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TRANSPORT RISK ASSESSMENT OF THE DAILY RAIL SHIPMENTS OF PETROLEUM PRODUCTS ACROSS MONTREAL

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Abstract

Hazardous materials are potentially harmful to people and environment due to their toxic ingredients. Although a significant portion of dangerous goods transportation is via railroads, prevailing studies on dangerous goods transport focus on highway shipments. The differentiating features of trains, notably volume and nature of cargo, need to be incorporated in assessment of the associated transport risk. We focus on hazardous materials that are airborne upon an accidental release into the environment. Each railcar is a potential source of release, and hence risk assessment of trains requires representation of multiple release sources in the model. We report on implementation of a novel approach for assessment of the population exposure associated with "Ultra-train" that passes through the city of Montreal everyday.

Keywords: Hazardous materials; Railroad shipments; Risk assessment; Gaussian plume model
Topic Area: C2-SIG3 Safety Analysis and Policy

1. Introduction

In industrial societies vast amounts of hazardous materials (hazmats) are being shipped from their points of origin, such as refineries and chemical plants, to their points of consumption, such as manufacturing facilities, gas stations and homes. For example, the daily number of dangerous goods shipments in the U.S. through roads, railways, pipelines, waterways and air amounts to well over 800,000 (U.S Department of Transportation, 1998). Mitigation of the public and environmental risks associated with these shipments has become a popular concern. Prevailing literature reviews show that an overwhelming majority of the research on hazmat transportation focuses on road shipments (Erkut and Verter, 1995). Although trucking companies do carry a larger share of dangerous goods shipments in many countries, railroad shipments can easily reach comparable levels. In Canada, for example, 48 million tons of hazardous freight was carried via rail while 64 million tons was shipped via trucks in 2000. Consequently, there is a need for development of risk assessment methodologies that incorporate the specific nature of railroad shipments.

There are a number of factors that differentiate rail transport from truck shipments. A train usually carries non-hazardous and hazardous cargo together, whereas these two types of cargo are almost never mixed in a truck shipment. A rail tank-car has roughly three times the capacity of a truck-tanker (80 tons and 25-30 tons respectively) and the number of hazmat railcars varies significantly among different trains. The resulting variability in the total amount of hazardous cargo needs to be taken into account in assessing the transport risk associated with trains. In the event of an accident more than one railcar can be ruptured simultaneously or a fire in one of the railcars can easily lead to a larger fire involving multiple railcars.

Therefore, train risk assessment models need to represent multiple sources of release in estimating the potential undesirable consequences. Empirical evidence suggests that trains have lower accident rates than trucks (Saccomanno et al., 1990). Train accidents, however, can have much worse consequences due to the higher amounts of hazmats involved and the interaction between railcars. A well-known example is the 1979 accident in Mississauga, Ontario, where a train carrying toxic chemicals was derailed and chlorine leaking from damaged tank cars forced the evacuation of 200,000 people (Swoveland, 1987).

Traditionally, the *impact area* of an incident is assumed to be a circle centered at the incident location and it is called the danger circle (Batta and Chiu, 1988). The radius of a danger circle depends on the type of hazmat being shipped. For example, according to the North American Emergency Response Handbook (2000), 800 meters around a fire that involves a chlorine tank, railcar or tank-truck must be isolated and evacuated. The implicit assumption is that only the people within the pre-defined *threshold distance* from the incident site are exposed to hazmat transport risk It is possible to consider the hazmat shipment over a transport link as the movement of the danger circle along that link. This movement carves out a band (on both sides of the link) that is called the exposure zone (ReVelle et al., 1991). Although this fixed bandwidth approach is practical for initial emergency response, it ignores the impact of released hazmat volume and weather conditions in determining the possible undesirable consequences. Thus, the traditional approach can grossly underestimate transport risk, particularly in the case of trains.

Although a large number of researchers studied railroad transportation (for a comprehensive survey, see Cordeau et al., 1998), the literature on the use of trains for dangerous goods shipments is sparse. Early work on railroad shipments focused on the impact of spills within one mile around the accident site. Analyzing past data on train derailments, Glickman and Rosenfield (1984) derived and evaluated three forms of risk. These are probability of the number of fatalities in a single accident, probability of the total number of fatalities from all the accidents in a year, and frequency of accidents which result in any given number of fatalities. The trade-off between the societal and individual risks of hazmat shipments is addressed in Saccomanno and Shortreed (1993). More recent work focused on the comparison of rail and road shipments in terms of transport risk. Glickman (1988) concluded that the accident rate for significant spills (when release quantities exceed 5 gallons or 40 pounds) is higher for for-hire truck tankers compared to rail tank cars, whereas rail tank cars are more prone to small spills. Saccomanno et al. (1990) pointed out that differing volumes complicate comparison between the two transport modes, and showed that the safer mode varies with the hazmat being shipped.

The remainder of this paper is organized as follows: Section 2 provides an overview of the most relevant literature. Section 3 reports on an application of the Verma and Verter (2003) methodology in the province of Quebec, Canada. Section 4 provides some directions for future research.

2. Review of the most relevant literature

In this paper, we focus on railroad transportation of petroleum products that become airborne after an accidental release. In contrast with incidents where undesirable consequences are confined to the vicinity of accident site, airborne contaminants can travel long distances due to wind and expose large areas to health and environmental risks. This section presents a brief summary of the prevailing work that is most relevant.

Patel and Horowitz (1990) were the first to use the Gaussian plume model, coupled with a geographical information system (GIS), for hazmat transport risk assessment. In an effort to develop closed-form expressions, they assumed that dispersion parameters are equal to one. They developed a numerical method to determine the minimum risk path under four scenarios: specific wind direction, uniform average wind direction, maximum concentration wind direction and wind-rose averaged wind directions and speeds. Patel and Horowitz (1990) represented risk as the total expected contaminant concentration due to a potential spill. Zhang et al. (2000) modeled the probability of an undesirable consequence as a function of the concentration level, and used the traditional expected consequence representation of transport risk. They adopted a raster GIS framework that approximates the plane with a set of discrete points i.e., pixels. This enabled the authors to compute the concentrate levels without having to make the linearity assumption as in (1990) that essentially ignores atmospheric stability conditions. The method proposed in (2000), however, assumes a pre-specified wind direction and speed.

In a recent paper, Verma and Verter (2003) also used the Gaussian plume model in estimating spatial distribution of the toxic concentration level. Concentration increases with release rate of hazmat, whereas it decreases with distance from the accident site and wind speed. At a given distance from a release source, the maximum concentration is observed at the downwind location. Verma and Verter (2003) used the Immediately Dangerous to Life and Health (IDLH) concentrate levels of the hazmat being shipped in determining the threshold distances for fatality and injuries. Thus, in the model, the impact area around the accident site depends on the type and volume of hazmat released. Verma and Verter (2003) adopted a worst-case approach to risk by assuming least favorable weather conditions and focusing on maximum concentrate levels. The model captures the multiple release source nature of train accidents via a novel railcar referencing procedure. Since exact calculation of transport risk associated with railroad shipments proves to be quite cumbersome, Verma and Verter (2003) also present an approximation procedure that is effective and robust to train make-up.

3. Assessment of the "Ultra-train" shipments

In this section, we present an application of the Verma and Verter (2003) methodology in the province of Quebec, Canada. Everyday, CN (Canadian National) runs a train from Ultramar's refinery near Quebec City to its terminal in Montreal. This 68 tank-car train, which CN calls the "Ultra-train" is devoted to finished petroleum products such as, gasoline, diesel, jet fuel and propane. Ultra-train uses the CN main-line, which is the southern route in Figure 1. The public is sensitized to the Ultra-train shipments due to a 1999 accident near Mont-Saint-Hilaire, that killed two CN employees. A popular newspaper pointed out that if the derailment occurred in a residential area, rather than an industrial zone, its impact could have been much worse. Consequently, there is considerable concern with the circuitous nature of the current route in the city of Montreal, which is depicted in Figure 2.

According to a report commissioned by the U.S. Environmental Protection Agency, bulk evaporation is typically quite high for refined petroleum products e.g., 90 to 100 percent for gasoline. The report also suggests that these products can be modeled as neutrally buoyant gasses, although their vapors are heavier than air. The content of Ultra-train varies daily, and the information regarding its cargo is not publicly available. In order to arrive at a conservative estimate of population exposure, we model the entire cargo as a propane shipment. Propane is shipped as a liquefied gas, which becomes airborne immediately after an accidental release.

Gasoline, for example, is initially released as a liquid, which results in a spill, and then evaporates gradually. The capacity of each tank-car is 80 tons.

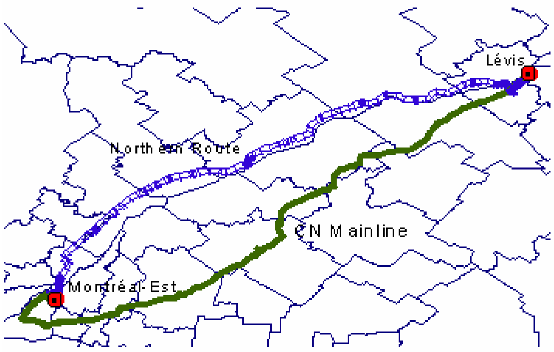

Figure 1 Ultra-train routes through Quebec

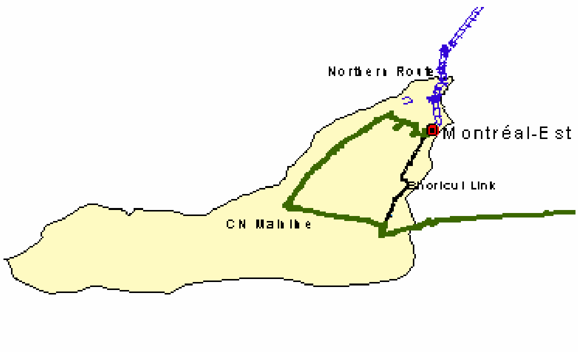

Figure 2: Ultra-train routes through Montreal

The aggregate IDLH levels for propane exposure are 4,200,000 ppm and 600,000 ppm for severe and non-severe consequences, respectively. Using Verma and Verter (2003) model, the fatality threshold distance for the Ultra-train is 2 kilometers, whereas people within 7.7 kilometers of the railroad are exposed to injury risk (CN uses a single threshold distance of 800 meters in their risk assessment). We use ArcView, a popular Geographical Information System, in generating the corresponding exposure zones around the CN main-line. Then, we overlay these zones on the population centers (i.e., the polygons in Figure 1) and identify the intersection areas. The total number of people in the severe zone is 492,195, whereas the population within the non-sever zone is 986,206. In total, Ultra-train exposes about 1.5 million people to varying degrees of transport risk.

During our analysis of the existing railroad network, we identified two alternative routes for Ultra-Train. The “shortcut link” allows for a detour from the CN main-line via a north turn upon entering the island of Montreal (see Figure 2), which results in a 16 kilometer reduction in inner-city travel. The “northern route”, however, avoids the island of Montreal almost entirely by entering from northeast (see Figure 1). Using Verma and Verter (2003) model, we also assessed the transport risk associated with these two routes. If the shortcut link is used, the number of people in the severe zone will reduce 36% and there will be a 24% reduction in the exposure to non-severe consequences. The use of northern route, however, will result in a 57 % reduction in both fatality and injury exposures. The northern route is only 3.4% longer than the current route, whereas the shortcut link provides a 5.6% reduction in travel distance. The primary reason for CN to continue using its main-line, which has much higher population exposure, is track quality. The company is deterred from using either of the two alternate routes by the significant capital outlay required for track upgrades and installation of monitoring equipment.

The large amount of refined petroleum products shipped through the city of Montreal on a daily basis is a significant concern for the emergency response planners in Quebec. Our analysis shows that a reduction in the volume of hazmats will not pay off in term off the resulting decrease in the threshold distance. If the number of tank-cars in Ultra-train is halved, for example, the threshold distance of the current severe zone will decrease only 9%. In this case, CN will have to run two 34 tank-car trains daily in order to satisfy Ultramar's demand. Each shipment exposes 437,176 people to fatality risk, and hence total exposure in the severe zone will increase 78% due to the use of 34 tank-car trains. Due to the non-linearity of concentrate curve, the impact is less drastic within the non-severe zone: Threshold distance for injuries decreases 38%, which puts 619,099 people at injury risk and results in a 26% increase in exposure to non-severe consequences. It is interesting to note that emergency response planners are more concerned with the number of people within the exposure zone than the total exposure. Clearly, this amounts to ignoring the number of times an individual is exposed to a certain risk. A common response to hazmat incidents is evacuation of the impact area around the site of accidental release. Reducing the impact area of an accident, through decreasing the volume of hazmat involved, certainly makes emergency response planning easier. Therefore, emergency response planners in Quebec prefer any reduction in the length of Ultra-train despite the associated increase in population exposure.

4. Future research directions

There are a number of future research directions. First, the methodology can be extended to incorporate accident probabilities. This requires a solid understanding of how accident probability varies with train length. Since train accidents are very rare events, validation of such a probabilistic model against accident data constitutes a formidable challenge. Second, the development of a methodology to analyze the cost-risk trade off in the context of railroad shipments would be a significant contribution. This would certainly facilitate the negotiation between the railroad companies and regulators towards mitigating the public and environmental risks associated with trains. Finally, the increasing popularity of multimodal transportation calls for the development of an integrated risk assessment methodology that incorporates both railroad and highway shipments

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