PROCEEDINGS —

Twenty-fourth Annual Meeting

Volume XXIV • Number 1 1983

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TRANSPORTATION RESEARCH FORUM

PROCEEDINGS —

Twenty-fourth Annual Meeting

Theme:

"Transportation Management, Policy and Technology"

November 2-5, 1983
Marriott Crystal City Hotel
Marriott Crystal Gateway Hotel
Arlington, VA

Volume XXIV • Number 1 1983

TRANSPORTATION RESEARCH FORUM

Risk Analysis: Regular Implications for Dangerous Goods Transportation

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ABSTRACT

THIS PAPER attempts to review the existing theories, methodologies, and empirical studies of risk to derive meaningful regulatory implications. Existing theories of risk attempt to explain it in terms of an expected value and/or variance. Empirical studies reveal that estimated risk varies according to a number of factors: the mode of transport for given types of dangerous goods, route characteristics, population density adjacent to the route, types of dangerous goods, types of transport equipment utilized for a given mode, and the speed agent releases from the container. To further improve safety, a comprehensive system of safety measures is required, including: (i) development of a data base; (ii) risk analysis and evaluation programs; and (iii) implementation of safety programs.

INTRODUCTION

Just before midnight on Saturday, November 10, 1979, a CP Rail freight train derailed at Mavis Road in the City of Mississauga, Ontario. Among the 24 rail cars that were derailed were 21 tank cars, 19 of which were carrying dangerous commodities such as chlorine, propane toluene, and caustic soda. Fire ensued and three cars carrying propane exploded causing considerable damage to neighbouring properties. Almost a quarter of a million people were evacuateed from their homes and businesses for periods of up to six days in order to prevent possible harmful consequences from chlorine gas which was released from one of the tank cars. After the spectacular derailment at Mississauga, railway safety in relation to dangerous commodity traffic received nationwide attention. Derailments involving dangerous commodities, however, remain possible.

Estimates by Transport Canada (1980 a and 1980 b) for 1979 indicate that 207,371 cars carried dangerous commodity traffic by rail in Canada while the for-hire truck industry made 1,047 shipments (i.e., about 22 million metric tonnes) during that year. Total dangerous commodity shipments as a percentage of total commodity traffic by the for-hire trucking industry was about 3.2% in 1979. Unfortunately, a similar figure for railway traffic is not available at this moment. There were, however, 350 derailments which took place during that year, and 42 cases or 12% of the total derailments were accidents where dangerous commodities made up all or a portion of the train involved in the mishap (Canadian Transport Commission).

Since derailments involving dangerous goods continue to remain a top national concern, it seems appropriate to develop an appreciation and understanding for the subject of risk analysis and its application to the field of transport. Such an endeavor entails a review of the existing theories, methodologies and empirical analyses. This insight may prove useful in the formulation of improved safety regulations.

The objectives of this study, therefore, are threefold: i) to review literature on the theory of risk and methodologies applicable to risks associated with dangerous commodities transportation; ii) to review empirical studies and evaluate their findings from selected studies; and iii) to assess regulatory implications in relation to dangerous commodity traffic.

THEORY OF RISK

(1) Concept of Risk

A review of the literature on risk analysis appears to offer no universal consensus as to the notion of risk. The term has been employed in numerous fields of endeavor ranging from finance to mathematical statistics. Inasmuch as the notion of risk differs depending on the field of application, the respective theory of risk inevitably varies accordingly. Following the statistician's approach for example, the definition of risk commonly adopted is in terms of losses (consequences) and their respective probabilities. In actuarial literature, the word "disk" traditionally followed Tetens' definition of "one half of the mean deviation." This terminology, now obsolete, persisted in actuarial circles until the Second World War, and led to the eventual development of risk theory (Borch). Economists may recall Frank

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Knight's distinction between the concepts of "risk" and "uncertainty." According to Knight, risk is present in a situation where an action can lead to several different, mutually exclusive outcomes each of known probability. If these probabilities are unknown, the situation will, according to Knight, contain uncertainty (Hirshleifre, p. 215). Recently, this distinction between risk and uncertainty has become less clear because the Bayesian approach to probability assumes that all probabilities are subjective and that there is hardly ever a complete lack of knowledge. The development of the Bayesian approach to statistics and decision theory seems to have made Knight's distinction between the concepts obsolete, or at least to indicate that the distinction is not essential to a systematic study of the subject (Borch).

(2) Theories of Risk

Since the notion of risk differs depending on the scientific field, the respective theory of risk will inevitably vary to some extent. In addition, there exist different theories for risk preference, risk estimation and risk management. For the purpose of this paper, only theories related to risk estimation will be discussed.[1]

Modern Utility Theory

Modern Utility Theory (pioneering work of vonNeumann and Morgenstern) treats risk in the following manner. A lottery, L, is defined as a probability distribution over outcomes, i.e., the lottery yields outcome x_i with probability P_i, where $i = 1, 2, \ldots, n$. The uncertain outcomes of a lottery are conceived as a random variable $\tilde{x}$. The expected outcome is given by

$$\bar{x} = E\,[(\tilde{x})] = \sum_{i=1}^{n} p_i x_i \qquad (1)$$

and the expected utility by

$$E\,[u(\tilde{x})] = \sum_{i=1}^{n} p_i u(x_i) \qquad (2)$$

where $u(x_i)$ denotes the utility attached to outcome x_i. It is assumed in this theory that the decision-maker wishes to choose the lottery which maximizes expected utility.

The certainty equivalent of a lottery is the amount $\hat{x}$ such that the decision-making is indifferent between lottery L and the sure thing (riskless) $\hat{x}$. The utility of $\hat{x}$ is given by $u(\hat{x})$, the utility of the lottery is defined by its expected utility in equation (2), so we have:

$$u(\hat{x}) = E\,[u(\tilde{x})] \qquad (3)$$

The certainty equivalent $\hat{x}$ is smaller than the expected outcome of $\bar{x}$ of lottery L; this is generally true for all risk averse decision-makers who have increasing utility functions over non-degenerate lotteries.[2]

The difference between $\bar{x}$ and $\hat{x}$ is called risk premium (RP), as shown in Figure 1, since the decision-maker is cautious in the sense that he is willing to give up some amount as compacted with the expected outcome in order to get a smaller amount $\hat{x}$ for sure:

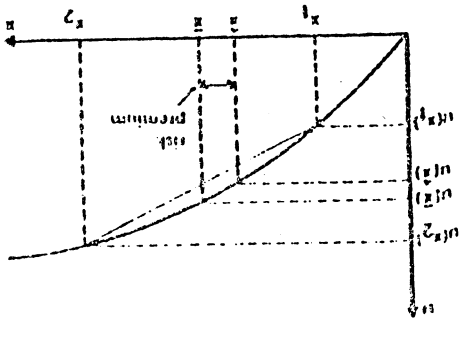
$$RP(\tilde{x}) = \bar{x} - \hat{x} \qquad (4)$$

In other words, the risk premium equals the difference between the expected consequence $(\bar{x})$ and the certainty equivalent $(\hat{x})$.

Expected Risk Theory (Huang's)

Huang (1971) proposed a theory of risk in which "risk" is defined as expected risk:

EXAMPLE OF A UTILITY FUNCTION OF A RISK AVERSE DECISION MAKER



Source: Schaefer, Ralf E., p. 10.

FIGURE 1

$$ER = \sum_{x \epsilon X} P(x)\, f(x) \quad (5)$$

where ER = expected risk; f = a real valued function on x, the risk function; $x \epsilon X$ = an outcome, or consequence; P = a probability measure on X; and X = the set of all possible outcomes.

A lottery or gamble g_1 is subjectively not more risky than g_2, $g_1 \underset{\sim}{L} g_2$ if the following conditions are fulfilled[3]:

$$g_1 \leq g_2$$

$$\text{iff } r(g_1) \leq r(g_2);$$
$$\text{iff } \sum_i P_{1i}\, f(x_{1i}) \leq \sum_i P_{2i}\, f(x_{2i})$$

Lottery g_1 is no more risky than g_2 if the risk value of g_1 is less or equal to that of g_2, which is the case if the weighted sum of the risk values of the outcomes, i.e., $f(x_i)$ or g_1 is not greater than that of g_2. The weights are the probabilities of occurrence, therefore, the risk function is called expected risk function.

Expected utility theory is a special case of expected risk theory in that the probability component is the same, but $u(x_i)$ is replaced by $f(x_i)$. Expected utility for discrete probability distributions can be written as:

$$EU = \sum_{x \epsilon X} P(x)\, u(x) = \sum_{x \epsilon X} [u(x) - x]\, p(x) + \sum_{x \epsilon X} p(x)$$
$$= EV + \sum_{x \epsilon X} [u(x) - x]\, P(x) = EV + R \quad (6)$$

where EU = expected utility; R = the influence of a "risk" factor which relates the expected value to the expected utility; and EV = the expected value.

Pollatsek and Tversky's Risk System

Risk theory developed by Pollatsek and Tversky (1970) is based on a set of assumptions on the orderings of perceived risk. A relational system such as $< S, O, \underset{\sim}{>} >$ is a risk system if the axioms of extensive measurement (i.e., weaker order, monotonicity, compatability, positivity, solvability, archimedean, etc.) are fulfilled. A relational system leads to an important theorem: if $< S, O, \underset{\sim}{>} >$ is a regular system, then there is one and only one θ, $0 < \theta \leq 1$, such that for all A, B in S (with finite expected value and variance):

$$A \geqq B \text{ iff } R(A) \geqq R(B), \text{ with}$$
$$R(A) = \theta V[A] - (1 - \theta\, E[A] \quad (7)$$

where V = variance; E = expected value; S = A, B, C, . . . probability distribution over R; $\underset{\sim}{>}$ = binary relation of corporate risk, i.e. "$A \underset{\sim}{>} B$," is to be read as "A is at least as risky as B."

This result shown in Equation (7) states that, in a regular risk system, a risk ordering is generated by a linear combination of expected value and variance, i.e., the perceived riskiness of a lottery depends only on the expected value and the variance and on a single parameter, θ, which, of course, is person specific.

Actuarial Theory of Risk

The actuarial risk theory, to a large extent, was developed outside the mainstream of the probability theory and mathematical statistics.

Most people dislike risk, and are willing to pay something to get rid of it. The function of an insurance company is to accept and carry risk against compensation, in the hope of usually making profits. The basic concept in insurance is the insurance contract. An insurance contract by definition will give a person—the insured—the right to claim an amount of money, S, from the company, if certain events should occur. The insured pays the company a premium, P, to be entitled to this right.

If the probability of events leading to a claim is p, the premium is determined so that

$$P = pS \quad (8)$$

This equation illustrates the principle of equivalence, which constitutes the very foundation of insurance theory. This principle states that the expected value of claim payments under a contract should be equal to the expected value of premiums received.[4]

A more general insurance contract can be defined by using a probability distribution F(x), where F(x) is the probability that claim payments under the contract shall not exceed x. The net premium for this contract is, by the principle of equivalence,

$$P = \int_0^\infty x\, dF(x). \quad (9)$$

In order to obtain a measure of the risk of a contract, Tetens defined risk as expected loss to the company, if the contract leads to a loss. This gives the risk as:

$$R = \int_{P}^{\infty} (x - P)dF(x) =$$

$$\tfrac{1}{2} \int_{O}^{\infty} |x - P|dF(x). \qquad (10)$$

Tetens' definition shown in Equation (10) led to suggestions that risk should be defined as (standard deviation of claim payment), where M is determined by the following equation:

$$M^2 = \int_{O}^{\infty} (x - P)^2 \, dF(x). \qquad (11)$$

The Equation (11) represents actuarial risk in the classical theory of risk.

Despite the numerous theories and approaches to the subject, a common element involved in risk estimation appears to be the notion of the variance or some deviation from the expected value. As will be evident from the subsequent sections, the methodological approach to risk estimation involves an additional step. Once the probability distribution has been ascertained, the variance is known. The level of risk according to operations research literature is then the product of the probability and a consequence component.

RISK ANALYSIS METHODOLOGIES APPLICABLE TO DANGEROUS COMMODITY TRANSPORTATION

In applying risk analysis to the subject of transportation of dangerous goods, certain methods would appear to be more appropriate, namely: the Delphi Estimation Process, Bayesian Statistics, Fault Tree Analysis, and the Expected Value Model (e.g. Atzinger et al.; Philipson et al.; Horodniceanu et al.). Analysts may often use a combination of methods in the estimation of risk and associated costs.

(1) Delphi Estimation Process

The Delphi process is a method of developing values for the parameters associated with a risk analysis model (e.g., likelihood and cost) from subjective estimates by experts. This method is particularly useful in cases in which adequate statistical data does not exist.

The Delphi process employs an initiation period and three successive survey and analysis phases. In the Initiation period, a panel of experts is assembled. The panel focuses on the development of accident likelihood data, normal shipment costs, and the average costs of accidents for different possible accident severity classes under normal transportation environmental conditions. It is emphasized to the panel members that the responses given in the questionnaires will be held in strict confidence. The results of the analysis of each questionnaire are summarized statistically with no identification of individual inputs. The final results are a group assessment and not an individual projection.

This Delphi method can be integrated with Bayesian statistics by combining the Delphi estimates with statistical data from observations of accident frequencies and costs. The Delphi process that has been described results in the values of the lower and upper limits of the middle 50% range of each likelihood estimated, as well as an estimate of the likelihood value itself (given by the mean of the estimates provided by the panel). If a particular distribution function is assumed by the panel to hold for the set of estimates of this likelihood, these 50% limits and the mean will, in most cases of practical interest, permit the specification of the parameters of the distribution. This distribution can then be assigned to the role of the **a priori** distribution in a Bayes revision process, becoming improved when a sample of actual accident experience data is introduced. The mean of the improved distribution then provides an imposed estimate of the value of the likelihood under consideration, combining both the Delphi and sample information.

(2) Bayesian Statistics

Bayesian statisticians believe that it is possible, at any time, to express the state of knowledge about a random variable in the form of a possibility density function. Any quantity whose value is unknown is considered a random variable by Bayesians. As additional experimental evidence becomes available, Bayes' Theorem is used to continue this evidence with the previous probability density function in order to obtain a new posterior probability density function representing his updated state of knowledge. In turn, this serves as a quantitative basis for any future decisions.

A Bayesian statistician attempts to show how the evidence of observations should modify previously held beliefs in the formation of rational opinions, and how on the basis of such opinions and of value judgements, a rational choice can be made between alternative available actions. He is concerned with judgements in the face of uncertainty, and he tries to make the process of judgement as explicit and orderly as possible.

(3) The Expected Value Model

The risk calculation for any given segment of the transportation system is determined by an expected value risk model. It computes the probable number of injuries, fatalities, and dollars of property damage associated with the transport of dangerous commodities summed over all possible events.

"Expected value" is defined as the likelihood of a loss-generating event times the amount of loss resulting from that event. In this model, all loss events must be preceded by an incident: splash, fire, explosion, etc. And, since all possible occurrences leading to loss events must be considered, the model requires a summation of the expected value of loss for each type of incident.

It has been assumed that risk would change along a route according to the phase of transport operation underway and according to the demography associated with each phase. Therefore, risk values are determined separately for each segment and are then summed across all segments for an entire route.

According to this model, "risk" is the product of a level of loss for each segment (in injuries, fatalities, or dollars of property damage) and the likelihood of incurring that level of loss. In turn, this loss is really the product of three likelihoods: that of an accident, the probability of an incident given an accident, and the probable severity level given that incident. The term "accidents" refers to those events during any part of a shipment which are potential causes of incidents. "Incidents" are the unintended release of hazardous materials. "Severity levels" are usually described in terms of injury, fatality and damage radius with respect to incident location.

(4) Fault Tree Analysis

Fault tree analysis (FTA), similar to decision analysis, depicts a graphic diagram of decisions that lead to a major failure. It provides information to enable the assessment of the magnitude of the potential hazards that exist. Fault tree analysis is a technique which uses logic diagrams to represent and record a deductive reasoning process. This type of analysis serves as a useful aid in identifying structural or design failures and human errors.

The foundation of a fault tree is the notion of "logic gates," which was borrowed from the field of electrical engineering. The gates indicate whether a single event or a combination of them is required to produce the next level of events. To perform a fault tree analysis, only two types of gates are necessary: AND and OR gates. The AND gate is defined as a logical operation which produces an output event requiring the coexistence of all the input events. The OR gate is defined as a logical operation which produces an output event if one or more of the input events exist.

EMPIRICAL STUDIES ON RISK ANALYSIS BY MODE OF TRANSPORTATION

Four major empirical studies were selected to illustrate risk analysis and their empirical findings. Philipson et al. (Research Center of the University of Southern California) investigated the feasibility of applying the Delphi process to develop subjective estimates of parameters of the risk analysis model. The study combines estimates of various likelihoods of several types of accidents (e.g., enroute, loading/unloading, leaks, externally caused) with hazardous materials, likelihoods of several severity classes consequential to accidents (e.g., explosion, fire and escape of toxic liquids or gas), and the costs potentially accruing to the occurrence of a particular type of accident. The specification of the model is:

$$\text{Total Cost} = \text{Normal Cost} + \text{Risk} \qquad (12)$$

where the normal cost is that of shipping the particular material in the specific manner defined, and for the given instance. Risk has three components including expected property damage, injuries, and fatalities.

The risk model is specified as

$$R_i = \sum_{j}\sum_{k}\sum_{l} L_{ijkl}\ D \cdot C_{ijkl}\ D \qquad (13)$$

where $L_{ijk}D$ denotes likelihood of an accident due to kind j, resulting in severity class k and causing loss of kind l; $C_{ijkl}D$ refers to cost of an accident due to kind j resulting in severity class k and causing loss of kind l; i refers to index of alternatives involving mode, material, route, etc.; j refers to index of accident kind such as enroute accidents, loading/unloading, leaks and container failure, and external causes (fires, etc.). In estimating parameters associated with the normal cost and the risk component of the model, Philipson et al.

used the Delphi process. Philipson et al. have concluded that very low risk accrues to a single shipment of H_2S (hydrogen sulfide) in any of the four modes considered—tank truck, flat bed truck, rail tank car, and rail flat car. By comparing relative levels of risk among four modes, Philipson et al. concluded that the rail tank car has the lowest risk and total cost. Moreover, the tank truck has the highest risk with an estimated total cost below average.

Garrick et al. (Holmes & Narver, Inc., Los Angeles, California) developed a working mathematical model to evaluate the risk associated with handling and transporting biological weapons in stockpile-to-target-sequence (STS). The risk is measured in terms of the number of initial infections which may be expected when transporting a specific biological weapon system through an identified STS. Actual computation of risk is performed by organizing STS's into a network of storage nodes and transportation links. For each node and link (S), a set of probabilities, P(S,Q), is generated for discrete magnitudes, Q, of giological agent release. Concurrently, the number of people infected N(S,Q), is estimated for each release magnitude. The expected number of infections at location S with the transport of one bioweapon is formulated as:

$$E(S) = \sum_{\text{all } Q} P(S,Q)N(S,Q), \qquad (14)$$

for each set of nodes and links which form an STS path, P. A risk estimate, R(P), for that path is therefore,

$$R(P) = \sum_{S \epsilon P} E(S). \qquad (15)$$

Garrick et al. derived minimum and maximum risk estimates based on four sets of situations (standard case, expedited delivery, changed agent and changed container). The minimum risk, 2.75×10^{-10} infections/trip, would be achieved when transporting the agent in an improved shipping container via the shipbased route (i.e., STS path 1). The maximum risk, 1.38×10^{-5} infection/trip, would occur with expedited delivery via the air route (i.e., STS path 2). In addition, Garrick et al. examined the relative significance of three release types: instantaneous, large continuous, and small continuous. Results show that the instantaneous release (type 1) is the dominant source of risk.

Kloeber et al. (ORI, Inc., Silver Spring, MD), conducted a risk assessment study comparing the transport of certain hazardous materials by air with the transport of these materials by alternative modes—rail, highway and water. The materials analyzed were Class A Explosives (CAE) namely TNT, dynamite, Slurries and blasting caps, and Flammable Cryogenic Liquids (FCL) such as liquid hydrogen (LH_2).

The risk calculation for any given segment (S) is determined by an expected value risk model. The specification of the model is:

$$R(S) = \sum_{ijk} L(i)S \cdot L(j/i) \cdot L(k/j) \cdot C(jk)S \qquad (16)$$

where R(S) is the likelihood of incurring a certain level of loss; L(i)S is the likelihood of accident type i in segment S; L(j/i) is the likelihood of incident j given an accident i; L(k/j) is the likelihood of loss in severity level k, given incident j; and C(jk)S is the potential loss associated with severity level k and incident type j in segment S.

Kloeber et al. estimated risks in terms of the expected number of injuries, fatalities, and dollars of property damage associated with the air and non-air route alternatives. The relative risks of the air alternatives, for both CAE and FCL carriage, are generally lower than their respective non-air alternative routes. However, relative risks among modes are highly route dependent. The reason for the lower air risks is due to the low risk characteristic of the inflight phase. Air is relatively safe over longer distance routes, since its risks are more contingent upon take-off and landing than on distance. Rail risks, on the other hand, are dominated by terminal risks due to high population densities surrounding rail terminal areas, and highway risks are dominated by truck accident rates and by population densities.

Ang et al. (Department of Mechanical Engineering, University of Illinois) developed the overall framework for the systematic risk analysis. The basic risk model is:

$$f_A = \sum_{i=1}^{n} P(A/f_i) \cdot f_i \qquad (17)$$

where f_A is the frequency of accident A; f_i is the frequency of fault i; $P(A/f_i)$ is the proportion of fault i that will lead to accident A.

Ang et al. have demonstrated practical usage of the model by using numerical illustrations of three modes of transportation—air, highway, and rail. Let us take the Highway mode, for example, Ang et al. considered specific factors on accident occurrence such as the steering free play, tiretread depth, brake lining thickness, and tire inflation pressure since these factors account for the majority of vehicle accidents. Fault trees for the highway mode were also developed and they were divided into the human, machine (i.e., vehicle) and environmental aspects in the process of illustrating the model.

Based on the review of selected empirical studies, it was found that the estimated risk varied according to a number of factors: the mode of transportation for given types of dangerous goods, the route characteristics, the population density adjacent to the route, the type of dangerous goods, type of transport equipment utilized for a given mode, and the speed of release of agent from the container.

REGULATORY IMPLICATIONS

Regulations pertaining to the transportation of dangerous commodities in Canada are administered by a number of Federal government agencies. Railway regulation is administered by the Railway Transport Committee (RTC) of the Canadian Transport Commission (CTC). Air and water modes are regulated by the Regulations and Licensing Branch of the Civil Air Operations and Regulations Division and the Marine Regulations Branch, respectively, of Transport Canada. Regulatory authority over the transport of dangerous commodities by road[5] and by private railway rests with the Explosives Division of the Department of Energy, Mines and Resources. It should be noted that because of the difference in conditions between the various forms of transportation, commodities classified as dangerous for one mode of transportation may or may not be so classified for the other modes of transportation. Therefore, in cases where more than one type of transportation is to be used, the shipment must satisfy the regulation of each.[6]

The Transportation of Dangerous Goods Act, which applies intermodally, was proclaimed in 1980 and is designed to augment existing regulations. The Act will be directed at federal transport undertakings, including railways which are governed by the Railway Act[7] of Canada, all air transportation, all marine and water transportation and highways that cross provincial boundaries.

Regarding transportation of the rail mode, which is administered by the Commission, the Railway Act[8] of 1903 (and subsequent amendments) provides most of the railway safety requirements which include: inspection, accident investigation, and grade crossing and dangerous commodities safety-related activities. The RTC inspection programs include: track, car and locomotive operations, dangerous commodities, fire prevention, mechanical equipment, structures, signals, and grade crossings.

To further improve safety associated with dangerous commodities transportation, regulatory agencies may require a comprehensive system of safety measures which include (i) the development of data base programs, (ii) the development of risk analysis and evaluation program, and (iii) the implementation of safety programs. The interface of such a comprehensive system is illustrated in Figure 2.

(1) The Data Base

Accident occurrence by location, material, mode, type of container, severity level and associated costs of property damage are the kinds of basic information needed for risk analysis. These data enable the estimation of the incident type and severity loss likelihoods and costs required for the risk analysis model. Supplementary data such as causes of certain types of accidents over time is also needed to develop predictive models on accident causes and effects. Data requirements for such a causality model are freight-train activities (e.g., train hours of operation, miles of track, freight car-miles, various measures of operating expenses, dangerous commodity traffic, etc.).

The foundation for evaluation of safety prospects rests on the answers to the questions, "What causes accidents?" and "What can be done to reduce their incidence and severity?" The answers to these questions—cause, effect, and remedial or preventive action—must be expressed, ideally, in physical terms so that risks and benefits can be identified and quantified. It is not sufficient to know the percentage of deaths and property damage caused by 'derailments,' it is necessary to know why derailments occur, what the probability of derailment is, and how a specific action will change the distribution of derailments and the distribution of the consequences of derailments (Schwier, Lake and King).

(2) Risk Analysis and Evaluation

Risk analysis offers one of the planning costs necessary to cope with the anticipated problems related to public safety. Risk analysis, therefore, provides a prediction model from which regulators might benefit by obtaining the fol-

INTERFACE OF ACCIDENT DATA, RISK ANALYSIS, AND SAFETY REGULATIONS

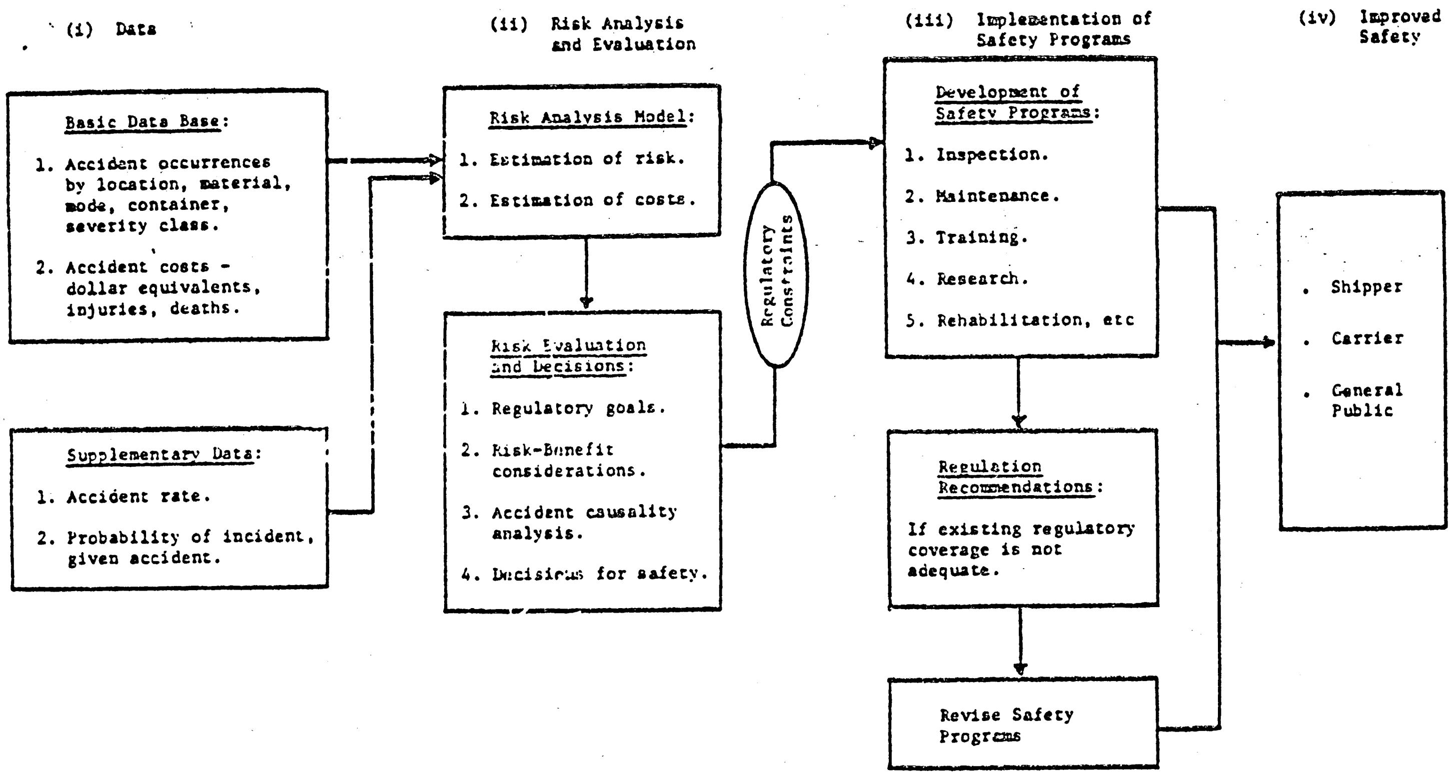


FIGURE 2

lowing information: (i) description of a sequence of events leading to an accident; (ii) description of the interrelationships of the human (operator, passenger, etc.)—machine (vehicles, equipment, etc.)—environment (weather, road conditions, etc.) and managerial infrastructure (procedures including rules and regulations); (iii) determination of the points at which traffic flows could be terminated or redirected to moderate the consequences by considering population density surrounding terminal areas as these areas account for high probabilities for all three risk measures: injuries, fatalities, and property damage; and (iv) a means for the comparison of risks between modes of transportation and/or between routes (i.e., providing a framework for quantitative assessment of vulnerability) and also counter-measures by comparing sensitivity test results for certain safety improvement measures (e.g., impact of increased rail car inspection (both vehicle and material related) on the lowering of risks).

To evaluate safety measures, identification of goals is an important first step in the development of risk-reducing strategies. Salem et al. (1980) suggested the use of one of the following: minimization of maximum accident consequence; probability of most probable accident and normal operational risk; only accident risk; socially perceived risk; peak risk; as low as reasonably achievable risk; equitable share of risks and benefits; or equalization of personal risks (both general and occupational population).

Whichever goals are chosen, a risk-benefit analysis is required to evaluate safety measures. The following are two of the major areas of methodological problems associated with risk-benefit analyses.

The first problem is the determination of benefits from reducing the risks of certain situations. The major benefit from reducing risks is usually the saving of lives. To determine the extent of the benefit obtained from reducing the risk, in terms of lives saved, an explicit value for life, in dollar terms, is required (Bailey). The second major area of debate is the degree of certainty about the level of risk. Both decision-makers and the public do not appear to be willing to accept the probability of risk. They prefer to know exactly the odds, and not play any game.

To determine the public's acceptance levels of risk, two methods are usually employed; revealed preferences and expressed preferences. The revealed preference method advocated by Starr (1969) assumes that, by trial and error, society has arrived at a nearly optimal balance between the risks and benefits associated with any activity. The expressed preference method is a more straightforward means of determining what people find acceptable. The method involves the expression of individual preferences.

Theoretically speaking, safety programs should be undertaken if the benefits in terms of increased safety exceed the cost of implementation. In addition, at the evaluation stage, multi-modal consideration should be given. The implementation of rigorous safety measures must be appreciated with reference to the competitive position of the mode. Undesirable modal shifts may result in certain commodities being carried by 'less safe' modes of transport.

(3) Implementation of Safety Measures

In pursuing the ultimate objective of reducing risks, regulators are required to upgrade safety programs within the boundaries of the existing regulatory framework. A rigorous enforcement of rules or regulations is required, in the context of multimodal transport or even beyond the transportation industries to include manufacturers of transportation equipment, manufacturers of dangerous commodities and packages, and shippers' handling procedures.

Since risk is not invariant of time, the interface of data base, risk analysis and evaluation, and implementation of the safety program (as shown in Figure 2) should be reviewed periodically to make the system up-to-date. Revision of regulations may be recommended if existing ones are not adequate.

Safety improvement measures may be effected through the development of a diverse and comprehensive safety program incorporating such facets as inspection, maintenance, manpower training, research and development, and rehabilitation. The implementation of such measures should ultimately be reflected in the improved safety for the parties concerned, namely the shippers, the carriers, and the public in general.

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FOOTNOTES

1 This section relies largely on the work by Schaefer, and Borch.

2 A lottery is called non-degenerate if no single consequence has the probability of one of occurring; a sure thing is therefore a degenerate lottery.

3 $\precsim$ = is not preferred.

4 Strictly speaking the equation determines the so-called net premium. In practice one must add to this premium a "loading" to cover the expected administrative costs of the company.

5 Transportation by road of dangerous commodities other than explosives is controlled by the provinces concerned.

6 Canadian Transport Commission, **Regulations for the Transportation of Dangerous Commodities by Rail**, p. 479.

7 According to Sections 295 and 296 of the **Railway Act**, it is a requirement that dangerous commodities not be transported over railways subject to the jurisdiction of the CTC except in conformance with the Commission's regulations. In addition, Sections 383 and 384 of the Act provide penalties for violation of the Commission's regulations.

8 **The National Transportation Act** was enacted in 1967. It established the CTC and transferred to it the functions previously assigned to the former Board of Transport Commissioners.