ASSESSING SAFETY & SECURITY RISKS FOR TRUCK SHIPMENTS OF HAZARDOUS MATERIALS

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Abstract

Recent terrorist events, most notably September 11, 2001, have taught us that transportation risk management must be performed with a different lens to accommodate terrorism scenarios that would have previously been considered unlikely to warrant serious attention. Given these circumstances, a new paradigm is needed for managing the risks associated with highway transport of hazardous materials. In particular, this paradigm must: 1) more explicitly consider security threat and vulnerability, and 2) integrate security considerations into an overall framework for addressing natural and man-made disasters, be they accidental or planned.

This paper summarizes the results of a study sponsored by the U.S. Department of Transportation, Federal Motor Carrier Safety Administration for the purpose of exploring how a paradigm might evolve in which both safety and security risks can be evaluated as a systematic, integrated process. The work was directed at developing a methodology for assessing the impacts of hazardous materials safety and security incident consequences when transported by highway. This included consideration of the manner in which these materials could be involved in initiating events as well as potential outcomes under a variety of release conditions. The methodology is subsequently applied to various classes of hazardous materials to establish an economic profile of the impacts that might be expected if a major release were to occur. The paper concludes with a discussion of the findings and implications associated with this effort.

Keywords: Risk assessment; Risk management; Safety; Security; Hazardous materials; Truck transportation; Economic impact
Topic Area: C2 Safety Analysis and Policy

1. Study background and objectives

The purpose of performing risk management has and continues to be to protect human health and the environment while maintaining economic vitality. For highway transportation of hazardous materials (HM), this translates into a focus on spill prevention as well as mitigating the consequences of a release when a spill does occur.

Until recently, the approach to risk management, including highway transport of hazardous materials, assumed that when man-made disasters occurred, they were accidental in nature and not due to malicious intent. Terrorist activities, leading to the tragic events of September 11, 2001, have dramatically changed this landscape. In particular, we have learned that transportation risk management must be performed with a different lens to accommodate terrorism scenarios that heretofore would have been

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considered too unlikely to warrant risk management attention. Specifically, we must now consider HM incidents that are the direct result of terrorist acts; incidents in which HM are used as the weapon.

Given these circumstances, it is apparent that a new paradigm is needed for managing the risks associated with highway transport of hazardous materials. In particular, this paradigm must: 1) more explicitly consider security threat and vulnerability, and 2) integrate security considerations into the overall framework for addressing natural and man-made disasters, be they accidental or planned.

This study was sponsored by the U.S. Department of Transportation, Federal Motor Carrier Safety Administration (FMCSA) for the purpose of exploring how a paradigm in which both safety and security risks can be evaluated as a systematic, integrated process might evolve. The work was directed at developing a methodology for assessing the impacts of hazardous materials safety and security incident consequences when transported by highway. This included consideration of the manner in which these materials could be involved in initiating events as well as potential outcomes under a variety of release conditions. The methodology was subsequently applied to various classes of hazardous materials to establish an economic profile of the impacts that might be expected if a major release were to occur.

In the remainder of this paper, the new paradigm is introduced, methodological components and their interactions are described, application of the methodology to various HM categories is presented, and implications of the results are discussed.

2. Risk analysis methodology

Treating safety and security risk assessment under a single, all-hazards approach requires a system-oriented perspective. This perspective must capture all possible combinations of events, represented in the proper sequence and leading to specific outcomes. To accommodate this perspective, a generalized HM highway transport incident flow diagram was developed (see Figure 1). This chart depicts the chronology of event logic as discussed below.

2.1 Event components and interactions

The event process begins with consideration of whether the potential for a release is unintentional (accidental) or intentional (terrorist-induced). In both instances, the type of material involved and the size of the shipment become important parameters.

For an unintentional release, depending on the nature of the HM, a spill can result in one or more of the following outcomes: 1) fire, 2) explosion, 3) toxic release, 4) radioactive release, or 5) infectious release. Based on the pathway through these components and interactions, consequences of the release are modeled accordingly along with an estimate of the associated impacts. As shown in Figure 1, release impacts can be potentially widespread, affecting human health, ecology, economic interests and travel mobility. The process does not consider emotional, political, and social "costs" associated with such releases.

Returning to the top of Figure 1, if the event is terrorist-driven, different conditions may apply. First is the question of whether the quantity of the material being subjected to the intentional act is significant enough to cause a major consequence. Intuitively, different types of HM will have different threshold quantities that would be necessary to cause a major event. If a terrorist were to steal a shipment of hazardous material of quantity below the threshold for that material type, then this act alone may have little or no impact. The potential for a serious event may still exist, however, if this shipment is combined with like material to reach (or exceed) the threshold amount, or if the material is combined with a different material known to cause a reaction.

Assuming that sufficient material exists to cause a terrorist act of significant consequence, the next consideration is whether the incident is planned to occur on the shipment route or whether the load will be diverted from the route and used at another location. The act could also involve either a directed or undirected release. For the purposes of this study, an "undirected release" is one where the release mechanism for an intentional act is the same as for an unintentional event. For example, an act would be undirected if a truckload of explosives is driven into a building on a road and that same event could have occurred as the result of an accident. A "directed release" is one where the release mechanism for an intentional act is different than that for an unintentional act. Examples of a directed release would be where a load of explosives is driven around barriers to reach a target or a detonation device is used to cause a release while the vehicle is on its planned route. A directed release would also be considered to be any incident where the terrorist uses a device to detonate the release.

Once these distinctions are made, the chronology progresses much like the unintentional release logic. That is, one determines the potential for the material to be flammable, explosive, toxic, radioactive, or infectious, followed by an assessment of the impacts.

It is important to note that while the outcomes may be the same, the consequences (impacts) are expected to be more severe for intentional acts because the event is more likely to be intended for a specific exposure (e.g., heavily populated area, major structure, etc.). The assumption made in the study is that there are four graduated classes of consequence severity:

- typical unintentional release (Type 1)
- "reasonable" worst case unintentional release (Type 2)
- "reasonable" worst case intentional and undirected release (Type 3)
- "reasonable" worst case intentional and directed release – with or without detonation (Type 4)

The term "reasonable" is used to bound worst case scenarios to those that are considered plausible and with a probability of occurrence that is sufficient to be formally considered in the risk assessment.

The approach described in Figure 1 is generalized in nature and will vary depending on the class of hazardous material under consideration. It suggests that a new HM classification scheme that is threat-based may be needed, since terrorists are likely to have different uses for materials that currently appear under the same HM class. To address this consideration, a revised classification scheme was utilized in this study as will be discussed later in this paper.

2.2 Sample flow diagram

Event trees are one technique for describing incident sequences. To illustrate how the flow diagram in Figure 1 can be applied on a material-specific basis, sample event trees were developed for various classes of hazardous materials. Figure 2 presents the sample tree for poisonous-by-inhalation (PIH) materials. Across the top of the tree is a list of the sequential events that might occur. As shown in the figure, the first entry in the tree is "event occurs." Moving from left to right, each branch leads to a subsequent consideration or characteristic that helps to shape potential final outcomes for the event. For the event trees in this study, the second branch is defined as either "intentional act" or "accidental release", depending on the nature of the event. For example, in Figure 2, after the "event occurs," if the act is intentional, the "intentional act" branch is followed. If sufficient materials exist to cause extensive damage, the "sufficient material" branch is taken, followed by the "target on route" branch if a route deviation is not required to reach a potential target. The release would be "undirected" if no special actions, such as driving around barriers or through fences, are taken to approach the target.

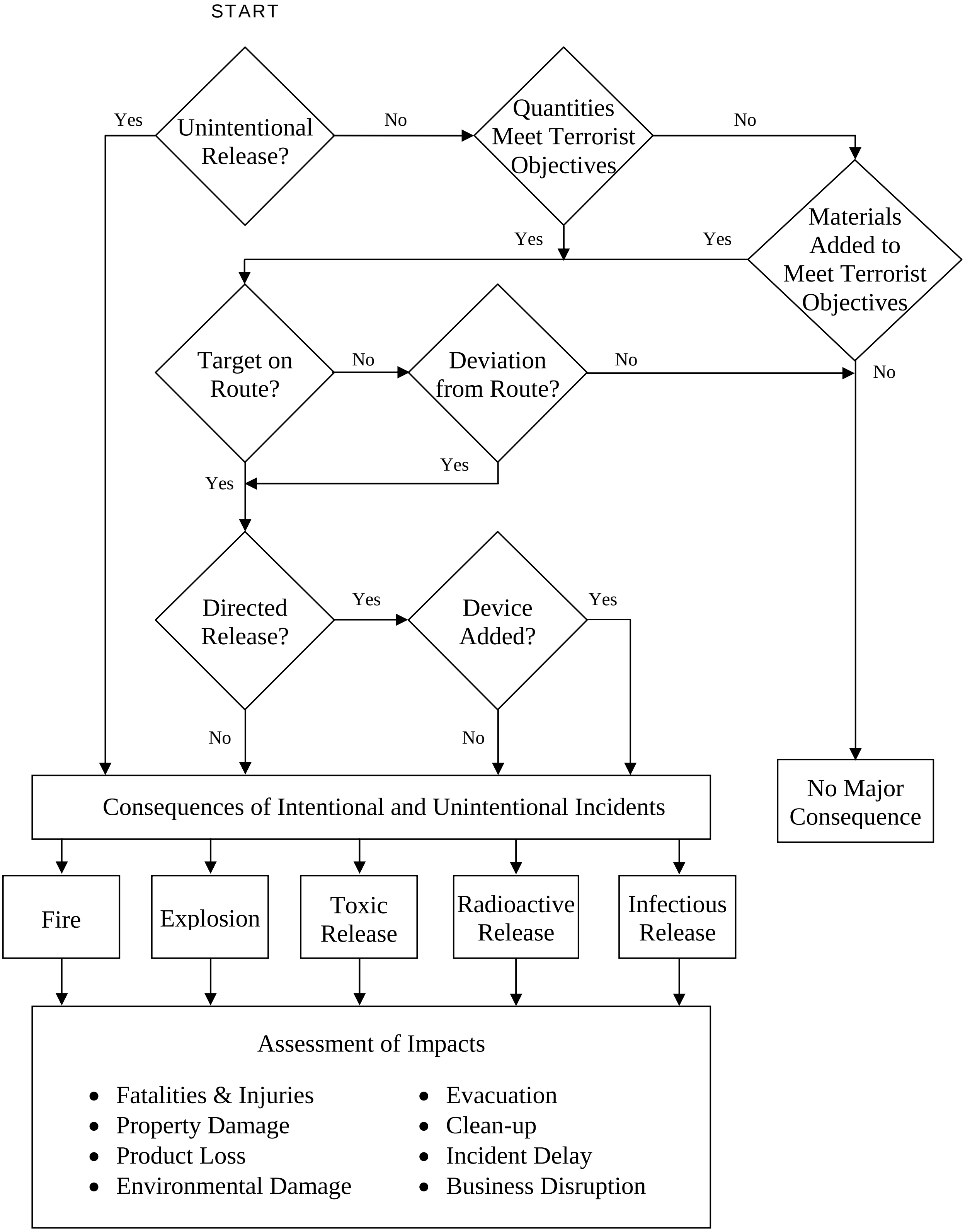

Figure 1. HM Highway Transport Incident Flow Diagram

At the far right of the tree is the final outcome for each unique pathway, which are sequentially numbered for ease of reference. The scenario described above corresponds to path 1 and the final outcome is described as "outside casualties," meaning that all casualties are likely to occur "outside" any buildings or facilities and not to people indoors.

While the event tree for each class of hazardous materials may be similar in structure, there are subtle differences in the branches corresponding to intentional acts. In Figure 2, many PIH materials are shipped under pressure and therefore have a built-in dispersal mechanism. In the case of an insensitive explosive, however, a detonator must be added for these materials to explode. Thus for insensitive explosives, adding branches that consider the "explosive device added" becomes important.

The event tree structure also affords the opportunity to assign branch probabilities. While probabilities could be estimated for many branches using traditional approaches, others would be difficult to develop. For example, the probability that a fire or explosion will occur following an accident can be estimated by querying existing accident databases. Utilizing demographic data, reasonable estimates of the probability that an HM vehicle will pass close to an attractive target can also be made. The most difficult branch probability to estimate would be that associated with the probability of an intentional act. The pattern of historical terrorist acts cannot be assumed to continue as in a classical risk assessment because the terrorist often makes adjustments based on past experiences and protective features employed around an attractive target. If the protection is judged to be sufficiently robust, the terrorist may choose to select a less attractive target with fewer protective features. These adjustments can affect both the likelihood of a successful attack as well as the relative attractiveness of the various HM. For example, explosives are often a terrorist's tool of choice, but if it became too difficult to obtain in significant quantities, they could become a less attractive tool.

Assuming that a reasonable approach to assigning probabilities can be established, it would then be possible to rank order the risk of an intentional act by hazardous material category as well as the relative importance of each branch that comprises the event. If countermeasures or deterrent strategies can be identified that would change branch probabilities, these strategies could also be ranked in terms of benefit/cost ratio (even if the initiating probability of an intentional act has not been quantified).

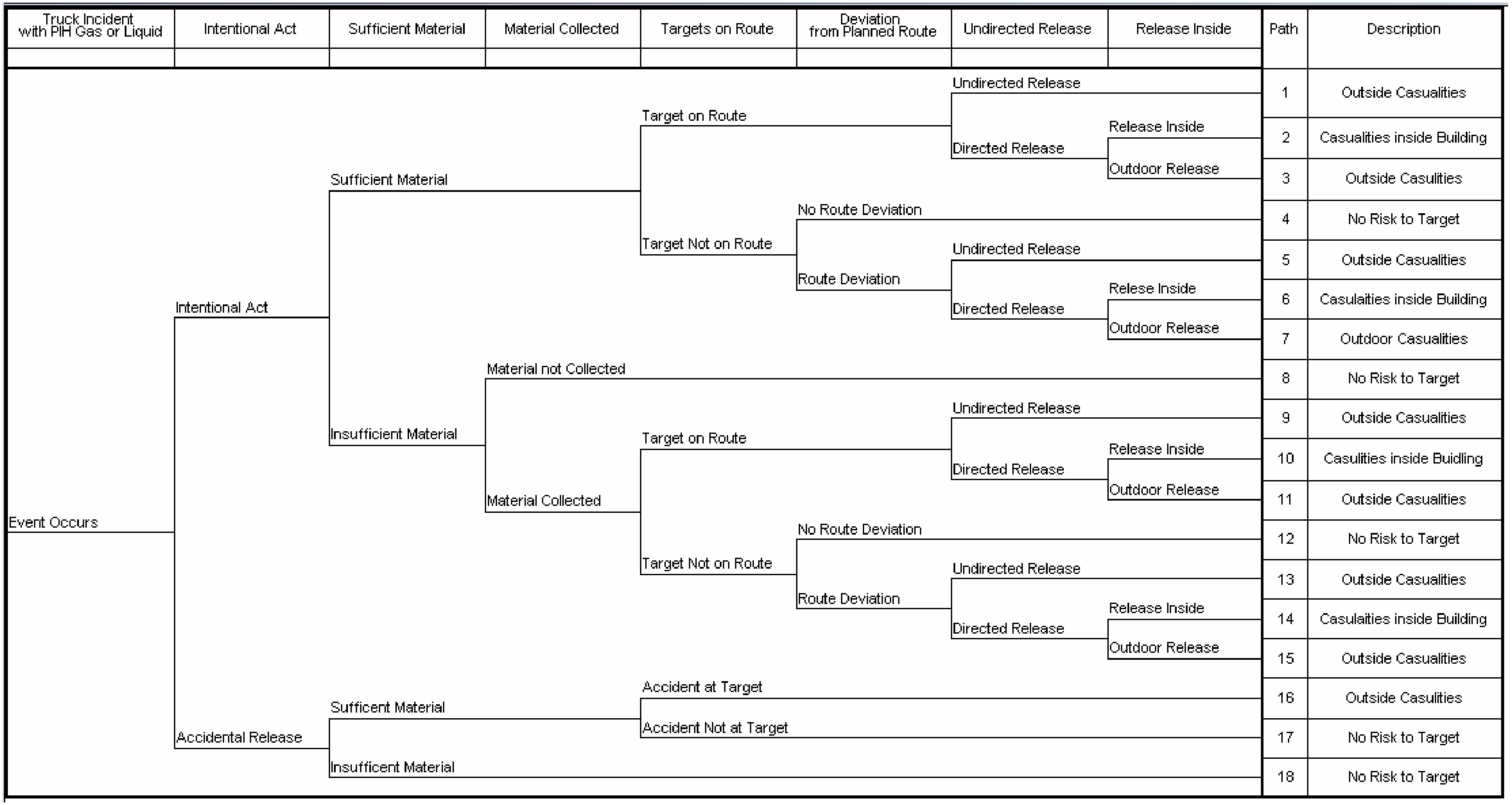

Figure 2. Event Tree for PIH Material Incident

3. Threat-based hazardous materials classification system

As mentioned previously, the consequences that might arise from a terrorist-initiated incident could differ and be more severe than for an unintentional release. This is because the terrorist can select the time, location and other circumstances to maximize the impact of the release.

In its current form, the existing U.S. Department of Transportation (USDOT) hazard classification scheme is not structured to make all of the appropriate distinctions as to how various materials might be effectively used in a terrorist attack. For example, from a safety perspective, it is appropriate to place all explosives in a single USDOT hazard class. To a terrorist, however, sensitive explosives can be used not only to detonate insensitive explosives, but also to detonate reactive chemicals or chemical mixtures that contain their own oxidizer. Thus, from a terrorist perspective, the explosive category has been broadened to include reactive chemical compounds and reactive chemical mixtures that are not currently classified as explosives.

For the purposes of this study, a preliminary modified hazard classification scheme was developed. This scheme is ordered according to the threat of hazardous materials being used for intentional acts. The threat for each of the hazardous material groups was ordered based on professional judgment that considered how a terrorist might use the materials as well as the material's availability, ease of use, and potential consequences. This modified classification scheme, shown in Table 1 along with the respective USDOT hazard categories, considers potential threats while maintaining the original intent of addressing the safety hazards associated with unintentional releases. Those materials judged to have the greatest threat are located at the top of the table and those with the lowest threat at the bottom.

4. Defining threshold quantities and shipment profiles

Intentional acts require the availability of a threshold quantity of a hazardous material to be effective. This quantity differs depending on the HM in question. The following discussion describes the process developed for establishing threshold quantities based on the revised HM classification scheme.

4.1 Threshold quantities

Figure 1 presented two different ways in which a terrorist might consider utilizing hazardous materials in a manner that could result in a major consequence: 1) as a direct hazard where sufficient materials are available to threaten targets and 2) where insufficient materials are available to threaten targets, requiring the terrorist to either add additional similar materials to exceed the threshold quantity or combine incompatible materials that would result in a reaction causing severe consequences. The following discussion focuses on how the threshold quantity concept is applied to each of these scenarios.

Table 1. Revised Threat-Based HM Classification Scheme

New Threat Grouping Name	HM Class/Division in Threat Groupings
Sensitive Explosives	Divisions 1.1, 1.2, 1.3
Reactive Chemicals	Divisions 1.4, 1.5, 1.6, some Class 3, Class 4, and Class 5 Materials
Flammable Gases	Division 2.1 Flammable Gases
Flammable Liquids	Class 3 Flammable Liquids
PIHs	Divisions 2.3 and 6.1 Hazard Zone A and B (PIH), Poisonous Gases and Liquids respectively
Infectious Materials	Division 6.2 Infectious Substances
High Activity Radioactives	Class 7 High Activity Radioactive Materials – > A_2 quantities of normal form or A_1 special form isotopes per package, includes Highway Route Controlled Quantities
Low Activity Radioactives	Class 7 Low Activity Radioactive Materials – commonly medical isotopes and wastes from nuclear reactors or from the processing of radioactive materials
Other HM	Division 6.1 other than Hazard Zone A and B, Class 8 Corrosives, Class 9 Miscellaneous HM, and Division 2.2 Non-flammable Gases

4.2 Direct hazards

What is considered a sufficient quantity of a hazardous material to trigger a major consequence will clearly be a function of the material's basic properties. While this is captured to some extent by the existing HM classification scheme, threshold quantity may differ dramatically among similarly classified materials. To address this consideration, relationships were established between representative materials and threshold quantities within each HM classification (IAEA, 1998). If a single shipment or a combination of shipments results in the threshold quantity being met or exceeded, then sufficient material exists to produce an incident with major consequences. As an example, a tank truck containing 25,000 lbs. of aniline would be considered of sufficient size to produce a major consequence from an unintentional release or an intentional act. Conversely, a shipment of 100 lbs. of sodium cyanide would not be considered a serious threat, unless this shipment is combined with additional sodium cyanide collected from another source.

4.3 Reactions

Reactions can occur in both accident and intentional scenarios. If the reaction is intentional, then the possibility of a precursor being added to the shipment must be considered. Precursors are those materials which, when mixed with a hazardous material being shipped, result in a consequence that is potentially more severe than the consequences should any of the individual materials be released separately. In addition to bulk detonating materials, chemicals that could be detonated by a small quantity of explosive can also be considered as precursors. Moreover, precursors need not be hazardous materials; for example, when water is added to a Division 4.3 material, a violent reaction can be anticipated (Battelle, 1992).

Accidental reactions occur when two packages of incompatible chemicals are involved in an incident and are inadvertently mixed. The DOT regulates these potentially dangerous interactions by requiring segregation among classes/divisions if any member of one class/division is known to
react with a single member of the other class/division (Code of Federal Regulations, 2003). The regulations further specify that two commodities known to react but not specifically segregated by the regulation must be segregated.

Intentional reactions occur when two chemicals are purposely mixed, with the chemical intentionally added considered to be the precursor. As part of this study, some specific examples of adverse reactions that cross the boundaries between hazardous material classes/divisions were developed. The list was not intended to be exhaustive, as the effort to identify all of the hazardous material interactions that could occur was beyond the scope of this study.

The specific examples were intended to serve as a generalized representation of the possible adverse reactions that could occur among chemicals in various hazardous material classes/divisions. In doing so, it was recognized that while two chemicals in two different chemical groups might react, not all chemicals in those two groups will react or react in the same way. For example, benzene and toluene are both aromatic compounds. The reaction of nitric acid with benzene proceeds very slowly whereas the reaction with toluene is much more rapid.

Overall, adverse chemical reactions were judged to affect consequences in three basic ways: 1) when the energy of the reaction is added to the energy of the detonator to make an explosive out of material that would not normally explode, 2) when the package pressurizes and a toxic gas or aerosolized liquid or solid is released, or 3) when a reaction over pressurizes the package and the rupture of the package results in a fireball and an energy release that is less than the equivalent of 100 pounds of TNT.

5. Consequence assessment

As described earlier, the outcome of an unintentional release or intentional act can result in a fire, explosion, toxic release, radioactive release, and/or infectious release, with the impact severity likely to be greater with intentional acts. To estimate the impacts associated with an event, the following consequences were considered:

- fatalities & injuries – attributed to the effects of the hazardous cargo or to other non-hazardous material-related causes
- property damage – damage to the truck, other involved vehicles, or to other public and private property
- product loss – quantity and value of the HM lost during a spill
- environmental damage
- evacuation – predominantly short-term relocation of people and business operations
- clean-up – stopping the spread of a release and removing spilled materials
- traffic delay – additional travel time experienced by the motoring public due to delays caused by the incident
- business disruption – businesses having to reduce or cease operations because the facility is inaccessible, supplies cannot be received, or due to other constraints imposed by the incident

The following discussion focuses on the method used to assess these consequences in economic terms for both safety-related and terrorist-initiated incidents.

As a starting point, the study reverted to an impact assessment methodology previously developed for FMCSA as part of an analysis of the comparative risks of hazardous materials and non-hazardous materials highway shipment accidents/incidents (Battelle, 2001). Focused exclusively on unintentional accidents and incidents involving HM highway shipments, the study estimated the economic impacts associated with actual release events. The same impact categories were considered as listed above, with the exception of business disruption.

In that study, several sources of information were reviewed in order to establish reasonable estimates of the economic impacts of each consequence. A literature review was conducted, as was an empirical analysis of relevant federal and state databases. Impact estimates not readily available from these sources, such as traffic delay, were modeled. Finally, all impacts were converted to dollar values to permit comparison among impact categories and to compile a total impact cost.

The approach to monetizing fatalities and injuries used in this study was to estimate the value of a fatality or injury based on the amount of money that would be spent to prevent them from occurring. Fatality and injury costs were based on valuations published by government sources (NHTSA, 1996), with an inflation factor applied to normalize costs to the current period. This resulted in study values of $3,000,000 for a fatality and $214,000 for an injury.

Based on the relative contribution of each consequence category, a key metric, the "fatality/injury multiplier," was introduced. This represents the ratio of the overall economic impact of an event divided by the "cost" associated with fatalities and injuries. Using this approach, it was determined that an HM highway shipment in which an unintentional release occurs results in a fatality/injury multiplier of 1.2. This relationship holds true for both a typical unintentional release (Type 1) and a reasonable worst-case unintentional release (Type 2).

5.1 Economic cost of business disruption

As the aforementioned cost estimation approach did not include the cost of business disruption, the associated economic impact for this consideration was investigated using information sources related to natural disasters that were not HM in nature, but where the transferability of the findings appeared reasonable.

Of particular interest was a recently completed study on the economic costs of natural disasters performed Australia, (Bureau of Transport Economics, 2001). One aspect of this activity was an examination of the economic effects of a disaster on business activity. Using the concepts of consumer and producer surplus, the study argues that while there may be a significant economic impact due to business disruption on local businesses, the nation as a whole does not suffer a measurable effect. The reasoning is that the loss of supply from disaster-affected businesses will be offset by an increase in demand for similar goods from other businesses, as well as in the demand for disaster-relief supplies (e.g., rebuilding activity following the disaster stimulates the construction industry).

The overarching conclusion is that the gain in the producer surplus by businesses unaffected by a disaster will be roughly equivalent to the loss of surplus experienced by the disaster-affected businesses. One caveat to this argument is that if post-disaster products/services must be sought from overseas rather than domestically or the loss of business production was destined for the export market, there may be different implications on the net impact to the domestic economy.

The implication from this study is that although business disruption can be a substantial cost to a particular business or geographical area, the net economic impact of these disruptions will typically be small. Based on this finding, business disruption costs were dropped from consideration in the impact assessment methodology.

5.2 Relationship of fatality/injury cost to overall economic impacts

With business disruption costs removed from consideration, the aforementioned 2001 FMCSA study represents an important benchmark for estimating the overall economic impacts of HM highway shipment releases. The use of a fatality/injury multiplier of 1.2 for Type 1 and Type 2 releases enables generalized economic impact estimates to be made based on an estimate of human health loss, which is typically the most readily available characteristic when a release scenario is described. For example, if the economic cost of the fatalities and injuries associated with an unintentional release amounted to $3,856,000 (representing one fatality and four injuries), then the overall economic impact of the event would be estimated to be $4,627,200.

For this reason, use of a fatality/injury multiplier is also appealing for estimating the economic impacts associated with intentional acts (Types 3 and 4). What follows is a discussion of how these multipliers were derived.

Due to the lack of literature documenting the overall economic impacts of more severe HM highway incidents, an attempt was made to develop a proxy measure for measuring this effect. Fires were considered a reasonable proxy in that a large-scale hazardous materials incident often includes a fire and/or explosion, affecting multiple residences/businesses and resulting in traffic delays and community disruption. A comprehensive fire impact cost study was recently completed in the United Kingdom, in which an estimate was made of the overall cost of fires on an annual basis in the country (Home Office, 2001). While this included costs associated with anticipation, consequence, and response, of interest to this study are the costs in the latter two categories, since the anticipation category relates to planning rather than contingent costs. Costs associated with consequence and response were further sub-divided into: 1) fatalities/injuries, 2) property loss, 3) fire service response, and 4) business loss.

The fire impact costs of interest are shown in Table 2, along with the results of related studies performed previously in 1993 and 1999, respectively. A comparison of the absolute numbers is not advised, as the methodologies used in each study may not be directly comparable. However, it is appropriate to examine the relative contribution of each fire impact category to the overall cost within each study. These appear as percentages beside the absolute numbers.

Below the totals, the fatality/injury multiplier is shown. While the multiplier varies across the three studies, they are in general agreement that an event of this scale can be expected to have an economic impact that is dominated by losses other than those associated with fatalities and injuries. Note also that the relative contribution of business disruption loss to overall fire impact costs is slight, under ten percent in every case. This result supports the conclusion reached in the previous discussion that business disruption costs are not likely to be a major component of the overall economic impact of a major release.

As this relates to Type 3 and 4 scenarios, one can envision widespread impacts similar in nature to the consequences associated with a fire. For this reason, applying a fatality/injury multiplier of 3.0 was considered a reasonable surrogate for economic impact.

Table 2. A Comparison of Fire Impact Costs by Category

	Fire Impact Costs		
Fire Impact Category	**2001 Study**	**1999 Study**	**1993 Study**
Fatalities/Injuries	1,070 (30%)	1,124 (29%)	1,206 (37%)
Property Loss	1,420 (40%)	1,119 (29%)	850 (26%)
Response Cost	1,020 (29%)	1,312 (34%)	1,018 (31%)
Business Loss	40 (1%)	296 (8%)	216 (7%)
TOTAL	3,550	3,851	3,290
Fatality/Injury Multiplier	**3.32**	**3.43**	**2.73**

Table 3 shows the four incident types and corresponding fatality/injury multipliers. It should be noted that while the fatality/injury multiplier appears to be a viable approach for most "reasonable" worst case release scenarios, there are exceptions where this approach will be of limited use. Most prevalent would be certain release scenarios involving radioactive or infectious materials. In these instances, it may be possible for an entire area to be rendered unusable for an extended period of time with little to no human health effect. The presence of anthrax in the U.S. Senate Building is a classic example of this phenomenon. Development of an alternate impact assessment approach for these special cases was not addressed in this study due to resource constraints.

Table 3. Fatality/Injury Multipliers by Incident Type

Incident Type	**Fatality/Injury Multiplier**
Type 1: Unintentional Release	1.2
Type 2: Worst Case Unintentional Release	1.2
Type 3: Intentional Undirected Release	3.0
Type 4: Intentional Directed Release	3.0

6. Assessment results

The methodology described in the previous section was applied to each HM class for the purpose of estimating the economic impacts of Type 2, 3, and 4 releases. To assist in performing this assessment, scenario descriptions were developed utilizing the event logic presented in Figure 1. The human health consequences of each scenario were used as a basis for deriving an overall economic impact, followed by application of the appropriate fatality/injury multiplier. Where feasible, reasonable worst case accidents were based on actual accidents and then modified to occur at a location where the exposure would have greater. For example, the accident for sensitive explosives was based on an incident in Washington D.C. where a semi truck loaded with black powder overturned near the confluence of two major Interstates. Although in this accident the black powder did not explode, the scenario for the reasonable worst case accident incorporated the assumption that the cargo did explode. The impacts were then estimated based on locating the incident in a densely populated metropolitan area. Economic costs were assigned to deaths and injuries, and then the appropriate multiplier was applied to arrive at the overall impact estimate.

As with unintentional incidents, impact dollar estimates for intentional acts (directed and undirected) were derived by developing scenarios of potential intentional acts, estimating the likely human casualties and corresponding costs, and applying the appropriate multiplier. Note, that there are limited data relating to the actual cost of terrorist acts involving the transportation of hazardous materials and, therefore, limited analyses or data that clearly define the true cost of terrorism. Consequently, the values placed on intentional acts represent best estimates based on the limited data and the professional judgment of the authors.

With the exception of the typical unintentional release category, the results are considered order of magnitude estimates. Moreover, as a reminder, these scenarios are believed to be *reasonable* but no determination has been made to assess their likelihood. Other scenarios with lower consequences might be more likely to be selected by a terrorist.

In reviewing these results, the following observations can be made:

- As expected, the economic impacts increase as release scenarios move from accidents to intentional acts.
- With the exception of radioactive materials incidents, directed releases result in far more serious economic impact than undirected releases.
- The economic impact of safety (accident) and security (intentional act) based releases lead to a different rank ordering of most severe HM categories. In particular, the economic impacts associated with accidents involving flammable and radioactive materials present relatively greater concerns in safety scenarios, with the opposite being true for infectious materials.
- The estimated impacts associated with worst case unintentional and intentional acts suggest that efforts to prevent (rather than manage) these impacts from being realized will have the greatest benefit.
- The impacts for the reasonable worst-case scenarios for both the low- and high-activity radioactive material (RAM) are similar. High-activity RAM is shipped in engineered packaging such that releases are likely to involve very low amounts of material, lessening the potential consequences. Incidents involving shipments of low-activity RAM are more likely to release greater quantities, but the overall level of radioactivity would be similar to that of a release of high-activity RAM.

7. Findings and implications

This study has made a number of important contributions to the evolving challenge of how to ensure both safe and secure transport of hazards materials by highway. This includes both the manner in which safety and security risks should be assessed as well as how to estimate the exposure to and economic impacts of high consequence releases, whether they are accidental or intentional in nature.

A new paradigm was introduced in which both safety and security risks can be evaluated as a systematic, integrated process. This enables risk managers to recognize the full impact of safety and security risk on a specific operation, and allows one to understand the tradeoffs associated with the allocation of resources across safety and security initiatives.

The methodology developed to reflect this paradigm resulted in the creation of a new logic flow diagram for representing safety and security risks, a revised (threat-based) HM classification scheme and a technique for estimating the economic impacts of “reasonable” worst case scenarios for unintentional and intentional releases.

Impact assessments were performed for each release scenario in each threat-based HM category. In reviewing these results, it is apparent that the economic impacts associated with intentional acts far outweigh those of unintentional impacts, particularly when the intentional act involves a directed release. There are also differences in the rank ordering of various HM categories according to economic impact, depending upon whether safety or security criteria are being applied.

It is anticipated that study findings will be used to support government decisions involving hazardous materials transportation regulations, as well as to guide investments in hazardous materials safety and security initiatives. In addition, the methodological tools developed as part of this project can be utilized in future risk studies and management practices, either collectively or stand-alone.

Several areas of improvement have been identified that serve as opportunities for further research. First, more reliable data is needed to identify the number of shipments and shipment weights for HM highway transport in both bulk and non-bulk configurations. This data will help to more clearly identify the vulnerability of shipments in the major HM threat-based groupings. Second, additional methodological work is needed to more effectively establish multipliers for incidents involving infectious and radioactive materials. Data describing impacts for both of these incident types is currently limited.

Finally, additional effort should be expended to develop a spectrum of typical intentional act scenarios for each of the HM threat-based categories. One potential approach to accomplishing this objective would be to use the accident sequences depicted by the branches of each event tree. Determining the branch probabilities for each hazardous material class would provide sufficient information to develop these additional intentional act scenarios. Although this would be challenging due to the limited availability of data on actual incidents, the analysis should help to provide a more useful product for security applications. Quantifying the branch probabilities for each hazardous material class would result in an estimate of the relative intentional risk for that class of hazardous material. Standard sensitivity analysis tools could then be used to rank the importance of each of the branch probabilities relative to overall risk. This approach would enable officials to both estimate the cost effectiveness of detection tools and techniques and rank them in terms of their benefit/cost ratio for shipments of various classes of hazardous material.

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