Risk Analysis of Transporting Crude Oil by Rail: Methodology and Decision Support System

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ABSTRACT

In 2014, there were around 500,000 carloads of petroleum crude oil on the U.S. railroad network, an 80-fold increase since 2005. A spate of crude oil release incidents has attracted national attention to railroad transportation safety. This paper describes a practical probabilistic risk analysis (PRA) model to estimate the in-transit risk of transporting crude oil by rail in unit-trains on mainlines. The model accounts for 1) track segment specific characteristics, including segment length, FRA track class, method of operation, and annual traffic density; 2) train-specific characteristics such as train length, train speed, and tank car safety design; and 3) population density along each segment. The risk model estimates segment-specific risk that is measured by the expected number of affected persons. The model also estimates the average interval between release incidents. The model is implemented into a decision support tool that automates risk calculation, interpretation, and visualization. The methodology and implementation tool developed in this paper can be adapted to specific train configurations on any given railroad network. This research aims to provide methods and tools for optimal safety risk management of rail transport of crude oil and other hazardous materials.

1 INTRODUCTION

The United States is experiencing a boom in the production of petroleum crude oil from shale. Consequently, the rail transport of petroleum crude oil has increased dramatically. Since 2005, the volume of rail transport of crude oil has increased 80-fold, from around 6,000 carloads in 2005 to around 500,000 carloads in 2014 (*1*). Although over 99.99 percent of railroad crude oil shipments safely reached their destinations (*2*), a release incident may have potentially significant consequences. A notable example is the Lac-Mégantic crude oil train derailment in Canada in July 2013, which claimed 47 fatalities and resulted in thousands of evacuees and millions of dollars in damages (*3*). In order to effectively and efficiently manage the risk of rail transport of crude oil, an accurate and implementable risk management solution is useful for both private and public sectors.

2 RESEARCH OBJECTIVES AND SCOPE

The objective of this paper is to develop an implementable, practical risk analysis model for rail transport of petroleum crude oil in unit trains on main tracks. A crude oil release incident, albeit at a relatively low probability, may cause considerable consequences, especially when an incident occurs in populated or environmentally sensitive areas. In this paper, the risk model estimates the probability of a train-derailment-caused crude oil unit-train release incident as well as the consequences of that release (e.g., measured by the affected population in the evacuation area). The specific objectives of this paper include:

1) To develop a probabilistic risk analysis (PRA) model that will quantify the likelihood and consequence of a crude oil release incident, accounting for route-specific and train-specific characteristics;
2) To implement the risk analysis methodology into a geographical information system (GIS) based decision support tool that automates risk calculation, interpretation and visualization;
3) To propose future research directions and technical roadmaps for risk management of rail transport of crude oil and other hazardous materials

The paper begins with a comprehensive literature review, followed by model development and implementation. The paper thereafter introduces a decision support tool that calculates and visualizes location-specific crude oil release risk. Finally, the paper provides its principal findings and describes possible future research directions.

3 LITERATURE REVIEW

3.1 Event chain of a hazardous materials release

A train-accident-caused hazardous materials release results from a chain of events (Figure 1). A number of factors affects the occurrence of each event. The literature has discussed the effects of certain risk factors through context-specific risk models.

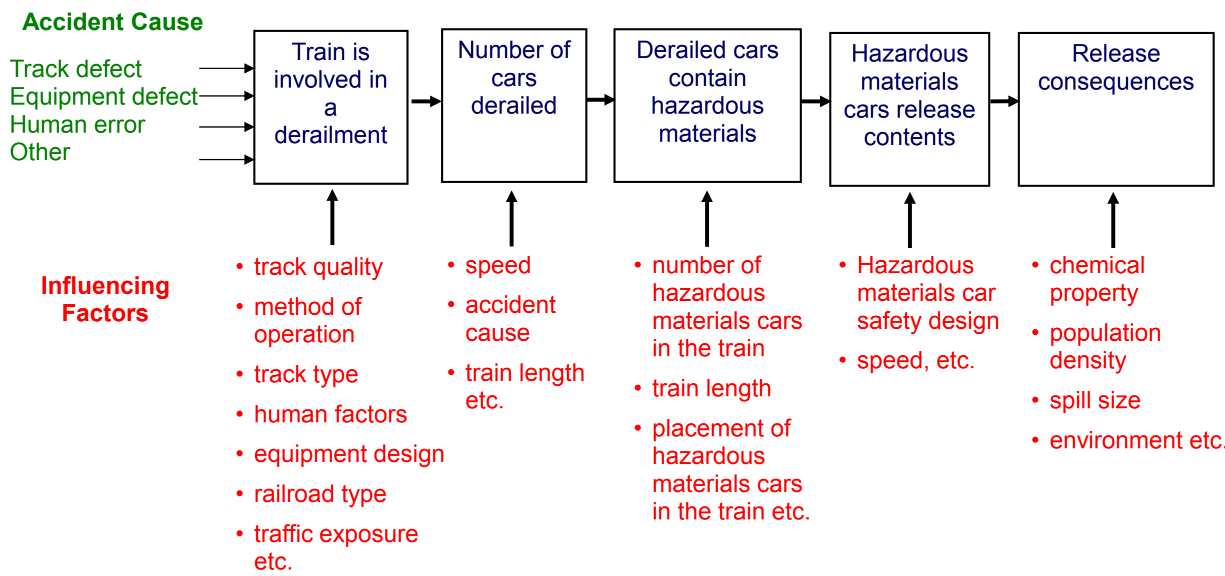

FIGURE 1 Event chain of a railroad hazardous materials release incident (*4*)

The literature focuses on five areas of risk factor research, including 1) train derailment rate; 2) the number of cars derailed; 3) the number of tank cars derailed; 4) the number of tank cars releasing contents; and 5) release consequences. Each of these are explained in detail in the following subsections.

1) Train derailment rate. Derailment is a common type of freight train accident in the U.S. (*5*). Most major hazardous materials releases occurred in train derailments (*6*). Train derailment rate, which is defined as the number of accidents normalized by traffic exposure, is a proxy for train derailment likelihood. Train derailment rate correlates with FRA track class (*7, 8*), the method of operation, and annual traffic density (*9*). The latest industry-wide study found that all three factors (FRA track class, method of operation, and traffic density) significantly affect train derailment rate (*9*).

2) Number of railcars derailed. The number of cars derailed is related to accident kinetic energy and has been used to measure train derailment severity (*6*). A number of studies have investigated the effects of train derailment severity factors, such as accident speed (*6, 10-13*); point of derailment (the position of the first car derailed) (*10, 11*); train length (*10, 11*); and accident cause (*5, 6, 8, 12*).

3) *Number of tank cars derailed*. If a train carries both tank cars and other types of cars, the probability that a tank car will derail depends on the amount and placement of tank cars in a train (*14*). Glickman et al. (*15*) estimated the number of tank cars derailed based on a hyper-geometric distribution assuming that tank cars were randomly placed throughout a train. Bagheri et al. (*14, 16, 17*) estimated the number of tank cars derailed given their positions in a train using a derailment profile approach. Liu et al. (*4*) considered different types of derailed tank cars using a multivariate hyper-geometric model. The derailment of a crude oil unit train would typically derail crude oil tank cars, except for those with only locomotives or buffer cars derailed (buffer cars separate locomotives and tank cars).

4) *Number of tank cars releasing contents.* The conditional probability of release (CPR) of a derailed tank car measures tank car safety performance. The CPR for a specific tank car depends on tank car design features (*18, 19*), derailment speed (*20*), and derailment severity (*21*).

5) Release consequences. The release consequence can be evaluated by several metrics, such as the number of casualties and evacuees, property damage, traffic delays, environmental impact, litigation, business loss, and other factors. The affected area is subject to many variables, such as chemical properties, quantity released, rate of release, meteorological conditions, and local terrain (*22*). The USDOT Emergency Response Guidebook (ERG) recommends that emergency responders determine initial isolation and protective action distances for specific chemicals and scenarios of release (*23*). According to the recommended evacuation distance, geographical information system (GIS) techniques were used to estimate the affected population (*24, 25*).

3.2 Risk modeling research

Some studies used a so-called "car-specific" model to calculate railroad transportation risk (*20, 26, 27*). This model uses the average tank car derailment rate, regardless of train-specific characteristics, such as train length or tank car positions in a train. The car-specific risk model is suited to a preliminary, high-level risk assessment in the absence of detailed train-related information. However, this model does not account for the probability of an incident involving the releases of multiple tank cars. To address the limitations of car-specific risk models, Bagheri et al. (*14, 16, 17*) developed a more sophisticated "train-specific" risk model which accounts for train length, derailment speed, accident cause, point of derailment, and tank car positions in a train. Their model assumes that all of the derailed tank cars have equal release probabilities. That work was later extended by Liu et al. (*4*) by incorporating heterogeneous release probabilities of different tank car safety designs.

Risk analysis models are often used to evaluate and compare risk mitigation strategies. The literature has largely focused on an individual risk reduction option, including infrastructure upgrade (*12*), rolling stock condition improvement (*28*), speed reduction (*20*), tank car safety design enhancement (*19*), routing (*27*), placement of tank cars in a train (*14, 16, 17, 29*), and emergency response (*26*). There is little research regarding the optimal integration of multiple risk reduction strategies, except studies by Lai et al. (*30*), which is based on a simplified car-specific risk model.

3.3 Knowledge gaps in the literature

Much crude oil is shipped in unit trains, which usually have at least 50 and sometimes more than 100 cars, consisting of a single commodity. A unit-train accident can potentially cause the derailment and release of a large number of tank cars. To date, there is limited research regarding an integrated practical crude-by-rail risk model that encompasses all principal risk factors and risk mitigation strategies. Furthermore, there are few decision support tools available to automate complex risk assessment and communication processes, thereby constraining the implementation of research in the practice. This research aims to narrow those knowledge gaps by developing a practical crude-by-rail risk analysis model based on up-to-date railroad risk research and safety statistics.

4 RISK ANALYSIS METHODOLOGY

This paper focuses on risk analysis of crude oil transported in unit trains. Ongoing effort is underway to adapt the current risk model to other train types. In this paper, the risk is defined as the expected consequence, measured by a product of the probability and consequence of a release incident (*27*):

$$R_i = P_i \times C_i \tag{1}$$

Where:
R_i = crude oil train release risk on the i^{th} segment per train shipment
P_i = probability of a crude oil release incident on the i^{th} segment per train shipment
C_i = consequence of a release incident on the i^{th} segment

Segment-specific release probability (P_i) is estimated as a product of train accident probability, and the conditional probability that the train accident results in at least one tank car releasing crude oil:

$$P_i = P_i(A)P_i(R \mid A) \tag{2}$$

Where,
$P_i(A)$ = train accident probability on the i^{th} segment per train shipment
$P_i(R|A)$ = probability that a derailed crude oil train causes at least one tank car releasing

Crude oil train accident probability, $P_i(A)$, can be estimated using the following equation (*31*):

$$P_i(A) = Z_i L_i \exp(-Z_i L_i) \approx Z_i L_i \qquad \text{(if } Z_i \text{ is sufficiently small)} \tag{3}$$

Where:
Z_i = train accident rate per mile
L_i = segment mileage

Assuming that there are D crude oil tank cars derailed in a train accident, the probability of at least one tank car releasing crude oil is estimated by a binomial distribution assuming that the release probabilities of different tank cars in the same train accident are statistically independent:

$$P_i(R \mid A) = 1 - (1 - CPR_i)^{D_i} \tag{4}$$

Where:
CPR_i = average conditional probability of release of a derailed tank car on the i^{th} segment
D_i = average number of crude oil tank cars derailed per accident on the i^{th} segment

Based on Equations (2) to (4), route-specific crude oil train release risk is expressed as:

$$R=\sum_{i=1}^{N}\left\{Z_iL_i[1-(1-CPR_i)^{D_i}]C_i\right\} \quad (5)$$

Where:
R = total route risk per train shipment
N = number of track segments on the route

The annual route risk is equal to a multiplication of the risk per train shipment (R) and annual number of trains on the route (denoted as Q). The model focuses on mainline risk, without an explicit consideration of the risk in yard (*32*). Although mainline train accidents account for a significant proportion of the risk, future research can include the risk in other sectors, thereby providing a system-level risk assessment.

In order to estimate mainline transportation risk, the following parameters are needed:

- Train accident rate (Z)
- Segment mileage (L)
- Conditional probability of release of a derailed crude oil tank car (CPR)
- Number of crude oil tank cars derailed per accident (D)
- Release consequence (C)

The following section leverages the latest train safety data to develop statistical estimators of those parameters. Where certain proprietary data are not available, the most relevant literature is used. Model users can update the results based on specific infrastructure, train, and operational information available to them.

5 PARAMETER ESTIMATION

5.1 Train accident rate, Z_i

The majority of hazardous materials release incidents occurred in train derailments (*6*). The latest freight train derailment rates were developed as a function of FRA track class, method of operation, and annual traffic density (*9*). That study was based on data from 2005 to 2009. In recognition of declining train derailment rates (*31*), a temporal adjustment factor is used to extrapolate future derailment rate. Liu found an average of 5.6 percent annual declining rate in Class I mainline freight train derailment rate from 2000 to 2014(*31*). Assuming that this trend continues, a statistical model can be used to estimate freight train derailment rate now and in the near future. The development of a three-factor derailment rate and a temporal adjustment factor have been detailed in (*9*) and (*31*) and thus are not repeated herein.

$$Z=\exp(0.9201-0.6649X_{trk}-0.3377X_{moo}-0.7524X_{den})(1-5.6\%)^{T_i-2009} \quad (6)$$

Where:
Z = estimated freight train derailment rate per billion gross ton-miles
X_{trk} = FRA track class (1 to 5)
X_{moo} = method of operation (1 for signaled track territory, 0 for non-signaled)
X_{den} = annual traffic density level (1 for ≥ 20 million gross tons (MGT), 0 for < 20 MGT)

T_i = year (for example, T_i is equal to 2014 for year 2014)

There is limited historical data to statistically evaluate crude oil train derailment rate by various factors. Hence, this research used the average derailment rate of all freight trains as a proxy for crude oil train derailment rate. The underlying assumption is that there is no statistical difference of derailment rate between hazardous materials trains and other types of trains. A similar assumption has been used in previous studies (8, *14*). Future research is needed to better understand crude oil train accident rate and its affecting factors.

5.2 Average number of crude oil tank cars derailed, D_i

The FRA Rail Equipment Accident (REA) database records the number of railcars derailed (both loaded and empty) and the total number of railcars in a train (*33*). Table 1 presents the average portion of railcars derailed per freight train derailment based on the data from 2000 to 2014.

TABLE 1 Average Portion of Railcars Derailed by Train Length and Speed, U.S. Class I Mainline FRA-Reportable Freight-Train Derailments, 2000 to 2014

Train Speed (mph)	Train Length (Total Number of Cars)	Number of Train Derailments	Average Portion of Railcars Derailed per Derailment
20-30	50-70	167	0.126
	71-90	253	0.093
	91-110	346	0.097
	111-130	260	0.081
31-40	50-70	105	0.159
	71-90	161	0.134
	91-110	187	0.117
	111-130	184	0.110
41-50	50-70	97	0.212
	71-90	169	0.149
	91-110	200	0.124
	111-130	193	0.132

For example, for train derailments occurring at speeds between 31 and 40 mph, and with 91 and 110 cars in length, an average of 11.7 percent of railcars in this train may derail. The use of Table 1 is illustrated as follows. If a 100-car crude oil unit train derails at 40 mph, an average of 11.7 percent of tank cars might derail. Within these parameters, around 12 tank cars are expected to derail (100×0.117). This categorical statistical analysis provides a high-level estimation of the number of tank cars derailed in a unit train. Depending on questions of interest, some other researchers develop more complex position-dependent railcar derailment probability models (*10, 11, 14, 16, 17*). Those models are useful for risk analysis of a manifest train shipment when specific tank car positions are known. Incorporation of position-dependent tank car derailment probability for risk analysis of manifest crude oil trains is the next step of this research.

5.3 The conditional probability of release of a derailed crude oil tank car, CPR_i

The Railway Supply Institute (RSI) and the Association of American Railroads (AAR) developed industry-wide tank car CPR statistics. The AAR published the average CPR estimate by tank car design (*34*) (Table 2). For example, if a non-jacketed 111A100W1 (7/16" tank thickness) derails, its release probability is 0.196. Given 100 cars of this type derailed, an average of approximately 20 tank cars are expected to release. By contrast, the release probability of a jacketed CPC 1232 car (7/16" tank thickness) is reduced to 0.046. The USDOT recently issued a final specification for the new tank car standard, which is DOT-117 (TC-117 in Canada) (*35*). Table 2 summarizes different tank car specifications and the corresponding CPR values.

TABLE 2 Tank Car Design Specifications and Mainline Conditional Probability of Release (*34*)

Tank Car Design	Head Thickness (inch)	Shell Thickness (inch)	Jacket	Head Shields	Top Fittings Protection	Conditional Probability of Release (CPR)*
Conventional, Non-Jacketed	0.4375	0.4375	No	None	No	0.196
Conventional, Jacketed	0.4375	0.4375	Yes	None	No	0.085
Non-Jacketed CPC 1232	0.5000	0.5000	No	Half Height	Yes	0.103
Jacketed CPC 1232	0.4375	0.4375	Yes	Full Height	Yes	0.046
DOT-117	0.5625	0.5625	Yes	Full Height	Yes	0.029

**The CPR of a tank car in Table 2 is for a release of more than 100 gallons*

If a unit train contains multiple types of crude oil tank cars with different CPRs, the weighted average CPR for the train can be estimated when tank cars are randomly distributed throughout a train:

$$CPR_{ave} = \frac{\sum_{k=1}^{K} CPR_k Q_k}{\sum_{k=1}^{K} Q_k} \quad (7)$$

Where:

CPR_{ave} = the average CPR for the train

CPR_k = the CPR for the k^{th} type of tank car

Q_k = the number of the k^{th} tank car in a train

K = total types of tank car

For example, if unit train has 70 jacketed CPC-1232 crude oil cars (7/16 ” tank thickness) (its CPR is 0.046) and 30 conventional jacketed cars (7/16 ” tank thickness) (its CPR is 0.085), the weighted average CPR for the train is (0.046×70+0.085×30)/(70+30) = 0.058. Note that the AAR published CPR statistics were based on 26 mph train derailment speed (*21*). This paper used a linear speed-dependent adjustment factor to extrapolate the CPRs at other speeds. This paper assumes that as the speed increases, the estimated CPR will increase by the same percentage based on a previous study (*20*). The RSI and AAR are anticipated to publish a new study that explicitly quantifies the effect of speed on the CPR. However, that study is not publicly available at the time of writing this paper. The upcoming tank car safety statistics can be used in a revised risk model in future research.

5.4 Release consequence, C_i

Population in the affected area was often used in previous studies (*36, 37*). The hazard exposure model in the U.S. DOT Emergency Response Guidebook (ERG) recommends a 0.5-mile-radius circle as the affected area for a fire caused by flammable hazardous materials releases. Once the affected area is determined, the number of people affected can be estimated by multiplying the size of the affected area by the average population density within the affected area.

6 RESEARCH IMPLEMENTATION

A GIS-based decision support system was developed to implement the risk analysis methodology described above. This tool, called Crude Oil by Rail Risk Analyzer (abbreviated as *CBR-Risk)*, has three major modules (Figure 2):

Input Module: The user provides crude oil route information including the origin, destination, and several en route stations. Where the actual proprietary crude oil route information is unavailable, the tool generates the shortest path to connect all of these locations by using Dijkstra's algorithm (*38*). Generally, the more en route stations that a user provides, the better the generated path could represent the actual crude oil route. In addition, the user also provides train-specific information, including the annual number of crude oil unit trains on a route, the amount of each type of crude oil tank cars in a train, and the tank car safety specifications. In addition to data privacy, certain information may not be available for some segments. In these cases, proper assumptions need to be made to conduct a preliminary risk analysis. The methodology can be modified in accordance with the best available information.

Calculation Module: Based on train- and route-specific inputs, the calculation module automates risk calculation, on both the segment level and the route level, using the methodology presented in section 3.

Output Module: The risk analysis results are displayed on a GIS interface. The “high risk” locations that cumulatively account for 80 percent of the total route risk are displayed. When the user clicks each segment, a pop-up table will display segment-specific risk information.

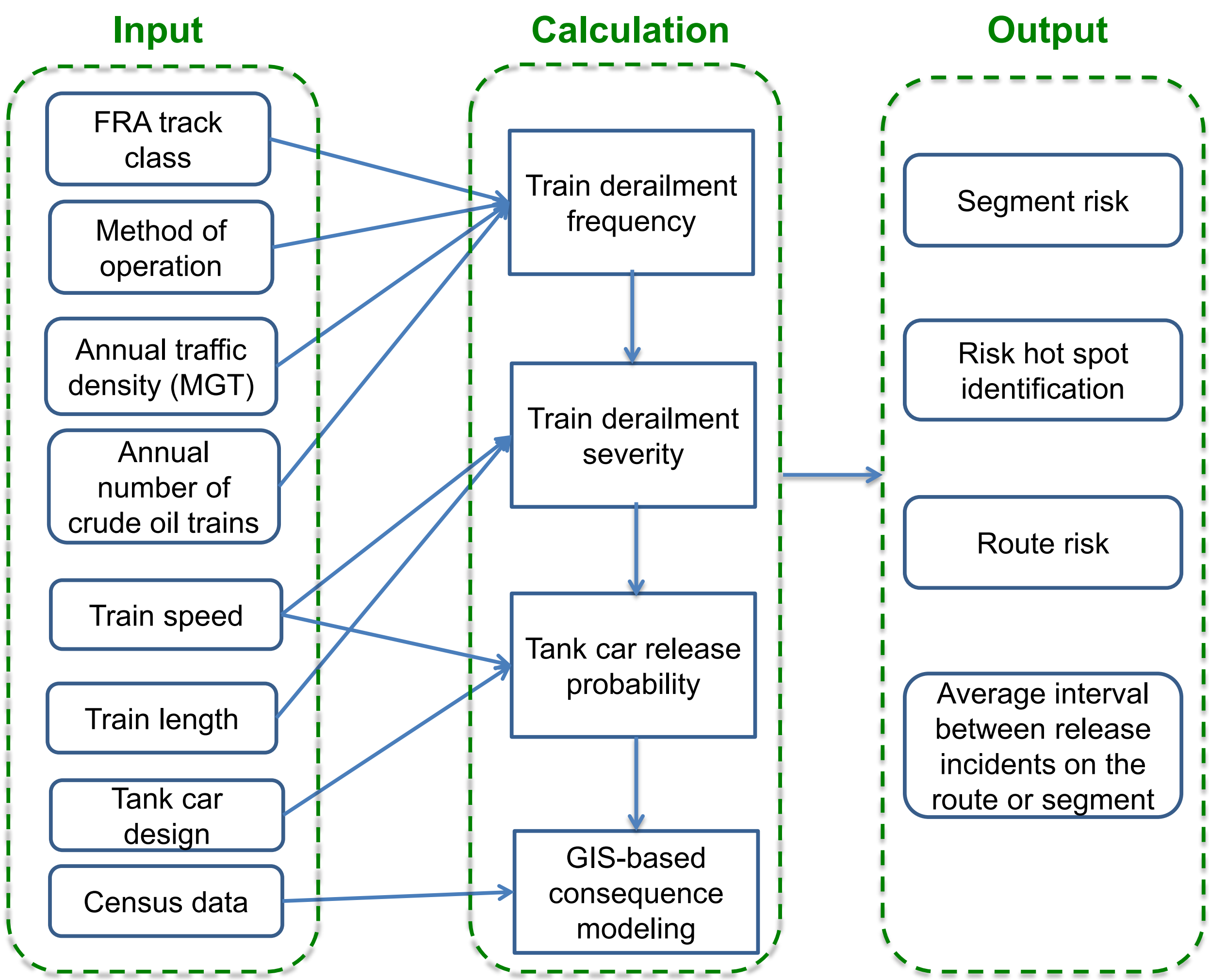

FIGURE 2 Implementation tool input and output

An accurate risk assessment requires carrier-specific network and traffic information, which is typically not publicly available. To verify and illustrate the technical feasibility of the model, the current *CBR-Risk* tool is built on hypothetical railroad infrastructure information. Consequently, the risk values presented in the following numerical example are for illustration only. Railroad carriers interested in using the tool should incorporate their network and operational information.

7 NUMERICAL EXAMPLE

This section presents a step-by-step procedure for using the *CBR-Risk* tool to assess route-specific crude oil transportation risk, based on an example in the State of New York. Based on a study published by the New York State government (*39*), this paper uses the Buffalo-Syracuse-Albany route as an example. For model illustration, it is assumed that the Buffalo-Syracuse-Albany route has 500 crude oil unit trains per year, and each train has 100 crude oil tank cars. For the purpose of comparison, it is assumed that all of the tank cars are conventional non-jacketed DOT-111 tank cars (7/16 inch) cars. It is assumed that the train speed on this route is 30 mph. Based on these assumptions and segment-specific FRA track class, method of operation and traffic density (hypothetical values are used here because the actual information is proprietary to the railroad), the *CBR-Risk* tool automatically calculates segment-specific risk and the corresponding reoccurrence intervals between release incidents (Figure 3).

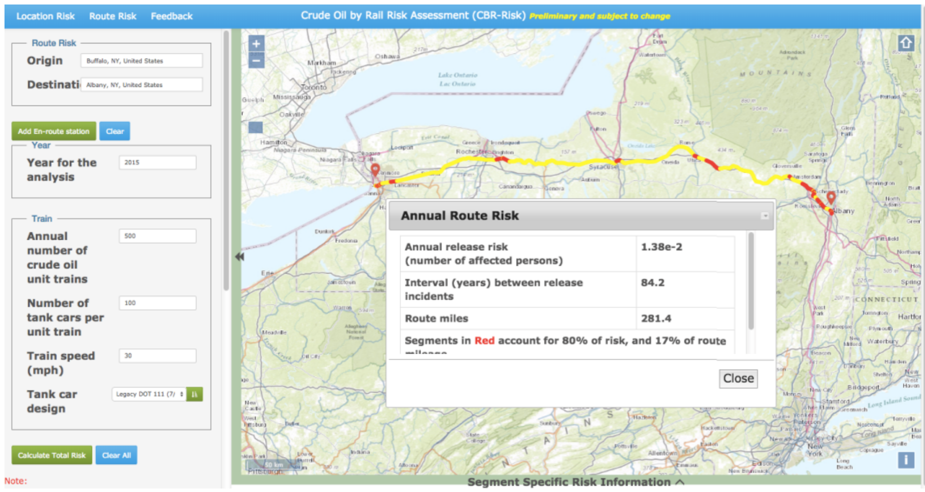

FIGURE 3 Screenshot of CBR-Risk tool used in the numerical example

Note: the route and risk values presented herein are hypothetical and for illustration only

It shows that annual crude oil release risk on this route in the year 2015 under the above-mentioned assumptions would be 0.0138 (expected number of persons affected), equaling to one incident every 84 years. In addition to the route risk estimator, a risk curve was also presented (Figure 4). The risk curve depicts the probability distribution of the affected population (consequence) on the studied route. For example, Figure 4 shows that the annual probability of affecting 1,000 or more people due to a possible release is around 6 out of 1 million (6.0E-6) on the studied route.

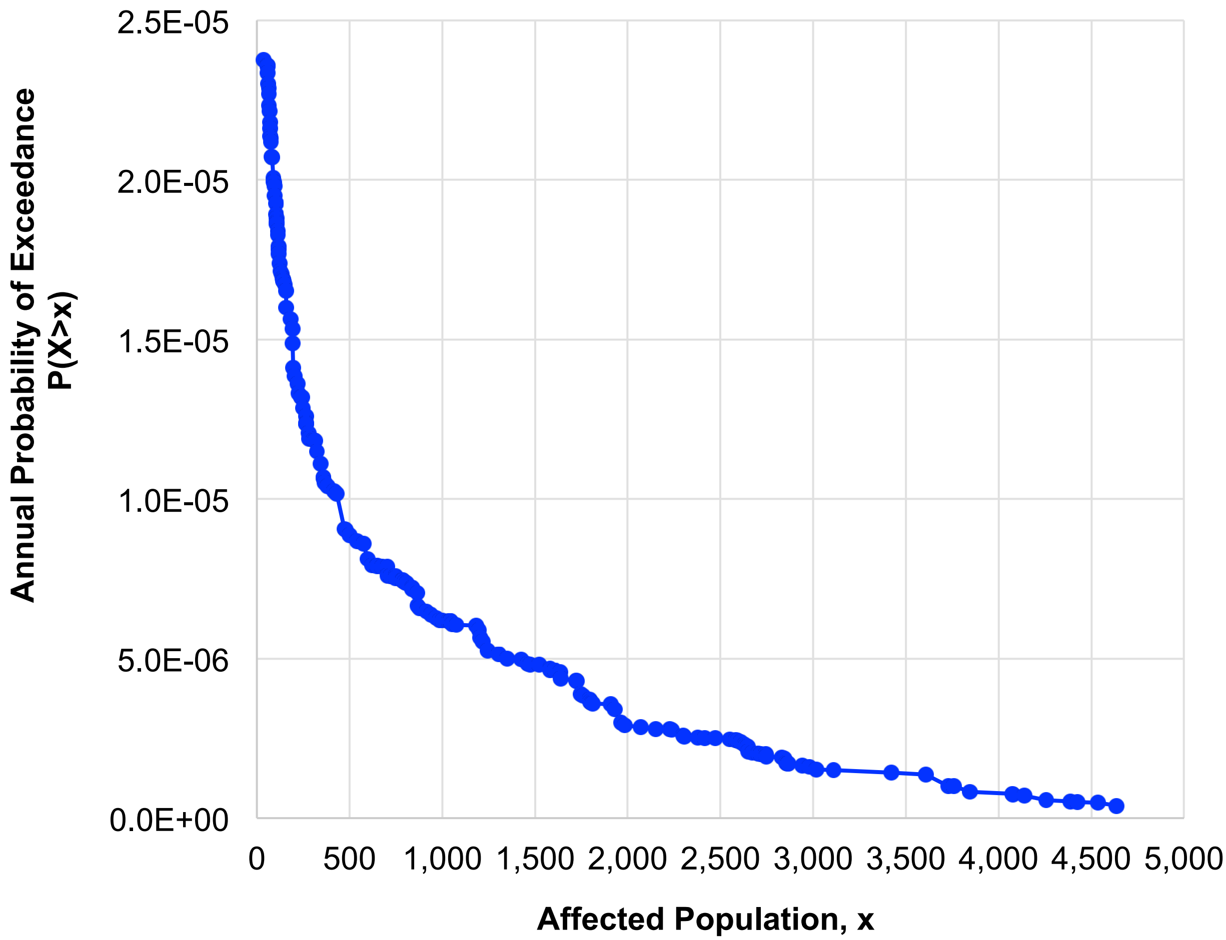

FIGURE 4 Risk curve on the hypothetical route.

Furthermore, segment-specific risk distribution was analyzed to understand risk variation by population density and other factors (Figure 5). The segment risk is ranked in a descending order. It shows that at some segments, high population densities contribute to high risk estimates, whereas some other densely populated locations still have low risks due to low crude oil release probabilities that are attributable to better infrastructure or operational conditions.

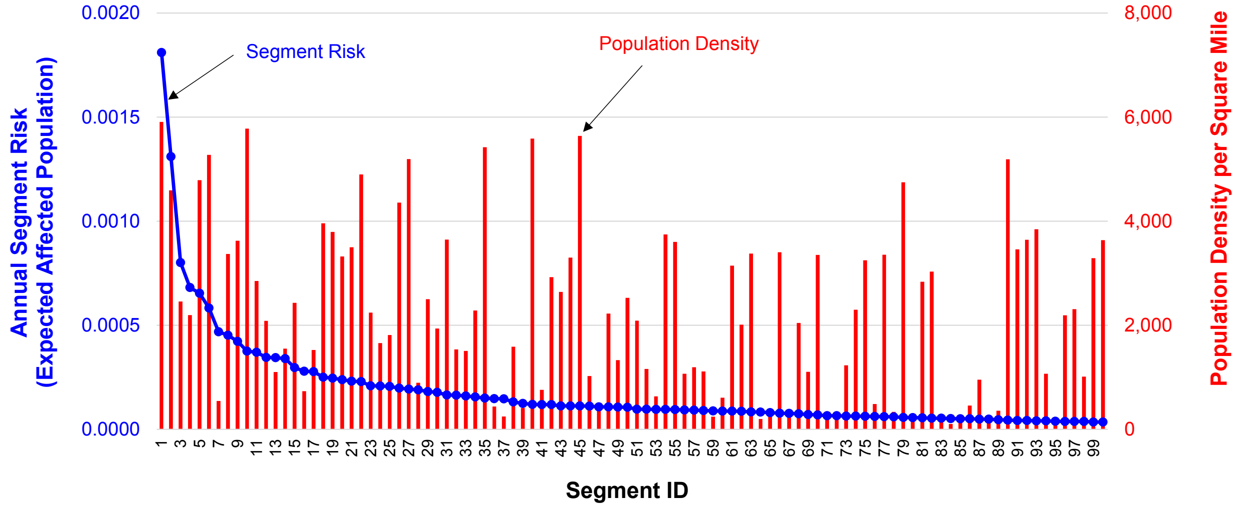

FIGURE 5 Segment risk and population density distributions (the risk is ranked in a descending order; the top 100 segments are displayed)

Finally, the route risk is interpreted in terms of the recurrent period (years) between release incidents by tank car design and traffic volume on the same route (Table 3). The analysis shows that higher annual traffic volume will increase the risk and shorten the incident recurrence interval. By contrast, an enhanced tank car design can reduce the risk and increase the interval between release incidents. For example, if all tank cars conform to DOT-117 specifications, given 500 trains per year, the release interval would increase to 172 years, compared to 84 years when all tank cars are conventional non-jacketed DOT-111. Note that the absolute interval values are hypothetical because of hypothetical railroad network data.

TABLE 3 Average Interval between Release Incidents (years) by Annual Number of Crude Oil Trains and Tank Car Design

Annual Number of Crude Oil Unit Trains	Conventional Non-Jacketed DOT-111	Jacketed CPC-1232	DOT-117
300	140	217	287
500	84	130	172
1,000	42	65	86

8 DISCUSSION

This section discusses how this research can contribute to the body of knowledge and how it can potentially be applied to practice.

8.1 Implications to literature

This research aims to develop a practical risk analysis model suited to rail transport of crude oil and other flammable liquids in unit trains. Previous studies developed several hazardous materials transportation risk models. The majority of previous models focused on a single railroad tank car release for toxic-inhalation-hazard (TIH) materials, except Bagheri et al. (*14, 16, 17*) and Liu et al. (*4*) that can analyze multiple-car release probabilities. Built upon the existing work, this research aims to bring two contributions to the literature:

- This research incorporates the latest train and tank car safety statistics in crude oil transportation risk analysis that accounts for specific train and track characteristics.
- This research provides a general methodological framework for evaluating crude-by-rail risk via unit train shipments. One unique aspect of unit train transport of hazardous materials is the potential for a multiple-tank-car release. This paper provides insights into the probability of a crude oil train release given multiple tank cars derailed and possibly releasing contents.

8.2 Implications to practice

One practical deliverable of this research is a GIS-enabled risk management decision support tool that automates all the analytical procedures. This tool can potentially be linked to a railroad-specific safety management system to permit an expedited screening of location-specific risk. Another important use of the tool is to identify, evaluate, compare, and prioritize potential risk mitigation strategies. This would address the optimal investment strategies to improve crude-by-rail safety in a cost-justified manner in the future. Public entities like municipalities could use this tool, with no other alternative tool is available. They would need a proper level of cooperation from carriers if possible.

9 SUGGESTED FUTURE RESEARCH

Because the current study is limited by the availability of information, intensive future research might be conducted:

1) The tool requires actual crude oil rail network information (e.g., crude oil route information, segment-specific FRA track class, method of operation and annual traffic density). This information needs to be provided by railroad carriers. Since acquiring this information is beyond the scope of this study, caution should be made when using the current tool to make risk-based decisions.
2) The current analysis focuses on unit train shipments of crude oil. Ongoing effort is underway to adapt the model to manifest trains when tank car positions are given.
3) This research focuses on releases caused by mechanical damage incurred by tank cars in train accidents, without accounting for releases resulting from thermal tear, which is a process by which a fire impinging on the tank causes the steel to weaken (*1*). Accounting for thermal-tear-caused tank car release risk is the next step of this work.
4) The risk analysis tool can evaluate and compare different risk mitigation strategies. Accident prevention strategies affect train accident rates, and tank car safety design improvement reduces the probability of tank car release following derailment. An integrated crude oil transportation risk management system is needed to optimize the allocation of limited resources on multiple risk reduction options- either alone or in combination- accounting for their respective safety benefits and costs (*40, 41*).
5) Finally, risk assessment involves the estimators of several input parameters. The statistical variances of these parameter estimators affect the variance of the risk estimator (*42*). The variance of risk estimator might be quantified by either statistical inference methods or Monte Carlo simulation approaches (*43*).

10 CONCLUSION

A variety of infrastructure, train, and operational characteristics affect crude-oil-by-rail transportation risk. This paper develops a risk analysis model to integrate these factors in order to estimate transportation risk in unit trains on mainlines. The methodology is packaged into a GIS-based decision support tool that automates risk calculation, visualization, and interpretation processes. The methodology and implementation tool can potentially assist decision makers in development of risk-informed policies and practices to manage the risk of rail transport of crude oil and other hazardous materials.

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DISCLAIMER

At present, the *CBR-Risk* tool can only be used for methodology demonstration in the absence of detailed proprietary crude oil network information. A specific user can modify the tool based on their own information with the author's assistance. The current tool shall not be used for any commercial or legal purposes.

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