Equity and Social Acceptability in Multiple Hazardous Materials Routing through Urban Areas

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Extended abstract

Objectives and motivation

The transportation of potentially harmful products has attracted the attention of scientists, authorities and general public from a long time ago. However, recent events, such as the urban densification and homeland security threats have brought this topic to a new level of awareness imposing an urgent pressure over all the relevant actors to guarantee a safe and fair transportation of these products while at the same time keeping it cost at a minimum. The topic of hazardous materials (HAZMAT) routing has been extensively treated in the specialized literature; however, the main focus has been the transportation of one type of merchandise from an origin to a destination through an optimal route. The latter approach produces a socially beneficial solution only when a single shipment is to be sent. However, if the optimal route were used on a periodic basis, people living in the surrounding areas become more exposed to the risks than the rest of the population, even though the total social risk may be at a minimum level. Then, the issue of social justice or equity on the risks borne by different segments of the population become an important part of the routing problem, as a new restriction: to guarantee that none of the population segments are exposed to a risk higher than a given threshold. The problem becomes more complex as more than one HAZMAT is being transported on a network because different products impose different risks on the population and the total risk will be a compounded effect. Thus, the problem to be solved in this article is that of finding a set of routes in a transportation network, that allow the movement of several types of HAZMAT on a regular periodic basis, without exposing any part of the population to a risk level higher than a predefined threshold.

The main safety concerns for HAZMAT transportation are accidents that cause multiple fatalities. That scenario typically occurs when a vehicle transporting HAZMAT, gets involved in an accident spilling out its material over densely populated areas. Accordingly, one of the main goals in the route choice process is to reduce the probability of an accident with fatalities. However, this is not the only objective to pursue, especially when multiple shipments of different HAZMAT take place over a highly populated area. In this context, parts of the population might be exposed to a variety of risks depending on the properties of the HAZMAT to be transported. Therefore, reducing the total risk as well as the consequence after an accident seems to be more appropriate.

General description

Risk-Assessment for HAZMAT Transportation

Even though risk is accepted as a central issue in HAZMAT transportation, there is no agreement between researchers on how to incorporate it into a modeling framework. However, researchers agree on the close relationship between risk and probability and consequence associated to an undesirable event. Even though there are a high number of undesirable consequences (such as environmental damage, economic losses or injuries), many risk assessment methods focus on fatalities due to a HAZMAT release. Certainly, the latter approach simplifies the risk assessment process but its final result could be far from the actual consequences inherent to a potentially dangerous activity. Moreover, the sole valuation of risk as a number of fatalities due to an incident is extremely difficult to assess in most practical cases due to the fact that the direct and indirect impacts of a HAZMAT release is not well known and most of the time, dependent on unknown conditions. Fortunately, for many strategic decisions related to HAZMAT management, a comparison of relative risk choices is more adequate than the absolute risk quantification. Hence, the concept of risk is understood here as the relative magnitude of the potential damage that a HAZMAT may cause (rather than its absolute value).

Estimation of the Consequences

The consequences associated to a specific HAZMAT spill are measured in terms of the potential damage (e.g. fatalities, morbidity) that an incident may cause. This magnitude is evaluated using the concept of λ-neighborhood (Batta and Chiu, 1988), which establishes the effective dispersion radius that a spill may reach. Erkut and Verter (1995) and, Erkut and Verter (1998) show that this is a necessary simplification due to available data limitations. The area delimited by the λ radius defines the Area of Impact (AI) for a given substance.

Routing HAZMAT

Sherali et al. (1997) proposed a model that allows considering low probability high consequence events for HAZMAT routing. To achieve this goal, the model selects a unique path to service the HAZMAT shipment between an O-D pair. That model will be referred to as the single product single shipment (SPSS) HAZMAT routing problem. Then, if various shipments per unit of time were required, the procedure would still identify a single optimal route for the whole group of shipments. Intuitively, if f is the flow of HAZMAT per unit of
time, Sherali’s solution would generate a risk exposure for the surrounding population, \( f \) times higher than that of the rest of the network. Hence, this method is not directly applicable to multiple shipments on an urban transportation network because it does not produce a socially fair (equitable) distribution of the risk over that network. We propose an extension of the SPSS model including shipments for different categories of HAZMAT within the objective function in a multi-product network model incorporating the diversity and heterogeneity found in urban population densities.

Population Acceptance and Equity in the Risk Distribution

A risk distribution technique found in the literature is the selection of multiple routes to avoid overexposing a single path. However, the standard formulation does not consider either multiple products or the potentially exposed population (PPE) to the system’s risk. We assume that the urban transportation network can be divided into \( K \) zones, and that every person is uniformly exposed to the risks generated by the HAZMAT transportation. Therefore, a socially desired outcome is to find a set of constraints that ensure that when several types of HAZMAT are periodically moved on a given transportation network, the risk level on the PPE in every zone does not exceed a predetermined threshold, named zonal acceptability (\( A_k \)). \( A_k \) may vary among zones and it considers not only the risk imposed by the HAZMAT shipments but all kinds of risks that a given zone may be exposed to. Indeed, in actual urban settings, the population is exposed to several types of risks and the distribution of the base-line risk is not necessarily homogeneous among the zones. Thus, the decision maker must consider the level of risk at which each zone is exposed before establishing the acceptability for the HAZMAT transportation; in cases where the base-line risk is the same across the study area, the zonal acceptability should be equivalent among zones.

In addition, the urban transportation network must usually accommodate the routing of more than a single HAZMAT. Consequently, This article presents a generalization and extension of the model posed by Sherali et al., (1997) and is aimed to solve the problem of finding a set of routes that minimize the conditional expectation of the consequence of transporting several types of HAZMAT given that a catastrophic accident occurs, ensuring that the probability of an accident and the risk associated to any route are lower than given thresholds, and none of the populated zones in the city is subjected to unacceptable levels of risk. This problem is formulated as a multi-product multi-shipment HAZMAT routing problem with equity constraints.

Results and conclusions

The proposed methodology was theoretically developed and also implemented in Santiago, Chile. This case allows us to compare the performance and results between the standard approach (in this case represented by the SPSS) and the proposed model, showing the contribution that this methodology could have in actual scenarios, especially in large or highly populated cities.

References


Keywords: HAZMAT; Routing; Urban Transportation; Risk; Equity