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Event Probabilities and Impact Zones for Hazardous Materials Accidents on Railroads

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Development
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16. Abstract

Procedures are presented for evaluating the probability and impacts of hazardous material accidents in rail transportation. The significance of track class for accident frequencies and of train speed for accident severity is quantified. Special attention is given to the analysis of track-caused accidents. Quantitative estimates are provided of the amount of hazardous material released per accident, as well as of the area affected by these releases. An error analysis is made of the various probabilities.

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PREFACE

This report presents methods for the quantitative estimation of the risk associated with the transportation of hazardous materials by rail. The work was sponsored by the United States Department of Transportation, Federal Railroad Administration (FRA), Office of Research and Development, Washington, DC, and performed by Arthur D. Little, Inc. under contract DOT-TSC-1607. The project was monitored by the Transportation Systems Center (TSC), Department of Transportation, Cambridge, Massachusetts.

The authors are grateful to Dr. Theodore S. Glickman* of the Transportation Systems Center for his support and guidance in the course of their investigations. We also wish to acknowledge the extensive support provided by Mr. Paul Brenner of Arthur D. Little, Inc., and by our erstwhile colleague, Mrs. Antoinette Musser Bradley.** Finally, we wish to mention the exceptional job done by Mr. Hans Sachdeva in preparing this report for publication.

*Now at Virginia Polytechnic Institute and State University.

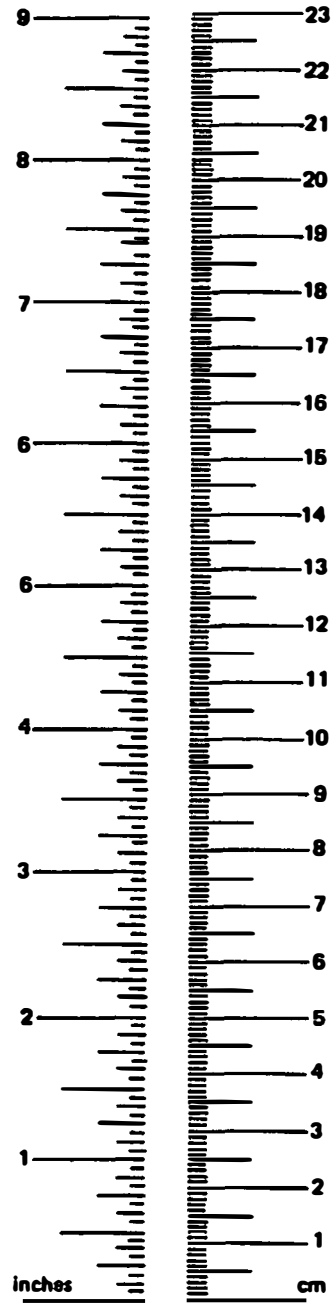
**Now at Mitre Corporation.

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

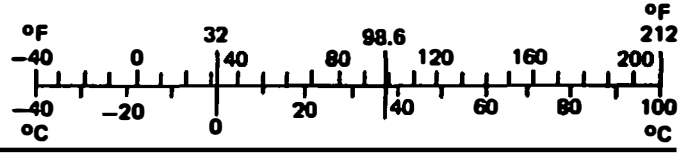
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.6	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in. = 2.54 cm (exactly). For other exact conversions and more detail tables see NBS Misc. Publ. 286, Units of Weight and Measures, Price $2.25 SD Catalog No. C13 10 286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	36	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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GLOSSARY OF SYMBOLS

Symbol	Meaning
a_R	Amount of hazardous material released per car (gallons)
A_R	Amount of hazardous material released per accident (gallons)
AC	Accident cause
AT	Accident type
d	Regression constant for m_{N_D} on v
D	Traffic density on a link
e	Regression constant for σ_{N_D} on v
E	Exposure
$\mathcal{E}$	Number of events in collision rate model
E(x)	Expected value of $x = m_x$
f	Regression constant for q on v
F	Frequency
F^*	Statistic for significance testing
g	Regression constant for m_{a_R} on v
G	Gross tons per train
G_H	Group or block size for grouping of cars in trains
h	Regression constant for σ_{a_R} on v
HM	Hazardous material
I	Radiation intensity
J	Time integral of radiation intensity
k	Number of cars suffering a secondary release due to fire from a primary release
K	Constant of proportionality between $\mathcal{E}$ and F for collisions
L	Link length
m_x	Mean (or expected) value of x
N_D	Number of cars derailing in an accident
N_H	Number of hazardous material cars in a train
N_{HD}	Number of hazardous material cars derailing in an accident
N_R	Number of hazardous material cars releasing their contents in an accident

Symbol	Meaning
N_T	Total number of cars in a train
$p(x)$	Probability distribution of x
$P(x)$	Probability of x
$P(T)$	Pressure as a function of time
p_R	Percentage of a resource affected by aftermath of a release
P_A	Probability of an accident
P_{AH}	Probability of an accident to a train carrying hazardous material
P_C	Conditional probability that a particular commodity is released given that one of a group of commodities is released
P_{CD}	Probability that at least one car is derailed or damaged in a collision
P_H	Probability that a train carries hazardous material
P_R	Probability of a release given an accident
q	Probability that a derailed hazardous material car will release its contents
r	Probability of a secondary release, caused by fire from a primary release impinging on other cars
t	Time of exposure
t_a	Time of arrival of blast wave
t_o	Time of passage of blast wave
TT	Track type
TC	Track class
v	Train speed at time of accident (mph)
Var(x)	Variance of x = σ_x^2
x	A random variable
$x\|y$	x given y
y	A random variable
Z	Accident rate

Symbol	Meaning
α_{INJ}	Area within which injuries occur (km^2)
α_{IRR}	Area within which severe irritation occurs (km^2)
α_L	Area within which lethal effects occur (km^2)
α_{PD}	Area within which property damage occurs (km^2)
β	Parameter for discretizing the continuous gamma distribution
Φ	Constant of proportionality in collision analysis
λ	Parameter of the gamma distribution
η	Parameter of the gamma distribution
π_H	Expected value of the ratio of N_H to N_T
σ_x	Standard deviation of x

1. SUMMARY

This report presents methods for the quantitative estimation of the risk associated with the transportation of hazardous materials by rail.

Accident rates are developed separately for yard and mainline accidents. For each of these, derailments and collisions are treated separately. For derailments, track-caused accidents are also analyzed separately. Furthermore, for mainline accidents, the effect of track class on accident rate is developed. This effect is found to be extremely important, as can be seen from the following tabulation.

Track Class	1	2	3	4	5&6
Mainline derailment rate (accidents per million gross ton-miles)	53.2	17.3	5.59	0.589	0.840

The empirically developed rate for Classes 5 and 6 (which were combined because of a lack of data for Class 6) is considered to be an anomaly, resulting from either a small sample size, or mis-reporting of track class, or errors in the estimation of the number of gross ton-miles for these two classes of track. The true rate for Classes 5 and 6 is almost certainly less than the rate for Class 4.

The severity of an accident, as defined by the number of cars derailing or damaged, is found to be strongly dependent on the speed at which the accident takes place. For derailments, the mean number of derailing cars, m_{N_D}, is found to be:

$$m_{N_D} = 1.7\ v^{0.5}, \qquad (1\text{-}1)$$

where v is the train speed in miles per hour. The variance of the number of cars derailing is found to be:

$$\sigma^2_{N_D} = 2.7\ v. \tag{1-2}$$

The distribution of train speed varies significantly from one track class to another. The mean speeds for mainline derailments are given in the following tabulation:

Track Class	1	2	3	4	5&6
Average train speed (mph)	8.0	14.9	21.3	29.7	37.6

Thus, the average accident severity increases as track class increases.

A similarly strong dependence on speed is found for the probability of release, q, which is the probability that a derailed hazardous material car will release all or part of its contents. For all accidents, the following expression provides a good approximation to q:

$$q = 0.045\ v^{0.5}. \tag{1-3}$$

Furthermore, the mean amount of material released from a car that does release also depends on the speed:

$$m_{a_R} = 2000\ v^{0.5}, \tag{1-4}$$

where m_{a_R} is the mean value of the amount released per car (in gallons).

Thus, speed is seen to have a three-fold effect on the hazardous impact of an accident. As speed increases:

1. The number of cars derailing increases, thus increasing the probability that hazardous material cars present in the train will derail.

2. The probability that a derailed hazardous material car will release its contents increases.

3. The amount released from a releasing car increases.

The report provides rigorous analytical models for analyzing these effects, as well as quantitative results, leading to probability distributions for the total amount released in an accident, A_R. These are presented in Chapter 10.

The final step in the analysis procedure is to estimate the impacts on people and property of the accidental release of hazardous material. These impacts are estimated in terms of the area surrounding the site of the accident within which one or more of the following impacts may be expected:

- fatalities,
- injuries,
- severe irritation, or
- property damage.

The impacts are found to be strongly dependent on the total amount released, A_R, as well as on the type of hazardous material that is released. Estimates of these impacts are presented in Chapter 12.

Among the major contributions of this report are the rigor with which data was analyzed; the innovative models that were developed of the behavior of a train in an accident; the quantitative analysis of the effects of track class and of train speed; the quantitative analysis of the effects of track-caused accidents; and the development of confidence bounds or error estimates for the various probabilities.

2. INTRODUCTION

A. OBJECTIVES

This report presents the results of work performed by Arthur D. Little, Inc., for the Transportation Systems Center (TSC) of the U.S. Department of Transportation (DOT) under Contract Number DOT-TSC-1607. The objective of this work was to develop analytical techniques for assessing the risk involved in the transportation of hazardous materials (HM) on the network of U.S. railroads. Specifically, the contract called for three tasks to be performed:

1. The development of probability distributions for the severity of hazardous-material accidents in rail transportation, aggregated over all possible causes of accidents.

   Due consideration was to be given to the basis for measuring accident rates (e.g., ton-miles, car-miles, or train-miles); the definition of severity; important factors controlling the desired probability distribution; intended use of these distributions by TSC; and also the methods by which traffic flow estimates were to be developed by TSC.

   Specific thought was to be given to the use of statistical techniques and analytical models for enriching what was expected to be a relatively sparse historical record and which would not, therefore, be a firm basis for direct extrapolation into the future.

2. The development of probability distributions similar to those developed in Task 1 with attention, in this case, confined to track-caused accidents.

3. The development of accident impact models which, given that an accident of specified severity had occurred, could be used to estimate the magnitude of the impact on the people and their property in the vicinity of the accident.

In this task, consideration was to be given to the nature of the hazardous material being released; methods by which traffic flow estimates were to be obtained; and to the need for grouping hazardous materials (when appropriate) to simplify the application of the models.

In planning the study, certain objectives were defined; viz., that the effects on risk of at least the following variables ought to be quantified:

1. The condition of the track over which the hazardous materials are being transported;

2. The speed at which the transport occurs;

3. The nature of the hazardous material being transported;

4. The quantity of hazardous material being transported in a typical train; and

5. The presence of classification yards en route, through which the hazardous materials must pass.

The effect of route-dependent characteristics, such as population density and property density, were to be accounted for separately, by superposing demographic statistics on the Federal Railroad Administration (FRA) Network Model [1].*

With the achievement of these objectives, as reported herein, it is possible to examine several aspects of risk-identification and reduction, of which the following are representative:

1. Identification of high-risk areas in the country;

2. Speed reduction for trains carrying hazardous materials;

3. Improvements in track quality;

4. Re-routing of trains to avoid poor-quality track;

5. Re-routing of trains to avoid areas of dense population;

6. Use of through trains to avoid classification yards; and

7. Changes in train consists, such as the use of unit trains of hazardous materials.

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*See References at the end of this Chapter.

It is also conceptually straightforward, using the methods presented herein, to forecast future risk(s), taking into account possible changes in the flow of hazardous materials, demographic shifts, track deterioration or upgrading, as well as changes such as limits to tank capacity or the installation of head or thermal shields on tank cars.

The capabilities of the analytical models presented herein may be compared with the results of recent parallel work conducted elsewhere. Work sponsored by the Department of Energy (DOE) at Battelle [2,3] has concentrated on the broad issue of the transportation risk arising from the consumption of materials important in energy production. The rail transportation portion of these studies [3] has concentrated heavily on risk-reduction measures associated with tank-car redesign, whereas in the study documented in this report, these possibilities were intentionally ignored.

On the other hand, the Battelle work does not address the analysis of risk-reduction options involving changes in train make-up, speed, track upgrading, or routing, which are the focus of the Arthur D. Little study. It is worth noting that the results of the analysis of risk-reduction redesign obtained by Battelle [3] can be introduced into the Arthur D. Little approach via a change in certain empirical parameters. A further interesting aspect of the Battelle work is the analysis of evacuation subsequent to a release of hazardous material. This is certainly an important factor in risk analysis, and is a useful complement to the work in the present report.

This study also sought to overcome certain deficiencies in other earlier analyses of the transport of hazardous materials by rail, a representative sample of which is cited in the Bibliography in Appendix A. The differences:

1. These studies are often concerned with qualitative methodology rather than with quantitative analysis of risk.

2. The models they use are generally applicable to one specific hazardous material or another.

3. The techniques were not suited to a nationwide analysis of risk, this being an important objective for the Transportation Systems Center, since it was, and is, its intention to use the FRA's Railroad Network Model to conduct a computerized, nationwide risk analysis.

B. CONCEPTUAL BACKGROUND

Any analysis, whether statistical or theoretical, must be based on a conceptual model, which then defines the kinds of questions that are to be asked and the types of analyses to be made. Within any given conceptual analysis, one approach to the analysis varies from another, not in any fundamental sense, but in the extent to which it relies on historical data as opposed to a theoretical model.

The conceptual model underlying the analyses presented in this report is based on certain observations and goals:

1. The harmful exposure of people or property to a hazardous material requires a series of events in an event chain. Each event is probabilistic, in the sense that its occurrence is not certain, given that the prior event in the chain has taken place: one can only assign a probability to its occurrence. This is also true of the first event in the chain, the occurrence of a train accident.

2. Many factors determine the conditional probability of an event, which is the probability that it will occur; given the condition that the prior event in the chain has occurred. These factors must be taken into account.

3. Several aspects of the event chain are common to accidents that do and do not involve hazardous materials. For example, it is likely that on a given class of track and in the absence of any special rules, the speeds at which trains travel on a given segment of track are independent of whether they carry hazardous materials or not. (Despite the recommendation by the Association of American Railroads (AAR) that trains carrying DOT 112 and DOT 114 tank cars be slowed down by 10 miles per hour (mph), the historical record of accidents does not indicate that trains carrying tank cars operate at lower speeds than other trains.)

As another example, the number of cars that derail when a train derails may depend on such factors as the speed of derailment or the number of cars in the train, but the number is not likely to depend on whether or not the cars carry hazardous materials. This observation is particularly important, since it justifies the use of a much larger set of data--all accidents--in modeling those portions of the event chain that are not influenced by the presence of hazardous materials.

4. The model must do more than fit past experience accurately; it must provide a basis for analyzing future conditions that have not occurred in the past, and also for estimating the probability of occurrence of unusually severe incidents. Such catastrophic events may not have occurred in the past, partly because their probability of occurrence is low, and partly because the history of large movements of hazardous materials is a relatively recent one.

C. APPROACH

1. Overview

Figure 2-1 shows the approach to modeling that was used. The events in the chain are most easily described by grouping them into three major categories:

1. The occurrence of a train accident;

2. The occurrence of a hazardous-material release, conditional upon a train accident having occurred; and

3. The impact upon people and property of hazardous materials, conditional upon a release having occurred.

Each of these segments is discussed separately in the following paragraphs.

2. Train Accident Rates and Frequencies

A train accident (or "rail equipment accident/incident") is defined [4] as "any collision, derailment, fire, explosion, act of God, or other event involving operation of railroad on-track equipment (standing or moving), which results in more than $1,750 in damages to railroad on track equipment, signals, track, track structure, and roadbed."

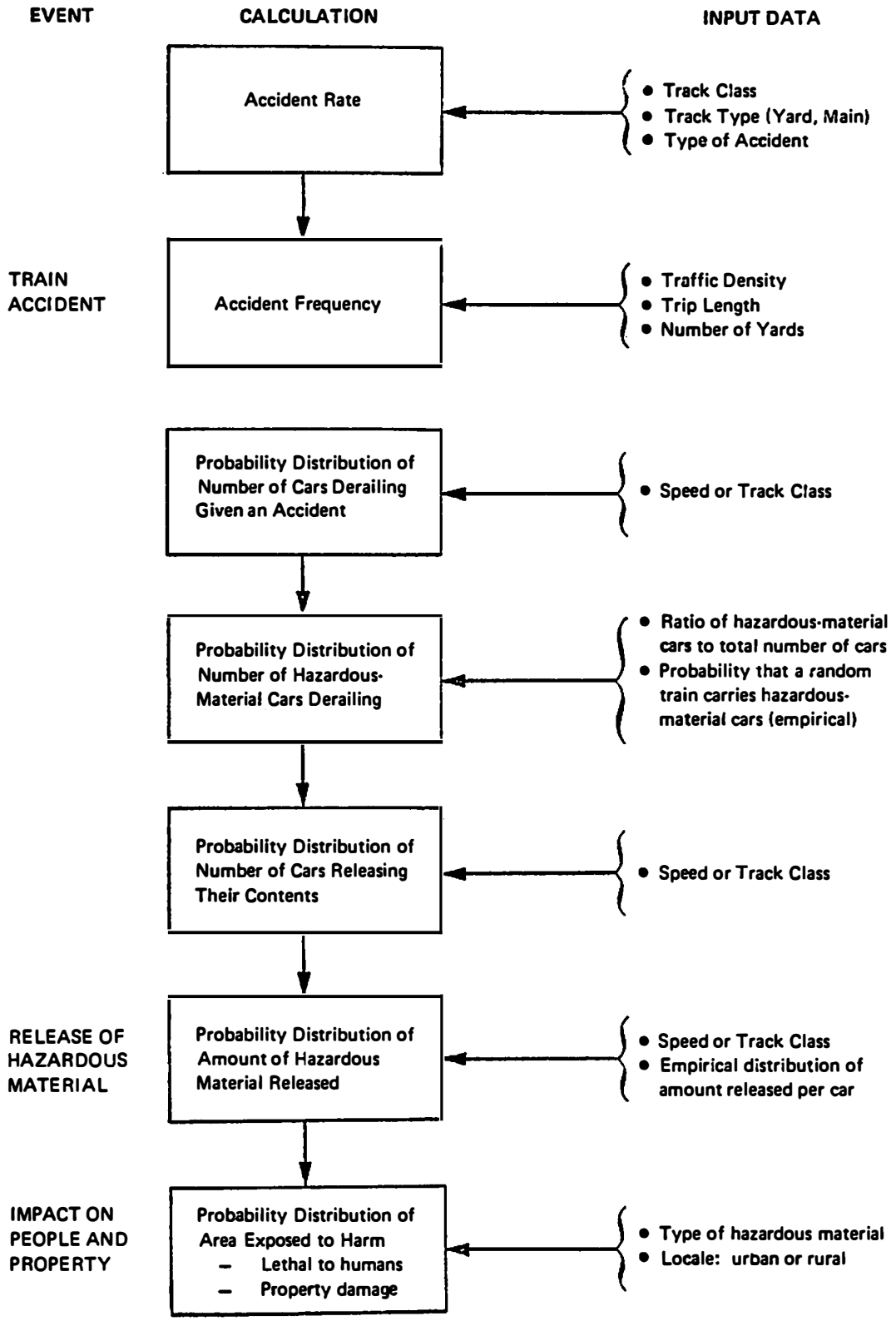

FIGURE 2–1. STRUCTURE OF THE MODEL FOR ANALYZING THE POTENTIAL IMPACTS OF HAZARDOUS MATERIALS TRANSPORTED OVER A RAIL LINK

The threshold of $1,750 has been gradually increased since 1977 to account for the effects of inflation.

The accident frequency for a link in a railroad network is stated in terms of the expected number of accidents per year. This frequency depends on the exposure on that link and on the accident rate. For example, the rate for derailments might be stated in the expected number of accidents per gross ton-mile (GTM); the complementary measure of exposure on a link is then the GTM per year.

The rate of train accidents depends on certain significant factors, each of which is described below.

1. The type of track determines the appropriate measure of exposure and, therefore, the accident rate. There are four generic track types used by the FRA [4] in its accident reporting system; viz., mainline, yard, siding, and industry. This report is confined to an analysis of mainline and yard accidents. The inclusion of siding and industry track accidents would have substantially complicated the models without significantly improving the accuracy of the analysis of risk.

2. For mainline accidents, the class of track [5] is shown to be an important determinant of accident rates. While the true underlying variable is track quality, it is not yet known how quality is to be defined and measured. Track class was therefore used as a surrogate for track quality. In making this approximation, it is important to note that true track quality may vary widely within a given track class. See Chapter 11, Section B.

3. The type of accident obviously affects the accident rate. The measure of exposure for derailments is different from that for collisions, and the rates are therefore different. The FRA [4] classifies accidents into 11 different types, of which only the most important types are included in this report: derailments and collisions of all types. These two accident types account for more than 90 percent of all accidents, and for a similar proportion of the risk from hazardous materials transportation.

4. Accidents can be grouped according to their cause; rates then depend on the cause. For this study, two broad groups of causes were used: "all causes" and "track causes."

The rate of accidents may also depend on other factors, such as train speed and make-up, variations of true track quality within a given track class (such as might reflect variations from one railroad to another), or weather conditions. Although these other factors were examined in detail, it was not found to be feasible to include them in the model either because supporting data were unavailable, or because future users of the model would not have access to information regarding these factors.

Estimates of accident rates were made purely on the basis of historical statistics, with the exception that in the choice of a basis for measuring accident rates (the gross ton-mile was eventually chosen for derailments), analytical reasoning was employed. The basis of this choice of a measure of "exposure," as well as the accident rates determined from historical data, are presented in Chapter 3.

Once the accident rate is known and the exposure on a rail link is specified, the expected frequency of accidents can be determined by multiplying the two together. The frequency can either be stated on a temporal basis (per year) or on a traffic basis (per million gross tons or MGT).

In summary, the first step determines the expected frequency of accidents:

$$m_F = Z(TT, TC, AT, AC) \cdot E \qquad (2\text{-}1)$$

where

m_F = mean value of F,

F = frequency of accidents,

Z = accident rate,

TT = type of track,

TC = track class,

AT = accident type,

AC = accident cause, and

E = exposure.

Note that the appropriate measure of the exposure E, and therefore of the accident rate Z, depends on both the "type of track" variable, TT, and the "type of accident variable," AT, as shown at greater length in Chapter 3.

3. Hazardous Materials Release Given an Accident

If an accident occurs and its characteristics (such as track class, track type, etc.) are known, one may derive the probability distribution of the amount of hazardous material released in the accident as follows.

The conditional probability that the train contains hazardous material is first obtained. It is denoted by:

$$P_H(TT, TC, AT, AC).$$

Then the conditional probability distribution for the number of cars derailing is obtained. It is represented by:

$$p(N_D|v),$$

where N_D is the number of cars derailing and v is the speed at which the accident occurs.

Next the probability distribution of the number of hazardous-material cars derailing, N_{HD}, which is conditional on the number of cars derailing, is obtained. It has an additional parameter, π_H, the proportion of hazardous-material cars to all cars. The conditional distribution is denoted by:

$$p(N_{HD}|N_D, \pi_H).$$

Then, the probability distribution of the number of cars releasing their contents, conditional on the number of hazardous-material cars derailing, is obtained:

$$p(N_R|N_{HD}, q).$$

In this expression, q is the release probability, which is a function of the speed at which the accident occurs and is thus written q(v).

The probability distribution of the total amount of hazardous material released, A_R, is then found. It is denoted by:

$$p(A_R|N_R, v).$$

4. Impact Given a Hazardous Material Release

Finally, the area within which lethal effects will be felt by human beings, denoted by α_L, is shown as a deterministic function of the amount of hazardous material released, conditional on the type of material that is released:

$$\alpha_L(A_R|HM),$$

where HM designates the hazardous material. Similar impact areas exist for injurious or irritating effects on people and for property damage, and are denoted by:

$$\alpha_{IN}(A_R|HM),\ \alpha_{IRR}(A_R|HM),\ \text{and}\ \alpha_{PD}(A_R|HM).$$

The expected impact area is estimated for several groups of chemicals and for each of the types of impacts listed above. The development of these estimates presented a considerable challenge, since the need for relatively simple results that could be used in a nation-wide risk analysis conflicted with the known complexity of the phenomena that can occur after the release of certain hazardous materials. This conflict was resolved by taking the following steps:

- The various hazardous materials were grouped into a relatively small set of categories, based on their physical and chemical properties, including the types of phenomena that have been observed to occur upon their release.

- Two specific chemicals were chosen to represent each category: a "representative" one and a "worst-case" one.

- When necessary, reasonable assumptions were made regarding the probability of occurrence of competing post-release scenarios. Examples of competing scenarios, for a compressed flammable gas, include: a torch fire; a pool fire; a boiling liquid expanding vapor explosion (BLEVE) combined with one of the above two; a vapor cloud fire; a vapor cloud detonation; and a vapor cloud that disperses without igniting.

- Reasonable estimates were made of the input parameters required by many of the impact models for the various scenarios. Examples of these parameters are the stability condition of the atmosphere, the wind velocity, and the density of ignition sources.

The procedures used in applying these four steps are described in subsequent chapters, as are the results. The underlying models are described in Appendix C.

5. Synthesis

All of these probability distributions are synthesized as follows:

1. Given an accident characterized by TT, TC, AT, and AC, the probability that the train carries hazardous material is P_H.

2. Given an accident of a train carrying hazardous material, as well as TT, TC, AT, and AC, the probability distribution for the lethal area is:

$$p(\alpha_L | TT, TC, AT, AC, N_H > 0, HM) =$$

$$\int_v p(v|TT, TC, AT, AC) \sum_{N_D} p(N_D|v) \sum_{N_{HD}} p(N_{HD}|N_D, \pi_H, N_H>0) \sum_{N_R} p(N_R|N_{HD}, q)$$

$$\times \int_{A_R} p(A_R|N_R, v)\ \alpha_L(A_R|HM)\ dA_R\ dv. \qquad (2\text{-}2)$$

In this expression, N_H is the number of hazardous-material cars in the train, and

$$p(v|TT, TC, AT, AC)$$

is the conditional probability distribution for the speed at which an accident occurs, given the various accident characteristics of TT, TC, AT, and AC.

An equation similar to (2-2) holds for the areas of injury or property damage α_I and α_{PD}.

Equation (2-2) is the central result of this report; the rest of the report is concerned with either developing approximate versions of it or with estimating the conditional probability distributions that occur within it.

The subsequent analyses in this report first show:

$$p(N_D|v).$$

Next, both

$$p(N_{HD}|N_D, \pi_H, N_H > 0)$$

and

$$p(N_{HD}|TT, TC, AT, AC, N_H > 0)$$

are shown, the latter being derived by combining the former with the conditional probability distribution for accident speed,

$$p(v|TT, TC, AT, AC).$$

Here, in addition to the distribution of accident speeds, the historical dependence of π_H on TT, TC, AT, and AC is taken into account.

Finally, both

$$p(N_R|N_{HD}, q)$$

and

$$p(N_R|TT, TC, AT, AC, N_H > 0)$$

are presented, as are:

$$p(A_R | N_R, v),$$

and

$$p(A_R | TT, TC, AT, AC, N_H > 0).$$

In each case, the second distribution, which is conditioned by the track type, track class, accident type, and accident cause, assumes historical values for important parameters. The other less restrictive versions of the probability distributions allow the user to insert arbitrary values of these parameters.

6. Application

Equation (2-2) was applied in three different ways. One approach was aimed at determining the mean and variance of the probability distribution of A_R, and gaining an approximate idea of the shape of the overall distribution. In this approach, many of the intermediate probability distributions described above are not explicitly derived, nor are they necessary. Only the mean and variance of each distribution are necessary.

The second approach involved the use of actual historical distributions of the amount released per car in combination with the means and variances of the number of cars releasing, to obtain explicit distributions for the total amount released. The advantages of this approach are that the distributions themselves are obtained rather than just their parameters.

The third approach involved the development of a mathematical representation of a train consist, aimed at developing analytical estimates of the number of hazardous-material cars derailing (N_{HD}), given the total number of cars derailing (N_D). The approach then uses historical data to obtain distributions of the number of cars releasing (N_R), given N_{HD} and the amount released (A_R), given N_R. This approach allows one to examine specific policy alternatives not otherwise

amenable to analysis. An example of such a policy is a rule specifying a limit to the number of hazardous-material cars that may be carried in a train. The disadvantage of this approach is that the associated computational techniques are complex and ill-suited to the requirements of a nationwide or regional risk analysis. For this reason, this approach was not exercised to any great extent, except to make a brief comparison of its results with those of the other approaches described above.

For the sake of brevity, the analysis approach that estimates means and variances (parameters of probability distributions) is described as being based on "parameter models." The second approach is described as being based on "distribution models." The third approach is described as computer-based since the use of a computer is essential in its application.

D. DATA SOURCES: THEIR USES, AND LIMITATIONS

To develop and calibrate the models described in Section C, several sources of information had to be utilized:

1. The FRA Railroad Accident/Incident Report System (RAIRS);

2. The Materials Transportation Bureau (MTB) incident reports;

3. The National Transportation Safety Board (NTSB) investigations;

4. The Association of American Railroads (AAR) and Railway Progress Institute (RPI) Tank Car Safety Research and Test Project reports;

5. Information contained in state rail plans; and

6. Work on estimating flows of commodities, including hazardous materials, on the links of the FRA Network Model, being done at Princeton University [1].

The uses to which the FRA and MTB data sources were put are summarized in Table 2-1, and shown somewhat more explicitly in Table 2-2. Several problems were encountered in the quantitative analysis of the FRA/RAIRS and MTB data, examples of which are shown in Table 2-3 and Figure 2-2. A considerable amount of effort was expended in overcoming these problems and limitations. However, in the interest of brevity, the techniques used are not described in this report.

With reference to Figure 2-2, it is particularly worth noting that even when FRA and MTB records can be found for the same accident, the estimates of impact are not comparable. The FRA estimates include the number of cars releasing (but not the amount of hazardous material released), as well as the number of people killed or injured or the dollar damage to property due to all causes. The MTB estimates include the amount released, as well as the impacts on people and property--but only if they were caused specifically by the release of hazardous materials, and not by other consequences of the train wreck.

E. REFERENCES

1. "Federal Railroad Administration Network Model," Volume 1 (User's Manual), Report prepared by IBM Federal System Division, May 1975.

2. Andrews, W. B., "An Assessment of the Risk of Transporting Liquid Chlorine by Rail," Report No. PNL-3376, March 1980.

3. Geffen, C. E., "An Assessment of the Risk of Transporting Propane by Truck and Train," Report No. PNL-3308, March 1980.

4. "FRA Guide for Preparing Accident/Incident Reports," Federal Railroad Administration, 1975.

5. Code of Federal Regulations, Title 49, Part 213, "Track Safety Standards," 1977.