GIS Risk-Based Routes for Hazardous Shipments by Roads

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***Abstract*—Hazardous materials (HAZMATs) are products that pose risk to health, property, and safety. Because of its concentration, quantity, infectious or physical characteristics. Such material can cause significant health problems when released or spilled. Given all kinds of risks to public health caused by hazardous material, transporting these materials is a major concern for the public, authorities, institutions, and professionals. The risk associated with HAZMAT routing and its possibility of release makes it different from the conventional vehicle routing method. The main goal of this paper is to calculate the traditional risk to find the least risky routes for transporting HAZMAT between an origin-destination pair. This is accomplished through two major steps: (1) identifying and computing HAZMAT risk using traditional risk method on a segment-by-segment basis, and (2) finding the least-risky HAZMAT routes using shortest path algorithm in a GIS environment. In this paper, the traditional risk is assumed to be the product of the dose and the population exposed. Moreover, the segment risk is defined as the product of the incident probability and the population exposed, which can be used to obtain the HAZMAT risk along a route. This risk model, often termed as "traditional risk" measure, which has been used in numerous HAZMAT routing studies that are mentioned later in this paper.**

***Index Terms*—Traditional risk, GIS, HAZMAT, origin-destination, routes**

I. Introduction

HAZMATs transportation by roads is of great concern to any community because of the risks associated with transporting these materials. Community concerns are always related to accidents, noise, pollution quality of life, and property value. In terms of transporting HAZMAT, technical experts are not always trusted by the community to provide complete information about the level of associated risk. Although HAZMAT is transported safely throughout any city daily, people remain concerned about any potential release of HAZMATs and the direct or indirect consequences to health and environment.

Many researchers proposed to use risk analysis to find HAZMAT routes. Some of them calculated the minimum population exposed to risk, the minimum societal risk and minimum accident probability without using GIS [1]-[4]. Other researchers used GIS to calculate the minimum risk [5]-[10]. As have been seen in literature, HAZMAT routing is typically performed using traditional risk method and shortest path algorithm. A widely-used definition of risk is the product of the probability of an incident and its associated consequence. The consequences can range from fatalities to infrastructure and environmental damages. Therefore, risk is typically calculated based on exposed population that could be endangered from HAZMAT accident or release. However, HAZMAT routing is typically performed using traditional risk calculation.

All models presented in the literature performed routing based on traditional risk calculation. Although all researchers used different travel impedances, yet still the minimum risk was the utmost travel impedance that has been applied. Furthermore, very few applied the methodology on a segment-by-segment basis as [10].

Just to verify and differentiate between the study that was done by [10] and this paper, they developed a study to provide a comprehensive risk-based framework of vehicle routing to account for various objectives representing different perspectives. The objectives were: travel distance, delay risk, travel cost, accident risk, vehicle CO emissions risk, vehicle noise emissions risk and greenhouse gas (Co_2) risk. First, the mentioned objectives were calculated using the comprehensive risk-based approach which incorporates three main variables: dose, response factor and exposed population. Equation (1) shows the risk model used:

$$v\,(k) = \sum_{i=1}^{n} (r_i\,(k))^{-w_i} \qquad (1)$$

where:

v(k) = comprehensive total risk

ri(k) = risk associated with objective i

wi = importance weight corresponding with ri(k)

Next, the analytical hierarchy process was used to find the relative importance of each objective to the problem. After that, the individual risk-based objectives are

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combined in a single measure (i.e., combined risk). Then, the individual objectives, in addition to the combined risk, were defined as travel impedances to start the routing analysis in GIS. The proposed methodology was applied to City of Sharjah roadway network. The results were optimal routes for a defined origin-destination pairs, taking into consideration each risk-based objective individually in addition to the risk as travel impedances. This paper summarizes the work completed to find best routes for transporting HAZMAT in the City of Sharjah as a case study using risk-based analysis implemented in a GIS environment.

II. Materials and Method

To build a model that can find the best HAZMAT routes for a roadway network, the required data must be first prepared and then input to the system. After that, the risk is calculated for each roadway segment using the traditional method for calculating risk. Then, the best routes are found using a shortest path algorithm implemented in a GIS environment. A graphical representation of the proposed methodology to find the best HAZMAT routes is shown in Fig. 1.

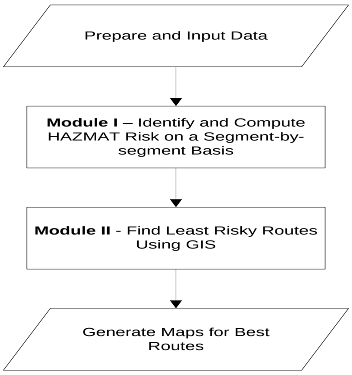

Figure 1. Methodology framework

There are two types of input data that must be collected. The first input data is the roadway network data including: segment length (kilometers), traffic volume (vehicle/hour), truck accident rate, and probability of HAZMAT release. The second input data is the population data which is used to calculate the number of people exposed to HAZMAT risk. It is worth mentioning that all data preparation were performed in a GIS environment to produce the end results in an implementable format. Preparing the roadway network data in GIS proved to be challenging because conducting routing analysis in GIS requires a special type of topological linear network data, which allows for traffic or any other commodity to flow on the network, especially enabling vehicles to make turns at intersections (nodes). If roadway segments, links or edges, are not digitized properly, errors will appear when attempting to use the shortest path algorithm in the GIS. Most of these errors occur as a result of inaccurate digitizing of the data in the original CAD file. Therefore to get accurate results, it is very important to fix such errors if they exist in the roadway network.

To demonstrate the applicability and accuracy of the proposed model, it was used to select the best HAZMAT route for the city of Sharjah roadway network, UAE. Most of the roadway network data were brought from Sharjah Road and Transport Authority, while the population data were obtained from Sharjah Department of Planning. However, some other required data were not available such as: truck accident rates and probability of HAZMAT release. So, a random variable function was generated to estimate them. Based on the literature, the truck accident rate was assumed to be in the range of 0.43x10-6 - 2.5x10-6 and the probability of release was assumed to be in the range of 6.2x0-3 - 9.0x10-3. Fig. 2 demonstrates the traditional risk methodology that was applied in this study.

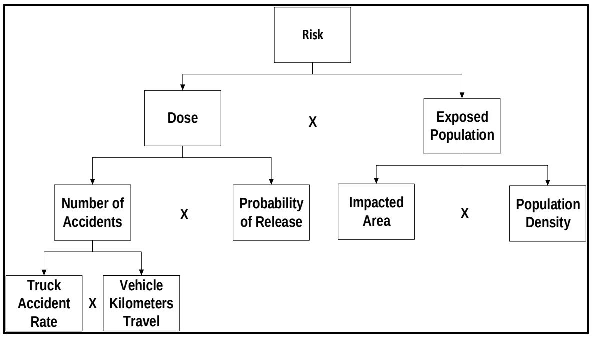

Figure 2. Traditional risk components

The data in Fig. 3 and Fig. 4 show the roadway network and the population blocks respectively for the City of Sharjah, UAE.

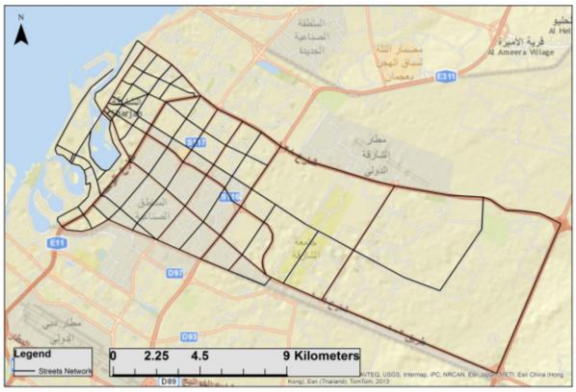

Figure 3. Roadway network for the emirate of Sharjah

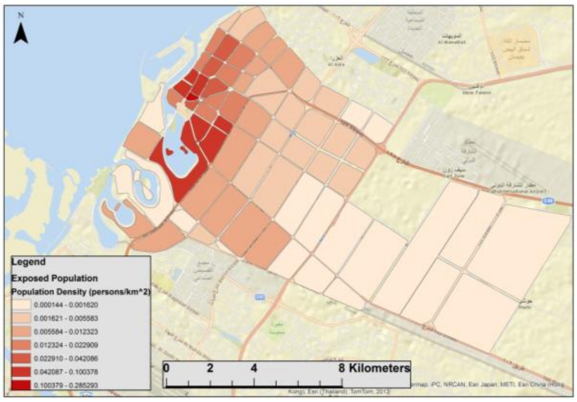

Figure 4. Population blocks for the emirate of Sharjah

The traditional risk in numerous HAZMAT routing studies such as [11]-[9] was calculated by using equation (1). Dose is defined as the quantity of risk causing agent, which is the accident that happens because of the release of HAZMAT. It can be calculated by using equation (3). On the other hand, the probability of HAZMAT release is defined as the probability of an incident involving a vehicle carrying HAZMAT and the release of a HAZMAT [9]. In the case study, it was assumed as a random number that varies from 6.2*10-3 to 9.0*10-3 [8].

$$Risk = Dose \times Exposed\ Population \quad (2)$$

$$Dose = Number\ of\ Accidents * Probability\ of\ Release \quad (3)$$

The number of accidents on a roadway segment was estimated by using equation (4).

$$Number\ of\ Accidents = Truck\ Accident\ Rate * Vehicle\ Kilometer\ of\ Travel\ (VKT) \quad (4)$$

The exposed population (EP) is an estimate of the population that is influenced by the consequences of general movement, accidents and the release of HAZMAT. The exposed population is assumed to be the multiplication of the population density and the impacted area as shown in equation (5).

$$EP = Population\ Density * Impacted\ Area \quad (5)$$

In order to be able to calculate the exposed population, the population density and the impacted area must be first determined. In the case study, the impacted area was chosen for one type of HAZMAT (which is flammable liquid), and was assumed to be a flammable liquid with an impact area = 0.5 mile [7]. The exposed population was obtained by calculating the population density in each population block as represented in Fig. 5. Then, a road buffer of 0.5 miles was created along each road segment using the buffer tool. After that, the resulted buffers were intersected with the population blocks in order to define the affected population, as seen in Figure 5. Each buffer segment can intersect with more than one population block. The highlighted area is a part of each population block, such that the line segment will take attributes from the four population blocks; for that, the average population density and the average impacted area is determined.

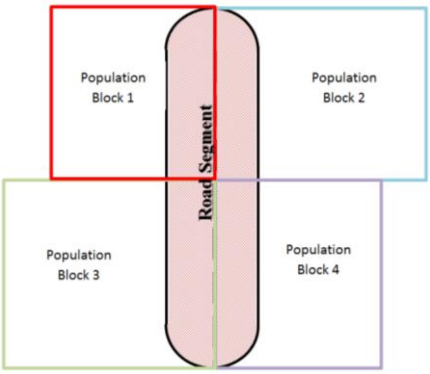

Figure 5. Representation of road segment buffer and the surrounding population blocks

Thus, the result of the intersection is pieces of semi-circles that must be summed up as one polygon for each population block by using the dissolve tool in GIS. The data in Fig. 6 show the results of the dissolve for the case study. Finally, the population density and the area of road buffer are determined and joined together to calculate the exposed population.

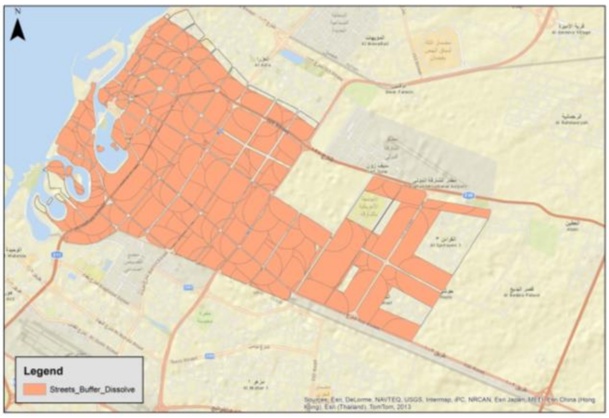

Figure 6. Map showing the result of dissolve

III. Results and Discussion

To demonstrate the applicability and accuracy of the proposed traditional risk-based method for HAZMAT routing, it was applied to find best routes (i.e., least risky) for a real-world roadway network of the City of Sharjah as a case study. While we can find best HAZMAT routes between any two points (origin-destination) in the network, we are only showing the results from two selected routes in the city as examples.

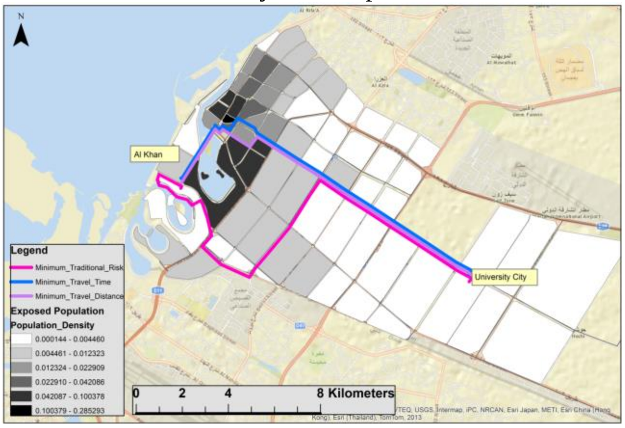

Figure 7. Origin-destination 1: From University City to Al Khan

The first example transports HAZMAT from University City to Al-Khan. Fig. 7 shows the three best routes obtained based on three impedances that are: minimum traditional risk, minimum travel time and minimum travel distance. Table I shows three resulting best routes for origin-destination example 1 from University City to Al Khan using the following three performance measures: route length, travel time, and traditional risk. As can be seen, route 1 (which is the minimum traditional risk route) has the least risk among the three routes with a value of 35.1; route 2 has the least travel time with 763 seconds; whereas route 3 as the least travel distance with 15.5 Km. It is hard to compare the three shown routes, since each route depends on a different criterion. But, one can easily see in Fig. 7 that the minimum risk route diverts away from the heavily populated areas.

TABLE I. PERFORMANCE MEASURES FOR ORIGIN-DESTINATION 1

Routes	Traditional Risk	Travel Time (sec)	Route Length (Km)
1. Minimum Traditional Risk	**35.1**	797	16.2
2. Minimum Travel Time	305	**763**	16.1
3. Minimum Travel Distance	75.1	768	**15.5**

The second example shows best routes to transport HAZMAT from Sharjah Airport to Khalid Port. Fig. 8 shows the three best routes obtained based on three impedances that are: minimum traditional risk, minimum travel time and minimum travel distance. Table II shows three resulting best routes for origin-destination example 2 from Sharjah Airport to Khalid Port using the following three performance measures: route length, travel time, and traditional risk. As can be seen, route 4 (which is the minimum traditional risk route) has the least risk among the three routes with a value of 87.4; route 5 has the least travel time with 769.6 seconds; whereas route 6 as the least travel distance with 15 Km. It is hard to compare the three shown routes, since each route depends on a different criterion. But, one can easily see in Fig. 8 that the minimum risk-based route diverts away from the heavily populated areas.

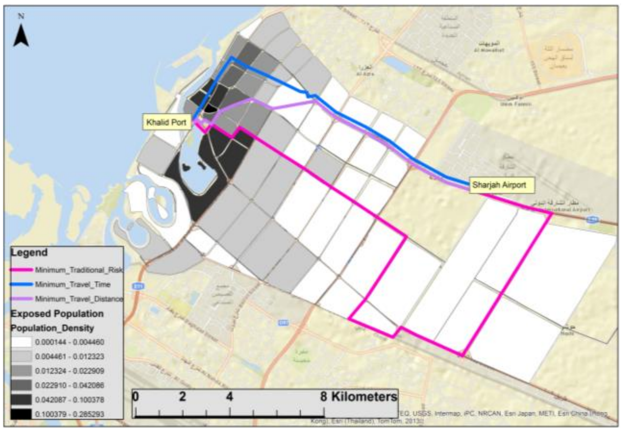

Figure 8. Origin-destination 2: From Sharjah Airport to Khalid Port

TABLE II. PERFORMANCE MEASURES FOR ORIGIN-DESTINATION 2

Routes	Traditional Risk	Travel Time (sec)	Route Length (km)
4. Minimum Traditional Risk	**87.4**	958.2	20.5
5. Minimum Travel Time	240.2	**769.6**	16.7
6. Minimum Travel Distance	199.8	722.8	**15**

IV. CONCLUSION

This paper summarizes a proposed approach to find the best routes (i.e., least risky) for transporting HAZMAT based on minimum risk. This was accomplished through two modules: identify and calculate HAZMAT risk on a segment-by-segment basis, and finding the least risky routes using GIS.

REFERENCES

[1] E. Erkut and V. Verter, "Modeling of transport risk for hazardous materials," *Institute for Operations research and the Management of Sciences*, pp. 624-642, 1997.

[2] F. Diernhofer, B. Kohl, and R. Horhan, "Risk assessment of transportation for the dangerous goods in austrian road tunnels," in *Proc. Fourth International Symposium on Tunnel Safety and Security*, Germany, 2010.

[3] D. Barilla, G. Leonardi, and A. Puglisi, "Risk assessment for hazardous materials transportation," *Applied Mathematical Sciences*, pp. 2295–2309, 2009.

[4] P. Leonelli, S. Bonvicini, and G. Spadoni, "New detailed numerical procedures for calculating risk measures in hazardous materials transportation," *Journal of Loss Prevention in the Process Industries*, pp. 507-515, 1999.

[5] K. El-Basyouny, D. Cheng, and L. C. Sayed, "A risk/cost-based algorithm for the routing of dangerous goods," in *Proc. Annual Conference of the Transportation Association of Canada*, Vancouver, British Columbia, 2009.

[6] V. Verter and B. Y. Kara, "A GIS-based framework for hazardous materials transport risk assessment," *Applied Mathematical Sciences*, pp. 2295–2309, 2001.

[7] R. Ak and B. Bozkaya, "A proposed risk model and a gis framework for hazardous materials transportation," Istanbul Technical University, Faculty of Management, Department of Industrial Engineering, Macka, Istanbul, 2008.

[8] Rahman and Lownes, "Risk assessment of hazardous materials transportation routes" *Transportation Research Board*, 2014.

[9] Y. Sun, "Risk-Based framework for freight movement analysis," Master thesis, Queensland University of Technology, Australia, 2002.

[10] Sahnoon, "Multi-Objective comprehensive risk-based vehicle routing analysis framework - Sharjah city as a case study," Master's thesis, University of Sharjah, UAE, 2014.

[11] E. Erkut and V. Verter, "Modeling of transport risk for hazardous materials," *Operations Research*, pp. 625–642, 1998.

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