CHAPTER 6: JOINT USE RISK ANALYSIS (AND GUIDE)

6.1 OVERVIEW

Risk analysis introduces that portion of the research directly addressing the key issue: Is joint use feasible in North America? Its placement in this report reflects on its importance in determining joint use feasibility on a case-by-case basis but within a national regulatory framework of more detailed and tested joint use risk research.

This chapter is intended to serve as a free-standing guide to a Preliminary Risk Assessment Method for analyzing joint running of transit cars and railroad trains concurrently on common tracks. The chapter offers guidance to state and metropolitan entities contemplating a risk assessment approach to rail transit alternative analysis.

As revealed in Chapters 6 and 7 on North American and European joint use, there are precedents for using risk assessments in a variety of joint track use applications. These applications include rail transit (LRT and DMU) on railroads, railroad trains on light rail, and high-speed rail operations blended with commuter and freight trains. These applications are directed at rail line segments, terminal operations, or entire corridors. The risk assessment techniques in this chapter demonstrate a generic approach which is relatively common on an international basis. It also demonstrates an ability to be applied in a wide variety of circumstances.

Note that there are several different techniques used in risk assessment other than the one used in this research. Among these is, for example, the Military Standard System Safety Program Requirements (MIL-STD-882-C, prepared by the U.S. Department of Defense, Air Force Systems Command, October 18, 1991). While not a strictly prescriptive risk assessment methodology, the Standard 882-C was employed by FTA in its multi-volume design guidelines for various alternative fuel buses. There are other industry-accepted risk methodologies as well, but they are all based on common risk assessment/management techniques. This research does not implicitly advocate one risk assessment method over another.

There are two classic challenges to any risk assessment. These include a) meager database/relatively few accidents, and b) meager information on exposure to risk (i.e., lack of traffic data). The former is due to the reduction of incidents, so that while the probability of accidents appears to be diminishing, the means to prove this is also diminishing.

6.2 PURPOSE OF THIS CHAPTER (AND GUIDE)

The purpose of this chapter is to assist decision makers in performing a preliminary risk analysis and assessment of a joint operation situation on their own system. It can, of course, be applied to rail transit improvements other than joint use. As this chapter is intended to serve as a guide, the terms "Chapter 6" and "guide" should be considered synonymous. For purposes of uniformity, "chapter" predominates. It is expected that this guidance would be used prior to and in support of a decision to undertake the development of firm proposals, discussions, and approvals for joint running operations. The preliminary risk assessment and risk management plan would provide inputs into the final design and operation plan for joint running.

It is further suggested that risk analysis be considered in the process for selecting alternatives in MIS and similar studies, but only if a joint use alternative(s) appears to be otherwise competitive and seriously under consideration. In large-scale studies, having technical support for decisions helps promote the decision for or against a capital intensive project.

While this chapter is directed at decision-makers at the state and metropolitan level, it is but one tool used early in a comprehensive planning process leading to potential new rail starts. It presumes that local officials of rail transit, railroad freight, and state and metropolitan governments are able to consider and act on joint use in their jurisdiction based on an assessment of risk and other criteria. It also presumes that these officials and the organizations they represent are prepared to cooperate in making investment decisions in support of a variety of joint use practices and invest in a range of mitigations to reduce risk to a tolerable level. Finally, this approach assumes that the risk analysis would be submitted in support of any application for waiver or exception to permit joint use/shared track between rail transit and railroads.

The contents of this chapter are consistent with the proposed FRA rule on CFR 49 Part 216, et al., as published in the Federal Register of Tuesday, September 23, 1997, pages 49728-49824 on rail safety practices.

6.3 DEFINITION OF TERMS

Hazard - Source of potential harm or a situation with a potential for harm.

Joint Running - co-mingled railroad and rail transit train operation using equipment that is significantly different in terms of buff strength, floor height, and other performance characteristics that impact the consequences of accidents.

Mitigation - also known as risk controls - actions, including regulation, supervision, redundant systems, equipment modifications, operating practices, and apparatus, etc. that are designed to reduce either the frequency component of risk or the consequence component of risk.

Risk - The chance of injury or loss as defined as a measure of the probability and severity of an adverse effect to health, property, the environment, or something else of value. (as defined by CSA, 1997).

Risk - Combination of the frequency, or probability, of occurrence and the consequence of a specified hazardous event. (as defined by IEC, 1995).

Risk Analysis - Systematic use of available information to identify hazards and to estimate the risk to individuals or population, property, or the environment. (IEC, 1995).

Risk Assessment - Overall process of risk analysis and risk evaluation. (IEC, 1995).

Risk Evaluation - Process in which judgments are made on the tolerability of the risk on the basis of risk analysis, taking into account factors such as socioeconomic and environmental impacts. (IEC, 1995).

6.4 APPROACH

The proposed FRA rule (Federal Register, Tuesday, September 23, 1997) requires any passenger trains that have joint running with freight trains to either:

a) comply with the proposed rule, or

b) obtain a waiver of compliance from FRA by submitting a request supported by risk assessment that demonstrates that "equipment will operate at a level of safety equivalent to that afforded by the (rule)" (page 49755 re CFR 238.7). It is assumed that most proposals for joint running for commuter rail and urban rail applications will require a waiver for equipment requirements (e.g., 238.203 Static end strength - minimum of 800,000 pounds without permanent deformation of the carbody structure) as well as other requirements. This risk analysis can be an element of the FRA waiver application, but not routine within the transportation planning process associated with rail new starts overseen by FTA, States and MPOs.

The guide follows traditional methods of risk analysis and risk management, as specified in the international standard IEC 300-9-3 (1995) for risk analysis and the Canadian standard CSA Q850 (1997) for risk management. The general approach is given in Figure 6-1 (CSA Q850, 1997). It should be noted that these standards are also consistent with the U.S. Department of Defense MIL-STD-882(C), as well as other risk management standards and approaches. In all cases, these standards and approaches are general and must be custom-applied in order to carry out a specific risk assessment.

These standards set out a general process for managing risks and doing risk analysis. While these provide the approach, the substance must be developed from historical data and expert judgments from the stakeholders. In the present case, the limited availability of data means that surrogate and incomplete data (e.g., from the general railway industry and from available accident investigation reports) must be used, and the expert judgment becomes critical. As no true joint use in the sense of this research exists in North America, the surrogate domestic data is for all accident experience with emphasis on passenger and freight *railroad* incidents. As more data becomes available and as detailed risk analysis studies are done for proposed joint running projects, there will be increased evidence available and less reliance on expert judgment. It is therefore expected that enriched time series data will continue to refine and improve risk analysis results, though the fundamental process remains uniform. In the absence of experience and extensive data, the current focus is on the process and its potential application.

The proposed FRA rule of September 23, 1997 includes two examples of risk assessments that have been submitted for the NEC (North East Corridor high speed operation) and FOX (Florida Overland eXpress high speed trains) and indicate that these are "examples of what is expected to demonstrate equivalent safety for proposed operations where the equipment does not meet the Passenger Equipment Safety Standards". These approaches will be discussed later in this section.

In Figure 6-1 the "Initiation" step would be taken by an organization who was the sponsoring organization (public, private, or third sector) contemplating a joint running operation. After considering options set forth in the Screening Matrix (Chapter 9, Figure 9-1), they would perform a "Preliminary Analysis" of the risks (as well as preliminary estimates of the costs, benefits, stakeholders' concerns, and other considerations) using this guide. They would then proceed to a more detailed estimation of risks (as well as costs, benefits, stakeholders' concerns, and other matters) and if the joint operation was feasible, they would continue with the detailed design including the development of mitigation measures, or "Risk Controls," to manage the risks. Each step in this process would require affirmation by those risk takers who assume liability. Throughout the process, the decision maker would initiate two-way "Risk Communication" with the stakeholders. For example, the FRA and state rail transit regulators are key stakeholders, since the equipment must either comply with regulations or the risk assessment must demonstrate an "equivalent" level of safety.

Figure 6-1 is a process to guide decision makers. The decision points are conventionally shown in any decision tree. Figure 6-1 portrays points where the process has a decision choice: "End", or "Go back," or "Next step and/or take action." The "Preliminary Analysis" step leads to "Risk Estimation" and "Risk Evaluation", and together the three steps combined are called "Risk Assessment," which is the purpose of this guide. It should be noted that steps can be skipped; for example, if the risks identified in the Preliminary Analysis were negligible and if standard management controls were applicable, then the "Risk Estimation" step might be skipped. The decision maker would proceed directly to the end of the risk management process and decide in favor of joint operations or consider shared track among workable options, based on non-risk factors.

In this guide for the "Preliminary Analysis" of joint running, the following assumptions are made:

- Risk is of concern both in the operation of passenger service and in the associated regulatory oversight to ensure that the risk is "acceptable."

- There are reasonable and practical mitigation measures (or risk controls) in place to minimize risks.

- This guide assumes a "public" perspective for risk assessment, as represented by the regulatory oversight activity, and an emphasis on casualties rather than damages.

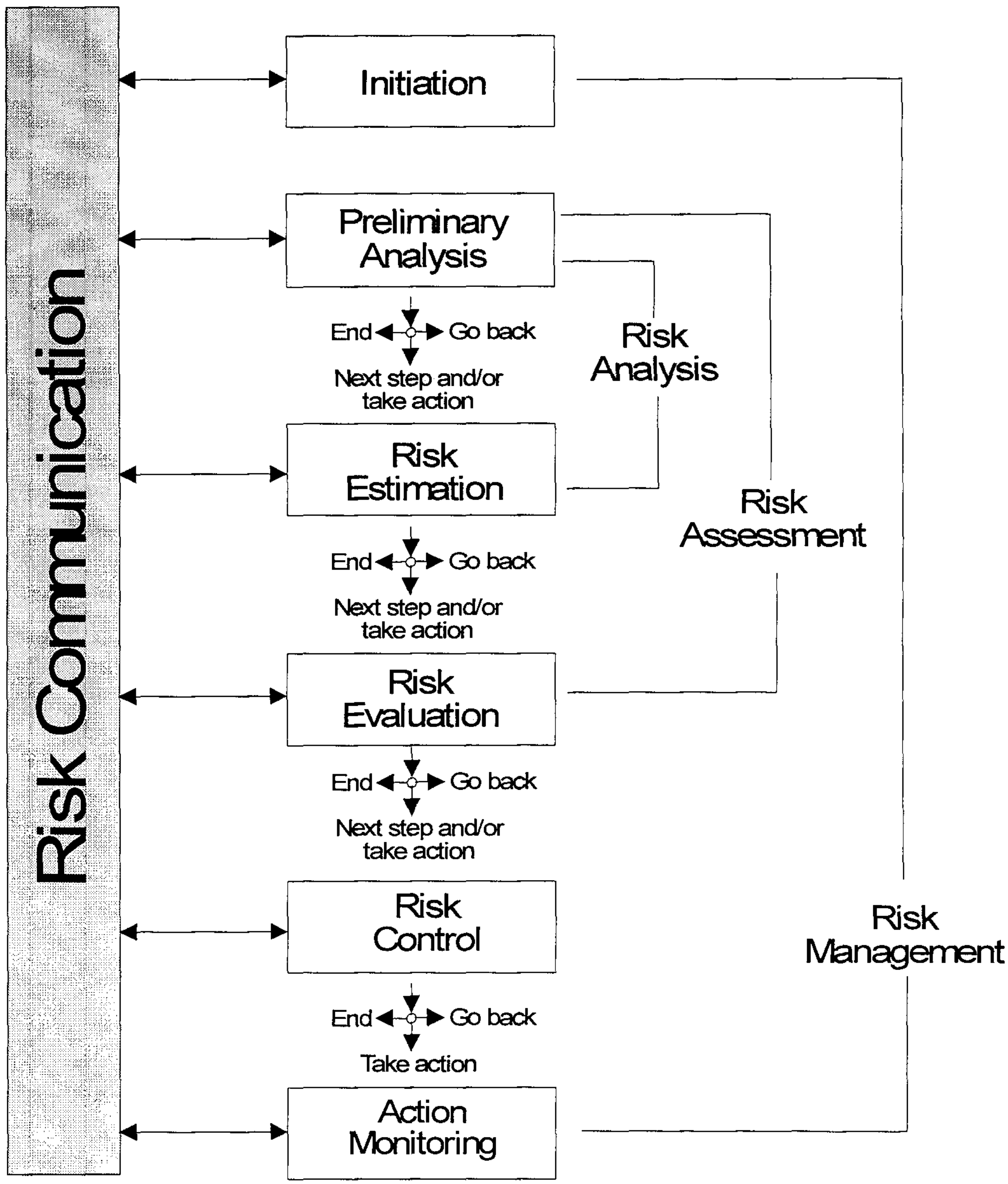
- The primary concern for joint operations is the incremental risk for joint passenger services, over and above the base risk associated with the operation of non-joint passenger services. "How much riskier is shared track?" One example, of an incremental risk is increased probability and consequence of a collision of a rail transit vehicle with a freight train. The incremental risks to non passenger railroad traffic are considered of secondary importance for the joint operation regulation of rail transit passenger services.

- Any railroad operation, joint or otherwise, will have increased risk due to the increase in volume of train movements or track usage. The mixing of two different types of operations, and disparity in scale of rail transit and railroad rolling stock, introduces an additional element of risk. The latter is the focus of this research.

- Some risks, such as the compatibility of platform loading heights, are not considered by the guide as incremental risk, since it is assumed that for joint operations to take place the joint operations design must "reconcile" these incompatibilities in any case to the satisfaction of the regulatory oversight body and the operator. Thus these risks, generally of a physical nature, will be reflected in normal costs of operation rather than as incremental risks. In addition, they are not unique to joint operations or shared track.

- For an "acceptable" risk assessment, there must be either a very low incremental risk or alternatively the increased risk caused by shared track must be offset by mitigation of the risk. That is, the increased risk of joint use must be balanced by reduced risks from additional risk mitigation measures relative to the "non-joint use" situation.

Risk Management Process - Figure 6.1



Note: *Risk communication with stakeholders is an important part of each step in the decision process.*

Source: Canadian Standards Association (1997)

- All estimates of increased or diminished risk are merely estimates and at least partly subjective. Expert judgment is required in the interpretation of risk estimates.

The approach taken in this guide is influenced by the lack of sufficient directly applicable data on which to base the risk analysis. Faced with this reality, the recommended approach is to try to relate the incremental risks of joint running to the increase in the risks of "non-joint" services by documenting the risks of "non-joint" running and then trying to estimate the likely percentage increase in risk due to joint running. This approach is developed in several study phases designed to use the available data. The study phases and their rationale can be summarized as follows:

Phase 1 - Risk Profile - Develop a risk profile of rail and rail passenger service to identify the "non-joint use" level of risk and the major sources or causes of that risk. This becomes the baseline. In this step the variation of the risk levels between properties is described. This step provides an overall estimate of the "non-joint use" risk against which the incremental percentage risk due to joint running will be assessed. The risk profile will also identify the sources or causes of risk, which are likely to be active in the "incremental" risk due to "joint running." The variation between railroads will reflect one measure of the inherent uncertainty in "acceptable" safety levels, and this will have an impact on the determination of "equivalent" levels of safety for compliance with FRA waiver requirements.

Phase 1 will use both passenger service and freight service to estimate the risk profile, since the data for passenger rail service by itself is limited. The basic source of the risk profile data will be FRA.

Phase 2 - Risk Factors for Base Risk and Incremental Risk - The incremental risks due to joint running will be identified based on classifications of causes in the base risk profile. Using these causes, and any expansion of this classification system, the available accident data will be analyzed to seek validation that the data used for the risk profile is a reasonable surrogate for the joint running risk assessment in the guide. As an example surrogate case, collision accidents involving rail transit services have been investigated by the National Transportation Safety Board (16 reports were available). In addition, the review of accident reports along with the risk profile will provide a list of risk factors for the preliminary analysis of a joint use proposal. These risk factors or causes of incremental risk can be used as a checklist to make a preliminary estimate of the incremental risk for a specific proposal. Also, the risk assessment studies for the NEC proposal and the FOX proposal done for the FRA can be used for validation of the proposed risk profile, to the extent possible.

Risk factors that impact consequences, given an accident (e.g., buff strength), will be discussed; however, resources preclude detailed analysis.

Phase 3 - Risk Assessment - A framework and procedure is developed to do a preliminary analysis of the incremental risk and to assess the risk in terms of the percentage increase in risk or the incremental risk to passengers due to joint running. This incremental risk is assessed in terms of meeting the criteria of "equivalent" level of safety (i.e., within the measurement error of risk estimation). In the event that the decision-makers decide that the incremental risk is unacceptable, then mitigation measures would be considered.

Phase 4 - Possible Mitigation Measures - A number of mitigation measures will be identified and general principles given for the estimation of the risk reduction due to these risk mitigation measures. Whenever possible, reference to available methods of analysis or case studies will be given. Examples of mitigation categories include:

- Signal systems upgrades,
- Train control and GPS enhanced technology,
- Rolling stock design, and
- Operating practices.

The approach is one of estimating the incremental risk as a conservative estimate of the percentage increase in risk due to joint running, and assessing the need for and the potential impacts of mitigation measures.

It must be recognized from the outset that there is considerable variation in risk levels between railroads, that there is considerable uncertainty in preliminary estimates, and that the effectiveness of mitigation measures is also uncertain. For these reasons, considerable judgment will need to be applied by the decision-makers.

Finally, the approach will be focused on the major issues (Chapter 5) in the overall assessment of joint use proposals and the technical characteristics of joint use as described in the earlier four chapters. For example, the separation of transit trains and freight trains is a key issue - this is similar to the key issue in Airports where separation of aircraft drives most of the requirements for the use of individual runways, and the acceptability of parallel runway operations. The separation of trains on the track has similar characteristics of being a dominant issue that must be addressed by mitigation measures until it is acceptable.

6.5 JOINT OPERATIONS: A WORKING DEFINITION AND REVIEW OF THE RISK ISSUES

For purposes of this guide the term "joint operations of light rail transit or diesel multiple-unit vehicles with railroads" is limited to the joint operation of the following situations.

Vehicles in Joint Operations

- Rail Transit Vehicles/Trains (non FRA-compliant):
  - Railbuses - (bus derivatives)
  - DMU - Categories 2 & 3 (light rail derivatives)
  - LRT - high and low floor cars

  Typical buff strengths are about 1/4 to 1/2 of railroad passenger cars compliant with FRA regulations.

- Freight and Passenger railroad/Trains (FRA-compliant, including Category 1 DMUs).

Infrastructure

Single or multiple railway track, usually under the control and ownership of a single operator. Track may be shared by host and tenant operator, or reciprocal running by rail ownerships connecting end to end. Station, tunnel, and other design conditions impose operating restrictions or require unique design solutions.

Operations

Controlled by conventional dispatching overlaid by various train control technologies which may be specified as a condition to sharing track. Permanent speed restrictions for certain types of train movements and restrictions on switching to create *de facto* train separation are applied.

Regulation

The joint use is under the jurisdiction of the FRA if a railroad, and under state jurisdiction if rail transit.

The incremental risk (key) issues identified in Chapter 5 can be regrouped for purposes of a preliminary risk assessment as follows:

- **Overall Risk Assessment (Key Issues 1a, 1b, 1c, 1d, 2b, 4a, 5a)**

The risk assessment should be able to inform the decision maker on the incremental risk by percentage increase in risk due to joint running. By using the risk analysis methods to quantify changes in the risk factors, it is possible to address the acceptability of the incremental risk and the impact of various mitigation measures, including those identified by use in other countries. The latter may have defined measures of their effectiveness.

- **Separation (Key Issues 1d, 3a, 5a)**

Separation can be either temporal or physical. For temporal separation the separation failure may depend on signal systems, location positioning and train control systems, human factors, etc. The risk analysis should be able to indicate the relative impact of various separation mitigation measures. Separation will mainly impact the frequency of accidents rather than the consequences of accidents.

- **Car Integrity (Key Issues 4a, 5a)**

Buff strength and structural integrity are the main issues. Differences in consequences with joint use can be estimated through the application of structural analysis and the correlation to crash tests and actual accidents. Resources will limit the attention to this issue to a general discussion.

- **Track Quality (Key Issues 1c, 2a, 4a, 5a, 5b)**

Joint use will generally mean the mixing of track maintenance requirements for transit operations with those for freight operations. The frequency of measuring track quality and maintenance activities to assure minimum track quality will affect risk.

- **System Integrity (Key Issues 1b, 1d, 2a, 3a, 5a)**

The management and supervision of operations can dramatically affect the risk. One mitigation measure would be a significant improvement in the system integrity due to new procedures. Another mitigation measure would be reduced operating speed. While important, it is not possible to provide detailed estimates and methods for assessing this issue in North America at this time.

Review of the Risk Issues

Safety in transportation has always been a major concern. Historically, safety has been addressed by careful review of accidents and, in response, the development of safety programs, regulations, inspections, enforcement, and other measures. The result has been a continuous increase in safety or lowering risk probabilities.

As transportation has become safer, three issues emerged:

- There was no longer sufficient historical data available to quantify estimates of risk. A risk model based on historical data was no longer adequate for use as a risk estimation model or to design prevention and mitigation measures (in Germany, where a greater variety and density of rail transit exists, the complaint of risk estimators is "lack of sufficient data").
- In the current rail safety climate where risk has been diminished, the inability of risk management to further significantly reduce risk and the high level of resources required for mitigation measures raised the question of cost effectiveness of

prevention and mitigation risk control measures. Typically given a "one off" accident, an inquiry would recommend regulations, equipment modifications, etc. to prevent the accident, but the probability of these providing safety to the overall system is very small and the measures might be cost ineffective relative to other safety investments or even to no further safety investment.

- There was a shift in the predominant root cause of accidents from equipment, signal systems, and other hardware (and software) to management and supervisory tasks of training, monitoring, and management of SOPs (Standard Operating Procedures), redesign of procedures to reduce human error, maintenance systems to maintain system integrity, provision of safety systems within operating organizations, and so forth.

In turn, these issues required two fundamental changes in the approach to risk management:

- Regulation emphasis and methods shifted from specification and inspection of equipment and industry-wide standard procedures towards performance requirements for management systems, such as FRA's Safety System requirements, and the introduction of the ideas of a regulator-approved Safety Case with continuous documentation of compliance and auditing by the regulator.

- Risk analysis methods were altered to supplement the "historical data as a model" approach, employing methods that use aggregate data for the whole country to inform the likely level of risk in a particular corridor, usually involving adjustment factors for local conditions again based on analysis of aggregate data, experiments, and/or analytical methods such as fault trees, event trees, Failure Mode, and Critical Effect Analysis.

The recent FRA-proposed rule is a good example in the railway industry of these general risk management trends. It requires operators to have a safety system in place, e.g., "that will cause railroads to re-examine their own inspection, testing, and maintenance procedures to determine that they are adequate to ensure that the safety-related components of their equipment are not deteriorating over time." Moreover, "FRA does not intend to prescribe how to perform these tasks. The proposed standard requires each individual railroad to think through how to safely perform these tasks and to develop procedures that are safe under its individual set of working conditions," (Federal Register, September 23, 1997, page 49762). FTA and APTA approaches are similar, with states and rail transit operators developing their own safety program plans which involve self monitoring and reporting.

Given this approach, where the responsibility for safety is assigned by regulation to the operators, the usual outcome is that the industry cooperatively develops a set of umbrella standards and procedures that will meet both the regulations and the test of due diligence. However, the shift in thinking and approach requires some time to achieve, partly because there must at the same time be an adoption of methods of risk management and risk analysis. Often the transition period is in the order of 5-10 years.

One example of the difficulty posed by the shift to respond to the three issues identified above will help to illustrate the characteristics of the process. With the shift in root cause from rolling stock and hardware (equipment) to supervision and management (people) systems, there is a shift from a regulatory environment that can say "yes that was done and no that equipment was not maintained" to an environment that must say "65% of the workers thought that the procedure for ensuring compliance to a standard operating procedure for switching was followed all the time, and 20% thought most of the time. On the other hand, for management, the estimates were 90% and 8%." In the proposed FRA rule, this example is illustrated by the expressed preference of organized labor for methods that can be answered "yes/no" and for procedures that meet the regulations before the fact, through qualification, inspections, etc., over the introduction of procedures that allow "unqualified" but trained people to do specific tasks and that can only be validated in a very general way as complying with the regulations.

A second example of the difficulties posed by these changes is the determination of "acceptable" safety cases. In the past, with its higher level of certainty and observability of safety measures, there was a preference for risk reduction measures that met these requirements, such as standards for equipment, procedures for inspections, and so forth. To a large extent, these measures focused on the consequence side of risk and on equipment such as signal systems that influence the frequency side of risk numbers. In either case if the requirement was met, then it was in place; it could be observed and it would reduce risk. With the new reality where risk reduction measures depend more on supervisory competence, good working relationships, many trained eyes looking for potential risky situations, and so forth, there is a shift of emphasis from reduction of consequences to the reduction of frequency of accidents. This is due, of course, to the success of regulations for equipment, signals, etc. to the point where risk is low, *if they are in place*, and the emphasis must shift to prevention of accidents.

This shift to prevention has occurred overseas, where crash avoidance is currently preferred to crashworthiness.

The second example illustrates the difficulty faced by regulators. Trade-offs must be considered between standards for equipment and other hardware (and software) to reduce risks and standards for management methods to improve supervision, redesign of work tasks, training in general accident prevention, etc. With the realization that the former is much more certain, visible, etc. than the latter, but the latter is more effective. For instance, in the proposed FRA rule, the term "equivalent safety" for compliance with equipment should include the introduction of equivalent safety provided through measures to reduce the frequency of risk, where these measures must be in addition to those normally in place in the industry. These trade-off decisions are complicated by the role of benefits and costs in the decision-making process, especially since a major benefit of rail passenger service is inherent safety of a shift from more risky surface modes of travel.

Finally, the transition period between the two regulatory environments raises issues for risk analysis. The transition is between "historical data as a risk estimation model" and risk estimation models based on local data plus aggregated data plus adjustment for risk factors based on analysis, experiments, and expert opinion. There will be a continuous development of risk analysis methods: as the resources become available, as risk assessments provide relationships for risk factors and indicators of acceptable risk evaluation criteria, as new regulations provide for methods of addressing supervisory and management causes of risk, and so forth. For purposes of this report, the next section outlines the general risk analysis issues in the near term and describes two examples that have been cited by FRA as "examples of what is expected" to demonstrate "equivalent safety" for waivers.

Risk Analysis Methods

Risk analysis is uniformly composed of the following tasks and follows accepted standards for risk analysis and management:

- ***Scope*** of the system and time period for the analysis. This includes the identification of the decision-maker, plans for risk communication, and the resourcing of the risk analysis task.
- ***Risk Identification*** through a process to identify a set of mutually independent risk scenarios that provide a comprehensive definition of the scope of the risk to be managed.
- ***Risk Estimation*** to find numerical (or qualitative, as appropriate) estimates of the frequency and consequences for each risk scenario.

The focus of this section is on risk estimation. Risk estimation methods can be graded according to the quality of the methods, with the highest quality method expected to be both an accurate and fairly certain estimate of future risks, with and without proposed risk prevention and mitigation measures. The following is one classification:

Class A risk estimate - developed using historical data for the specific location where the data is sufficient to inform all risk scenarios, where the risk estimates can be validated, and there is good expectation that past data reflects future conditions.

Class B risk estimate - local data is used to "anchor" risk estimates and surrogate data is used to provide risk estimates, where the surrogate data is aggregated data for systems that are essentially the same as the local system conditions.

Class C risk estimate - similar to B but surrogate data is not available for all scenarios (including the worst case) and information is substituted from experiments (tests of materials, human performance in simulations, etc.), from logical structure of drawing from experience and expertise (FMECA, fault trees, what if? analysis, etc.), and from other modeling methods (neural nets, Delphi techniques, etc.).

Class D risk estimate - risk estimates are basically expert opinions supported where possible by other system operating results, available local data, etc. These estimates are only defensible on the basis that a decision must be made and this is the best information available.

The data available and the resources available will in combination limit the "class" of risk estimation method used. The resources assigned are usually matched to the magnitude of the risk and the importance of the possible risk control options.

NEC Example Risk Analysis Approach

In the risk analysis of the Northeast Corridor Study (Arthur D. Little, Northeast Corridor Risk Assessment, August, 1994), the risk estimates were anchored with an analysis of serious accidents over the period 1986-1993. Serious accidents were defined as accidents with more than $50,000 damage or a casualty involved. The study considered main line and terminal accidents separately. There were three serious terminal accidents and six serious main line accidents in the period. (Minor accidents were one and four respectively.) Only collision and derailment accidents were studied. The identified causes of the 11 serious accidents were for collisions (two due to signals, and one due to equipment), and for derailments (two due to signals, two due to equipment, and two due to human factors). It should be noted that only FRA-type causes were considered, which do not include supervisory or management failures as root causes, such as NTSB does.

Accident frequencies were calculated on the basis of terminal visits and million train miles. There were 0.0265 trains in serious collisions per million train miles and 0.079 serious derailments per million train miles. The environment was excellent track and bi-directional signals with high traffic levels, with up to 269,805 annual train movements at the New York station. For stations, the accident frequencies were 4.2 serious accidents per million train movements.

Changes in the "base" or existing accident frequencies due to changes in risk factors were made using adjustment factors developed in research studies done by ADL for the Volpe Center. For example, the relative frequencies, i.e., with fair track and single direction signals being taken as 1.0, were as follows (given for illustration only; consult the original documents for specific conditions for these estimates):

Table 6-1
Illustration of Variation in Relative Risk due to Track Quality and Signal System

Track Quality	Single Direction	Bi-direction	Absolute Stop
Fair-Good (FRA Class 4,5) (moderate speed)	1.0 (set to 1.0 as a datum)	.83	.68
Good (FRA Class 6) (high-speed)	.93	.76	.61
Excellent (Exceeds FRA 6) (very high speed)	.87	.69	.55

For estimates of the impact of risk factors, the general approach was as follows:

Reduction in Risk = (% of accidents due to cause C in accident database) × (% reduction in C estimated due to prevention P)

For example, if 12% of serious collisions are due to Brake operations (FRA H008-H009) and full ATP is estimated to reduce these types of accidents by 33% with full ATC rather than the existing bi-directional ATC, then the reduction in risk would be 12 × .33 or 4%. (Note that in the preliminary analysis of "serious" collisions in Table 6.11 there were no observations for this cause.)

The report states that "these frequency (estimates) are based on very sparse data and are potentially unreliable with regard to absolute values. We consider, however, that the relative frequencies between collisions and other accidents are reasonable, as are the relative frequencies with the different signal system types and track conditions. Further support is provided by a comparison with accident data for other portions of the U.S. rail system." In terms of the classification given above, this would be a Class C quality risk estimate, since there are limited local data to anchor the risk estimate and the impact of changes in signals, etc. are estimated from analysis results. When a comprehensive risk-based approach is fully implemented in the U.S. rail system, it is likely that the estimate would still be a Class C, since there will still be limited data; however, a range of estimates would be given to provide an explicit measure of the uncertainty in the estimate.

The NEC report also includes estimates of casualty ratios with different crashworthiness designs based on Amtrak reports and Volpe Center proposals. For example, for a high-speed locomotive to conventional car type collision, the report indicates the following relative ratios for an operating speed (60-79 mph) with a higher casualty ratio being more dangerous:

car designed for low speed operation	0.60
car designed for medium speed operation	0.50
car designed for high speed operation	0.10

These results indicate a significant impact on the consequences of collisions for different car designs considered in the NEC Study.

FOX Example of Risk Analysis Approach

The Florida Overland eXpress (FOX) Risk Assessment was done by DLSF Systems Inc. in January, 1997, and estimated the risks for a high speed train by comparison to the TGV system in France with qualitative adjustment to reflect proposed improvement in risk factors. Also, the method used the NEC statistics as a benchmark for comparison of the safety of conventional rail systems with high speed rail systems design to TGV or higher standards. TGV was used since that is the high speed rail technology to be employed by FOX.

The base risk estimate for a U.S. high speed system was taken as the accident rate for TGV by considering the recorded accidents on the system from 1990-1996 (part of 1996 only), since prior to 1990 all accident records were in paper files. On high speed lines in this period, for both serious and minor accidents, there were two derailments, five collisions with animals, one collision with a concrete cover of an electrical system, and five equipment failures (two fires and three maintenance failures). In stations there was one collision during shunting, three low speed collisions, one runaway trainset, one equipment failure, and two falls from the train.

Accident rates were calculated for "serious" accidents only (more than $50,000 in damage or a casualty). There were no serious main line collisions in the data from TGV, and a frequency of 0 was estimated. For serious derailments and other incidents, the rate for TGV was 0.0269 compared to NEC "existing" of 0.0619 (difference from value of 0.079 given above is due to re-estimation of the NEC exposure to reflect only operations that are comparable to TGV operations, and for NEC "proposed improvements" of 0.051). Station accident rates were 0.23 per million train miles for TGV compared to 1.89 per million visits for NEC "existing," but with station usage redefined to reflect TGV type service (note from above that overall NEC rate was 4.2).

Given no serious accidents for TGV it might have been expected that the analysis would revert to all accidents (serious and minor) in order to make a more meaningful estimate of the collision risk.

The qualitative assessment of risk factors can be illustrated by the following examples from the report:

"Lower traffic density of commercial service. Train-to-train collisions...have been associated with high traffic density....The traffic density of the FDOT/FOX system will be lower than the TGV system."

"Collision of a train with people, foreign objects, or animals is highly unlikely on the FDOT/FOX system due to the totally fenced right-of-way. The right-of-way in the TGV system is open where high speed and conventional lines meet."

The report concludes "the FDOT/FOX system should surpass (i.e., be safer than) that of the TGV system in France....The safety level of the FDOT/FOX system should significantly surpass that of the NEC system even after future infrastructure improvements. . . . [It] should be less than 5.9% of that for the NEC system."

The report states that "it is recognized that these statistics (for TGV) are based on very sparse data. The scarcity of the data over a period of six and one half years is indicative of the safety of the TGV system." In terms of the classification given above, the risk estimate in this report is a Class D estimate since the base data were sparse and the risk adjustment factors were based on expert opinion. Note that this class of estimate was likely sufficient for the purpose of showing safety equivalence with existing U.S. rail systems, and given the stage of development of the FOX system.

Given the limited data available and the estimate of zero for collision risk (which is highly unlikely), the discussion of uncertainty and the provision of a range of estimates might have been considered. However, it is unlikely that this would have changed the conclusions.

Other Examples of Risk Analysis for Railway Operations

A German study conducted in 1994 by Deutsche Eisenbahn - Consulting GmbH, "Ergänzendes Gutachten zum Einsatz von LNT im Mischbetrieb mit EBO-Fahrzeugen auf Eisenbahnstrechen des öffentlichen Verkehrs" (the "Supplementary Report") is one in a series of studies of the risks of joint running of light rail passenger trains with regular rail traffic. The report is only partly translated for purposes of this analysis. The following comments are preliminary. The study was faced with limited data and followed the approach proposed in this research: a risk profile was established for the basic rail system and then the study focused on the risks that might be greater (or less) with the LRV operations. For example, the study quotes the following collision probabilities for the basic German rail system (all rates are per million train miles):

■ Flanking (passenger trains)	.008
■ Flanking (freight trains)	.107
■ Rear-end (passenger)	.08
■ Head-on (passenger)	TBD
■ Total collisions (passenger)	TBD

Next, the individual collision rates for the whole system are adjusted to reflect the reduction in risk due to specific differences between LRV trains and the trains in the general system. For example, LRV trains have improved braking capacity that was estimated to reduce accident probabilities by 10%, with rear-end and flanking accidents in particular reduced by 50%. On the other hand, accident consequences would be increased due to the lower passive safety of the LRV. The net implications for risk were lower and the German Ministry of Railways, in concert with rail operators, permitted joint use (an oversimplification of nearly a decade of work). It may be possible to give some overall risk results for specific operating conditions. This study provides an interesting example of the proposed approach and subsequent detailed studies that would be needed to estimate the risk changes for specific operating situations and conditions. Some of the methods developed for detailed analysis may be transferable. Six tables from the Landmark German Risk Analysis are included in Appendix N. Note parallel methodologies, discrete identity of accident types, and mix of rail mode involvements.

Currently, it is our understanding that the approach being used for the PTC study being done for the FRA's Railway Safety Advisory Committee (RSAC) is to consider historical data and then from this data select the individual accidents that might have been prevented by the proposed risk control (i.e., PTC). This is a common method of analysis for specific proposed measures to reduce risk. The difficulty is that the estimates often are upper bound estimates and usually overstate the risk reductions.

6.6 BASE RISK

The objective of this section is to describe, for "average" conditions for rail passenger and transit service in the United States, the typical risk and the characteristics of that risk. Surrogate data are used, since there are no real joint use operations and little data.

In February 1998, this research study team selectively surveyed operators for information on rail transit and rail commuter operations. Two responses were received, with only one accident between trains in total. The failure of the survey to produce a useable dataset may be due to the fact that data is not kept in a form that is amenable to risk analysis. In conclusion, the risk profile must be constructed from data from other sources (e.g., FRA, NTSB).

6.6.1 Rail versus Other Modes

The total passenger risk for Transportation Passenger Service in the USA is available from various government statistics and data and is summarized in Table 6-2. Of particular interest are the differences in Accident Rate for the different modes. At 0.38 accidents per 100 million passenger miles, Commuter Rail (which is likely to be similar in nature to the joint-use situation) has the lowest accident rate of all modes. A recently published paper (E.L. Tennyson, Rail Transit Safety Analysis, TRB, 1998) concludes, "for patrons and employees, all types of rail transit are two or more times safer than highway travel." Other data suggest, however, that *fatality* rates are higher for rail transit.

6.6.2 Trends in Rail Safety

Figures 6-2 and 6-3 provide an overview of trends in rail (freight and passenger) risk. In addition to being one of the safest modes of transportation, the trends indicate that rail has achieved an overall increase in safety over the past 20 years.

Figure 6-2 shows the trend for rail accidents between 1975 and 1996. The accident rate saw a rapid downward trend between 1978 and 1986 (from 11 to 5 accidents per million train miles). Between 1986 and 1996, the rate continued to drop but at a much slower pace (from five to four accidents per million train miles).

Figure 6-3 shows the trends in causes of train accidents for the years 1975-1996. During the period between 1978 and 1986, there were major reductions in accidents attributed to: 1) Track and Signal, 2) Human Factors, 3) Equipment, and 4) Other Causes, and to a much lesser extent, Highway-Rail accidents. The latter attribute remains the most vexing problem to be remedied. Discussions with other practitioners confirm that this drop in accidents was due largely to the investment in track, signal, equipment, and automation. Some have attributed the increased investment to substantial railroad industry deregulation in 1980. Between 1986 and 1996 the downward trend in the number of accidents seems to have stabilized; however, initiatives such as consolidation of the industry and the FRA requirement for "safety systems" should lead to improved levels of safety in

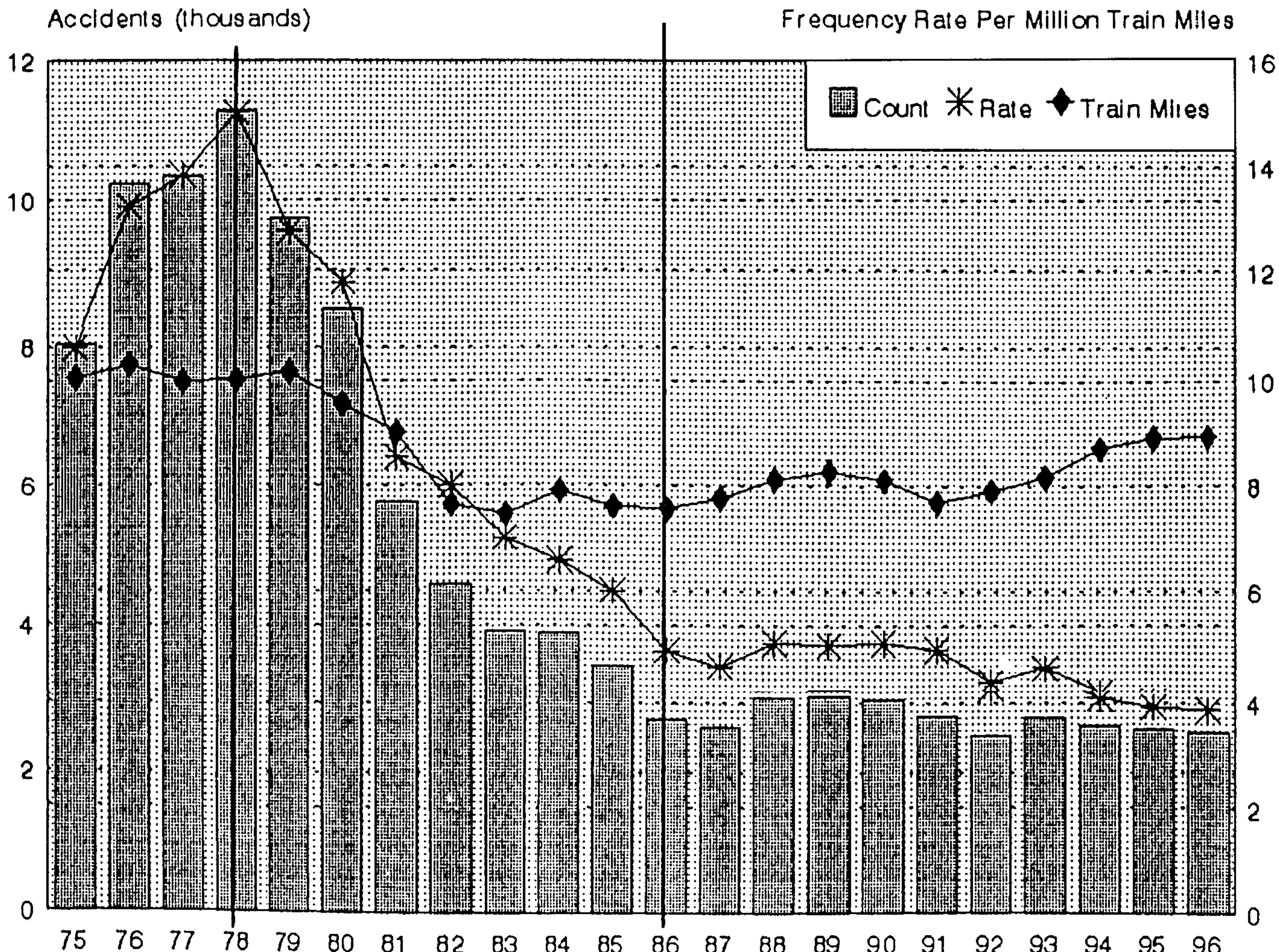
Table 6-2
Transportation Passenger Risks in the USA, 1993-1994-1995

Mode	Automobiles	Transit Buses	Light Rail	Rail Rapid Transit	Commuter Rail
Patron fatality rate per hundred million passenger miles	1.44	0.15	0.25	0.72	0.37
Patron injury rate per hundred million passenger miles	112	193	121	76	18
Station accidents (% of total)	n.a.	2%	20%	61%	32%
Collision accidents (% of total)	90%	58%	31%	5%	8%
Other accidents (% of total)	10%	40%	49%	34%	60%
Accident rate per million passenger miles	1.12	2.79	1.72	1.44	0.38
Cost of Accident (cents per passenger mile)	7.50*	2.16	2.06	1.02	1.25

* Includes only "serious" accidents as defined by the original source. Many states do not keep records of accidents with less than $200 or more in damages.

Source: E.L. Tennyson, P.E. *Rail Transit Safety Analysis.* TRB, 1998.

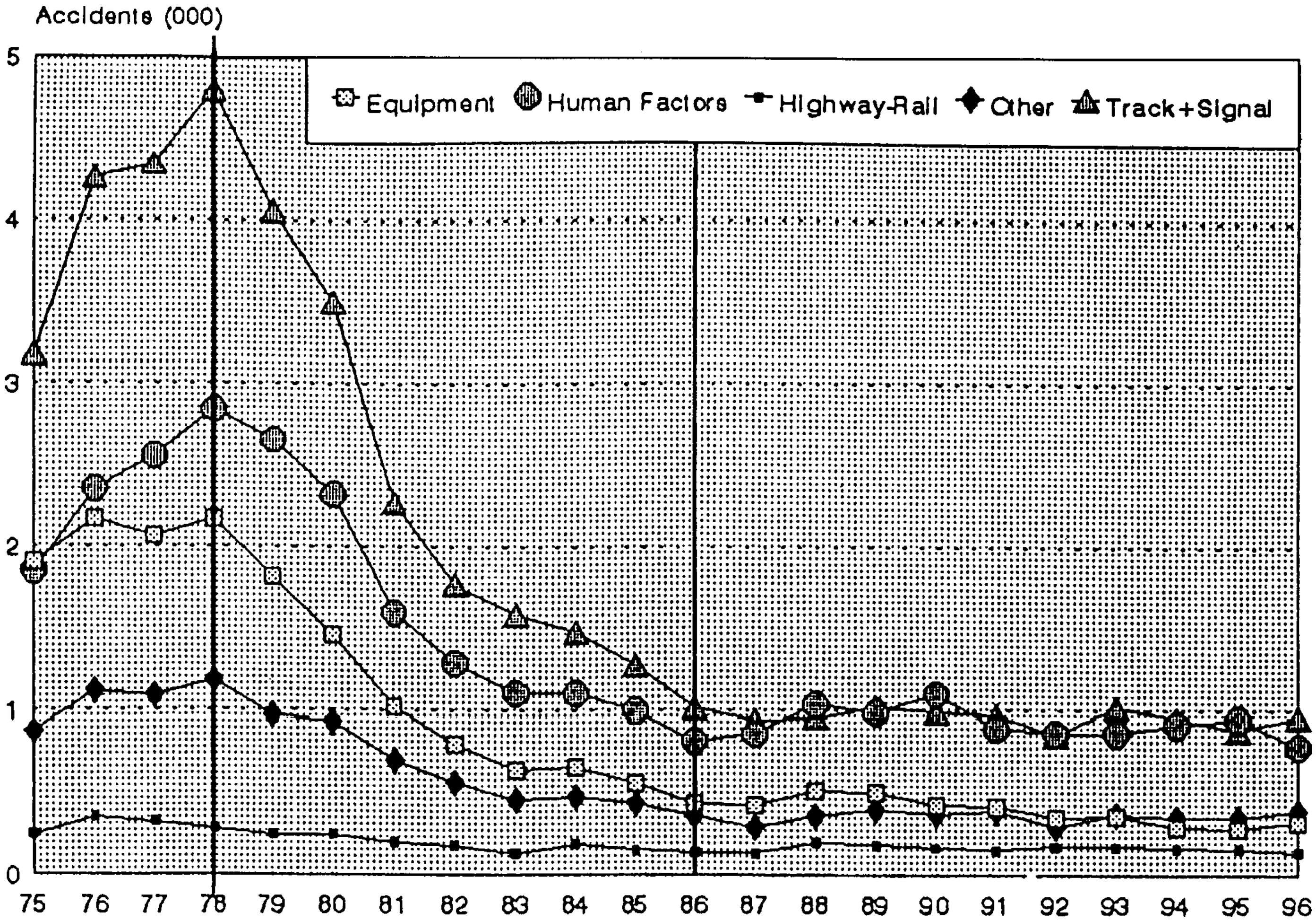
Train Accidents, 1975-1996 - Figure 6-2



In order to obtain comparable scaling, train miles have been divided by 100,000 in this chart
Train miles are displayed using the left axis.

Source: FRA, 1997

Train Accidents by Cause, 1975-1996 - Figure 6-3



Highway-rail accidents appearing in this chart are limited to those that resulted in reportable damage above the threshold for train accidents.

Source: FRA 1997

the future and resumption of the downward rate in accidents.

6.6.3 Estimation of the Base Risk of Passenger Operations

The base risk for passenger train operations and the causes of accidents is developed from the FRA incident database for 1992-1996. The analysis focused on serious accidents involving passenger trains and occurring on mainline track as being the most representative of the base risk for joint-use situations. An earlier analysis in this study was based on the data contained in the FRA Accident/Incident Bulletin for 1996 and is included in Appendices Ib1-Ib3. The main conclusion to be drawn from this Appendix is that there are similar train miles for commuter and intercity (as represented by Amtrak) passenger service, and that these have similar accident characteristics. Therefore, it is appropriate to consider all U.S. rail passenger data as relevant to joint use commuter operations in order to expand the data available for analysis.

The purpose of the analysis of FRA data for 1992-1996 was to obtain a relevant "base" risk estimate and profile (i.e., passenger service, mainline/station operations) for use in an "equivalent safety" risk assessment of joint use proposals. Table 6-3 summarizes the data available for this study. For collisions, the data was developed as train involvements while for other accident types the number of accidents were considered.

Analysis Step 1: Selecting only accidents that occurred on mainline (running) track

The full FRA data set was reduced by retaining only records of accidents that occurred on mainline track. Accidents occurring on siding, yard or industry track are not relevant to the joint use question and were eliminated.

Table 6-3
Summary of FRA Data (Mainline track only)

	No. of Records (1992-1996)	
	Non-Collisions	**Collisions**
ALL RAILROADS		
Total Involvements Total Accidents	n.a. 4968	519 n.a.
Serious[1] Involvements Serious Accidents	n.a. 2065	314 n.a.
PASSENGER RAILROADS		
Total Involvements Total Accidents	n.a. 474	39 n.a.
Serious Involvements Serious Accidents	n.a. 147	24 n.a.

[1]Serious accidents are those with a casualty of more than $50,000 in damages.

Analysis Step 2: Distinguishing between Accidents and Involvements

Because of reporting requirements, the FRA dataset contains multiple records for certain incidents, e.g., "All railroads having either on-track equipment or track involved in an accident must submit a report. If a single railroad has more than one equipment consist involved in an accident, it must submit a report for each consist. The index 'joint reporting code' is used to assign which railroads were involved." The first report received is assigned a value of 1 for the "joint code" field, while subsequent reports are assigned a "joint code" of either 2 or 3. This makes it possible to avoid double counting. The Institute for Risk Research (IRR) analysis examined only unique records (i.e., "joint code" = 1) for "derailments," "highway-rail," and "other" accidents. However, in the case of "collisions," the analysis included all reports because this is a measure of involvements which more accurately reflects the nature of collisions (i.e., there are often at least two trains involved).

The 519 records corresponding to collision involvements from 1992-1996 were recoded to reflect the total injuries and fatalities in collision incidents. This was done by matching records for the same incident and creating new fields for "total injured - all records" and "total killed - all records" for all trains involved in the incident. For example, in a collision with multiple reports, each report would record the total number of injuries and fatalities sustained by the reporting railroad. The new fields for "total injured - all records" and "total killed - all records" was set to the sum of the "total injured" and "total killed" for all records filed for a particular accident.

Analysis Step 3: Calculating Train Mile Exposures

The following method was used to calculate the exposure rate for *all railroads.* "Mainline miles" were derived by subtracting "Yard/Switching Train Miles" from "Total Train Miles." For all railroads, there were 583,100,106 total mainline train miles for 1996, which was used for the exposure for the five-year period (see Table 6-4).

The following method was used to calculate the exposure rate for *major passenger railroads.* The study team identified railroads, in Table 36 of the FRA Accident Incident Bulletin No. 165, which were passenger railroads or freight railroads on which passenger trains operate. "Mainline miles" were derived by subtracting "Yard/Switching Train Miles" from "Total Train Miles." To ensure that only major passenger railroads were included in the exposure data, only those railroads with more than 100 "Passenger Miles" per "Mainline Train Miles" were used. Using these criteria, data for the following passenger railroads were used:

- Amtrak (National Railroad Passenger Co.),
- Long Island Rail Road,
- Massachusetts Bay Transit Authority,
- Metro North Commuter Railroad Co.,
- Northern Indiana Commuter Trans.,
- Northeast Illinois Regional Commuter,
- New Jersey Transit Rail Operations,
- Port Authority Trans Hudson,
- Southern California Regional Rail.

These railroads account for 86% of all passenger miles. For major passenger railroads, the exposure rate used was 63,516,047 total mainline train miles per year. The analysis is shown in Table 6-4.

Analysis Step 4: Calculation of Accident Rates (All Railroads)

Table 6-5 gives a breakdown of Accidents on Mainline track by type for the years 1992-1996 for all Railroads. Accidents classified as "Highway-Rail" and "Other" accounted for 14% and 13% of all accidents and are not expected to increase with joint use.

"Collisions", which are expected to be the main source of incremental risk, account for only 9% of all accidents. Sixty-four percent of all accidents are due to "Derailments." However, an increase in derailments due to joint use would not be expected if track quality is maintained at levels similar to the current rail transit situation. The accident rate for collisions and derailments, per million mainline miles, is 0.18 and 1.20 respectively, for all railroads.

Table 6-6 gives a breakdown of serious accidents on mainline track by type for the years 1992-1996. Serious accidents are defined as accidents with a fatality or injury, or more than $50,000 in damages.

Table 6-4 - Calculation of Mainline Train Miles (1996)

	Total Train Miles	Yard/Switch Train Miles	Total Mainline Train Miles	Passenger Miles *	Passenger Miles Per Mainline Mile
MAJOR PASSENGER RAILROADS					
AMTRAK (Nat'l Railroad Passenger Co)	33,840,497	1,769,655	32,070,842	5,218,443,714	163
Long Island Railroad	8,171,689	112,889	8,058,800	2,074,296,403	257
Massachusetts Bay Transit Authority	1,688,552	0	1,688,552	209,695,666	124
Metro North Commuter Railroad Co	7,432,638	702	7,431,936	1,772,601,338	239
Northern Indiana Commuter Trans	714,143	0	714,143	100,704,437	141
Northeast Illinois Regional Commuter	3,381,424	75,556	3,305,868	684,399,679	207
New Jersey Transit Rail Operations	7,767,180	526,551	7,240,629	1,095,799,668	151
Port Authority Trans Hudson	2,019,297	263,386	1,755,911	290,190,118	165
Southern California Regional Rail	1,249,366	0	1,249,366	198,765,002	159
subtotal (major passenger railroads)	66,264,786	2,748,739	63,516,047	11,644,896,025	183
OTHER PASSENGER RAILROADS (Not used in the analysis.)					
Penninsular Commuter (San Mateo County)	442,246	0	442,246	0	0
Alaska Railroad Corp.	861,756	144,215	717,541	14,748,739	21
Southeastern Pennsylvania Trans	5,066,606	0	5,066,606	301,194,372	59
subtotal (other passenger railroads)	6,370,608	144,215	6,226,393	315,943,111	51
FREIGHT RAILROADS ON WHICH PASSENGER TRAINS OPERATE (Not used in the analysis.)					
Burlington Northern Santa Fe Corp.	145,803,928	18,799,466	127,004,462	276,797,050	2
Consolidated Rail Corp.	45,727,919	8,214,816	37,513,103	0	0
CSX Transportation	83,486,310	12,867,510	70,618,800	71,941,314	1
Denver & Rio Grande Western Railroad	7,680,491	0	7,680,491	0	0
Illinois Central Railroad Co	7,949,030	13,471	7,935,559	0	0
Norfolk Southern Corp.	63,655,055	9,744,774	53,910,281	0	0
Soo Line Railroad Co.	9,874,119	2,240,346	7,633,773	0	0
Southern Pacific Transportation Co.	43,893,368	7,858,551	36,034,817	0	0
Union Pacific Railroad Co	115,272,529	9,565,284	105,707,245	522,106,589	5
Delaware & Hudson Railway Co	1,742,818	252,818	1,490,000	0	0
Guilford Railroad System	1,066,519	117,133	949,386	0	0
Wisconsin Central Ltd (also Railway)	5,042,370	1,035,936	4,006,434	648,548	0
subtotal (freight w/ passeng.)	531,194,456	70,710,105	460,484,351	871,493,501	2
OTHER					
All other including: Grand Trunk Western Railroad, Inc , Kansas City Southern Railway Co , Alton & Southern Railroad, etc					
subtotal (other)	67,093,510	14,220,195	52,873,315	754,327,066	14
total all railroads	670,923,360	87,823,360	583,100,106	13,586,659,903	23

* Passenger-mile: Movement of a passenger for one mile.
(Source: Based on Table 36 in FRA, 1997)

Table 6-5
All Accidents (All Railroads) on Mainline Track by Type, 1992-1996

	Total Accidents[1]	Collisions[1]	Derailments	Other	Hwy-Rail Crossing
ALL ACCIDENTS (All Railroads) Number of accidents	5,487	519	3,488	689	791
Average number of accidents per year	1,097	104	698	138	158
Rate per 10^6 mainline miles [2]	1.88	0.18	1.20	0.24	0.27
% of Total	100%	9%	64%	13%	14%

1 For Collisions, the number of involvements is shown, e.g., a collision between 2 passenger trains would be 2 involvements but only 1 accident. Involvements is used instead of accidents for Collisions because Collisions tend to involve more than one consist. Because the other accident types (i.e., Derailments, Hwy-Rail, Other) tend to involve a single consist, the number of accidents is shown.

2 Total mainline miles (all railroads 1996) = 583,100,106.

Source: derived by IRR from FRA data.

Table 6-6
Serious Accidents (All Railroads) on Mainline Track by Type, 1992-1996

	Total Accidents[1]	Collisions[1]	Derailments	Other	Hwy-Rail Crossing
SERIOUS[2] ACCIDENTS (All Railroads) Number of accidents	2,379	314	1,643	169	253
Average number of accidents per year	476	63	329	34	51
Rate per 10^6 mainline miles [3]	0.82	0.11	0.56	0.06	0.09
% of Total	100%	13%	69%	7%	11%

1 For Collisions, the number of involvements is shown, e.g., a collision between 2 passenger trains would be 2 involvements but only 1 accident. Involvements is used instead of accidents for Collisions because Collisions tend to involve more than one consist. Because the other accident types (i.e., Derailments, Hwy-rail, Other) tend to involve a single consist, the number of accidents is shown.

2 Serious accidents involve a fatality or an injury or have over $50,000 in damages.

3 Total mainline miles (all railroads 1996) = 583,100,106.

Source: derived by IRR from FRA data.

Comparing all accidents to serious accidents, the "Highway-Rail" category falls from 14% to 11%, the "Other" category drops from 13% to 7%, "Collisions" increase from 9% to 13%, and "Derailments" increase from 64% to 69%. The rate of serious accidents per million mainline train miles for collisions and derailments on all railroads is 0.11 and 0.56, respectively.

Analysis Step 5: Calculation of Accident Rates for Passenger Trains

An analysis was done of all accidents on mainline track for the five-year period from 1992 to 1996 that listed "passenger train" as the type of equipment involved.

Table 6-7 summarizes the results of this analysis for all accidents involving passenger trains. Accidents classified as "Highway-Rail" and "Other" accounted for 29% and 46% of all passenger train accidents. "Collisions" account for only 8% of all accidents. Seventeen percent of all passenger train accidents are due to "Derailments." The passenger train accident rate per million mainline passenger train miles for collisions and derailments is 0.13 and 0.28, respectively.

Table 6-8 gives a breakdown of serious accidents involving passenger trains on mainline track by type for the years 1992-1996. Serious accidents are defined as accidents with a fatality or injury, or more than $50,000 in damages. Comparing all passenger train accidents to serious passenger train accidents, the "Highway-Rail" category rises from 29% to 38%, the "Other" category drops from 46% to 29%, "Collisions" increase from 8% to 14%, and "Derailments" increase from 17% to 18%. The rate of serious passenger train accidents per million mainline train miles for collisions and derailments for passenger trains is 0.07 and 0.09, respectively.

6.7 CAUSES OF ACCIDENTS

In Section V of this chapter, the analysis identified major differences in terms of broad accident types and the average accident rates for passenger and freight railroad operations. This section will provide a more in-depth look at specific accidents with the objective of identifying causes of accidents. Special attention was paid to accident types, such as collisions, which would be incremental risks in joint use situations.

A sample of 16 NTSB railroad accident reports were selected based on their similarity to the joint use situation, i.e., collisions, accidents involving passenger trains (especially commuter rail), or passenger and freight trains. The reports provide insight into actual (and perhaps in some cases typical) accident scenarios. These reports are summarized in Appendix Ia-1. For each accident selected, the table in Appendix Ia lists the following data abstracted from the actual NTSB reports:

- Accident Date
- Report Number and Title
- Injuries
- Damages
- Probable Cause (as determined by NTSB)

In addition to NTSB data, Appendix Ia-1 also lists:

- a Synopsis (including details relevant to Car Integrity) and
- IRR Cause Categories (as defined for this risk analysis)

The IRR Cause Categories for the selected accidents is shown in Table 6-9. The purpose of assigning cause categories to the accidents is to begin to list typical factors that contribute to collision and derailment accidents. These factors will help to identify and evaluate potential mitigation measures.

Table 6-7
All Accidents (Passenger Trains) on Mainline Track by Type, 1992-1996

	Total Accidents[1]	Collisions[1]	Derailments	Other	Hwy-Rail Crossing
ALL ACCIDENTS (PASSENGER TRAINS) No. of accidents (1992-96)	513	39	88	234	152
Ave. no. of accidents/year	103	8	18	47	30
Rate per 10^6 (passenger train) mainline miles [2]	1.62	0.13	0.28	0.74	0.48
% of Total	100%	8%	17%	46%	29%

1 For Collisions, the number of involvements is shown. For other accident types (i.e., Derailments, Hwy-rail, Other) the number of accidents is shown.
2 Total mainline miles (major passenger railroads 1996) = 63,516,047.
Source: derived by IRR from FRA data.

Table 6-8
Serious Accidents (Passenger Trains) on Mainline Track by Type, 1992-1996

	Total Accidents[1]	Collisions[1]	Derailments	Other	Hwy-Rail Crossing
SERIOUS[2] ACCIDENTS (PASSENGER TRAINS) Number of accidents (1992-96)	171	24	30	52	65
Ave. number of accidents/year	34	5	6	10	13
Rate per 10^6 (passenger train) mainline miles [3]	0.52	0.07	0.09	0.16	0.20
% of Total	100%	14%	18%	29%	38%

1 For Collisions, the number of involvements is shown. For other accident types (i.e., Derailments, Hwy-rail, Other) the number of accidents is shown.
2 Serious accidents involve a fatality or an injury or have over $50,000 in damages.
3 Total mainline miles (major passenger railroads 1996) = 63,516,047.
Source: derived by IRR from FRA data.

Table 6-9 - Mapping of FRA and IRR Accident Cause Categories
(For Summary of this Table see Table 6-10)

IRR Cause Category	Sample of NTSB Investigations (1)		FRA Cause Category (2)	FRA Data (3) for Serious (4) Passenger Train Accidents (1992-1996)	
	Collisions	Derailments		Collisions (Involvements)	Derailments (Accidents)
SEPARATION					
- SUPERVISORY/MANAGEMENT (10)					
- inadequate programs/procedures	96-04, 96-01, 93-03, 87-02, 88-01	92-01			
- failure to follow standing operating practices					
"	85-11		BRAKES, USE OF (H008-H009)	–	–
"			FLAGGING, FIXED, HAND & RADIO SIGNALS (H204-H316)	5	2
"			MAIN TRACK AUTHORITY (H401-H499)	7	2
"	88-05		CAB SIGNALS (H821)	–	–
"			MISCELLANEOUS H994 Human Factors - signal	–	–
- speed	88-01, 87-02		SPEED (H602, H604-H699) (5)	2	–
- FAILURE OF SIGNAL SYSTEM					
- design of signal (or train control) system	96-04, 96-03, 96-01, 88-05, 87-04	92-01			
- signal failure			SIGNAL AND COMMUNICATION FAILURES (S003, S006, S008-S009) (6)		
- maintenance	90-01				
CAR INTEGRITY (7)					
- PASSENGER CAR BREACHED	97-01, 96-04, 96-03, 96-01, 93-03, 90-01, 88-01, 87-04, 85-11	93-02, 92-01, 91-01			
- BREACH OR CONTROL/CAR OPERATOR (NOT OF PASSENGER) COMPARTMENT	95-02, 88-05, 85-09	93-02, 92-01, 91-01			
TRACK QUALITY					
- SUPERVISORY/MANAGEMENT (10)					
- inspection & maintenance			ROADBED DEFECTS (T001-T099)	–	1
			TRACK GEOMETRY DEFECTS (T101-T199)	–	5
			RAIL & JOINT BAR DEFECTS (T201-T299)	–	1
"		93-02	FROGS, SWITCHES AND TRACK APPLIANCES (T301-T399)	–	1
"			OTHER WAY & STRUCTURES (T402, T499)	–	1
			MISCELLANEOUS H993 Human factors - track	–	1
			OTHER WAY & STRUCTURES (T401, T403)	–	–
- DESIGN					
SYSTEM INTEGRITY					
- SUPERVISORY/MANAGEMENT (10)					
- inadequate program/procedures	97-01, 96-01 95-02				
- failure to follow standard operating practices					
"	95-02		LOADING PROCEDURES (M201-M299)	1	–
"			TRAIN HANDLING/TRAIN MAKE-UP (H501-H599)	–	1
"			SWITCHES, USE OF (H701-H799)	–	2
"			MISCELLANEOUS H999 Other train operation/human factors	–	–
- fitness for duty	97-01, 96-03, 88-01		EMPLOYEE PHYSICAL CONDITION (H101-H104)	–	–
- training/experience	90-01, 88-05, 88-01, 87-04, 85-11, 85-09	92-01			
- inadequate maintenance	87-04				
"		91-01	LOCOMOTIVES (E71L-E79L)	–	–
"			BRAKES (E0HC-E09C)	1	–
			TRAILER OR CONTAINER ON FLAT CAR (E11C)	–	–
			BODY (21C-E29C)	–	–
			COUPLER AND DRAFT SYSTEM (E30C-E39C)	–	–
			TRUCK COMPONENTS (E4TC-E49C)	1	–
			AXLES AND JOURNAL BEARINGS (E51C-E59C)	–	–
			WHEELS (E6AC-E69C)	–	1
			DOORS (E81C-E86C)	–	–
			GENERAL MECHANICAL & ELECTRICAL FAILURES (E99C-E99L)	1	–
			MISCELLANEOUS H995 Human factors - motive power & equipment	–	–
OTHER					
- e.g. no independent safety authority	87-04				
			ENVIRONMENTAL CONDITIONS (M101-M199)	–	–
			HIGHWAY-RAIL GRADE CROSSING ACCIDENTS (M301-M399) (8)	–	–
			UNUSUAL OPERATING SITUATIONS (M401-M406, M409) (9)	3	–
			OTHER MISCELLANEOUS (M505-M599)	2	12

(1) - The Railroad Accident Report (RAR) number is shown to indicate which IRR cause categories were assigned to which NTSB investigation. N.B. The table may include multiple cause category entries for an individual accident.
(2) - GENERAL SWITCHING RULES (H301-H399). Not included because they are mostly yard accidents.
(3) - Note only "collision" & "derailment" categories shown, "other" and "Hwy-Rail crossing" not shown on this chart. Collision count is for total involvements, whereas derailment count is for total accidents.
(4) - Serious accidents are those resulting in an injury or fatality or more than $50,000 in damages.
(5) - H601 & H603 not included because they consist mostly of yard accidents.
(6) - S007 not included because it pertains to yard accidents.,
(7) - Related to consequence, thus not part of "FRA cause category."
(8) - Although there were no "collision" or "derailment" accidents for these categories, there were 138 "Hwy Rail Crossing" accidents.
(9) - M408 not included because it pertains to yard accidents.
(10) - Table 6-9 "Supervisory and Management" characterizes the "human error" historical category. The Supervisory Management term is more inclusive. It includes some operator failures which could be reduced with improved supervision and management.

The IRR categories are organized into the following main areas (see Section 6.5):

- Separation
- Car Integrity
- Track Quality
- System Integrity, and
- Other

These main areas are broken down into sub-categories and into sub- sub-categories which, in many cases, correspond to FRA Cause categories. Table 6-9 shows the mapping between the IRR Cause Categories and the FRA Cause Categories (as assumed by IRR). In most cases, there is not a direct 1:1 mapping of the FRA and IRR categories. A discussion of the major similarities and differences between the FRA and IRR classification systems follows.

In general, the FRA classification does not include a sub-category for "Supervisory and Management." However, from the limited sample of NTSB reports listed in Appendix Ia-1, the importance of the "Supervisory and Management" factor is clear, especially as it relates to putting in place "adequate programs and procedures" and to ensuring that those procedures and programs are adequately implemented by diligently following "standard operating practices" in a safety system.

Following recent practice in characterizing the causes of risks, Table 6-9 assigns historical accidents of "human error" on the part of the operator to the category of "supervisory and management" failure. The rationale is that operator error is expected from time to time but improved supervision can reduce the frequency of errors and better management systems can provide more redundancy for and improved checking of critical operations to minimize the impacts of human error. This is the general approach of the NTSB.

Since many of the accidents in the selected NTSB sample are collisions, they tend to have causes that fall into the "Separation" category. The mapping of the IRR and FRA categories provides some validation of the IRR sub-categories under "Separation" for "failure to follow standard operating practices", "speed", and "signal failure".

The "Car Integrity" category is included to provide information on *consequences* that result from an accident. There is no corresponding FRA category since the FRA categories all relate to cause rather than consequences. A "Synopsis" was included in Appendix Ia-1 to provide information relevant to the IRR Category of "Car Integrity." The Synopsis includes information on the type of train(s) involved (especially with respect to compliance with FRA buff strength requirements), the consist make-up, the speed at impact, and the angle of impact.

Table 6-10 shows a comparison of the "Car Integrity" factor for cars that are FRA compliant (passenger railroad cars) and those that are not FRA compliant (e.g., subway cars). In all accidents involving non-FRA compliant vehicles, the passenger compartment was breached; whereas, for FRA compliant cars, 69% were breached. This evidence supports the position that for joint use situations, in which passive safety measures are to prevail, buff strength is an issue that must be addressed. The information in the NEC report given in Section 6.5 indicates that crashworthiness has a significant impact on the casualties but also that speed reductions can compensate for lower levels of crashworthiness. (The German Ministry of Railways agrees and treats the speed reduction as one of several mitigations for lesser crashworthiness.)

Table 6-10
Summary of Car Integrity Factor for NTSB Sample

<table>
<tr><th></th><th colspan="2">FRA COMPLIANT</th><th colspan="2">NON-FRA COMPLIANT</th></tr>
<tr><th>Accident</th><th>Damage to Passenger Compartment</th><th>No Damage to Passenger Compartment</th><th>Damage to Passenger Compartment</th><th>No Damage to Passenger Compartment</th></tr>
<tr><td>February 9, 1996, RAR-97-01</td><td></td><td></td><td>X</td><td></td></tr>
<tr><td>January 6, 1996, RAR-96-04</td><td></td><td></td><td>X</td><td></td></tr>
<tr><td>June 5, 1995, RAR-96-03</td><td></td><td></td><td>X</td><td></td></tr>
<tr><td>February 9, 1995, RAR-96-01</td><td></td><td></td><td>X</td><td></td></tr>
<tr><td>May 16, 1994, RAR-95-02</td><td colspan="2">X
(damage to control compartment only.)</td><td></td><td></td></tr>
<tr><td>January 18, 1993, RAR-93-03</td><td>X</td><td></td><td></td><td></td></tr>
<tr><td>July 31, 1991, RAR-93-02</td><td>X</td><td></td><td></td><td></td></tr>
<tr><td>Dec. 12, 1990, RAR-92-01</td><td>X</td><td></td><td></td><td></td></tr>
<tr><td>March 7, 1990, RAR-91-01</td><td></td><td></td><td>X</td><td></td></tr>
<tr><td>March 10, 1989, RAR-90-01</td><td></td><td></td><td>X</td><td></td></tr>
<tr><td>November 12, 1987, RAR-88-05</td><td>X
(damage to control car only.)</td><td></td><td></td><td></td></tr>
<tr><td>January 4, 1987, RAR-88-01</td><td>X</td><td></td><td></td><td></td></tr>
<tr><td>August 23, 1986, RAR-87-04</td><td></td><td></td><td>X</td><td></td></tr>
<tr><td>May 7, 1986, RAR 87-02</td><td></td><td>X</td><td></td><td></td></tr>
<tr><td>August 17, 1984, RAR-85-11</td><td></td><td></td><td>X</td><td></td></tr>
<tr><td>July 23, 1984, RAR-85-09</td><td colspan="2">X
(mostly end-crush damage.)</td><td></td><td></td></tr>
<tr><td>Total</td><td>5.5</td><td>2.5</td><td>8</td><td></td></tr>
</table>

Although Appendix Ia provides details of the damage sustained, Table 6-9 only shows two sub-categories in the "Car Integrity" category. The "Passenger Car Breached" sub-category indicates that the passenger car was breached and as such, the risk of passenger injury was increased. Accidents that did not result in damage to the passenger car compartment but did sustain end-crush damage or damage to the control car fall into the "Breach of control car/operator compartment" category.

For the "Track Quality" category, "inspection and maintenance" is the IRR sub-sub-category with the highest number of corresponding FRA cause categories in Table 6-9.

For the IRR category "System Integrity", the most common sub-category in the NTSB sample is "Supervisory/ Management". The "fitness for duty" sub-sub-category corresponds to the FRA categories relating to "employee physical condition". The "inadequate programs/ procedures" and "training/experience" sub-sub-categories occur frequently in the NTSB sample but there is no corresponding category in the FRA classification scheme.

The data from the NEC study as well as other studies of rail accidents strongly link track quality with accident rates for derailments. An ADL study cited in the NEC study indicates that main line track accidents are approximately as follows:

- FRA class 4 track 1.0 accidents per million train miles
- FRA class 3 track 2.5 accidents per million train miles
- FRA class 2 track 5.0 accidents per million train miles

Table 6-1 gives estimates for FRA class 5, 6, and better track. There is a relationship between track quality and permissive operating speed, which is not known quantitatively. In addition, it is likely that the consequences of accidents on lower FRA class tracks are less severe, due to the reduced operating speeds; however, these relationships are not known at this time. The NEC study above quotes some results for high speed operations.

To the extent that joint running will expose passenger trains to track quality that has deteriorated due to freight operations, derailments could be a significant incremental risk. If, on the other hand, track inspection and maintenance programs are in place to ensure that track quality is maintained, there will not be an incremental risk due to derailments caused by track quality.

The Risk Profile according to the IRR Cause categories can be summarized numerically as in Table 6-11.

Appendix Ib (page Ib-8) has a section "B3: Analysis of FRA Accident Causes of Serious Collisions and Derailments (Passenger Train Data, 1992-1996)," which provides some guidance on the causes of serious collisions and derailments of passenger trains for a five year period based on an analysis of FRA data. The analysis is based on limited data, even though all U.S. passenger train accident data was used.

Table 6-11
Summary of FRA and NSTB data by IRR Cause Category

	Number of Serious Passenger Train Accidents FRA data for 1992-1996 (NTSB sample[1])		
	Total (Collisions + Derailments)	**Collisions**	**Derailments**
SEPARATION			
■ SUPERVISORY/MANAGEMENT			
- inadequate programs/ procedures	n.a.	n.a. (5)	n.a.
- failure to follow standard operating practices	16	12 (4)	4
- speed	2	2 (2)	0
■ FAILURE OF SIGNAL SYSTEM			
- design of signal (or train control) system	n.a.	n.a. (5)	n.a.
- signal failure	1	1 (0)	0
- maintenance	0	0 (1)	0
CAR INTEGRITY[2]			
■ PASSENGER CAR BREACHED	n.a.	n.a. (9)	n.a.
■ BREACH OF CONTROL CAR/ OPERATOR (NOT OF PASSENGER) COMPARTMENT	n.a.	n.a. (3)	n.a.
TRACK QUALITY			
■ SUPERVISORY/MANAGEMENT			
- inspection & maintenance	10	0 (0)	10
■ DESIGN			
SYSTEM INTEGRITY			
■ SUPERVISORY/MANAGEMENT			
- inadequate programs/ procedures	n.a.	n.a. (3)	n.a.
- failure to follow standard operating practices	4	1 (1)	3
- fitness for duty	0	0 (5)	0
- training/experience	n.a.	n.a. (6)	n.a.
- inadequate maintenance	4	3 (1)	1
OTHER	17	5 (1)	12

1 Number of occurrences in NTSB sample is shown in parentheses for collisions only.
2 Related to consequence, thus not part of "FRA cause category."
3 "Human Failure" is subsumed into "Supervisory and Management" category.

6.8 RISK ASSESSMENT FOR JOINT OPERA-TIONS

Making decisions involving risk issues can be viewed from many perspectives. From the risk perspective the decision is often referred to as ALARA - As Low As Reasonably Achievable. Figure 6-4 illustrates the idea by showing risk as the horizontal width of the triangle and identifying two dividing concepts. The higher risk dividing line is the division between unacceptable and acceptable risks for any extenuating circumstances. It is generally set by the ethical values of society as a level of risk that is unacceptable under any situation. The lower division is the "de minimus" risk as defined by the law at the point where risk is so low that a reasonable and prudent person would take no action to reduce the risk.

Between the two dividing lines lies the ALARA region. Most regulatory activities take place in the ALARA region and they represent the assessment of society of the level of risk that is acceptable in light of the benefits of the activity and the costs of further reduction in the risk. The range of the ALARA region approaches both the "de minimus" region, where simple cost benefit analysis is sufficient to balance risks, costs, and benefits; and the unacceptable region, where expenditures in "gross disproportion" to the risk reductions are required.

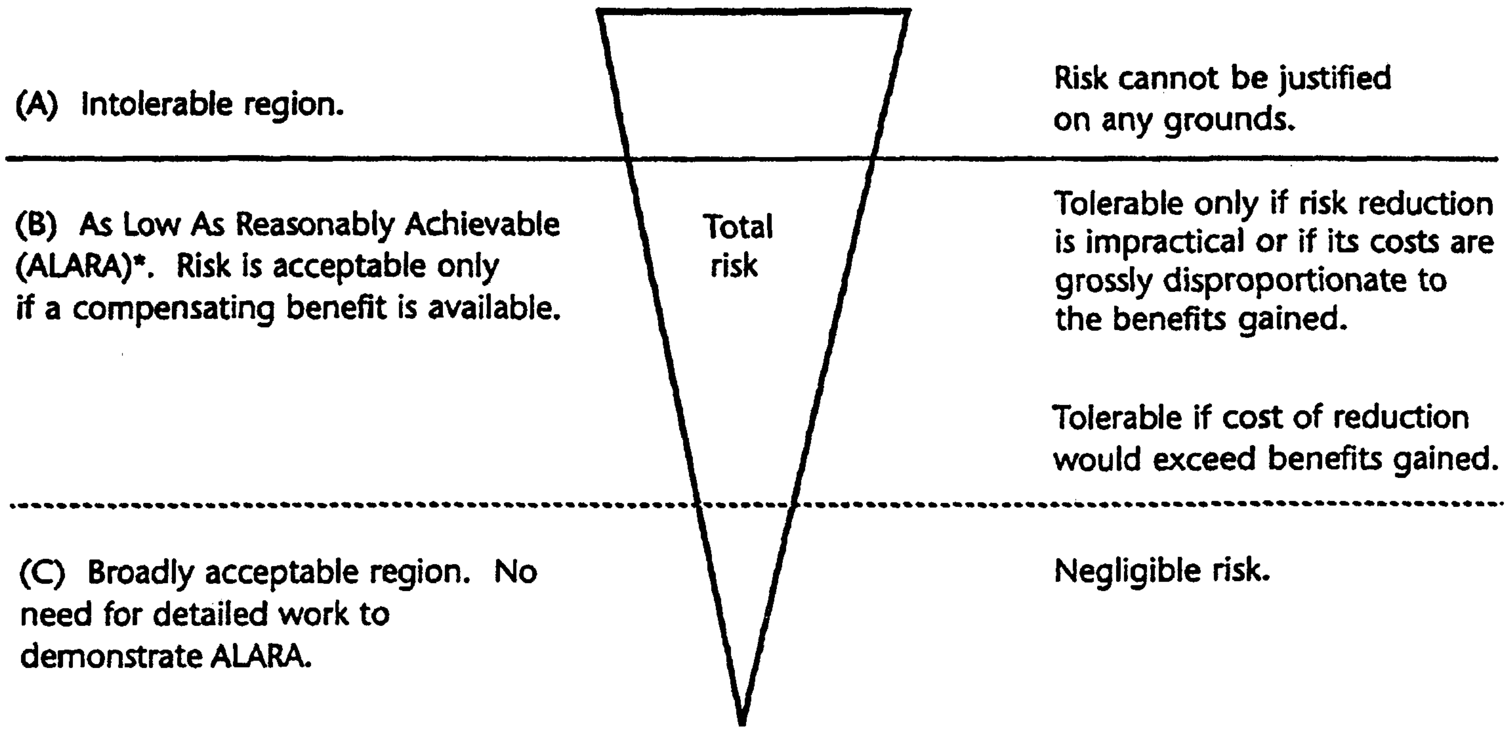
Transportation is a good example of how the ALARA regulations change over time and result in a long-term trend to reduced risk, especially expressed as risk per unit of output, such as passenger miles. As society becomes wealthier and as technology improves, it is to be expected that what is reasonable and achievable will change. The current regulations could be interpreted as "an acceptable level of risk with an expectation that the risk would be reduced in the future," unless demand outpaces capacity supply.

As a starting point in the risk assessment, the changes in risk alone could be considered. Incremental risks estimated in the risk analysis can be measured as the expected percentage increase in risks, where the percentage is relative to the total risk to the passengers, employees, members of the public, property, and operations. Very low percentages, say, less than a 2% increase, might be considered as acceptable and within the range of errors in risk estimation, while higher percentage increases would require balancing through reductions in risk by improvements in signaling, vehicle design, control of operations, selective separation, or other mitigations.

In terms of the ALARA diagram it could be argued that the regulatory oversight of passenger rail travel is towards the "de minimus" level of risk (i.e. the line between ALARA and Negligible risk). As indicated in Figure 6-4, risk in this region is "tolerable if the cost of reduction would exceed benefits gained." In other words, the results of a cost-benefit analysis are sufficient to determine the acceptability of the mitigation measures. This criterion is also supported by the fact illustrated in Table 6-2 that rail passenger travel is very safe relative to other modes and should therefore be encouraged from a safety perspective.

From a practical perspective, the risk assessment must meet the FRA criteria of "equivalent safety" in order to obtain a waiver for operating equipment that does not meet FRA standard specification. It is argued here that the determination of "equivalent safety" is compatible with the

ALARA Diagram - Figure 6-4



**Another term which is often used is ALARP — as low as is reasonably practical. ALARP and ALARA are similar in concept and application.*

Source: Canadian Standards Association (1997) notion of ALARP and the high level of uncertainty associated with the estimates of risk. In particular there is an expectation that safety levels should be constantly improving over time.

"Equivalent safety" is interpreted here as safety associated with "serious" accidents. This is consistent with studies done previously for FRA (NEC and FOX) and is reasonable, since serious accidents include all accidents that result in a casualty (injury or fatality). Moreover, the use of serious accidents is likely to improve the accuracy of the analysis since the problem of under-reporting of accidents is minimized.

"Equivalent safety" based on serious accidents that are defined as any accident with damages greater than $50,000 or any accident with a casualty would focus on the end result-damages and casualties. Safety is defined by both the frequency of accidents and the severity. Given this interpretation, failure to meet crashworthiness criteria will increase risk, but a reduction in accident frequency can be used to meet the "equivalent safety" criteria.

6.8.1 Proposed Methodology

The proposed method of risk assessment can be summarized as follows:

Purpose: The method will assess whether FRA's "equivalent safety" criteria are met or not.

Step 1. The method will first establish a "base" risk consisting of an expected frequency and consequences for total risks due to passenger operations. This base risk can be estimated in two ways:

a) using historical data for the corridor; usually this would only be possible for very high-density corridors, such as the Northeast Corridor, or

b) use of the recent accident statistics for U.S. passenger train operations.

Step 2. The components of the base risk that might be an incremental risk of "joint running" are identified.

Step 3. For each incremental joint use risk component, estimate the proportional increase or decrease in percentage of base risk associated with that component.

Step 4. Mitigating measures that are proposed for the joint use operation will be selected based on their cost effectiveness. The percent decrease in the base risk due to each mitigating measure will be estimated.

Step 5. The risk assessment will be summarized in terms of the results of Steps 1-4, and the net effect on the risk. Each item will be described in detail including the sources of estimates, descriptions of mitigating measures, assumptions made, limitations of the analysis, possible ranges of estimates, and other items that will aid in interpretation of the assessment.

Step 6. Benefits of the joint use operations will be estimated in terms of the improvements in safety associated with incremental traffic. (There are, of course, other major types of benefits such as cost savings which, for purposes of risk analysis, are not introduced into this process.) For example, if traffic is diverted from the auto mode, then the injury and fatality rates can be taken directly from road accident statistics for the roads in the commuting corridor, while the passenger rail safety would be estimated by Step 2.

Step 7. "Equivalent safety" will be determined based on a "conservative" interpretation of the risk estimates (i.e., erring on the side of safety).

In the following sections, each step in the method is described in detail. Note that the method as presented is preliminary. Analysis support and data availability will improve as studies are performed for individual joint running proposals. Studies and demonstrations done for FRA will provide additional experience and results to support this method or indicate where it should be modified. For example, the NEC study included an accident type, "collision following a derailment," which is not included in this study. Further work on the analysis of the FRA data, looking at and classifying individual accidents (similar to the work done here on collisions where the data on over 500 collision involvements were reviewed and recoded), would likely start with this accident type, since it would likely be included as an incremental risk due to joint use.

Step 1 - The base risk, assuming local data are not available, is the average total risk for serious accidents for all passenger operations in the U.S. for the period 1992-96 and is based on FRA data as described in Section 6.7.

The expected frequency of serious accidents by type of accident and cause of accident is given in Table 6-12. Only deterministic values are given and the reader should be aware that the data is limited (which is good) and that there is considerable variation in the results for individual railroads. Table Ib-1 indicates that the range of accident rates for individual passenger railroad operations is from 20% to 250% of the average.

Step 2 - Identify possible increases in risk due to non-compliance with FRA standards. The main difference for LRV and other joint use vehicles will be a reduced buff strength, with typical values of two times the car weight (TRB, 1997) or values that are about 1/4 to 1/3 of the 800,000 lbs. static strength required.

An area for further (but potentially costly) research is to determine the percentage increase in risk due to different buff strengths. This is a standard physical testing procedure in automotive vehicle design. It is suggested that such a study of buff strength risk be performed at the national level. The results could be available for those transit or other agencies to input in their more locally-based risk analyses. The increase in risk would depend on the actual buff strength of the car, the provision of "crush zones" in the design to protect the passenger compartment in a crash, and the operating speed of the LRV and freight trains. However, it is expected, based on the data quoted in the NEC study, that the impact on risk would be significant. Clearly, this is an area that requires further work before the risk assessment method can be applied in detail.

Some risk reductions due to noncompliance with FRA standards, such as the reduced stopping distance of LRVs as compared to typical passenger trains, would be noted in the specific categories in Step 3, rather than being recorded here, since they will depend on specific types of accidents.

Step 3 - Estimate incremental risks due to joint use based on the risk profile developed in Section 6 and the following assumptions. Table 6-13 identifies a set of

Table 6-12
Base Passenger Train Risk Profile for Joint Use (Developed from Tables 6-8 and 6-11)

		Total	Collisions[1]	Derailments	Other	Hwy-Rail Crossing
TOTAL Number (Mainline, Passenger Train, Serious) (FRA, 1992-1996)		171	24	30	52	65
TOTAL Rate[4]		0.52	0.07	0.09	0.16	0.20
% of Total		100%	14%	18%	30%	38%
BREAKDOWN BY IRR CAUSE CATEGORY						
Separation	(% FRA data)		63%	13%		
	(% of NTSB sample)[2]		37%	--		
Car Integrity[3]	(% FRA data)		n.a.	n.a.		
	(% of NTSB sample)[2]		26%	--		
Track Quality	(% FRA data)		0%	33%		
	(% of NTSB sample)[2]		0%	--		
System Integrity	(% FRA data)		17%	13%		
	(% of NTSB sample)[2]		35%	--		
Other	(% FRA data)		21%	40%		
	(% of NTSB sample)[2]		2%	--		

[1] For collisions, the number shown is involvements. All other accident types (i.e., Derailments, Hwy-rail Crossing, Other) shows the number of accidents.
[2] Since the NTSB reports were primarily selected for collisions, the % is only shown for collisions.
[3] Related to consequence, thus not part of "FRA cause category."
[4] "Total Rate" is the rate of train accidents per million train miles.

incremental risks and a format for calculating the incremental risk due to joint use. The assumptions are:

- Any risks due to incompatibility of platform heights or clearance distances are to be dealt with by physical improvements and are neutral with respect to risk increments.

- The attached table of incremental risks is for situations where there is insufficient data for local conditions and average U.S. passenger train data must be used.

In Table 6-13, the proportional change in the base risk can be estimated based on other studies, as in the NEC or FOX studies, or alternatively estimated based on analysis models. In the interim, when limited analyses or data are available, these proportions will have to be estimated using expert judgment anchored by the best available information on the expected effects. The basis for these proportional changes must be documented and appended to the Table. The percent increase in risks are in terms of casualties rather than dollar damages, since this is the most important safety dimension from a regulatory perspective.

Table 6-13
Form for Estimating Incremental Risks due to Joint Use

Incremen-tal Risk	% of Base Risk (from Table 6.12)	Proportional Change in Risk (document analysis method)	% Change in Risk (% of base risk times propor-tional change)
Collision	14%		
Derailment	18%		
Other and Hwy-Xing	68%		

As indicated earlier, derailment risk can be largely eliminated by increasing the inspection and maintenance schedule to ensure that the track quality is maintained at the design level. If this is the case, then the proportional increase for this component can be set to zero. However, the increase in risk due to collision following a derailment should be estimated based on further analysis of the FRA data, and this risk would be estimated based on the expected frequency of derailments of the freight traffic and the probability of a passenger train in joint use being involved in a collision. For example, for the operating conditions in the NEC study this was estimated as the probability that a "train within two minutes of the accident would be unable to stop".

Step 4 - Decreases in risk due to proposed mitigation measures. Possible mitigation measures and their impact that have been identified by this study are given below. This list is not comprehensive. In each case the increase or decrease in risk is identified as relating to risk frequency or risk consequences and the total percent reduction in risk is given in terms of the expected impact on casualties rather than damages in dollars. Table 6.9 or 6.11 and the causes listed there with observed number of accidents, can be used to identify effective mitigation measures. Mitigation measures include:

- <u>reduced operating speed.</u> It can be expected that the reduction in speed would have an effect proportional to the square of the speed. This is a function of momentums and dissipation of momentum in a crash. Thus a decrease from 60 to 50 mph would result in a 31% reduction in risk of casualties. This would represent a reduction in consequences.

- upgrading the signal system. As indicated in Table 6-1, the upgrading of the signal system can have a significant impact on risk levels; for example, going from a single direction to a bi-direction signal system would have about a 15% reduction in the risk frequency for collisions.

- upgrading of track quality. Again from Table 6-1, the improvement of track from class 4/5 to class 6 could lead to about a 7% decrease in risk frequency for derailments. Since track class is also a function of speed, which for LRVs is typically limited to 55-60 mph, the improvement in track results in a marginal improvement in safety– particularly if conventional railroad trains are speed limited in shared track sections.

- improvement in crashworthiness of LRV. Data from the NEC risk analysis (Arthur D. Little, August, 1997) indicates that special designs for improved crash resistance can neutralize the increased risk in Step 2 for risk consequences. The analysis of this mitigation measure will normally involve "finite element analysis" (standard sophisticated analysis in a variety of transport modes) validated by experiments. This level of analysis might typically be a centralized, cooperative effort between car builders, trade associations, and the Federal sector.

- improved system integrity. This is potentially one of the most important mitigation measures. If there is evidence of considerable differences in risk between operating railways (the variation in accident rates for individual railroads, given in Appendix Table Ib-1, is from 20% to 250% of the average) then it is reasonable to expect that improvements in supervision and management systems can have a significant impact on risk frequency, and risk consequences (e.g., improved discipline of emergency response in accidents). Alternatively, the system integrity can be improved by redundancy and/or higher performance in warning systems, signal systems, etc. For example, the use of PTC will have a risk reduction impact that will be estimated by simulation studies proposed to be undertaken by the the FRA-AAR-IDOT PTC Program. In most cases, the improvements to system integrity should be based on a detailed risk analysis to identify the most effective improvements in integrity. The results of risk analysis can also be used in communication with operators and supervisors to improve understanding of risk and thus improve performance of standard operating procedures that are critical to the safety of the system.

Step 5 - Summary of the Risk Analysis. The purpose of this summary is to establish if the FRA "equivalent safety" criteria are met or not, based on just the risk analysis. A one-page summary, containing all the assumptions, references for estimates of the impact of risk mitigations, and other key information for decision makers. At this level of detail it should be possible to compare the risk assessment results with operating data for other properties with similar conditions, with other studies, with other risk assessments, etc., in order to validate the risk assessment.

In summarizing the risk estimate, care must be taken in combining the estimated percentage increases and decreases in incremental risk from Steps 1-4. Since most of these estimates will be uncertain, it is recommended that for increases the maximum probable increase be used, and for decreases the minimum probable value be used. This may initially overestimate the risks to the extent that no large risk will be left our of the analysis. Later, in more detailed risk analyses, the use of mean values is more acceptable. In addition, the percentages should be combined by finding the percent of the base rate in terms of expected accident frequencies rather than combining the percent directly. If there are logical concerns about the combined estimate, sensitivity analysis should be done.

Step 6 - Estimation of Benefits and Costs. In the event that the Risk Analysis in Step 5 is within the estimation error of meeting or not meeting the FRA criteria, then the benefits of the passenger service will be important in assisting the decision maker. As indicated, the most important safety benefit will relate to the improved safety for passengers who shift from the auto mode to the rail mode. Other significant benefits will relate to mobility benefits, and service to centers of business activity; these benefits may be substantial, especially given the relative safety of rail transportation as demonstrated in Table 6-2. For most proposed services, the costs will be recovered from the farebox and other sources and the impact of costs on the safety of the system will not be a consideration. In a few situations, especially with the passage of time and higher expectations for acceptable safety in rail passenger systems, costs may have to be considered in an ALARA framework. In this case, detailed cost studies will be needed to compare to estimates of risk reduction due to specific mitigation measures.

Step 7 - Assessment of the risk in terms of "Equivalent Safety." This determination must be made by the decision maker and as indicated may be possible based on the summary of the risk analysis from Step 5, without consideration of benefits and costs of the proposed service.

The proposed method has not been tested with an example, due to time constraints and the lack of a suitable example situation. In future work on joint use, this method should be tested, and it should be recognized that the method might change. Also, there is considerable work necessary to develop an effective method that can be applied with some confidence. Fortunately, this will chiefly involve review and documentation of existing data and studies. The recommendations in Section 6.9 of this chapter give specifics of work that should be considered.

6.9 RISK SUMMARY AND RECOMMENDATIONS

6.9.1 Summary

This risk assessment study was challenging, particularly since the availability of data and other risk assessments continued to flow during and beyond the course of the study. For example, the RSAC study and other demonstrations will shortly become available and their results will modify this research by providing some specific impact estimates of the risk reduction due to advance train control systems.

This research is at the leading edge of a change in approach to safety, as indicated by the proposed FRA rule and the NEC and FOX risk assessment studies. Because of seven years' lead time, overseas progress in risk assessment for joint use applications will add credence to domestic shared track applications. Thus, the conclusions should be treated with caution and be reviewed carefully. In particular, the data and analysis to support a risk-based approach will take a number of years to fully develop. In the meantime, considerable expert judgment will be required.

The conclusions are:

- A risk-based approach to the approval of joint use rail services is appropriate and is consistent with the proposed FRA precedent, rules, and policy.
- There are currently insufficient data and analysis results to support a fully comprehensive numeric risk assessment method in North America. Moreover, given the improved safety record of rail passenger travel, and its proportionally low use outside of defined corridors and metro areas, there will *always* be insufficient accident data available.
- Rail travel is one of the safest modes of travel and its use should be encouraged in the name of safety.
- The proposed risk assessment method, given in this chapter's Section 6.8, is consistent with developing national and international standards and conventional approaches to risk analysis and assessment. It has overseas precedents where application is already nearly a decade old.
- It is necessary to use all the available FRA data for passenger rail travel in the U.S. as a basis for the risk assessment. Even then, there were only 24 serious passenger train collisions on mainline track in the last five-year time period.
- Following the NEC and FOX studies, risk assessment should use "serious" accident data, i.e., those which involve a casualty or damages in excess of $50,000.

6.9.2 Recommendations For Further Research

Based on the work done to develop the risk assessment method, the following recommendations can be made:

- Further analysis of existing data should be conducted to support the risk assessment method. Examples of analysis using existing data are:
  - study of collisions following a derailment or other accident;
  - separation of mainline risks into station risks and track risks;
  - detailed study of train involvements versus accidents, looking at individual accidents and adding fields to the data, as was done in a preliminary way for collisions.
- Review and documentation of risk analysis methods and results available in the literature and in government agencies, to produce a compendium of expected risk reductions or increases with

variation in risk factors, such as braking distance, buff strength, speed, system integrity, i.e., crashworthiness *and* crash avoidance.

- Comparative studies of groups of railroads that have higher or lower than average safety records, in terms of the accident causes identified in this study, to determine the most effective safety intervention and mitigation measures.

- Study of casualties per accident as a function of accident characteristics. This dimension of the risk was beyond the scope of this study, but is a critical element in the risk assessment.

- A case study of the use of the risk assessment method in several real situations to validate the approach and to identify missing steps in the method.

- Continued monitoring of overseas advancements in risk analysis applied to joint use.

- Consider enrichment of the safety database to collect data in a form that can be used directly in risk analysis.