A Risk Assessment Framework for TIH Train Routing

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ABSTRACT:

In the United States, freight railroads are required to transport Toxic by Inhalation (TIH) hazardous materials, where mitigating the consequences of attacks on trains carrying these materials is of high priority. The federal government and railroad industry are aware of local concerns and are developing performance based regulations to mitigate the consequences of a TIH material release. The performance-based regulation under consideration seeks to minimize the total risk across alternative rail paths. To assist officials in selecting these routes, especially in the situation of TIH chemicals, we propose a new framework that systematically evaluates risk. This framework will enhance the security enforcement efforts of the Department of Homeland Security and safety enforcement efforts of the Department of Transportation.

Keywords: Toxic Inhalation Hazards, Security, Safety, Routing, Railroads

INTRODUCTION

The Surface Transportation Board requires U.S. railroads, as common carriers, to move a class of materials called Toxic by Inhalation (TIH) material [1]. TIH material, also known as Poison by Inhalation (PIH) material, is a subset of hazardous materials formally defined by the Federal Government as "gases or liquids that are known or presumed on the basis of test to be so toxic to humans as to pose a health hazard in the event of a release during transportation" [2]. Although TIH materials constitute only 0.3% of all hazardous material shipments by rail [3], this still equates to over of 21.6 million ton miles of TIH movements per year [4]. These movements have the potential for catastrophic consequences in the event of an accidental discharge or deliberate sabotage. Six toxic-by-inhalation (TIH) chemicals (ammonia, chlorine, SO_2, hydrogen fluoride, fuming nitric acid and sulfuric acid) account for more than 90% of the total TIH transportation related risk [5]. Chlorine and ammonia account for 70% and 84 % of the transported TIH material. The distribution of the TIH risk indicates that the four liquefied gases (chlorine, ammonia, SO_2, and HF) account for over 95% of the total risk

when transported by rail. Recent major rail accidents illustrate the damage caused by uncontrolled TIH material releases (Table 1).

Location	Chemical(s)	Consequences	Year
Graniteville, SC [6]	Chlorine gas	9 dead, 554 injured, 5400 evacuees	Jan 2005
Macadona, TX [7]	Chlorine gas	3 dead, 30 injured	Jun 2004
E. Saint Louis, MO [8]	vinyl acetate	140 evacuated	Sept 1994
Tamora , IL [9]	Hydrochloric acid, formaldehyde, vinyl chloride fire	3 mile evacuation zone, 850 evacuated	Sep 2002
Freeport, TX [10]	fuming sulfuric acid ,sulfur trioxide cycloheanxanoe oxine, cycloheanxanoe	1 mile evacuation zone, 28 injured,	Feb 2003
Minot, ND [11]	Anhydrous Ammonia	1 dead, 333 injured, 11,600 evacuated	Jan 2002

Table 1: Recent Major TIH Rail Accidents

While the preceding were accidental releases, the potential for deliberate attacks by mal-actors [12] could result in significantly higher casualty figures. For example, each year 8500 tank cars of chlorine move by rail through the middle of Washington, DC passing within 2 blocks of the U.S. capital. In a worst-case scenario, the complete release of the contents of just one 90-ton car of chlorine in the center of Washington, DC has the potential to kill or injure 100,000 people [13]. Chlorine gas exposure levels from a compromised tank car as low 430 parts per million for periods of 30 minutes are fatal. Death is by slow suffocation as the chlorine gas reacts with moisture in the lungs, forming hydrochloric acid that in turn inflames the lungs. Exposure, even if not fatal, can result in lung congestion, pulmonary edema, pneumonia, pleurisy, or bronchitis [14].

TIH ROUTING REQUIREMENTS

According to a study by the Federal Agency for Toxic Substances and Disease Registry (ATSDR): "Although a statistically rare occurrence, the effects on public health from the release of hazardous substances during rail transportation are potentially catastrophic."[15]. In view of the potential consequences of a TIH release, major municipalities have attempted to prohibit shipment of these materials through their jurisdictions. Washington DC, Philadelphia PA, Las Vegas NV, Baltimore MD, Chicago

IL, Boston MA, and Cleveland OH have either passed, or are in the process of passing legislation to ban shipments [16]. While the federal courts have overturned these bans under the Interstate Commerce Clause of the U.S. Constitution [17], the Hazardous Materials Transportation Uniform Safety Act [18], and the Federal Railroad Safety Act [19], the Federal Railroad Administration (FRA), the Pipeline and Hazardous Materials Safety Administration (PHMSA), and the Transportation Security Administration (TSA) are seeking to augment existing industry hazmat routing practices with performance based federal regulations requiring risk based routing [20] to mitigate local concerns.

AAR Circular OT 55-1 [21] gives the rail industry routing guidance for TIH material. OT 55-1 defines a list of TIH materials in Appendix A, as well as technical and handling requirements for key trains, key rail routes, and facilities. A key train is defined as any train that caries 5 or more carloads of TIH and a key rail route as any route that caries more than 4,000 carloads of TIH, flammable gasses, explosives, spent nuclear fuel, and high level radioactive waste. Key trains are limited to a maximum speed of 50 miles per hour and consist of cars that must meet certain technical standards. In the event that a wayside device detects an abnormal condition in a key train, further speed restrictions and car handling requirements are imposed. Key routes must have wayside defect sensors not more than 40 miles apart, all main track must be inspected at least twice per year and all sidings at least once per year using rail defect detection and geometry cars, and all track must have periodic track inspections between track defect and geometry cars inspections to detect cracks and breaks in joint bars. Additionally Track must be rated FRA Class 2 or higher.

Under OT 55-1 AAR member railroads are responsible for tracking the location of TIH shipments from shipper to consignee, and ensuring the timely delivery of the material in accordance with US Department of Transportation guidelines [22]. They are also required to provide, on request by a jurisdiction's public safety official's, a list of the top 25 hazardous materials that are transported through the jurisdiction.

The proposed federal regulations expand on these industry and existing federal security requirements [23] in three ways. First would be to requiring railroads to use compiled annual data to analyze safety and security risks along routes where materials are transported and assess alternative routing options. Second would to require routing

decisions based on those assessments. Third would require additional en route storage, delays in transit, delivery notification, and security inspection requirements.

Although FRA considers rail transportation safe, some routes provide a higher level of safety than others. Public interest necessitates that these "safer" routes be used for the transport of TIH, while commercial and other economic factors suggest routes with a lower level of safety be used. The routing risk analysis therefore must be based on four factors:

1. Minimizing the rate of accidents resulting in releasing of hazardous material;
2. Minimizing the rail route population exposure,
3. Minimizing the length of the rail route.
4. Minimizing economic impacts of rerouting

The later is an essential factor because routes that minimize risk may be so circuitous that they can be economically unfeasible, or at least impractical.

RISK AS AN INFLUENCE ON ROUTING

Traditionally risk has been considered as the product of the probability of occurrence of a hazardous event and the associated potential consequences [24]. The risk associated with a TIH material incident (R_{TIH}) can be represented as the product of the probability of release ($P_{RELEASE}$) and the consequence of the release ($C_{RELEASE}$).

$$R_{TIH} = P_{RELEASE} * C_{RELEASE}$$

The higher the numerical value of R_{TIH}, the greater the inferred risk [25]. The consequences are generally undesirable effects that have been normalized to a standard unit such as deaths and injuries (or their dollar equivalents).

The consequences of a hazardous material release ($C_{RELEASE}$) can be expressed in terms of a function ρ of the direct damages (D_{DAM}) and indirect damages (D_{IDAM}) where:

$$C_{RELEASE} = \rho(D_{DAM} + D_{IDAM})$$

Direct damages are related to operating costs. Operating costs [17] on a particular rail segment are a function of fixed and variable costs. Fixed operating costs include items such as the equipment deprecation, insurance, other capital costs, and property taxes while variable costs include crew wages and benefits, fuel usage and losses due to materials damaged in transport. These costs for a particular link can be expressed in

terms of cost per unit time or cost per unit distance of vehicle operations over the rail segment. Direct damages reflect costs associated with the incident, such as damage to railroad property, that affect the railroads operating costs. Direct Damages (D_{DAM}) is a therefore a function ϕ of the location of the incident ($S_{INCIDENT}$), the trains involved (TR), and the railroads operating costs (OC).

$$D_{DAM} = \phi (S_{INCIDENT}, TR, OC)$$

Indirect damages reflect such things such as non-railroad property damage and deaths. Non-railroad property damages include a range of other elements, such as lost production time for businesses, cost to hospitals and insurance companies, out-of-pocket expenses of those needing medical or housing assistance, employee lost work days, lost jobs, and disability payments. Like direct damages, indirect damages affect the railroad's operating costs. The indirect damages (D_{IDAM}), like direct damages, can be considered a function (δ) of the location of the incident ($S_{INCIDENT}$), the trains involved (TR), and the railroads operating costs (OC).

$$D_{IDAM} = \delta (S_{INCIDENT}, TR, OC)$$

A full economic accounting of the impact of direct and indirect damages on a railroad's operating costs would be the subject of further research.

Perhaps the significant of the indirect damages are the costs associated with the deaths of personnel at or near the site of a TIH release ($S_{INCIDENT}$). Death occurs when the dispersed hazardous material has a concentration level above the threshold where a human being can survive at those concentrations of these materials. This is when the exposure dosage (L_{DOES}) by an individual of a toxic substance is greater than the fatal threshold value (L_{THRES}). One simplistic approach to determining the probability of death occurring (P_{DEATH}) is as follows:

L_{THRES} = Fatal Threshold of TIH

L_{DOES} = Exposure dosage to TIH

μ = Mean of the fatal dosage threshold distribution

σ = Variance of the fatal threshold distribution

$$P_{DEATH} = \mathrm{Prob}(L_{THRES} < L_{DOES}) = \frac{1}{1 + \exp(\frac{-(L_{DOES} - \mu)}{\sigma})}$$

While L_{THRES} is constant dependent upon the material, $L_{DOES,}$, μ, σ, are functions of the dispersion. The hazardous material dispersion models define the specific relationships between $L_{DOES,}$, μ, σ in terms of a function of geographical area of dispersion ($A_{DISPERSION}$) and the site of the incident ($S_{INCIDENT}$). More complex, TIH specific estimators are available, for example [26,27,28].

The most widely used model for evaluating the dispersion of vapors from gas, liquid, or other multi-component compounds is called HGSYSTEM [29]. HGSYSTSEM is a family of models developed by a consortium of industry and government agencies consisting of Shell, Amoco, Phillips Petroleum, the American Petroleum Institute, Chevron Research, Texaco Research, AlliedSignal, Mobil, DuPont, Exxon, and the US Department of Energy. HGSYSTEM consists of a number of validated models modules to evaluate consequences based on the release of atmospheric dispersion of accidental pollutant releases with emphasis on denser-than-air materials under different dispersion scenarios (jet dispersion, heavy gas dispersion, passive dispersion) for both chemically reactive and non-reactive gases. HGSYSTEM modules are a database of chemical properties (DATAPROP), Source release models (SPILL and LPOOL), near field dispersion models (AEROPLUME and HEGABOX), far field dispersion (HEGADAS and PGPLUME), specialized Hydrogen Fluoride specific modules (HSPILL, HFPLUME, and HFFLASH) and data post processing programs (POSTHS/HT, PROFILE and GET2COL). The modules can be used together, or separately, depending on the type of simulation desired.

Dispersion of radioactive materials is generally modeled using RADTRAN [30] or RISKIND [31]. Using user provided information regarding routing, population densities, material packaging, health physics, and meteorological data, RADTRAN calculates the anticipated radiological consequences of a radiological event during transport. A separate program called RISKIND augments the Sandia National Laboratory RADTRAN program. Unlike RADTRAN, which deals with radiation affects

on a composite population, RISKIND addresses radiological affects on individuals or specific population subgroups exposed to radiation materials.

ROUTE SELECTION

The usual procedure for a quantitative transportation routing analysis is to first divide the transport routes into segments (also called links) along which a set of parameters of interest can be reasonably estimated. Cost functions that relate the parameters of interest for each link are defined and then evaluated. These costs are aggregated in some manner for combinations of links representing valid paths from origin to destination. Depending on how the cost function is defined, the optimal route is the one where the aggregation is either a maximum or minimum value.

A simplistic cost function is to estimate risk (R_{TIH}) for a route as the product of the route segment with the worst consequences $(C_{RELEASE-SEG})_{MAX}$ and the route segment with the highest probability of incident of route segment occurrence $(P_{RELEASE-SEG})_{MAX}$.

$$(R_{TIH})_{ROUTE-I} = (C_{RELEASE-SEG})_{MAX} * (P_{RELEASE-SEG})_{MAX}$$

The optimal route $(R_{TIH})_{OPTROUTE}$ is the minimum of the risks $(R_{TIH})_{IROUTE}$ for each individual routes

$$(R_{TIH})_{OPTROTE} = \min \{(R_{TIH})_{ROUTE-1}, (R_{TIH})_{ROUTE,-2} \ldots (R_{TIH})_{IROUTE-I}\}$$

The disadvantage of this approach is the resulting level of risk level may be significantly overestimated or underestimated.

Because an incident can occur at any point on a rail route used to move hazardous materials. With the possible variations in the population distribution along a route and differences in the probability of an incident at any location, the consequences may vary widely. A much better estimator of the level of risk for a route is to consider the total risk for each route. The total risk for a route (R_{TIH}) is the sum of the level of risks on each of the segments (R_{SEG}) on the route.

$$R_{TIH} = \Sigma (R_{SEG})$$

where

$$(R_{SEG}) = (C_{RELEASE-SEG}) * (P_{RELEASE-SEG})$$

The probability of release ($P_{RELEASE-SEG}$) is the product of the accident rate probability ($P_{ACCIDENT-SEG}$) and the conditional release probability give an accident

($P_{RELEASE-ACCIDENT-SEG)}$). The consequences of a release on a segment ($C_{RELEASE-SEG}$) is a function of the sum of the direct ($D_{DAM})_{SEG}$ and indirect damages direct ($D_{IDAM})_{SEG}$ for that segment. If one considers the direct damage ($D_{DAM})_{SEG}$ for a segment to be a constant, and considers indirect damages ($D_{IDAM})_{SEG}$ to be primarily a function of the number of deaths on the route segment, then ($C_{RELEASE-SEG}$) can be considered a product of size of the exposure area for the segment ($A_{DISPERSION-SEG}$), the population in the neighborhood of the exposure area (N_{SEG}) and the probability of that population being exposed to a lethal dose for each link (P_{DEATH}).

$$(R_{SEG}) = (P_{ACCIDENT-SEG})(P_{RELEASE-ACCIDENT-SEG})(P_{DEATH})(N_{SEG})(A_{DISPERSION-SEG,})$$

This ensures that the consequences of a particular accident on a segment of railroad ($P_{DEATH} * N_{SEG} * A_{DISPERSION-SEG,}$) correlate with the corresponding probability of occurrence ($P_{ACCIDENT-SEG} * P_{RELEASE-ACCIDENT-SEG}$) on the same segment. It also ensures that the risk over the entire length of the route is considered when evaluating the overall risk for alternative routes. The optimum route is the route where R_{TIH} is a minimum.

$$(R_{TIH})_{OPTROTE} = min \{(\Sigma R_{SEG})_{ROUTE-1}, (\Sigma R_{SEG})_{ROUTE-2} \dots (\Sigma R_{SEG})_{ROUTE-I}\}$$

This approach of optimizing route while minimizing public exposure is not without precedent. Similar risk optimization strategies have been done for high-level nuclear wastes. Cashwell et al. [32] conducted an extensive study using minimal societal risk for Sandia National Laboratory on transporting nuclear wastes, based on use of models developed at Sandia National Laboratories using routing selection as input, and then the potential exposure to the population along the routes. It should be noted that there are other approaches to risk modeling. For example, a multi-objective shortest path integer-programming model has been developed by Cox [33] to select the best route for transporting toxic materials from a set of known routes for highway vehicles based on operating cost and risk. Another approach [34] selects the route with the minimum value for the product of potential population exposure along a TIH transport route multiplied by the volume of TIH material to represent risk. Other approaches are explored in references [35,36,37,38,39,40,41,42,43,44,45]

Current rail operation models [46,47] do not consider optimal routing across multiple rail carriers. Consequently while optimal routes for a particular carrier can be determined, routes across multiple carriers are generally suboptimal. The Oak Ridge

National Laboratory has developed for the Federal Railroad Administration a uni-modal model that overcomes this limitation for estimating optimal routes for rail operations. Called the Rail Routing and Visualization Application (RRVA) [48], it allows for the evaluation of optimal rail transportation routes based on the type of train routing, travel time, distance traveled, classification of the track, population along the proposed route, the type of rail operations (passenger, freight, mixed) on the proposed route, the density of traffic along the proposed routes, delays associated with yard and interchange switching, consist inspections and crew hours of service. RRVA is based on the multi-modal Transportation Routing Analysis Geographic Information System (TRAGIS) [49] originally designed for evaluating routing options for radioactive shipments to the proposed Yucca Flats Long Term Nuclear Waste Repository.

RRVA utilizes a similar approach to the one first defined in TRAGIS by calculating an optimal route using a shortest-distance criterion by minimizing a total "impedance" function between the origin and destination. The system minimizes the number of transfers between railroads and it lowers impedances for shipments that stay within the same railroad net. The general RRVA impedance function for non-unit trains is given by

$$L_{ROUTE} = \min \left\{ \Sigma(\alpha_i f_i d_i) + \Sigma(T_n) \right\}$$

where
L = total impedance of a route;
α_i = setout and pickup railroad factor for link i,
f_i; = track classification factor
d_i = distance traveled along a link i
T_n = transfer penalty factor at node n

The track classification factor f_i reflects the type of track for a particular segment (mainline or branch and the operating railroad). Setout and pickup factor α_i reflects the cost of removing a car from one consist, storing it, and then adding it to another consist on the same railroad, while T_n reflects the cost of interchanging a car between railroads.

The impedance function preferentially routes a shipment along mainlines, while minimizing interchanges between railroad companies. In general, shipments will utilize branch lines only as a connection between the mainline network and the origin or destination. Frequently, several railroads will provide service at the same location. Selection of an originating railroad has an impact on the estimated route because the originating railroad will preferentially attempt to move the shipment on its own system before interchanging with another railroad in order to maximize its portion of the revenue. Because of this rail routes are not necessarily symmetric. A different route may be determined if the origin and destination are reversed.

RRVA encourages traffic to be routed along mainline segments and minimizes the number of transfers between railroads. The number of alternative routes that RRVA can calculate is dependent upon the density of the rail network between the origin and destination. A sparse network may not provide any other path. Alternatively, where there is more connectivity in the network, RRVA may provide several alternative routes. RRVA, however, does not take into effect the consequences of a particular risk of material release or the probability of a release. When risk is considered in the route selection new issues, such as the availability of en-route facilities for managing emergencies, avoidance of population centers or tunnels, and existence of alternative rail routes must be considered. To perform a complete route risk analysis, it is therefore necessary to determine the consequences associated with the route links and their associated populations first identified using RRVA.

Once a route has been determined using RRVA, the potentially affected population (N_{SEG}) for each segment along the route is identified. The area affected (A_{SEG}) and the probability of death (P_{DEATH}) can subsequently calculated using a dispersion model appropriate for the TIH of concern. The probability of accident on that route segment ($P_{ACCIDENT-SEG}$) is determined as a function γ of railroad characteristics such as speed of operation (V_{SEG}), traffic density (D_{SEG}), the type of signal and train control system (SIG_{SEG}), rail age and weight bearing capacity (TRK_{SEG}) and track geometry (GEO_{SEG}).

$$P_{ACCIDENT-SEG} = \gamma\ (V_{SEG},\ D_{SEG},\ SIG_{SEG},\ TRK_{SEG,},\ GEO_{SEG})$$

The probability function $P_{RELEAS-SEG}$ is a function κ of the car being used to transport the TIH. It includes such parameters as the car type (T_{CAR}), structural material the car is made of (M_{CAR}), age of the car (AG_{CAR}), type of incident (I_{TYPE}) (derailment or collision), the speed at which the collision occurs ($V_{COLLISION}$), as well as the physical parameters (PC_{COL}) of the object with which it is colliding.

$$P_{RELEAS-SEG} = \kappa \ (T_{CAR}, M_{CAR}, AG_{CAR}, I_{TYPE}, V_{COLLISION}, PC_{COL})$$

In 2004, the National Transportation Safety Board (NTSB) found that more than half of the 60,000 rail tank cars used to transport hazardous materials were not built according to current standards and were susceptible to rupture in the case of an accident. The NTSB also reported that a 1989 requirement for tougher steel has made all new tank cars safer, but about 60 percent of pressurized tank cars currently in use were built before 1989. [50] Discussions of car integrity are outside the scope of this paper, but are a separate topic of active research. [51,52, 53,54]

In recent years a new concern has developed that has a significant impact on risk estimation and routing decisions, that of sabotage. Sabotage (S) refers to malicious tampering and destruction. It is a specific undesirable event resulting in damages that may be result of a deliberate act of terrorism. Sabotage, however, does not necessarily mean terrorism. The ultimate objective of a saboteur's attack is to maximize the damage. In the case of terrorism, the ultimate goal is to advance a political or social cause [55]. The level of damage caused by either may be indistinguishable. Both can be represented by an artificial and significant increase in the level of risk.

The saboteur or terrorist can increase the level of risk in a number of ways. One is to drive the product ($P_{ACCIDENT-SEG}$ *$P_{RELEASE-ACCIDENT-SEG}$) to 1. This is accomplished by the saboteur taking specific actions to increase both the likelihood of an incident occurring $P_{ACCIDENT-SEG}$ as well as the likelihood that the incident results in a release of a TIH material ($P_{RELEASE-ACCIDENT-SEG}$). Alternatively the saboteur or terrorist can work to increase the adverse consequences of a TIH release. This can be accomplished in several ways. One is by choosing targets that have minimum structural integrity (SI_{CAR}) where (SI_{CAR}) is a function β of the type of car (T_{CAR}), the structural material the car is made of (M_{CAR}), and the age of the car (AG_{CAR}).

$$SI_{CAR} = \beta \ (T_{CAR}, M_{CAR}, AG_{CAR})$$

Another way is for the attacker to select targets (T_{CAR}), that contain a material (M_{TIH}) which maximizes the probability of death (P_{DEATH}), executing the attack in a location ($S_{INCIDENT}$) that maximizes the number of personnel potentially affected (N_{SEG}), and using an attack method (ATK_{METHOD}) that maximizes the area affected by the material covered by the discharge ($A_{DISPERSION-SEG}$).

$N_{SEG} = \theta\ (T_{CAR}, M_{TIH}, S_{INCIDENT}, ATK_{METHOD})$

$A_{DISPERSION-SEG} = \tau\ (ATK_{METHOD}, M_{TIH}, S_{INCIDENT})$

The choice of attack methods (ATK_{METHOD}), as well as selection of location ($S_{INCIDENT}$) is primarily under the control of the attacker. They can be mitigated, to some extent, by the defender. The defender can identify critical locations in advance, and put protective countermeasures put in place to limit the effectiveness of the attack. Identification of critical locations, as well as protective countermeasures is a complex socio-economic problem rooted in game theory [56] that is outside the scope of this paper.

Determination of the least risk route for the defender becomes an optimization problem that simultaneously satisfies the system of equations.

$$R_{TIH} = \min \Sigma\ (R_{SEG})$$

$$(R_{SEG}) = (P_{ACCIDENT-SEG})(P_{RELEASE-ACCIDENT-SEG})(P_{DEATH})(N_{SEG})(A_{DISPERSION-SEG,})$$

$$SI_{CAR} = \min\ (\beta\ (T_{CAR}, M_{CAR}, AG_{CAR}))$$

$$P_{DEATH} = Prob\ (L_{THRES} < L_{DOES}) = \frac{1}{1 + \exp(\dfrac{-(L_{DOES} - \mu)}{\sigma})}$$

$$L_{ROUTE} = \min\{\ \Sigma(\alpha_{\ i} f_i\ d_i) + \ \Sigma(T_n\ )\}$$

$$P_{ACCIDENT-SEG} = \max\ (\gamma\ (V_{SEG}, D_{SEG}, SIG_{SEG}, TRK_{SEG,}, GEO_{SEG}))$$

$$P_{RELEASE-ACCIDENT-SEG} = \max\ (\kappa\ (T_{CAR}, M_{CAR}, AG_{CAR}, I_{TYPE}, V_{COLLISION}, PC_{COL}))$$

$$A_{DISPERSION-SEG} = \max\ (\tau\ (ATK_{METHOD}, M_{TIH}, S_{INCIDENT}))$$

$$N_{SEG} = \max\ (\theta\ (T_{CAR}, M_{TIH}, S_{INCIDENT}, ATK_{METHOD}))$$

$$1 \geq P_{ACCIDENT-SEG} \geq 0$$

$$1 \geq P_{RELEASE-ACCIDENT-SEG} \geq 0$$

$$1 \geq P_{DEATH} \geq 0$$

The solution of this system of equation represents the desired favorable outcome for the defender. Depending on the functions γ, κ, τ and θ will determine what class the optimizing problem falls in, and will suggest an appropriate combinatorial, dynamic, or evolutionary optimization algorithm for the analyst to use.

OTHER ISSUES IN RISK MANAGEMENT

Risk management, as related to material routing, involves quantifying various levels of risk resulting from the product of the various probabilities and consequences, and then taking actions that minimize that product to the greatest extent possible. By approaching this is a structured manner; alternatives can be compared in a systematic way. Despite any systematic quantitative approach to evaluate risk, it should not be forgotten that, qualitative public opinion could greatly affect the outcome of any quantitative analysis, regardless of the accuracy of the former. The public's perception of the both the probability of occurrence and the consequences may greatly exceed the actual probability and consequences. Anecdotal evidence, despite statistics to the contrary, may result in misallocation of resources to address perceived problems. Optimal risk management solutions may also suffer from the NIMBY (Not in my backyard) factor. Optimal Risk minimization solutions may be precluded as a consequence of public objections to the transference of risk from one segment of the population to another.

Any risk assessment of TIH movement by rail must also consider the complexity of the rail network and the volume of chemicals being transported. The multiplicity, sheer volume, their potential impact in the event of an incident and the number of locations incidents can occur significantly complicate the development of risk minimizing routing algorithms. The risk assessments must also deal with significant uncertainties when assessing risks, because the associated probability and consequence data is often sparse and of questionable quality. These uncertainties arise because modelers are attempting to estimative very small probabilities associated with events that may have never occurred. Therefore any risk model must explicitly recognize uncertainty. While the probability of release of TIH material either as the result of a train accident or terrorist incident is small, it is not impossible. The risk of a low-probability

high-consequence accident involving a significant release of hazardous materials must be given adequate consideration.

SUMMARY

The 1990 Hazardous Material Transportation Act (49 USC Chapter 51) provides the statutory emphasis to assess the costs and benefits associated with the rail transportation of hazardous materials. Since that passage of that act, various models have been proposed to minimize the risks associated with the transfer of these materials in general, and TIH's in particular. Models have been developed at both the macroscopic level to address least risk route modeling in the event of an accidental or deliberate discharge as well as at the microscopic level to address the loss of car containment due to collision, derailment or car failure. The microscopic model, while not addressed in this paper, provides designers mechanisms for improved car safety, while the macroscopic models provides railroads, shippers, and the government a mechanism for addressing the consequences of either and accidental or deliberate breach of a TIH .

While dispersion and routing models for macroscopic incidents exist, further work is needed to more fully integrate them to provide a single source analytical tool that will optimize, from a safety and security standpoint, the shipment of TIH. Although not discussed in this paper, the microscopic work on TIH containment and the prevention of a TIH release requires both further study and integration with the macroscopic risk analysis models.

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