topic. It discusses the risk factors that will be considered in the development of the route optimization model based on the risk related issues that have not been covered in previous research studies. It discusses briefly the importance of the risk perception and the trade-off analysis in risk management for HazMat transport problems. This chapter also discusses the role and the limitation of Geographic Information Systems in the modelling of route optimization problems. A review of the research studies done in previous years about the modelling approach for routing problems related to the transport of HazMat is made. Finally based on this review, the modelling approach suitable for the route optimization model that will be develop through this research study is given in the conclusions of the chapter.

Chapter Three gives the definition of the basic elements of the transport network, which are needed for the right understanding of the methodology proposed for the model development. It describes the solution approach for solving the route optimization problem. It defines the decision variable used in the route optimization problem. Towards the end it discusses the constraints and the objectives, which are the main component for the route optimization model, listing as well in this last part the mathematical equations that define the constraint and objective functions of the model.

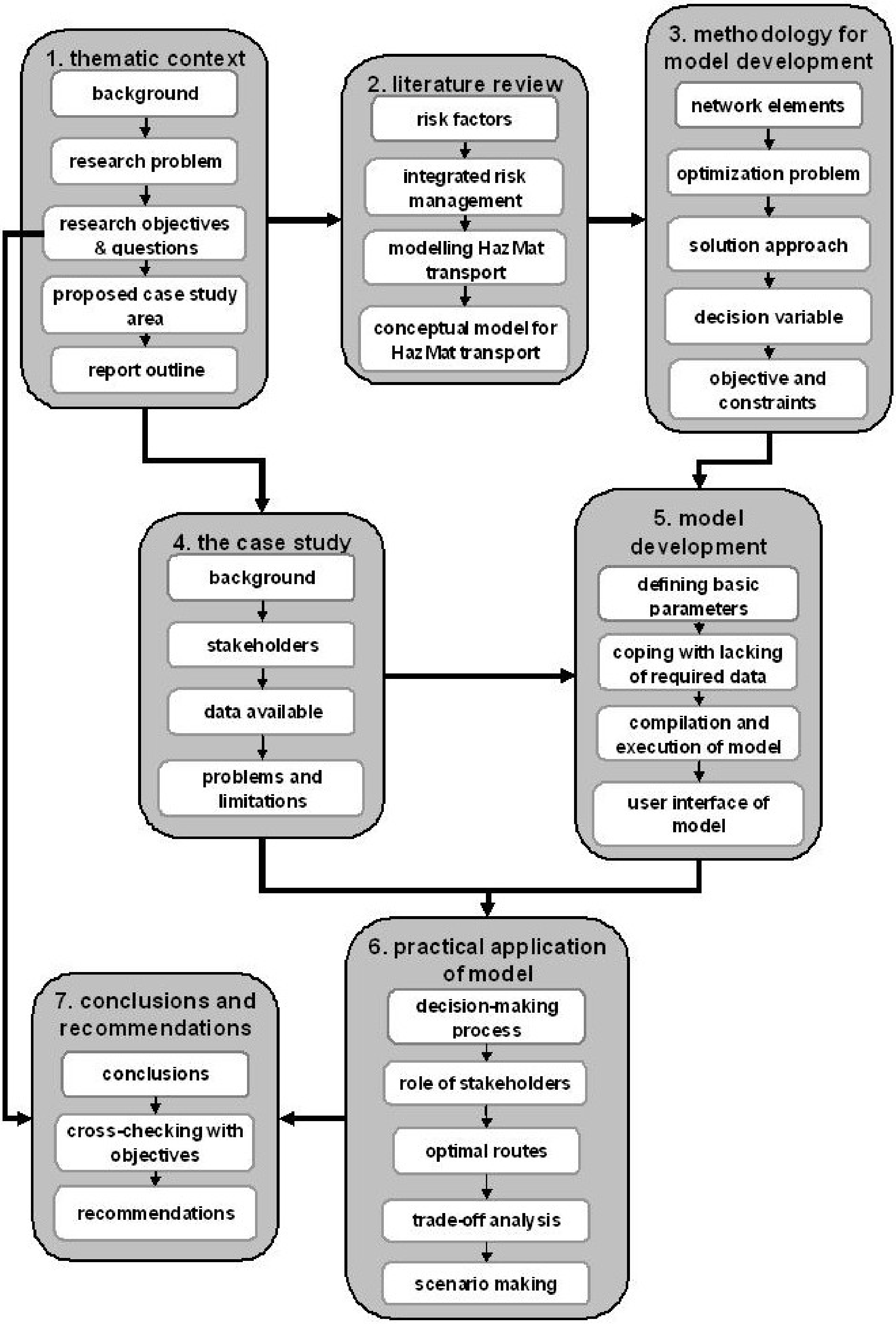


Figure 1-7 Research flowchart

Chapter Four discusses the relevant issues related to the case study area and case study problem. The chapter start by giving a background on the transport of petrol derivates in Nepal, and particularly in the Lalitpur city. It introduces who are the stakeholders related to the transport of petrol derivates in Lalitpur. Then the chapter focus on discussing the data that is available for use in the route optimization model; data related to the transport network, population, and building is described. The chapter ends by listing the problems and limitation related to the availability of data for the development of the route optimization model.

Chapter Five discusses how the model is developed using the limited available data from the case study area. This chapter discusses how the problems and limitations related to the available data described in the previous chapter are solved in order to fulfil the data requirements of the route optimization model. It discusses how the population and building data are estimated and modelled. It describes what software is used for solving the optimization problem, and what information flows from the GIS to the optimization software and vice versa. It describes briefly the development of a user interface for the route optimization model for the interaction of the end users with the model itself.

Chapter Six discusses the applicability of the route optimization model in a real decision-making problem. It makes emphasis in the contribution to the decision-making process given by the use of the route optimization model. For this purpose the route assessment for transporting petrol derivates to one particular gas station in the Lalitpur city is carried out. The findings of the route optimization model are discussed, these are: ideal optimal routes, trade-off among objectives, and scenarios for multi-objective optimization, level of satisfaction of each objective. At the end of the chapter a final remark about the applicability of the route optimization model is given.

Chapter Seven discusses the conclusions drawn from the proposed research study and finalizes with recommendations given by the author to be considered in future research studies.

2. Literature review

This chapter is divided into four parts. The first part is dedicated to the issues related to risk and risk management. The second part of this chapter discusses about the integration of different risk sources as a management approach. The third part of this chapter focuses on the modelling tools that are available for HazMat transport problems, particularly by looking at route optimization models that have been developed in other research studies. Finally the chapter ends with the conclusions given in the fourth part of this chapter.

2.1 Risk management in HazMat transport: opportunity for research

I have mentioned earlier in this document the fact that there is a substantial amount of research studies, which have dealt with the topic of HazMat transport route optimization; however, there are still gaps left open for further research on this topic. It is the aim of the author to focus on a number of these gaps, thus contributing to the scientific community the analysis and findings achieved by this research study. To identify these gaps I will briefly discuss the relevant aspects mentioned in previous research studies, which are best comparable to the research study I am presenting in this document. However, due to brevity reason, in this section I will not go into detail on all the research studies found in the literature. Instead, I will first emphasise in defining the terms 'risk', 'hazards', 'vulnerability' and 'elements at risk'; secondly I will discuss the issue of what factors are considered 'risk factors' in some of the previous research studies without going into detail about the technicalities of the model development process; this will be discussed in the last part of this chapter. Thirdly based on the discussion in the previous part, I will define which risk factors will be the subject of the study in this research.

2.1.1 Defining and deriving risk

Earlier in this document I have mentioned that risk is often defined as the probability of a damaging event to occur, and the consequences produced by this event once it has occurred. Some researchers define risk as the interaction between hazard and vulnerability factors (Blaikie, Cannon *et al.*: 1994; Lavell: 2000); where the hazard represents a potential damaging event that can affects a vulnerable population, production or infrastructure (Lavell: 2000); and the vulnerability factors represent the status of a given populace to be prone or susceptible to damage when a hazard event occurs (Blaikie, Cannon *et al.*: 1994). In a very simplified way it can be said that risk is like a warning signal that is telling us that a certain event can take place sometime in the future, and if this event does take place, we are to expect that somebody or something will be damaged by it. In this document the terms 'risk', 'vulnerability', and 'hazard' will be defined based on the definitions presented by the United Nations Disaster Relief Office (1991), see box *2-1* (page 17).

Hazards usually are divided into different types: Natural, socio-natural, man-made or technological, and social hazards. According to Lavell (2000) the 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. An example of a socio-natural hazard will be slope mining at the base of hills, which may lead to an increased probability of landslide occurrence. Man made or technological hazards include a wide range of different phenomena related to existing technical and technological conditions and the levels of insecurity they signify. Some examples are: contaminations of earth, water and air by toxic materials and explosions and conflagrations caused by an accident involving flammable materials. Social hazards refer to conflict situations ranging from war to civil strife and violence, including terrorism and the use of damaging artefacts.

Hazard in this document refers to the probability of a specific and potentially damaging event to occur. The probability value depends on the individual characteristics of the phenomenon being considered, but also on the spatial characteristics of the area where the hazard is being assessed. This approach defines the hazard as a spatial and temporal phenomenon. For example, a flooding hazard may have the probability to occur once every five years, but where? The flooding in an area adjacent to a river does not take place evenly in every square meter of land. The level of water will decrease inversely proportional to the elevation of the terrain. The probability of an earthquake to occur depends on the geological properties (and many other factors as well) of the soil. Usually, earthquakes are described in terms of their magnitude (M) and intensity (I). The United Nations Disaster Relief Office (1991) defines earthquake magnitude as *a measure of the strength of an earthquake, or the strain energy released by it, as calculated from the instrumental record made by the event on a calibrated seismograph;* and intensity as *a measure of the effects of an earthquake at a particular place.*

hazard (h):

the probability of occurrence, within a specific period of time in a given area, of a potentially damaging phenomenon.

vulnerability (v):

the degree of loss to a given element at risk or set of such elements resulting from the occurrence of a particular hazard and expressed on a scale raging from 0 (no damage) to 1 (total damage).

element at risk (e):

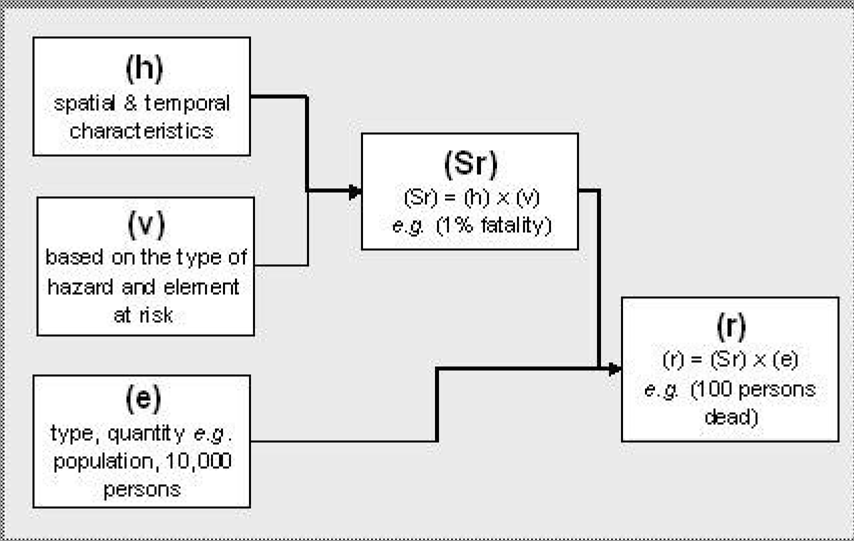
elements that can be damaged partially or totally when exposed to a hazardous situation. Some elements at risk are population, buildings, infrastructure, economic activities, public services, *etc*.

specific risk (Sr):

the expected degree of loss due to a particular hazard; calculated as a function of both vulnerability and hazard.

risk (r):

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 specific risk and element at risk.



Box 2-1 risk definitions

Adapted from United Nations Disaster Relief Office (1991)

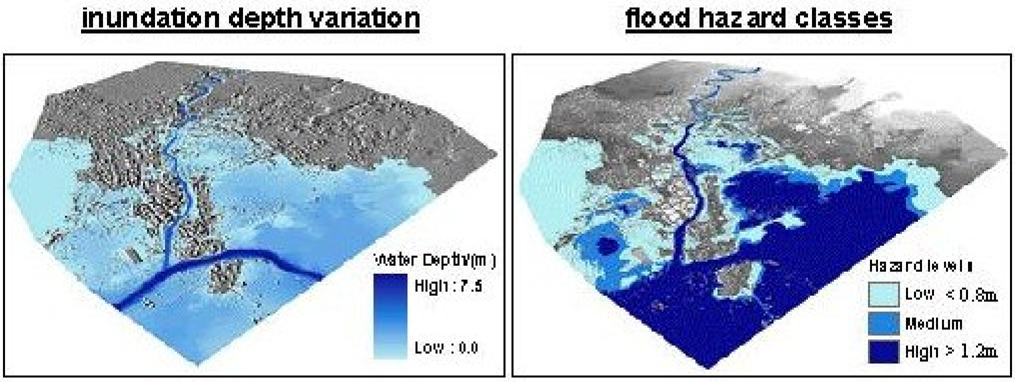


Figure 2-1 flood hazard map for Naga city, Philippines

Source Tennakoon (2004)

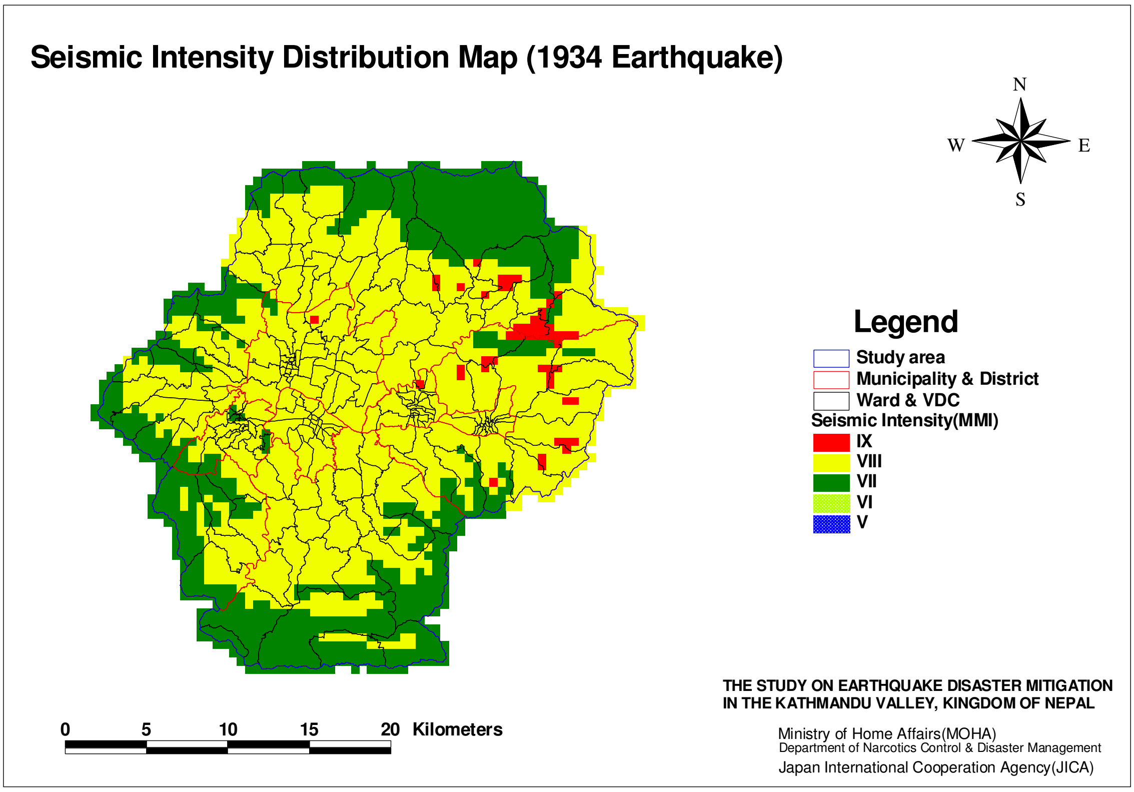


Figure 2-2 earthquake hazard map for the Kathmandu valley, Nepal

Source JICA (2002)

A man made hazard is for example the probability of an accident to occur in a certain section of a transport network, this is normally known as accident rate. To estimate the accident rate of a particular area, historical records of the accidents that have occurred in the area can be used. Nicolet-Monnier and Gheorghe (1996) mentions that 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 where no data is available assumptions are often made, Nicolet-Monnier and Gheorghe (1996) proposes as a typical accident rate value of *3.0 x* 10^{-6} *accidents/vehicle-km*. The accident rate can also be derived from the physical conditions of the transport network, such as the average traffic volume[1]. It is important to notice that an accident does not depend solely in the level of congestion of the network; human errors certainly contribute to produce accidents, driving at excessive speed, not leaving enough space between his/her car with the following one, over fatigue, failure to observe traffic warnings are some examples of human errors that can lead to an accident. Regardless of how the accident rate is estimated, it must be taken into account that there is a spatial component related to it; considering that the accident rate is not the same in every section of a transport network.

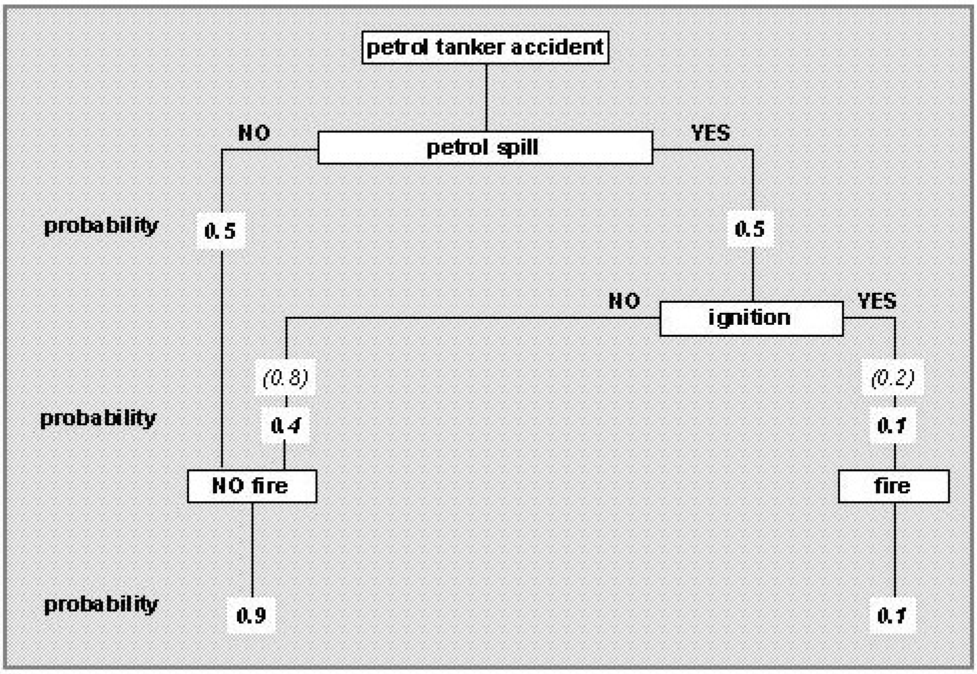


Figure 2-3 event tree for a petrol tanker accident
Source Nicolet-Monnier and Gheorghe (1996)

In the case of transporting HazMat a row of other events can be triggered after an accident occurs; events such as material spilling, explosion, and fire are three examples of triggered events. The hazard in this case will be expressed as the probability of the material to be spilled, or the probability of an explosion to occur, or the probability of the material to ignite (fire up). The probability values of each event triggered by an initial cause can be estimated using event trees. It is possible to use specialized computer codes to calculate the probability value of all the events displayed in a particular event tree. In their book, Nicolet-Monnier and Gheorghe (1996) give examples of an event tree for a petrol road

[1] Later in this document the approach to derive the accident rate from the traffic volume in the network will be discuss in detail

tanker accident. All the probability values shown in figure *2-3* were taken from the book mentioned above; the source and the criteria used for calculating these values is not explained though, therefore I limit myself to illustrate the figures. Nevertheless, it is logical to think that the event trees related to HazMat accidents will depend on the type of material being transported, on the physical characteristics of the transport unit, and other factors. Later in this document the probability value for fire ignition given figure *2-3* will be used.

The vulnerability of an element at risk depends on its characteristics and on the type of hazard being considered. Vulnerability is measured from a scale ranging from zero to one (UNDRO: 1991); where zero represents the situation when 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. To determine the vulnerability of a certain element at risk exposed to a given hazard, it is possible to use vulnerability curves (UNDRO: 1991). In cases where the hazard been considered is man made or technological, some researchers (*e.g*. Frank *et al*. (2000) and Zografos and Androutsopoulos (2004)) have used the term *potential impact area*, which is defined by a radial distance (λ) measured from the centre of the accident, assigning a vulnerability value of one to every element at risk located within the impact area, and zero to every element outside the impact area range.

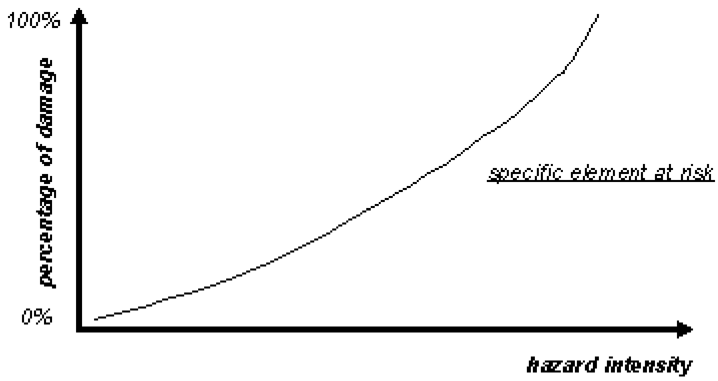


Figure 2-4 example of a vulnerability curve
Source UNDRO (1991)

When it comes to measuring risk it is necessary to use risk indicators or indexes. The risk index tells us how much risk there is for a particular element at risk exposed to a given hazard; the question that comes to play is: what units do we use to express risk? The answer to this question will depend of how specific we need to express risk. The specific risk is derived from multiplying the probability of a hazard with the vulnerability of an element at risk. The specific risk has no unit, but still can indicate what percentage is expected to be lost from an element at risk when 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 of debris, number of linear meter of road, number of millions of euros, are some examples of measurable units (see box *2-1* on page 17).

class of HazMat	impact area
combustible liquid	*0.8km* all directions
flammable liquid	*0.8km* all directions
flammable solids	*0.8km* all directions
oxidizers	*0.8km* all directions
non-flammable compressed gas	downwind *2.1km* wide x *3.2km* long
flammable compressed gas	*0.8km* all directions
poison/toxic	downwind *0.3km* wide x *0.5km* long
explosives	*0.8km* all directions
corrosive	downwind *0.8km* wide x *1.1km* long

Table 2-1 potential impact area based on the HazMat type
Source Nicolet-Monnier and Gheorghe (1996)

Other risk indexes are individual and societal risk. Bohnenblust and Slovic (1998) define individual risk as the annual probability of being harmed by an hazardous situation and societal risk as probability of a group of individuals, company or institutions to be affected by being exposed to a hazardous situation. Bohnenblust and Slovic refer to individual risk as the daily risks, like the risks to workers; and the societal risks as the one that affects the whole factory that employs the worker. Leonelli *et al.* (2000) stated that individual risk represents the yearly death frequency of an average person; societal risk represents the cumulated frequency of having an accident with a minimum number of fatalities.

individual risk:

represents the yearly death frequency of an average individual staying at the fixed point of the impact area.

societal risk:

represents the cumulated frequency (F) of having an accident with (N) or more fatalities.

Box 2-2 individual and societal risk definitions
Source Leonelli *et al.* (2000)

Individual and societal risk indexes are commonly used in risk analysis of fixed facilities; however these risk indexes can also be calculated as linear risk indexes for such cases as the transport of HazMat. Linear risk index because the route can be seen as a line formed by a continuous set of points, where every point represents a risk source; evaluating the contribution of these sources to the total risk over the route. According to Leonelli *et al*.(1999), to quantify these risk indexes, it is necessary to have access to a great amount of data, such as characteristics of the HazMat, meteorological conditions, and properties of the element at risk.

2.1.2 Risk factors considered in HazMat transport route modelling

Now that the basic terms of risk and its factors have been defined and discussed, I will look at previous research studies related to the topic of HazMat transport route optimization in order to answer the following questions: What type of risks and what risk factors have been considered when developing a route optimization model for HazMat transport? What risk indexes have been used in this research studies? By ‘risk factors’ I refer to hazards, vulnerability, and element at risk.

Leonelli *et al*. (2000) introduces a methodology based on the quantification of individual and societal risk indexes for the selection of 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, being affected in the case of an accident. The population value results from aggregating the population travelling on the transport network and the population located adjacent to the transport network. Leonelli *et al*. (1999) mentions that the use of individual and societal risk can give an accurate indication of risk, however to calculate these values, a great amount of data and programming effort is required. Due to this, a number of other simplified risk quantification techniques have been adopted in other research studies.

One research study that has considered a simplified approach to quantify risk is the one carried out by Frank *et al*. (2000). This research study focuses in the development of a spatial decision support system for the selection of route for the transport of HazMat within the United States of America. 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 extents to both sides of the route up to a predefined bandwidth. The hazard in this case is the probability of the HazMat transport unit to have an accident while travelling 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 time of the day. The risk for the population was calculated by multiplying the accident probability with the number of persons located in the impact area.

road type and condition	truck accident rate
dry urban expressway with **unrestricted** visibility	2.379×10^{-6} *accident per mile*
dry urban expressway with **restricted** visibility	4.054×10^{-6} *accident per mile*
highway with good weather, **day time**	1.440×10^{-6} *accident per mile*
highway with good weather, **night time**	1.470×10^{-6} *accident per mile*

Table 2-2 accident rate derived from historical data

Source Frank *et al.* (2000), based on the studies of Saccomanno and Chan (1985) and Jovanis and Delleur (1983) (this two sources are not listed in reference list)

As in the research studies mentioned above, Karkazis and Boffey (1995) also focus on the damage induced to the population in case of an accident. However, in this research study attention is given to the dispersion of the HazMat through air. Therefore, the impact area is not defined by a given band-width, but is a function dependant of the type of material transported and the meteorological conditions at the moment of the accident. Zografos and Androutsopoulos (2004) consider the population as the element at risk (as it has been considered as well in the research studies previously mentioned). In this research 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 the individual risk and the total population located in the impact area of the accident. The proposed simple equation used for estimating the individual risk however, does not consider all the parameters required by the equation proposed by Leonelli *et al.* (1999). Using the equation of Zografos and Androutsopoulos (2004), 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, explosion) in a certain release event, and the population within the impact area. The total risk for the population over the whole route will result from the summation of the risk values of every section in the route.

2.1.3 In search of other risk factors

It seems that technological hazards such as the probability of a HazMat transport accident, the probability of the spilling of the transported material after the occurrence of an accident, and the probability of an explosion triggered by the material spilled in an accident are the only types of hazard considered when doing a research study on route modelling for the transport of HazMat. The influence of external hazards such as natural and social hazards has not been considered in any of the research studies available. By external hazards I refer to those that are not related in any way with the phenomena of transporting HazMat, however if a damaging event derived by an external hazard occurs, the consequences of such an event can affect the transport operations, and generate other risks as well. As an example, consider the case when the area of HazMat transport operations has a high frequency of landslide occurrence, and therefore the HazMat transport should ideally be directed onto roads with the lowest probability value of landslide occurrence. On the other hand, it can be the case that the route with the lowest landslide probability is the one where the risk for the population derived from the accident probability on the route is at the highest level. In this case, deciding which route to take requires “a bit more thought”. Therefore, the integration of a number of different hazards (natural, man made or social) in the development of a route optimization model for the transport of HazMat will be the focus of this research study.

In the research studies previously discussed, the focus was centred on the analysis of risk in relation to the population. The models developed all aimed explicitly at reducing the number of persons expected to be killed in a HazMat accident. Damage produced to buildings or infrastructure by a HazMat accident has not been considered. In my opinion, this ‘omission’ becomes even more relevant when modelling the transport of HazMat through urban areas. Consider the scenario where a tanker transporting flammable liquid is routed through the city “X”. The tanker is involved in an accident while travelling in one of the areas with a high building density. The material spills from the tanker and a spark produced by the electrical system of the tanker generates the material to ignite, which seconds later creates a fire in the surrounding buildings. The fire spreads from one building to another until the fire squad is able to fight its way through the already congested and jammed street that is giving access to the accident site, and controls and extinguish the fire. The headings of the next morning newspaper recall the tragic events. This event might sound extreme, but an event of such magnitude can unexpectedly become reality, just as the gas explosions that inflicted major damage on the city of Guadalajara, Mexico, on the 22nd of April of 1992 (La Red: 1993).

Different functions used to quantify risk values have been proposed in previous research studies. Some of these functions aim to estimate the risk value as accurate as possible, thus requiring a great amount of data. There are other functions which give a simplified but still useful risk value. Quantifying risk in terms of individual and societal risk can give a good measure of risk; however it requires a great amount of available data, like data related to historical records of accidents, meteorological factors, and chemical properties of the material. It is a well-known fact that in developed countries such data is easier accessible, or there are enough resources to collect the required data, whereas in developing countries historical records and meteorological data for example may not be available. In most developing countries the lack of data is a fact that cannot be avoided and has to be dealt with when producing HazMat route optimization models. As the model that will be produced in the course of this research study is intended for use in developing countries, an approach of quantifying risk in a simplified and acceptable manner is pursued. A detailed explanation of how risk will be quantified in the model to be developed in the course of this research study will be given in the next chapter.

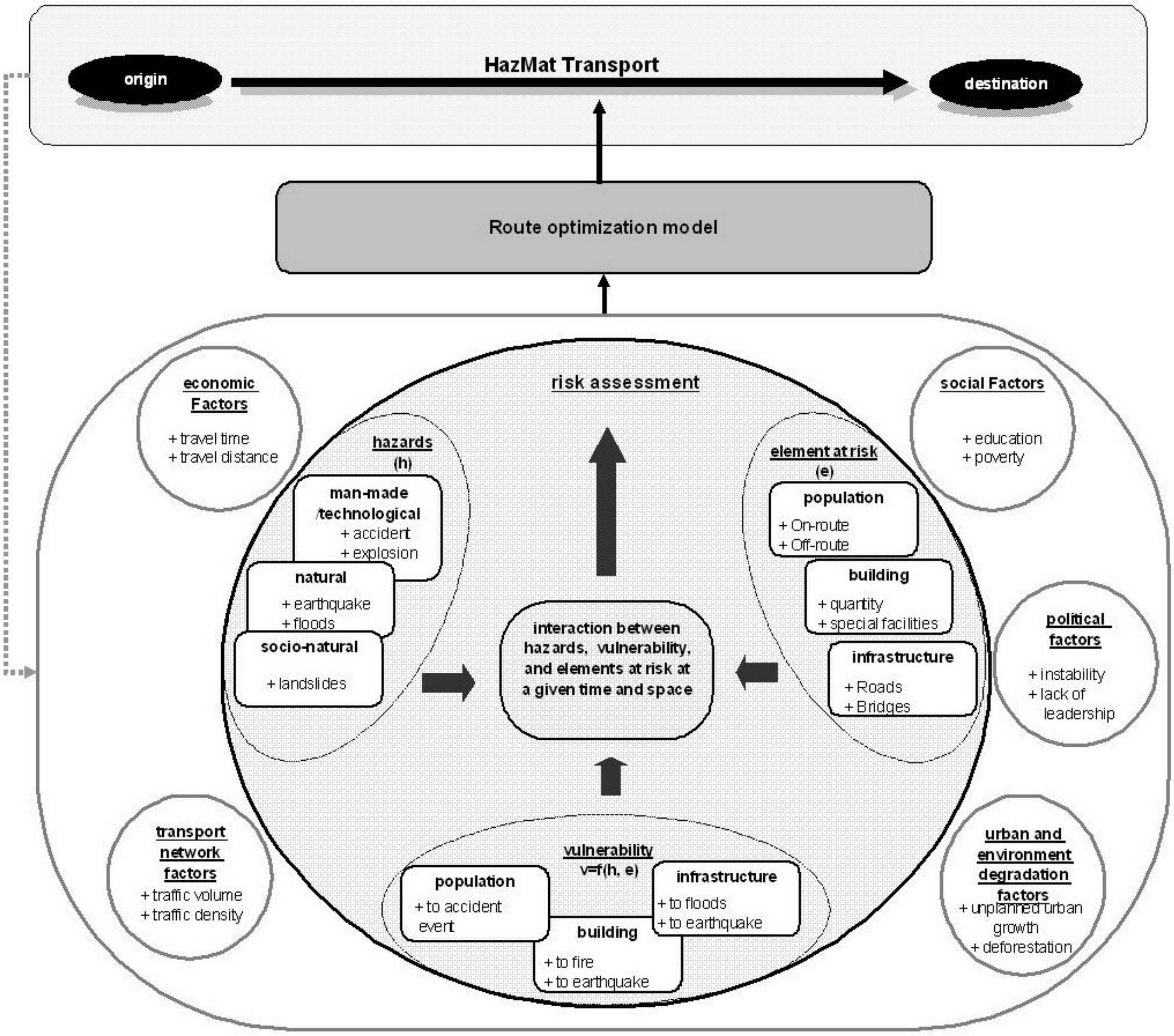


Figure 2-5 detailed conceptual model for research study

To make a précis, the research presented in this document aims to developing a route optimization model for HazMat transport, considering the followings points in the methodology:

- Integration of different types of hazards, such as natural, social, and technological.
- Extent the focus to other elements at risk than just population.
- Use of simplified quantitative risk analysis, in order to develop a model oriented to the use in developing countries.

The basic conceptual model presented in figure *1-4* (page 9) can now be shown as in figure *2-5*, where the small circles represent the factors that affect directly or indirectly the transport process of HazMat, and thus affecting the route selection for this purpose. The risk assessment considers the interaction of different hazards, different elements at risk, and the vulnerability of such elements at risk. When assessing the phenomena of transporting HazMat many inter-related factors can be considered, for example the risk factors can be influenced by other factors *e.g.* economic factors, political factors, social factors, *etc*. The conceptual model proposed for this research study tells the need to integrate as many factors (at least the most relevant) as possible for the modelling of optimal routes for the transport of HazMat.

2.2 Integrated risk management

Risk management activities reduce the probability of the risk event to transform into a real event. These risk management activities are called mitigation and prevention, where mitigation activities seek the reduction of vulnerability, and prevention activities try to reduce the hazard (Lavell: 2000; Mansilla: 2000). Risk management activities can be oriented to deal with specific and defined risk, and therefore allowing for an accurate assessment of the risk. Assessing risk individually does lead to the possibility of creating strategies that will reduce the risk level to its lowest value possible. Unfortunately, reality is far too complex to allow us to deal with risk individually, as most often one hazardous event is linked or related to one or more other hazardous events. Some events triggered others. Processes such as ‘urban degradation’ can influence the interaction process between different hazards and vulnerabilities. Urban degradation is a complex combination of processes that tend to disturb the balance in the urban system, increasing vulnerability levels, or creating new hazards factors and increasing vulnerability factors (Mansilla: 2000). Some of these processes are unplanned urban growth, bad construction practices, or constant immigration of people from the rural areas. In this document, integrated risk management refers to the management of different risks related to a certain phenomenon. A route optimization model that considers different risk sources for the selection of routes for HazMat transport can be used as an integrated risk management tool.

The importance of dealing with different risk sources lies on the fact that we cannot avoid to be exposed to every risk source. Perhaps by avoiding certain risk, we exposed ourselves even more to other risks. The government of any country cannot assure to protect the population against every risk source, or pursuing the reduction of every risk cannot be achieved because of economic reasons. By assessing risks and the processes that generate these risks a better management strategy can be formulated. Perhaps not all risk can be managed, but the decision of what risk should be managed or not can be based on the analysis made by the route optimization model.

2.2.1 Estimated risk versus perceived risk

Decision-making models are difficult to develop when different stakeholders are related to the problem. The interest of each stakeholder may conflict with the interests of each of the others. Adding to this, are the countless discussions that may follow if the problem studied is related to risk issues, due to the differences in the risk perception of the stakeholders. The risk values that one stakeholder may consider as acceptable, other stakeholders might consider unacceptable. In the integration of different risk sources for the management of risk, stakeholders may require a fair amount of time in discussing whether some risk are more important than others. The level at which risk is perceived will affect the way a decision-making problem is being modelled, as well as the way decision are taken.

Risk perception varies from person to person; it depends on many factors such as education level, cultural background, economical status, *etc.* (Rodes, de: 1994). The media also has influence on the risk perception of an individual or the risk perception of a whole society. A 'once a year' event that causes the death of 10 persons can receive more attention by the media than for example another event that causes the death of one person; but whereas the later occurs more frequently than the first one, therefore resulting in a much higher number of death per year. This means that risk perception can be highly influenced by the emphasis the media gives to the number of life losses in a disaster, regardless that the event has a lower occurrence frequency. Risk perception also depends on the benefits obtained. A person is willing to be exposed to some amount of risk if benefit is received back. The level of development or the economical situation of a country also influences the way risk is perceived. In a developing country, a low income family will be more concerned about having their basic need supplied than about knowing whether the family members are being exposed to some kind of risk.

In the case of transporting HazMat, the risk perception of the stakeholders involved strongly affects the way decisions are taken. For example the risk perception of the transport companies may differ from the one of the government. What may be perceived as unacceptable risk by the government may be perceived as acceptable for the transport companies, due to the economic revenue received from the transport activity. During the process of decision-making, a route optimization model can contribute to the debate and discussion about which route to use for the transport of HazMat. Furthermore, it contributes to determining which compensatory measures in the transport network can help reducing risk when no safe routes are found. By creating scenarios and analysing the scenarios' output, decision-makers can try to cope with the interest of every stakeholder related to the problem, even in cases where the risk perception levels are not common among all stakeholders.

2.2.2 The role of trade-off values

Part of the discussion regarding the selection of economical and safe routes for the transport of HazMat is the analysis of the trade-offs between the objective function values; in other words, the trade-off between the goals that may be pursued by the stakeholders. The term ‘trade-off’ in this document refers to the exchange of economical units for risk units, or vice versa. Since the integration of different risk sources is one of the components of the model discussed in this document, the trade-off between different risks also is possible. The trade-off analysis shows many units of costs are necessary to be spent in order to reduce one unit of risk. In routing problems of HazMat transport, the analysis of trade-offs gains importance when evaluating different scenarios. If many interests are considered in a decision-making process of a HazMat routing problem, some interests may be considered more important than others. Different scenarios can be created each time the level of appreciation for each interest changes. If each scenario, based on its initial parameters, suggests the use of a certain route, differing from the routes of other scenarios, the question that arises is which scenario should the decision maker consider in order to select the route that best satisfies the interest of the majority of the stakeholders? The answer to this question will be the result of the analysis of the trade-offs for each scenario.

It is also possible to analyse whether it is more feasible to invest in the improvement of the transport network in order to reduce the accident rate, thus reducing the risks derived from this event, than to construct new roads for the transport of HazMat; Furthermore, it can be analysed if it is necessary to chose longer routes in order to reduce the risks related to the transport of HazMat; and if the use of longer routes is necessary, it is possible to analyse how much subsidy the government should pay the transport companies in order to maintain the transport activity economically feasible. The participation of each of the stakeholders in the decision-making process becomes even more relevant when assigning the appreciation level to each of the criteria used for defining the route optimization model. A good model in my opinion is one that allows the stakeholders to create scenarios, while offering the possibility of customizing for each one of the scenarios the criteria to use and the priority given to each criterion, thus allowing the analysis of the trade-offs values of each scenario.

2.3 Modelling tools for HazMat transport problems

The process of developing a model for the optimization of routes for HazMat transport can be viewed as a two-stage process. In the first stage the planning part of the model takes place, whereas in the second stage the model for the use by the decision-maker or end-user is produced.

The planning stage focuses on the ‘what is going to be modelled’ part of the process, and the production stage focuses on the ‘how is going to be modelled’ part. In this section of the document attention is given to the question how models been developed in previous research studies. The aim of this section is getting an overview of the available modelling and programming tools that can be used to develop the route optimization model proposed in this document. To achieve this, some of the models developed in previous research studies will be mentioned, discussing how the route optimization problem was defined, what criteria were used in the route optimization model, and what tools were used for developing the route optimization model.

2.3.1 Geographic Information Systems (GIS) for transportation problems

The Geographic Information Systems (GIS) have proven to be a powerful and useful tool when modelling spatial data. In the last 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 provided with these extensions or capabilities are 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 processes (Lepofsky: 1996). With the use of GIS-T it is possible to find the shortest route between an origin and a destination point, based on the optimization of one objective. The objective can be used to represent time, or distance, population exposed, *etc*. Therefore, the optimal route can be found when minimizing either time, or distance, or population exposed individually. In the case the combination of different criteria is of interest, the units of each criterion must be converted into a single and common unit, such as monetary currency unit for example. Other GIS-T specialize in scheduling problems, using the same principle of finding the shortest route, being based on single-objective optimization and incorporating the temporal dimension into the problem, with the purpose of finding the best route to use and the best time for using/travelling the route.

The usefulness of GIS-T tools in the modelling of transport problems and especially in route optimization problems falls short when the problems modelled require more analytical power than is supported by the GIS-T (at least at the present stage of GIS-T 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 the 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 optimization software using mathematical programming codes can be use to perform the calculations required for the route optimization process.

2.3.2 Route optimization models developed for HazMat transport

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 can be misleading to thinking that only operational costs are considered in the route optimization model. However, the total cost in this research study results from the addition of the 'out-of-pocket' costs and 'risk-related' costs. The 'out-of-pocket' costs represent the operational costs related directly to the transport activity, whereas the 'risk-related' costs are related to the expected number of persons affected in case of the occurrence of an accident involving a HazMat transport unit. As it is important to express both out-of-pocket and risk-related costs with the same monetary currency unit, the Human Life Value (HLV) is used to express the risk-related costs in monetary terms. In this research, the operating costs are *0.86 Canadian$* km^{-1} $vehicle^{-1}$ and the HLV are *617,190 Canadian$* $fatality^{-1}$. In my opinion the use of HLV is not appropriate in a route optimization model intended for use in a developing country, as it may result in other unwanted consequences. The use of HLV requires constant updating, especially in those countries where an unstable economy leads to the devaluation of the currency exchange rate. If the HLV is not regularly updated, the value will not longer reflect the actual 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 politicians and authorities.

To estimate the number of fatalities along the route, Leonelli e*t al*. (2000) proposed to use the mathematical programming approach presented by Leonelli *et al*. (1999) which consist in the calculation of individual and societal risk using a 'rotation algorithm' and a 'translation algorithm'. The rotation algorithm is used to estimate the impact area around the accident site, whereas the translation algorithm is used to describe the movement of the vehicle along the route. Though, when performing the calculation for the optimal route, the use of a significant number of probabilistic values in the computation of individual and societal risk increases the uncertainty level. To avoid the increase of uncertainty in calculation of optimal route for HazMat transport, Bonvicini *et al*. (1998) proposed in their research study the reduction of the uncertainty in the estimation of the probability values later to be used in the calculation of individual and societal risk by means of fuzzy logic.

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 using a GIS environment for the visualization of the optimal routes, while in the model mathematical programming was used for the estimation of optimal routes. The optimization problem is defined as single objective temporal constraint shortest path using Dijkstra's algorithm. The model aims to minimizing the travel time between the origin and destination points, but the objective is subject to a set of constraints. The travelled distance, the accident probability on the route, the population exposed, and the risk for the population define the constraints functions of the model. The model allows the end 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 of a network section multiplied by the number of persons attributed to the same network section. Additionally, the model gives the end user the option to select through the user interface which constraint functions should be considered when solving the optimization problem. This allows creating different scenarios by either changing the upper bounds of the constraint or selecting different constraints, or changing both upper bounds and selection of constraints, finding for each scenario the optimal route. In this model the original units of the objective function values and the constraint function values are preserved, which I consider more appropriate than converting all units into one single monetary unit.

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. In pursue of this goal, 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 mathematical problem the weighting method is proposed. Using the weighting method the bi-objective formulation can be transformed into a set of single objective problems. The two objectives defined in the original problem are multiplied by their corresponding weights (appreciation indicator); the products of each multiplication are added and become the new single objective. The addition of both weights must add up to one. This research study is focused on the development of a new heuristic algorithm to calculate the optimal route. The heuristic algorithm is an insertion algorithm, which 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 the other research studies that I have discussed, in the number of objectives used to define the optimization problem. The purpose of this research study is to develop a multi-objective decision making model. The four objectives proposed to consider 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. As in all research studies previously discussed in this document, the risk for the population is calculated by multiplying the accident probability with the number of persons exposed. The term ‘special population groups’ is used for referring to groups of people that have evacuation difficulties, such as hospital patients, school children, elderly persons, *etc*. The travel time minimization is considered in order to pursue the reduction of operational costs. 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 the conversion of all objectives to a single monetary value when evaluating different scenarios, and, most important, it requires only a limited amount of information for the decision-maker.

2.4 Conclusions

In the last decades, several route optimization models for HazMat transport have been developed, but is there still a scope for doing more research on this topic? After reviewing all possible literature in the restricted time for this research study, I can conclude that there certainly is in fact a scope for improvement in the development of route optimization model for HazMat transport. The methodology that is proposed in this research will be shaped in such a way, as to deal with the issue of integrating different risk sources, taking into account different hazards, and different elements at risk with their respective vulnerability. I recall to the reader figure *2-5* (page 25) presented earlier in this chapter, which represents the integration of different factors that influence or are influenced by the phenomenon of transporting HazMat. In this research study factors related to economic issues will be considered in order to assure the economic feasibility of the transport operations; also factors related to risk issues will be dealt. For the risk issues man made and natural hazards will be considered, as well as population and buildings will be considered as elements at risk. In order to transport HazMat, a mode of transportation must be used; in this research study the mode of transport will be limited to road mode.

When developing a route optimization model for the transport of HazMat, the criteria defining the optimization problem must reflect the interests of the stakeholders related. Of course in order to model the criteria, a modeller must translate the interests of the stakeholders into the programming language used in the model. The stakeholders as well represent the end-users of the route optimization model, since they are in fact who have to make decisions related to the HazMat transport problem. For this reason it is important that the stakeholder can create and evaluate scenarios in the route optimization model in order to get a better understanding of the problem, thus making better decisions. For every scenario evaluated the model should easily allow performing a trade-off analysis among each of the criterion optimal values; it is the trade-off analysis that can greatly influence the final stage of the decision-making process for the route selection for HazMat transport.

The approach of using GIS software in combination with a specialized optimization software as well is proposed for the development of the route optimization model in this document. The use of GIS is without a doubt the most suitable tool for the management of the geo-data and for visualizing output generated by the model; however for solving the optimization problem *i.e.* calculating the optimal routes, specialized optimization software for handling the mathematical programming language will be used. The use of mathematical programming is based on the fact that multiple objectives will be considered in the development of the route optimization model proposed in this research study. In order for the end-user to make the most out of the model, a user-friendly interface is proposed to be developed. The user interface for the route optimization model must serve as a link between the GIS and the optimization software.

3. Proposed methodology for model development

This chapter contains the methodology proposed for the development of a route optimization model, which takes into consideration the integration of different types of hazards (man-made and natural), as well as the elements at risk that can be affected by the hazards. The chapter start however, by giving a background related to the basic elements that compose the transport network (arcs and nodes). Following this, the optimization problem is defined, discussing as well the process for solving the problem. It is then in the last part of the chapter that the methodology is presented.

3.1 Arcs and nodes: the basic network elements

The unit or tanker transporting the HazMat must make use of the available transport network. In simple terms the transport network is the set of roads that connect the origin and destination point. These roads can be highways or major arterial roads, as well as minor urban and rural roads. The transport network is divided into sections, where the beginning and ending of each section can represent an intersection where other road sections connect.

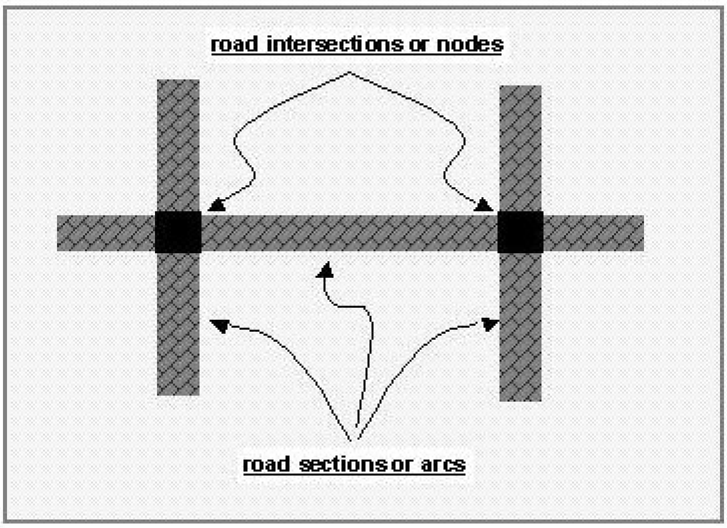


Figure 3-1 road sections and intersections

In Mathematical terms a network can be defined as a graph $G(V,E)$ composed by a set of nodes (V), where the nodes are connected through a set of arcs (E) (Chen: 1990). Other names used for nodes are 'points' or '0-simplex', and for arcs the terms '1-simplex', 'edge' or 'link' are also acceptable (By, de: 2001). In this paper however, the terms 'nodes' and 'arcs' will be further used. Arcs are composed of a pair of nodes (i, j) called 'starting node' and 'ending node' respectively, where every node belongs to the set V. The mathematical representation of the arcs will be:

E: $(i, j) \rightarrow i, j \in V$

To each arc, attributes can be assigned to represent the characteristics of the network itself, *e.g.* travel time, length, width, number of lanes, capacity, orientation, *etc*. The orientation for example is used to determine the type of traffic flow over the arc. The three types of orientation are: one way, two ways or no way (Rockafellar: 1984).

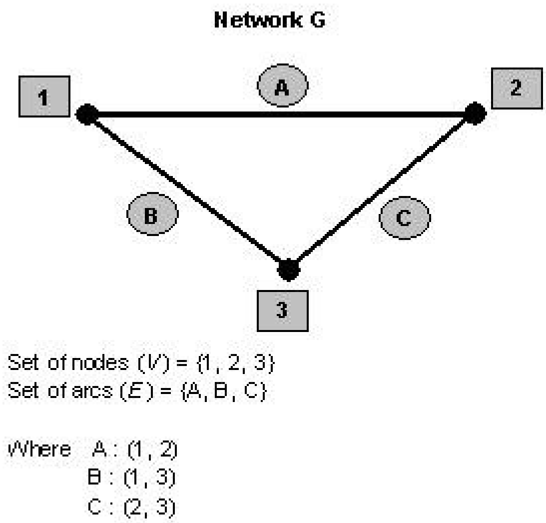


Figure 3-2 basic network G composed by set of nodes V and arcs E

3.2 Defining the optimization problem

As different objectives derived from the interest of the stakeholders will be considered as criteria for the evaluation and route selection for the transport of HazMat, the problem is defined then as a multi-objective optimization problem. The solution approach used in this research study is based on the approach used by Zografos and David (1989) in their research study with a few differences in the objectives been considered. By means of 'Multiple Objective Mathematical Programming' (MOMP), different and conflicting objectives were evaluated in order to find the route for HazMat transport that best copes with the optimization criteria. The objectives that will be used as criteria in the route optimization model presented in this research study are: minimization of travel time, minimization of travel distance, minimization of risk for the population, minimization of risk for the 'urban environment', and minimization of risk related to a natural hazard. The objectives are not fixed, as it has been stated in numerous occasions in this document that it is important that the objectives reflect the interests of the stakeholders involved in the decision-making process. However, in order to give an understandable explanation of the methodology for the model development, each of these objectives will be described throughout the chapter. In the next chapter, the issues of who are the stakeholders and how the objectives used in this model (mentioned above) manifest their interest will be discussed.

3.2.1 Multi-objective optimization problem

The original problem is defined by a set of (n) objectives (F), subject to a (m) number of constraints. The mathematical representation of the problem is as follows:

$$Minimize\_F = \begin{bmatrix} F_1 \\ F_2 \\ \vdots \\ F_{n-1} \\ F_n \end{bmatrix} \quad \text{(Eq - 1)}$$

Subject to:

$$\begin{Bmatrix} Con_1 \\ Con_2 \\ \vdots \\ Con_{m-1} \\ Con_m \end{Bmatrix} \quad \text{(Eq - 2)}$$

As solution method for multi-objective optimization problems, goal programming can be used. Solving this problem takes place in two steps; in the first step each objective is optimized individually, and in the second step the multiple objective optimization is performed. The purpose of the first step is to find the solution for which each objective is best achieved, regardless to the fact that the rest of the objectives may perform poorly. By doing this individual optimization it is possible to estimate the ideal point (read: value) that can be achieved by each objective. The purpose of the second step is to find a solution where each objective value can get as close as possible to the respective ideal point, taking into account the priority assigned to each objective. In order to achieve this, a deviation variable is assigned to each objective. The deviation variable represents the closeness to each objective ideal point. The original problem is reformulated to minimize the total deviation, which is defined as the summation of the products of each deviation variable and the priority assigned to each objective. The assignment of priority factors or weights implies that a higher priority objective should be satisfied before considering the satisfaction of any other objective that belongs to a lower priority level (Zografos and Davis: 1989). The transformed formulation for the optimization problem is:

$$Minimize\_F_g = P_1 d_1 + P_2 d_2 + \cdots + P_{n-1} d_{n-1} + P_n d_n \qquad \text{(Eq - 3)}$$

Subject to:

$$\begin{aligned} & F_1 - d_1 \leq b_1 \\ & F_2 - d_2 \leq b_2 \\ & \vdots \\ & F_{n-1} - d_{n-1} \leq b_{n-1} \\ & F_n - d_n \leq b_n \end{aligned} \qquad \text{(Eq - 4)}$$

In this new formulation the function F_g expresses the objective that seeks the minimization of the total deviation value. The b values express the desired ideal point *i.e*. the optimal solution for each individual optimization problem subject to the set of constraints (eq-1, 2). The P values represent the priority weight for each objective. The d values are the deviation variables correspondent to each objective function.

Just as one objective can differ and conflict with others, the units in which each objective is measured can also differ to the units of other objectives. In order to avoid converting all units into a common one, it is necessary to normalize the deviation values. In order to do so, each deviation variable is divided by the respective ideal value. In this case the equation (eq-3) must be substitute by the following:

$$Minimize\_F_g = \frac{P_1 d_1}{b_1} + \frac{P_2 d_2}{b_2} + \cdots + \frac{P_{n-1} d_{n-1}}{b_{n-1}} + \frac{P_n d_n}{b_n} \qquad \text{(Eq - 5)}$$

3.2.2 Solving the multi-objective optimization problem

The purpose of this section is to illustrate how the multi-objective optimization problem is solved, and specifically to show the role of the deviation variables. As an example, consider the case where the selection of route for the transport of a given type of HazMat is based on two objectives, let us call these objectives: objective “a” and objective “b”. The first step of solving the problem will be to optimize both objectives individually, from which we obtain the following output:

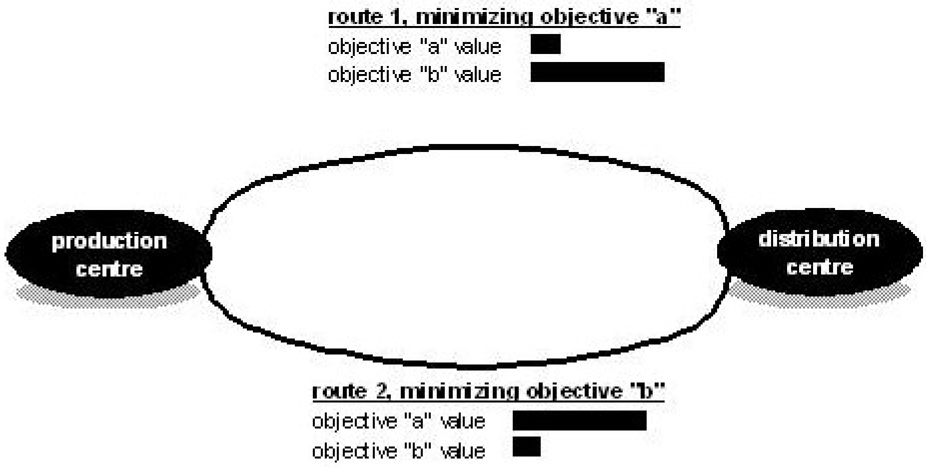


Figure 3-3 route optimization example

A different route is selected for every objective that is being minimized. The conflicting situation is that if one objective is being minimized, the value of the other objective function tends to increase. In order to try to optimize both objectives we then proceed to perform the calculation of the route, based on the minimization of the total deviation.

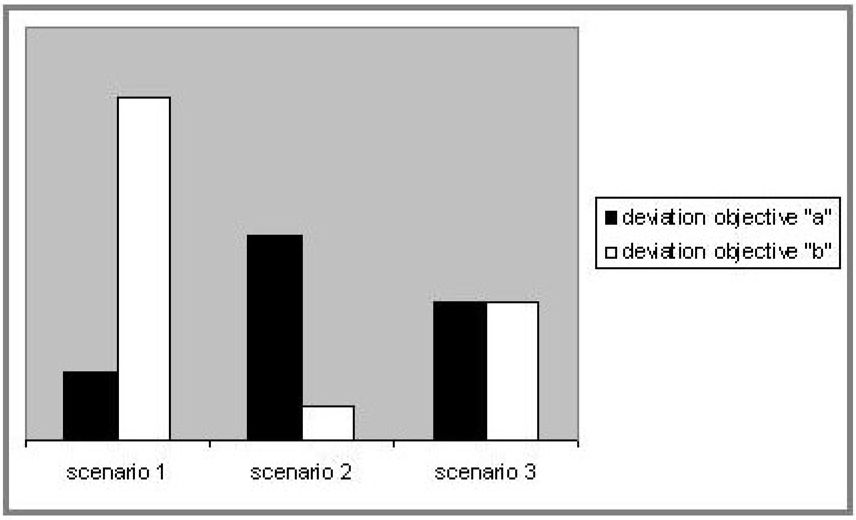


Figure 3-4 minimizing total deviation

Consider three possible scenarios: in the first scenario; objective “a” receives a higher priority; in the second scenario, objective “b” receives higher priority; and in the third scenario both objectives receive the same priority level. In the first scenario, since objective “a” has a higher priority, the optimization process will define the route in such a way that the value for objective “a” will differ as less as possible from the ideal attainment value. Thus achieving the lowest deviation value possible for the objective “a”, as well as achieving the lowest total deviation value. However, as seen in figure *3-4* the individual deviation of the objective “b” in this case does not necessarily represent its lowest value. In the second scenario, the priority is set on the objective “b”; therefore the individual deviation correspondent to objective “b” has a lower value. The deviations and routes calculated can be summarized in figures *3-4* and *3-5*.

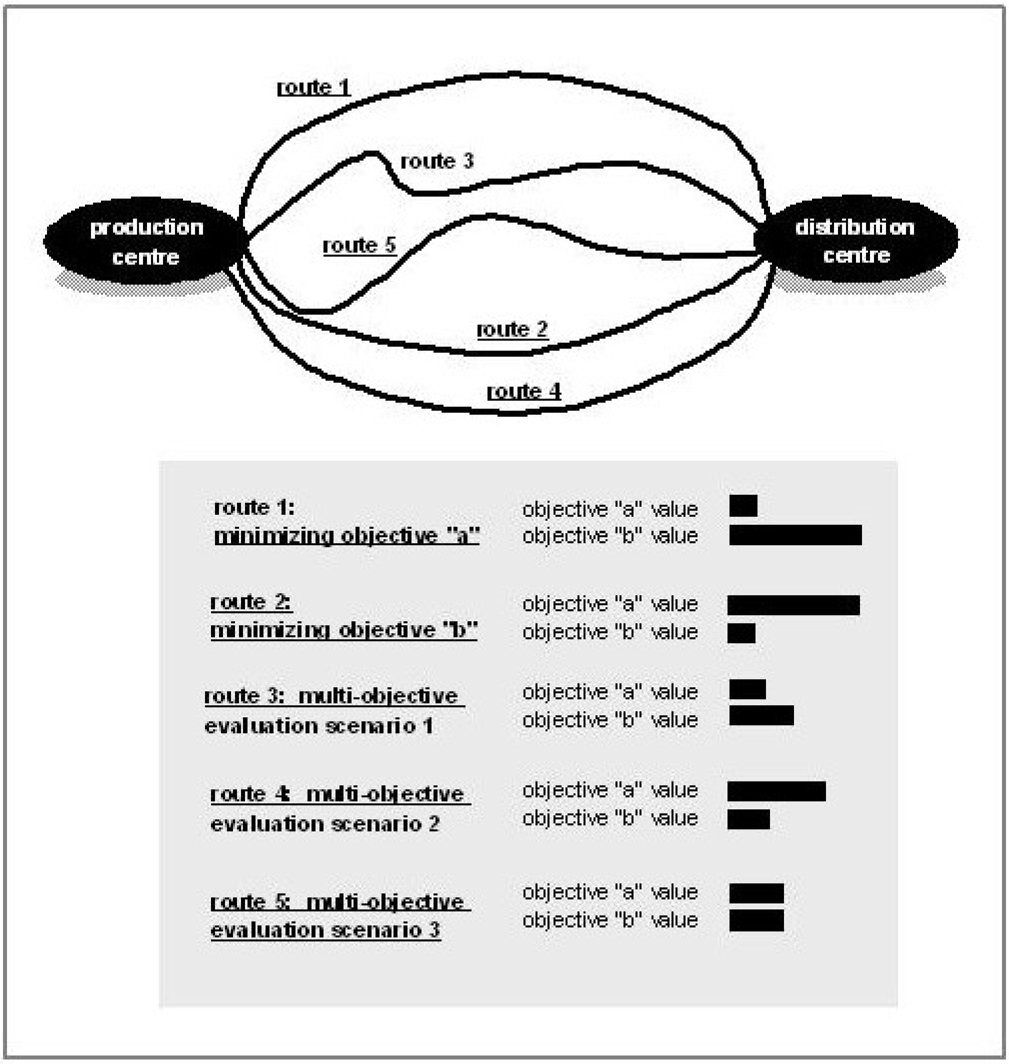


Figure 3-5 finding routes for different scenarios

The final selection of the route can be subject to discussion, as in a real case the actual values of the trade-off should be taken into account.

3.3 Route optimization model

One important aspect of the route optimization model to be developed is a 'flexibility' high enough to allow for the modification and/or addition of objective functions set by the stakeholders. Therefore, I propose to follow a phase-wise methodology, determining in each phase the optimal routes for the transport of HazMat, based on the objectives and scenarios set for that particular phase and the previous phases. The first phase is intended to model the typical routing problem, based on the economical factors only. In the second phase, a HazMat accident event and population are introduced as man-induced hazard and element at risk respectively. In the third phase, a fire event triggered by the HazMat accident (technological hazard) and building (vulnerability in relation to the fire) are introduced. In the fourth phase, a natural hazard is introduced, and with it the building vulnerability related to the natural hazard. The final scope of the fourth phase is to be able to incorporate hazards that are not directly related to the HazMat transport phenomena; but where such hazards could influence the selection of optimal route for the transport of HazMat.

Before going into detail with the phases of the proposed methodology, I will define what is the decision variable to be used in the optimization problem, and what the constraints are considered that will affect the evaluation of optimal routes. These constraints are applicable for every phase of this methodology.

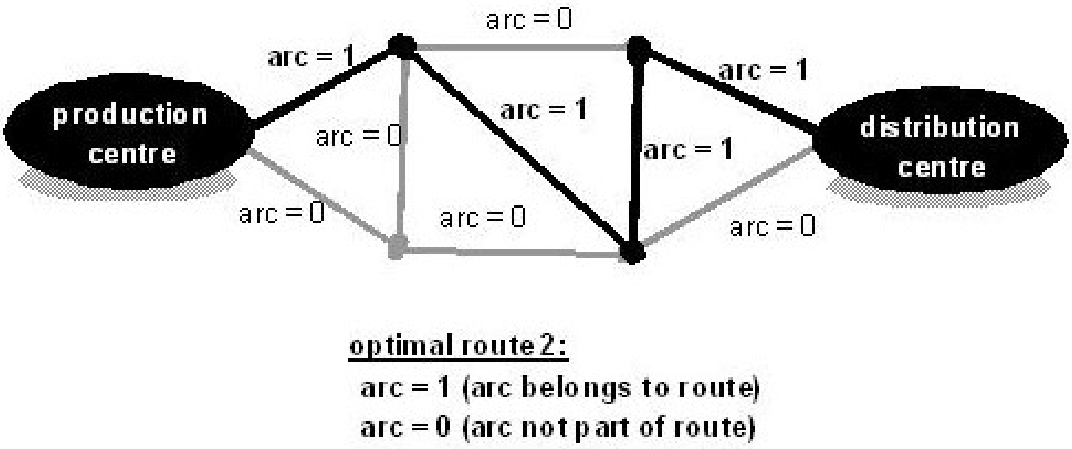


Figure 3-6 individual decision variable of each arc

3.3.1 Decision variable

In order to identify the arcs that are part of an optimal route after solving the optimization problem, it is necessary to use a binary decision variable. Each arc in the network is assigned to one binary decision variable. Each time the optimization problem is solved, the decision variables of every arc on the network are calculated. A decision variable with a value of one will indicate that the arc forms part of the route, a value of zero will indicate that the arc does not form part of the route.

3.3.2 Series of constraints

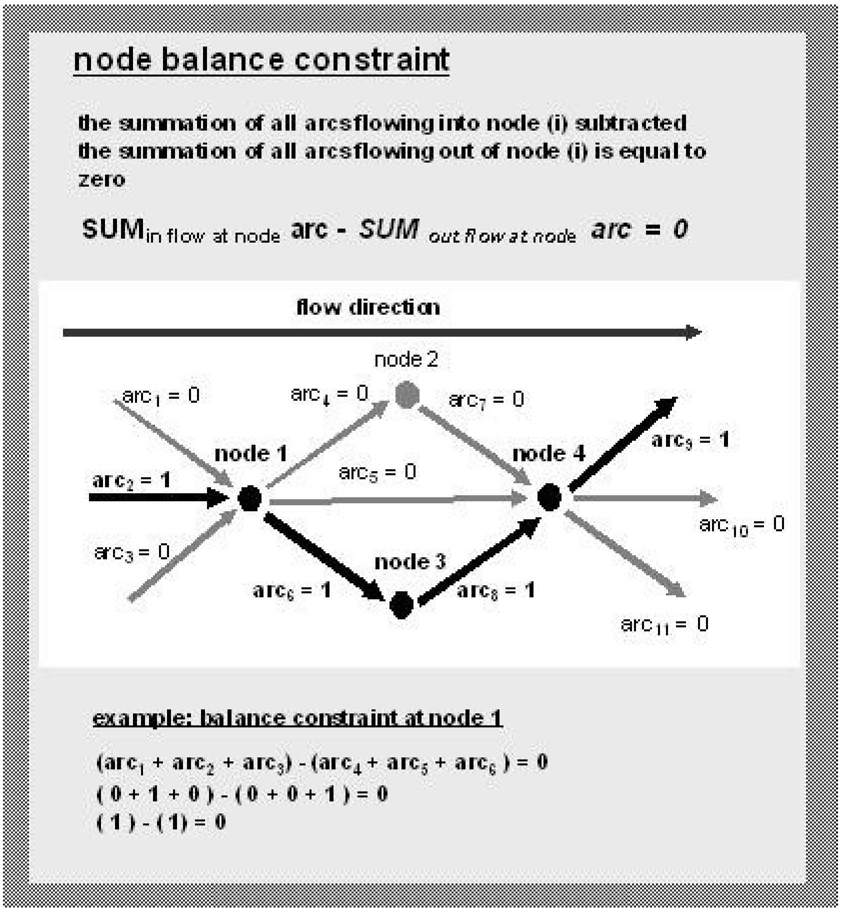
The first constraint is used to define the set of admissible arcs. Every arc on the transport network can be labelled either as ‘admissible’ or ‘not admissible’. The arc selected for a route must belong to the set of arcs labelled ‘admissible’. This means that special cases considered by the stakeholders could be handled by constraining the roads where it is allowed to transport petrol derivates. One example would be trying to avoid the selection of an arc on which hospitals, schools, and other important facilities are located. Another example is the case when considering that the arcs where the transport units will be travelling along need to be able to support the gross weight of such units; these arcs also must have a minimum width. The same approach is applicable when having to cross bridges or high level crossings not capable of supporting heavy traffic. One last example is the case of trying to avoid the selection of arcs that have been affected by other natural or man-made events, such as earthquake, landslides, road maintenance, or concentration of workers on strike.

The second constraint is used to ensure that over the whole route, at every ending node of each arc one and only one starting node is selected. In other words, the constraint is used to maintain the balance for every node in the route. For every node in the route (except the first and last node of the route) there must be only two arcs connected to it, one arc representing that a vehicle is entering or passing by the node and the other representing the direction that the vehicle took after exiting the node.

The mathematical expressions for the constraints described above are:

$$\forall arc \in admissible\_arc \qquad \text{(Eq - 6)}$$

$$\sum\nolimits_{in\_flow\_at\_node} arc - \sum\nolimits_{out\_flow\_at\_node} arc = \begin{cases} 1 \rightarrow at\_origin \\ 0 \\ -1 \rightarrow at\_destination \end{cases} \qquad \text{(Eq - 7)}$$



Box 3-1 node balance constraint example

3.3.3 Phase "A": typical routing problem

The phase "A" will focus on the minimization of travel time and distance between the points of origin and destination. The objective functions used in this phase will deal with the minimization of operational cost and maximization of profit for the companies that transport the HazMat from the source points to the destination points. In order to reduce costs, private or public companies in charge of transporting HazMat often use of the shortest routes available. The shortest route available can be identified as the route with the lowest travel distance and/or travel time (Zografos and Davis: 1989; Leonelli, Bonvicini *et al.*: 2000; Fabiano, Curro *et al.*: 2002). The travel distance is simply the length of each arc. The total travel distance is the sum of length values of every arc in the route. The travel time required for a given arc can be estimated by dividing the length of the arc by the arc speed. Impedance time values can be added to the estimated arc travel time value. The purpose of using an impedance time is to represent average waiting time at road intersections. The total travel time for a given arc will be the sum of the simple arc travel time and the impedance time attributed to its end node. The mathematical equations to be used in phase "A" are:

$$Minimize\begin{Bmatrix} travel\_distance \\ travel\_time \end{Bmatrix} \qquad \text{(Eq – 8)}$$

$$travel\_distance_{route} = \sum_{arc} length_{arc} * arc \qquad \text{(Eq – 9)}$$

$$travel\_time_{route} = \sum_{arc} \left[\left(length_{arc} * avg\_speed_{arc}\right) + imp\_time_{arc}\right] * arc \qquad \text{(Eq – 10)}$$

Where $travel\_distance_{route}$: travel distance for the route

$travel\_time_{route}$: travel time for the route

$length_{arc}$: length for each arc

avg_speed_{arc} : average speed for each arc

imp_time_{arc} : average waiting time at arc intersections

arc : binary decision variable, indicating that an arc belongs to the route (see section *3.3.1*)

3.3.4 Phase “B”: accident as hazard and exposed population as element at risk

Phase “B” will focus on the minimization of the risk for the population, in addition to the two objective functions used in the previous phase. The approach to calculate the risk for the population in relation to a HazMat transport accident used in this document is based on the approach proposed by Zografos and Androutsopoulos (2004). The risk for the population is defined as the product of the probability of the HazMat transport accident and the population being exposed. The probability of the HazMat transport accident is proportional to the accident rate over the transport network and the probability of the HazMat transport unit to be involved in an accident.

$$acc\_prob_{arc} = acc\_rate_{arc} * hazmat\_prob \qquad \text{(Eq – 11)}$$

Where acc_prob_{arc} : accident probability on each arc involving a HazMat transport unit

acc_rate_{arc} : accident rate for each arc in the transport network

$hazmat\_prob$: probability for a HazMat transport unit to be involve in an accident

The total population exposed to the hazard is the sum of the on-route and off-route population. The first is the population estimated to be travelling on the arcs that could be affected by the accident; this is the number of vehicles on the arc multiplied by the average number of persons per vehicle. The latter is the population situated within the impact area of the accident. The definition of the impact area was discussed in section *2.1.1*. The mathematical equation use for calculating the population exposed is as follows:

$$pop\_exposed_{arc} = tot\_pop_{arc} \qquad \text{(Eq – 12)}$$

If $tot\_pop_{arc} = pop_{on\_route\_arc} + pop_{off\_route\_arc}$ (Eq – 13)

Then the equation (Eq – 12) becomes

$$pop\_exposed_{arc} = \left(n_{vehicles} * n_{\frac{persons}{vehicle}} \right)_{arc} + \left(population(\lambda) \right)_{arc} \qquad \text{(Eq – 14)}$$

Where

$pop\_exposed_{arc}$	: number of persons exposed to an accident event along one arc
tot_pop_{arc}	: total population attributed to each arc
$pop_{on\_route\_arc}$	: estimated population on-route for each arc
$pop_{off\_route\_arc}$	: estimated population off-route for each arc
$n_{vehicles}$	: average number of vehicles travelling on one arc
$n_{\frac{persons}{vehicle}}$	: average number of persons per vehicle travelling on one arc
$population(\lambda)$	: number of persons situated within the impact area of the accident site (in section 2.1.1 the definition of (λ) is given)

The risk over the whole route will be the summation of the risk values of every arc in the route. This risk measure will indicate the number of persons expected to be injured or dead in case of a HazMat accident to occur. The evaluation of this objective should result in choosing the route with the lowest values of risk for the population. The mathematical equations to be used in phase “B” are:

$$Minimize\begin{Bmatrix} travel\_dis\tan ce \\ travel\_time \\ risk\_pop \end{Bmatrix} \qquad \text{(Eq – 15)}$$

$$risk\_pop_{route} = \sum_{arc} \left(acc\_rate_{arc} * hazmat\_prob * pop\_exposed_{arc} \right) * arc \qquad \text{(Eq – 16)}$$

Where $risk\_pop_{route}$: risk measure over the route in terms of number of persons affected

arc : binary decision variable, indicating that an arc belongs to the route (see section *3.3.1*)

3.3.5 Phase "C": fire as hazard and exposed building as element at risk

Phase "C" will focus on the minimization of specific risk for the urban physical environment in case of an accident. In this case, the risk will be composed of the interaction of the probability of fire as hazard, and the building vulnerability. The probability of fire to occur once a HazMat transport accident has taken place can be estimated by multiplying the ignition or fire probability and the probability of a HazMat transport accident (which has been already defined in the previous phase). With the aid of the event tree shown in figure *2-3* (page 19) the fire probability can de determined, nevertheless as said earlier defining the fire probability for a given case study can be subject of further analysis. To estimate the building vulnerability in case of fire, the predominant building material type per arc is required, which will then be assigned to each arc, based on the building vulnerability. For areas with a predominant type of building material of reinforced concrete, a low building vulnerability value will be assigned, whereas the areas where wood is the predominant building material type will have a higher building vulnerability assigned. The aim of this objective is to minimize the expected urban damage produced by an accident-triggered fire event involving a HazMat transport unit. The specific risk for the urban environment will be the result of multiplying the HazMat accident probability, the fire probability, and the estimated building vulnerability in relation to fire. The final result will be a value without units, which will serve as indicator for areas with high or low expected urban damage in case of fire (specific risk). The mathematical equation to use in this phase is:

$$Minimize\begin{Bmatrix} travel\_dis\tan ce \\ travel\_time \\ risk\_pop \\ risk\_urban \end{Bmatrix} \qquad \text{(Eq – 17)}$$

$$risk\_urban_{route} = \sum_{arc} \left[\left(acc\_rate_{arc} * hazmat\_prob * fire\_prob \right) * buil\_vul_{arc} \right] * arc$$

(Eq – 18)

Where $risk\_urban_{route}$: relative risk value estimated to represent the degree of urban damage along the route produced in case of fire triggered by a HazMat transport accident

$fire\_prob$: fire probability

$buil\_vul_{arc}$: building vulnerability in relation to fire assigned to each arc

arc : binary decision variable, indicating that an arc belongs to the route (see section *3.3.1*)

3.3.6 Phase “D”: earthquake as hazard and building as element at risk

In phase “D” the focus is on the integration of other natural hazards into the model of route optimization for HazMat. If the HazMat are being transported through a city, and the building vulnerability to the natural hazard is known, the route selection for the transport of HazMat should also consider these risk factors (the hazard and vulnerability to the hazard). Consider the case of an earthquake; the amount of debris produced by the collapse of buildings during the earthquake event increase the hazard of an accident to occur, and therefore the hazard of fire. In the case where two routes are available for the transport of HazMat for example, one of the routes has a low accident rate but with high building vulnerability for earthquake; the second route on the other hand, has a high accident rate, but low building vulnerability for earthquake. The question is now, which route should be used for the HazMat transport? In the first case, the chances of an accident to occur are low. However, if an earthquake takes place, it is most probable that the transport unit would not be able to use this route, and in the worst case the chances for an accident to occur are much higher. In the second case, there is a greater chance of accidents to occur. However, even after an earthquake event, it is most probable that the route could still be used for the HazMat transport. Still, the answer to the question previously postulated is not clear yet. To answer this question, the population factor can be taken in account: if the expected number of affected persons is determined for both routes, a decision can be made based on this last factor. For this phase the input of an earthquake model for the study area is necessary. The output required from such a model is the degree of building damage expected in case of an earthquake *i.e.* the specific risk for buildings in case of an earthquake. Through a GIS overlaying process this specific risk can be assigned to each individual arc. The value assigned to each arc can be labelled as earthquake-building risk score, making reference to the fact that the natural hazard considered is related to an earthquake and the vulnerability is based on buildings. The route optimization equation will be then:

$$Minimize\begin{Bmatrix} travel\_dis\tan ce \\ travel\_time \\ risk\_pop \\ risk\_urban \\ risk\_eq-buil \end{Bmatrix} \qquad \text{(Eq – 19)}$$

3

$$risk\_eq-buil_{route} = \sum_{arc} risk\_eq-buil_{arc} * arc \qquad \text{(Eq – 20)}$$

Where $risk\_eq-buil_{route}$: qualitative risk measure of the amount of expected building damage in case of an earthquake along the route

$risk\_eq-buil_{arc}$: earthquake-building specific risk score assigned to each arc

4. Transporting petrol derivates in Nepal

This chapter focuses on describing the findings of the fieldwork that was carried out in the case study. In the first section of the chapter a background about the transport of petrol derivates in Nepal, and particularly in the Lalitpur city is give. In the second section the main stakeholders are introduced, discussing as well their interest related to the case study problem. The following three sections in this chapter describe the data that was collected during the fieldwork. The last section lists the problem and limitations in relation to the available data from the case study.

4.1 Background

In geographical terms, Nepal is located between India and China, very well known for having within its territory the "top of the world", Mount Everest. It has a diverse geography, which ranges from the high-elevated mountains of the Himalayas to the low lands in the southern part of the country. The country is politically divided into five geographical regions: eastern, central, western, mid-western, and far western region. The Kathmandu valley is located in the central region where the cities of Lalitpur, Bhaktapur, and Kathmandu are located.

The Urban growth in the Kathmandu valley has increased dramatically in the last decade. In Lalitpur city alone, the population increased almost 50% between 1990 and 1999 (105 thousand and 157 thousand inhabitant in 1990 and 1999 respectively) (UNESCAP: 2003). The important fact in relation to the topic of this research study is the considerable increase in the number of vehicles in the Kathmandu valley in the last decade, see figure *1-5* (page 10). The increase in the number of vehicles certainly led to an increment in the overall petrol derivate consumption. The increase in the demand for petrol derivates means that the number of units transporting industrial amount of these type of HazMat will be increased as well. From this point onward the units used for transporting the petrol derivates will be called 'tankers'.

Figure 4-1 map of Nepal showing the five regional divisions
Source (Thakur: 2004)

The petrol derivates consumed in Lalitpur city as well as in the rest of the country, are imported from India. These materials are transported by mode of the transport network, and using tankers with capacity of 10,000liter and 12,000liter. These tankers are relative small in size compared to the tankers often used in other countries. However, due to characteristics of the topography and the transport network of the country, the use of bigger tankers with higher capacity will make the transport operation too complicated to perform.

The imported materials are transported to petrol depots that serve as storage and distribution centres. In the Kathmandu Valley the Thankot petrol depot, located in the outskirts of the valley, serves as main supply source for the petrol derivates consumed in the cities of Lalitpur, Kathmandu, and Bhaktapur. From the Thankot petrol depot the petrol derivates are transported to the gas stations spread across the Kathmandu valley. In this research study the focus is set on the transport of petrol derivates within the limits of the Lalitpur city.

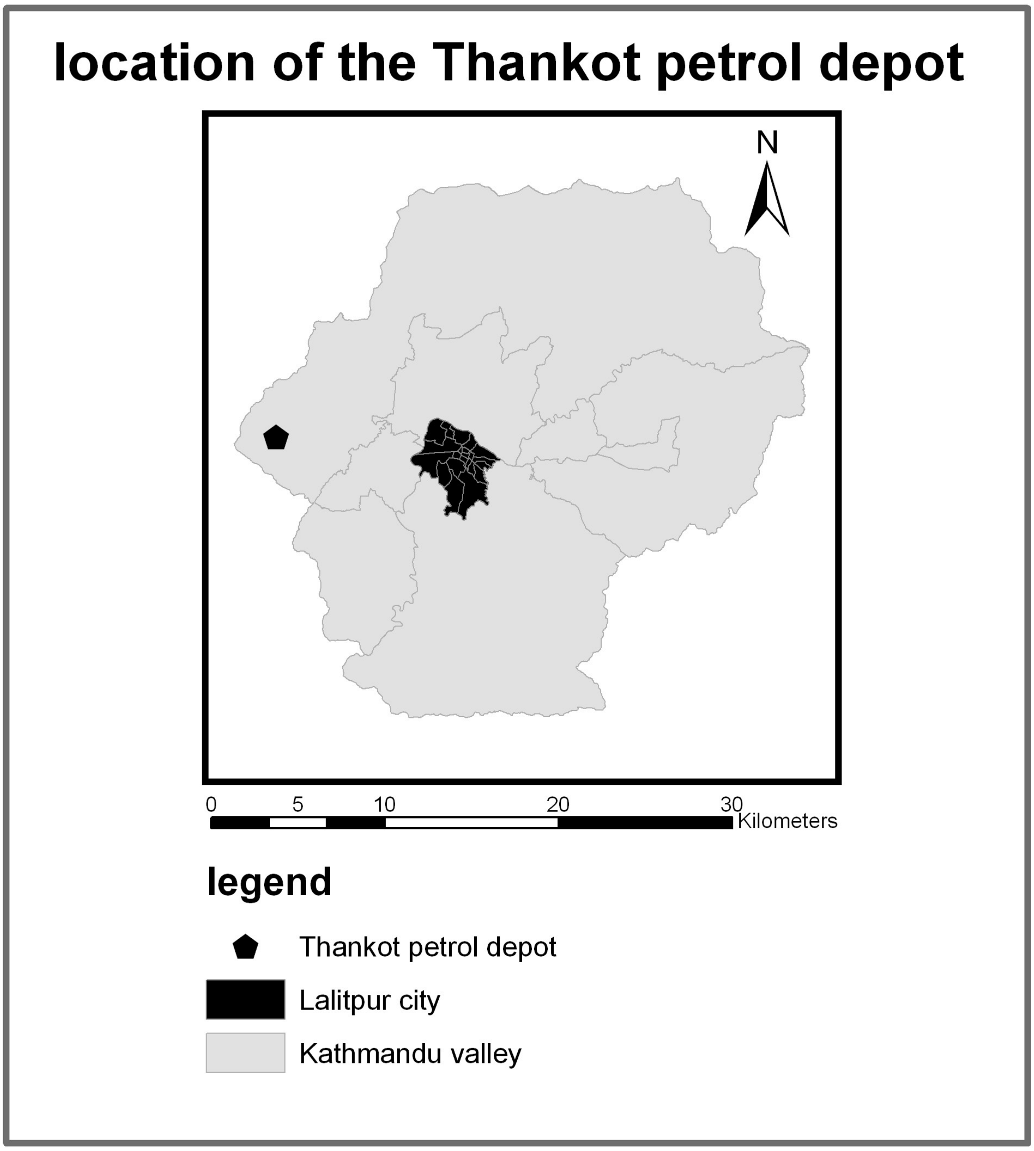


Figure 4-2 location of the Thankot petrol depot

4.2 Stakeholders in the transport of petrol derivates

The petrol derivates consumed in Nepal are imported from India. The import of the petrol derivates from India to Nepal is under the control and management of the 'Nepal Oil Corporation' (NOC), dependant on the Nepalese government. The NOC is also in charge of the management of the petrol depots, such as the Thankot petrol depot. However, for all the transportation operations the NOC sub-contracts independent transport operators, whose duty includes transporting the material from the Indian border to the different petrol depots in the country, and from the petrol depots to the gas stations. These private sub-contractors normally own at least three tankers, and. it is possible for the owner of a gas station to own tankers and be sub-contracted by the NOC to transport petrol derivates. The owners of the tankers and the gas stations have organized themselves and have established the Nepal Petrol Dealers Association (NPDA). In this document I will refer to the owner(s) of petrol derivates tankers as NPDA operator (s).

Figure 4-3 tankers used for transporting petrol derivates

Figure 4-4 view of the storage tankers at the Thankot petrol depot

In terms of risk management, the NOC pursues maintaining a ‘risk free’ environment in all of their fixed installations. Safety codes and regulations are implemented in every operation that is carried out in their installations. This includes the operation of loading and unloading the petrol derivates in the tankers used for transporting the materials. The tanker used for the transport of petrol derivates must be subject to a safety test one time per year before being allowed to transport the materials. Once the tanker has been certified that it meets all the specification asked by the NOC, the tanker unit is allowed to transport petrol derivates for as long as the engine keeps running, since there is no age limit.

Figure 4-5 loading deck at the Thankot petrol depot

Figure 4-6 gas station located at the Pulchowk intersection, Lalitpur

The safety codes and regulation surely help to reduce the overall risk of handling the petrol derivates within the fixed facility premises. However, as soon as the tanker leaves the premises of Thankot petrol depot for example, the NOC does not interfere in the management of the transportation process. Any risk management and reduction measure that the NOC enforces in their fixed installations, is not applied to the transportation operation. Since the transport operations are left out in the hands of the NPDA operators, pursuing the safe transport of the petrol derivates becomes a responsibility of the NPDA operators.

Certainly, the best-case scenario will be one where the NPDA operators are considering safety issues in the first place, and then the economic issues. Unfortunately this does not comply with reality, where the NPDA operators must ensure first that the transport operation is economically feasible (by coping with their operational costs) and that the transport operation is profitable. It is only then that the term ‘safe’ can be a subject for consideration. Of course this is a sensitive topic, because NPDA operators can argue that safety measures are enforced in their daily transport operations by having fire extinguishers in the tankers. Fire extinguishers can be useful but only after the hazardous event has occurred, it is a mean to deal with the situation once an accident has occurred, but what is it done to prevent a damaging event (such as an accident) from happening? Training of personnel is not being carried out; unqualified personnel is hired and handed the responsibility of carrying thousands of liter of flammable material.

The NOC has set fixed prices for the transport of petrol derivates, depending on the distance range travelled from the petrol depot to the gas station. In the case of supplying the gas stations that are located in the Kathmandu valley, all the petrol derivates are transported from the Thankot petrol depot. The rates are fixed, based on the area where the petrol derivates must be transported and delivered, *e.g.* for the transport of petrol derivates within the Kathmandu valley, the rate is set constant, whereas if the material is to be transported and delivered out of the valley, the rate increases. Due to confidentiality reasons the fixed price paid by the NOC to the NPDA operators will not be expressed in this document. Considering that the amount of money paid by the NOC to the NPDA operators to transport the petrol derivates is fixed and constant for the whole Kathmandu valley range; and that there is no applicable code or regulation for the transport of petrol derivates; the NPDA operators can increase their profit margins by reducing their operational costs.

One more stakeholder to be mentioned in this particular case study is the local government, represented by the municipality of Lalitpur. The representatives of the municipality were very keen on the applicability of the model in their planning and risk management activities when introduced to the topic of route optimization for HazMat transport. The municipality is particularly concerned about the safety of the general population. Therefore, determining routes for the transport of petrol derivates where the least number of persons will be affected in case of an accident is one of their interests. The municipality can serve as moderator in a debate between the NOC, the NPDA and the municipality itself. The focus of the debate is to analyse the issue of transporting petrol derivates within the city limits. The route optimization model as a decision-making tool, creating different scenarios and calculating optimal routes for each of these scenarios, can contribute to draw the right conclusions out of the debate.

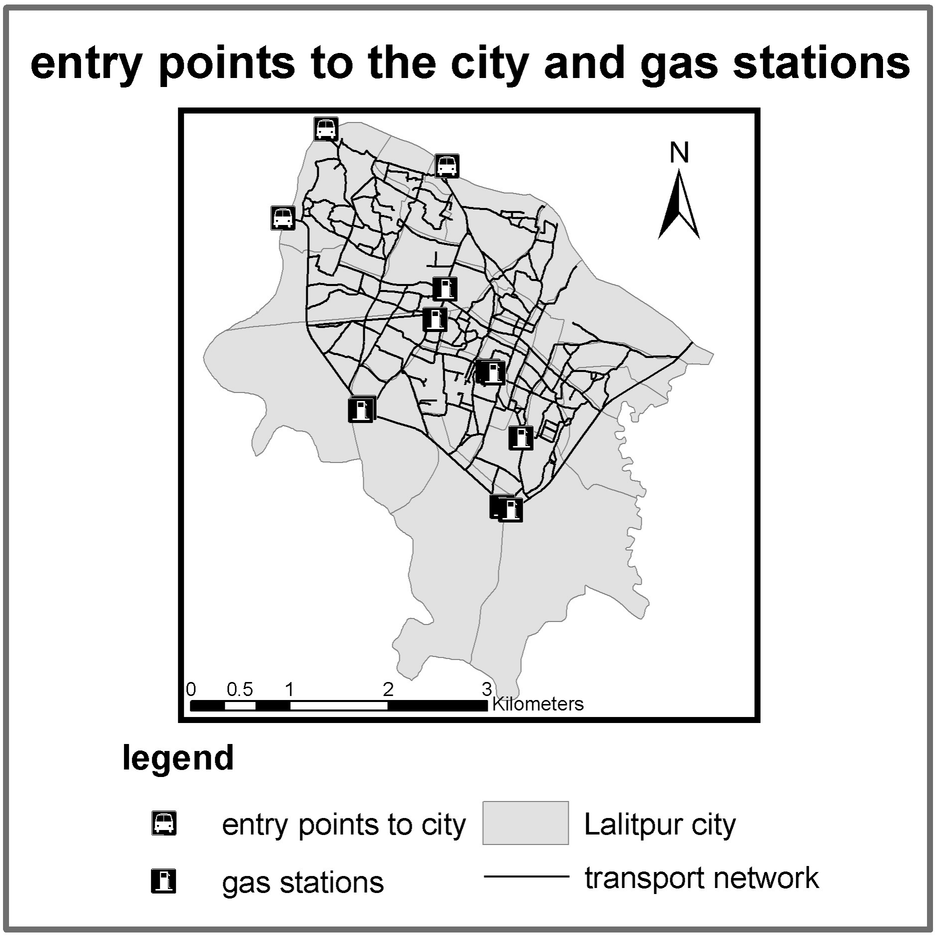


Figure 4-7 entry points to the city and gas stations

4.3 Transport network of lalitpur city

The total length of the transport network of Lalitpur is approximately 130km, and out of this more than 70 km are paved roads. In this research study not all the transport network, which extents throughout the whole area of the city, will be considered for use in the route optimization model, but only the transport network in the area enclosed by the Bagmati River and the ring road, see figure *1-6* on page 11. A field survey was carried out to assess the width of each arc of the transport network.

The purpose of this measurement is to analyse the situation, as there are a considerable amount of road sections with a cross section of three, two, and even less than two meters wide. It is not advisable developing a model that selects a route containing road sections that a tanker cannot access due to width restrictions. In this document the roads that can be used by a tanker must have a minimum section width of four meter. Another finding of the filed survey is that every road section within the transport network of the case study has a two-way traffic flow.

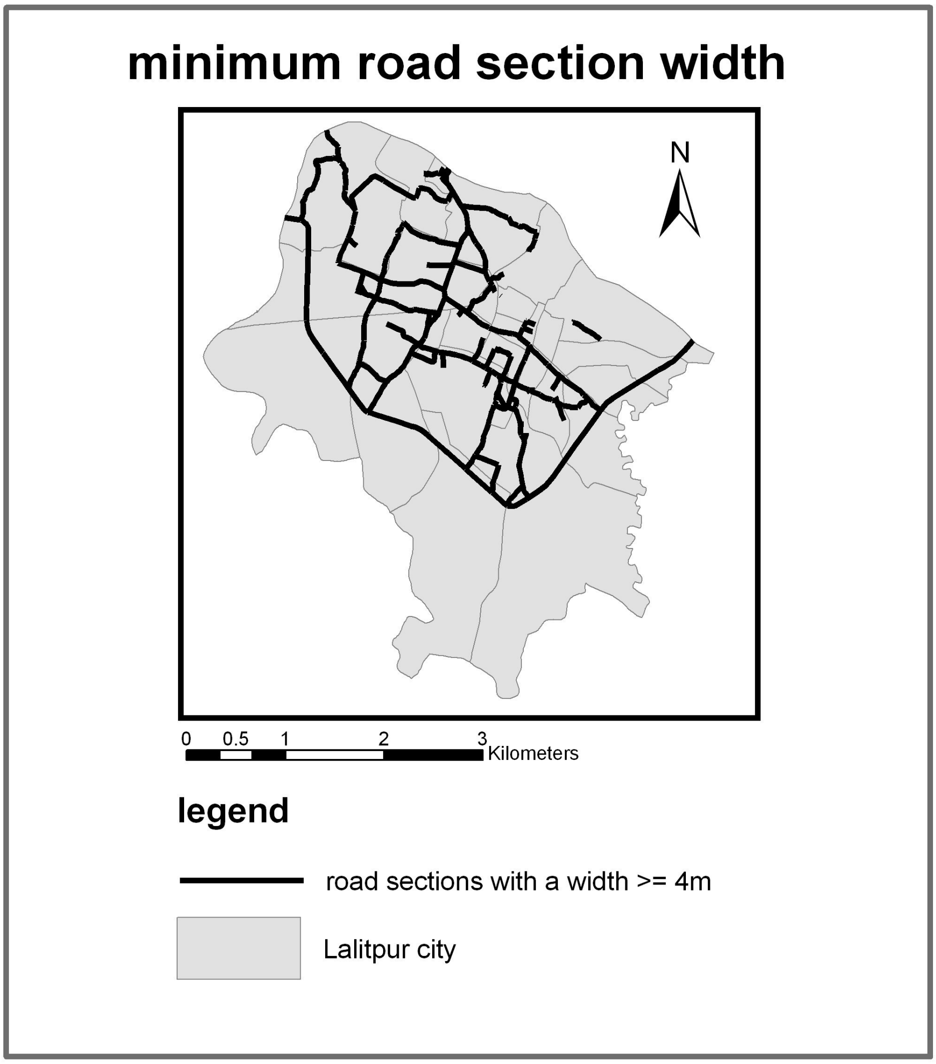


Figure 4-8 roads sections with minimum width of 4m

It is important to define which nodes in the network will be considered as starting nodes in the route optimization model, considering that the Thankot petrol depot is outside the area covered by the transport network considered for the route optimization model. The starting nodes are labelled “entry points” for the tanker to the transport network, and are shown in figure *4-7*. In the same figure, the locations of the nine gas stations found in the study area are shown.

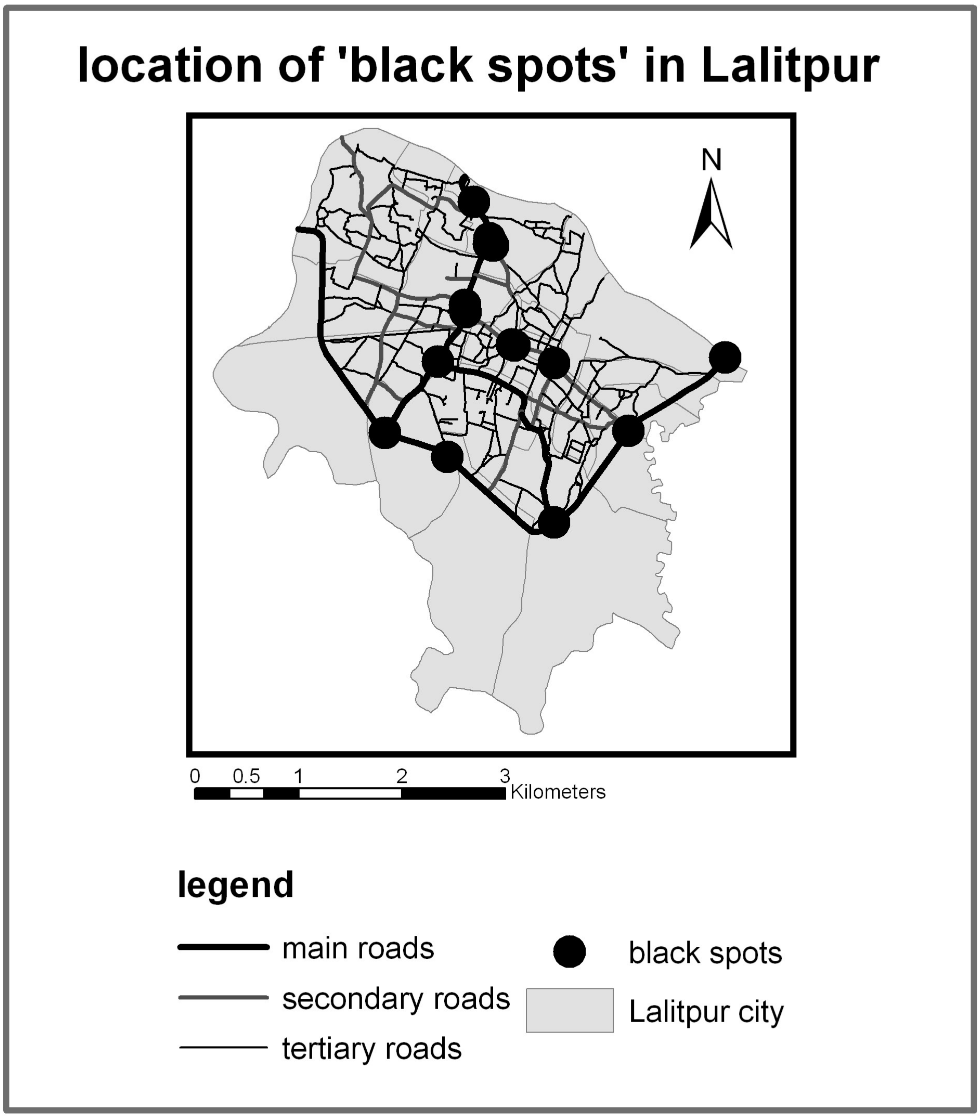


Figure 4-9 location of the black spots in Lalitpur

4.3.1 Black spots in the transport network

According to the Kathmandu valley traffic police, the ‘black spots’ in the transport network are those intersections where accidents are more likely to occur. Accident rate values are not available for the area, neither for the black spots, nor for other intersections of the transport network. The accidents that occur in Lalitpur are recorded manually in paper notebooks, with all the related details of the accident, such as location, time, number and type of vehicles involved, number of persons injured, and number of fatalities.

These records certainly can be used to estimate a more accurate accident rate for different sections of the transport network. However, in order to compute the accident rate values, a great amount of effort and time will have to be expended for transforming these hand-written records into a digital database format, or even better into a digital geo-database format. Nevertheless, when estimating the accident rate for the case study, a higher accident rate value will be assigned to the arcs connected to a black spot. The approach to estimate the accident rate for each of the arcs located within the case study will be described in the next chapter.

4.3.2 Traffic volume in the network

Estimating the traffic volume data for the transport network represents a drawback, due to the fact that detailed data about traffic volume is only available for intercity roads, whereas roads at city level have not been surveyed. However, the Department of Roads (DoR) has carried out a qualitative assessment of the traffic volume for the transport network in Lalitpur. This qualitative traffic volume indicator tells whether the flow of vehicles over a certain road section is considered to be high, medium, or low.

According to the DoR the low traffic flow indicates that no more that 150 vehicles per day travel over a specific road section. Medium traffic flow indicates that more than 150 but less than 500 vehicles per day are passing by the road section. High traffic flow indicates that at least 500 vehicles per day travel over the road section. These values however, might not represent accurately the reality of the case study. Based on the observations made during the fieldwork period, I consider that the upper limits for each of the traffic flow classes are to be much higher.

4.4 Population data in Lalitpur

At the moment this research study is carried out, the only population data available is spatially distributed at ward level. This can represent a drawback in the model development when estimating the population attributed to each arc in the network. There is another research study being carried out by Islam (2004) though, which has as main objective determining the building vulnerability in case of an earthquake. Part of the output of his research is the distribution of the population in Lalitpur city at a much more detailed level than the data actually available at ward level. This output can then be used as input for the model being developed in my research study.

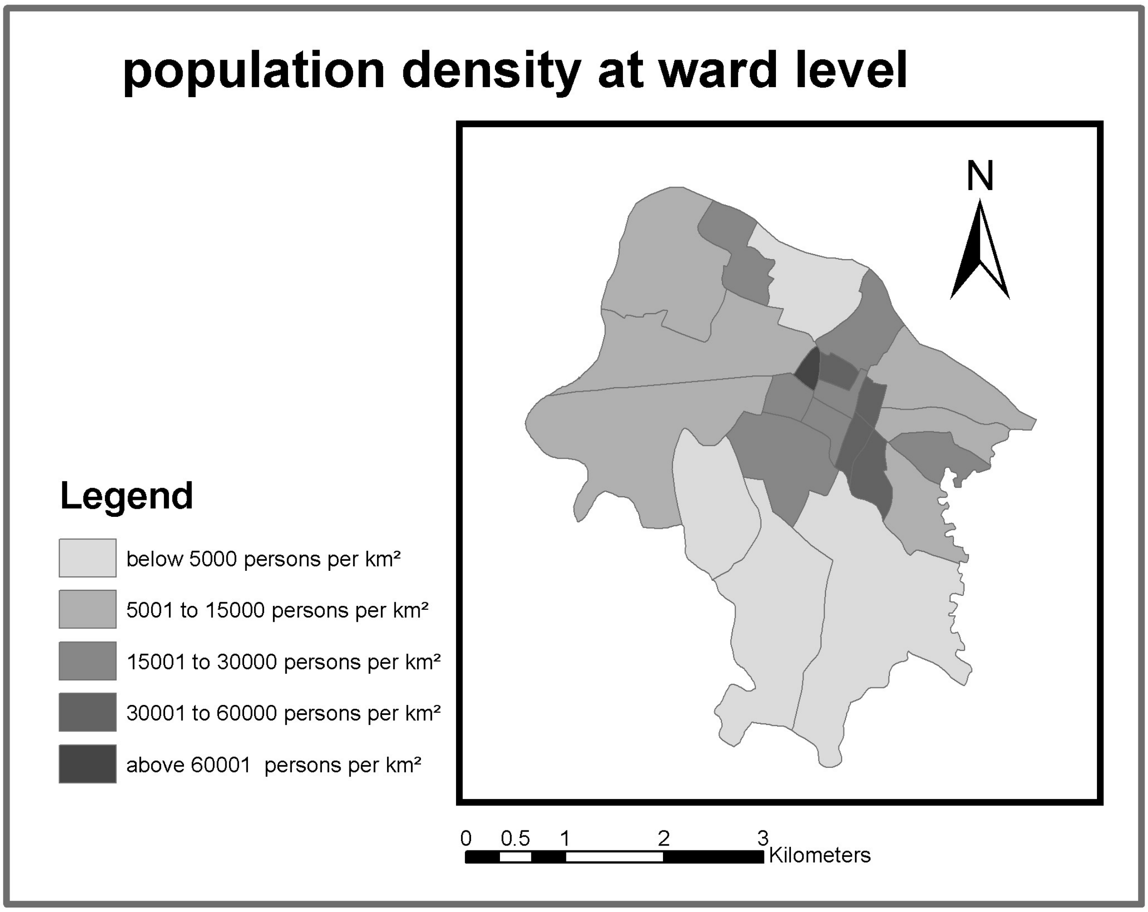


Figure 4-10 population density at WARD level in Lalitpur
Source JICA (2002)

4.5 Building data in lalitpur

Just as there is a research study on population vulnerability that is being carried out at the moment of writing this document, there is also another research study carried out by Guragain (2004) on the topic of GIS for seismic building loss estimation. The case study considered in Guragain's research also takes place in the city of Lalitpur, Nepal. Some of the outputs of this research study are the construction of a spatial database of the buildings in Lalitpur, and the assessment of the building vulnerability in relation to earthquake hazard. Unfortunately the output of the research study of Guragain is not yet available, therefore for developing the present model the secondary data acquired from JICA (2002) will be used. Figure *4-11* gives the building map of the case study, which shows the predominant type of building on a grid cell measuring 500mt by 500mt.

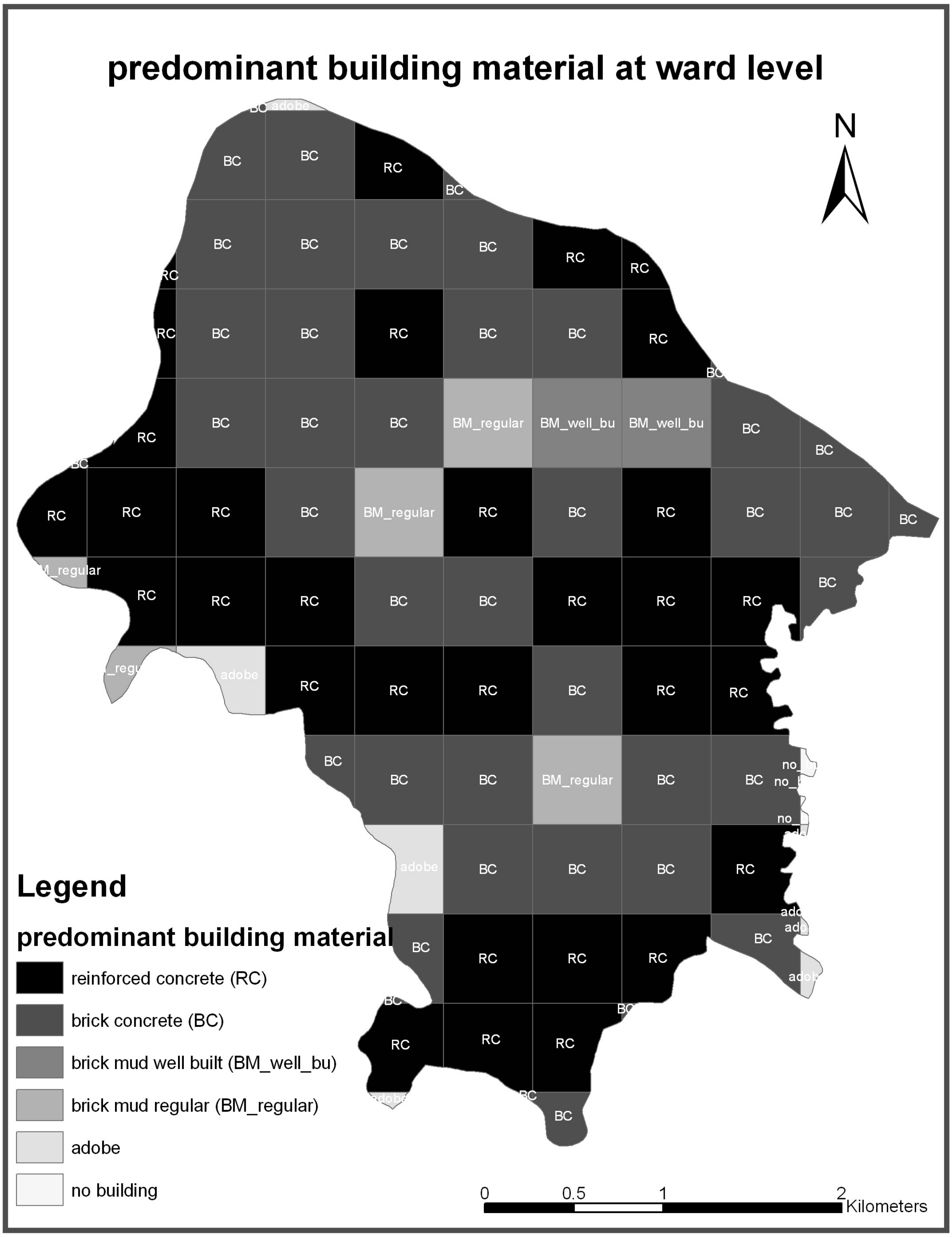


Figure 4-11 predominant building material in Lalitpur, Nepal

Grid cell 500x500mt, source JICA (2002)

4.6 Problems and limitations

The route optimization model developed in this research study has to prove its functionality in a real life situation. In this chapter, the transport of petrol derivates in the city of Lalitpur has been presented as case study. The model to develop then can be used to find the optimal route for the transport of petrol derivates to the gas stations located inside the case study area. However, there are some problems related to the availability of data, representing a limitation in the development process of the model. The problems that I can identify are the following:

- Besides the identification of the accident-prone intersections (black spots), there are no accident rate values available for the road sections contained in the transport network of the study area.
- There is no quantitative measure of the traffic volume of the road sections of the network. The only data available is the qualitative classification of the arcs in terms of high, medium, and low traffic volume.
- The population data available at the moment is distributed at ward level, which is not detailed enough to estimate the exact number of persons attributed to a given arc neither to estimate the distribution of the population at different times of the day.
- The distribution of buildings according to the type of material has been aggregated in sections of *500x500m*.

Although these problems may represent an obstacle for the development of the route optimization model, it is still possible to overcome these problems; however this will be discussed in the following chapter.

5. Developing the model

The purpose of this chapter is describing how the route optimization model was developed, explaining and discussing how the methodology proposed earlier in this document in combination with the available data from the case study made possible to develop the route optimization model. The reason for doing this is to show how the methodology can be adapted to a particular case study, in this case the transport of petrol derivates. The rationale of the chapter is to show how the problems encountered through out the process of developing the model were overcome. In addition to this two sections at the end of the chapter are dedicated to describe how the model is executed and what interface has been developed for the manipulation of the model.

5.1 Basic parameters for the model

The starting point in the process of developing the route optimization model for the transport of petrol derivates in Lalitpur is defining the set of arcs from the transport network in which the transport of petrol derivates will take place. In other words it is defining the arcs in which the decision-making problem of selecting the routes for the transport of petrol derivates will be based. This section discusses the definition of the set of admissible arcs and the estimation of the individual speed, volume, and density of every arc in the transport network.

5.1.1 Defining the admissible arcs

One of the constraints for the route optimization problem previously discussed in the methodology chapter is the definition of the admissible arcs. The admissible arcs are those arcs where the transport of petrol derivates is preliminarily acceptable, in the sense that the physical characteristics of the arc enable the tanker to travel over the arc. Some of these characteristics are: the width, the load capacity, and the condition of the surface. In this document the arcs that posses a minimum section width of four meters will compose the set of admissible arcs. The admissible arcs constraint is oriented to reduce the computational effort required to solve the route optimization problem, since the number of admissible arcs is much lower than the total number of arcs found in the network. In the transport network of the case study the total number of arc is 613, whereas the number of admissible arcs is only 273. Figure *4-8* (page 56) shows the arcs with a minimum section width of four meter.

5.1.2 Traffic speed-density-volume relation

In order to calculate the average speed, density and volume attributed to each arc, I will make use of the speed-density-volume relational curves presented by Khisty and Lall (1998). The main contribution of the speed-volume-density curves to the development of the route optimization model is the possibility to model different traffic conditions on the transport network. The traffic conditions of the transport network change over time, for example traffic conditions at rush or peak hours are different than at valley or non-rush hours, and the latter are different than night time hours. Being able to model the different traffic conditions on the network will contribute to the scenario-making of the model. Consequently, the speed, volume, and density values that are calculated for each arc will contribute to the estimation of travel time, accident rate, and the on-route population. It is important however, to define the terms speed, volume, and density.

speed:

rate of motion of a vehicle, as distance per unit time (kilometre per hour, km/hr).

volume:

is the actual number of vehicles observed or predicted to be passing a point during a given time interval (vehicle per hour, veh/hr).

density:

is the actual number of vehicles occupying a given length of lane or roadway, average over time (vehicles per kilometre, veh/km).

Box 5-1 speed, volume, and density definitions
Source Khisty and Lall (1998)

The relationship between speed, volume, and density is defined by the curves shown in figure *5-1*. The speed-volume-density curves are calculated based on empirical studies, which means that if a study on the traffic conditions of the case study network is carried out, more accurate relational curves can be estimated. However, for the development of the route optimization model for the case study presented in this document, the basic relational curves presented by Khisty and Lall (1998) will be used.

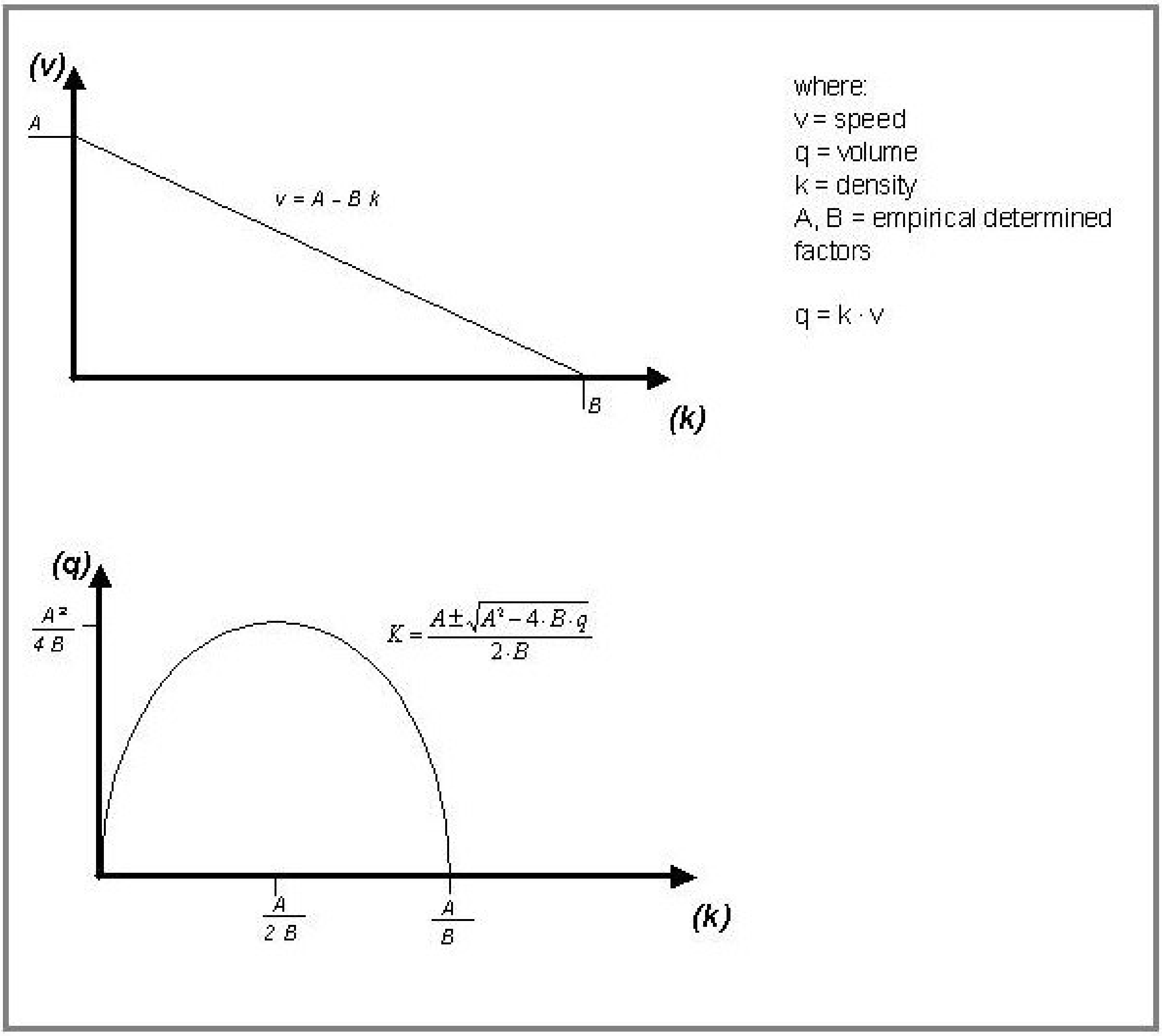


Figure 5-1 speed-volume-density curves
Source Khisty and Lall (1998)

The average speed of the vehicles travelling on a given arc is inversely proportional to the density of the arc, *i.e.* speed decreases, as the number of vehicles on the arc increases. In order to estimate the individual speed of every arc in the network it is necessary to estimate the density on each arc. To do so, first the empirical values of 'A' and 'B' used in the speed equation have to be calculated, where the term 'A' is equivalent to the maximum value of the average speed in the network. In this document the maximum average speed in the network will be derived from the type of each specific arc. In figure *5-2* the types of arcs found in the study area are shown, where the maximum average speed for main, secondary and tertiary roads are 70km/hr, 50km/hr, and 30km/hr respectively.

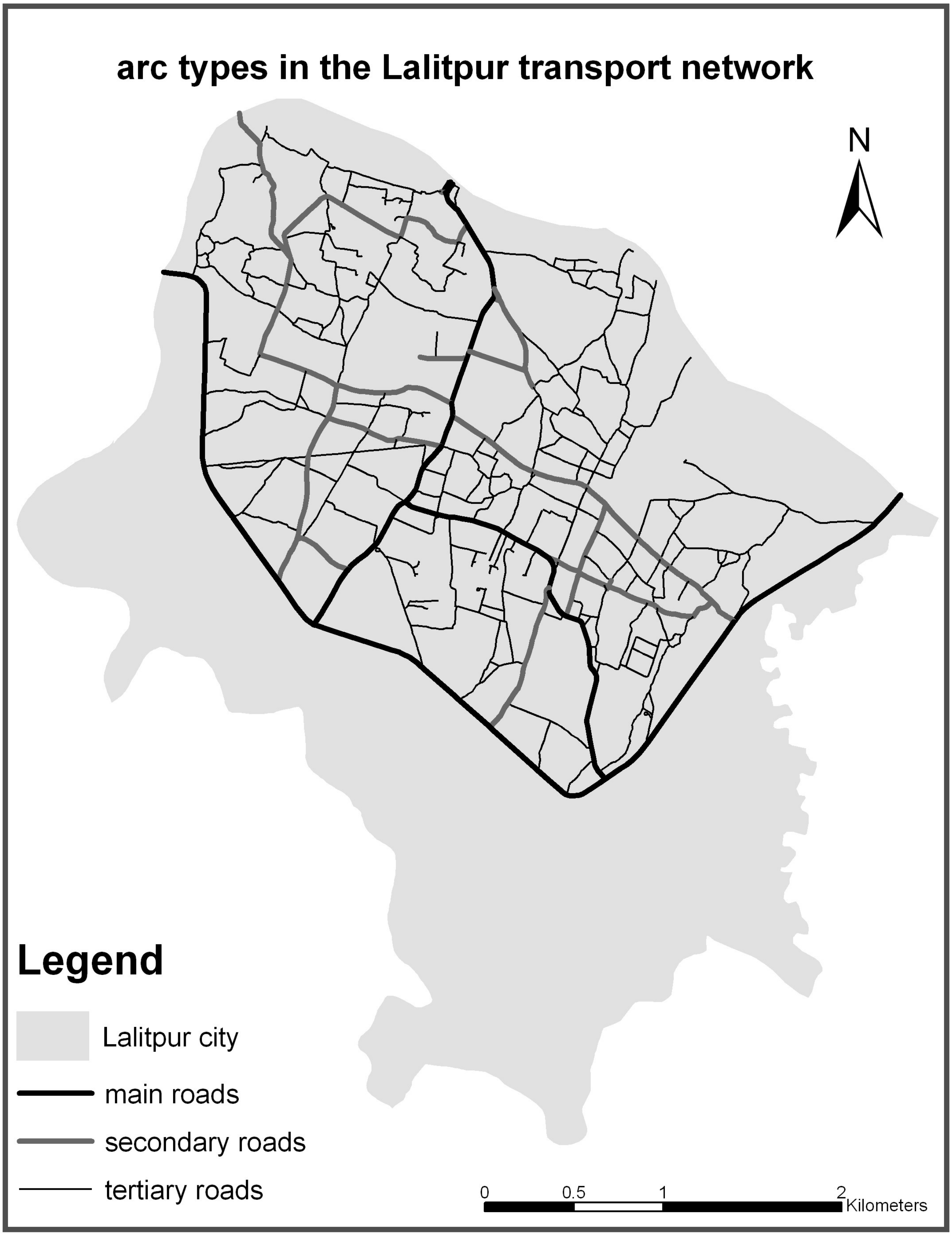


Figure 5-2 arc types in the Lalitpur transport network

determining 'A' and 'B'

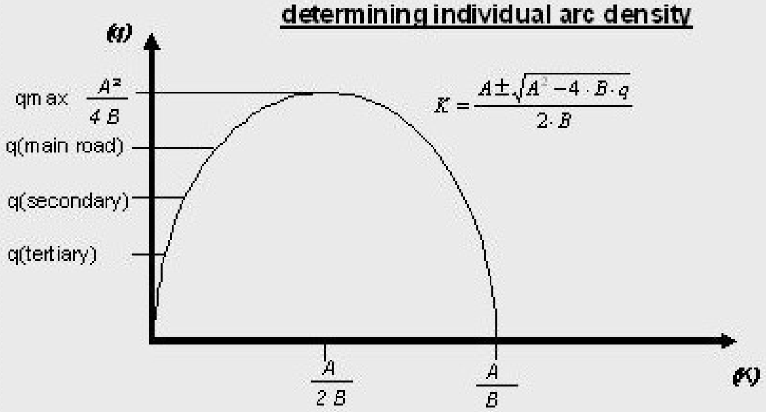
	main roads	secondary roads	tertiary roads
A (maximum average speed):	70km/hr	50km/hr	30km/hr
ratio of occupancy:	sum of length of the vehicles found in a road section divided by the total length of the road section		
average vehicle length:	7 metres		

B :

$$B = \frac{A}{k_{max}}$$

$$B = \frac{A \cdot avg\_veh\_length}{ratio\_of\_occupancy}$$

determining individual arc density



q_1 = q(main road) = 3/4 qmax

q_2 = q(secondary) = 1/2 qmax

q_3 = q(tertiary) = 1/4 qmax

$i = 1 \rightarrow main\_roads$
$i = 2 \rightarrow secondary\_roads$
$i = 3 \rightarrow tertiary\_roads$

$$\overset{n}{\underset{z=1}{K}} = \frac{A - \sqrt{A^2 - 4Bq_i}}{2B}$$

$$z \rightarrow arc$$

determining individual arc speed

$$\boxed{v = A - Bk}$$

Box 5-2 summary of speed, volume, and density calculation

The term ‘B’ is proportional to the maximum speed divided by the maximum density value in the network. It was not possible to acquire the density values in the network during the fieldwork period. Therefore, in order to estimate the maximum density value for the network, I propose to use the following equation also presented by Khisty and Lall (1998).

$$k_{\max} = \frac{ratio\_of\_occupancy}{avg\_length\_vehicle} \qquad \text{(Eq-21)}$$

Where the *ratio of occupancy* is proportional to the measure of length of the vehicles on a given road section, *i.e*. the sum of length of the vehicles found in a road section, divided by the total length of the road section. In this document, the ratio of occupancy in rush hours has values higher that 0.50, whereas non-rush hours have a ratio of occupancy with a value below 0.50.

5

Once the empirical values of ‘A’ and ‘B’ have been calculated, the individual density and speed values for each arc can be calculated. The equation used to calculate density expresses density as proportional to the volume of the arc. However, the densities for each of the arcs in the network are not available in a quantitative way, but rather in a qualitative way, where to each arc on the network a high, medium, or low volume class is given. To overcome this problem, I propose to derive the individual volume based on the type of each arc and the maximum volume estimated for each arc type. For arcs with a volume class of high, the volume value will be proportional to three quarters of the maximum volume value; for arcs with a volume class of medium, the volume value will be proportional to two quarters of the maximum volume value; and arcs with a volume class of low, the volume value will be proportional to one quarter of the maximum volume value.

5.1.3 Accident rate

Besides data on the location of the most accident-prone areas, there were not enough historical data to estimate the accident rate at arc or intersection level in the transport network. However, it is necessary to estimate the accident rate for calculating the risk for the population and for the urban environment. In order to estimate these values, I will make use of the prediction model for accident rate, developed in the research study of Gharaibeh *et al*. (1997). In their research study Gharaibeh e*t al*. focus on the development of simplified prediction model for accident rate, taking into account the relationship between the congestion levels of the transport network.

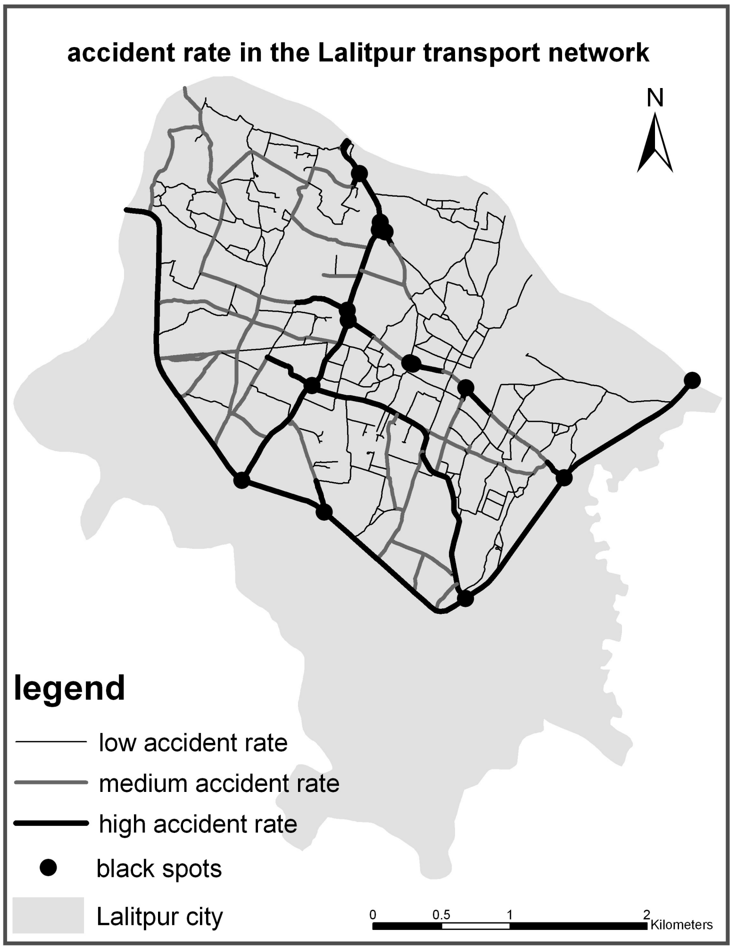


Figure 5-3 estimated accident rate map

The data used in this research study was acquired from the Illinois Department of Transportation Geographic Information System, and represents the route system in the Champaign County, Illinois. In order to find an equation that represented the relationship between the accident rate and the congestion level of a particular road section, the authors of this research study used regression techniques as a solution approach. After making a considerable amount of evaluations of equations derived in many different forms such as linear, exponential, *etc*. the authors concluded that the following model is the most suitable one, representing the accident rate - congestion level relationship:

$$AR = 0.004 \cdot ADT^{0.66} \qquad \text{(Eq-22)}$$

$$R - square = 0.45$$

Where AR = Accident rate, accident per kilometre.

ADT = Average daily traffic, vehicle per day.

5

The above model has a coefficient of determination (R-square) of 0.45, which indicates that the variable included in the model (ADT) explains or justifies 45% of the predicted Accident Rate (AR). The other 55% may be explained by other factors such as road geometric features, the pavement surface condition, the driver, the vehicle, and the weather.

The prediction model for accident rate presented by Gharaibeh *et al*. (1997) was developed based on the data of the particular case study transport network. The traffic conditions most probably differ from the traffic conditions of the transport network in Lalitpur. Despite this, and considering that there is no data available that can be used for calculating the accident rate in the Lalitpur network, I will make use of the above described equation in the research study presented in this document. An advantage of the use of this approach is that the value of the accident rate changes when the basic traffic conditions are modified, enabling to simulate different scenarios where the accident rates change over time. When estimating the accident rate per each arc, the model considers the maximum ADT in those arcs that are connected to one or more black spots node; and for those arcs that are not connected the one black spot, the normal ADT calculated for the arc is considered. This ensures that the arcs that are connected to the black spots receive a higher accident rate value.

5.2 Population attributed to each arc

estimating the off-route:

off-route pop per arc = population per length unit x length of arc

estimating the on-route:

on-route pop per arc = number of persons per vehicle x individual arc density

estimating the total population attributed to each arc:

total pop per arc = off-route pop per arc + on-route pop per arc

Box 5-3 estimating the population attributed to each arc of the network

5.2.1 Off-route population

At the moment of developing the route optimization model, the population data is not available at a more detailed level than the ward level. Therefore, in order to continue with the development of the model, an alternative approach for estimating the population attributed to each arc will be followed. To estimate the population assigned to each arc, the total population and the total road length of each ward will be taken into account. By the means of GIS overlaying capabilities, the process for estimating the population per unit of length can be carried out. The diagram below shows the GIS overlaying process between the base map and the network layer of the case study area. The population per length of each arc will be used to estimate the off-route population by multiplying this value with the individual length of each arc.

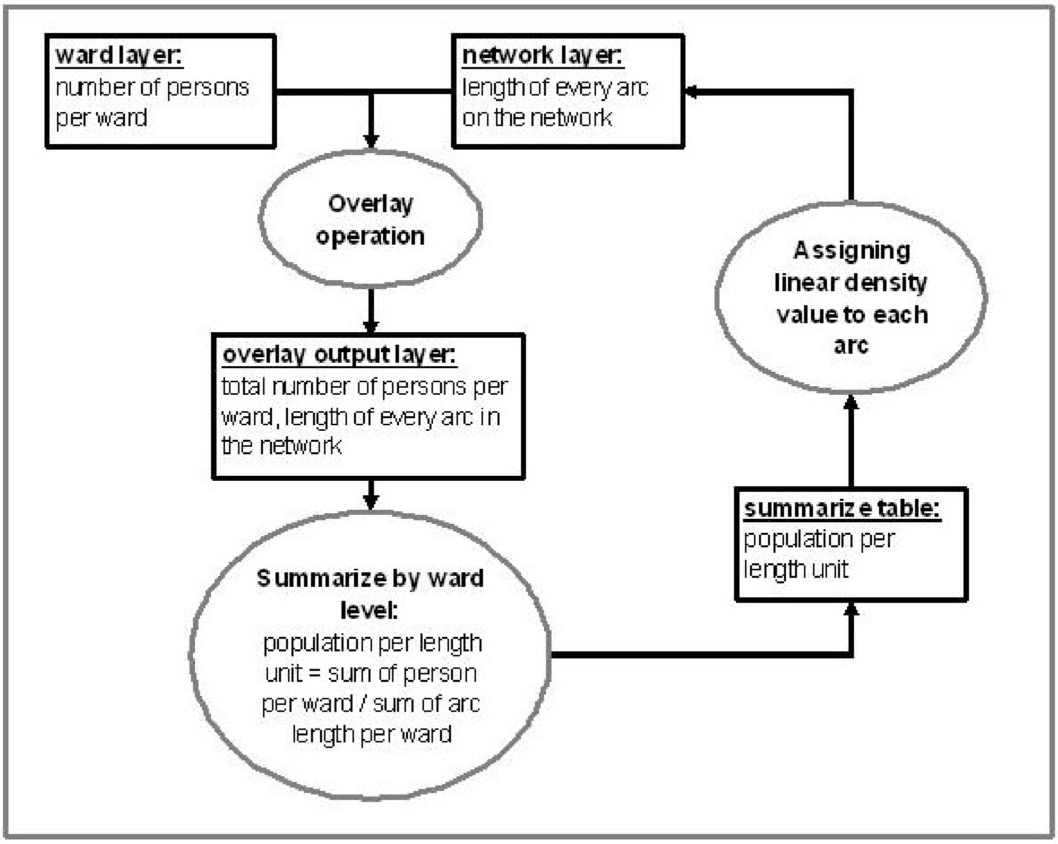


Figure 5-4 diagram for assigning the population to each arc

5.2.2 On-route population

The on-route population results from multiplying the individual density of each arc with the average number of persons on each vehicle. A more accurate estimation of the on-route population will be one that is calculated based on the detailed estimation of the number and types of vehicles travelling on each arc, and the average number of persons that regularly travel on each type of vehicle. However, as such detailed data is not available; an average number of three persons per vehicle are considered for the estimation of the on-route population.

5.3 Modelling building data

5.3.1 Building vulnerability in case of fire

The building vulnerability in case of an explosion hazard will be dependant of the type of material that is used for the building, as certain types of materials are more vulnerable to fire. Wooden buildings for example are more vulnerable to fire than buildings constructed with concrete materials. I have been, and still am, searching for vulnerability curves for buildings in case of a fire. As I have not succeeded in this search yet, I propose to use the vulnerability values described in the table *5-1*, knowing that these values should be subject to discussion and correction in case a specialized study is found in the literature in relation to building vulnerability in case of fire triggered by an explosion produced after a HazMat accident. In order to assign these values to each arc, a GIS overlaying approach will be used (figure *5-5*).

5

type of building material	vulnerability value
adobe	0.8
brick mud regular	0.4
brick mud well built	0.3
brick concrete	0.2
reinforced concrete	0.1

Table 5-1 building vulnerability values in case of fire

.

5.3.2 Damaged building ratio in case of an earthquake

In order to estimate the ratio of buildings damaged in case of an earthquake (this is in fact the specific risk of buildings in case of an earthquake), it is necessary to consider the hazard magnitude and intensity, and the building vulnerability in relation to the earthquake hazard. It is out of the range of study of this research to go deeper into the analysis of building vulnerability, since this is a research topic on its own. Therefore I propose to use the model developed by JICA (2002), a model which has also been used for acquiring the population data. The earthquake scenario that will be considered is one labelled as “Kathmandu Valley local” earthquake, which has a magnitude of 5.7 and an intensity of *MMI – VI* to *MMI – IX*. With the aid of the model developed by JICA it is possible to visualize the hazard map based on the intensity of the earthquake, and most important to find out the damaged building ratio for the particular scenario.

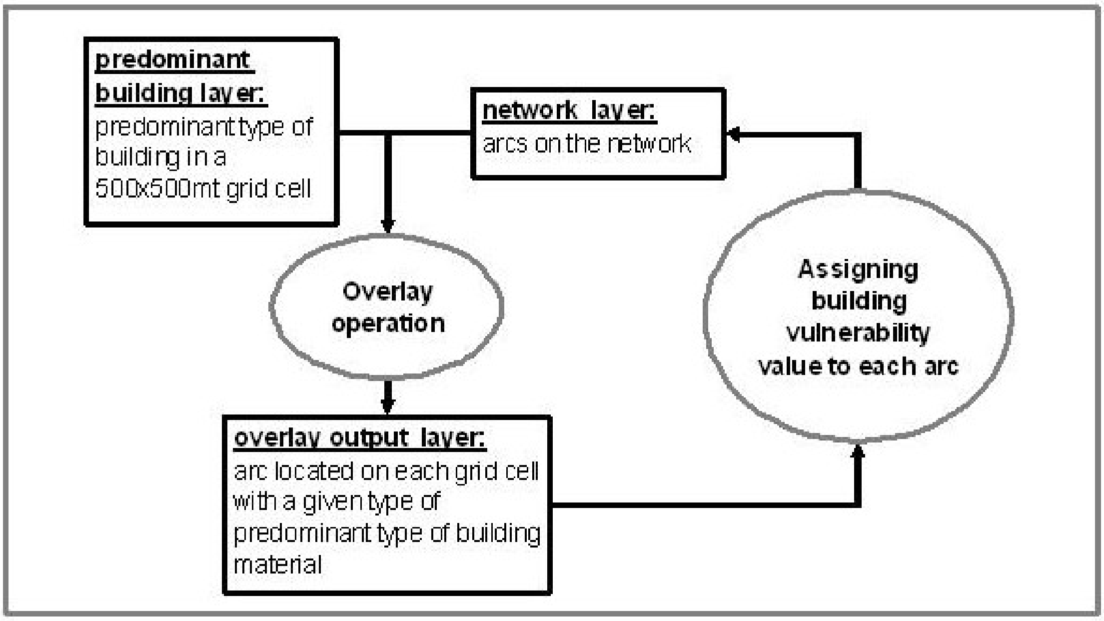


Figure 5-5 diagram for assigning building vulnerability to each arc

MMI	description	MMI	description
I	Not felt except by a very few under especially favourable circumstances	VII	Everybody runs outdoors. Damage negligible in building of good design and construction; slight to moderate in well-built ordinary structures; considerable in poorly built or badly designed structures; some chimneys broken. Noticed by persons driving motorcars.
II	Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing.	VIII	Damage slight in specially designed structures; considerable in ordinary substantial buildings, with partial collapse; great in poorly built structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Persons driving in cars disturbed.
III	Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognise it as an earthquake. Standing motorcars may rock slightly. Vibration like passing of truck. Duration estimated	IX	Damage considerable in specially design structures; well-designed frame structures thrown out of plumb; great in substantial buildings, with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken.
IV	During the day felt indoors by many, outdoors by few. At night some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Standing motorcars rocked noticeably.	X	Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations; ground badly cracked. Rails bent. Landslides considerable from river banks and steep slopes. Shifted sand and mud. Water splashed
V	Felt by nearly everybody, many awakened. Some dishes, windows, *etc*., broken; a few instances of cracked plaster; unstable objects overturned. Disturbances of trees, poles, and other tall objects sometimes noticed. Pendulum clocks may stop.	XI	Few, if any, (masonry structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipelines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.
VI	Felt by all, many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster or damaged chimneys. Damage slight.	XII	Damage total. Practically all works of construction are damaged greatly or destroyed. Waves seen on ground surface. Lines of sight and level are distorted. Objects are thrown upward into the air.

Table 5-2 MMI scale (Modified Mercalli Intensity Scale)

Source Montoya (2002)

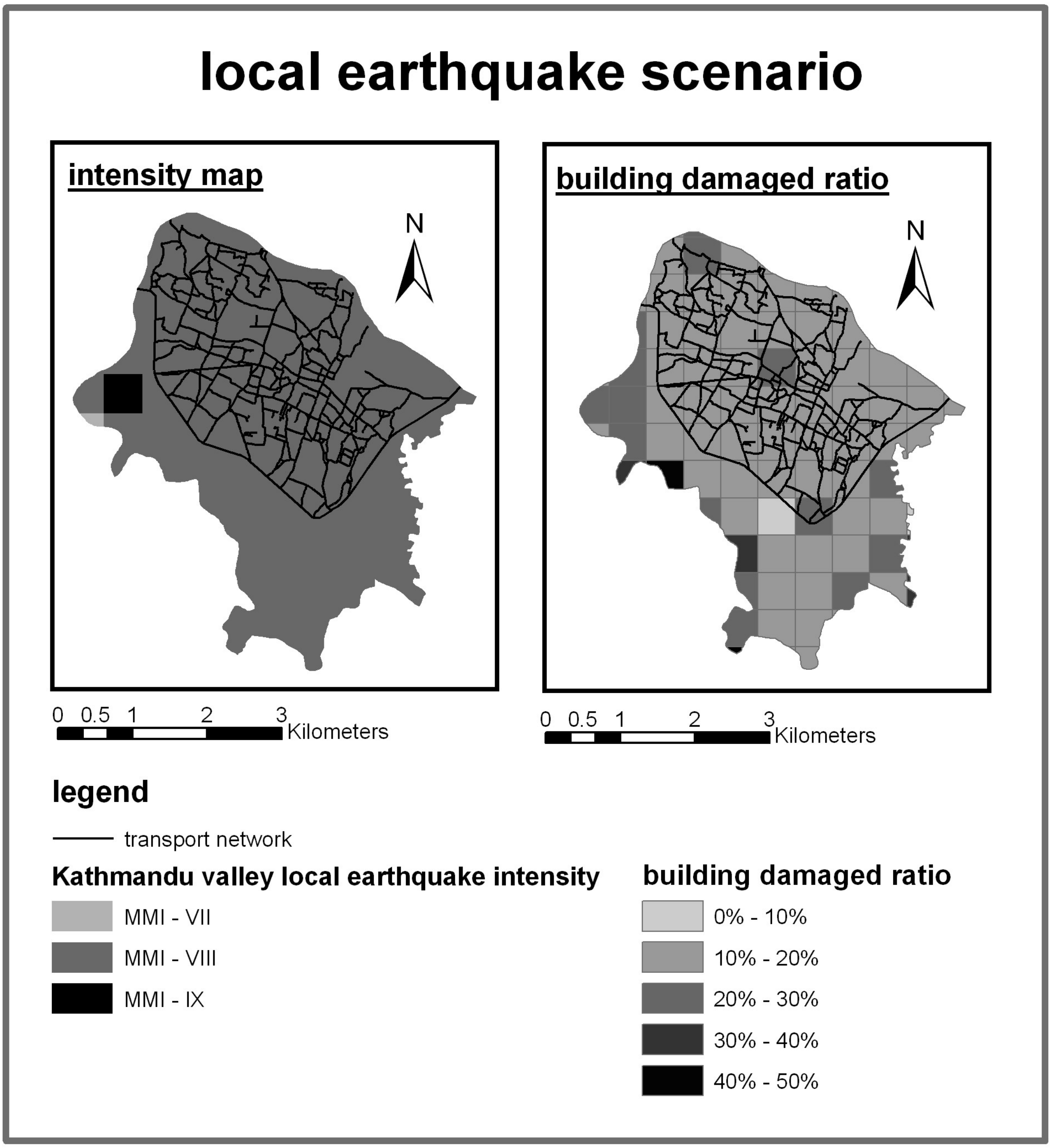


Figure 5-6 intensity map and building damaged ratio map for lalitpur

Considering a Kathmandu valley local earthquake scenario, source JICA (2002)

In a “Kathmandu Valley local” earthquake scenario, the model developed by JICA identifies 500x500m block areas with 20% and 30% damaged building ratios within the case study of my research study. The damaged building ratio indicates the area where is most probable to have a road blockage due to the building debris fallen into the road in case of an earthquake. The damaged building ratio serves to assign to each arc in the network an earthquake-building risk score. The purpose of the earthquake-building score is to restrict the tanker from travelling on arcs where the damaged building ratio is above the acceptable limit. For example, if the damaged building ratio of 20% is set as threshold, the tanker will be restricted to travel on arcs with a damaged building ratio of 30%. However, the use of the damaged building ratio can be subjective if the actual number of buildings is not considered. A better and more accurate earthquake-building risk indicator for each individual arc will be one that results from the multiplication of the damaged building ratio with the number of buildings situated alongside the arc. As mentioned earlier, a detailed map of the buildings in Lalitpur is been produced as part of the research study of Guragain (2004). Therefore, I will use only the damaged building ratio to estimate the earthquake-building score, keeping in mind that if the building data becomes available the process of estimating of the earthquake-building score will be modified.

To estimate the earthquake-building score I proposed the following approach: for arcs with a damaged building ratio of 20%, a value of one will be assigned as earthquake-building score, whereas for arcs with a damaged building ratio of 30%, a value of 100 will be assigned as earthquake-building score. Since the objective function aims to minimize the sum of the earthquake-building score over the route, then the optimal route will be composed by arcs with individual earthquake-building score values of one.

5.4 Compiling and executing the model

The route optimization model is composed of two main elements, the GIS element and the optimization element. The GIS element refers to the use of GIS software for the management of the spatial data, whereas the optimization element refers to the use of specialized software for multi-objective optimization problem solving. The software used for the development of the route optimization model (in this research) is ArcGIS version 8.3 and GAMS version 19.2. GAMS stands for General Algebraic Modelling System. I have divided the solution process of the route optimization model in two parts, *i.e.* in two sub-models. The first part deals with the input of the required data and the initial parameters into GAMS, this means importing data from GIS to GAMS. The second part is solving the optimization problem based on the data and parameters input from the first part of the solution process. The solution of the optimization problem can then be exported back into GIS for visualization purposes, thus continuing with the decision-making process.

The purpose of splitting the model into two sub-models is reducing the running time when evaluating different scenarios, where the initial parameters do not change. For example evaluating different scenarios where the origin and destination points do not change, but where the objectives and their respective priority weights do change. Figure *5-7* shows the compiling and execution process that takes place in the route optimization model. However, the process of compiling and execution must not be confused with the internal processes of compilation and execution that takes place within GAMS. The compilation and execution processes in GAMS refers to the process of acquiring the data and performing the data manipulation respectably (Brooke, Kendrick *et al.*: 1998).

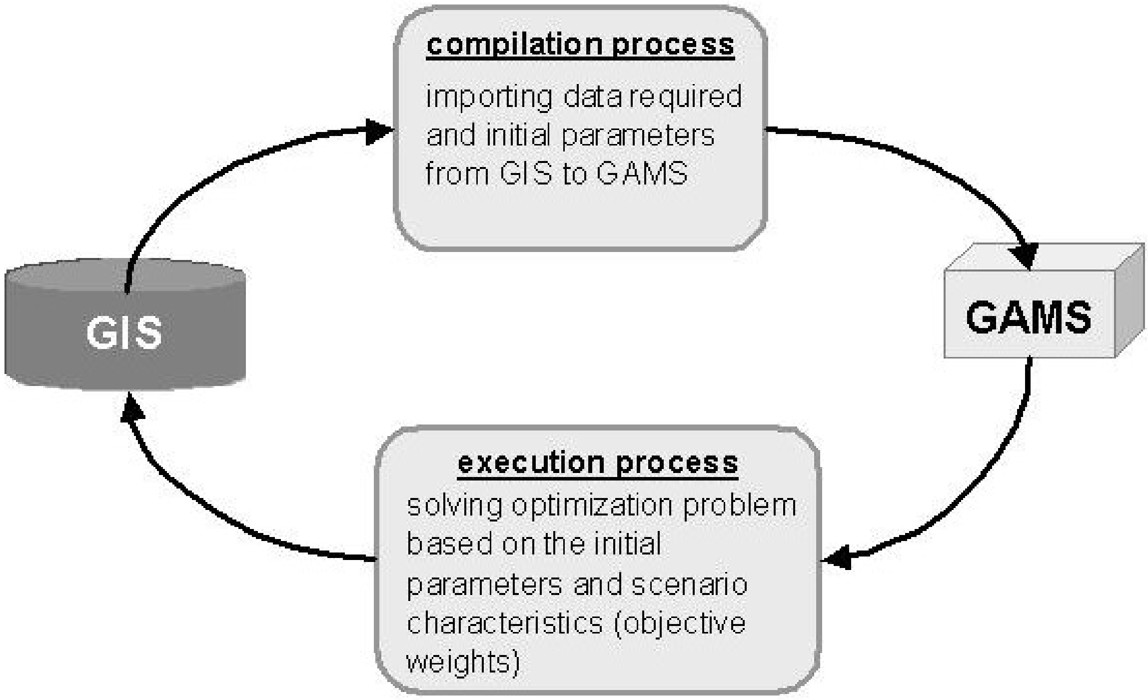


Figure 5-7 compilation and execution process

5.5 User interface for the route optimization model

In a certain way the utility of any decision-making model depends on the right visualization of the output produced by the model. The user interface serves as a communication channel between the model and the end user of the model. A good user interface can enable the end user to manipulate and create different scenarios, and consequently to make better decisions. In order to ensure that the model developed in this research study is visualized in the most suitable manner, the development of an user interface was proposed. In pursue of this, a research study on the Potential of SVG (Scalable Vector Graphics) as an interface to a route optimization model for the transport of hazardous material has been carried out parallel to the research presented in this documents.

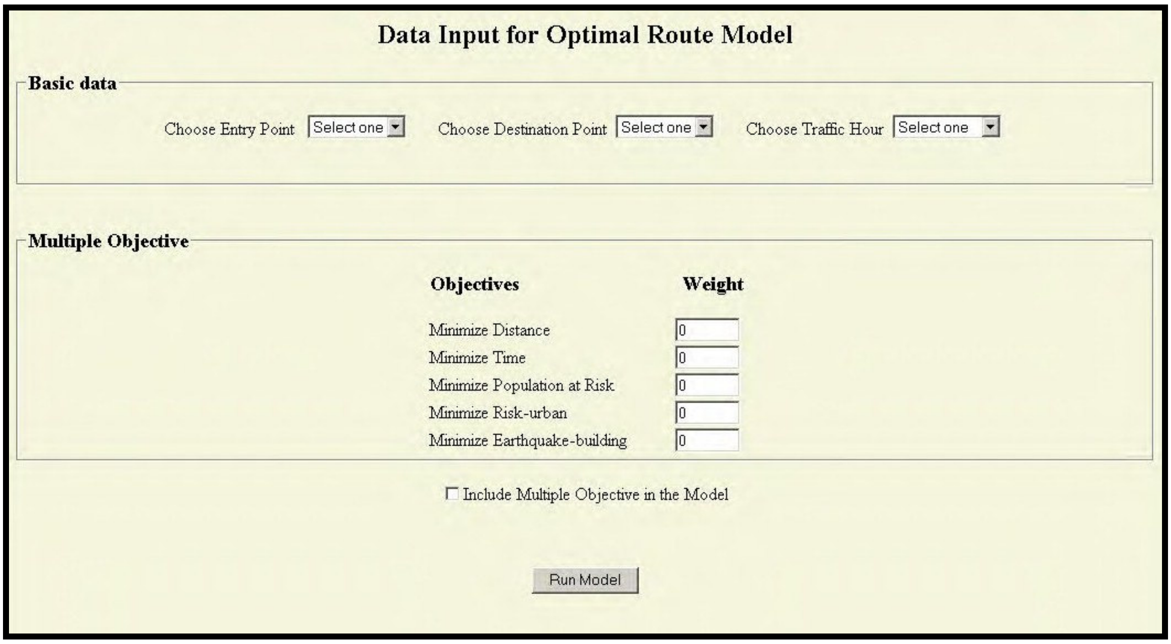


Figure 5-8 data input window of the user interface

Source Hegde (2004)

5

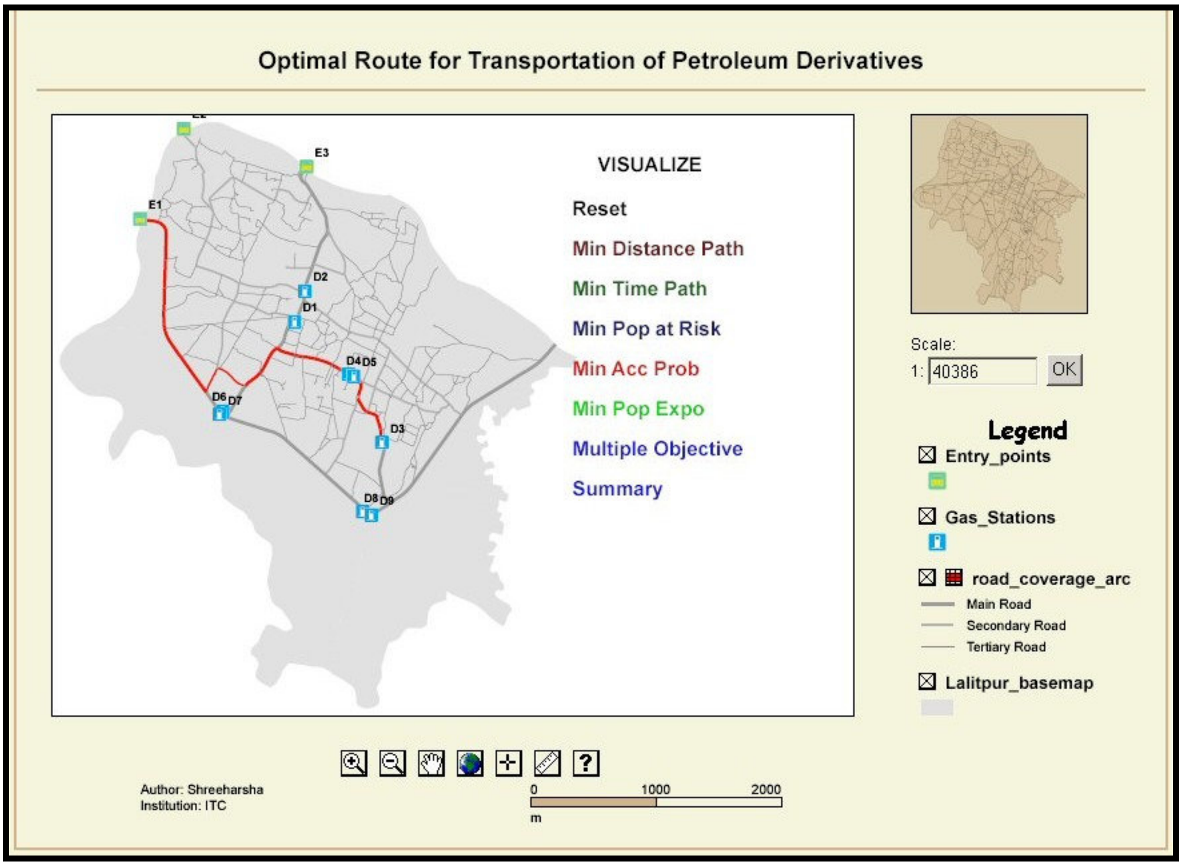


Figure 5-9 visualizing the optimal routes in the user interface

Source Hegde (2004)

The research study by Hegde (2004) aims at developing a user interface for the route optimization model in order to maximize the usefulness for the end user of this model. Figure *5-8* and *5-9* show the windows proposed by Hegde for the user interface for the route optimization problem of petrol derivates transport.

Figure *5-8* is used to define the initial parameters of the problem and to assign the priority weights to each objective. The initial parameters are the origin and the destination for which the route optimization will be performed, as well as the time horizon which serves to determine the traffic conditions in the transport network. There are other parameters that must be included in the interface, but because of time restriction these were not included for the moment. The first window is related to the compilation process discussed in the previous section (see figure *5-7*).

After the model has performed the optimization *i.e.* after the execution process of the model, the output given by the model is visualized in the second window of the interface (see figure *5-9*). In this window the user of the interface can select which route to visualize *e.g.* when optimizing a particular objective or when performing the multiple objective optimization.

6. Practical application of the model

The purpose of this chapter is to illustrate to the reader the applicability of the route optimization model. In order to achieve this, the chapter is composed of three main parts. The first part discusses the contribution of the model to the decision making process. The second part presents the case for which the route optimization model will be used to calculate the ideal routes based on single objective optimization; the case will consist of an origin-destination defined by a selected entry point to the city and gas station. In the third part the multiple objective optimization is performed, after which a discussion on the achievement of each objective is made. Thereafter the chapter ends with a final remark from the author of this document.

6.1 Contributing to the decision making process

When managing the transport of HazMat, particularly when selecting routes for the transport of these materials there are questions that may arise in the decision-making process. In my opinion the following are some examples:

- What routes for HazMat transport allow the transportation operations to be economically feasible without exceeding the acceptable risk levels?
- What measures can improve the quality of the transport network in order to reduce the risk related to the transport of HazMat?
- Which of these measures tackles different risks at the same time?
- What risk management activities can be carried out without increasing the operational costs for transporting the HazMat?
- In the case of transporting petrol derivates, should the government subsidize the transport company in order to maintain the prices for the end-consumer stable?
- *Etc.*

Decision-making processes related to the route selection for the transport of HazMat are complex due to the fact that many controversial issues (economic and risk related) can be taken into account; and when controversial issues are dealt with in relation to a given phenomenon, making decisions must be sustained in formal analysis (Bohnenblust and Slovic: 1998). The route optimization model for HazMat transport therefore can serve as a tool that can ease the decision-making process and may help to reach consensus among the parties involved. The route optimization model can give an overview of the consequences when using certain routes for the transport of HazMat. Even though the route optimization model does not generate the solution to the problem related to the economic and safe transport of HazMat; it can provide valuable information related to the routing problem, thus contributing to the decision-making process.

In this document the decision-making process refers to the process where the stakeholders related directly or indirectly to the transport of HazMat meet to: discuss how the transport operations can be carried out in an economic and safe manner; and discuss which routes should be designated for the transport of HazMat.

6.1.1 The role of the stakeholders

I have mentioned earlier in this document three of the stakeholders related to the transport of petrol derivates in Lalitpur: The Nepal Oil Corporation (NOC), the Nepal Petrol Dealers Association (NPDA), and the Municipality of Lalitpur. I have not been able to carry out a complete stakeholder analysis; however, based on the interviews held with the stakeholders' representatives during the fieldwork period of this research study, I state my opinion in relation to the stakeholder interest towards the petrol derivates transport in Lalitpur, Nepal. Table *6-1* below shows the qualitative appreciation level (priority weight) that each stakeholder gives from my point of view to each objective considered for the route optimization model. The size of the black dot is proportional to the appreciation level of each stakeholder; the bigger the dot the more appreciation or interest of the stakeholder can be allocated towards one objective.

The NOC is interested in satisfying the demand for petrol derivates in Nepal. In order to cope with the demand, the NOC must rely on the service provided by the NPDA operators, which are in fact the only counterpart transporting the material to the gas stations. The NOC is aware of the fact that the NPDA operators aim at making a reasonable profit from the transportation of petrol derivates. Therefore, the NOC does not apply any restriction to the NPDA operators on which routes are should be used for the transport of petrol derivates within the Lalitpur city boundaries, and neither for transporting the material within the rest of the Kathmandu valley area. For this reason I can say that the NOC's lack of regulation in the transport activities contributes to the use of routes where the operational costs are minimized, which in fact may represent the use of unsafe routes.

	objective	stakeholder		
		Nepal Oil Corporation (NOC)	Nepal Petrol Dealers Association (NPDA)	Lalitpur municipality
economic issues	minimize travel distance	●	⬤	•
	minimize travel time	●	⬤	•
risk issues	minimize risk for the population	•	•	⬤
	minimize risk for the urban environment	•	•	⬤
	minimize risk related to earthquake	●	●	⬤

Table 6-1 appreciation level given to each objective by the stakeholders

The size of the black dot is proportional to the appreciation level of each stakeholder

The NPDA is interested in minimizing the operational costs involved in the transport of petrol derivates. In order to achieve this, the NPDA operators suggest the drivers of the tanker units to make use of the shortest route available in terms of time. The Municipality of Lalitpur is concerned about the reduction of any type of risk related to the transport of petrol derivates. This includes risk for the population and risk for the urban environment.

In relation to the risk related to an earthquake hazard and the building vulnerability, the three stakeholders showed at least some moderate degree of interest. This interest reflects the level of awareness that exists about the proneness to earthquake hazard in the Kathmandu Valley, as well as in the whole country. The stakeholders are aware that in case of the occurrence of an earthquake, the post-event situation can be worsened if one tanker happens to be travelling through a place where the amount of debris is higher than other; thus producing a secondary risk.

The role of the stakeholder in the decision-making process related to the transport of petrol derivates consists of defining the criteria on which the selection of routes will be carried out. For the development of the route optimization model I have pre-defined the criteria, which in my own perception reflect the interest of the stakeholders previously mentioned in this document. However, in a real life application of the model, each stakeholder can suggest a different criterion or number of criteria, which reflect the particular interest(s) in relation to the decision-making problem. Another role of the stakeholder in the decision-making process is to define what scenarios should be created and evaluated by the route optimization model. One scenario differs from other scenarios by having different priority weight values assigned to each of the objectives. Every time a scenario is evaluated with the route optimization model, the output can be analysed by the stakeholders, and based on this analysis new priority weights can be assigned to each objective, therefore creating a new scenario for further evaluation.

In summary, the stakeholder has an important role in the use of the route optimization model when defining the criteria that are to be considered for calculating optimal routes, as well as defining what scenarios should be evaluated. The information generated by the route optimization model can be then made available for the discussion table in order to contribute to the decision-making process.

6.1.2 Flexibility of the route optimization model

The possibility of the stakeholders of having an important role in the definition of the objectives and scenarios that need to be evaluated is what I refer to as the “flexibility” of the route optimization model. Changing the priority weights and performing single and multiple objective optimizations can be easily achieved with the route optimization model. Incorporating other objectives into the route optimization model can also be accomplished with very little effort. The model can be customized to cope with the requirements of the end users.

Another example of the model’s flexibility is the ability of creating scenarios for different time horizons. The traffic conditions during morning, afternoon, or evening times can be considered for evaluating optimal routes. The population behaviour at different times of the day can be added to the model in order to quantify risk more accurately.

It is important to mention that the model also can be used in combination with urban growth models, in order to do an integrated urban plan for future development. If the data produced by an urban growth model is available, the route optimization model can be used to assess if in the near future new developments could be exposed to risk related to the transport of petrol derivates, or any type of HazMat. The route optimization model in combination with an urban growth model can also be used to find optimal routes considering future urban features.

6.2 Running the route optimization model

There are 9 gas stations located within the case study area; and it is possible to calculate the optimal routes based on the optimization of each objective individually. However, I will restrict the analysis discussed in this chapter to the route optimization for the transport of petrol derivates to the gas station shown in figure *6-1*.

initial parameter	value
ratio of occupancy on the network	*0.4*
average number of persons per vehicle	*3 persons per vehicle*
average vehicle length	*7m*
maximum average speed assigned to each arc	*main = 70km/h, sec. = 50km/h, ter. = 30km/h*
minimum section width for admissible arcs	*4m*
probability of HazMat tanker to be involved in accident	*0.0001*
fire ignition probability (see figure 2-3)	*0.1*

Table 6-2 initial parameters input into the model

Besides defining the origin and destination point for which routes will be calculated, it is necessary to define some initial parameters before performing the route optimization. The ratio of occupancy, average number of persons per vehicle, average vehicle length, maximum average speed, minimum section width, and HazMat accident probability values are defined by the author of this document for the purpose of evaluating the route optimization model. These values (previously mentioned) can be modified, upon further analysis, to model more accurately the reality of the case study area. The fire ignition probability value shown in figure *2-3* (page 19) is considered one of the initial parameter for solving the route optimization problem.

In order to estimate the routes based on multi-objective optimization it is necessary to evaluate each objective individually. Evaluating each objective individually has two purposes: first to estimate the ideal route and value of each objective function, second to analyse the trade-off values between the ideal values calculated on the single objective optimizations.

6.2.1 Finding optimal routes

The ideal route found when optimizing a particular objective individually represents the route with the maximum degree of satisfaction for the objective being evaluated. Since every objective function that has been considered in the route optimization model developed in this research aims to the minimization of a certain value, such as for example time or risk for the population, then the ideal objective function value indicates the lowest value that the objective can receive; in other words there is no other route with a lower objective function value.

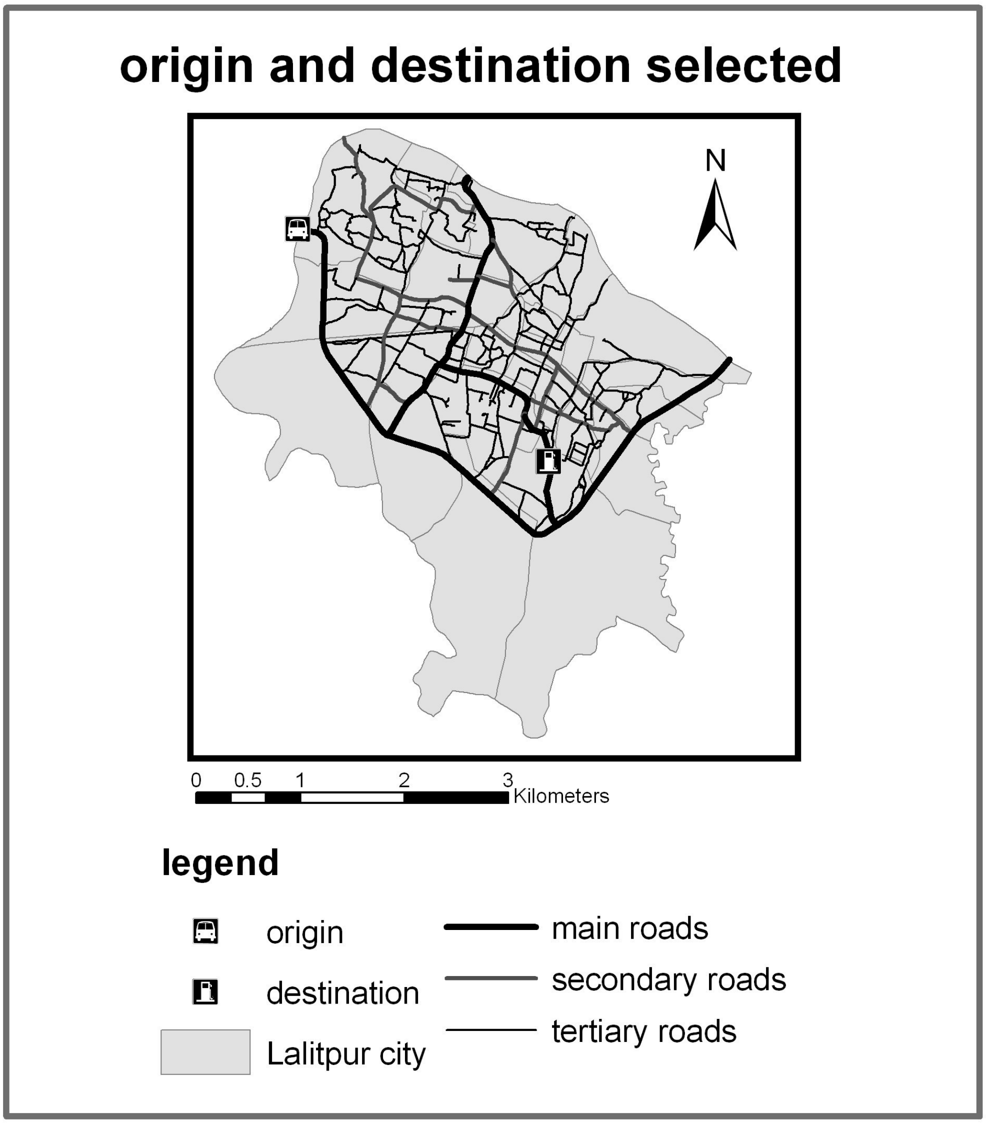


Figure 6-1 origin and destination for route optimization evaluation

The ideal route calculated by the model when minimizing travel time reflects in fact the route that the NPDA operators suggest to the drivers of the tanker units. The suggested route given by the NPDA operators is to travel through the ring road until in reaches the intersection that connects to the road where the distance from the ring road to the gas station is the shortest possible. This indicates that the routes calculated by the route optimization model fairly represent the reality.

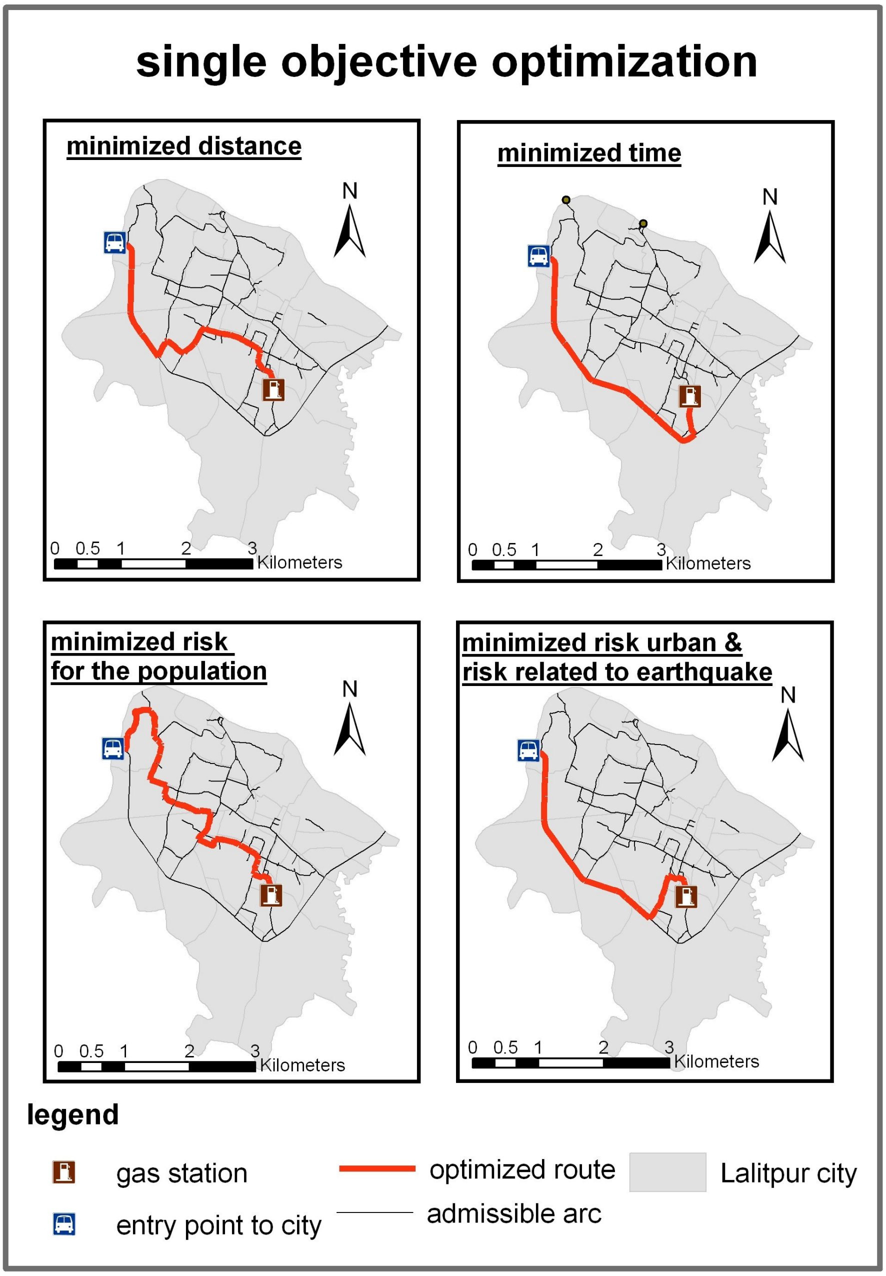


Figure 6-2 optimal routes based on single objective optimization

Considering that the extension of the transport network is small in size, the number of available routes is limited. The reader is reminded that from 613 arcs found in the network of the case study area; only 273 arcs are used for the calculation of optimal routes (section 5.1.1). As a result of this, some routes will be identically even when optimizing for different objectives, for example when minimizing risk for the urban environment and risk related to earthquake.

6.2.2 Trade-off among the objective function values

I want to call the attention to the route calculated when minimizing risk for the population. This route is certainly the most un-economical route when considering that the total distance and time calculated for the route are the highest. This means that if this specific route is used for the transport of petrol derivates, the operational costs for transporting the petrol derivates will increase. On the other hand the route with the lowest time value has high values for the risk for the population and the risk for the urban environment; additionally, this route has the highest number of arcs with a damaged building ratio in case of earthquake above 0.20.

objective function value	objective been minimized				
	distance	time	pop_risk	risk_urban	risk_eq_buil
distance	4,745m	5,008m	5,798m	4,750m	4,750m
time	5.25min	5.02min	9.26min	5.19min	5.19min
risk for the population	160 persons	150 persons	99 persons	142 persons	142 persons
risk for the urban environment	0.00009669 *	0.00009208 *	0.00010658 *	0.0000511 *	0.0000511 *
risk related to earthquake	40 **	1020 **	160 **	29 **	29 **

* this is actually the specific risk for buildings in case of a fire produced by an petrol derivates accident

** this value results of minimizing the sum of total earthquake-building scores in the route. Arc with a damaged building ratio less or equal to *0.20* a score of *1* is assigned; whereas arcs with a damaged building ratio higher than *0.20* a score of *100* is assigned. The damaged building ratio was calculated based on the scenario of an earthquake of magnitude *5.7* and intensity *MMI-VI* to *MMI-IX*. If the objective function value is higher that *100*, it means that at least one arcs of the route has assigned a damaged building ratio higher than *0.20*.

Table 6-3 objective function values calculated when doing single objective optimization

Table *6-3* represents the information available for the stakeholders on each of the routes that best satisfy each objective. The time and distance values can be transformed into economic units, which then can serve to estimate how much the operational costs increase if the safest route for the population is considered for use for the transport of petrol derivates. Secondly, these values are needed in order to evaluate the scenarios in which multiple objectives are optimized in order to calculate the routes.

6.3 Evaluating scenarios based on multi-objective optimization

I will proceed now to perform the multi-objective optimization. For this purpose the model considers the ideal function values calculated when performing the individual single objective optimizations, and the priority weight assigned to each objective. I will evaluate four scenarios where the priority weights of the first three scenarios are defined based on the appreciation level given to each objective by a particular stakeholder (see figure *6-1*), and in the last scenario an equal priority weight is assigned to all objectives.

	objective	priority weights			
		scenario 1 (NOC)	scenario 2 (NPDA)	scenario 3 (municipality)	scenario 4 (equal-weight)
economic issues	minimize travel distance	0.30	0.40	0.05	0.20
	minimize travel time	0.30	0.40	0.05	0.20
risk issues	minimize risk for the population	0.05	0.03	0.30	0.20
	minimize risk for the urban environment	0.05	0.03	0.30	0.20
	minimize risk related to earthquake	0.30	0.15	0.30	0.20

Table 6-4 priority weights assigned to each objective

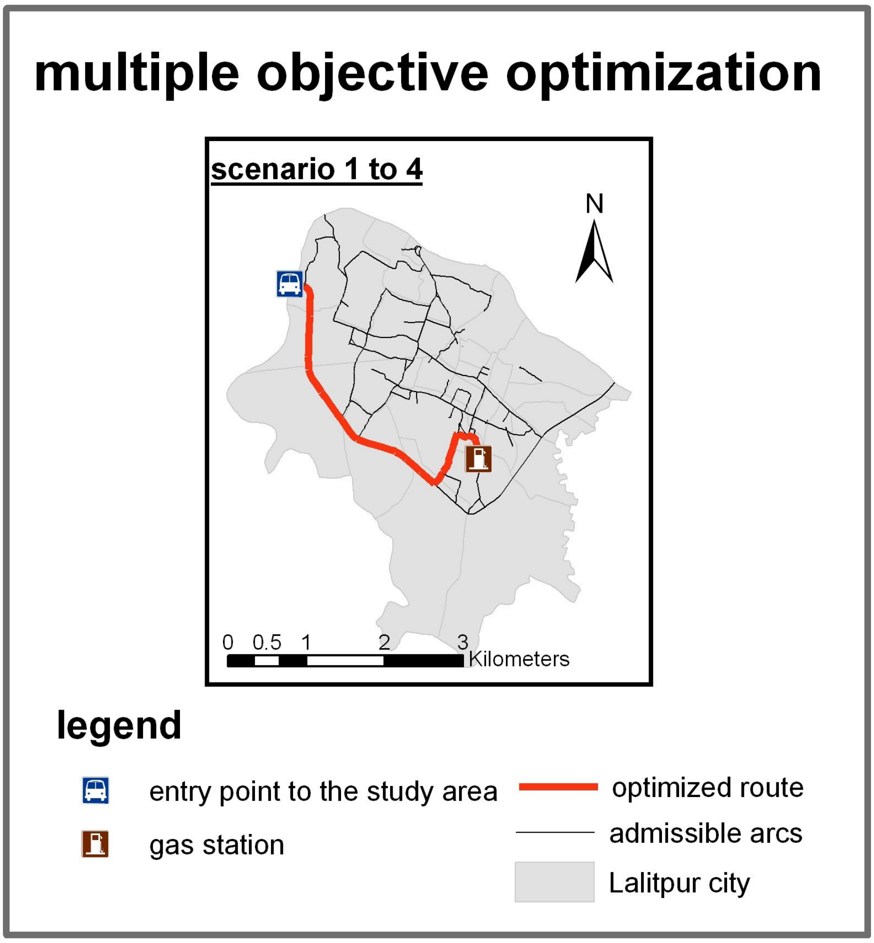


Figure 6-3 optimal route evaluated from scenario 1 to 4

After evaluating the four scenarios, the model suggested the same route for all scenarios. Why did this happen? When performing the multi-objective optimization, the model searches for the route where the total deviation value is the lowest possible. The total deviation results from the addition of the deviation of each objective multiplied by the respective priority weight. Each objective deviation actually indicates how much the objective function value differs from the ideal objective function value. The priority weight indicates which deviation contributes more to the total deviation value, thus indicating which objective is more important compared to others. For every possible route available in the transport network, the total deviation is calculated. After calculating the total deviation of every route, the route with the lowest total deviation value is chosen. Since the number of admissible arcs in the transport network is low, the number of routes available is low as well. Therefore, the same route is chosen as optimal route even when assigning different priority weight to each objective.

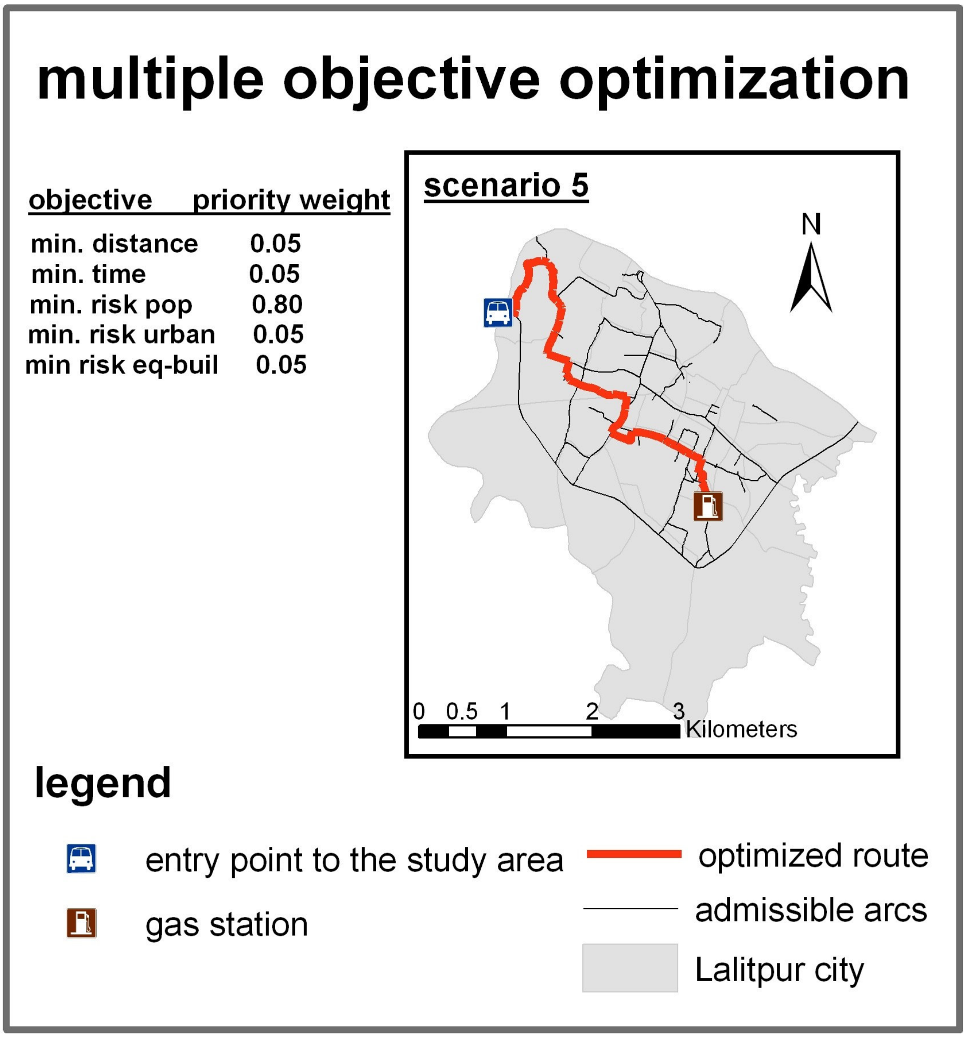


Figure 6-4 optimal route evaluated from scenario 5

What is the lowest priority weight value that must be assigned to the objective of risk for the population, in order to choose the route that best reduces the value of risk for the population? After running the model in different occasions, increasing on each run the priority weight to the objective of risk for the population; it was found that only when assigning a priority weight of 0.80 or higher to the objective of risk for the population, that the optimal route differs from the one calculated in scenario one to four.

6.3.1 Satisfaction level for each objective

In pursue of contributing to the decision-making process, the model gives the objective function values for each optimal route calculated. Additionally, the model can calculate the percentage of the total deviation attributed to each objective. The percentage of the total deviation results from dividing the objective deviation by the total deviation value. For each objective the following rule applies: the higher the percentage of the total deviation, the higher the objective deviation, indicating a greater difference between the objective function value and the ideal objective function value (when the objective is optimized individually). In other words, when calculating routes by optimizing multiple objectives the percentage of the total deviation can be used as an indicator of how satisfied each objective is.

objective	scenario 4			scenario 5		
	priority weight	objective function value	percentage of total deviation	priority weight	objective function value	percentage of total deviation
distance	0.20	4,750m	0.22	0.05	5,750m	3.20
time	0.20	5.19min	7.35	0.05	9.28min	12.84
risk for the population	0.20	142 persons	92.43	0.80	99 persons	0.91
risk for the urban environment	0.20	0.0000511 *	0.00	0.05	0.0001029 *	15.32
risk related to earthquake	0.20	29 **	0.00	0.05	159 **	67.73

* this is actually the specific risk for buildings in case of a fire produced by an petrol derivates accident

** this value results of minimizing the sum of total earthquake-building scores in the route. Arc with a damaged building ratio less or equal to *0.20* a score of *1* is assigned; whereas arcs with a damaged building ratio higher than *0.20* a score of *100* is assigned. The damaged building ratio was calculated based on the scenario of an earthquake of magnitude *5.7* and intensity *MMI-VI* to *MMI-IX*. If the objective function value is higher that *100*, it means that at least one arcs of the route has assigned a damaged building ratio higher than *0.20*.

Table 6-5 objective function values calculated on scenario four (4) and five (5)

From the two routes that have been selected, the decision makers can debate which route should be taken. The dilemma is whether to use the route with the highest value of risk for the population, which is the most economical one; or use the route where the risk for the population value is the lowest, but also where the operational costs are definitely higher. Perhaps the decision of selecting one route or the other can also be accompanied by other decisions oriented at the improvement of the transport network for example. Since the risk for the population results from multiplying the hazard probability with the total number of persons found alongside to the route and travelling on the route, the absolute value of risk for the population can be subjective in a certain way. The same risk value can result from high hazard and low number of persons, or low hazard but with a very high number of persons affected. In the case of the route for scenario four, the total population exposed along and in the route is half the one calculated for the route in scenario five (see figure *6-6*). However, the accident rate for the route in scenario four is higher, thus the value for risk for the population results higher than in scenario five.

It might be the case that if the physical condition of the ring road and other main roads is improved, the accident rate can be reduced, therefore reducing the overall risk for the population. Some improvements in the physical condition to these road sections can be the installation of traffic lights, or constructing a barrier to divide the lanes travelling in opposite directions, *etc*. This brings us to another question: How much money should be invested in order to reduce the hazard, and by doing so, reducing the risk?

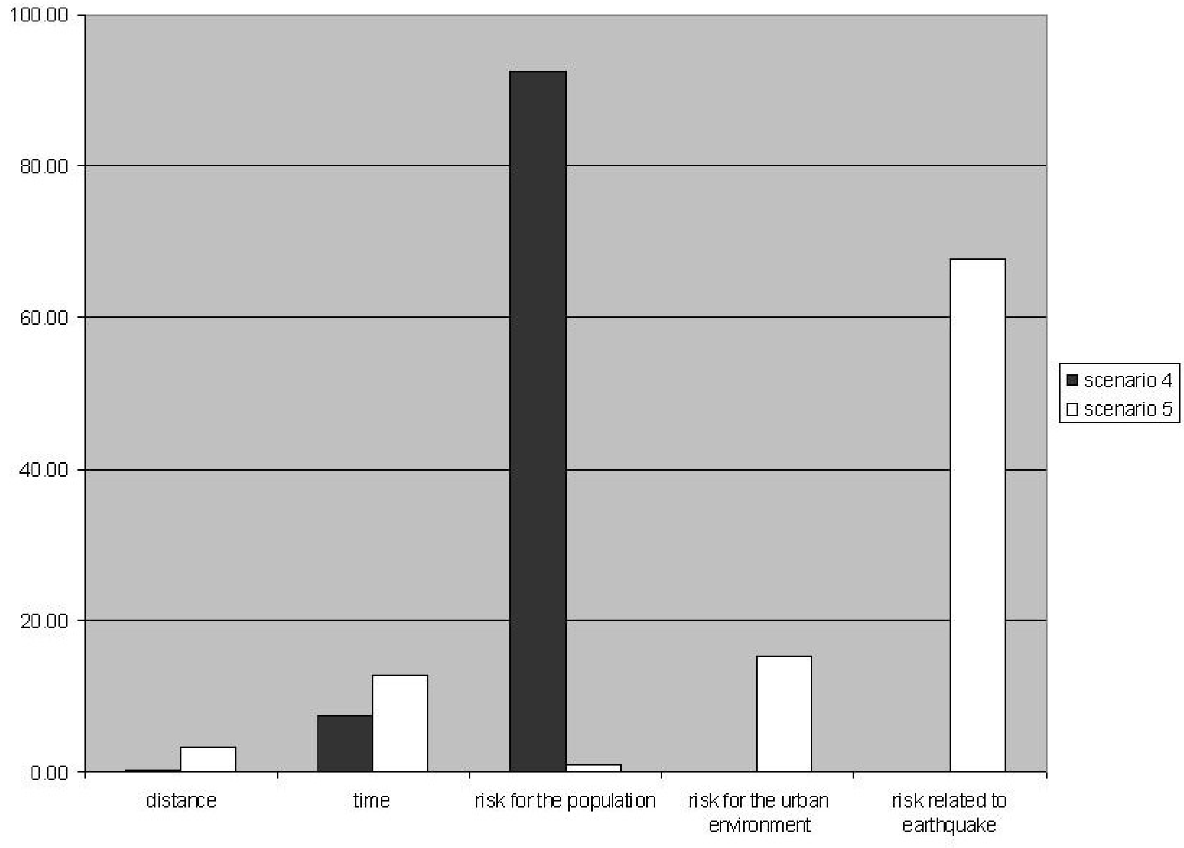


Figure 6-5 percentage of total deviation for each objective

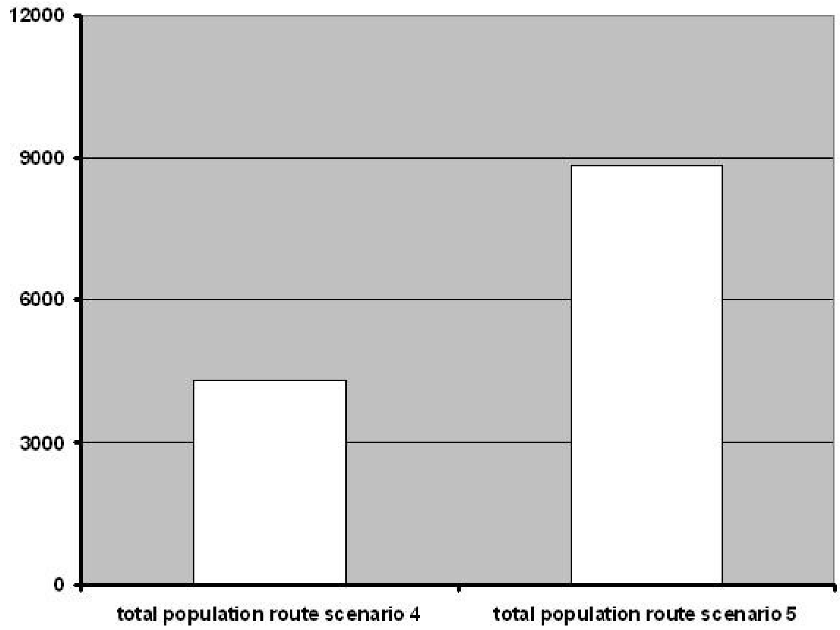


Figure 6-6 total population per route (scenario 4 & 5)

6.3.2 Cost-effectiveness analysis

Although preventing traffic accidents from happening is a utopian concept, it is possible to reduce the accident rate by improving the condition of the transport network. In order to assess the suitable amount of monetary investment needed to reduce risk (either to reduce the hazard or the vulnerability); a cost/effectiveness analysis can be carried out. Bohnenblust and Slovic (1998) mentioned the steps for performing a cost-effectiveness analysis. The purpose of the cost-effectiveness analysis is to determine the optimal amount of money to spend, which will effectively reduce risk. Due to the restricted time for this research study I was not able to carry out a detailed cost-effectiveness analysis for the case study of Lalitpur. Therefore, I can only recommend the use of cost-effectiveness analyses in the decision-making process related to the transport of HazMat in general and petrol derivates specifically, without including such an analysis in my research.

In the particular case of Lalitpur, the amount of money that is needed to be spent for the reduction of the number of accidents in the transport network can be estimated by performing a cost-effectiveness analysis. And perhaps the approach proposed by Bohnenblust and Slovic (1998) can be followed in order to produce a risk-cost diagram applicable to the case study of the research study presented in this document.

step 1:
identification of all possible safety measure.

step 2:
assessing the effectiveness and the cost of all safety measures and meaningful combination thereof. The effectiveness is measured as the reduction of the monetary risk. The cost includes the initial investment cost as well as the ensuing annual operating and maintenance cost.

step 3:
representing all safety measures and meaningful combination thereof in a risk-cost-diagram.

step 4:
identifying the optimal risk reduction curve or efficiency frontier. The efficiency frontier is defined by connecting all points of the risk-cost-diagram that lead to the largest risk reduction at all cost levels.

step 5:
the optimal safety measure is indicated by the point where the slope of the efficiency frontier changes to a value greater than negative one (-1).

Box 6-1 cost-effectiveness-analysis basic steps

Source Bohnenblust and Slovic (1998)

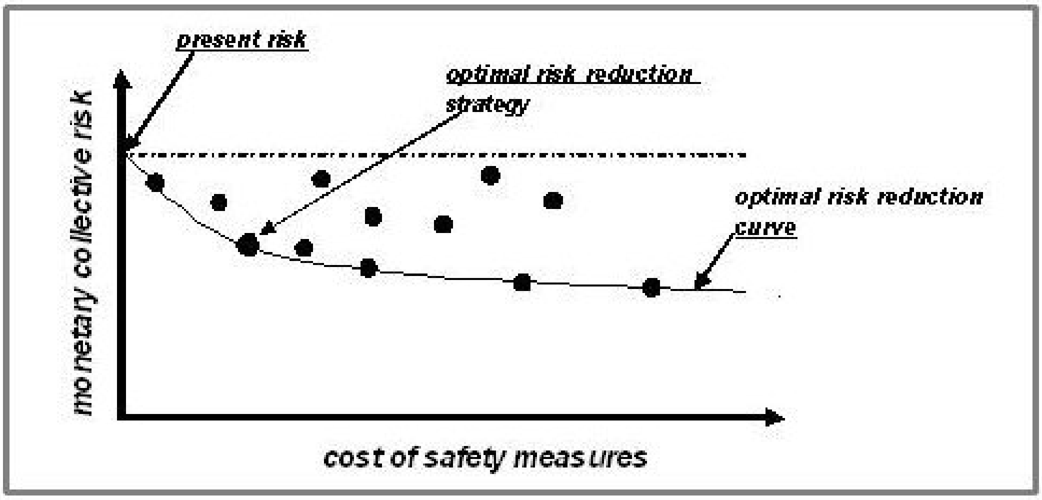


Figure 6-7 optimal risk reduction curve

Source Bohnenblust and Slovic (1998)

Each dot in the graph showed in figure *6-7* represents one safety measure. Every safety measure achieves a different reduction of risk. This graph suggests what the threshold is for the amount to invest in safety measures. The contribution to risk reduction of every investment above this threshold will not be efficient enough for consider it to be implemented. The optimal risk reduction strategy is set upon the identification of this threshold, which is in fact the safety measure that best contributes to reduce risk.

6.4 Final remark

Certainly the decision-making process related to the transport of petrol derivates in Lalitpur, and as well in rest of the country, can greatly benefit from the use of the route optimization model. As it has been shown in this chapter it is possible to evaluate routes considering many different and conflicting objectives. The amount of time required to solve the optimization problem is considerably low (less than 5 minutes to be exact), which means that in a very short period of time many scenarios can be created and analysed. It is in this sense that the model can be used even at the same moment that the stakeholders are meeting and discussing the problem of transporting petrol derivates.

7. Conclusions and recommendations

The last chapter of this document is divided into four sections. The first section gives the conclusions drawn from this research study. The second section is dedicated for cross-checking the content of this document with the objective and sub objectives listen in the first chapter. The third section discusses the recommendations given by the author in relation to the improvement that can be done to the output of this research study; in this section recommendation to the representatives of the Municipality of Lalitpur are given, as well as recommendations for further research opportunities in relation to the topic of HazMat transport. The fourth and last section gives a final remark from the author.

7.1 Conclusions

Risks cannot be avoided, but they can in fact be managed. The management of risk before its occurrence is oriented towards the management of the hazards, or the vulnerability, or both. Any risk factor that is managed properly can contribute to the reduction of risk. It is important to realize that eliminating every risk source completely is utopian, although the overall risk can certainly be reduced as it has been said already. In this document I have labelled as risk factor: the hazard, the element at risk, and the vulnerability of the element at risk in relation to a hazard; these risk factors are often the result of complex processes. Consider for example the case where there is a constant growth in the number of vehicles in one city; the growth in the number of vehicles can be linked to the economical progress of the population, since a person, group, or organization must have a certain income to buy and maintain a vehicle. At the same time the growth in the number of vehicles in the city can lead to increase in the number of accidents, in addition to this is the fact of not having traffic lights installed in the transport network. The process of installing traffic lights in the transport network may not be achieved because lacking of political willingness to assign the necessary economic resources to the entity in charge of managing the transport network. Another example is the one related to bad urban practices that allow the construction of hazardous facilities near dwellings, or the other way around, the development of dwellings near existing hazardous facilities.

This is the logic behind the conceptual model proposed in this research study (see figure *2-5* on page 25). There are many risk sources that can affect the selection of routes for the transport of HazMat, and at the same time there are other processes that influence these risk sources; for example economic interest ruling over the safety of the population, or lack of regulating laws for the HazMat transport due to government instability. When it come to make decisions towards a better management for the transport of HazMat it is necessary to get a broader picture than just looking at the sole transport operations. In my own opinion there will be no fixed answer to what risk factors should be considered when developing a route optimization model. Since this will depend to the own characteristics of each case study. Nevertheless it was the aim of this research study to consider the integration of different factors (economic, transport, risk) when developing a route optimization model.

It is my personal conclusion that assessing different risk sources and the processes that generate risk can result in a better management strategy, a strategy that best achieves to reduce risk at the lowest cost possible. The route optimization model developed in this research study can contribute in defining this strategy that will make that transport of HazMat a safe activity and that will maintain the economic attractiveness for the transport companies.

The methodology proposed in chapter *3* (page 35) was proposed in pursue of integrating different risk and economic factors. In a route optimization problem the objectives that serve as criteria for the calculation of routes 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 calculate routes based on conflicting objectives, a multiple objective mathematical programming (MOMP) approach was proposed. By means of the MOMP it is possible to evaluate the routes without having to transform the units of the objective function into a common one. Furthermore the phase-wise methodology proposed in this document allows the modeller to construct the model by parts, adding complexity as each phase is accomplished. The methodology proposed in this research study suggests that the development process of the model can continue until the desired requirements are met.

The approach of developing a model that can be customized to other case studies and not just the one presented in this document is of great relevance when considering applying the methodology in developing countries. What is special about a developing country? In my opinion the reality in a developing country can be so much different and complex than in developed countries. The level in which risk is perceived by the government in a developing country may be diminished by the need to satisfy the basic services to the population. In cases where there is awareness of the need to manage risk, the access to modelling tools that can aid to the risk management may not be available. Another case could be one where modelling tools are available but the lacking of information required by the model can represent a drawback in the management process of risk. For this reason I proposed a methodology that can be easily adapted to fit the reality of a given case study. This flexibility aspect of the model is the main ingredient for a successful model.

The model flexibility also refers to its capability of creating and evaluating scenarios. The scenarios can give a better understanding of the problem to the stakeholders and by doing so the stakeholders can make better decisions. The model allows the stakeholders to define their own scenarios by modifying the priority weights that are assigned to each objective. After all, decisions are going to be taken as a result of a debate carried out by the stakeholders; the model does not give an absolute solution to the problem of route selection for HazMat transport, but it will certainly ease the decision making process.

7.2 Cross-checking with research objectives

In this section I want to cross-check whether I have achieved or not the research objective mentioned in the first chapter of this document (see section *1.5* on page 7). In order to achieve with the research objective I proposed a series of five sub objectives, each with a set of questions that were to be answered (or at least I tried to answer) throughout this document. In pursue to do this cross-checking in a more simplified and straight-forward manner and avoiding double writing of what have been said in this document, I present the table *7-1* which associate each research sub objective with the chapter number where a relevant and related discussion about each sub objective is made.

Sub objective	Reference
To determine the different risk related factors that can influence directly and indirectly the transportation activities of HazMat and that can be considered in the route optimization model	Chapter *2*
To propose a methodology for the development of a route optimization model	Chapter *3*
To develop a GIS based model for the selection of optimal routes for the transport of HazMat based on the proposed methodology	Chapter *4* and chapter *5*
To assess the influence of the stakeholders in the selection of routes for the transport of HazMat	Chapter *4* (section *4.2*) and chapter *6* (section *6.1*)
To apply the route optimization model in the selected case study of this research	Chapter *6*

Table 7-1 cross-checking achievement of research objective

7.3 Recommendations

There are 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 model if more accurate and reliable data is acquired. In this section first I will give recommendations to the representatives of the Municipality of Lalitpur in relation to the data that can be locally collected; data which can then be used by the route optimization model. Secondly I will list out the areas where future research studies can focus on.

7.3.1 For the Municipality of Lalitpur

When I mention recommendations for the Municipality of Lalitpur I am not stating that the municipality is solely responsible for the collection of the data that can improve the output of the route optimization model; but that I consider that the municipality has a 'key' role in this matter. The model that has been developed uses data that in a number of cases was not reliable; in other cases where it was not available other secondary sources were used in order to 'fill in the gaps'. In terms of data that needs to be collected or revised locally, I give the list below:

- Data related to the traffic condition of the transport network is needed. Traffic data such as Average Daily Traffic (ADT) and traffic density per each road section (arc) at different times of the day. In this research study the three traffic flow classes given by the DoR were use in the model (see section 4.3.2 on page 58); it is recommended to revise the threshold of each traffic flow class.
- Data related to average and maximum speed of one vehicles travelling one each road section. The average maximum speed values per section type (main, secondary, and tertiary, see figure 5-2 on page 66) were defined arbitrarily and they were used to determine the travelling speed of each arc in the transport network. These individual speed values of each arc were then used to calculate the travelling time over the arc. A better assessment of the travelling speed and times over the arcs of the transport network is recommended to increase the accuracy of the model output.
- In relation to the accident rate. I recommend to convert the hand-written records of the accidents occurred in the case study into a digital format. The accident records in digital format can then be analysed in a GIS environment in order to calculate the accident rate taking into account the spatial dimension.
- I recommend using population data at a higher level of detail than the data used in this research study. This is needed to make a better estimation of the population assigned to each road section of the network. I also recommend using population behaviour patterns i.e. where does the population concentrate at different times of the day. Better population data leads to a

better quantification of risk for the population. It is expected that by the time this document is printed, the output of the research study of Islam (2004).

- Similarly to the population data, I recommend using more accurate building data that the one used in this research study. In relation to this there is already some effort made by a building survey that gave as a result the building footprints of Lalitpur. The Building footprint were use by Guragain (2004) in his research study for the construction of a spatial database of the buildings in Lalitpur. This indicates that by the time his thesis work culminates improvement in this area is to be expected.

7.3.2 Further research opportunity

I can identify the following areas that are subject for further research:

- **Accident rate estimation:** normally the accident rate is estimated along the extension of a given arc, however the probability of an accident to occur is not distributed evenly in every point of the arc. In my opinion there are more chances of been involved in an accident when passing by a road intersection. Some questions that arise are: Can the accident rate be estimated at the nodes instead of estimating along the whole length of the arc? Can the man made hazard be only concentrated at the nodes and the natural one along the length of the arc?
- **Triggered event on a HazMat accident:** in order to make a better risk assessment in relation to a HazMat accident, more accurate probability values are necessary. The probability values of events triggered by a HazMat are often taken from event trees, like the one shown in figure *2-3* on page 19. I recommend doing more research on how to create event trees taking into account the characteristics of a particular case study. Some questions that arise are: How does the physical condition of the transport unit influence in the calculation of probability values for HazMat accidents? Are the probability values for triggered event of a HazMat accident modified or altered by the physical characteristics of the transport network?
- **Natural hazard assessment:** more research on modelling the influence of a natural hazard on the route selection for HazMat transport is recommended. The interaction among different natural hazards and socio-natural ones has often been subject of research; however the integration of natural hazards in the risk assessment of HazMat has not. In this research study I proposed to consider the influence of natural hazards to the route selection process. Even though I have achieved this, I still consider that more research in this area should be carried out.
- **Scheduling capabilities:** the capability of being able to determine the optimal schedule for transporting HazMat can be very useful in management terms. There are GIS software already develop that can handle this type of operation (scheduling). As far as I am aware, in most of

the commercial GIS software the scheduling of transport activities is determined based on the supply and demand parameters of the problem and taking into account the optimization of one objective, which can be time, distance, cost, *etc*. I consider a relevant topic of research of being able to find the optimal schedule for the transport of HazMat considering multiple objectives as criteria, in other words extent the capabilities of the model developed in this research study to solve scheduling problems as well.

- **Evaluation alternative routes:** as the model has been developed, it is possible to calculate routes from a predefined origin-destination pair. This means that the model can generate different routes between the origin and the destination taking into account the objectives and the priority weight assigned to each objective, where each route that is calculated by the model can be labelled as one alternative. If we know that there is a given number of entry point to the city (as shown in figure *4-7* on page 55) then different alternatives can be generated for each entry point. The question is which alternative is the best? To answer this question the model can be extended in order to assess from all the alternatives available, which one is the best one. If the capabilities of the models are extended to deal with this kind of problems, the answer can be given to questions like: Through which entry point should the tanker enter the city when transporting petrol derivates to a given gas station?

7.4 Final remark

As a final remark I want to emphasize in the fact that the route optimization model is a decision support tool, it does not give the solution to the problem related with the economic and safe transport of HazMat, but it does ease the decision making process with the information that generates. Even more important is the fact that the model deals with the integration of different risk factors in combination with economic factors, which certainly contributes to perform an integrated economic and risk management of HazMat transport.

List of references

Berdica, K., 2002. "An introduction to road vulnerability: what has been done, is done and should be done." **Transport Policy** 9(2): 117-127.

Blaikie, P., T. Cannon and I. Davis, 1994. **At risk : natural hazards, people's vulnerability, and disasters**. London, Routledge.

Bohnenblust, H. and P. Slovic, 1998. "Integrating technical analysis and public values in risk-based decision making." **Reliability Engineering & System Safety** 59(1): 151-159.

Bonvicini, S., P. Leonelli and G. Spadoni, 1998. "Risk analysis of hazardous materials transportation: evaluating uncertainty by means of fuzzy logic." **Journal of Hazardous Materials** 62(1): 59-74.

Brooke, A., D. Kendrick, A. Meeraus and R. Raman, 1998. **GAMS, A USER'S GUIDE**. Washington, DC, GAMS Development Corporation.

By, R. A. d., Ed. 2001. **Principles of Geographic Information Systems**. ITC Educational Textbook Series. Enschede, ITC.

Chen, W.-K., 1990. **Theory of nets : flows in networks**. New York, Wiley.

Fabiano, B., F. Curro, E. Palazzi and R. Pastorino, 2002. "A framework for risk assessment and decision-making strategies in dangerous good transportation." **Journal of Hazardous Materials** 93(1): 1-15.

Frank, W. C., J.-C. Thill and R. Batta, 2000. "Spatial decision support system for hazardous material truck routing." **Transportation Research Part C: Emerging Technologies** 8(1-6): 337-359.

Gharaibeh, N. G., J. E. Hicks and J. P. Hall, 1997. Analysis of Accidents, Traffic, and Pavement Data. **Traffic Congestion and Traffic Safety in the 21st Century : challenges, innovations, and opportunities : proceedings of the conference, Chicago, Illinois, June 8-11, 1997**. R. F. Benekohal. New York, NY, American Society of Civil Engineers (ASCE): XX, 639.

Glickman, T. S., D. Golding and E. D. Silverman, 1992. **Acts of God and Acts of Man: recent trends in natural disasters and major industrial accidents.** Discussion Paper CRM 92-02, Center for Risk Management, Resources for the Future, Washington, D.C.

Guragain, J., 2004. **GIS for seismic building loss estimation: A case study from Lalitpur Sub-Metropolitan City area, Kathmandu, Nepal**. MSc. thesis. Earth Resources and Environmental Geosciences, International Institute for Geo-Information Science and Earth Observation (ITC). Enschede, The Netherlands.

Hegde, S., 2004. **Potential of SVG as an Interface to a Route Optimization Model for the Transport of Hazardous Materials**. MSc. thesis. Geoinformatics, International Institute for Geo-Information Science and Earth Observation (ITC). Enschede, The Netherlands.

R

Islam, M., 2004. **Population vulnerability assessment for earthquakes in Lalitpur, Nepal**. MSc. thesis. Urban Planning and Land Administration, International Institute for Geo-Information Science and Earth Observation (ITC). Enschede, The Netherlands.

JICA, 2002. **The Study on Earthquake Disaster Mitigation in the Kathmandu Valley, Kingdom of Nepal**. Japan International Cooperation Agency, Ministry of Home Affairs, His Majesty's Government of Nepal.

Kalvelagen, E., 2000. **Interfacing GAMS with other applications**, GAMS Development Corp. http://www.gams.com/~erwin/ Access date: June - 2003

Karkazis, J. and T. B. Boffey, 1995. "Optimal location of routes for vehicles transporting hazardous materials." **European Journal of Operational Research** 86(2): 201-215.

Khisty, C. J. and B. K. Lall, 1998. **Transportation engineering : an introduction**. Upper Saddle River, NJ, Prentice Hall.

La_Red, 1993. **Las explosiones de Guadalajara**, http://www.desenredando.org/public/revistas/dys/rdys01/dys1-LEG-oct-24-2001.pdf Access date: November 1993

Lavell, A., 1996. Degradacion Ambiental, Riesgos Urbanos y Desastres. **Ciudades en Riesgo**. M. A. Fernandez. Peru, USAID: 30.

Lavell, A., 2000. **An Approach to Concept and Definition in Risk Management Terminology and Practice**, La Red, red de estudios sociales en prevencion de desastres en America Latina. http://www.desenredando.org/public/articulos/2000/acdrmtp/ACDRMTP2000_mar-4-2002.pdf Access date: 27-October-2003

Leonelli, P., S. Bonvicini and G. Spadoni, 1999. "New detailed numerical procedures for calculating risk measures in hazardous materials transportation." **Journal of Loss Prevention in the Process Industries** 12(6): 507-515.

Leonelli, P., S. Bonvicini and G. Spadoni, 2000. "Hazardous materials transportation: a risk-analysis-based routing methodology." **Journal of Hazardous Materials** 71(1-3): 283-300.

Lepofsky, M., 1996. "An integrated approach to transportation hazard management utilizing a geographic information systems environment." **Transportation Research Part A: Policy and Practice** 30(1): 57.

Mainguenaud, M., 2000. "A query resolution engine to handle a path operator with multiple paths." **Transportation Research Part C: Emerging Technologies** 8(1-6): 109-127.

Mansilla, E., 2000. **Riesgo y Ciudad**, La Red. http://www.desenredando.org/public/libros/2000/ryc/RiesgoYCiudad-1.0.1.pdf Access date: 25-October-003

Montoya, L., 2002. **Urban Disaster Management: A Case Study of Earthquake Risk Assessment in Cartago, Costa Rica**. Enschede, The Netherlands, ITC.

Nicolet-Monnier, M. and A. V. Gheorghe, 1996. **Quantitative risk assessment of hazardous materials transport systems : rail, road, pipelines, and ship**. Dordrecht ; Boston, Kluwer Academic Publishers.

Rockafellar, R. T., 1984. **Network flows and monotropic optimization**. New York, Wiley.

Rodes, D. M. D., 1994. "Risk Perception and Risk Communication in the Public Decision-Making Process." **Journal of Planning Literature** 8(3): 324-334.

Tennakoon, K., 2004. **Parameterisation of 2D hydrodynamic models and flood hazard mapping for Naga city, Philippines**. MSc. thesis. Urban Planning and Land Administration, International Institute for Geo-Information Science and Earth Observation (ITC). Enschede, The Netherlands.

Thakur, N. C., 2004. http://ncthakur.itgo.com/ Access date: 27-January-2004

UNESCAP, 2003. **Air Pollution in Kathmandu Valley**, Environment and Sustainable Development Office.
http://www.unescap.org/esd/environment/kitakyushu/urban_air/Kathmandu%20Final.pdf Access date: May 2003

United Nations Disaster Relief Office (UNDRO), 1991. **Mitigating natural disasters : phenomena, effects and options : a manual for policy makers and planners**. New York, N.Y., United Nations.

Zhang, J., J. Hodgson and E. Erkut, 2000. "Using GIS to assess the risks of hazardous materials transport in networks." **European Journal of Operational Research** 121(2): 316-329.

Zografos, K. G. and K. N. Androutsopoulos, 2004. "A heuristic algorithm for solving hazardous materials distribution problems." **European Journal of Operational Research** 152(2): 507-519.

Zografos, K. G. and C. F. Davis, 1989. "Multi-Objective Programming Approach For Routing Hazardous Materials." **Journal of Transportation engineering** 115(6): 661-673.

Glossary

Algorithm	A step-by-step problem-solving procedure, especially an established, recursive computational procedure for solving a problem in a finite number of steps.
Earthquake Intensity	A measure of the effects of an earthquake at a particular place.
Earthquake Magnitude	A measure of the strength of an earthquake, or the strain energy released by it, as calculated from the instrumental record made by the event on a calibrated seismograph.
Element at risk	Physical elements that can be damaged partially or totally when exposed to a hazardous situation.
Hazard	The probability of occurrence, within a specific period of time in a given area, of a potentially damaging phenomenon.
Hazardous material	Any Material that is classified as explosive, flammable liquid, oxidizing substance, poisonous gas or radioactive material.
Individual risk	The yearly death frequency of an average individual staying at the fixed point of the impact area.
Ratio of occupancy	The measure of length of the vehicles on a given road section, i.e. the sum of length of the vehicles found in a road section, divided by the total length of the road section.
Risk	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 specific risk and element at risk.
Societal risk	The cumulated frequency (F) of having an accident with (N) or more fatalities.
Specific risk	The expected degree of loss due to a particular hazard; calculated as a function of both vulnerability and hazard.
Traffic density	The actual number of vehicles occupying a given length of lane or roadway, average over time.
Traffic speed	The rate of motion of a vehicle, as distance per unit time.
Traffic volume	The actual number of vehicles observed or predicted to be passing a point during a given time interval.

Vulnerability	The degree of loss to a given element at risk or set of such elements resulting from the occurrence of a particular hazard and expressed on a scale raging from 0 (no damage) to 1 (total damage).

G

Appendix 1: GAMS programming code

```
$ontext
The program used for the route optimization model for HazMat
transport has been divided in two parts. The first part is called
route data and the second part is called route model. The route
data programming code is used to input all the initial parameters
and the data required for the model. The route model programming
code is used to evaluate the individual and multiple objective
optimization models.

ROUTE_DATA PROGRAMMING CODE
$offtext

**********************************************************************
*defining the general conditions for each time scenario,
*each time scenario refers to different time frames of the day
**********************************************************************
set ts time scenario
/
$call =C:\nepal\ndb2gms @C:\nepal\time_serie.txt
$include C:\nepal\time_serie.inc
/;


parameter ro(ts) ratio of occupancy for each time series (unit less)
/
$call =C:\nepal\ndb2gms @C:\nepal\ratio_occupancy.txt
$include C:\nepal\ratio_occupancy.inc
/;


parameter avl(ts) average vehicle length for each time series (m)
/
$call =C:\nepal\ndb2gms @C:\nepal\avg_veh_len.txt
$include C:\nepal\avg_veh_len.inc
/;

parameter kmax(ts) maximum density per time series (veh_p_km);
kmax(ts) = ( ro(ts) / avl(ts) ) * 1000 ;


**********************************************************************
*defining the nodes of the network, origin and destination node
**********************************************************************
parameter n_n total number of nodes
/
$call =C:\nepal\ndb2gms @C:\nepal\number_nodes.txt
$include C:\nepal\number_nodes.inc
/;

file nodes /nodes.inc/;
put nodes;
```

```
put '1','*',n_n:0:0/
;
putclose;

set i nodes
/
$include nodes.inc
/;

set s(i) origin node of the route
/
$call =C:\nepal\mdb2gms @C:\nepal\origin.txt
$include C:\nepal\origin.inc
/;

set g(i) destination node of the route
/
$call =C:\nepal\mdb2gms @C:\nepal\destination.txt
$include C:\nepal\destination.inc
/;

alias (i,j,k);

************************************************************************
*right hand side values for the node balance constraint
*for the origin node the rhs value is -1
*for the destination node the rhs value is 1
*for any other node in the route the rhs value must be equal to 0
************************************************************************
parameter b(i) rhs;
b(s)=-1;
b(g)=1;

************************************************************************
*defining if the flow between each node pair is one way or two ways
*refer to the attribute called tra_way where 1= one way and 2=two ways
*this is done first, because for each arc with two ways flow,
*a node pair must be defined
************************************************************************
parameter f(i,j) flow direction
/
$call =C:\nepal\mdb2gms @C:\nepal\flow_direction.txt
$include C:\nepal\flow_direction.inc
/;

************************************************************************
*assigning the distance value for each arc
************************************************************************
parameter d(i,j) distance between each node pair in meters
/
$call =C:\nepal\mdb2gms @C:\nepal\distance.txt
$include C:\nepal\distance.inc
/;
*if flow on the arc is two ways, then the "distance value" is equal
*in both directions
parameter dts(i,j,ts) distance d(i j) per time scenario (m);
dts(i,j,ts) = d(i,j);
dts(j,i,ts)$(f(i,j)=2) = d(i,j);

```

```
*************************************************************************
*dummy parameter to input the number of lanes to-from node per arc
*this parameter is use to define lijts(j,i,ts) see below
*************************************************************************
parameter dlji(j,i) number of lanes to-from node
/
$call =C:\nepal\mdb2gms @C:\nepal\lanes_to_from.txt
$include C:\nepal\lanes_to_from.inc
/;

*************************************************************************
*assigning the number of lanes from-to node for each arc
*************************************************************************
parameter lij(i,j) number of lanes from-to node
/
$call =C:\nepal\mdb2gms @C:\nepal\lanes_from_to.txt
$include C:\nepal\lanes_from_to.inc
/;
parameter lijts(i,j,ts) number of lanes per arc for each time series;
lijts(i,j,ts) = lij(i,j);
lijts(j,i,ts)$(f(i,j)=2) = dlji(j,i);


*************************************************************************
*assigning the traffic flow class for each arc
*1=high traffic flow
*2=medium traffic flow
*3=low traffic flow
*************************************************************************
parameter q(i,j) individual traffic flow class
/
$call =C:\nepal\mdb2gms @C:\nepal\flow.txt
$include C:\nepal\flow.inc
/;
parameter qts(i,j,ts) individual traffic flow class per time series;
qts(i,j,ts) = q(i,j);
qts(j,i,ts)$(f(i,j)=2) = qts(i,j,ts);

*************************************************************************
*assigning the road section width for each arc
*************************************************************************
parameter w(i,j) width of road section in meters
/
$call =C:\nepal\mdb2gms @C:\nepal\width.txt
$include C:\nepal\width.inc
/;
parameter wts(i,j,ts) width of road section in meters per time series;
wts(i,j,ts) = w(i,j)/2;
wts(j,i,ts)$(f(i,j)=2) = wts(i,j,ts);

*************************************************************************
*assigning the road section type for each arc
*1=primary or main
*2=secondary
*3=tertiary
*************************************************************************
parameter st(i,j) section type
/
$call =C:\nepal\mdb2gms @C:\nepal\section.txt
```

A

```
$include C:\nepal\section.inc
/;
st(j,i)$(f(i,j)=2)=st(i,j);
************************************************************************
*assigning the individual maximum speed to each arc
*the maximum individual speed depends on the type of each arc
************************************************************************
parameter maxsp(i,j) maximum speed for each arc (km per h)
/
$call =C:\nepal\mdb2gms @C:\nepal\max_speed.txt
$include C:\nepal\max_speed.inc
/;
maxsp(j,i)$(f(i,j)=2)=maxsp(i,j);
************************************************************************
*calculating the B empirical factor
*the B factor is used in the speed-volume-density equations
************************************************************************
parameter bf(i,j,ts) b factor;
bf(i,j,ts) = maxsp(i,j) / kmax(ts);
************************************************************************
*defining from the whole set of node pairs, which ones are admissible.
************************************************************************
parameter ac(i,j) admissible arcs
/
$call =C:\nepal\mdb2gms @C:\nepal\admissible.txt
$include C:\nepal\admissible.inc
/;
parameter acts(i,j,ts) admissible arcs for each time series;
acts(i,j,ts)$(ac(i,j)=1) = ac(i,j);
acts(j,i,ts)$(f(i,j)=2) = acts(i,j,ts);
************************************************************************
*the arc ID are input into the model
*the purpose of this parameter is to be able to identify the arcs
*assigned to each route when the model output is exported back to the
*road attribute table in the GEO-database
************************************************************************
parameter arcid(i,j) arc ID of existing arcs in the network
/
$call =C:\nepal\mdb2gms @C:\nepal\arcid.txt
$include C:\nepal\arcid.inc
/;
arcid(j,i)$(f(i,j)=2)=arcid(i,j);
parameter arcid_acc_rate(i,j) arc ID (use in acc_rate put_statement)
/
$include C:\nepal\arcid.inc
/;
************************************************************************
*calculating the individual arc density values
*this values will be use to calculate the speed and time values
************************************************************************
parameter ki(i,j,ts) density value for each time series veh per km;
```

```
ki(i,j,ts)$(qts(i,j,ts)>0 and bf(i,j,ts)) = (maxsp(i,j) -
sqrt((sqr(maxsp(i,j)) - (qts (i,j,ts) * sqr(maxsp(i,j)))))) /
(2 * bf(i,j,ts));
**********************************************************************
*calculating the individual arc speed values
*this values will be use to calculate the time values
**********************************************************************
parameter spi(i,j,ts) speed value for each time series km per hr;
spi(i,j,ts)$(lijts(i,j,ts)>0) = maxsp(i,j) - bf(i,j,ts)
* ki(i,j,ts)
/ lijts(i,j,ts);
**********************************************************************
*calculating the individual arc time values
**********************************************************************
parameter ti(i,j,ts) individual travel time per time series (minutes);
ti(i,j,ts)$(spi(i,j,ts)>0) = dts(i,j,ts) * 60 / (1000
* spi(i,j,ts));
**********************************************************************
*calculating accident rate per arc and accident probability
**********************************************************************
parameter black_spot(i,j) arcs defined as black spots
/
$call =C:\nepal\mdb2gms @C:\nepal\black_spot.txt
$include C:\nepal\black_spot.inc
/
;
parameter acc_rate(i,j,ts) individual accident rate based on ADT;
acc_rate(i,j,ts)$((black_spot(i,j)=1) and bf(i,j,ts)>0 and
ki(i,j,ts)>0 and dts(i,j,ts)>0) =
(0.004 * ((8 * sqr(maxsp(i,j)) /
(4*bf(i,j,ts)))**0.66));
acc_rate(i,j,ts)$((black_spot(i,j)=0) and bf(i,j,ts)>0 and
ki(i,j,ts)>0 and dts(i,j,ts)>0) =
(0.004 * ((8 * qts(i,j,ts) * sqr(maxsp(i,j))
/ (4*bf(i,j,ts)))**0.66));
**********************************************************************
*creating the txt file to export to the geo-database and visualize
**********************************************************************
file acc_rate_value /accident_rate.txt/;
acc_rate_value.pc=5;
put acc_rate_value;
loop((ts,i,j)$((arcid_acc_rate(i,j)>0)),
put i.tl, j.tl, arcid(i,j):0:0, acc_rate(i,j,ts):0:12, ts.tl/
);
putclose;
**********************************************************************
*accident probability of the petrol tanker
**********************************************************************
scalar accident_prob probability to tanker to be involved in accident
/
$call =C:\nepal\mdb2gms @C:\nepal\accident_prob.txt
$include C:\nepal\accident_prob.inc
/;
```

A

```
***************************************************************************
*probability for the petrol derivate to ignite
***************************************************************************
scalar fire_prob probability of the material to ignite
/
$call =C:\nepal\mdb2gms @C:\nepal\fire_prob.txt
$include C:\nepal\fire_prob.inc
/;


***************************************************************************
*calculating the total population
***************************************************************************
***************************************************************************
*OFF-ROUTE POPULATION
***************************************************************************
parameter pop_den(i,j) population number of persons per length unit
/
$call =C:\nepal\mdb2gms @C:\nepal\pop_den.txt
$include C:\nepal\pop_den.inc
/
;
pop_den(j,i)$(f(i,j)=2)=pop_den(i,j);

parameter off_route_pop(i,j,ts) off route population per time series;
off_route_pop(i,j,ts) = pop_den(i,j) * dts(i,j,ts);

***************************************************************************
*ON-ROUTE POPULATION
***************************************************************************
parameter avg_pop_veh(ts) average number of persons per vehicle
/
$call =C:\nepal\mdb2gms @C:\nepal\avg_pop_veh.txt
$include C:\nepal\avg_pop_veh.inc
/
;
parameter on_route_pop(i,j,ts) on route population per time scenario;
on_route_pop(i,j,ts) = avg_pop_veh(ts) * ki(i,j,ts);

***************************************************************************
*TOTAL POPULATION = OFF-ROUTE POPULATION + ON-ROUTE POPULATION
***************************************************************************
parameter total_pop(i,j,ts) total population per arc per time series;
total_pop(i,j,ts) = round(off_route_pop(i,j,ts) +
on_route_pop(i,j,ts));

*parameter suma_population(ts) total population on and off route;
*sumapopulation(ts) = sum((i,j), total_pop(i,j,ts));

***************************************************************************
*inputing the building vulnerability
*in case of a fire
***************************************************************************
parameter buil_vul_fire(i,j) building vulnerability in rel. to fire
/
$call =C:\nepal\mdb2gms @C:\nepal\buil_vul_fire.txt
$include C:\nepal\buil_vul_fire.inc
/
```

```
;
parameter buil_vul_fire_ts(i,j,ts) building vulnerability;
buil_vul_fire_ts(i,j,ts) = buil_vul_fire(i,j);
buil_vul_fire_ts(j,i,ts)$(f(i,j)=2) =
buil_vul_fire_ts(i,j,ts);
************************************************************************
*earthquake-building score that represent the building damaged ratio
*in case of an earthquake
************************************************************************
parameter relative_dbr_eq(i,j) relative value for DBR in earthquake
/
$call =C:\nepal\mdb2gms @C:\nepal\relative_dbr_eq.txt
$include C:\nepal\relative_dbr_eq.inc
/
;
parameter relative_dbr_eq_ts(i,j,ts) DBR per time series;
relative_dbr_eq_ts(i,j,ts) = relative_dbr_eq(i,j);
relative_dbr_eq_ts(j,i,ts)$(f(i,j)=2) =
relative_dbr_eq_ts(i,j,ts);
```

```
$ontext
ROUTE_MODEL PROGRAMMING CODE
$offtext
************************************************************************
*calling route_data.gms or use the DOS command line
************************************************************************
*$include route_data.gms
************************************************************************
*creating a dynamic set based on the admissible arcs
*this ensures that only the admissible are considered for the
*route optimization
************************************************************************
set arc(i,j,ts) existing links in the network;
arc(i,j,ts)$acts(i,j,ts)=yes;
************************************************************************
*MULTIPLE OBJECTIVE OPTIMIZATION
************************************************************************
************************************************************************
*Defining the variables
************************************************************************
variables
z_distance total distance for the shortest route
z_time total time for the shortest route
z_pop_risk total population at risk
z_risk_urban total risk for the urban environment
z_risk_eq_buil total risk for building in case of earthquake
x(i,j,ts) variable indicating path;
binary variable
x(i,j,ts) variable indicating path;
```

A

```
***********************************************************************
*Defining the equations
***********************************************************************
equations
obj_dist objective function to minimize distance
obj_time objective function to minimize time
obj_pop_risk objective function to minimize population at risk
obj_risk_urban objective function to minimize building at risk
obj_risk_eq_buil objective function to minimize risk eq-buil
nodebal(k,ts) node balance;

obj_dist.. z_distance =e= sum(arc, dts(arc)* x(arc));
obj_time.. z_time =e= sum(arc, ti(arc)* x(arc));
obj_pop_risk.. z_pop_risk =e= sum(arc, acc_rate(arc) * accident_prob
* dts(arc)
* total_pop(arc)
* x(arc));
obj_risk_urban.. z_risk_urban =e= sum(arc, acc_rate(arc) * accident_prob
* fire_prob
* buil_vul_fire_ts(arc)
* x(arc));
obj_risk_eq_buil.. z_risk_eq_buil =e= sum(arc, relative_dbr_eq_ts(arc)
* x(arc));


nodebal(k,ts).. sum(arc(i,k,ts), x(arc)) - sum(arc(k,j,ts),x(arc)) =e= b(k);


***********************************************************************
*Running the models
***********************************************************************
***********************************************************************
*Minimizing DISTANCE
***********************************************************************
model distance /all/;
solve distance using rmip minimizing z_distance;

scalar zd_d z_distace value when minimizing distance;
scalar zt_d z_time value when minimize distance;
scalar zpr_d z_pop_risk value when minimize distance;
scalar zru_d z_risk_urban value when minimize distance;
scalar zreb_d z_risk_eq_buil value when minimize distance;

zd_d = z_distance.l;
zt_d = z_time.l;
zpr_d = z_pop_risk.l;
zru_d = z_risk_urban.l;
zreb_d = z_risk_eq_buil.l;

display zd_d;
display zt_d;
display zpr_d;
display zru_d;
display zreb_d;

file results /result_distance.txt/;
results.pc=5;
put results;
loop((ts,i,j)$((arcid(i,j)>0) and (x.l(i,j,ts)>0)),
```

```
put i.tl, j.tl, arcid(i,j):0:0, x.l(i,j,ts), ts.tl/
);
putclose;

**********************************************************************
*Minimizing TIME
**********************************************************************
model time /all/;
solve time using rmip minimizing z_time;

scalar zd_t z_distace value when minimizing time;
scalar zt_t z_time value when minimize time;
scalar zpr_t z_pop_risk value when minimize time;
scalar zru_t z_risk_urban value when minimize time;
scalar zreb_t z_risk_eq_buil value when minimize time;

zd_t = z_distance.l;
zt_t = z_time.l;
zpr_t = z_pop_risk.l;
zru_t = z_risk_urban.l;
zreb_t = z_risk_eq_buil.l;

display zd_t;
display zt_t;
display zpr_t;
display zru_t;
display zreb_t;

file results2 /result_time.txt/;
results2.pc=5;
put results2;
loop((ts,i,j)$((arcid(i,j)>0) and (x.l(i,j,ts)>0)),
put i.tl, j.tl, arcid(i,j):0:0, x.l(i,j,ts), ts.tl/
);
putclose;

**********************************************************************
*Minimizing RISK FOR THE POPULATION
**********************************************************************
model population_risk /all/;
solve population_risk using rmip minimizing z_pop_risk;

scalar zd_pr z_distace value when minimizing population risk;
scalar zt_pr z_time value when minimize population risk;
scalar zpr_pr z_pop_risk value when minimize population risk;
scalar zru_pr z_risk_urban value when minimize population risk;
scalar zreb_pr z_rizk_eq_buil value when minimize population risk;

zd_pr = z_distance.l;
zt_pr = z_time.l;
zpr_pr = z_pop_risk.l;
zru_pr = z_risk_urban.l;
zreb_pr = z_risk_eq_buil.l;

display zd_pr;
display zt_pr;
display zpr_pr;
display zru_pr;
display zreb_pr;
```

```
file results3 /result_population_risk.txt/;
results3.pc=5;
put results3;
loop((ts,i,j)$((arcid(i,j)>0) and (x.l(i,j,ts)>0)),
put i.tl, j.tl, arcid(i,j):0:0, x.l(i,j,ts), ts.tl/
);
putclose;

**************************************************************************
*Minimizing risk for the urban environment
**************************************************************************
model risk_urban /all/;
solve risk_urban using rmip minimizing z_risk_urban;

scalar zd_ru z_distace value when minimizing risk for the urban environment;
scalar zt_ru z_time value when minimize risk for the urban environment;
scalar zpr_ru z_pop_risk value when minimize risk for the urban environment;
scalar zru_ru z_risk_urban value when minimize risk for the urban environment;
scalar zreb_ru z_rizk_eq_buil value when minimize risk for the urban environment;

zd_ru = z_distance.l;
zt_ru = z_time.l;
zpr_ru = z_pop_risk.l;
zru_ru = z_risk_urban.l;
zreb_ru = z_risk_eq_buil.l;

display zd_ru;
display zt_ru;
display zpr_ru;
display zru_ru;
display zreb_ru;

file results4 /result_risk_urban.txt/;
results4.pc=5;
put results4;
loop((ts,i,j)$((arcid(i,j)>0) and (x.l(i,j,ts)>0)),
put i.tl, j.tl, arcid(i,j):0:0, x.l(i,j,ts), ts.tl/
);
putclose;

**************************************************************************
*Minimizing risk for buildings in case of an earthquake
**************************************************************************
model risk_eq_buil /all/;
solve risk_eq_buil using rmip minimizing z_risk_eq_buil;

scalar zd_reb z_distace value when minimizing risk eq-buil;
scalar zt_reb z_time value when minimize risk eq-buil;
scalar zpr_reb z_pop_risk value when minimize risk eq-buil;
scalar zru_reb z_risk_urban value when minimize risk eq-buil;
scalar zreb_reb z_rizk_eq_buil value when minimize risk eq-buil;

zd_reb = z_distance.l;
zt_reb = z_time.l;
zpr_reb = z_pop_risk.l;
zru_reb = z_risk_urban.l;
zreb_reb = z_risk_eq_buil.l;

```

```
display zd_reb;
display zt_reb;
display zpr_reb;
display zru_reb;
display zreb_reb;

file results5 /result_risk_eq_buil.txt/;
results5.pc=5;
put results5;
loop((ts,i,j)$((arcid(i,j)>0) and (x.l(i,j,ts)>0)),
put i.tl, j.tl, arcid(i,j):0:0, x.l(i,j,ts), ts.tl/
);
putclose;


***********************************************************************
*MULTIPLE OBJECTIVE OPTIMIZATION
***********************************************************************
***********************************************************************
*Introducing Utopian points for multi-objective analysis
***********************************************************************
scalar dist_wg weight for objective distance
/
$call =C:\nepal\mdb2gms @C:\nepal\dist_weight.txt
$include C:\nepal\dist_weight.inc
/;

scalar time_wg weight for objective time
/
$call =C:\nepal\mdb2gms @C:\nepal\time_weight.txt
$include C:\nepal\time_weight.inc
/;


scalar pop_risk_wg weight for objective population risk
/
$call =C:\nepal\mdb2gms @C:\nepal\pop_risk_weight.txt
$include C:\nepal\pop_risk_weight.inc
/;

scalar risk_urban_wg weight for objective risk for the urban environment
/
$call =C:\nepal\mdb2gms @C:\nepal\risk_urban_weight.txt
$include C:\nepal\risk_urban_weight.inc
/;

scalar risk_eq_buil_wg weight for objective risk for the urban environment
/
$call =C:\nepal\mdb2gms @C:\nepal\risk_eq_buil_weight.txt
$include C:\nepal\risk_eq_buil_weight.inc
/;

variables
d_distance deviation for distance
d_time deviation for time
d_pop_risk deviation for population risk
d_risk_urban deviation for risk for the urban environment
d_risk_eq_buil deviation for risk for building in case of earthquake
tot_dev total deviation value;
```

```

equations
tot_dev_eq total deviation equation
obj_dist_d objective function for distance plus deviation variable
obj_time_d objective function for time plus deviation variable
obj_pop_risk_d objective function for population at risk plus deviation variable
obj_risk_urban_d objective function for risk_urban plus deviation variable
obj_risk_eq_buil_d objective function for risk_eq_buil plus deviation variable;

tot_dev_eq.. tot_dev =e= (dist_wg*d_distance/zd_d) +
(time_wg*d_time/zt_t) +
(pop_risk_wg*d_pop_risk/zpr_pr) +
(risk_urban_wg*d_risk_urban/zru_ru) +
(risk_eq_buil_wg*d_risk_eq_buil/zreb_reb);

obj_dist_d.. sum(arc, dts(arc)*x(arc)) - d_distance =l= zd_d;
obj_time_d.. sum(arc, ti(arc)*x(arc)) - d_time =l= zt_t;
obj_pop_risk_d.. sum(arc, acc_rate(arc) * accident_prob * dts(arc)
* total_pop(arc) * x(arc))
- d_pop_risk =l= zpr_pr;
obj_risk_urban_d.. sum(arc, acc_rate(arc) * accident_prob * fire_prob
* buil_vul_fire_ts(arc)
* x(arc))
- d_risk_urban =l= zru_ru;
obj_risk_eq_buil_d.. sum(arc, relative_dbr_eq_ts(arc)* x(arc))
- d_risk_eq_buil =l= zreb_reb;


************************************************************************
*Running multi-objective model
************************************************************************
model multiple /all/;
solve multiple using rmip minimizing tot_dev;

scalar zd_m z_distace value when minimizing multiple objectives;
scalar zt_m z_time value when minimize multiple objectives;
scalar zpr_m z_pop_risk value when minimize multiple objectives;
scalar zru_m z_risk_urban value when minimize multiple objectives;
scalar zreb_m z_risk_eq_buil value when minimize multiple objectives;

zd_m = zd_d + d_distance.l;
zt_m = zt_t + d_time.l;
zpr_m = zpr_pr + d_pop_risk.l;
zru_m = zru_ru + d_risk_urban.l;
zreb_m = zreb_reb + d_risk_eq_buil.l;

scalar pgd_d percentage of goal deviation for distance objective;
scalar pgd_t percentage of goal deviation for time objective;
scalar pgd_pr percentage of goal deviation for population risk objective;
scalar pgd_ru percentage of goal deviation for risk urban objective;
scalar pgd_reb percentage of goal deviation for risk eq-buil objective;

pgd_d = (dist_wg*d_distance.l/zd_d) * 100 / tot_dev.l;
pgd_t = (time_wg*d_time.l/zt_t) * 100 / tot_dev.l;
pgd_pr = (pop_risk_wg*d_pop_risk.l/zpr_pr) * 100 / tot_dev.l;
pgd_ru = (risk_urban_wg*d_risk_urban.l/zru_ru) * 100 / tot_dev.l;
pgd_reb= (risk_eq_buil_wg*d_risk_eq_buil.l/zreb_reb) * 100 / tot_dev.l;
```

```
display x.l;
display tot_dev.l;
display zd_d;
display z_distance.l;
display zt_t;
display z_time.l;
display zpr_pr;
display z_pop_risk.l;
display zru_ru;
display z_risk_urban.l;
display zreb_reb;
display z_risk_eq_buil.l;

file results6 /result_multiple.txt/;
results6.pc=5;
put results6;
loop((ts,i,j)$((arcid(i,j)>0) and (x.l(i,j,ts)>0)),
put i.tl, j.tl, arcid(i,j):0:0, x.l(i,j,ts), ts.tl/
);
putclose;

file results7 /result_summary.txt/;
put results7; results7.nd=8;
put 'summary fo results'/
'objective distance time pop_risk risk_urban risk_eq_buil multiple %deviation'/
'distance (meters) ',zd_d," ",zd_t," ",zd_pr," ",zd_ru," ",zd_reb," ",zd_m," ",pgd_d/
'time (min) ',zt_d," ",zt_t," ",zt_pr," ",zt_ru," ",zt_reb," ",zt_m," ",pgd_t/
'pop_risk (persons) ',zpr_d," ",zpr_t," ",zpr_pr," ",zpr_ru," ",zpr_reb," ",zpr_m," ",pgd_pr/
'risk_urban(Sr=h x e) ',zru_d," ",zru_t," ",zru_pr," ",zru_ru," ",zru_reb," ",zru_m," ",pgd_ru/
'risk_eq_buil(revise) ',zreb_d," ",zreb_t," ",zreb_pr," ",zreb_ru," ",zreb_reb," ",zreb_m," ",pgd_reb/
putclose;

************************************************************************
*calculating the population found along and on the route
************************************************************************
scalar tot_population_m total population;

tot_population_m = sum(arc, total_pop(arc) * x.l(arc));

display tot_population_m;
```

Appendix 2: queries used in the compilation process of the model

As it may be noticed in the appendix 1, whenever GAMS needed to import data from the geo-database, GAMS calls an external application called "mdb2gms.exe". This application especially developed by Kalvelagen (2000) enables to import data from the database by reading a query, and putting the output of the query in a INC (include) file. The INC file is latter called by GAMS and includes the data stored in the INC file to the model. As an example consider the following code lines:

Line 1 $call =C:\nepal\mdb2gms @C:\nepal\origin.txt
Line 2 $include C:\nepal\origin.inc

Line 1 tells GAMS to call the external application 'mdb2gms.txt' and run the query store in the text file called 'origin.txt'. The text file contains the following:

I=C:\nepal\Road.mdb
Q=select from_node from entry_points where entry_points.origin=1
O=C:\nepal\origin.inc

The term 'I' stands for input, 'Q' for query, and 'O' for output. The path and name of the database is specified in the input line, the query is stated in the query line, and in the output line the path and the name of the INC file is written. Once the external application 'mbd2gms'has finished extracting the data from the geo-database and have created the INC file, GAMS runs the line 2. Line 2 then tells GAMS to include the entire data store in the file called 'origin.inc'. This approach enables the model to be completely independent when it comes to acquire the data needed to solve the optimization problem. The following table display the text file containing the query used in the model developed. The queries are sorted alphabetically by the text file name.

A

Text file name	Content
accident_prob.txt	I=C:\nepal\Road.mdb Q=select accident_prob from HazMat_info O=C:\nepal\accident_prob.inc
admissible.txt	I=C:\nepal\Road.mdb Q=select fnode_, tnode_, admissible from road_coverage_arc O=C:\nepal\admissible.inc

Text file name	Content
arcid.txt	I=C:\nepal\Road.mdb Q=select fnode_, tnode_, road_cover from road_coverage_arc O=C:\nepal\arcid.inc
avg_pop_veh.txt	I=C:\nepal\Road.mdb Q=select time_serie, avg_persons_veh from time_serie where dyn_set=1 O=C:\nepal\avg_pop_veh.inc
avg_veh_len.txt	I=C:\nepal\Road.mdb Q=select time_serie, avg_veh_len from time_serie where dyn_set=1 O=C:\nepal\avg_veh_len.inc
black_spot.txt	I=C:\nepal\Road.mdb Q=select fnode_, tnode_, black_spot from road_coverage_arc O=C:\nepal\black_spot.inc
buil_vul_fire.txt	I=C:\nepal\Road.mdb Q=select fnode_, tnode_, buil_vul_fire from road_coverage_arc O=C:\nepal\buil_vul_fire.inc
destination.txt	I=C:\nepal\Road.mdb Q=select from_node from gas_station where gas_station.destination=1 O=C:\nepal\destination.inc
dist_weight.txt	I=C:\nepal\Road.mdb Q=select obj_weight from objective where id=2 O=C:\nepal\dist_weight.inc
distance.txt	I=C:\nepal\Road.mdb Q=select fnode_, tnode_, Shape_Length from road_coverage_arc O=C:\nepal\distance.inc
fire_prob.txt	I=C:\nepal\Road.mdb Q=select fire_prob from HazMat_info O=C:\nepal\fire_prob.inc
flow_direction.txt	I=C:\nepal\Road.mdb Q=select fnode_, tnode_, tra_way from road_coverage_arc O=C:\nepal\flow_direction.inc
flow_factor.txt	I=C:\nepal\Road.mdb Q=select time_serie, flow_factor from time_serie where dyn_set=1 O=C:\nepal\flow_factor.inc
lanes_from_to.txt	I=C:\nepal\Road.mdb Q=select fnode_, tnode_, lanes_ft from road_coverage_arc O=C:\nepal\lanes_from_to.inc
lanes_to_from.txt	I=C:\nepal\Road.mdb Q=select tnode_, fnode_, lanes_tf from road_coverage_arc O=C:\nepal\lanes_to_from.inc
max_speed.txt	I=C:\nepal\Road.mdb Q=select road_coverage_arc.fnode_, road_coverage_arc.tnode_, sec_type.max_mean_speed from road_coverage_arc, sec_type where road_coverage_arc.sec_type = sec_type.sec_type O=C:\nepal\max_speed.inc
number_nodes.txt	I=C:\nepal\Road.mdb Q=select max(objectid) from road_coverage_node; O=C:\nepal\number_nodes.inc
origin.txt	I=C:\nepal\Road.mdb Q=select from_node from entry_points where entry_points.origin=1 O=C:\nepal\origin.inc
pop_den.txt	I=C:\nepal\Road.mdb Q=select fnode_, tnode_, pop_per_len from road_coverage_arc O=C:\nepal\pop_den.inc
pop_risk_weight.txt	I=C:\nepal\Road.mdb Q=select obj_weight from objective where id=5 O=C:\nepal\pop_risk_weight.inc
ratio_occupancy.txt	I=C:\nepal\Road.mdb Q=select time_serie, ratio_occ from time_serie where dyn_set=1 O=C:\nepal\ratio_occupancy.inc
relative_dbr_eq.txt	I=C:\nepal\Road.mdb Q=select fnode_, tnode_, relative_dbr_eq from road_coverage_arc O=C:\nepal\relative_dbr_eq.inc
risk_eq_buil_weight.tx t	I=C:\nepal\Road.mdb Q=select obj_weight from objective where id=7 O=C:\nepal\risk_eq_buil_weight.inc

Text file name	Content
risk_urban_weight.txt	I=C:\nepal\Road.mdb Q=select obj_weight from objective where id=6 O=C:\nepal\risk_urban_weight.inc
section.txt	I=C:\nepal\Road.mdb Q=select fnode_, tnode_, sec_type from road_coverage_arc O=C:\nepal\section.inc
time_serie.txt	I=C:\nepal\Road.mdb Q=select time_serie from time_serie where dyn_set=1 O=C:\nepal\time_serie.inc
time_weight.txt	I=C:\nepal\Road.mdb Q=select obj_weight from objective where id=1 O=C:\nepal\time_weight.inc
width.txt	I=C:\nepal\Road.mdb Q=select fnode_, tnode_, width from road_coverage_arc O=C:\nepal\width.inc

A