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URBAN GOODS TRANSPORT ANALYSIS-A RISK-BASED APPROACH

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Abstract

Community concerns regarding road-based urban goods transport are related to the negative impacts of the activity, including: collisions; noise; emissions; and other hazards associated with transported materials. Road-based urban goods transport can negatively impact human health, the environmental and surroundings business activity and infrastructure. In addition to the community, the urban goods transport industry is realizing the need for a risk-based approach to manage its business. As such, the need exists and is growing for a comprehensive, systematic and flexible system to assist decision makers in managing urban goods transport in a flexible and responsive manner. Such a system must be based on actual data that is accumulated, analysed and managed within a geographic database, preferably GIS. To contribute towards meeting this need, a risk-based framework and computer model were developed to assist decision makers and professionals involved in managing urban goods transport in performing the following tasks: (i) analyse the risk associated with alternative transportation routes; (ii) assess alternative transportation periods on the same route; (iii) assess impacts of urban goods routing decisions; (iv) define major routes based on relative "safety"; (v) balance the importance of environmental, human health, and business "values" on decisions; (vi) locate emergency response facilities, especially those that are relevant to hazardous urban goods transport; and (vii) evaluate impacts of development projects on risk associated with transportation routes.

Keywords: Risk assessment; Comparative risk; Urban goods transport by road; Hazardous urban goods; Non-hazardous urban goods; Route assessment; Human health; Environmental health; Business activity and infrastructure
Topic Area: B5 Urban Goods Movement

1. Introduction

Efficiency and safety are two of the most important transport management issues. Efficiency strategies are designed to serve economic development and improve accessibility. The major aim of safety policies and action plans is to reduce the number of road fatalities and injuries. In the past few decades, health and environmental concerns due to emissions and noise and transported hazardous material have surfaced and gained significant attention from the community.

Risk assessment is an important aspect of planning and managing the transport of hazardous materials. However, risk assessment in relation to route selection for transporting hazardous materials has yet to be adopted as a formal activity. The Australian code for the transport of dangerous goods by road and rail (Australian Department of Transport and Regional Services, 1999) is not focused on route assessment and selection

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for transporting hazardous goods. The code contains information relating to requirements for transportation of hazardous materials such as: packaging requirements; prohibitions on goods; vehicle and urban goods container suitability; loading of dangerous goods; and emergencies during use of road and rail vehicles. The United Nations (UN, 1995) report titled “Recommendations on the Transport of Dangerous Goods” is focused on issues such as the desirability of uniformity at world level for all modes of hazardous goods transport; classification of the various types of dangerous goods carried; training of dangerous goods transport workers; and appropriate emergency procedures.

Previous work on risk assessment was focused on transporting hazardous materials. For example, the Queensland (Australia) Transport authority uses a comparative risk-assessment model (Middleton et al., 1992) that is based on assigning ranks (scores) for a variety of parameters (Table 1) that are used in the model for predicting the accident probability and severity of effects. Other similar risk assessment models for transporting hazardous material were reported in the literature (Pijawka et. al., 1985 ; Harwood et al.,1990).

Table 1. Risk assessment parameters (Middleton et al., 1992).

Accident Probability Factors	**Accident Severity Factors**
❑ Traffic Volume	❑ Exposed population numbers
❑ Truck Container Volume	❑ Hazardous goods characteristics
❑ Road or intersection layout	❑ Emergency response time
❑ Truck Speed	❑ Local physical features
❑ Road Condition	❑ Accident type
	❑ Emergency response facilities
	❑ Special facilities nearby
	❑ Adjoining development type
	❑ Information availability

The impacts of transportation activities are not limited to the impacts of collisions and release of hazardous material, but also include health and environmental effects related to emissions and social and health impacts related to noise. In addition, the negative impacts of transportation incidents may disrupt business activity and infrastructure. As such, this work is based on extending the risk-assessment concept used in assessing the transport of hazardous materials to a more comprehensive assessment for any type of urban goods, mainly hazardous or non hazardous urban goods.

A conceptual illustration of risk assessment along routes designated for hazardous urban goods transport is presented in Figure 1 (Shanableh et al., 1999). In this case, the risk to human health is highest near to the residential area while the risk to the environment is highest near the sensitive ecosystem. The risk of an accident is highest at the un-signalized intersection.

The major objective of this study was to develop a risk-based framework (RBF) for analyzing the risk posed by urban goods transport by land on human health, the environment and business activity and infrastructure. This paper outlines a comprehensive risk-based framework for analyzing alternative routes based on evaluating the associated human and environmental impacts in addition to the impacts on business activity and infrastructure. The system is based on identifying the main factors that contribute to the probability and severity of transportation related negative impacts, ranking such factors, then combining them using a special weighing system. The resulting risk is a comparative system that is useful for comparison among alternatives.

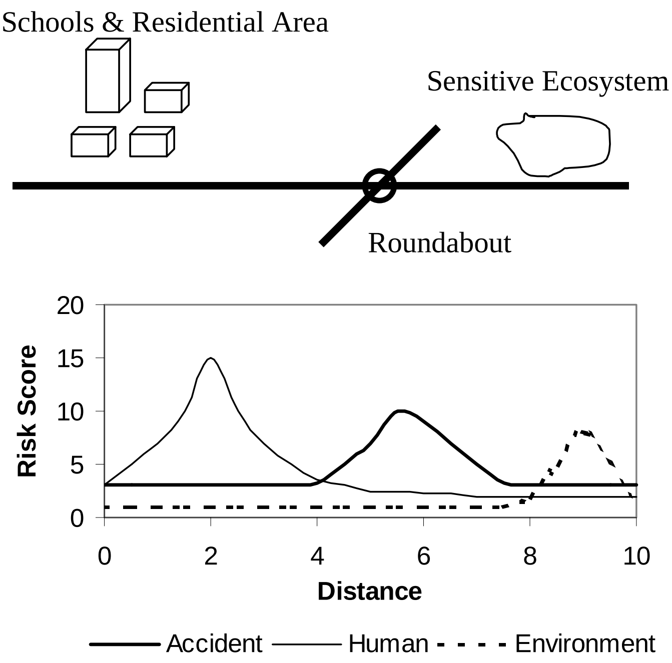

Figure 1. Conceptual interpretation of risk posed along a transportation route.

2. Development of the risk assessment framework

2.1 General risk assessment model

Risk-based assessment is an approach that is increasingly being used by decision makers for setting priorities associated with actions and budgets and managing socio-economic and environmental projects and impacts. Risk is defined as the chance (likelihood, probability) of a specified level of harm occurring within a specific period, or being associated with a specific activity. In this study, the basic risk assessment model that is used in the public health field was adopted and systematically translated into a framework suitable for assessing the risk associated with transporting hazardous or non-hazardous urban goods. The basic risk model used in the health field (USEPA, 1989) is identified in Equation (1). The health risk model is based on multiplying the exposure dose (i.e., quantity of toxin ingested) by a potency response factor that represents the inherent toxicity of the ingested material by the exposed population (i.e., number of people who ingested the toxin). The result is the probability that an individual among the exposed group (i.e., one person per one million exposed people) might suffer negative consequences as a result of exposure.

$$Risk = (IDF)*(RF)*(POP)*(RMF) \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

Where, IDF = impact dose factor (i.e., exposure dose); RF = response factor (i.e., potency factor); POP = exposed population; and RMF = risk management factor.

In the following sections, the general risk assessment model in Equation (1) is translated into a comprehensive risk-assessment system for urban goods transport analysis.

2.2 Impact dose factor

The impact dose factor (IDF) refers to the quantity and frequency of exposure to hazards (i.e., air pollutants, noise, collisions, hazardous chemicals). In transportation terms, the impact dose factor is translated into risk-producing events. The risk producing events recognized in this study are: (1) general urban goods transport; (2) accidents; and

(3) release of hazardous chemicals. These events are further discussed in the following sub-sections.

The impact dose factor is related to the probability of occurrence of events (frequency) such as accidents and also to the severity of such events in terms of the quantities of harm added by such events (emissions, noise, hazardous chemicals and collisions). The impact dose factor can be defined by the relationship described in Equation (2):

$$IDF = (P_{Event})*(S_{Event}) \quad (2)$$

The probability of the risk resulting from emissions and noise due to general traffic movement is certain no matter how small it is. However, the probabilities of accidents and release of hazardous chemicals require assessment. The severity of events is related to the quantities of emissions, noise, accidents and transported hazardous materials.

Assessing the impact dose factors for general movement, accidents and release of hazardous materials requires historical data and statistical analysis specific to the assessed transport routes in addition to expert advice and assessment. To help in the assessment, the framework designed in this study allows evaluation based on factors such as the characteristics of the traffic flow, route, surrounding physical environment and special factors such as weather conditions.

For the release of hazardous materials, the impact dose factor can be evaluated using the relationship described in Equation (3). The probability of release depends on the probability of accidents times the probability of release given that an accident has occurred times the quantity of hazardous material transported

$$IDF_{H.M.Release} = (P_{Accident})*(P_{Release/Accident})*(Q_{HM}) \quad (3)$$

2.2.1 General urban goods transport

Even without accidents, the movement of vehicles on roads without accidents unavoidably leads to direct or indirect impacts on humans and the environment. These impacts are mainly related to noise and air pollution. The impacts resulting from general urban goods transport are generated irrespective of accidents, and are assessed assuming no accidents while the vehicle is traveling on a specific route.

The impacts of general urban goods transport can be related to factors such as vehicle characteristics, road characteristics, characteristics of the surrounding physical environment, traffic flow, human factors and other factors such as weather conditions. These factors such contribute to increasing or decreasing the risk resulting from noise and air pollution in addition to affecting the operational cost and efficiency of urban goods transport. For example, a summary of the general urban goods transport risk related factors are summarized in Table 2.

2.2.2 Accidents

Accidents can directly cause injury, death and damage to the surrounding environment and to business activities and infrastructure. The negative consequences of accidents extend to affecting travel time and operational costs.

Table 2. Factors and sub-factors related to risk resulting from general movement, accidents, and release of hazardous materials.

Factor	Sub-Factors
Vehicle Characteristics	Dimensions Performance Vehicle's safety features
Traffic Flow Characteristics	Normal vehicle volume Heavy vehicle volume
Road Characteristics	Road length Road alignment, vertical and horizontal Road pavement condition Lane characteristics Intersection/roundabout/point of conflict Traveling speed
Other Factors	Weather conditions Period of day Physical environment
Hazardous Materials Factors	Container Reliability Transported quantity

2.2.3 Release of hazardous materials

Accidents may lead to the release of transported hazardous materials from vehicles carrying such urban goods. This may result in direct and severe risk to human health, the environment and business activity and infrastructure. The probability of chemical release is assessed assuming that an accident has occurred (Equation 2). The probability of release depends on the severity of accidents, type of accidents and the characteristics of the storage container. The hazardous material quantity, physical environment, and weather conditions contribute to increasing or decreasing the risk associated with the release incident.

2.3 Impact response factor

The response factors are generally defined for chemicals and are used to differentiate between the various types of impacts according to the chemicals inherent toxicity/injury potential characteristics. In the urban goods transport context, the response factors can be identified for chemicals (i.e., air pollutants, transported hazardous material). For harm and injuries related to non-chemicals, there are no defined response factors and as such relative response factors need to be assigned.

The inherent characteristics of the risk agents (noise, air emissions, injuries, transported hazardous materials) are the same regardless of which route is used to transport urban goods. Used defined weighing factors that are based on surveys are used to differentiate among the risk levels caused by air pollutants, transported hazardous material, and direct injuries resulting from accidents. In effect, the approach used in this framework amounts to using the user-defined weighting factors as response factors. In case the assessment is meant to compare the risk associated with transporting two different hazardous materials, then it is possible to assign impact response factors to each material depending on its inherent hazardous characteristics using the generally available data on hazardous materials.

2.4 Risk management factor

An allowance is made for a risk management response factor, which has the potential to reduce risk substantially. For example, the availability of efficient emergency response following an accidental release of chemicals can minimize risk. Two risk management factors were included in this framework. These are: (1) emergency response quickness; and (2) emergency response capacity and facility.

The risk management factor does not apply for general traffic movement but mainly applies to accidents involving the spill of hazardous material and accidents involving injuries.

2.5 Exposed population and risk categories

In the risk assessment context, populations are used to describe human or animal populations. This concept is extended to an equivalent population type, that is business activity and infrastructure. The comparison of routes for urban goods transport is based on comparing impacts on three population categories: human population, environmental population, and business activity and infrastructure "population".

The exposed population factor is assessed through assessing the population density surrounding the route, the vulnerability of the exposed population and the separation between the exposed population and the route.

The risk to the exposed population categories represents the probability that part of the exposed population will be harmed by the negative consequences of transportation activity. The negative impacts on each of the population categories are described below:

1) Human health impacts. This refers to direct impacts resulting from injury and loss of lives and indirect impacts resulting from emissions and noise pollution.
2) Environmental impacts. This relates to impacts on ecosystems and special flora and fauna communities. Such impacts also relate to the general degradation of environmental quality.
3) Business activity and infrastructure impacts. This is associated with the economic loss due to disruption of business activity and damage to special roadside infrastructure or facilities during accidents or release of hazardous material.

Each of the risk generating events (general traffic movement, accidents, and release of hazardous materials) can impact any or all of the population categories. The impacts considered in the risk assessment system is summarized in Table 3.

Table 3. Risk generating events and their impacts as populations surrounding the route.

Risk/Cost Category	**Risk-Producing Events**		
	General Movement	Accidents	Release of HM
Surrounding Human Population	X	X	X
Surrounding Environmental Population	X	X	X
Surrounding Business Activity and Infrastructure "population"	X	X	X

2.6 Comprehensive risk and route selection

Once the risk to the individual population categories is determined, a comprehensive risk can be estimated by weighing the importance of each risk group against the others. The comprehensive risk is calculated using the simple relationship identified in Equation (4).

$$Risk_{Comprehensive} = (W_{HH} * Risk_{HH}) + (W_{Env} * Risk_{Env}) + (W_{BAI} * Risk_{BAI}) \ldots \quad (4)$$

Integrating the operational cost of transporting urban goods with the comprehensive risk provides a basis for making choices among alternative routes.

3. Comparison of alternative routes - risk ranking assessment

Estimating the absolute risk and the probabilities and severities of accidents and spills of hazardous chemicals is almost an impossible task. Fortunately, absolute estimates are not required in the assessment because the intention is to compare routes not to assess absolute risk. As such, the intended assessment is a risk ranking, or comparative, risk assessment. Routes can be compared and ranked in terms of the characteristics of the vehicles, traffic flow, road and surroundings. These comparisons can be translated into logical ranking arguments (i.e., higher, equal or lower).

The ranking system used in this study is based on assigning a risk score (rank) and an importance score (weight) for each factor identified as contributor to increasing or decreasing risk. For example, the data in Table 4 present an example of the major factors (sub-factors are presented in Table 2) that were identified as contributors to increasing or decreasing risk. For each item contributing factor, a rank (R) and a weight (W) are assigned using guidelines developed for this purpose. The impact dose factors (IDF) for general movement (emissions, noise), accidents and release of hazardous materials are then estimated as in Equations (5-7). Note that in Equations (5-7), the factors: traffic characteristics (TC); Road Characteristics (RC); and Other Conditions (OC) are ranked (R) and weighted (W). The hazardous material factor is ranked as (REL).

Table 4. Major factors related to assessing the impact dose factor.

Factors	GM Emission/ Noise	Accidents	Release of HM
Traffic Characteristics Factor	X	X	
Road Characteristics Factor	X	X	
Other Conditions (Whether, Physical Environment,..) Factor	X	X	X
Hazardous Material Quantity and Containment Factor			X

$$IDF_{G.Move} = (R_{TC}^{Gm} * W_{TC}^{Gm}) * (R_{RC}^{GM} * W_{RC}^{GM} + R_{OC}^{Gm} * W_{OC}^{Gm}) \ldots\ldots\ldots\ldots\ldots \quad (5)$$

$$IDF_{Accident} = (R_{TC}^{Ac} * W_{TC}^{Ac}) * (R_{RC}^{Ac} * W_{RC}^{Ac} + R_{OC}^{Ac} * W_{OC}^{Ac}) \ldots\ldots\ldots\ldots\ldots \quad (6)$$

$$IDF_{H.M.Release} = (IDF_{Accident}) * (R_{OC}^{HM} * W_{OC}^{HM}) * (REL_{HM}^{HM} * W_{HM}^{HM}) \ldots \quad (7)$$

The use of ranks (R) and weights (W) allows flexibility in the assessment system because it allows ignoring any factor as irrelevant or considering any factor as important. The ranks allow the assessor to assign a relative value when comparing conditions on alternative routes regardless of the importance of the ranked parameter itself. For example, heavy traffic flow may be given a high rank for route A and a low rank for route B regardless of whether the traffic flow parameter is important or not. The weights however give the assessor the opportunity to decide whether this factor is important or irrelevant for the assessment. Irrelevant factors are assigned similar scores for each assessed alternative.

The risk (i.e., to human health, HH) is estimated by multiplying the impact dose factors (IDF) by the response factors (RF) by the exposed population factor (POP) by the risk management factor (RMF). The response factors are weighting factors that compare the risk related to the emissions and noise in terms of general movement and delays to the risk of injuries in the case of accidents and release of hazardous chemicals. The risk to human health is estimated for each impact dose factor as follows (Equations 8-10):

$$Risk_{H.H}^{GM} = IDF_{GM} * RF_{GM}^{HH} * RMF_{GM}^{HH} * POP_{Human} \ldots \quad (8)$$

$$Risk_{H.H}^{Ac} = IDF_{Ac} * RF_{Ac}^{HH} * RMF_{Ac}^{HH} * POP_{Human} \ldots \quad (9)$$

$$Risk_{H.H}^{HM} = IDF_{HM} * RF_{HM}^{HH} * RMF_{HM}^{HH} * POP_{Human} \ldots \quad (10)$$

The overall risk to human health can then be estimated by weighing and adding the various components as in Equation (11). The process is repeated for risk to environmental health and for risk for business activity and infrastructure (Equations 12 and 13).

$$Risk_{H.H} = Risk_{H.H}^{GM} + Risk_{H.H}^{Ac} + Risk_{H.H}^{HM} \ldots \quad (11)$$

$$Risk_{Env} = Risk_{Env}^{GM} + Risk_{Env}^{Ac} + Risk_{Env}^{HM} \ldots \quad (12)$$

$$Risk_{BAI} = Risk_{BAI}^{GM} + Risk_{BAI}^{Ac} + Risk_{BAI}^{HM} \ldots \quad (13)$$

The comprehensive risk is then estimated from the following relationship:

$$Risk_{Comprehensive} = (W_{HH} * Risk_{HH}) + (W_{Env} * Risk_{Env}) + (W_{BAI} * Risk_{BAI}) \ldots \quad (14)$$

The above equations describe only some of the rules used to summarize the major groups of relevant parameters. For example, the traffic characteristics factor is assessed based on many sub-factors related to traffic volume and composition, vehicle characteristics, and traffic flow characteristics (Table 2). The development of the model involved the assessment of a great number of parameters. The model parameters can be classified into the following categories: (i) vehicle characteristics; (iii) trip characteristics; (iii) route characteristics; (iv) characteristics of surroundings; (v) transported materials hazardous characteristics; and (vi) emergency response data. A complete set of guidelines was designed to assist the user in selecting uniform ranks and weights for the various parameters. To further assist the users in applying the risk assessment system, a computer software called RBF-FMA was developed. Details of model development were described by Yu (2002). In the model, the user assigns scores and weights for each relevant parameter based on the provided guidelines. It is recognized that the guidelines for assigning scores and weights are useful in standardizing the scores and weights, but subjectivity remains. For decision makers, the judgment of a panel of experts and the community may be consulted. The mathematical formulas included in the model were based on available models and best judgment, but remain a subject for further research and development.

4. Segmentation of routes for assessment

The risk assessment framework is best achieved through assessing routes segment by segment. In assessment, two types of segments are recognized. These are: (1) travel segments; and (2) point segments. Example point segments include intersections and roundabouts. Route assessment proceeds segment by segment on each route alternative.

Travel segments are typically selected between two end point segments. The end points of travel segments can also be the starting and ending points at which the conditions change enough to warrant starting a new segment.

Enough data addressing the factors in Table 1 need to be collected on each route segment to allow adequate assessment. The assessment can be performed using very specific conditions, for example during a certain time of the day, or can be performed in broad terms to reflect the general risk conditions associated with alternative routes, or can be performed based on best or worst case scenarios on the alternative routes.

Geographic information systems (GIS) provide excellent media for hosting a risk management database for land transportation routes. A GIS system can be easily created using existing data available to local, state, and federal government and private organizations. Such data include road networks, population centers, land use, economic infrastructure, sensitive ecosystems, industrial activity, physical environment, and route and traffic data. Additional data can be collected for routes under consideration and used to expand the GIS database.

The advantage of creating a GIS database is that it can provide a visual display of transportation routes and the risk associated with them. In addition, the digital information in the database can be refined and updated. Accumulation of information in a database can also help provide a framework for instant decisions on redirecting trucks in cases of road closures and emergency. The GIS database can also highlight the most vulnerable areas in terms of impacts on human health, the environment, and economic infrastructure.

5. Subjectivity and other limitations

The framework developed in this work is a ranking system that applies for comparing alternatives. One way to develop a base-line score for "safe" routes is to rely on experts and community judgment of what is considered to be a safe route then develop the risk scores for such a route. Still, the assigning of the various weights and scores for the various factors and sub-factors in the model is a subjective exercise. As such, the best approach is to develop a set of clear guidelines to unify the assignment of ranks and weights and that can be used to guide users in ranking and weighing factors and sub-factors. The assessment system however requires adequate calibration by users before it can be used to assess their particular situations. The system is however flexible enough to allow users to focus on any of the risk factors or ignore any other factor.

The issues of concern here are not only the value of the ranks and weights but also the issues associated with comparing risk along alternative routes. The main issues are: (i) quality of data used to produce the assessment; (ii) quality of model in terms of accounting for the appropriate parameters and integrating them into mathematical models in a proper manner; (iii) subjectivity of assigning weights and scores; and (4) interpretation of results. Each one of these issues requires extensive research and effort on its own. This work represents a starting and significant effort towards addressing some of these issues.

Risk scores generated by the model are meaningless until compared with each other. A high difference in the resulting risk scores (assessment output) should not be used directly as an indicator for a major difference in actual risk. The differences in scores merely indicate that according to the input ranks and weights, a certain route or route segment may be more risky in terms of potential impacts on human health, or environmental health or business activity and infrastructure than the other route or route segment. The system is most useful in for quickly ranking routes according to relative risk and pointing out areas of potential significant risk. This should trigger a more informed and detailed assessment of the route segments that pose extra risk.

6. Example – Summarized assessment data needs

The discussion presented in this section is meant to illustrate how the data can be organized to conduct the assessment. In this case, two alternative route segments are assessed. The user must assign a system for ranks, R (i.e., on a scale from R=0 to R=10, with 0 being least contribution to risk and 10 being the highest contribution to risk). Another system must be used for weighing (W) factors and sub-factors (for example 0 to 1 (with W=0 being irrelevant factor and W=1 being factor with maximum relevance). The weights and scores can then be assigned as shown in Table 5. It should be noted that this discussion is limited to the summarized version of the risk assessment system. A more detailed assessment system was developed and is based on assessing the basic factors and sub-factors related to assessing traffic characteristics, route characteristics, vehicle characteristics, physical environment characteristics, weather conditions, hazardous material characteristics and other such factors (Yu, 2002).

Table 5. Data needs for comparing risk associated with two alternative route segments.

Item	General Movement			Accidents			Release of H M		
	Rank Route A	Rank Route B	Weight	Rank Route A	Rank Route B	Weight	Rank Route A	Rank Route B	Weight
Traffic Characteristics	R	R	W	R	R	W	---	---	---
Road Characteristics	R	R	W	R	R	W	---	---	---
Other Conditions	R	R	W	R	R	W	R	R	W
Hazardous Material Factors	---	---	---	---	---	---	R	R	W

The next data sets needed relate to the exposed "population" groups. Data on the various population groups must also be ranked as in Table 6. The ranks should reflect population numbers, densities, vulnerability and distribution and separation from the route. In Table 7, the response factors, which reflect the harmful characteristics of noise, emissions, collisions, and hazardous materials in relation to each other must be ranked (i.e., the inherent harmfulness of noise and emissions is assessed to be lower than the harmfulness of transported hazardous materials). The risk management factors, such as the availability and quickness of response of chemical response units and fire fighting units must also be ranked for each route segment (Table 7).

Using Equations 5-13, the numerical assessment can be conducted easily. To make the calculation results out of 10 for example, the calculation output from each equation was divided by the maximum possible value for the calculation output then multiplied by 10. The ranking results (R_R) of the calculations are summarized in Table 8.

Table 6. Relative population ranks needs for assessment.

Population Group	Route A	Route B
Human	R	R
Environmental	R	R
Business Activity and Infrastructure	R	R

Table 7. Relative response factors and risk-management factors.

Response Factor Category	Emissions Noise	Collisions	Hazardous Material
Human Health	R	R	R
Environmental Health	R	R	R
Business Activity and Infrastructure	R	R	R
Risk Management Factor Route A	R	R	R
Risk Management Factor for Route B	R	R	R

Table 8. Summary of comparative risk assessment results

Comparative Risk	Due to General Movement		Due to Accidents		Due to Release of HM		Total Risk	
	Route A	Route B	Route A	Route B	Route A	Route B	Route A	Route B
Risk to Surrounding Human Health	R_R	R_R	R_R	R_R	R_R	R_R	R_R	R_R
Risk to Surrounding Environmental Health	R_R	R_R	R_R	R_R	R_R	R_R	R_R	R_R
Risk to Surrounding Business and Infrastructure	R_R	R_R	R_R	R_R	R_R	R_R	R_R	R_R

The assessment results reflect the input data. A comprehensive risk score can be obtained by weighing risk to human health against risk to the environment and risk to business activity and infrastructure. If the risk to human health is given the highest weight, and the risk to the environment and business activity and infrastructure are given lower weights, then the comprehensive risk will reflect the value of human health vs. the values of the environment and business activity and infrastructure. The weights also reflect the main concern in the area being assessed. If human health is the main concern, then the other risk categories are reduced in comparison.

7. Field application of comparative risk assessment

The risk based framework computer model (RBF-FMA) was applied by a group of senior undergraduate students at the University of Sharjah to assess the transport of hazardous material along three alternative routes (Figure 2). The three routes connect the University City (start point) to the Sharjah City port on the Gulf (end point). The basic route information is provided in Table 9.

Table 9. Basic characteristics of the alternative routes.

Item	Route A	Route B	Route C
Length (km)	23	19	23
Average Travel Time During Rush Hour (Minutes)	50	39	45
Average Travel Time During Low Traffic (minutes)	17.5	14.3	17.3
No. of Route Segments Assessed	26	25	25
Route Surroundings	Mainly Commercial/ Residential Area	Mainly Commercial/ Residential Area	Mainly Industrial/ Commercial/ Residential Area

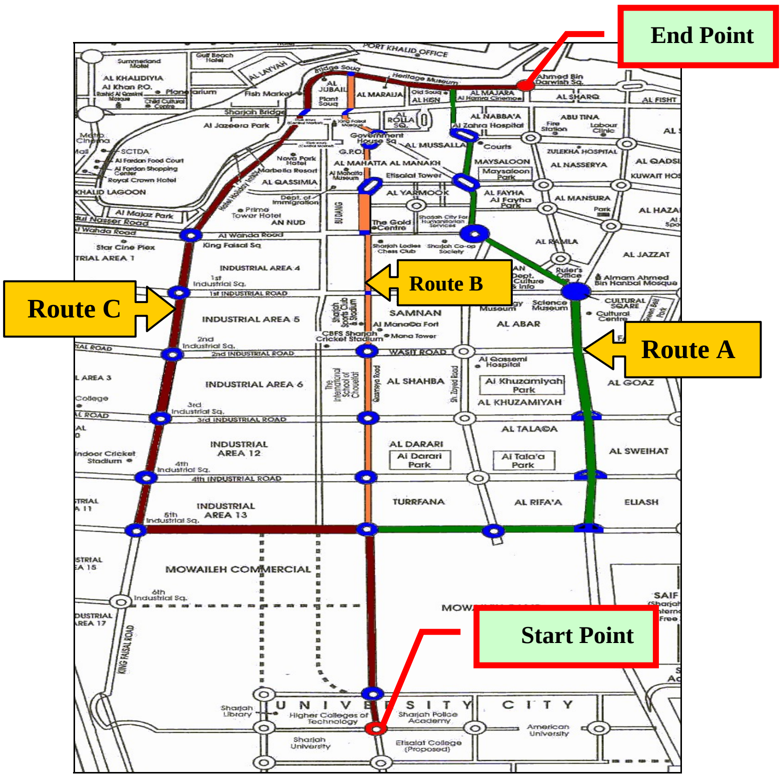

Figure 2. Map of Sharjah City showing the three routes assessed.

Route A is approximately 23 km in length. The route starts from the University City, passes through the lightly developed area near the University City then turns right to join the airport road, then passes through the center of the town and along the narrow entrance of the sea water lagoon. The average travel time on Route A during rush hour was measured to be 50 minutes, which reduces to 17.5 minutes during low traffic.

Route B is the shortest of the three routes (approximately 19 km) and is generally straight. The route starts from the University City traveling straight all the way through mixed commercial/residential areas passing through the downtown of Sharjah and meeting route A along the narrow entrance of the sea water lagoon. The average travel time on Route B during rush hour was 39 minutes, which reduces to 14.5 minutes during low traffic.

Route C is approximately 23.3 km in length. The route starts from the University City and travels through the mixed industrial(light)/commercial/residential area passing through the downtown of Sharjah then joining Routes A and B along the narrow entrance of the sea water lagoon. The average travel time on Route C during rush hour was 45 minutes, which reduces to 17.3 minutes during low traffic.

Each of the three routes was divided into travel and point segments: 26 segments for Route A; 25 segments for Route B; and 25 segments for Route C. The basic data were collected for each segment including: traffic characteristics; road segment characteristics; and characteristics of surroundings. The data were integrated into an appropriate GIS database (Figure 3).

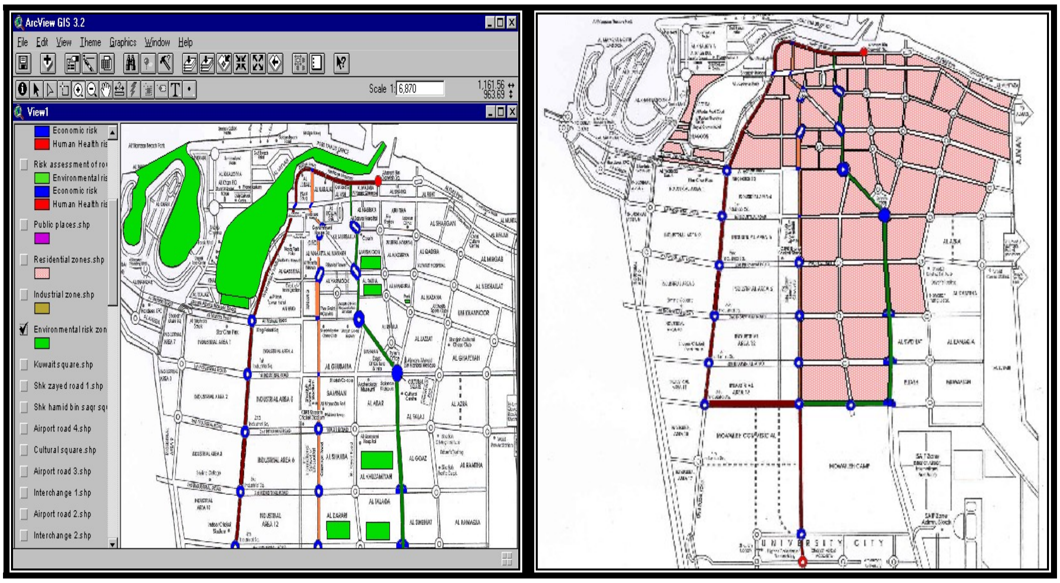

Figure 3. GIS maps showing environmentally significant areas and residential areas around the routes.

The general travel conditions on all three routes are relatively similar, except for Route A. A major part of Route A is heavily traveled and is surrounded by special facilities that attract more traffic and visitors. Nevertheless, the risk is more differentiated by the characteristics of the surrounding areas in terms of population density and vulnerability, environmental sensitivity, and economic activity and infrastructure.

In terms of risk to human health, the highest scores were assessed to be for routes A and C especially in the route segments that pass near schools and hospitals. Human health risk on Route A also reflects the heavy traffic on the route and the presence of special facilities and cultural centers that cause increased traffic and population. The most environmentally sensitive area was the sea water lagoon area. The risk scores associated with accidental spills of chemicals in the area surrounding the lagoon were high for all the three routes. The environmental risk scores for Route A was in general higher than the scores for the other two routes because Route A passes through more environmentally sensitive areas (Figure 2) than the other routes. The risk to economic activity and infrastructure is highest in the central business district for all routes. For Route A, the presence of special facilities in certain segments elevated the risk scores.

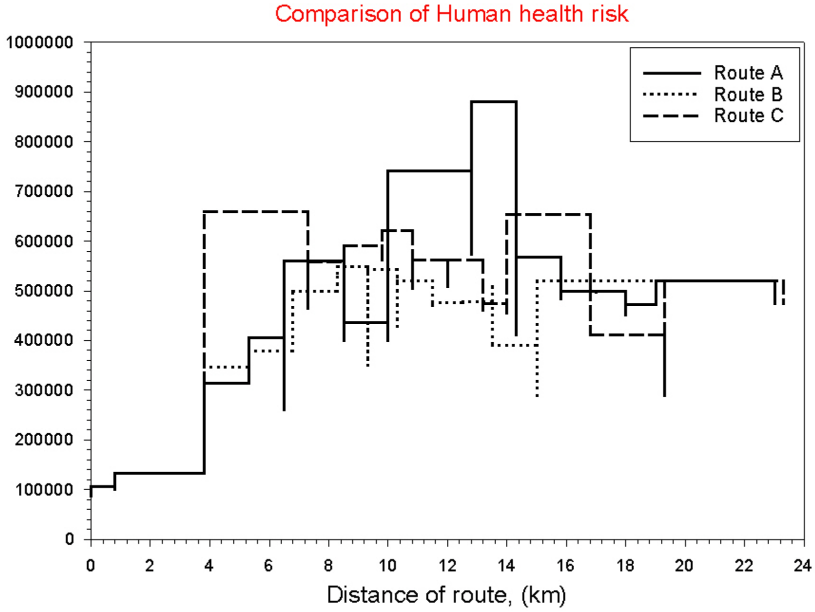

Figure 4. Ranking of risk to human health (relative risk scores vs. distance).

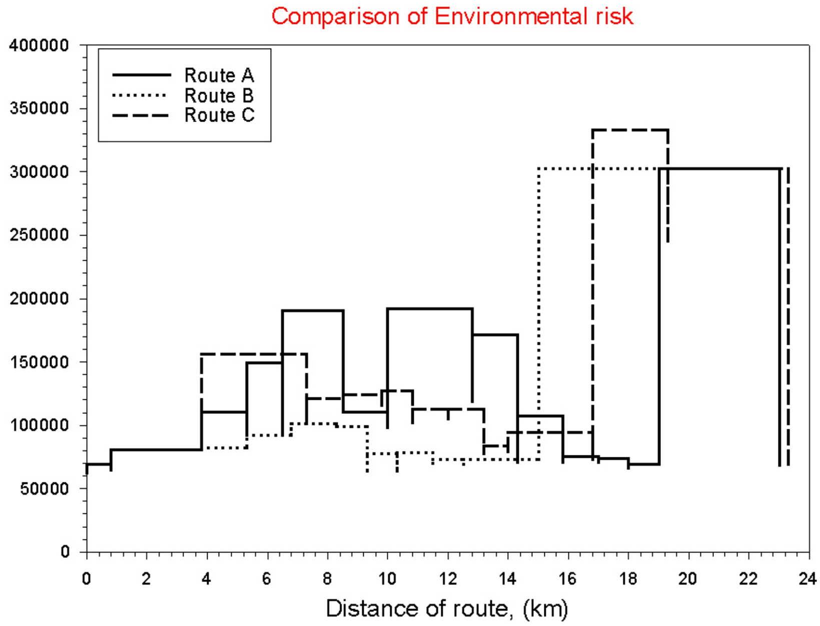

Figure 5. Ranking of risk to environmental health (relative risk scores vs. distance).

For illustration, the comprehensive risk score was estimated by adding all the three scores without weighting. Overall, the evaluation suggested that Route B was the least risky and Route A was the most risky. The areas under the curves allow estimation of cumulative risk on any particular route. Combining the risk ranks with the travel time also adds in favor of Route B.

The above assessment may produce different results if it was conducted by experts rather than by students. Nevertheless, the students who had little previous experience with risk assessment or environmental and public health concerns other than general education were able to use the model and produce reasonable results.

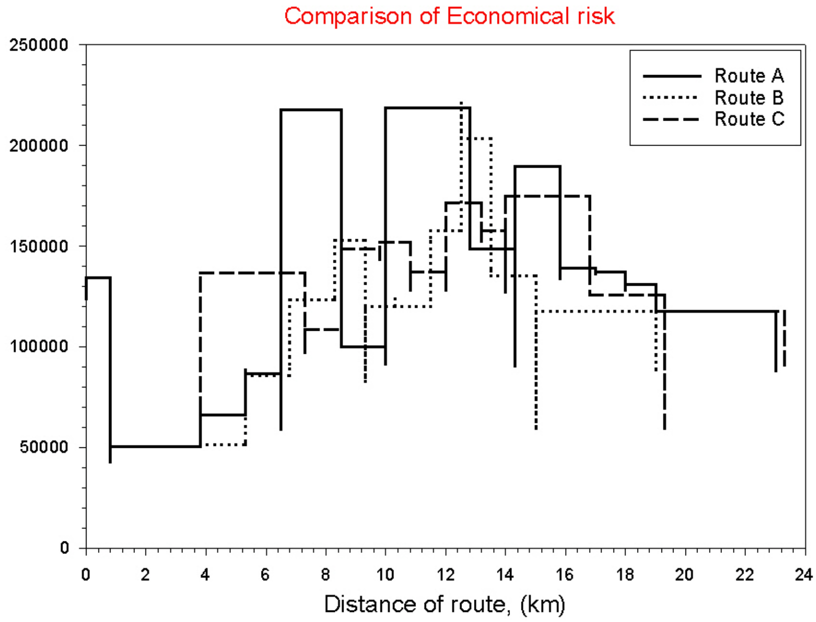

Figure 6. Ranking of risk to business activity and infrastructure (relative risk scores vs. distance).

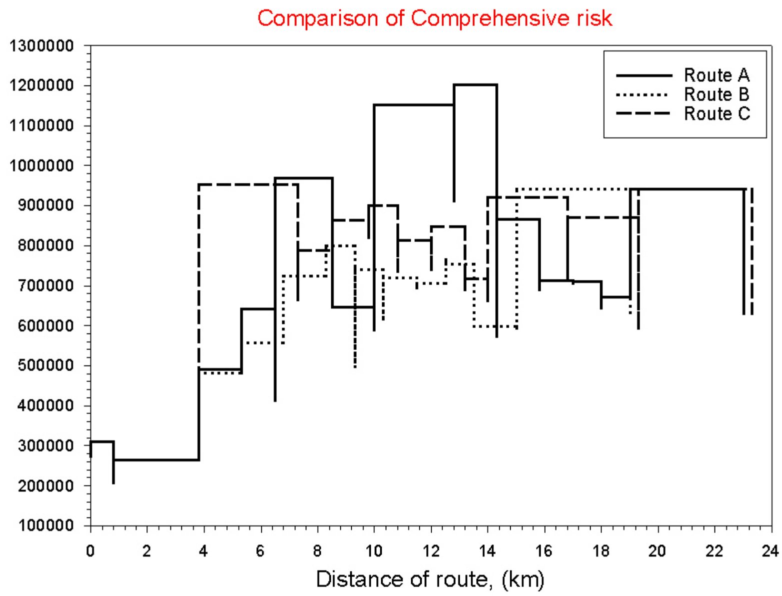

Figure 7. Comparison of Comprehensive risk (relative risk scores vs. distance).

8. Summary and conclusions

A simple and systematic system for urban goods transport analysis using a risk-based approach has been developed. The development of the system was based on systematically translating the risk assessment model used in the public health area into a system that can be used to compare risk along alternative routes. Risk assessment in the system was based on relevant indicators relating to traffic characteristics, route conditions, characteristics of the surrounding physical environment, and characteristics of transported material. The system considers risk to human and environmental health in addition to risk to business activity and infrastructure. The system relies on ranking and weighting the relevant factors relative to each other and allows integration of expert, public and special interest values. As with all risk assessment systems, the results are ranks reflecting probabilities not certainties and the quality of the results are highly dependent on the quality and understanding of the data and assumptions involved.

The assessment system can be used by decision makers and professionals involved in managing urban goods transport. The framework and model present a serious and significant efforts that can be used by researchers and practicing professionals as a starting point for further and continued development.

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