A Risk/Cost-based Algorithm for the Routing of Dangerous Goods

Karim El-Basyouny (Corresponding Author)
Research Assistant, Dept. of Civil Engineering
University of British Columbia
Vancouver, BC, Canada V6T 1Z4
604-716-4470
basyouny@civil.ubc.ca

Derek Cheng
GIS Administrator, Dept. of Civil Engineering
University of British Columbia
Vancouver, BC, Canada V6T 1Z4
604-822-8785
dcheng@bitsafs.ca

Clark Lim, P.Eng., MASc.
Dept. of Civil Engineering
University of British Columbia
Vancouver, BC, Canada V6T 1Z4
604-822-8785
clim@bitsafs.ca

Tarek Sayed, P.Eng., PhD.
Professor, Dept. of Civil Engineering
University of British Columbia
Vancouver, BC, Canada V6T 1Z4
604-822-4379
tsayed@civil.ubc.ca

Paper prepared for presentation

at the Innovations in Traffic Control Safety Session

of the 2009 Annual Conference of the
Transportation Association of Canada
Vancouver, British Columbia

ABSTRACT

This study develops a risk/cost-based dangerous goods routing algorithm. The algorithm focuses on mitigating the risks associated with the transportation of dangerous goods (DG) via route selection. The algorithm was applied to a large-scale transportation network representing the Metro Vancouver area. The network is represented spatially in a GIS database along with a real-time dispersion plume simulating a specific chemical release under local weather conditions. GIS facilitates the comparison between the various criteria by overlaying transportation networks characteristics on other spatially referenced data, such as population demographics or meteorological data. The algorithm and general methodology is used for the routing of dangerous goods on-demand, serving individual shipments in a permitting environment. The uniqueness of the proposed approach is in the "normalization" of risks and operating costs such that a cost-based DG routing optimization is achieved. Furthermore, the practicality of the algorithm is demonstrated by developing a computer application using Canadian and B.C. datasets.

INTRODUCTION

Each day products and materials defined as dangerous goods (DG) are shipped from one point to another within Canada. These products include: explosives, gases, flammable liquids and solid, oxidizing substances, poisonous and infectious substances, corrosive substances, and hazardous waste. As such, these products and materials require special precautions to ensure their safe transportation. The social, environmental, and monetary costs associated with DG incidents are high and every precaution has to be taken to avoid such catastrophic events. Therefore, it is essential to continually work towards minimizing the risk of incidents in the transportation of dangerous goods and their potential consequences.

The Commercial Vehicle Safety & Enforcement Branch of the B.C. Ministry of Transportation is presently collaborating with its counterpart from the Province of Alberta to develop a DG Decision Support System (DSS) that is specific to the needs, conditions, and data availability within B.C. The DSS should investigate the consideration of risks in the overall assessment of optimal routing based on least-cost objectives. It is desired that the risks, and ultimately the costs, associated with options of routing the transport of hazardous materials should consider factors such as population centers, vehicular traffic, restrictions (i.e. height, weight, regulatory, etc.) ecological characteristics, road classification, conditions and operations, proximity and access of emergency services, and time of day.

This study attempts to develop a risk/cost-based dangerous goods routing algorithm (DGRA). The algorithm focuses on mitigating the risks associated with the transportation of DG via route selection. The algorithm is applied to a large-scale transportation network representing Metro Vancouver area. The network is represented spatially in a GIS database along with a real-time dispersion plume simulating a specific chemical release under local weather conditions. GIS facilitates the comparison between the various criteria by overlaying transportation networks characteristics on other spatially referenced data, such as population demographics or meteorological data. The algorithm and general methodology is used for the routing of dangerous goods on-demand, serving individual shipments in a permitting environment. This is different than the use of such algorithms for just the planning of designated DG routes. The uniqueness of the proposed approach is in the “normalization” of risks and operating costs such that a cost-based DG routing optimization is achieved. Furthermore, the practicality of the algorithm is demonstrated by developing a computer application using Canadian and B.C. datasets.

LITERATURE REVIEW

The main objective of DG routing is to determine the optimal path(s) on a network subject to certain routing criteria. The objective, which can be either a single or multiple criteria, is typically based on risk, equity and cost considerations. The choice of the objective criteria highly influences the selection of the “best” route. Current literature includes different modeling techniques to aid in the routing of dangerous goods between a given origin and destination. The techniques differ in the type of criteria being examined and the methods by which these criteria are combined. The most common criteria considered in the literature to route DG is risk minimization.

Researchers have generally agreed that the term “risk”, in the context of DG, has to do with the probability and the consequence of an undesirable event. Although some authors define risk as only one of these terms (i.e., probability or consequence), it is more common to define risk as the product of both the probability of and the consequence of the undesirable event (***1,2***). The probability component is related to accident likelihood and the release probability. Undesirable events include spills, fires or explosions in the case of flammable liquids, or a toxic clouds or plumes in the case of pressure-liquefied gasses. The ensuing consequences include fatalities, injuries, damages to property, losses in property values, and environmental damage. This definition is known as "expected consequence" or as "traditional risk", primarily for the reason that it is the definition used in the U.S. Department of Transportation (DOT) 1989 (***3***) guidelines for transporting dangerous goods. Such models are probabilistic in nature and they use conditional probabilities of accidents and the magnitude of their consequences as the two main parameters. In general, such models differ in: (a) how the two parameters are combined to provide a risk estimate; (b) the types and levels of detail and quality of the data acquired; and (c) the methods of obtaining or estimating data and model parameters.

To develop probabilities some models use fault-tree analyses, whereas others use average accident rates by mode and vehicle. To determine the magnitude of consequences, atmospheric dispersion models and simulations are used to determine spill behavior and thus the population exposure. Additional details on the quantification and assessment of risk and the estimation of release rates are given in several references (***4-11***).

Several risk definitions and models have been proposed and examined in the literature (***2,12***). Alternative risk models that include either incident probability or population exposure or both to quantify risk were explored. The general consensus is that risk minimization problem is a bi-criterion optimization problem; one of minimizing incident probability and population exposure.

DG routing involves a number of decisions which require the consideration of multiple and conflicting objectives. Risk minimization seems to be the most common criterion examined in the literature. However, other factors such as: travel time, distance, emergency responsiveness, delay, etc. are also important. According to Leonelli et al. (***13***), if risk minimization is the sole criterion for routing DG, then the routes selected are likely to be more than twice as long as the fastest alternative and in most cases their feasibility comes in question for financial reasons. In the literature, the models are classified according to the number of criteria included in the analysis along with the method by which such criteria are combined to determine the best paths between origins and destinations.

The Single Optimization Criterion (SOC) is a widely used approach to combine several criteria into a single score or value (***14-17***). The new score/value is often taken to be a linear function of different attributes such as: population exposure, distance, time and accident probability. With a single link score/value, a simple solution method (e.g., Dijkstra’s shortest path algorithm) is used to connect the origin-destination pair. By varying the weights of the attributes, different routes can be generated. The process of varying the weights indicates the sensitivity that the criteria have on route selection. Leonelli et al. (***13***) criticized the weighing approach since the routing problem becomes a problem of fixing the values of the weight factors or the thresholds. In fact, their calculations have shown that different weights (or different threshold values) can produce different optimal routes. As such the determination of the optimal path becomes strongly dependent on the decision-maker, who has to adjust the value of weights and thresholds (***18***). However, this problem could be adequately addressed by having an expert panel suggest the weights/threshold values or through the use of a weighting system (such as an analytical hierarchy process or a genetic algorithm).

An alternative approach that has been recently gaining attention is the Multiple Objective Criteria (MOC). This approach attempts to minimize a number of criteria simultaneously for route selection purposes (***19-21***). Minimizing travel time and total population at risk is an example application of the multiple objectives routing criteria method. Multiple criteria routing models can be used to study tradeoffs between conflicting routing objectives. Using a MOC for dangerous goods transportation decisions usually means that it is not possible to identify a single "best" route but rather, the goal is to identify the set of "non-dominated" or "Pareto-optimal" routes so that trade-offs between different objectives can be represented explicitly. However, researchers have argued that many routes can exist within the solution set and as a result the number of "non-dominated" paths can become very large in networks, thus rendering the approach impractical (***22***). Alternatively, the Constrained Shortest Path approach is used to minimize one attribute while limiting the sum of other attributes (***22,23***).

GIS MODEL

DG routing analyses should adequately integrate the road network with its surroundings, since risk levels strongly depend on the characteristics of the region traversed by the shipments. As a result, several researchers decided to utilize the capabilities of GIS to aid DG route planning. Existing literature shows that the use of GIS in DG routing dates back to the early 1990's. Researchers have argued that the development of GIS could provide means to concurrently analyze network topology and spatial features (***18,24-26***). GIS provides useful techniques for data storage, data manipulation (for instance, to generate link attributes) and to display solutions on a map. Moreover, GIS provides an ideal environment for design and management of DG routes because of its ability to integrate multi-theme and multi-source data into an operational information system. This study made use of a number of available datasets from the province of BC. The datasets (variables) were collected and integrated into the GIS database. Information from each dataset was used to compute the different components of the DGRA.

Road segment data for Vancouver, BC were obtained from GIS Innovations' dataset titled Digital Road Atlas. This dataset includes all the official designated truck routes, which are primarily used for the transportation of DG. Spatial data including a set of EMME/2 traffic volumes (from TransLink) and the Metro Vancouver truck routes were combined in order to calculate the accident rates and determine route lengths.

Three types of datasets were used to describe the population distributions in the GIS database. The first dataset contained information relating to the location of regional town centers (RTC), which was obtained from Metro Vancouver's dataset. The second and third datasets contained evening and day population census information. The GIS data inventory included the Metro Vancouver evening population distribution from the Statistics Canada 2006 Census. Calculation of day time exposure was more complicated as the GIS data inventory did not include any daytime population spatial dataset. The only data file that could be used for analysis was a table containing 2008 day time population attribute data obtained from MapInfo. Using GIS capabilities, the evening and day-time populations were matched. RTCs, evening and day population census were incorporated as a second layer in the GIS environment.

An additional layer encompassed locations of emergency and special facilities. Facilities that were most vulnerable to the impacts of DG incidents were identified as either schools or hospitals. The number and proximity of these special facilities if an incident occurs is important. The locations of emergency response facilities such as ambulance stations, fire stations and police stations were necessary to determine the nearest immediate responder to commence evacuation procedures, provide on-site traffic management, and instigate incident mitigation measures. The relevant information about these facilities was obtained from a GIS Innovations' dataset called Places.

DISPERSION MODEL

The exposed population is a key factor in determining the consequence of a DG release. By overlaying the census information with the impact zone the number of individuals that might be exposed due to a release is estimated. There are different methods to create the impact zones. The first method uses the Emergency Response Guidebook (*27*) evacuation distances for large quantity of explosives as well as isolation and protection action distances for small and large spills. In that case, the impact distance serves as the radius that defines the impact zone. It is possible to consider the DG shipment over a road segment as the movement of a danger circle along that road segment. These movement carvers out a band on both sides of the road segment thereby defining the region of possible impact.

An alternative method to estimate the impact zone is to use a computer model to effectively incorporate climate conditions, release quantities, DG types, and topography into modeling the release, explosion, or dispersion of DG. This method refines the determination of the impact zone and allows for a more accurate representation of a specific chemical release. The Areal Locations of Hazardous Atmospheres (ALOHA) dispersion model was used to simulate the movement and dispersion of hazardous chemical gases. The tool provides estimates of pollutant concentrations downwind from the source of a release, while accounting for both toxicological and physical characteristics of the released material. Furthermore, ALOHA considers the physical characteristics of the release site, atmospheric conditions and the circumstances of the release.

This level of detail is lost when an impact zone is based on isolation and protective action distances. These distances are based on modeling spills assuming one set of topography conditions and quantities released. Furthermore, the guide does not indicate what constitutes a small or a large spill and it is up to the user to determine the spill category. There are two benefits from using a dispersion plume model. First, the model refines the estimation of the impact zone as it is based on a number of important inputs. Second, the generated impact zone includes both the size of the dispersion and the concentration within each level.

RISK/COST-BASED DANGEROUS GOODS ROUTING ALGORITHM (DGRA)

Routing of DG is a subject of considerable interest in the transportation community. There are two major difficulties that are associated with the routing problem. First, the problem is made up of multiple objectives (safety, security, efficiency and cost) that need to be optimized when selecting routes, making it conceptually more difficult from the perspective of the analyst as well as the decision-maker. Moreover, the size of the problem can become excessive (the size of the network and the number of different DG shipments are both large). For these reasons, an initial screening of the network should always be performed (REF).

Figure 1 shows a conceptual framework for the proposed risk/cost-based DGRA. The model contains two major components: a Dispersion Model and a GIS. The dispersion model uses site data, chemical, atmosphere and source information to generate a plume footprint. Afterwards, the footprint and a number of datasets are integrated together in a GIS environment to perform the analysis. Based on the study objectives, the proposed methodology involves a set of dangerous goods routing criteria pertaining to safety, efficiency, security, and cost. These are chosen to include: incident probabilities, incident consequence, operating costs, and human health impacts.

Incident probabilities were developed from B.C.-calibrated accident prediction models utilizing traffic volumes as measures of exposure as well as segment length. Incident's consequence is proportional to the number of individuals exposed due to the occurrence of an incident. To determine the incident's consequence a dispersion model is used to effectively incorporate climate conditions, release quantities, dangerous goods types, and topography into modeling the release, explosion, or dispersion of DG. As a result, a chemical release is simulated using a computer model to generate a dispersion plume footprint.

The generated footprint represents the extent of the chemical dispersion and is assumed to be of the same concentration (the Immediately Dangerous to Life and Health concentration), with its shape representing the spread of the released gas cloud to the level of concern. A typical footprint diagram contains four shaded areas representing three ground level concentrations and a 95% confidence interval. The inner most area inside the footprint is the region predicted to have ground level concentrations above the limit that is specified during the model run. The outer lines drawn on either side of the footprint reflect uncertainty in the wind direction and are computed based on a 95% confidence factor.

The above information is integrated into the GIS database. By overlaying census population information with the impact zone, the number of individuals that may be exposed (and degree of exposure) due to a release is estimated. This was achieved by first transferring the footprints co-ordinates from the dispersion model into the GIS database. For each concentration level a composite footprint was generated to determine the impact zone along an entire route. The analytical capability of the GIS software was then used to enumerate the effected population.

Finally, an optimal routing algorithm combining operating costs and risk costs was applied in the GIS environment to allow for the evaluation of a specific truck route or alternate truck routes between a particular origin and destination. The algorithm and general methodology were used for the routing of dangerous goods on-demand, serving individual shipments in a permitting environment. This is different than the use of such algorithms for just the planning of designated DG routes.

The proposed routing algorithm expands on the traditional risk definition. Total cost is expressed as a function of the traditional risk (converted into a dollar amount) plus operating costs. Traditional risk is expressed as the expected number of individuals that are affected in case of an incident. This is achieved by multiplying incident probabilities with consequences. Shortreed et al. (***28***) suggested a 5% conditional probability for the occurrence of an incident given a traffic accident involving a DG truck. To associate a dollar amount with this figure a cost value is assigned for each of the expected exposed individuals. Therefore, total cost along an entire route is considered a function of an aggregated accident probability along the route, the risks to human health from being exposed to a certain concentration level expressed in a dollar value and, the operating costs associated with that route. The total cost formulation is expressed as:

$$TC_r = \left[\left(\sum_{i=1}^{r} AR_i \times L_i \times 0.05\right) \times \sum_{j=1}^{m}\left(POP_j \times HI_j\right)\right] + \left(TT_r \times OC\right) \quad \textbf{(2)}$$

where

TC_r	Total cost on route *r*
AR_i	Accident rate (accidents per vehicle-km) for route segment *i*
L_i	Length of route segment *i* in (km)
m	Number of concentration levels (in this study $m = 4$ levels)
POP_j	Exposed population along entire route *r* at a specific concentration level *j*
HI_j	Health impacts in terms of $/person due to the exposure to concentration level *j*
TT_r	Travel time for route *r*
OC	Operating costs in terms of $/unit time

For each chemical, a footprint containing four shaded areas representing three ground level concentrations and a 95% confidence interval was generated. A dollar amount was associated to each concentration level. The inner most area inside the footprint is the region predicted to have ground level concentrations above the tolerable limit. Individuals living within this region are expected to suffer from severe health impacts. As a result, a higher dollar value was associated with high concentration levels and vice versa. It was assumed that health costs associated with the three levels of concentrations (from highest to lowest) are $1000, $500 and $100 per individual. As a safety precaution, individuals residing within the 95% confidence interval (the region representing the uncertainty in the wind direction) are evacuated at a cost $200/person.

In this study, the operating costs were assumed to be a fixed dollar amount regardless of the shipment type, size or time of day. The operating costs were based on the carrier's value of time as proposed by Waters et al. (***29***) and were assumed fixed regardless of shipment type, size or time of day. After conversion from US to Canadian dollars, it was estimated at CAD$55 per hour.

SCENARIO DEVELOPMENT

For demonstration purposes three routes connecting a pair of origin and destination (O-D) were investigated. It is assumed that only one shipment is going to traverse the O-D pair. Figure 2 depicts the study area and the three proposed routes. The three routes pass through almost the same number of intersections, albeit having variable lengths. Only route (R2) passes through Langley's regional town centre (RTC). There are no tunnels, bridges or HOV lane present along the three routes. Route (R1) is a major highway in the lower mainland region. The highway is known as Highway (1) and begins at Horseshoe Bay ferry terminal in West Vancouver and continues for 170 (km). Route (R2) traces part of Fraser highway but passes through Langley's town center. Route (R3) passes through a mixture of local arterials in the city of Langley.

To test the system, a hypothetical scenario involving the transport and the subsequent release of chlorine was investigated. In order to determine the impact zone a dispersion model was used to simulate the release. Input information is assumed to generate a footprint due to an accidental release of a shipment of chlorine in the atmosphere. Chlorine is a nonflammable gas in liquid state. However, like oxygen it is capable of supporting the combustion of certain substances. Many organic chemicals react readily with chlorine, in some cases with explosive violence. To generate the footprint, assumptions pertaining to the local weather conditions, type and amount of chemical released were made.

Figure 3 shows the generated footprint at three concentration levels as well as the 95% confidence interval. The footprint contains three shaded areas representing three ground level concentrations. Using a specific import feature (in GIS) the generated footprint was transferred from ALOHA into the GIS database. With the aid of the import feature the user is able to view and query the footprint output with other data layers available in the GIS database. However, the imported footprint resulted from a single release at a certain location. To determine the impact zone along an entire route a composite plume was generated by creating multiple footprints every 100 (m) and combining them into an impact zone as shown in Figures 4.

RESULTS

Table 1 provides a summary of the individual components of the DG routing algorithm. The results indicate that route (R1) minimizes travel time and consequently transport cost. On the other hand, route (R2) minimizes distance traveled as well as accident probability. Route (R3) is probably the worst choice since it has the highest accident probability, travel distance, travel time, and transport costs.

Table 2 summarizes population exposure numbers using the dispersion model to determine the impact zone. The results indicate that route (R2) minimizes population exposure at the three levels of concentrations during evening. However, during day route (R3) minimizes population exposure at highest concentration zone as well as the number of overall evacuees.

Table 3 summarizes the number of emergency and special facilities along the three routes. Route (R2) has the highest number of emergency response facilities among the three routes at 20 (ppm). This is very important since having several emergency response facilities along the route will result in a more responsive reaction to the incident and facilitate isolation and protection procedures. It is also important to note that exposure to chlorine at this concentration level is expected to have a very severe impact on human health.

Furthermore, routes (R2) and (R3) pass by the least number of schools and hospitals within the highest concentration zone. As the concentration level drops to 0.5 (ppm) route (R2) still has the least number of exposed special facilities. This is important since it minimizes the number evacuees in such sensitive facilities. On the other hand, route (R3) exposes 30 special facilities to probable danger. Should an incident occur during the transportation process this route places some school-aged children and potential ill individuals at the risk of being exposed to harmful materials.

The DGRA combines the risks and costs together in a single routing criterion by normalizing the risks into a cost-based approach. Table 4 summarizes the costs associated with routing DG based on evening- and day population exposure.

For evening and day-time exposure, route (R2) minimizes the total costs. However, it could be argued that route selection should consider not only the costs but also the number of emergency and sensitive facilities on-route. If that is the case then route R2 is still the best choice since it has more emergency response facilities and less schools and hospitals on route (Table 3). If a release does occur in the evenings, the number of schools along the route is not going to be an issue as they are typically unoccupied during this time. During the day, schools and hospitals are expected to be operating and therefore their presence will impact the analysis. Evacuating young children and potentially ill-individuals is a complex and time consuming process which needs to be minimized as much as possible. In contrast, route R3 has the highest cost because: (i) it exposes a large number of individuals to risk; and (ii) it has the highest operating cost.

DISCUSSION

Table 5 provides a summary of the "best route" by the different DGRA components. The table is going to be referenced throughout this section to compare and differentiate between the findings of each routing criteria. The results in Table 5 indicate that route (R2) minimized travel distance but did not minimize travel time. The difference in the results is explained by examining the speed profiles on both routes. The difference in speed profiles between routes (R1) and (R2) is explained by the fact the route (R1) is a major highway in the lower mainland region. The highway is known as Highway (1). As a result of having a higher speed, route (R1) minimized travel time. In contrast, route (R2) passes through the city of Langley's town centre where lower speeds are enforced. There is an apparent similarity between the travel time and transport cost criteria. These similarities can be explained by recognizing that transport cost is a function of travel time and operating costs. Therefore, it is expected that both measures would identify the same route. As expected incident probability and travel distance criteria identified the same route since both measures are based on road segment length.

Table 6 shows the percentage increase from the base values for each criterion. For travel distance, by choosing routes (R1) and (R3) over route (R2) the decision-maker is increasing the distance traveled by 22% and 52%, respectively. These percentages show that for this specific criterion, a significant difference in the results is apparent between the three alternative routes. Routing by travel time or cost increases the percentage by 9% and 78% for routes (R2) and (R3), respectively, relative to route (R1). This indicates that routes (R1) and (R2) could be considered as surrogate routes since the results are not significantly different under both criteria. Similarly, the incident probability criterion shows no significant difference between routes (R1) and (R2). Route (R3) is probably the worst choice since it has the largest distance, longest time, highest cost and incident probability while showing a significant increase in all criteria when compared to the best alternative.

Route evaluation is generally time-of-day dependent because many of the criteria for routing and risk assessment depend on traffic volumes and activity patterns that vary throughout the day. The time of day is factored into the analysis by accounting for variation in population distribution during the evening and day times. To estimate the incident consequence it is necessary to determine the population exposure due to a release. It is expected that the number of individuals exposed would vary by time of day. Residential neighborhoods are expected to be densely populated during the evening whereas commercial and industrial areas are expected to be sparsely populated. The relationship is reversed in the daytime where commercial and industrial areas are expected to be occupied. To capture the difference in population distribution and to properly estimate the incident consequence, the time of day was included in the analysis. Evening and day-time population distributions for the Metro Vancouver area were integrated with other spatially referenced data into the GIS database.

Examining the results in Table 5 reveals that route (R2) minimizes incident consequence during the evening and route (R3) during the day. This is a reasonable finding since route (R2) passes through Langley’s town center. The RTC is surrounded by a large number of commercial and industrial facilities which are expected to be occupied in the day and vacant at evening. Conversely, the landuse around route (R3) is mostly made up of residential areas that are densely populated during the evening and sparsely populated in the day.

The results of incident probability and consequence are sometimes conflicting as seen in Table 5. Route (R2) minimizes incident probability while routes (R2) and (R3) minimize incident consequence during the evening and daytime, respectively. In general, the traditional risk criterion is adequate as it accounts for both probability and consequence, but it fails to account for the operating and health impacts due to a DG release. As a result, the DGRA was adopted to expand the traditional risk definition. The approach normalizes the costs and risks into one routing criteria based on probability, consequence, human health impacts and operating costs.

The DGRA combines both the incident probability and consequence to estimate the risks associated at each concentration level. Exposure to different levels of chlorine concentration results in a variety of health impacts. Since using a dispersion model allows for the determination of the concentration levels within each impact zone then a cost value can be associated with each level. In essence, the approach recognizes that not all individuals are going to be affected in the same manner and that severe health impacts can result due to exposure to high levels of concentration. The approach calculates the indirect costs due to the occurrence of an incident involving DG. By changing the risks into a dollar value the indirect costs can be summed to other costs such as operating cost. Route (R2) minimized the overall costs for evening and daytime exposure.

There are two important findings to note: (i) the indirect costs associated with each of the three routes exceeded the operating costs by a large margin; and (ii) the indirect costs are higher during the day than during the evening.

CONCLUSIONS & FUTURE RESEARCH

In this study a risk/cost-based DGRA was developed. The algorithm had four major components. First, a chemical release was simulated using a dispersion model to determine the impact zone (IZ). The generated IZ is based on time of day, weather conditions and type/amount of chemical released. Second, the DGRA was formulated to include a set of routing criteria including: incident probability, population exposure, travel distance travel time and health cost. Third, all the above information was integrated into a GIS database. Lastly, the GIS database utilized an optimal routing algorithm to allow for the evaluation of a specific truck route or alternative truck routes between a particular origin and destination. The applicability of the algorithm was demonstrated using B.C. calibrated datasets representing the Metro Vancouver area.

There are many other uses of GIS models as DG incident management tools to identify evacuation plans, emergency responsiveness, re-routing of existing traffic, etc. The current study could be extended to include additional datasets. For example, locations of farms, crops, watersheds and other environmental locations can be used to determine the effects on the environment. The number of students enrolled in schools can be obtained to determine the exact number of evacuees; with a similar count for hospitals. Moreover, information on bus-stops, shared bicycle or bus lanes, transit stations, etc., can be factored into the analysis. Other topics include determining adequate release probabilities, obtaining accurate and recent truck accident rates, using operating speeds, and allowing some of these variables to vary by time-of-day. Finally, the health costs associated with an exposure to certain DG needs further investigation.

REFERENCES

1. Covellov , T. and Merkhofer, M. W. (1993) Risk Assessment Methods: Approaches for Assessing Health and Environmental Risks. Plenum Press, NY.
2. Erkut, E. and Verter, V. (1998) Modeling of Transport Risk for Hazardous Materials. Operational Research Letters. 46, 625-642.
3. USDOT (U.S. Department of Transportation) (1989). Guidelines for Applying Criteria to Designate Routes for Transporting Hazardous Materials. Report No. DOT/RSPA/OHMT-89-02, Federal Highway Administration, Washington, DC.
4. Abkowitz, M., A. Eiger and S. Srinivasan (1984). Estimating the Release Rates and Costs of Transporting Hazardous Waste. Transportation Research Record 977, pp. 22-30.
5. Pijawka, K., S. Foote and A. Soesilo (1985). “Risk Assessment of Transporting Hazardous Material: Route Analysis and Hazard Management,” Transportation Research Record 1020, pp. 1-6.
6. Radwan, E., K. Pijawka, A. Soesilo and F. Shieh (1986). “Transportation of Hazardous Wastes in Arizona: Development of a Data Base Management System for Basic Analysis,” Transportation Research Record 1063, pp. 1-7.

7. Abkowitz, M. and Cheng, P.D.-M. (1988) Developing a risk/cost framework for routing truck movements of hazardous materials. Accident Analysis & Prevention, Vol. 20, No. 1, pp. 39-51.
8. Glickman, Theodore S. (1991). “An Expeditious Risk Assessment of the Highway Transportation of Flammable Liquids in Bulk,” Transportation Science 25, pp. 115- 123.
9. Harwood W.D., Viner J.G, and Russell, E.R. (1991) Truck Accident and Release Rates for Hazmat Routing. ASCE Conference Proceeding Paper, pp. 177-190.
10. Harwood W.D., Viner J.G, and Russell, E.R. (1993) Procedure for Developing Truck Accident and Release Rates for Hazmat Routing. J. Transp. Eng. 119, 189-199.
11. Saccomanno, F. and J. Shortreed (1993). “HAZMAT Transport Risks: Societal and Individual Perspectives,” Journal of Transportation Engineering 119, 177-188.
12. Erkut, E. and Ingolfsson, A. (2004) Transport Risk Models for Hazardous Materials: Revisited. Operational Research Letters. 33, 81-89.
13. Leonelli, P., Bonvicini, S. and Spadoni G. (2000) Hazardous Materials Transportation: A Risk Analysis based Routing Methodology. Journal of Hazardous Materials, 71, 283-300.
14. Huang, B., Cheu, R.L. and Liew, Y.S. (2003) GIS-AHP Model for HAZMAT Routing with Security Considerations. IEEE 6th International Conference on Intelligent Transportation Systems, Shanghai, China.
15. Huang, B., Cheu, R.L. and Liew, Y.S. GIS (2004) GIS and Genetic Algorithms for HAZMAT Route Planning with Security Considerations. International Journal Geographical Information Science. VOL. 18, NO. 8, 769–787.
16. Dilgir, R., Zein, S.R. and Al Popoff (2005) Dangerous Goods Route Selection Criteria. Paper prepared for presentation at the Towards a Safer Road Network Session of the 2005 Annual Conference of the Transportation Association of Canada Calgary, Alberta.
17. Han, K. (2006). Developing a GIS-based Decision Support System for Transportation System Planning. Paper submitted to AASHTO GIS-T 2006 Student Paper Contest.
18. Panwhar S.T., Pitt, Robert. and Anderson, M.D. (2000) Development of a GIS-Based Hazardous Materials Transportation Management System. Publication of the University Transportation Center for Alabama. Report, 99244.
19. Nema, A. K. and Gupta, S. K. (2003) Multiobjective Risk Analysis and Optimization of Regional Hazardous Waste Management System. Practice Periodical of Hazardous, Toxic, and Radioactive Waste Management. ASCE, 69-77.
20. Huang, B. and Fery, P. (2005) Multiobjective Optimization for Hazardous Materials Transportation. Transportation Research Record: Journal of the Transportation Research Board, pp 64-73
21. Zhang, M., Ma, Y, and Wen, K. (2005). Location-routing model of hazardous materials distribution system based on risk bottleneck," ICSSSM, pp.362-368 Vol. 1, Proceedings of ICSSSM '05. 2005 International Conference on Services Systems and Services Management, Vol. 1
22. Frank, W.C., Thill, J.-C. and Batta, R. (2000) Spatial decision support system for hazardous material truck routing. Transportation Research Part C, Vol. 8, pp. 337-359.
23. Jin, H., Batta, R., and Karwan, M.H. (1995). On the Analysis of Two New Models for Transporting Hazardous Materials Operations Research, Vol. 44, No. 5, pp. 710-723
24. Lepofsky, M., Abkowitz, M. and P. Cheng (1993) Transportation Hazard Analysis in Integrated GIS Environment. Journal of Transportation Engineering, Vol. 119, No. 2, pp. 239-254.

25. Brainard, J., Lovett, A., and ParfittT, J. (1996) Assessing hazardous waste transport risks using a GIS. International Journal of Geographical Information Systems, 10, 831–849.
26. Lovett A, Parfitt JP, and Brainard, JS. (1997) Using GIS in risk analysis: A case study of hazardous waste transport. Risk Anal 17(5):625-33.
27. Emergency Response Guidebook (2008) US Department of Transportation, Transport Canada, Secretariat of Transport and Communications of Mexico.
28. Shortreed, J., Belluz, D., Saccomanno, F.F., Nassar, S., Craig, L., and Paoli, G. (1994). Transportation risk assessment for the Alberta special waste management system (Final Report). Waterloo, Ontario, Canada: Institute for Risk Research, University of Waterloo.
29. Waters, W. G., Wong, C. & Megale, K. (1995) Value of Commercial Vehicle Time Savings for The Evaluation of Highway Investment A Resource Saving Approach Journal of Public Economics, 35

Table 1: Risk Measures

Description	Routes		
	R1	R2	R3
Accident Probability	4.10E-04	***3.95E-04***	5.88E-04
Travel Distance (km)	33	***27***	41
Travel Time (min)	***23***	25	41
Transport Cost ($)	***21***	23	38

Table 2: Exposed Population by Time of Day

Description		Routes		
		R1	R2	R3
Evening Exposed Population	**20 (ppm)**	41,163	***36,230***	41,289
	2 (ppm)	19,932	***16,206***	21,085
	0.5 (ppm)	9,503	***4,538***	14,339
	Evacuated	92,870	***80,942***	90,315
Day Exposed Population	**20 (ppm)**	63,584	63,581	***47,608***
	2 (ppm)	19,861	***9,768***	13,194
	0.5 (ppm)	6,421	***2,756***	15,622
	Evacuated	104,841	104,632	***85,866***

Table 3: Number of Special & Emergency Facilities alongside each Route

Concentration Level	Facility Type	No. of facilities on each route		
		R1	R2	R3
20 ppm	**Sensitive**	11	***9***	***9***
	Emergency	1	***3***	2
2 ppm	**Sensitive**	20	21	***18***
	Emergency	4	***5***	***5***
0.5 ppm	**Sensitive**	25	***24***	30
	Emergency	5	7	***8***

Table 4: Costs Associated with routing DG during Evening

Description		Evening			Day		
		R1	R2	R3	R1	R2	R3
Risk Costs ($)	**20 (ppm)**	16,858	14,311	24,259	26,040	25,114	27,972
	2 (ppm)	4,082	3,201	6,194	4,067	1,929	3,876
	0.5 (ppm)	389	179	842	263	109	918
	Evacuated	7,607	6,394	10,613	8,587	8,266	10,090
	Total	28,936	24,085	41,909	38,958	35,418	42,856
Operating Costs ($)		21	23	38	21	23	38
Total Cost ($)		28,957	***24,108***	41,947	38,979	***35,441***	42,894

Table 5: Summary of the Routing Criteria Results

Description	Time	Routes		
		R1	R2	R3
Travel Distance	All		√	
Travel Time	All	√		
Transport Cost	All	√		
Incident Probability	All		√	
Incident Consequence	Evening		√	
	Day		√*	√
Risk/Cost DGRA	Evening		√	
	Day		√	

*** Based on concentration levels 2 (ppm) & 0.5 (ppm)**

Table 6: Percentage Increase from the base Value

Description		Routes		
		R1	R2	R3
Travel Distance (km)		22%	Base	52%
Travel Time (min)		Base	9%	78%
Transport Cost ($)				
Incident Probability (per million)		4%	Base	49%
Total Cost ($)	**Evening**	20%		74%
	Day	10%		21%

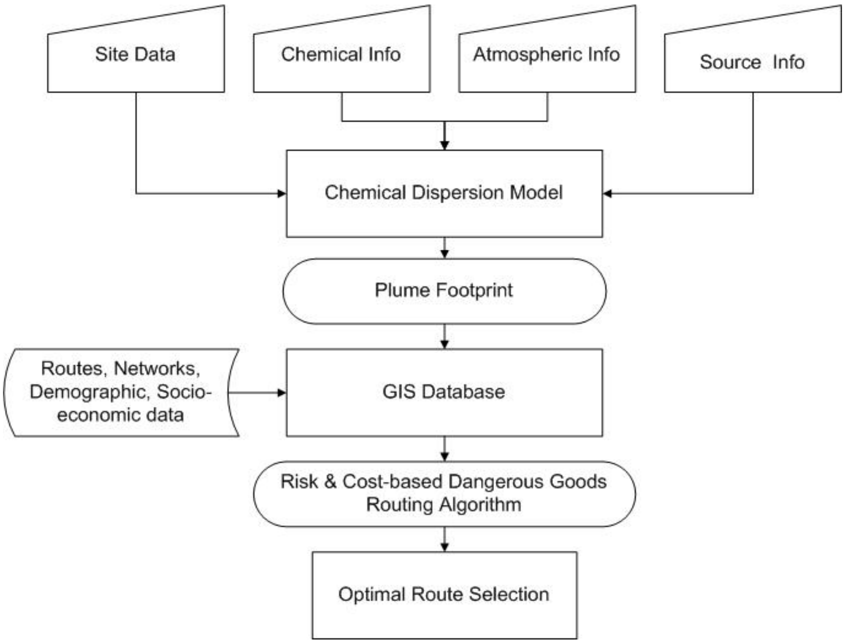

Figure 1: Dangerous Goods Routing Algorithm: Conceptual Framework

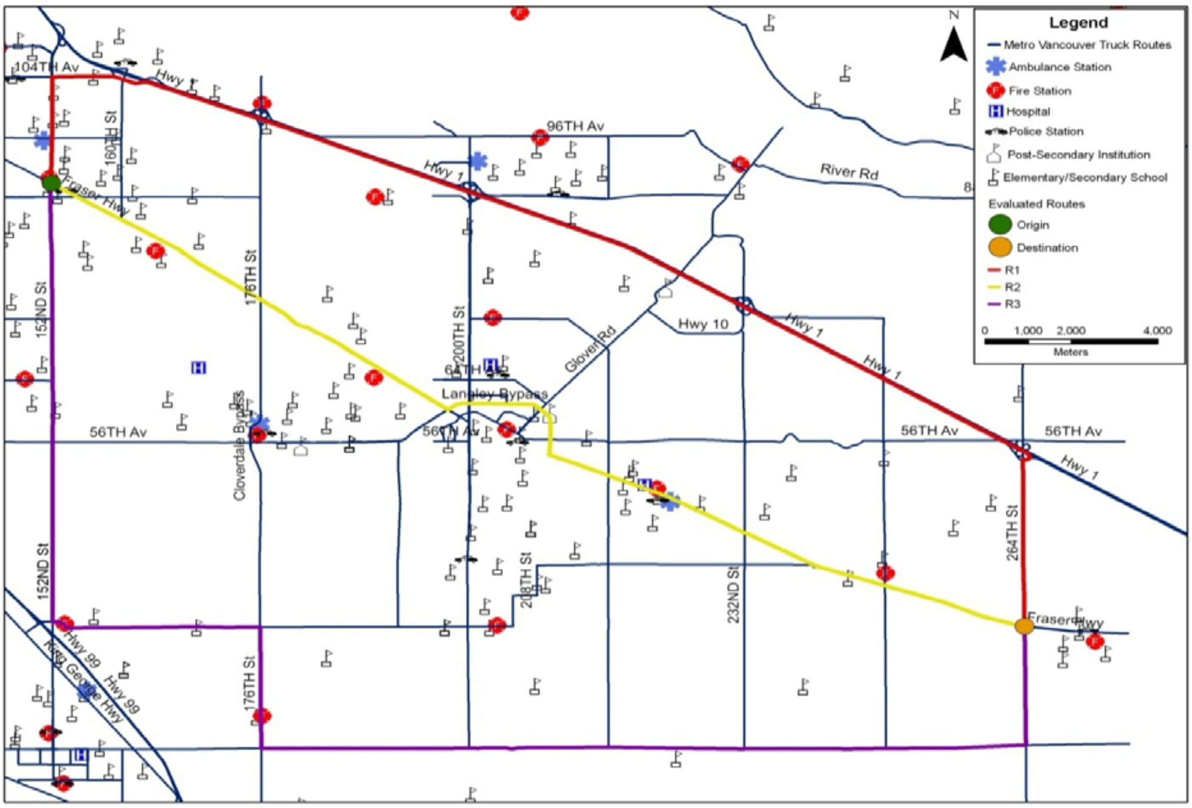

Figure 2: Study Area and Evaluated Routes

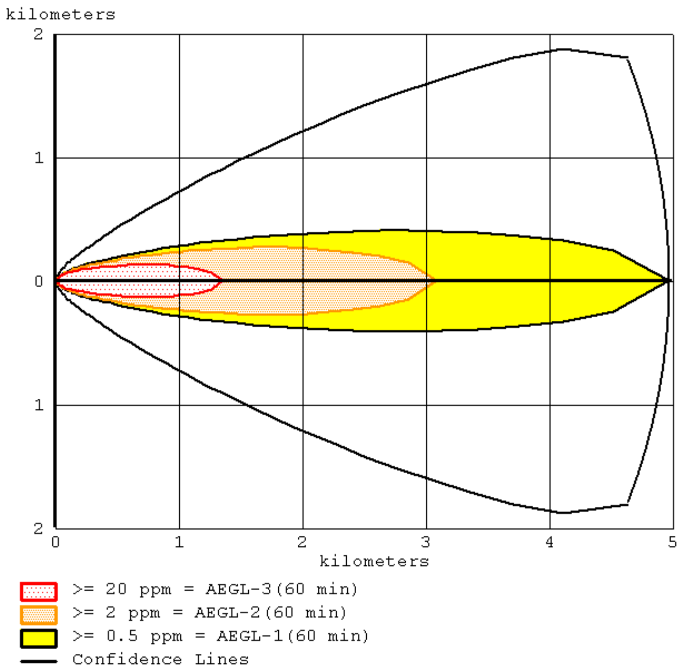

Figure 3: ALOHA Generated Plume Footprint for Chlorine

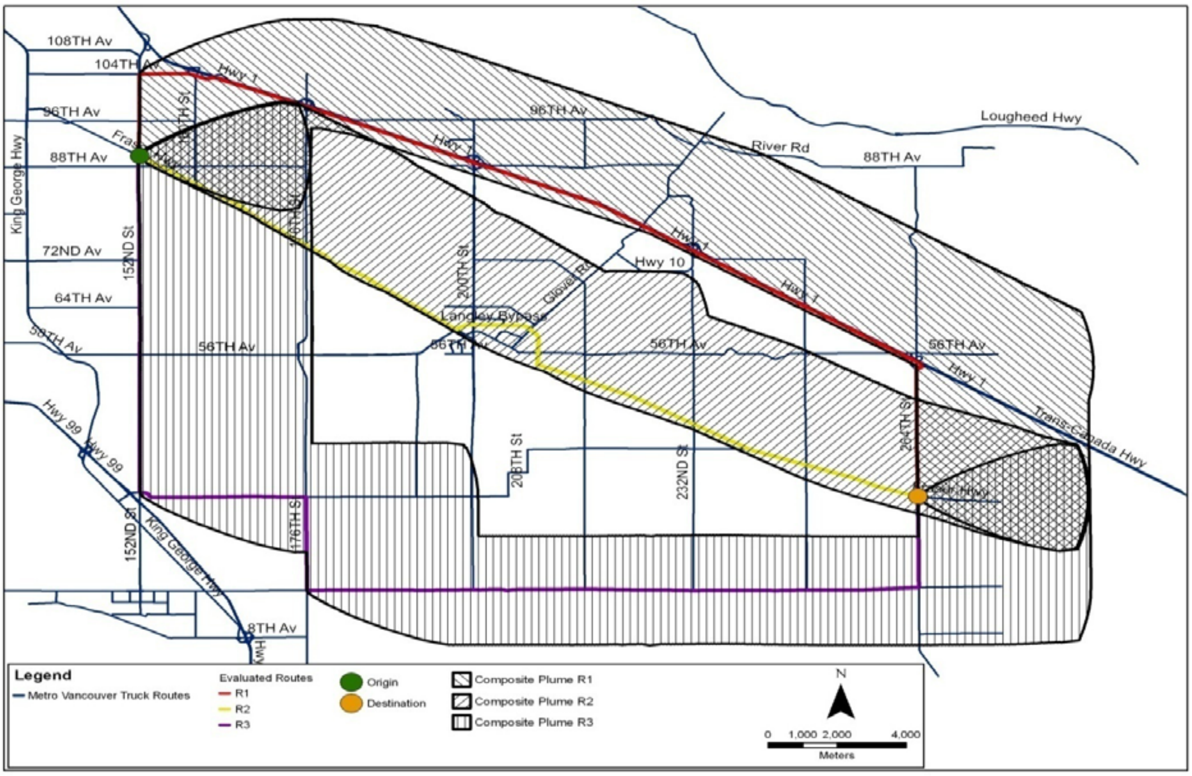

Figure 4: GIS Generated Impact Zones for all three Routes