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Environmental risk analysis of hazardous material rail transportation

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HIGHLIGHTS

- Comprehensive, nationwide risk assessment of hazardous material rail transportation.
- Application of a novel environmental (i.e. soil and groundwater) consequence model.
- Cleanup cost and total shipment distance are the most significant risk factors.
- Annual risk varies from $20,000 to $560,000 for different products.
- Provides information on the risk cost associated with specific product shipments.

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ABSTRACT

An important aspect of railroad environmental risk management involves tank car transportation of hazardous materials. This paper describes a quantitative, environmental risk analysis of rail transportation of a group of light, non-aqueous-phase liquid (LNAPL) chemicals commonly transported by rail in North America. The Hazardous Materials Transportation Environmental Consequence Model (HMTECM) was used in conjunction with a geographic information system (GIS) analysis of environmental characteristics to develop probabilistic estimates of exposure to different spill scenarios along the North American rail network. The risk analysis incorporated the estimated clean-up cost developed using the HMTECM, route-specific probability distributions of soil type and depth to groundwater, annual traffic volume, railcar accident rate, and tank car safety features, to estimate the nationwide annual risk of transporting each product. The annual risk per car-mile (car-km) and per ton-mile (ton-km) was also calculated to enable comparison between chemicals and to provide information on the risk cost associated with shipments of these products. The analysis and the methodology provide a quantitative approach that will enable more effective management of the environmental risk of transporting hazardous materials.

1. Introduction

An important aspect of railroad environmental risk management involves tank car transportation of hazardous materials. Initial work addressing environmental risk due to hazardous material rail transportation was presented by Barkan et al. [1]. They conducted a quantitative environmental risk analysis for the Association of American Railroads (AAR) using empirical environmental cleanup cost data from major railroads in the U.S. Anand and Barkan [2] developed geographical probability distributions of soil types and depths to groundwater along rail lines in the U.S. Subsequently, Anand [3] developed a risk analysis model that accounted for railroad accident probabilities, tank car safety performance, chemical characteristics and the variation of different soil types and depths to groundwater at the location of a spill.

Yoon et al. [4] developed a more comprehensive, quantitative screening model to assess light, non-aqueous-phase liquid (LNAPL) infiltration into soils, groundwater transport, and groundwater cleanup time. Hridaya [5] updated the Hazardous Materials Transportation Environmental Consequence Model (HMTECM) developed by Yoon et al. [4] to include a free product recovery module to simulate pumping extraction of low-solubility LNAPL

Abbreviations: AAR, Association of American Railroads; CONUS-SOIL, Conterminous United States multilayer soil characteristics dataset for regional climate and hydrology modeling; DOT, Department of Transportation; ERG, Emergency Response Guidebook; FRA, Federal Railroad Administration; GIS, geographic information system; HMTECM, Hazardous Materials Transportation Environmental Consequence Model; LNAPL, light, non-aqueous-phase liquid; NWIS, National Water Information System; PHMSA, Pipeline and Hazardous Materials Safety Administration; STB, Surface Transportation Board; TRAINII, TeleRail Automated Information Network; USGS, United States Geological Survey.

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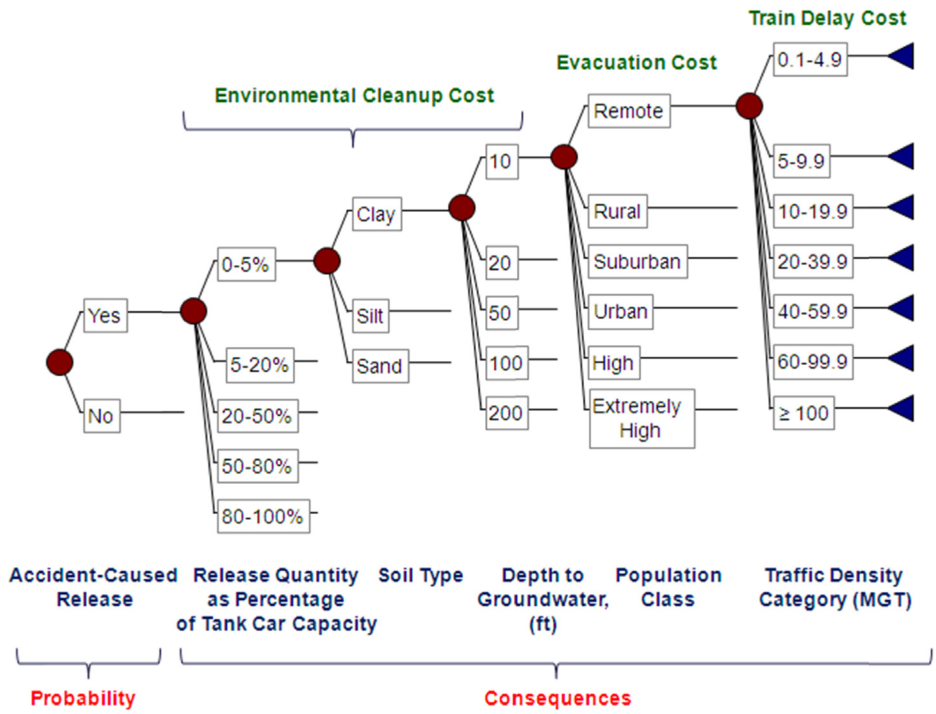

Fig. 1. Generic event tree summarizing risk analysis framework.

from the lens at the groundwater table, and Schaeffer et al. [6] conducted a series of validation and verification analyses of HMTECM.

In this paper, we used HMTECM to estimate the soil and groundwater cleanup costs. We extended the risk analysis model in Anand [2] by developing a more comprehensive groundwater geographic dataset and considered chemical-specific rail transportation routes to determine the exposure to different hydrogeological features along rail lines. We also considered the consequence costs related to potential exposure to human population and train delay. Accident-caused release rate was estimated based on the most common tank car specifications used to transport the set of LNAPLs under consideration, their total annual shipments, and train derailment accident rate. Resultant risk estimates are presented in terms of annual risk, and risk per car-mile (car-km) and per ton-mile (ton-km).

2. Risk analysis methodology

Risk in general can be defined as the product of the probability and the consequences of an event. In the context of railroad hazardous materials transportation, a simplified definition of risk is as follows:

$$R = \sum_{i} P_R \times P_{C_i} \times C_i \qquad (1)$$

where R, risk of transporting a hazardous material; P_R, probability or rate of accident-caused release; P_{C_i}, probability of a release impact i occurring; C_i, consequence level from a release impact i. i, release impacts to people, property, the environment and other risk receptors.

Fig. 1 shows a generic event tree summarizing the risk analysis framework used in this study. For simplicity, only one branch is expanded at each node. Each of the probability and consequence elements are described in more detail in the following sections.

3. Probability analysis

Accident-caused release rate from a tank car can be defined as follows:

$$P_R = P_{R|A} \times P_A \times M \times \frac{Cap}{Cap'} \qquad (2)$$

where P_R, tank car accident-caused release rate; $P_{R|A}$, conditional probability of a tank car release given the car is derailed in a Federal Railroad Administration (FRA) reportable accident; P_A, tank car derailment rate per car-mile; M, number of car miles; Cap, nominal gallon capacity of a baseline tank car; Cap', nominal gallon capacity of an alternate-design tank car.

3.1. Tank car conditional probability of release and capacity

The chemicals of interest are typically transported in general-purpose DOT 111A100W1 tank cars with 0.4375 in. (1.11 cm) head and shell thicknesses without top fittings protection. We assumed an inside tank diameter of 110.25 in. (2.81 m), and other product specific designs for the base case for each chemical in the analyses in the subsequent sections (Table 1). The set of chemicals represents the most commonly shipped pure LNAPL chemicals that can be analyzed using the HMTECM version used in this study. The conditional probability of release given a tank car is derailed in a mainline accident, $P_{R|A}$, was calculated using the statistical model in Treichel et al. [7]. Tank car payload capacity associated with the baseline designs were estimated using IlliTank, a tank car weight and sizing program [8]. For the base-case annual risk estimation in this study, the term Cap/Cap' is equal to 1.

3.2. Tank car derailment rate

Anderson and Barkan [9] developed estimates of Class 1 railroad mainline freight train and car accident rates based on the FRA safety statistics. In the nationwide risk analysis described here we used