SAFETY

by

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1. Introduction

The vast majority of lapses in safety in the transport provision cause injury and property damage, but have negligible effects on the environment. However, there are occasions when the release of harmful freight pollutes the environment, and poses a health risk to bystanders. While the official terminology varies, these types of freight are usually referred to as “hazardous materials and wastes” or “dangerous goods.” In the United States, the name is commonly shortened to “hazmats,” which is the term used in this chapter. In addition the term “release” will be used rather than “spill” as it more generically covers incidents involving solids, liquids or gasses, as well as incidents involving fire or explosion.

Some of these releases occur after collisions or other types of crashes. (Note that safety professionals prefer the word “crash” rather than “accident.”) However, many occur due to safety lapses that do not involve crashes and often are associated with loading and unloading of transport vehicles. These include ruptures of hoses, overfilling of tanks, valves that are not properly closed, and structural failure of tanks or other packaging. The foundation for the analysis of hazmat releases is understanding the incentives for firms to provide safe transportation. These issues are considered in a companion chapter in the *Handbook of Transport Systems and Traffic Control* (Savage, 2001). The current chapter provides a more detailed analysis of the subset of crashes or operational errors that cause negative spillover effects, called “externalities,” on third parties.

2. Estimating the Risks

2.1 The Big Picture

It is almost impossible to make risk comparisons across modes or across time. Data on the number and magnitude of releases are not reported in a consistent format across modes. In particular, for some modes, releases that occur during loading and unloading at customers’ premises or occur due to leaks that are not related to crashes are not reported. Unlike passenger transport, where a common metric such as fatalities can be used, it is difficult to compare incidents when the magnitude and the nature of the damage to the environment varies depending on the material involved. Moreover, it is very difficult to obtain data on the amount of various materials shipped each year, making calculation of release rates unreliable.

However, some information is available from government reports. United States rail statistics report that in 2000, there were 7,000 cars containing hazmats involved in crashes. Just less than 15% of these cars sustained damage, and 75 released some or all of their cargo. These crashes, primarily derailments, led to 13 occasions when a total of 5,000 people had to be evacuated from the surrounding area. However, no fatalities were recorded and only one employee suffered a non-fatal injury due to hazmat exposure following a collision or derailment.

On the highways, federal data only relate to trucks engaged in interstate commerce. Crashes involving firms that only provide local transport are not recorded in a central database. In 1999, 2,500 interstate trucks carrying hazmats were involved in crashes that were serious enough that an injury occurred or that a tow-truck was required. In 20% of cases there was a release of the hazmat and on 45 occasions there were some fatalities, mostly when flammable liquids were involved (although it is not clear what proportion were caused by exposure to the hazmat vis-a-vis injuries from the initial crash).

The United States Coast Guard reports that five incidents in 2000 resulted in 90% of the total accidental release of oil into the sea. Two-thirds of the spillage came from pipeline leaks or storage tank ruptures on the shore. There were two vessel-based spills, one resulting from a barge being overfilled at a dock, and the other from the sinking of a large luxury yacht. Pipelines carrying liquids, primarily crude oil and oil products, suffered 147 incidents in 2000 leading to the release of 4.5 million gallons, or seven times that spilled into the sea. Gas pipelines had 234 incidents causing 37 fatalities as compared with only one fatality in oil pipelines.

The number of fatal injuries, totaling about eighty, is a relatively small proportion of the 43,000 annual transport fatalities in the United States. However, the number can vary markedly from year to year due to a small number of rare but catastrophic incidents. High-fatality events in recent years in the United States include the 1996 crash of a commercial airliner near Miami with the loss of all 110 aboard, which was partly attributable to improperly packaged hazmats in the aircraft's hold. There have been other horrendous incidents elsewhere in the world in the past few decades including the deaths of more than 200 in the explosion of a road tanker of propylene at a holiday camp in Spain in 1978, and the deaths by burning of more than 500 Nigerians in 1998 after thieves ruptured an oil pipeline. The same is true for the amount of environmental damage. The grounding of the tanker *Exxon Valdez* in Alaska in 1989 led to the release of fifteen times more oil than was spilled in United States waters in the whole of the year 2000.

2.2 Health Risks Versus Environmental Risks

The risks posed by hazmats are very heterogeneous. It is useful to think in terms of a matrix that plots the risk to the environment on one axis, and the risk to the health of humans on the other. Such a matrix, with examples, is shown in Table 1. This table is an expansion of a table in Dennis (1996) where the health risk is based on standard U.S. Department of Transportation classification and the environmental risk is based on work by consulting engineers for a U.S. railroad. (More detail on classification of materials is given in the chapter by Waters in this handbook.) The extent of the environmental damage depends on whether the material evaporates with little damage, is a solid or pooling liquid (e.g., fuel oil) that is relatively easy to clean up, or is a liquid such as styrene that soaks into the soil and could possibly contaminate the ground water. The table is only a rough guide. The environmental impact depends on the precise chemical formulation of the product, the circumstances and location of the release, and whether after the release the product reacts with other materials or with naturally-occurring substances such as water. Likewise, the health risks to bystanders vary. Incidents involving fire, explosion or the release of poisonous fumes can cause a high level of localized health risk. In contrast, release of crude oil into the sea from a grounded oil tanker does not normally pose a significant threat to human health, albeit that the environmental damage can be severe.

Table 1
Categorization, with Examples, of Hazardous Materials
(with cost per major rail incident from Dennis (1996) in parentheses)

Health Hazard	Environmental Hazard		
	High	Medium	Low
Poison Inhalation	Anhydrous Ammonia, Chlorine (typically the environmental hazard is low, but this is not always the case) (US$1.6m)		
Flammable / Combustible	Phosphorus, Styrene ($4.5 m)	Acetaldehyde, Fuel Oil, Gasoline ($1.9 m)	Liquid petroleum gas (LPG), Methanol ($0.9 m)
Explosive			Ammonium Nitrate, Armaments
Radiological	Nuclear Wastes		
Other hazards such as corrosives	Perchloroethylene, Chloroform ($17.2 m)	Acrylic Acid, Caustic Soda ($0.8 m)	Acetic Acid, Molten Sulfur ($0.7 m)
Not normally a health hazard		Crude Oil	Asphalt

2.3 Quantitative Risk Assessment

There is a large literature in which government agencies, consulting firms and academics have tried to quantify the risks. Because the environmental and health consequences vary so much, these quantitative risk assessment (QRA) estimates tend to be very specific, and often relate to the movement of a given quantity of a certain material between two points. Analyses of this type have practical relevance when shipments can be made by different modes with a variety of routes. QRA models follow the principles of “event trees” which build sub-models and assign probabilities to different stages in the chain of events by which a relatively routine crash or operational error can turn into a major disaster (Rhyne, 1994; Nicolet-Monnier and Gheorge, 1996; Waters, in this handbook). Typically a QRA model will include some or all of the following branches in the event tree:

- (i) the probability that a crash or an operational error occurs,
- (ii) the probability that in the incident, there is a loss of containment of the hazmat,
- (iii) the rate of release of the hazmat from its container,
- (iv) the probability that an external ignition source exists or a fire occurs simultaneously with the release, which might lead to explosive or flammable products igniting or a “boiling liquid - expanding vapor explosion” (BLEVE) occurring,
- (v) the physical properties of the material, and models of how it disperses,
- (vi) the geography, wind speed and direction, or currents at the time of release,

(vii) a model of individual health impacts which depends on the land use around the site of the release, and
(viii) a model of environmental impacts.

In theory, QRA should be able to produce estimates of both health impacts (steps i to vii) and the environmental impact (step viii). However, full application of QRA to environmental impacts is relatively new. It is perhaps not surprising that the severe health consequences of some hazmats have attracted the most attention in a field that is only about twenty years old.

QRA has so many steps, assumptions and sub-models, that there is plenty of opportunity for competing models to produce differing answers. The University of Waterloo in Canada held a conference in 1992 that included an exercise where rival teams used their own models to estimate the risks of transporting three different hazmats (chlorine, LPG, and gasoline) by both rail and truck in a given 100-kilometer corridor (Saccomanno and Cassidy, 1993). The purpose of the conference was to try to identify best practice for the various parts of the QRA model. When measured in terms of expected annual fatalities, the results from the various models varied by orders of magnitude. The ratio of the highest to the lowest estimate for each hazmat/mode pair varied between 10 and 300! Moreover, in the transport of chlorine, the teams disagreed about the relative safety of rail and truck.

Yet the variability in results is to be expected. Analysts really cannot predict precisely where a release will occur, nor its magnitude and impacts. Therefore, unlike a QRA of a fixed facility such as a chemical plant, it is difficult to generalize on the number of people exposed and the physical characteristics of the site of the release. A release on a bridge or in wetlands can have considerable effects on water supply. A fire in a tunnel or other enclosed location is more serious than in an open, easily accessible, location. The effects of a maritime oil spill will depend on the proximity of the coast, direction of currents, presence of flora and fauna, the strength of the waves which will break up the oil, and the amount of sunlight which affects evaporation.

QRA is based on an event tree which can have multiple outcomes, with different probabilities. Consequently it provides information on the full range of possible outcomes, along with their associated probabilities, and not just a single most-likely outcome. The former information is usually displayed using a FN curve. This curve is plotted on a graph where the vertical axis shows the probability (or sometimes the frequency per period of time) and the horizontal axis is the magnitude of the consequences. The latter axis is usually denominated as the number of people killed, but in principle it could be the amount of material released. Both axises are plotted in logarithmic scale to accommodate the large range for both variables. The FN curve shows the probability that an incident of a certain magnitude *or greater* occurring. Consequently, the curve will always be downward sloping (or possibly flat for limited ranges) as illustrated in Figure 1. The precise intercept, slope and shape will vary depending on the nature of the risk.

The FN curve reflects the fact that while most hazmat incidents involve few, if any, fatalities and limited environmental damage, there are “doomsday” predictions of low-probability incidents that could cause mass destruction and a high number of fatalities. It is not difficult to point to at least one example of a major disaster for each hazmat type somewhere in the world during the past century. While large disasters invoke morbid curiosity, not to mention public fear, one should not ignore the relatively numerous smaller incidents. A good example is maritime oil spills. While, the legacies of the *Torrey Canyon* and the *Exxon Valdez* persist decades after the last bird or sea otter has been rehabilitated and the sea shore cleaned, a closer look reveals a different story. A 2002 report by the U.S. National Research Council revealed that 7.7% of oil in the sea originates from spills from tankers. However, three times that amount originates from discharge of bilge water, tank cleaning and loss of ships' fuel oil (none of which are usually included in annual accident reports), spills in port associated with the rupture of hoses during loading and unloading, and failures of dockside tanks and pipes. The pattern carries over to other modes. The probability of a hazmat release is far greater during the loading and unloading of a transport vehicle than it is *en route*, albeit that the quantities released are usually relatively small.

3. Risk Assessment

3.1 Intolerable and Negligible Risks

How should a FN curve be interpreted? A 1983 British Royal Society Report suggested some guidelines on acceptability of health risks. There are some risks that are so "negligible" that they do not merit study and no remedial actions are necessary. Typically, this is thought of as risks that are more unlikely than the probability of being hit by lightning, which is an annual risk of about one in three million. At the other extreme are risks that are so large that they are "intolerable" and should be eliminated even at great cost. The definition of these risks is open to some controversy. For employees of transport firms the often-quoted intolerable annual risk is one in 1,000, equivalent to some of the most hazardous occupations such as deep-sea fishing. The boundary for other parties is often quoted as an annual risk of 10,000. But there is a body of professional opinion that considers that this figure may be appropriate for customers or other people with some economic interest in the activity, but the risk for bystanders should be one in 100,000 or one in a million. To my knowledge, there are no equivalent metrics that deal with hazards that pose environmental rather than health risks. The dashed lines in Figure 1 illustrate how these boundaries may be represented in a FN diagram. The Royal Society report argues that if the FN curve falls beneath the lower dashed line then no further study is warranted. But if all, or parts, of it fall above the upper line then the risk (or at least certain aspects of it) should be ameliorated without regard to cost.

3.2 ALARP Risks

The area between the dashed lines in Figure 1 is called the "as low as reasonably practical" or ALARP region. ALARP risks should only be reduced after society has balanced the risks and the benefits that the product confers. The fact that most risks fall in ALARP region has prompted some critics to conclude that QRA by itself is not a particularly helpful public policy tool. Benefit-cost analysis is the tool of choice in the ALARP region, to provide insight and guidance in situations such as when hazmats could be shipped by a safer alternative mode or routing but at a higher cost, or when risk-reducing, but costly, regulations are proposed.

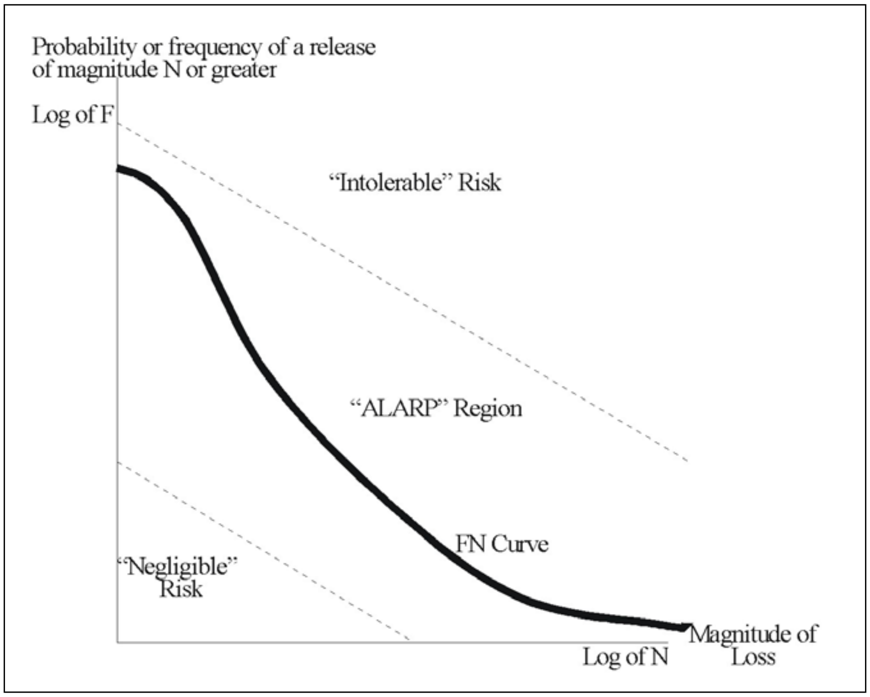

Figure 1: Example of an FN Curve

In an analysis, one side of the balance sheet is derived from the additional operational or capital expenses resulting from the proposed regulation or the alternative routing. Economists assume that these additional expenses will be passed along in higher prices to the ultimate consumer of the hazmat. Most consumers will therefore suffer reduced consumer surplus (the difference between what they are willing to pay and what they actually have to pay), and a few consumers will be priced out of the market. The other side of the balance sheet represents a valuation of the reduced risk of health and environment damage. The change in some types of damages can be measured relatively easily. These pecuniary losses include: the value of lost cargo; the costs of repairing transport vehicles and infrastructure; costs incurred in the cleanup of property proximate to the release; expenses incurred by emergency services; and compensation paid to third parties for damage to their health or property. (As with expenses, these financial items should be translated into their effect on the surplus of the ultimate user of the hazmat.) There are other categories of damages that are not normally measured in monetary terms, such as the pain and suffering from health problems, and environmental damage above and beyond that captured by the cleanup costs and compensation paid to affected parties such as farmers and the fishing industry.

There is a small literature on the magnitude of the damages that are measured in monetary terms (see the chapter by Waters in this handbook). Perhaps the most comprehensive is Dennis (1996), who collected data on financial payments by railroads after major releases of hazmats in the United States from 1982 to 1992. About a third of the payments were for environmental cleanup costs. Legal settlements with property owners and for personal injuries represented 56%, with the remaining 10% representing equipment damage, loss of cargo, and miscellaneous items such as evacuating neighboring residents. He found that the payments varied widely depending on the nature of the hazmat. The average payment, in current prices, for each of the groups of materials that he investigated are shown in parentheses in the various cells of the matrix in Table 1.

It is clear that payments escalate quickly for products with high environmental damage. Dennis notes that in his study the most damaging products are halogenated organic compounds (HOC's) that are commonly used as degreasing agents. These products "are denser than water and penetrate deeply into aquifers. In addition, the standards for remediation are stringent, since some HOC's are suspected carcinogens." Data are also available, from a consultant's report, on payments made following major oil tanker spills in the 1980s. The average cost, at current prices, of the environmental cleanup was $22 per gallon spilt, and legal settlements averaged $125 per gallon. Of course, the cost will vary depending on the circumstances of individual spills. The cleanup cost of the *Exxon Valdez* disaster is estimated to have been in the order of $270 per gallon spilled.

Transport economics has been at the forefront of benefit-cost analysis involving non-pecuniary losses. There is an extensive literature on the value that should be placed on averting a statistical death in excess of purely financial considerations such as medical and funeral expenses and lost wages. There is somewhat less of a consensus on the valuation of the pain and suffering from non-fatal physical injuries and adverse health consequences. Both of these issues are investigated in other chapters in this handbook and will not be elaborated on here. In much of the hazmat literature, the extent of the environmental damage is taken to be equivalent to the costs of the cleanup, site remediation, and the compensation paid to parties whose livelihood depends on natural resources. This has the limitation that animals, plants or fish that are not cash crops appear to have no value. Moreover, there is a perverse implication that a sea otter only has value if it survives and requires time and effort to clean its fur. There is also the assumption that remediation is sufficient to restore the environment to the condition it was before the hazmat release. Clearly in some circumstances this will be true, but it is not always the case. Part of the outcry over the *Exxon Valdez* was motivated by the despoiling of pristine Prince William Sound and its ecosystem.

There has been a long history of economists trying to attach a value to places of natural beauty or to specific species of animals (see Hanley *et al.*, 2001 for a textbook introduction). Calculations are complicated by the fact that scientists are unclear on the long-term environmental impacts of the release of some substances. The early literature used a "revealed preference" approach by arguing that the value of places of natural beauty was at least as much as the expense and time costs that individuals incur to visit these places. More recently, "stated preference" questionnaire surveys have been used to obtain "contingent valuations" from samples of the population. The latter allow for the possibility that some respondents derive pleasure from the knowledge that a particular location or species exists, even if they have no plans to actually visit or to witness the species first hand. This is known as "passive use." Contingent valuation studies are controversial because of the difficulty in asking appropriate questions and the risk of inflated valuation.

4. Market Forces and Failures

The preceding sections have clearly identified that the environmental and health risks are not trivial. But do they constitute "a problem?" After all, society has come to depend on products and manufacturing strategies that require shipment of oil and other hazmats. Where does the balance lie between the benefits and costs? The companion paper in the *Handbook of Transport Systems and Traffic Control* (Savage, 2001) discussed the market forces that combine to provide suitable levels of safety, and the possible reasons why markets may fail to perform properly.

In an ideal world shippers would be knowledgeable about the safety of the transport companies that they contract with, and the shipper ultimately bears both the costs of providing safety and the damages resulting from crashes and releases of hazmats. In such a world, shippers of hazmats are given the correct incentives to choose the level of safety that is not only the best from their point of view, but is also socially optimal. As discussed in Savage (2001), several different safety levels may prevail in the marketplace. There are incentives for shippers of particularly hazardous materials to select transport firms that offer a high level of safety. Shippers of less-hazardous substances may prefer to choose somewhat less safe, but less expensive, transport. Whatever level of safety they choose, it will probably be less than the maximum level of safety that would be technically possible. This is because it is commonly assumed that beyond a certain level of safety, the marginal costs of further ameliorating risk will be larger than the environmental and health damages averted. While society has chosen not to avert some releases, this is a socially-optimal decision because society prefers to bear these residual risks rather pay higher prices for the hazmat and the products that it might constitute.

4.1 Market Failures

The power of market forces to determine level(s) of safety that society desires should not be underestimated. However the power of the market will be lessened by one or more of the following six market failures:

(1) shippers are not aware of the safety performance of the carriers that they use;
(2) shippers have cognitive problems interpreting safety data on carriers;
(3) carriers make myopic safety decisions in order to “cheat” poorly informed shippers by posing as superior safety firms when in reality they provide poor safety;
(4) crashes or hazmat releases impose externality costs on innocent bystanders, which do not figure in the decision making by shippers and carriers;
(5) the probability of a crash or hazmat release depends on the amount of care taken by the carrier and another party, such as collisions between trucks and automobiles, and the initiating parties may not consider the externality impacts on others; and
(6) there is limited competition in the marketplace which reduces the choice of safety levels available to shippers.

Failure (4) is the most germane to this chapter, and will be discussed in detail in the following sections. That is not to say that some of the other failures are not present. Pipelines are characterized by imperfect competition, and trucks carrying hazmat collide with other road users. Imperfect information (failures 1 and 2) is probably less prevalent in freight markets than it is in passenger transport. Hazmat shippers tend to be large corporations who make repeat purchases of transport services. Therefore, they tend to be informed purchasers who can act in a dispassionate way in trading off between the price and safety performance of individual carriers. Moreover, because of their “deep pockets” as large corporations as compared with, say, relatively small trucking firms, hazmat shippers have even more incentive to select carriers in which they have confidence, so as to avoid being a co-defendant in a lawsuit resulting from a release. Firms such as DuPont, the chemical manufacturer, were pioneers in establishing programs to vet the safety practices of trucking firms that they use. Nonetheless, there is always the possibility that an unscrupulous carrier may misrepresent itself to shippers and provide a lower level of safety than desired, yet be willing to do so because they can declare bankruptcy if a large release occurs.

4.2. The Law and Economics of Externalities

Elementary economics suggests that a two-part market failure will result if the externality effects on bystanders are not incorporated (or "internalized") into the decision-making of carriers and shippers (Shavell, 1987). First, carriers do not take into account the losses incurred by bystanders when deciding in the level of safety to provide to shippers. Therefore they offer a lower level of safety than they would if they had to compensate the injured bystanders because there is now less incentive to provide higher levels of safety. Moreover, there is a second failure in that because carriers do not have to pay compensation, they can offer a lower price to shippers. As a result, shippers will purchase "too much" output. Bystanders consequently suffer double harm. Carriers provide less-safe service, increasing the probability of a release, and also increase the amount of exposure to the risk.

This market failure has been recognized for centuries, leading to longstanding legal requirements that carriers pay compensation to bystanders. The analytical rationale for such payments was discussed by Nobel-prize winner Ronald Coase in a 1960 paper. His famous theorem indicated that provided the carriers and bystanders can bargain at negligible costs then the market failure could be removed irrespective of whether the carriers or the bystanders have the "property right." By property right he meant whether the bystanders have the right not to have their health or property injured, or whether the carriers have a right to conduct their business. In the former case, the carriers have to compensate injured bystanders, and in the latter case bystanders have to make payment to carriers to convince them to provide a higher level of safety. The distribution of costs and benefits between the parties differs in the two circumstances, but both are a market resolution of the underlying problem.

In reality, legal precedent has come down in favor of the property right residing with the bystanders. This is because the carrier of hazmats determines the probability of a release and can influence this probability in the most cost-effective way. While it is conceivable that bystanders might take precautions to protect themselves, say by building a barrier next to their property, the law does not normally look for this. (Albeit that in one famous opinion in a complex appeals court case, the judge observed that the best use of land in a particular neighborhood was for a rail switching yard rather than for residential use, implying that the affected bystanders had exercised insufficient care by purchasing property next to the railroad.)

To claim legal damages for losses, bystanders have to file a "tort" law suit under the common law of negligence. The bystander has the burden of proof to show negligence on the part of the carrier. In the eyes of some courts, the bystanders have an even stronger position in that "strict liability" exists. This means that the carrier must pay for losses irrespective of whether negligence can be demonstrated. The legal precedent is an 1868 case in England where the water from a reservoir of a mill flooded a nearby mine. The current *Restatement of Torts* used in the

United States provides for strict liability for “abnormal or ultrahazardous activities.” It is unclear whether this applies to shipments of hazmats. In the United States the case law that supports the application of strict liability is a 1972 case involving the crash of a road gasoline tanker. Yet there are other courts and jurisdictions that have held that bystanders have to demonstrate negligence by the carrier.

With a regime of strict liability, the market failure is removed (Shavell, 1987). The carriers now internalize the externality costs and use it in calculating the level of safety that they offer to shippers. Also, the expected costs of paying damages are incorporated into the price paid by shippers. Consequently, shippers are given appropriate incentives to act in a socially optimal way. For example, faced with high prices due to elevated externality risks, shippers can choose to use a safer mode or route, or decide to relocate their manufacturing plants and warehouses.

This optimal result need not necessarily apply under a regime of negligence. In these situations, the carrier only has to pay damages if it can be shown that they were negligent in providing less than “due care.” One would hope that the courts would be able to define due care consistent with the levels of safety that society would wish a carrier of hazmats to provide. In this case, Shavell demonstrates that carriers have every incentive to provide the socially-optimal level of safety. Unfortunately, by doing so they escape liability and will not have to incorporate the costs of externalities into their pricing to shippers. Therefore a market failure exists because shippers will purchase too much transport and bystanders will face increased exposure to possible harm.

This distinction may have limited practical effect if, in practice, legal settlements approximate strict liability. The standards of proof of negligence may be quite low. Evidence that a train derailed and spilled cargo on neighboring property may be sufficient to prove negligence on the basis of the legal principle of *res ipsa loquitur* (“the facts speak for themselves”). Even if injured bystanders are required to show evidence of negligence, this should be relatively easy to obtain. Most releases are “caused” because someone has done something wrong: an employee has deviated from operating rules; a piece of equipment was not inspected properly; or a particular safety device had not been installed or was not working.

5. Is Liability Sufficient?

It would seem that under legal standards of strict liability, or those that in practice approximate it, that carriers internalize most of the externality. They have to compensate bystanders for losses, and generally pay directly for the costs of cleanup and remediation. In theory, the market failure should be ameliorated. Yet, the considerable public unease with hazmat transport seems to suggest otherwise. Why is this? It is a combination of seven limitations of a liability regime.

5.1 Some Types of Financial Harm are Ineligible for Compensation

Not all types of harm are recoverable. For many years, plaintiffs were unable to recover purely economic losses such as increased business expenses or lost revenue. However, there is a trend to allow such claims. Experienced lawyers suggest that carriers will typically offer to pay for costs incurred by businesses such as cleanup and damage to inventory, but will probably not pay for profits foregone due to the interruption of business. Individuals will be offered compensation, based on their actual hourly wages, if they are unable to go to work due to evacuation of their homes or workplace. People displaced from their homes are usually offered compensation for actual out-of-pocket expenses, but not for any emotional costs they may incur.

Moreover, claims are only permissible if the bystander is both proximate to the site of the release, and is also a foreseeable victim of the accident. Juries have to find an uninterrupted sequence of events from the carrier's actions to the bystander's harm. Major disputes occur when an intermediate event occurs between the initial negligent act by the carrier and the bystander. In a well-known case, the owners of a barge that had spilled oil were found not liable to compensate a sailor on another barge many miles downstream who, several days later, slipped on the oil that had been washed onto his deck.

5.2 Emergency Response Costs are Borne by the Public

Hazmat releases usually require the attendance of emergency services. At the very least, ambulances and the fire department will attend. If an evacuation is necessary, police will be called to help in the evacuation and provide security for the affected area. Local schools may have to be opened to provide temporary accommodations for those displaced, and the Red Cross may be called to provide bedding and food service for the residents and emergency workers. Typically there is no legal liability for carriers to compensate emergency services. Some fire departments do have schemes whereby industrial concerns contribute after a major incident, while other fire departments take pride in the fact that no charge is made for their services. There is a trend for more local authorities to charge for attendance by emergency services.

5.3 Non-Pecuniary Losses

Earlier in the chapter, several types of non-pecuniary losses were identified, comprising pain and suffering from health risks and the despoiling of places of natural beauty and injury to flora and fauna that are not cash crops. Plaintiffs are often able to collect compensation for the former, especially in the case of fatal injuries or long-term disablement. For the latter, there is often not an appropriate party who can file a law suit on behalf of deceased frogs or sea otters. The only legal remedy is for the courts to award punitive damages over and above compensatory damages. These can only be assessed when the court finds that the carrier has engaged in "willful or wanton conduct." It can be argued that uncompensated non-pecuniary losses loom large in the public's view of hazmat transport.

5.4 Liability is not Accurately Reflected in Pricing

Shippers play a vital role in determining the risk to bystanders because they determine the quantity of transport produced, and hence the number of releases that occur. For them to make correct decisions, the prices charged by carriers should reflect the costs of cleanup and liability payments for the specific commodity. Some carriers may specialize in the carriage of only one type of hazmat (gasoline road tankers for example) and can easily build these costs into their pricing. However, most carry many different commodities. For an optimal market solution, carriers should charge different prices depending on the externalities associated with that particular product.

The differences in price may be large. Dennis (1996) extended his analysis of the cost of the cleanup of rail crashes to estimate the cost per car-mile. Products such as LPG that pose a low environment hazard would only pay a risk premium of 0.6% on the basic cost of transport. But products that pose high environmental risks, such as phosphorus, would have to pay a premium of 5.2% and chloroform a substantial 13.6%. If a carrier cannot or does not differentiate in this way, and charges a standard price markup to recoup total release costs and liability claims, then shippers are sent the wrong signal. Such a pricing scheme will result in the transport of *too much* extremely-hazardous materials, and *too little* less-hazardous or non-hazardous materials. At the time of Dennis' study, some railroads had tried to incorporate specific costs into their rate structure, but the practice was not widespread or particularly refined.

5.5 Bystanders Prefer Zero Risk

Bystanders rationally prefer zero risk of externalities, because they believe that the costs of risk reduction are borne solely by the carrier. Consequently they will always lobby for further risk reductions. Of course, it is not strictly true that bystanders do not bear the cost of risk reduction. These costs are passed onto shippers, and will be reflected in the prices paid by consumers of goods that directly or indirectly utilize hazmats. In many cases the consumers and the bystanders may be one and the same, and thus rationally they should trade off the risks and the benefits. However, in practice they may not recognize this connection. In some circumstances, there may be concern that the benefits are widespread but the risks are disproportionately imposed on one group of people. This "environmental justice" argument has particular application to manufacturing plants or toxic waste dumps that may be located in poorer neighborhoods, but can also arise in transport applications such as the location of terminal facilities or the concentration of traffic on certain routes.

5.6 Risk Perceptions may Differ from Reality

There is a school of thought that suggests that bystanders are intolerant of risks even if they are fully compensated for any losses, and are aware that as consumers they will ultimately pay for any risk reduction. This is because they perceive that the risks occur more frequently, and have more severe consequences than is really the case. Carriers and shippers make decisions on safety based on the amount of compensation that is paid for actual harm. But bystanders use other metrics to determine their attitudes to various risk, and these need not be in line with the pecuniary harms.

There is a large literature in which psychometric researchers have asked respondents to rate risks based on various characteristics (see Slovic, 1993). Because most of these characteristics are collinear with each other, factor analysis has been used to boil these down to two major factors. The first is whether the probability and consequences of a risk are known in advance and generally understood. This is referred to as the "unknown factor." The second is that certain types of risk engender "dread." The dread factor is an amalgam of various risk attributes including whether the victim is exposed involuntarily, whether the risk involves a nasty drawn-out form of death, and whether the consequences can be mitigated by the diligence or skill of the victim when a risky situation occurs. Researchers have found that the higher the unknown or dread rating of a risk, the more that society is intolerant of it. In particular, there is a literature dating from the 1960s that suggests that people are far more intolerant of risks to which they were exposed involuntarily compared with risks which they had, in some sense, voluntarily decided to assume.

The perceptions of various risks can be plotted as points on a two-axis diagram, such as Figure 2. The empirical literature seems to suggest that the relevant hazmat risks fall in the shaded area. The exception is the risk perception of nuclear wastes which appears in the top right-hand corner. The perceptions of conventional explosives appear at the bottom of the graph because the consequences of the risk are well understood. Many chemicals are toward the top of the graph because people doubt that even scientists fully understand the long-term consequences of exposure after a release. Because most respondents are involuntary bystanders to these risks, they tend to have high dread factor scores. This effect is heightened because the dispersion of poisonous fumes can endanger people who live or work in places that are distant from obvious sources of danger such as rail lines, manufacturing plants or major highways. Some high fatality scenarios such as explosions of road tankers engender very high levels of dread even though the nature of the risk might be reasonably well known.

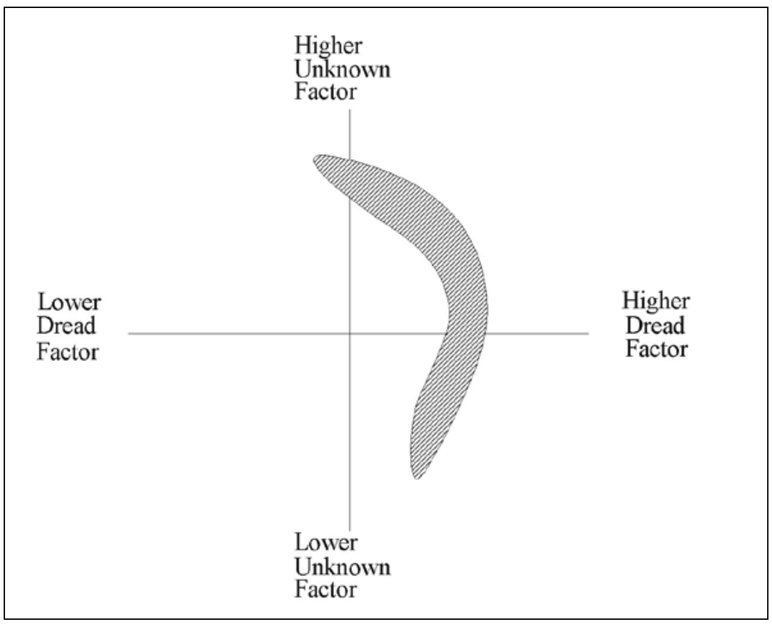

Figure 2: Location of Hazmats in Unknown-Dread Factor Space

The intolerance of hazmat risks is compounded by misjudgments of the frequency of risky events (Lichtenstein et al, 1978). The literature indicates two effects. The first is called "primary bias" and is the tendency to overestimate infrequent causes of death such as botulism, floods and tornados and underestimate more frequent causes such as heart disease and cancer. The crossover point where reality was closest to perception was for risks with an annual probability of one in 225,000 such as appendicitis. All hazmat risks are much smaller than this level. A second effect known as "secondary bias" suggests that people overestimate the frequency of dramatic and sensational events which claim multiple victims at one time, and downplay unspectacular events that claim one victim at a time. Hazmat releases would appear to suffer from an overestimation of frequency on both counts.

The overall effect is that society tends to regard hazmat risks as occurring more frequently, and are of a more intolerable nature, than would be warranted by an analysis of the actual probabilities and losses incurred. This means that society regards the expected externalities posed by hazmats to be larger than the actual legal settlements, and consequently views liability as providing insufficient incentives.

5.7 Liability is an "After the Fact" Remedy

Liability is inherently an after-the-fact, *ex-post*, form of risk control. Carriers only have to bear the externality cost after a release has occurred, is detected, and damages are paid for losses. There is an inherent assumption that rational carriers will take into account the frequency and magnitude of possible losses when deciding on their safety precautions and their pricing. Hazmat releases are rare events, and most carriers will not have direct experience of the consequences of releases. It is easy to argue that many carriers will be myopic in their decisions. Some will do so for avaricious reasons, hoping that a release will not occur, and seeking bankruptcy protection in the event of large adverse legal judgments. Other carriers may act in good faith, but not anticipate the possible environmental costs. After all, evidence earlier in this chapter demonstrates that experts differ by orders of magnitude in quantifying the risks. The implication of this and the other limitations of liability is that society may justifiably demand pro-active regulations and controls on hazmat transport rather than passively accept that the problem will be taken care of by the operation of a legal liability regime.

6. Public Policy

Even legal scholars argue that liability often has to be complemented by before-the-fact, *ex-ante*, safety regulation (Shavell, 1987). There has been a long history of public policy intervention in hazmat transport, dating back to early legislation dealing with the movement of explosives by, or for, the military. A convenient way to catalogue the various possible public policy responses is to work sequentially through the various stages in the event tree of a QRA. That is to say, first look at policies that may affect the probability of a crash or operational error occurring, then those that reduce the probability of the loss of containment or slow the rate of release, and finally those that minimize the effects on the surrounding environment.

Clearly the hazmat problem will be mitigated by more general public policy on safety, which are discussed in the companion chapter in volume 3 of this handbook series (Savage, 2001). If crashes or errors in general are reduced then externalities will fall. Sometimes the relationship is reversed. The presence of externalities motivates the promulgation of general safety regulation. For many freight modes, potential externalities are the primary market failure. If a freight train of non-hazardous materials has a wreck on the private right-of-way, it is certainly an important issue for the railroad, its customers, employees and insurance company, but the public concern is less clear. The same is probably true if a ship carrying lumber breaks up in open ocean. But as soon as a plume of chlorine gas envelopes a small town or oil reaches the coastline, public policy is invoked. The implementing of comprehensive safety regulation of U.S. railroads by the *Federal Railroad Safety Act* of 1970, while a response to generally deteriorating safety, was given impetus by a string of wrecks in 1969 involving ruptures of tank cars containing hazmats in the center of small towns.

While general safety regulation will affect the probability of a crash or operational error, the remainder of the QRA event tree is influenced by specific hazmat regulations. One strand of these regulations deals with ensuring that hazmats are contained following a crash or operational error. This is a design issue. The requirement by Congress following the wreck of the *Exxon Valdez* that oil tankers must be built with double hulls is supposed to reduce the probability of a release if there is a collision or a grounding. For many years a major factor in releases from rail tank cars was the tendency in a wreck for couplers of neighboring cars to ride up and puncture the tank. This risk can be mitigated by mandating the installation of "head shields" that protect the ends of tanks, and by designing the coupler so that its puncturing ability is reduced. Inlet and outlet valves can be designed to reduce the possibility that they are torn away in a crash. Other hazmats are carried in smaller packages or cylinders, and there are design issues regarding the robustness of these packages. The consensus is that packaging standards have been generally non-controversial as they typically specify the performance characteristics for the packaging and the specific design is left up to the industry and its suppliers. Finally there are requirements to reduce risk by placing hazmat vehicles in the center of trains and by ensuring that products that would produce a particularly lethal combination if mixed, are not coupled next to each other.

For some hazmats the main danger is a post-crash fire. Even if the hazmat itself remains contained during the crash, there is the risk of a BLEVE if there is external heating. One solution is to require thermal insulation of tank cars and trucks. This ensures that the internal temperature does not rise above a certain point for a specified period of time despite the presence of external fire. Prompt attendance by fire departments can complement the insulation by extinguishing the fire or applying foam to undamaged tanks to keep the temperature in check.

Discussion of the fire department leads to the next mitigating intervention: the equipping and location of response teams such as fire departments to respond to hazmat incidents. Aside from the suppression of fire, these response teams can contain the rate of release and dispersion of liquid or solid hazmats, and apply some initial remediation. In addition, they work with police authorities to recommend evacuating parties who are in danger. The effectiveness of emergency response depends on the ability to quickly determine the nature of the hazmat involved and applying the proper procedures and precautions. Public policy has required the placarding of hazmat vehicles with information on the specific cargo and the hazards posed. There have also been requirements that vehicles contain detailed manifests and carriers provide a 24-hour telephone service that emergency services can call to obtain information. Government has also worked with industry to produce emergency response information that is provided to fire departments.

Fire departments are usually the first responders to hazmat releases. In locations, such as large industrial cities, the departments are well trained and equipped to deal with chemical and other industrial fires. However, many serious truck and rail releases occur in small towns and rural areas where the fire department usually only responds to domestic and agricultural fires and routine highway crashes. In many cases, the departments are staffed by volunteers. The extent to which additional training, protective clothing, special equipment and remediation agents are provided to these departments is a costly public policy issue.

In some cases, a limited number of specialized hazmat response teams are formed. Some large shippers or industry associations may support hazmat response teams. An analytical issue is where these teams should be located so as to minimize average response times. There is a large literature on this subject, a literature which is interwoven with that on a related issue: the choice of routes for hazmats. Road transport obviously provides considerable flexibility, but rail often has several possible routes. Tradeoffs exist between longer routes that increase the time that hazmats are in transport, and use lower quality roads, yet pass through less-populated areas. Public policy might use these analyses to mandate that hazmat travel be concentrated on a limited number of less-populated or less environmentally-sensitive corridors to facilitate provision of emergency response teams. Models of this type are typically based on QRAs (for an introduction, with examples, see the papers by Abkowitz (1993) or Turnquist and List (1993) or the review by Waters in this handbook). Such models can also be used for modal choice decisions. Sometimes it may be more desirable to move certain hazmats by road rather than rail because, while trucks might have a higher crash rate, they can be routed around populated areas whereas the railroad has traditionally operated through the center of towns.

7. Summary

Movement of hazardous materials is a fact of modern industrial society, and transport has an inherent risk of crashes and operational errors. While the probability of a loss of containment of hazmats is small, some materials pose considerable dangers both to humans and the environment. Because of the nature of some of these risk, psychologists have found that people tend to overestimate the probability and consequences. Due to this and other factors, legal mechanisms that require victims to be compensated for actual losses are seen as inadequate to provide for the level of safety demanded by society. Public policy has intervened by working with transport firms on the packaging of hazmats, routes to reduce public exposure and the provision, equipping and training of emergency response teams. Analytically, the desirability of these policies can be determined using quantitative risk assessment (QRA) models. These models are multifaceted and dependant on many sub-models and assumptions. Rival models can provide very different results and divergent conclusions. They also tend to focus exclusively on the effects on humans. There is much work still be done on evaluating the probability and the consequences of hazmat releases on the environment.

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