RISK AND TRAIN CONTROL: A FRAMEWORK FOR ANALYSIS

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Final Report
January 2001

Submitted to the
Volpe National Transportation Systems Center
Cambridge, Massachusetts

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Abstract

The report develops and demonstrates a framework for examining the effects of various train control strategies on some of the major risks of railroad operations. Analysis of a hypothetical 1200-mile corridor identified the main factors that increase risks. Passenger traffic is the most important factor, because adding passenger trains creates the possibility of catastrophic accidents with dozens of fatalities. Increasing the number of trains per day leads to more than proportional increases in the risks of collisions. Single track operations are much more susceptible to collisions, while higher train speeds increase both the likelihood and consequences of accidents if there is a signal overrun or a failure to obey a slow order. Positive train control systems can reduce most, but not all of the collisions and overspeed derailments, as improper train handling or equipment failure could still lead to accidents. Establishing a digital communications link to the train should also allow the possibility for improved grade crossing protection. For the hypothetical corridor, the potential grade crossing benefits were on the same order of magnitude as the predicted benefits from PTC systems. If new technologies are developed to detect broken rails, the digital communications link could also be used to implement braking immediately, thereby preventing some additional derailments. The risk-based approach demonstrated herein may provide a more complete assessment of rail risks than a methodology that estimates safety benefits based upon documentation of accidents that might have been prevented if more advanced train control techniques had been in place. Risks include the possibility of catastrophic accidents, whether or not such accidents have recently occurred. A causal-based methodology also allows greater flexibility in sensitivity analysis and in assessment of trends in traffic volume, traffic mix, and other factors.

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Acknowledgments

This research was sponsored by the Federal Railroad Administration and supervised by the Volpe National Transportation System Center. The work was administered as part of the "Basic Ordering Agreement" between VNTSC and the MIT Center for Transportation Studies. Peter Metz and Joe Coughlin and the CTS administrative staff were all very helpful in coordination and administration.

At FRA, Steve Ditmeyer and Jim McQueen were the champions for this project, and their insights and feedback were instrumental structuring our models and in honing our research hypotheses. At VNTSC, this was one of many projects underway related to positive train control, rail accident analysis, and grade crossing safety; we appreciate the chance to work with Herb Weinstock and so many others in his group who are seeking to understand and improve railroad safety. John Hitz and Neil Meltzer were responsible for supervising this research for VNTSC during Phase I and Phase II respectively, and we appreciate their efforts in organizing review meetings, establishing research priorities, and providing feedback throughout the past three years.

In both Phase I and Phase II, we had an on-going series of technical meetings with VNTSC staff. In addition to the people already mentioned, Bob Dorer, Sherry Borener, Anya Carroll, and Dawn Linden-France participated in these meetings and helped us find and interpret data, locate relevant research reports, and focus our analysis on key issues.

At MIT, Prof. Tom Sheridan and his graduate students provided generous assistance, helping us to understand how human factors relate to safety and the potential benefits of train control. Several people in the rail industry were also helpful in discussing the concepts and objectives of this research, especially Peter French and John Reoch.

While we have received a great deal of assistance from many people, we alone are responsible for the actual structure of the research, the interpretation of the results, the conclusions, and the recommendations included in this report.

Chapter 1
Introduction

1.1 Motivation

This research provides a framework for examining how rail transportation risk varies with train control systems and strategies. With many new train control technologies under development and being considered for deployment, it is important that all parties - in the public and private sectors - develop an understanding of how risk may change as a function of the characteristics of the systems under consideration. Only in this way can sound information about the trade-offs between costs and benefits be developed as a guide to public policy decisions regarding train control

Over the past 20 years, a great deal of progress has been made toward various approaches to what was, in North America, originally called "Advanced Train Control Systems" (ATCS). The basic concept of ATCS is that the provision of a digital communications link to an intelligent locomotive provides a means of enforcing compliance with dispatching decisions. The locomotive knows where it is; it knows where it is authorized to operate; and it will if necessary decelerate so that it does not run past a signal or any other limit specified in its operating authority. This technology therefore can eliminate head-on and rear-end collisions caused by overrunning signals or other human errors. The same principles can be used to enforce speed restrictions and protect maintenance crews.

While the technical feasibility of various approaches to train control is evident, financial feasibility and effectiveness in reducing risk are unclear. The safety benefits of advanced control systems do not justify the required investment, a conclusion reached by Burlington Northern [Hertenstein and Kaplan, 1991], the Federal Railroad Administration [FRA, 1994], and the Rail Safety Advisory Committee [RSAC, 1999]. This conclusion in part results because advanced train control only provides an added level of protection to a system that is already quite safe. The conclusion also reflects the high costs of the technology and an assumption that the technology would be applied system-wide or to a large portion of the system, as there is a substantial investment that is necessary for the control center, the system software, and the establishment of a digital communications link. With high fixed costs and complexities related to equipping locomotives, it is not feasible for a major railroad to consider implementing PTC for a small portion of the system.

It is conceivable that a different conclusion would be reached if the cost of the technology declines (which it is), if the technology were applied only in high-risk corridors, or if only the most cost-effective elements were implemented. This research was initiated in order to provide some insight into these possibilities. In particular, it addresses two basic questions that have been prominent in the on-going debate over train control:

1. How do risks and the potential for risk reduction vary from one rail corridor to another?
2. How much reduction in risk can be expected from different train control strategies?

Much of the debate is whether or not the federal government should require the freight railroads to implement PTC. The National Transportation Safety Board and FRA would both like to see that "the potential safety benefits of Positive Train Control be realized at the earliest possible date" [RSAC, 1999, p. 1]. FRA's 1994 study left open the possibility that implementation might be justifiable on certain corridors. Subsequent studies [RSAC, 1999] found that the safety benefits of PTC per train mile vary by two orders of magnitude across different portions of the network.

The RSAC analyses, like the earlier studies supporting FRA's 1994 report to Congress, applied a carefully crafted set of procedures and assumptions to the analysis of the benefits of PTC. On the benefits side, the most critical assumption was that historical accidents can be used to estimate the benefits of PTC by applying the concept of "PTC Preventable Accidents" (PPAs). More than 800 PPAs were identified by reviewing the more than 25,000 accidents reported to the FRA between 1988 and 1997. The FRA and the AAR agreed to estimate the benefits of PTC by determining how many accidents (and the corresponding fatalities, injuries, and damages) would have been or might have been eliminated for a given level of PTC. This approach has the very great advantage of providing a clear, factual basis for the benefits analysis. However, additional insights into risks can be achieved by using a parametric approach to study risk. With a parametric approach, there are several key benefits:

1. Risks can be examined for any set of traffic, network, and operating conditions, not just those that were observed during a study period.
2. Risks can include the possibility of catastrophic accidents, even if there were no such accidents during the historical study period. The possibility of a catastrophe should affect what we do in the future, whether the potential catastrophe is a major hazardous materials accident requiring evacuation of thousands or a passenger train collision resulting in dozen of fatalities and hundreds of injuries.
3. Risks can reflect the underlying engineering and human factors that relate to either the probability of accidents or their consequences.

In short, a parametric approach complements the historical approach by providing a flexible method to estimate risks and risk reduction, taking into account physics, human factors, and railroad operating conditions.

This study was conducted at a more aggregate level than some of the prior engineering-based studies [e.g. Kokkins & Snyder; Schor and Rosch, 1994], as we did not try to model train performance or the dynamics of an accidents. Instead, we assumed train speeds and deceleration rates for typical operations and used equations from prior research to estimate casualty and mortality rates for estimating casualties as a function of train speed, type of accident, and train make-up.

In effect, we pursued a level of analysis intermediate between a) the highly detailed modeling of train behavior and crash analysis and b) the application of historical measures for accident probabilities per million train miles or for the consequences of accidents. This approach allowed us to probe the engineering relationships more thoroughly than was possible in the RSAC studies and to examine many more situations than would be possible using the more detailed engineering models.

1.2 Train Control and Risk

A systems approach is necessary to identify and analyze the factors that influence the effects of train control systems on transportation risks. A train control system provides two functions that are essential for safe rail operations: issuance of track authority and enforcement of speed limits. Some sort of track authority is required to allow trains to operate safely in situations where their sight distance exceeds their stopping distance. Speed limits are needed to ensure safe operation over curves, turnouts and interlockings, and track segments with varying degrees of track quality. Temporary speed restrictions may also be needed as a result of track maintenance activities, e.g. to protect maintenance-of-way workers or to reduce speeds over track that has recently been surfaced.

In this study, train control systems are broadly defined. They certainly include the hardware and software associated with dispatching and signaling systems, along with the dispatchers, train crews and other people who interact with these elements of the system. The train control system also includes the operating rules, training efforts, supervision, and other organizational efforts aimed at improving safety. All of the components of train control systems have evolved for more than a century and a half to allow trains to operate more safely at higher speeds and at closer headways. Advances in communications and signaling have, in general, tended to reduce the human element in train control while increasing both safety and the efficiency of line operations.. The operating rules have been expanded, clarified, and improved, often in order to eliminate a particular type of accident. Training facilities, including locomotive simulators, have advanced greatly through the use of new technology.

If the train control system were 100% effective, then there would be no head-on or overtake train collisions and no derailments caused by operating at excessive speeds. In practice, train control systems are very good, but they are not 100% effective. Although the reliability of the train control hardware and software approaches 100%, there are portions of the system that still depend upon people and that are prone to human error. In addition, mechanical failure in the locomotive (e.g. braking failure) could lead to either a collision or derailment.

The objective of this research is to demonstrate how the risks of rail transportation relate to the train control strategy that is used. In particular, how would specific changes in the train control system produce incremental reductions in risk?

1.3 Overview of the Methodology

Risk is measured as the expected consequences of accidents, summed over all of the accident categories that are affected by train control systems. The probabilities of accidents are based upon fault tree analysis and thereby related to underlying metrics of exposure (e.g. number of train meets in single track territory) and factors related to train control (e.g. the probability that a train will run a red signal). The consequences of accidents relate to the type and speed of the train(s) involved, the number of people on board, the terrain and environment at the point of the accident. Prior studies and analysis of FRA's train accident data base provide the necessary information to calibrate the risk calculations.

This approach creates an analytical framework that can be used to consider the effects of changes in any element of the train control system. For example, consider the risks associated with train collisions resulting from a signal overrun. The probability of an accident is a function of six major factors:

1. Exposure (number of times that a train approaches a signal)

2. Action required (probability that the signal requires the train to slow down or stop)
3. Response (probability that the engineer attempts to take the required action)
4. Correct response (probability that the engineer takes the correct action)
5. Brakes (reliability of braking system)
6. Stop (probability that train will stop before encountering another train)

The exposure is related to the traffic on the line, the number of tracks, block length, type of signaling system. The probability that some action is required will increase with the traffic volume, but could be reduced through better meet/pass planning. The probabilities that the engineer will respond and respond correctly are related to the visibility of the signal, the experience and condition of the engineer, the number of people in the cab, and other human and environmental factors that might affect engineers' recognition of the need for action and their ability to respond. The braking capabilities could relate to the training and condition of the engineer as well as to the mechanical reliability of the locomotive. Finally, the probability that their will be an accident if the signal is overrun depends upon the location, speed, and response of the approaching train.

Risk also takes into account the expected consequences of the accident, which will vary with at least four sets of factors:

1. Speed at the time of the accident
2. The terrain and land use at the location of the accident
3. The characteristics of the trains involved (e.g. number and locations of passengers and hazardous loads, if any)
4. The number of people in the cabs of the locomotives

Train control technologies and systems might have some effect on the speed at the moment of impact, but probably little or no effect upon the other factors.

The approach taken in this study builds upon and expands prior studies sponsored by VNTSC. Those studies have included the development of sophisticated risk analysis techniques linked to detailed simulation of specific corridors. Instead of proceeding at that level of detail, we chose to developed a spreadsheet model that can quickly estimate the risk per segment as a function of any of the various factors described above; a corridor analysis can then be built up as a set of segment analyses. With this approach, it is possible to examine many different situations and to conduct sensitivity analysis concerning the key elements of the train control systems and the corridors where they might best be deployed. This approach is more realistic and more useful than just using past history to determine the accidents that would have been avoided with a particular train control system along with the reduction in fatalities, injuries, and other consequences.

1.4 Structure of the Report

In Chapter 2, we review several key studies of rail transportation risk. In Chapter 3, we develop a methodology to estimate how risk can be reduced through advanced train control capabilities as a function of the operating environment. In Chapter 4, we apply the methodology to conduct some simple sensitivity analyses to highlight some of the factors affecting risk and to demonstrate the capabilities of the model. In Chapter 5 (and Appendix A), we present the results of a more ambitious study that examines risks on high density corridors where advanced train control systems would have the greatest safety benefits. Sensitivity analysis is used to illustrate how traffic density, route characteristics, and other factors affects risk under various train control systems. Appendices B and C investigate the potential for using PTC systems to reduce grade crossing risks.

Chapter 6 describes how the methodology used in this research might be used more generally for "technology mapping", i.e. for relating other technological changes to changes in rail safety. Chapter 7 discusses the ways that human factors relate to risk and how changes in human factors might affect either the base case risk or the effectiveness of advanced train control systems. Finally, Chapter 8 provides a summary discussion of the relationship between risk and train control along with conclusions, and recommendations.

Chapter 2
Literature Review

2.1 Introduction

This study is concerned with the extent to which improvements in train control systems can reduce the risks associated with railway operations. The study builds upon prior research concerning railway safety as well as methodologies of probabilistic risk assessment. Section 2.2 reviews recent research supported by the U.S. Department of Transportation that relates the frequency of accidents to the characteristics of the railway line. Section 2.3 reviews a comprehensive application of probabilistic risk assessment techniques to operations on the East Japan Railways (JR East). Section 2.4 considers how human factors affect the risks and consequences of accidents. Section 2.5 considers the potential ability of new train control systems to reduce certain kinds of grade crossing accidents.

2.2. DOT Research on Railway Safety and Risk Analysis

In recent years a number of studies have been conducted for the Federal Railroad Administration (FRA) in the field of risk and safety analysis, often with a view to better understanding the safety requirements of the introduction of high-speed passenger rail (HSR) in the United States. This series of reports was published under the general title ("Safety of High Speed Ground Transportation Systems". As part of this series, Arthur D. Little, Inc. (ADL) and Parsons Brinckerhoff Quade & Douglas, Inc. (PBQD) conducted a study in 1993-4 entitled "High Speed Passenger Trains in Freight Railroad Corridors: Operations and Safety Considerations" [6]. This study focuses on the impact on safety of introducing HSR on corridors already used for freight and conventional intercity passenger service, the main objective being to maintain current safety levels. Several measures were considered in terms of train control systems, including potential migration to Automatic Train Control (ATC) or more advanced train control system (ACTS).

Chapter 2 of their report contains a description of the so-called "1010 corridors" and other candidate corridors for implementing HSR. It also establishes a "Hypothetical Corridor" meant to aggregate the characteristics of actual candidate corridors. It is made of a single link where freight, conventional intercity passenger and HSR services operate jointly. Three scenarios are envisaged: (i) Single track with passing sidings, (ii) Double track with Automatic Block Signaling (ABS) and (iii) Double track with Centralized Train Control (CTC). Traffic data from actual corridors are used to calculate train-kilometers of operation, which serve as a metric for assessing accident frequency and severity. Chapter 3 is concerned with braking and signaling systems and their potential implications in HSR. Chapter 4 provides a summary of the history and recent advances in train control systems as well as a discussion of potential applications to HSR in the United States.

In terms of risk and safety assessment methodology, the study is based on historical accident data. Accident frequency and severity are both estimated separately. Accident frequencies are derived from accidents reported in the FRA Accident Database for freight trains in Class 4 Track. The rates of occurrence are calculated for four classes of accident, namely train-to-train collisions, collisions with other objects, derailments and grade-crossing collisions. Accident severity is broken down into property damage in monetary terms and number of casualties (i.e. fatalities and injuries). For each accident class considered, an average number of casualties per train-kilometer (per grade-crossing accident for grade-crossing collisions) and an average amount of property damage is calculated based on Amtrak operations in 1986-93.

In order to analyze the impact of HSR, the authors assume that the consequences of accidents are proportional to the maximum authorized speed (MAS) on the link. Using this assumption, they derive a measure of the reduction needed in accident frequency in order to maintain the same level before an after introduction of HSR in terms of consequences.

Three levels of signal and train control systems are envisaged: (i) the "minimum FRA ATC" that includes automatic train stop capability, automatic cab signaling and train control; (ii) the current Northeast Corridor ATC that has cab signaling with automatic, continuous enforcement of speed restrictions; and (iii) an advanced ATC system that enforces all permanent and temporary speed restrictions, signal indications as well as stops at interlockings. The impact of each train control systems in terms of accident frequency reduction is estimated from the study team's expert judgment, based on assumed accident causes and the potential prevention of those causes by ATC.

Another report of interest to the present study is the "Case Studies in Collision Safety" [6] prepared by a team led by Foster Miller, Inc. This report, published in late 1997, was the result of a four-year study in collision safety and risk assessment.

The objective of the study was to provide methodological foundations and demonstrate the application of a full-blown, detailed risk analysis of railway operations on a corridor involving freight, conventional intercity, commuter and HSR service. The study does not explicitly include any discussion of potential measures aimed at reducing risk, but provided a methodological approach to do so.

The study assesses the risk for a single corridor, termed "Composite Corridor" that would be representative of current and proposed railway operations in the United States. The impact of terrain is included through the use of twenty environmental codes that describe the curvature and adjacent terrain of each track segment.

Accident frequency assessment is based on a "first principles" approach that does not require the use of historical accident data. A total of eighteen accident "subscenarios" are modeled. The method uses metrics that estimate the number of opportunities for each subscenario to occur (e.g., meets and passes, number of grade crossings traversed, etc.). For each occurrence, the subscenario is decomposed using a fault-tree methodology.

The accident severity estimation is based on detailed simulation of crash situations using a finite elements method. Estimates of casualties in a crash are derived as a function of speed and consist using criteria such as the head injury criterion (HIC) that relate the severity of an injury for train occupants.

Finally, the impact of the train control system was not examined directly. However, the composite corridor includes a mix of different train control systems, including an Automatic Train Protection (ATP) system that can automatically apply the brakes "when conflicts between trains are imminent".[1]

Table 2.1 compares the Foster-Miller and the ADL & PBQD studies with the approach taken in the current study. The Foster-Miller study demonstrated a sophisticated methodology capable of detailed analysis of a particular corridor using a combination of simulation and analytical models. The ADL & PBQD study used a simpler, statistical approach to examine accident rates on several corridors. The great advantage of the Foster-Miller approach is its ability to deal with intricacies of train control systems and of route and train characteristics; the great disadvantage is the complexity of the methodology and the time and resources required to examine multiple corridors. The ADL & PBQD approach produces statistics that are more readily used, but it cannot address the technological and geographic factors that are so important to risk. The MIT study seeks an intermediate level of analysis; by using analytical models rather than more detailed simulations, it is possible to develop a parametric approach that provides much of the capabilities of the Foster-Miller methodology with the time and resource requirements closer to the ADL & PBQD approach.

[1] Cf. [6], Vol. 1, p.26

Table 2.1: Comparison of Three Safety and Risk Assessment Studies

	Foster-Miller	ADL & PBQD	MIT
Level of Effort per Run	High	N/A	Low
Type of Model	Mixed Simulation / Analytical	Statistical	Analytical
Estimate of Accident Rate	f (metric, scenario)	Average per train-mile	f(metric, scenario)
Estimate of Consequences	Simulation	Average Historical	f(speed, terrain, load)
Corridor Structure	Fixed	3 Cases	Parametric

2.3 The MIT/JR East Cooperative Program in Risk Assessment

JR East operates extensive passenger rail operations in and around Tokyo, Japan. As a relatively new and extremely safe railroad, JR East was unable to use historical accident data to determine how best to reduce future risks. Specifically, since they had never had a catastrophic accident, they could not use history to assess the relative risks associated with different types of accidents. JR East therefore initiated a research program in cooperation with the MIT Center for Transportation Studies to develop techniques to estimate the risks associated with various types of accidents and to identify potential strategies for reducing those risks.

The research program identified four areas of risk for in-depth analysis: a) natural hazards, especially earthquakes, b) train collisions, c) grade crossing accidents, and d) human factors in inspection and maintenance. In each area, extensive analysis was conducted to determine the probabilities of accidents as a function of the characteristics of the traffic, the route, the train control system, and other relevant factors. The consequences of accidents were then estimated as a function of train speed, the terrain, and the nature of the impact.

The nature of the risks and the opportunities for reducing risks varied greatly among the four areas. Natural hazards pose a very high risk in this mountainous region of Japan that is subject to frequent earthquakes. Reducing these risks requires a mixture of investment in sensor and communication technologies (e.g. systems to stop trains in the event of a severe earthquake or excessive rainfall in locations prone to mudslides) and investment in upgrading the infrastructure to deal with the hazards (e.g. strengthening bridges to withstand more powerful earthquakes.)

Train collisions, while very rare, were of great concern to JR East management. High speed collisions on a passenger railroad would likely be catastrophic, and the railroad would very likely be clearly responsible for these accidents. Hence, JR East was very interested in train control systems that would prevent collisions.

As in other countries, grade crossing accidents are a continuing problem on JR East. Although generally not the fault of the railroad, these accidents cause the vast majority of fatalities and injuries related to rail operations. There is also a potential for a catastrophic accident with many passenger fatalities if a train hits a large vehicle such as a dump truck.

The joint JR East/MIT study developed a methodology for predicting the risk associated with each of these (and other) types of accidents. The methodology was used to estimate the risk for each track segment, taking into account traffic volumes, train speeds, train control systems, terrain, number of grade crossings and other factors related to the probability of accidents or of the consequences of an accident. The risk was expressed in terms of the expected fatalities per million train-km and per year, for each segment and for the system. The risk profiles for each line could then be used to identify the riskiest locations and to assess which strategies were most appropriate for each region of the railroad.

2.4 Human Factors and Train Control

2.4.1 Background

Human factors accounted for approximately one third of all railroad accidents from 1985 to 1997 [FRA Office of Railroad Development, 1999]. The FRA research program addresses several levels of problems that affect the ability of engineers and dispatchers to make safe decisions. First, the operating rules and practices may be confusing for people who must interpret them. Second, the communication process or the way that information is displayed may either omit or obscure data or hinder its interpretation. Third, the individuals may be so stressed or fatigued that they fail to respond correctly. And fourth, all of these potential problems can be exacerbated by the noisy environment of the locomotive cab.

The FRA research program is based upon the premise that understanding the abilities and limitations of the operators is one key to reducing the number of accidents caused by human factors. For example, FRA is studying the effects of erratic work/rest cycles (typical of some railroad jobs) on stress, fatigue, and job performance. Either more regular working hours or provisions for napping could be introduced to counteract the effects of erratic work/rest cycles.

2.4.2 Framework

There are several key ways that human factors influence risk-based safety analysis. First, human error is an important cause of rail accidents and therefore an important component of the base-line risk for any system where advanced train control will be implemented. The greater the level of accidents related to human error in the base case, the greater the improvement that will be predicted from implementing systems designed to prevent or overcome human error. Hence, the assumptions or conditions underlying the calculation of risks in the base case are actually tied to particular operating conditions, employee characteristics, and job characteristics. Significant improvements in base-line safety may be achieved by various approaches aimed directly at reducing human errors:

- Changes in operating rules in order to avoid situations where human errors are very risky
- Enforcement of operating rules (supervision)
- Personnel selection and training
- Selection, training, and workload of supervisors
- Changes in workload and working conditions (including working times)
- Substance abuse programs and testing programs
- Allowing employees to take naps

Research related to any of these areas would ideally be translated into the base-line risk for any scenario addressed by the model.

Second, an advanced train control system can reduce the probability of accidents caused by human error in several ways:

- The system may be able to override human actions so that accidents do not occur (e.g. ensuring that a train does not overrun a signal)
- The system may provide certain features that reduce the likelihood of human error (e.g. systems that require frequent operator input to establish that they are alert)
- The system may recognize and respond to unsafe conditions (e.g. a locomotive diagnostic system that will report when repairs have not been properly completed)
- The system may reduce the frequency of situations where human errors are likely to lead to accidents (e.g. computer-assisted dispatching systems may help dispatchers reduce the number of train meets by speeding up average travel times)

Third, advances in technologies unrelated to train control could reduce the likelihood of human error. For example, better communications capabilities could give maintenance workers much more information concerning train locations and speed, which would help them plan track work and alert them as trains approach (e.g. research by VNTSC & MIT "Improved Railroad Worker Safety Through Better Communications"). Technologies that can determine when an individual is falling asleep would help train operators stay awake or at least urge them to stop the train if they are not alert enough to continue operations.

2.4.3 Human Factors and Safety in Transportation

There are many examples in transportation where attention to human factors has had a large effect on safety. For railroads, the clearest example are the educational programs such as Operation Lifesaver that have are widely credited with reducing grade crossing accidents and fatalities.

In the trucking industry, fatalities dropped nearly 2% from 1997 to 1999 despite increases in truck travel. From 1992 to 1999, truck fatalities rose 21% from a recent low of 4,462, but this was less than the estimated 30% increase in truck mileage. "The American Trucking Associations hailed the news as an indication that industry and government partnerships in safety education and outreach programs are working ... Alcohol-related deaths in trucking are virtually nonexistent, thanks to drug- and alcohol-testing programs." [Schulz, 1999]

Experience and management procedures can have a 25-50% effect on accidents. Corsi and Fanara [1989] found that new entrants to the trucking industry had higher accident rates than established carriers and were more likely not to have basic elements of a safety management plan. They found that carriers that were certified by the ICC before 1980 had an rate of reportable/preventable accidents of 0.55 per million truck-miles; carriers certified between 1980 and 1984 had an accident rate of 0.62 and those certified after 1984 had an accident rate of 0.81. The older carriers were twice as likely as the newest carriers to have a system to effectively control hours of service and a driver safety training program; they were a third more likely to comply with vehicle inspection procedures. The study was updated in 1995, and the accident rates were found to be 0.411 for carriers in business at least 10 years vs. 0.505 for carriers in business less than a year. While the accident rates were, on the average, much lower than in the previous study, the new entrants still had accident rates much higher than the experienced carriers.

The financial condition of carriers is another safety concern, because carriers on the verge of bankruptcy might be tempted to cut corners in areas such as hours of service or maintenance. Hunter and Morgen [1995] studied safety in U.S. motor carrier industry over the tumultuous period following deregulation. While their results varied for different sectors of the trucking industry, they concluded that "the evidence strongly suggests differential accident rates across alternative employment relations systems and different regulatory environments". For example, they found that there was great pressure on owner-operators to cut their costs and to work longer hours and "these intensified work efforts translated into increased hours on the road, increased fatigue, and ultimately an increase in preventable accident rates."

2.4.4 Human Factors and Train Control

Prior research has demonstrated one way to incorporate human factors into an assessment of the effects of different levels of train control systems on railroad safety. Schor and Rosch [1994] found that

> *"Human errors must be an input to any PTS system accident model (and, in fact, turn out to be the prime cause of accidents under both PTS and conventional systems). The most objective value of human error rate is the measurable result of human errors, namely human-caused accidents under current control systems operation. Because human error rate in the PTS system model is derived from current accident statistics, any accident rate prediction under PTS system operation is necessarily relative to current system operation." (p. 1-2)*

Their approach assumes that the people involved in the system will go on making the same types of errors made previously, with the same effects except in those cases where the PTS system will be able to prevent an accident. They do not try to model the psychological or workload factors that result in human errors nor do they try to determine the likelihood that human error will cause an accident. Instead, they look at what they call the "relative" rather than the "absolute" accident rate for errors made by both engineers and by dispatchers.

They estimated some interesting system numbers based upon an analysis of accidents that were expected to be preventable by PTS (these were the 117 accidents that occurred between January 1988 and August 1993 in the US that were identified as PTS-preventable by representatives of the FRA, AAR, and labor). The summary numbers are of interest in terms of the relative importance of crew and dispatcher errors:

Calculated crew error rate: 0.005339 accidents/crew/year
0.005094 PTS preventable accidents/crew/year

Calculated dispatcher error rate: 0.00328 accidents per dispatcher per year

Note that even with PTS, there would still be some accidents because of equipment and control failures (i.e. it is not possible to prevent all of the preventable accidents). Although the predicted rates per crew and per dispatcher were close, there were typically 10 times as many crews (500) as there were dispatchers (55). The following types of errors were identified as causing 95% of the accidents related to human error:

Improper authority or speed limits issued by dispatcher (6 accidents)
Failure of train to stay within proper authority or speed limits (107 accidents)

This suggests that errors in the locomotive cab are the dominant problem. Hence, for this system at least, selection, training, workload, rest, and supervision of crews would seem to be the area where human factors have the greatest effect on rail safety.

2.5 Grade Crossings and Train Control

2.5.1 Introduction

Accidents involving grade crossings and trespassers are by far the greatest cause of fatalities involving railroad operations. In 1997, there were 461 fatalities in highway-rail grade crossing accidents and 533 trespasser fatalities, accounting for 93% of all railroad fatalities that year. A great deal of effort has been devoted toward reducing these kinds of accidents, including education and enforcement programs as well as the development of better protection devices. These efforts have been quite successful with respect to grade crossing accidents, which declined nearly 50% from 10,611 in 1980 to 5713 in 1990 and another 33% to 3,865 in 1997 [as reported in the FRA Highway/Rail Crossing Accident/Incident & Inventory Bulletins]. Efforts have been less successful with trespassers, as trespasser fatalities and injuries were fairly constant from 1992 to 1997, with roughly 500 fatalities and 500 injuries annually to trespassers [FRA, 1998]. In a study of railroad fatalities in North and South Carolina, Pelletier found that most trespassers killed on railroad property were intoxicated [Pelletier, 1997, cited by French, 1998].

There are two reasons to consider the risks associated with these accidents in this report, where our focus concerns the relationship between risk and train control systems. First, we want to consider the risks associated with train control within the broader risks associated with rail transportation, which clearly are dominated by accidents involving grade crossings and trespassers. Second, we want to consider the potential of train control technologies for reducing risks associated with trespassers or grade crossings. Since PTC systems assume a digital radio link to trains, it does not require a great leap of logic or technology to consider using this digital radio to communicate with grade crossing protection devices or even with certain classes of highway vehicles.

Four types of potential benefits can be envisioned:

1. Constant warning time: the digital link could provide a relatively cheap means of providing constant warning time for crossings, which is believed to reduce the tendency of some drivers to run around the gates or through flashing lights.

2. Cheaper active protection devices: the digital link would make it considerably less expensive to provide active warning devices, if track circuits are not needed to detect trains. A signal from the train could easily activate gates or flashing lights. If active

protection becomes much cheaper, then more crossings could be protected for the safety investment budget.

3. Direct communication with highway vehicles: the digital link could also provide a way for the train to send a signal to individual cars, trucks or buses. While it would be complex and cumbersome to try to equip all vehicles for safe operation in all locations, it might be relatively straightforward to equip certain fleets for certain locations. For example, good applications might involve school buses or a business with a fleet of trucks that is continually operating over a limited number of crossings (e.g. trucks leaving a gravel pit or a steel mill).

4. Direct communication from devices at grade crossings to on-coming trains: obstacle detectors or digital cameras can be used to monitor crossings to determine if there are vehicles or other obstructions that would cause an accident. Direct digital communication to the train could be faster - and therefore more effective - than a more expensive and less flexible system based upon track circuits and the signal system.

It is beyond the scope of this report to go into the technological details associated with any of these strategies for reducing grade crossing risks, as these strategies are all documented elsewhere.

2.5.2 The DOT Model of Grade Crossing Risks

DOT has developed a model of grade crossing risks that takes into account characteristics of the rail line, the highway, rail and highway traffic and other factors [Farr, 1987]. This model was recently used in a study of grade crossing risks on the portion of the Empire Corridor in New York between Albany and Poughkeepsie [Mironer, 1998]. Mironer applied the DOT model to each of 27 grade crossings in this corridor and examined the effects of changes in train speed and crossing closings on the overall crossing risks for this 94-mile section.

The DOT model was based upon regressions of accident data; it is designed to predict the number of accidents at a particular crossing based upon the characteristics of the crossing, the highway traffic, and the rail traffic. Separate equations were calibrated for crossings with gates, flashing lights, or only passive protection. Each equation predicts the number of accidents per year (a) at a crossing:

$$a = NF \times K \times EI \times MT \times DT \times HP \times MS \times HL$$

where

a = accidents per years at the crossing

N = normalizing factor (which adjusts for changes in rates over time)
= 0.8239 for passive protection (as of 1992 update)
= 0.6935 for crossings with flashing lights
= 0.6714 for crossings with gates

K = initialization factor for type of protection
= 0.0006938 for passive protection
= 0.003351 for crossings with flashing lights
= 0.0005745 for crossings with gates

EI = exposure index based on product of highway and train train traffic

MT = factor for number of main tracks
DT = factor for number of trains/day in daylight
HP = highway pavement factor
MS = factor for maximum timetable speed
HL = factor for number of highway lanes

Each of the factors is given by a more complicated expression. The exposure index EI is the product of the highway traffic and the train traffic raised to a power that varies with the type of protection:

$$EI = ((\text{daily highway vehicles} \times \text{daily trains} + 0.2)/0.2)^{ei}$$

where the exponent ei equals 0.37 for passive, 0.4106 for flashing lights, and 0.2942 for gates. [Note: the use of 0.2 in two places in this expression (and in the following expression for daylight trains) means that this expression will equal 1 if either highway traffic or train traffic equals zero. This is a great help in the regression analysis, since the natural log of zero is undefined.]

The factor for daylight trains is similar:

$$DT = ((d+0.2)/0.2)^{dt}$$

where the exponent dt equals 0.178 for passive, 0.1131 for flashing lights, and 0.1781 for gates.

The other factors all have an exponential form:

$$MT = e^{a \times \text{main tracks}}$$

$$HP = e^{b \times (hp - 1)}$$

$$MS = e^{c \times \text{max speed}}$$

$$HL = e^{d \times (\text{highway lanes} - 1)}$$

Table 2 - 2
Coefficients in DOT Grade Crossing Accident Model

Factor	Passive	Flashing Lights	Gates
Normalizing factor	0.8239	0.6935	0.6714
Initialization factor	0.0006938	0.003351	0.0000574
EI exponent (ei)	0.37	0.4106	0.2942
MT exponent (a)	0	0.1917	0.15
DT exponent	0.178	0.1131	0.18
HP exponent (b)	-0.5966	0	0
MS exponent (c)	0.0077	0	0
HL exponent (d)	0	0.1826	0.142

Each of these factors applies to only one or two of the crossing protection categories. For example, the main tracks factor equals 1 for passive protection (i.e. a = 0 in the above equation), so that the number of main tracks does not affect the predicted number of accidents at a crossing with only passive protection. The exponent a is 0.1917 for flashing lights and 0.1512 for gates, so the factor MT is 1.21 for flashing lights and 1.16 for gates. Highway pavement and maximum speed affect only passive crossings; the number of highway lanes only affects the crossings with active protection.

2.6 Summary

Prior studies have demonstrated that it is possible to estimate the risks of train operations to parameters that describe the traffic, operations, terrain, train control systems and other factors. Historical studies, such as the ADL & PBQD study, provide some insight into the differences in accident rates associated with different types of lines. Historical analysis, however, is limited by the small number of severe railway accidents, which makes it difficult to establish clear relationships between risk and corridor characteristics. Moreover, historical analysis is of limited value in estimating the effects of new technologies or of new operating practices. The Foster-Miller study showed that it is possible to develop detailed models for calculating accident probabilities and consequences for a particular corridor. The JR East research demonstrated that it is possible to use simpler models to map the risk profile of an entire railroad, taking into account all of the major types of railway accidents.

Human factors must be considered in any study of risk, as they are generally one of the most important cause of any type of accident. For railroads, human factors influence the probabilities that people respond incorrectly or fail to respond at all to signals or instructions. Personnel selection, training, hours of service and other factors therefore affect the level of the risk in the system, which in turn affects the potential improvements that might be obtained with better train control. Train control systems can attempt to reduce human error, to overrule incorrect human decisions, or to ensure that the train crew are alert.

Accidents and fatalities at grade crossings are a far more common than accidents and fatalities in PTC preventable accidents. Therefore, even a small improvement in grade crossing safety could be an important benefit from advanced control systems.

Chapter 3
Methodology and Model Structure

3.1 Overview

We used probabilistic risk assessment techniques to estimate the potential benefits of using PTC technologies to improve rail safety. Probabilistic risk assessment is a methodology that has been widely applied in studies of transportation and infrastructure safety, especially in studies of nuclear power plants. A cornerstone of this methodology is that risk is defined as the product of accident frequency and the expected consequences if there is an accident. The risks associated with very rare, but potentially catastrophic accidents can exceed the risks of common, but much less serious accidents. Probabilities and fault trees can be used to estimate frequencies and consequences of potential types of accidents, even when there have been very few such accidents. This approach is therefore quite useful for analyzing rail safety, since the possibility of catastrophic accidents, though low, is an ever present factor

We developed a spreadsheet model to predict the frequency and consequences of collisions and derailments that might be preventable by a PTC system. We incorporated variables in the model to represent the capabilities of improved train control technologies so that we could estimate risks under various assumptions concerning train control:

The spreadsheet model considers one segment at a time. The key inputs are the number of freight and passenger trains and their speeds, the route characteristics such as the number of curves, and parameters related to the probability of accidents. The model considers collisions (head-on and rear-end) and several types of derailments. For each type of accident, there is a metric for exposure to a potentially dangerous event and one or more parameters related to the probability that something will in fact go wrong. For head-on collisions, for example, the metric is the square of the number of trains per day, because that will be proportional to the number of train meets per day. The key parameters for a head-on collision include the number of tracks, the probability that opposing trains will be routed on the same track if there are multiple tracks, and the probability that a signal will be overrun. Hence, risks will increase with train volume (more meets), poor supervision or poor employee selection (more likely that employees will be over tired or under the influence of drugs or alcohol), poor equipment maintenance or training (more likely that there will be braking problems), higher speed (more difficult to stop a train that has passed a restrictive signal and more damages if there is an accident), or train mix (more fatalities and injuries if there are more passenger trains).

The model uses simple fault trees to relate the probabilities of human or mechanical error to the probability that a train will overrun a signal, approach a curve at too great a speed, or encounter several dangerous situations. These probabilities have been estimated in prior studies, so we did not have to conduct any research into the fundamental human factors or system failure rates. Given the probability that a train will enter a dangerous state, the model then estimates the ability of and the time required for the train control system to respond, either by warning the crew or by taking action to stop or slow the train.

3.2 Discussion of Model Structure

The principal objective of the model is to assess the impact of PTC on risk reduction using a parametric representation of a rail corridor. The modeling approach therefore relies on a probabilistic estimation of risk rather than a statistical prediction based on historical data. Risk is viewed as the sum of consequences of several accident types occurring on the corridor. The expected value of the accidents' frequency and severity (that are together used to calculate total consequences) are calculated as functions of the corridor's operating and physical characteristics as well as train control system specifications.

The present risk assessment model differs from traditional statistical analyses of accident risk in two fundamental ways:

- First, risk is here defined as the total expected consequences of accidents, and not simply their rate of occurrence. Therefore, rare events such as catastrophic accidents are better represented with this framework.
- Second, the model is meant to relate risk not only to train control systems specifications but also to a corridor's physical and operating characteristics. Risk may therefore vary as a function of parameters such as speed and traffic volume.

In statistical analyses it is difficult to isolate the effects of train speed, traffic volume, and other explanatory variables. Indeed, actual corridors with higher traffic volumes and higher maximum authorized speeds (MAS) might exhibit accident rates per million-train-miles (MTM) that are not significantly higher than those of corridors with fewer trains per day and/or lower speeds. Yet it is highly likely that what these observations reflect are significant underlying differences between corridors in terms of train control technology, track quality, braking capability, employee training and working schedules, rule enforcement, etc. The present model is therefore an attempt to capture the impact of some of these critical underlying parameters.

Therefore, as illustrated by Figure 3.1, comparisons of model results between corridors or even segments of a same corridor should be understood in the sense that "all else is equal".

This risk assessment model estimates the rate of occurrence and total consequences of several accident scenarios (with or without PTC) in a parametric corridor. The model is implemented on spreadsheets and therefore easy to use, and requires no simulation.

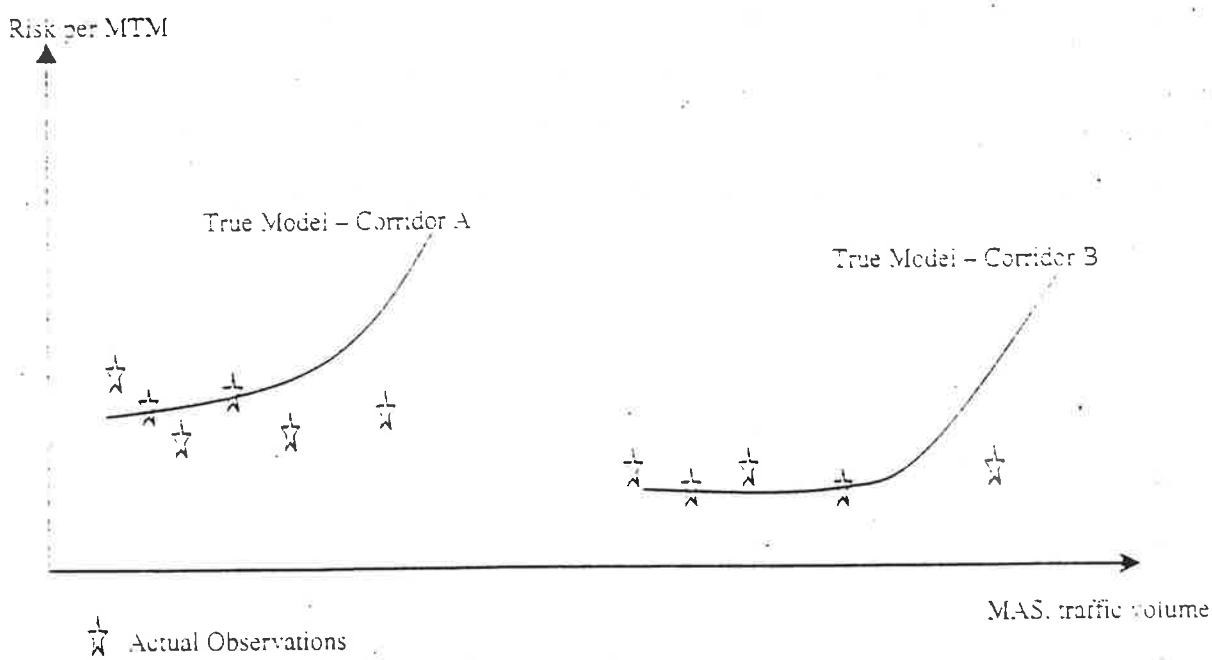


Figure 3.1: Change in Corridor Parameters Affects Model Results

Importantly, this spreadsheet-based model provides a structured conceptual framework for evaluating the risk along a route with and without PTC. Numerical values of several parameters have been estimated using results from previous studies and are thought to reflect "typical" values thereof. In addition, results from the model show that these "typical" values yield estimates consistent with accident rates in actual corridors. However, the structure of the model is independent of those numerical values, even though the results obtained apply to those values assumed to be representative. For instance, PTC characteristics are let to vary and, as a result, the impact of different PTC specifications can be assessed using the model.

3.3 Corridor Specification and Modeling

A corridor is defined here as a collection of segments. A segment is a unit of railroad line where all parameters can be considered to have the same value. Each segment in a corridor is handled separately in the model. Consequently, a given corridor can be represented with varying levels of detail, either with fewer, longer segments, or with more, shorter segments. The latter approach allows capturing finer variations in the physical and operating characteristics of the corridor. This definition of a corridor also enables a flexible modeling approach whereby the level of work (i.e. obtaining and entering parameter values for all the segments) can be controlled.

3.4 Train Control System and Train Characteristics

3.4.1 Train Control Systems

The representation of Positive Train Control systems (PTC) follows the fundamental property that they provide automatic enforcement of speed and authority restrictions through either application of brakes or automatic speed control. In addition, those systems provide communication links and authority monitoring capabilities. In the model, three levels of PTC have been considered. They are termed PTC1, PTC2 and PTC3, from least to most advanced.

Table 3.2 provides a summary of the capabilities of each PTC under consideration. All of the systems have a data communications link for transmitting authorities to trains; the trains are able to monitor their positions relative to their authority and the on-board system will enforce the authorities. PTC1 is not safety-critical; PTC1 and 2 operate as an overlay on the existing signal system; PTC3 replaces the existing signal system. In PTC1, the on-board system will institute full emergency braking to prevent a train from exceeding its authority; in the other systems, the speed will be controlled to enforce authorities without requiring full emergency braking. PTC1 will enforce temporary speed limits, but only if they are loaded into the on-board computer at the start of the run; the other systems will enforce temporary limits automatically. PTC1 has no link to grade crossings, while PTC2 provides equal warning time capabilities (i.e. the on-coming train can broadcast its location and speed to properly equipped crossings). PTC3 has a communications link with the wayside interface unit (WIU) controlling the grade crossing, so it can receive an alert if the crossing is not functioning properly or if a vehicle is stalled in the crossing and it can send or receive a message from a properly equipped vehicle that is near the crossing (e.g. school buses or heavy trucks that commonly use a crossing could be equipped with some sort of device to allow emergency communications with the train).

In order to assess the overall risk reduction achieved with PTC, it is necessary to establish a benchmark or "base-case" train control system. In the absence of PTC, the model therefore assumes the presence of a four-aspect Automatic Block Signaling (ABS) system with wayside signals at each block.

Table 3.2 Three Levels of Positive Train Control

Feature	PTC1	PTC2	PTC3
Safety critical	No	Yes	Yes
Replace signals	No	No	Yes
Communications link	Yes	Yes	Yes
Authority monitoring	Yes	Yes	Yes
Intervention	Upon exceedance	Upon exceedance	Before exceedance
Speed monitoring	Yes	Yes	Yes
Temporary speed limits	If uploaded	Yes	Yes
Intervention	Full braking	Speed control	Speed control
Grade crossing link	No	Yes	Yes
Equal warning time	No	Yes	Yes
Malfunction alert	No	Yes	Yes
Train-WIU link	No	No	Yes
Train-Vehicle link	No	No	Yes

3.4.2 Train Speed and Braking

Train speed and braking capabilities are critical in determining the behavior of a train in a situation where a signal overrun or authority violation may result in the occurrence of an accident. They are key in estimating the probability of occurrence of the accident and in assessing the expected consequences thereof.

To this end, the model handles five discrete braking states corresponding to different braking rates, as shown in the following table. Note that the probabilities of braking failures are corrected upwards when the braking operation is performed by the operator. This reflects a potential inadequate use of the brakes by the operator for various reasons including drug and alcohol impairment in addition to equipment failure (a detailed discussion of this aspect can be found in [16], Appendix B).

Table 3.3: Braking States

BRAKING STATE	PROBABILITY (OPERATOR BRAKING)	PROBABILITY (AUTOMATIC BRAKING)	DECELARATION RATE (M/S^2)
0	$2.01.10^{-8}$	2.10^{-8}	Varies with speed[2]
1	$2.52.10^{-7}$	1.10^{-7}	0.2
2	$1.28.10^{-5}$	$6.9.10^{-7}$	0.3
3	$1.13.10^{-2}$	1.10^{-2}	0.5
4	0.989	0.990	0.7

Determining a train's trajectory given its braking state is thus made possible. It is assumed that the deceleration rate a remains constant throughout the braking operation. Therefore, the equation governing train speed for braking states 1 to 4 is given by:

$$V = \sqrt{\left(V_0^2 - 2a(x - x_0)\right)}$$

Where x denotes train location, $V0$ being the initial speed.

[2] The train is assumed to slow down with energy dissipation only, the speed decreasing exponentially with time

For braking state 0, the trajectory equation becomes:

$$V = V_0 - k \cdot (x - x_0)$$

i.e. $$V = V_0 \cdot \exp(-k \cdot t)$$

Where t denotes time.

3.5 PTC-Relevant Accident Scenarios

No two accidents are rigorously identical in the sense that the number of parameters needed to represent exactly the occurrence of a single accident is far too large to be captured by a simple model. However, three main classes of accidents can easily be identified: (i) collisions with other trains or maintenance of way equipment, (ii) collisions with obstacles other than trains, and (iii) single-train derailments (excluding those caused by a collision).

With this first classification of accidents in hand, one must define finer groupings of accidents into scenarios in order to simplify the analysis and modeling of individual accident scenarios. The following is a list of eight accident scenarios whose rate of occurrence and/or total expected consequences can be reduced with PTC:

- *Train collisions:*
    1. Head-on
    2. Rear-end
    3. With maintenance of way (MOW) equipment
- *Derailment, due to:*
    4. Overspeed speed restriction
    5. Overspeed diverging interlocking movement
    6. Train fault
    7. Track fault

- *Collision with other obstacles:*
    8. Grade-crossing collisions

Of the eight above-defined accident scenarios, the present model handles four instances: (i) all of train collisions (head-on, rear-end and with MOW) and (ii) derailments due to track fault (broken rail). In addition, Section 3.8.5 provides a discussion of potential PTC benefits in the reduction of grade-crossing collision risk, which we investigated using a separate model (see Appendices B & C)..

Derailments due to train faults (such as broken wheel) were left out because the detection of train faults was considered to be outside the realm of train control *per se*. As for other instances of derailments due to overspeed (either in restricted speed areas or in diverging interlocking movements), it is clear that PTC may contribute significantly to risk reduction through automatic enforcement of speed restrictions. Those scenarios could be included as part of future modeling work.

3.6 Accident Frequency Assessment Methodology

The fundamental approach in assessing the probability of occurrence of each of the accident scenarios defined above is two-fold. First, the occurrence of each accident scenario is related to a measure of the likelihood of a train being in that particular accident scenario. Such a measure is called the accident scenario's metric. A metric basically measures the exposure to risk and estimates the number of times a given train will be placed in a situation that could result in one of the accident scenarios under consideration. For instance, a "natural" metric for the head-on collision scenario is the number of meets and passes between trains on the segment. Such metrics are analytically estimated using traffic and operational characteristics of the segment. Table 3.4 lists the metrics that apply to the five accident scenarios considered in the following sections.

Table 3.4: Metrics of Different Accident Scenarios

Accident Scenario	Applicable Metric
Head-on collision	Meets and passes
Rear-end collision	Overtakes
Collision with MOW	Encounters with MOW gangs
Derailment due to track fault	Track defects encountered
Grade-crossing collision	Grade-crossings traversed, highway traffic

A discussion of the relevance and estimation process of the above metrics can be found in Section 3.8.

Second, given a proper metric, each accident scenario is decomposed into a logical AND/OR sequence of events using the fault-tree methodology. Probabilities of most individual events in the fault-tree are empirically estimated drawing upon results of previous studies of human factors and train control systems characteristics. Note that these numerical values are also parameters of the model; if supporting studies or models are available, then these parameters can be adjusted to reflect the effects of factors such as rule enforcement, employee training and working hours, etc.

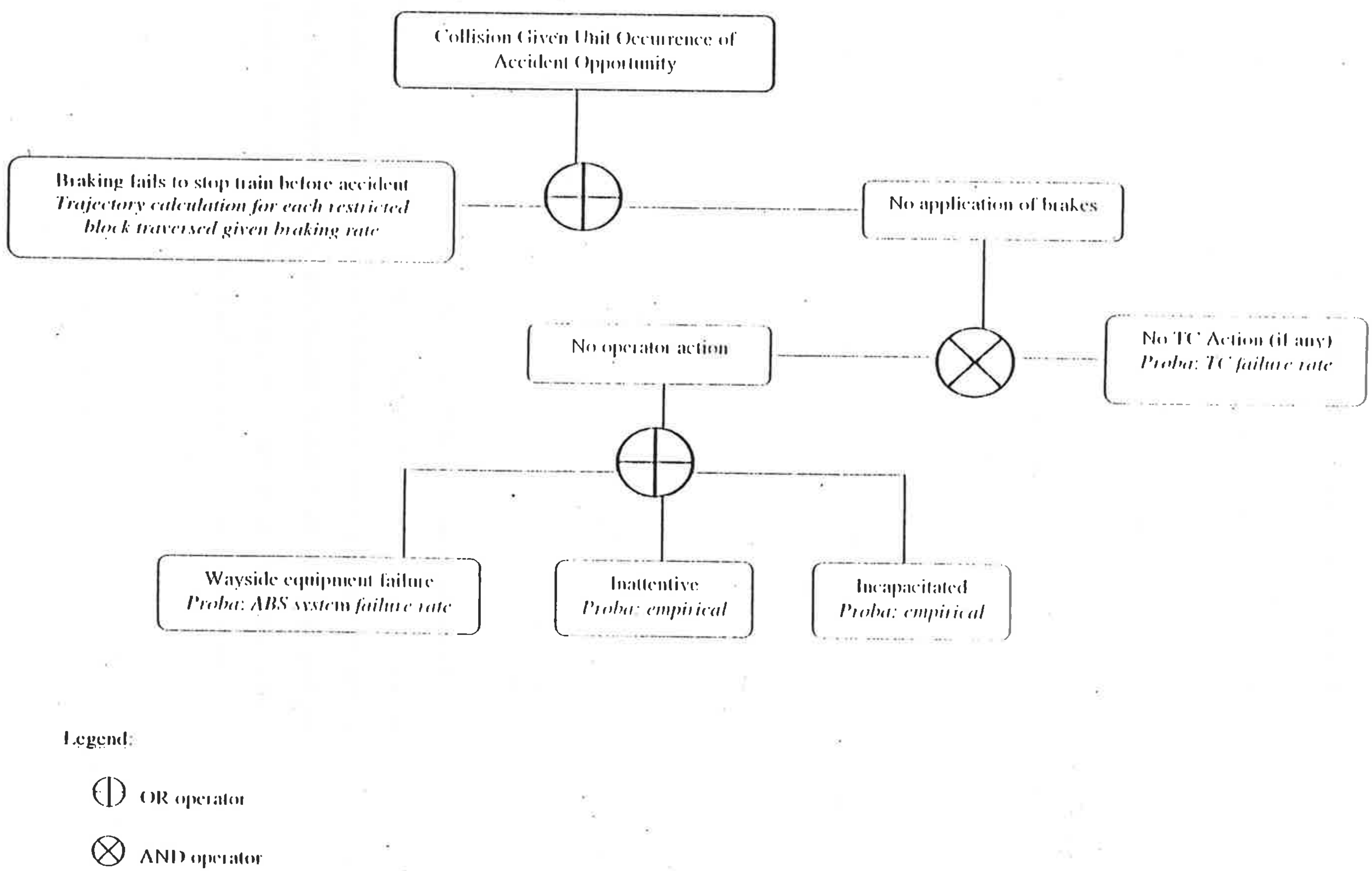
Figure 3.6 gives an example of fault-tree decomposition. The top node of the tree indicates that the collision is the result of either (i) the absence of application of brakes, or (ii) a late or insufficient application of the brakes that fails to stop the train before the collision occurs. The probability estimation of the second alternative requires the recursive application of the fault-tree in order to determine the trajectory of the train given its braking state and the action taken (braking or no braking) for each restricted block traversed. The first alternative is due to both a PTC failure (if PTC is present) and the absence of any operator action. Therefore, the presence of a PTC system will provide a "redundant" layer of safety and greatly decrease the probability that no braking action is taken (the latter will be inversely proportional to the probability of a PTC failure, which represents several orders of magnitude).

Table 3.5 gives a numerical illustration of this feature. Numbers in italic are the basic parameters needed to calculate other probabilities in the fault-tree. These values are based on the discussion of signaling systems (unsafe) failure rates and operator inattention provided in [16] (Appendix B). However, the parameters are all allowed to vary in the model. For instance, the probability of operator inattention is corrected upward for rear-end collisions, as the exposure to risk in a following movement is greater than in a meet in terms of time spent and potential for making a mistake.

Table 3.5: Numerical Values of Probabilities in the Head-On Collision Fault-Tree

	Train Control System			
	ABS	PTC1	PTC2	PTC3
No Application of Brakes	8.10^{-7}	$2.4.10^{-13}$	$1.6.10^{-13}$	8.10^{-14}
No PTC Action	*1*	$\mathit{3.10^{-7}}$	$\mathit{2.10^{-7}}$	*1.10*[illegible]
No Op. Action	8.10^{-7}			
Op. Inattentive	$\mathit{2.10^{-7}}$			
Operator Incapacitated	$\mathit{4.5.10^{-14}}$			
Wayside Equip. Failure	$\mathit{6.10^{-7}}$			

Figure 3.6: Fault-Tree Decomposition for Train Collisions



3.7 Estimation of Accident Consequences

3.7.1 Scope of the Analysis

The model predicts risk in terms of direct consequences related to loss of human life and injury, excluding property damage and other events such as the release of hazardous material.

Throughout the analysis, a linear cost function is assumed, even though a more-than-linear cost function could be arguably be used in order to account for the intangible consequences of catastrophic accidents. It is understandable that 10 fatalities in ten different accidents would have lower consequences among the public than a single accident with 10 fatalities. However, for illustrative purposes, a linear cost function is used. In line with DOT practice, the cost of a fatality was assumed to be $2.7 million, and the cost of an injury $100,000.

Therefore, the total expected consequences can formally be written in monetary terms as:

$$E(cons) = 2.7 \cdot 10^6 \cdot E(fatalities) + 10^5 \cdot E(injuries)$$

3.7.2 Estimating Fatalities and Casualties

For a given accident we define the casualty ratio (CR) as the ratio of the number of injuries and fatalities to the total number of occupants in the train(s) involved in the accident. Similarly, the fatality to casualty ratio (FCR) is defined as the ratio of the number of fatalities to the number of casualties. If we denote by Pax the total number of occupants in the train(s) involved in the accident, then:

$$fatalities = Pax \cdot CR \cdot FCR$$

$$injuries = Pax \cdot CR \cdot (1 - FCR)$$

3.7.3 Damage Transfer Function

Typically, in a collision or derailment, the first car(s) involved in the accident will suffer relatively higher damage than those cars further from the impact site. In order to account for this differential effect of on the train consist, JR East researchers defined a "damage transfer function" [14] to model the consequences of an accident in each car of the consist. Along the same lines, we hypothesize that the casualty ratio in the car in the n^{th} position (n=1 meaning that the car is the first in the collision or derailment, not necessarily the lead or rear-end car) is of the form:

$$FCR(n) = \exp(-s \cdot (n-1)) \cdot FCR(1)$$

JR East researchers found s to be in the order of 1.9, using the mortality ratio (i.e. $CR.FCR$) rather than the fatality to casualty ratio in the above equation.

Therefore for a train set with N cars, assuming that the occupants are evenly distributed across cars[3], an aggregate casualty ratio can be calculated as follows:

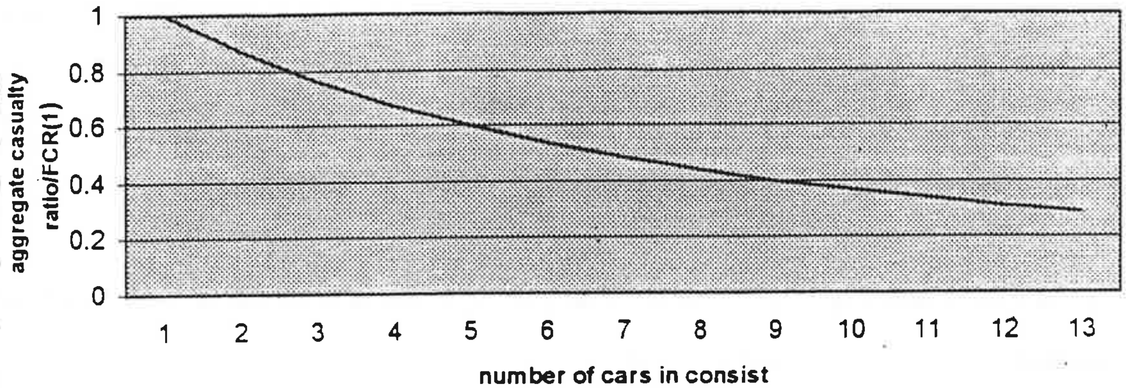
$$FCR = \frac{1}{N} \cdot \frac{1-\exp(-s \cdot N)}{1-\exp(-s)} \cdot FCR(1)$$

Where $FCR(1)$ is the fatality to casualty ratio in the first car involved in the accident.

The following graph shows the impact of train length on the aggregate fatality to casualty ratio FCR by taking the ratio of the latter to $FCR(1)$ (with s =0.3):

[3] This assumption does not hold for freight trains, for which we will assume that all of the occupants are in the lead locomotive.

Figure 3.7: Impact of Train Consist on Aggregate Fatality to Casualty Ratio



3.7.4 Consequences as a Function of Accident Speed and Terrain

In a study of train collision safety by Foster Miller and others [16] both CR and FCR were estimated as a function of the accident speed V, with specifications as follows:

$$CR = \frac{1}{1 + \exp(\alpha - \beta \cdot V)}$$

$$FCR(1) = \frac{1}{1 + k / V^{r}}$$

Using regression analysis on a database of accidents including several transportation modes, the parameters in the above equations were estimated in [16] as follows (for V in meters per second):

$$\alpha = 2.19337$$
$$\beta = 0.0533$$
$$k = 164563$$
$$r = 2.926 \qquad (*)$$

In order to include the influence of terrain on the accident consequences, the speed exponents are here linearly weighed using terrain factors, as follows:

$$\beta = \beta_0 \cdot [a + b \cdot (\%curve)] \cdot [k_g \cdot (\%grade) + k_e \cdot (\%elevated) + k_t \cdot (\%tunnel)]$$

$$r = r_0 \cdot [\lambda + \mu \cdot (\%curve)] \cdot [\varepsilon_g \cdot (\%grade) + \varepsilon_e \cdot (\%elevated) + \varepsilon_t \cdot (\%tunnel)]$$

Where $(\%curve)$, $(\%grade)$, $(\%elevated)$ and $(\%tunnel)$ denote respectively the proportion of track in the segment located in curves, at or near grade, on elevated structures (bridges or viaducts), and in tunnels or rock cuts. Note that curvature is here independent of other terrain factors.

The numerical values are empirically estimated as follows:

$$a = \frac{17}{18} \qquad \lambda = \frac{89}{90}$$
$$b = \frac{5}{9} \qquad \mu = \frac{1}{9}$$
$$k_g = 1 \qquad \varepsilon_g = 0$$
$$k_e = 2 \qquad \varepsilon_e = 0.2$$
$$k_t = 0.5 \qquad \varepsilon_t = -0.1$$

For the average parameters $\beta 0$ and $r0$, the numerical values estimated in [16] are used as shown in equation (*) above.

3.7.5 Illustration: *CR* and *FCR* as Functions of Speed and Terrain

For a passenger train set with N=12 cars and with the above numerical values, the following graphs show how the casualty and the fatality to casualty ratio vary with "impact" speed for different types of terrain.

Figure 3.8: Casualty Ratio, First Car

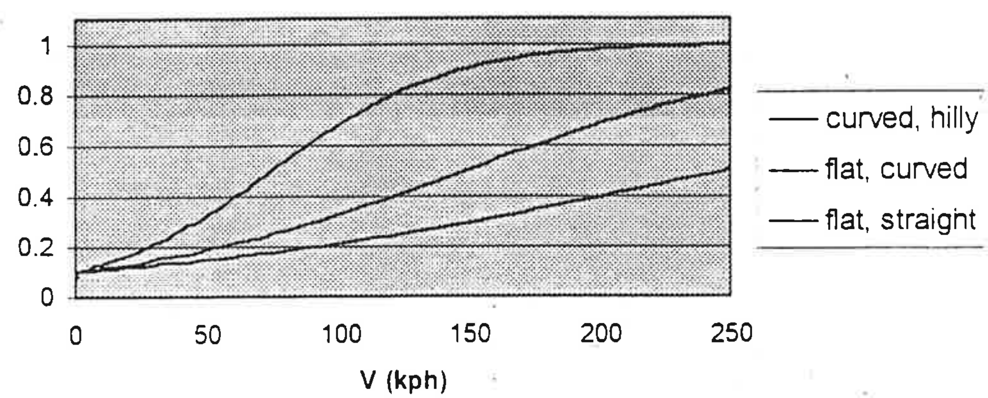
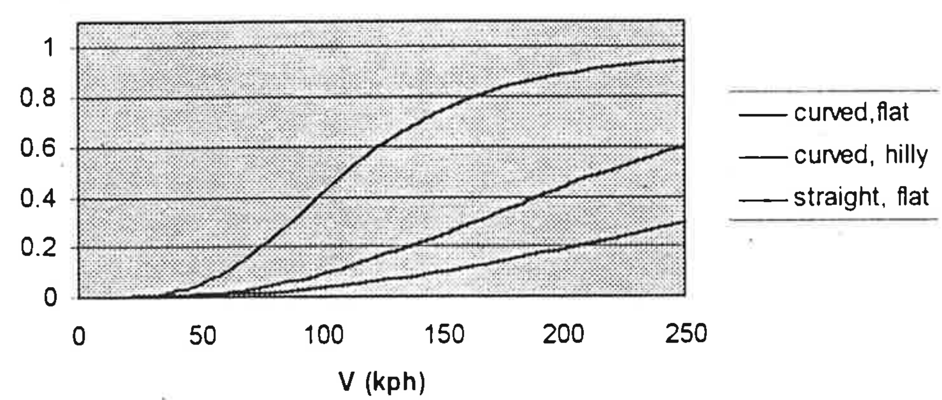


Figure 3.9: Fatality to Casualty Ratio, First Car



3.8 Analysis of Accident Scenarios

3.8.1 Head-On Collisions

3.8.1.1 Scope of the Analysis

A head-on collision is defined here as a collision between two opposing trains, including side collisions at rail crossings. A head-on collision will be the result of a primary train overrunning a home signal protecting a secondary train opposing it. The signal overrun can be caused by operator failure, insufficient braking, or by a failure of the control and signaling system.

The presence of a PTC system will help reduce the risk due to head-on collisions in two principal ways:

- It will cause an automatic application of brakes upon the overrun of a restrictive signal in order to comply with the applicable speed limit;
- It will reduce the time necessary to alert the secondary train of the signal overrun and therefore have it commence braking sooner.

Note that PTC will not prevent all collisions, as brake failures may prevent the control system from stopping the primary train.

3.8.1.2 Metric for Exposure

The basic metric used to estimate the risk of a head-on collision is the number of meets between trains. In addition to the number of meets, it is necessary (for double-track territory) to estimate the probability that two meeting trains be routed on the same portion of track. This may occur during maintenance work or if either of the two trains is engaged in a passing maneuver immediately prior to the meet. In [16], this probability was estimated to be in the order of 2% given a meet in multiple track territory. In order to assess the consequences of head-on collisions for different train types, the number of meets between trains of any two given types need be estimated.

In order to estimate the number of meets, consider two train types denoted *i* and *j*. Let *ni* and *nj* be their respective departure rates, and *Si* and *Sj* be their respective speeds. Let *D* be the segment length. A type i train departing at time t will meet all type j trains that depart in the time window $\left(t-\frac{D}{S_j},t+\frac{D}{S_i}\right)$. There are exactly $\int_{t-\frac{D}{S_j}}^{t+\frac{D}{S_i}} n_j(u)\cdot du$ such type j trains. Assuming that all trains operate in a time interval *[0, T]* over the period of analysis (typically a day) the total number of meets between type i and type j trains is:

$$M_{ij}=\int_0^T n_i(t)\cdot \int_{t-\frac{D}{S_j}}^{t+\frac{D}{S_i}} n_j(u)\cdot du$$

Further assuming that the departure rates are uniform, the number of meets reduces to:

$$M_{ij}=T\cdot n_i\cdot n_j\cdot D\cdot(\frac{1}{S_i}-\frac{1}{S_j})$$

Consequently, the number of meets with type j trains per type i train is given by:

$$\frac{M_{ij}}{T\cdot n_i}=n_j\cdot D\cdot(\frac{1}{S_i}+\frac{1}{S_j})$$

Note that the uniform departure rate assumption is clearly violated when peaking or fleeting of trains occurs during the period of analysis, as is the case for commuter service. To this end, a multiplicative factor of 2 in the above formula is added to yield a more realistic estimate when j corresponds to commuter service, with two symmetric morning and afternoon peaks.

3.8.1.3 Modeling of an Accident Situation

A primary train is coming towards the entrance of an interlocking protecting a secondary train. During its course, the primary train will encounter three types of restrictive signals: (i) advance approach (two blocks before the home signal – H-2), (ii) approach (at block H-1), and (iii) stop - at the home signal (H).

At each block traversed, the primary train will either initiate/continue braking or continue at its previous speed. The conditional probability (given the state at the previous block) of either situation occurring at the entrance of each block is given by the fault-tree. Given a braking state and initial speed, the complete trajectory of the primary train can thus be determined assuming level terrain.

When the primary train encounters the first restrictive signal, the secondary train is located somewhere in the B blocks between the pair of interlockings. It is assumed that the probability distribution of the location of the secondary train between the pair of interlockings is uniform. After a time lapse T, the secondary train is warned of the danger resulting from the presence of the primary train past the home signal and starts braking. It is assumed that the secondary train always has full emergency braking capability. Given the initial location of the secondary train between the interlockings, its initial speed and the time lapse T, its complete trajectory can be determined.

A straightforward comparison of the two trajectories will enable determining (i) whether a collision will occur and (ii) the closing impact speed given the occurrence of a collision.

3.8.1.4 Determination of Head-On Collision Risk

In order to calculate the closing impact speed for a single instance of a collision, the following variables are needed:

1. The separation between trains (i.e. in which of the B blocks between interlockings the secondary train is located);
2. The block before the home signal at which the primary train commences braking;
3. The braking state of the latter.

As these variables can be assumed to be independent and discrete (calculating a separation between train in terms of number of blocks), there are ($15xB$) different cases which probability can be estimated. Knowing the probability of each situation (the presence of the secondary train in one of the blocks and the braking action of the primary train being two independent events), an expected value of the risk per meet can be calculated. Multiplying by the expected number of meets per year yields a measure of the annual head-on collision risk.

3.8.1.5 Estimating the Time Lag *T*

T is the defined as the time lapse between the overrun of the home signal by the primary train and the start of emergency braking by the secondary train. The presence of PTC will greatly reduce *T* thanks to (i) better communication and data transmission between trains and central control and (ii) monitoring of trains' location. Reducing *T* will be critical in decreasing the trains' closing speed and therefore eliminating the occurrence of some head-on collisions, and reducing the severity of those occurring.

Specifically, when the primary train passes by the first restrictive signal at an excessive speed, PTC may ideally instantly alert the secondary train of the potential danger, especially if the separation between trains is small in terms of time or distance available for braking. On the other hand, under ABS with voice communication by radio, the primary train must first alert central control, which must then in turn order the secondary train to initiate emergency braking. A study of voice and data communication conducted by Burlington Northern Railroad ([30], [31]) indicates that the time to perform a single exchange between central control and a train can take up to several minutes with radio communication. It is assumed here that *T* equals 60 seconds in the base case, which is also consistent with the hypothesis formulated in [16].

Under PTC, in an ideal case *T* may even be negative since the secondary train can be automatically set to commence braking as soon as the primary train is found to run at an excessive speed past the first restrictive signal. For the most advanced PTC system (PTC3), however, it will conservatively be assumed that T=0, i.e. the secondary train commences braking as soon as the primary train overruns the home signal. As *T* can vary according to PTC capability as well as operating rules and policies, it will further be assumed that T is in the order of 15 seconds for PTC2 (the next most advanced system) and 30 seconds for PTC1.

Finally, note that T is a basic parameter in the model and can therefore be adjusted for any of the four train control systems under consideration, or varied in the context of sensitivity analysis.

3.8.2 Rear-End Collision

3.8.2.1 Scope of the Analysis

The analysis of rear-end collisions is very similar to that of head-on collisions, with some simplifications in modeling accident situations. A rear-end collision accident will be the result of a primary train overrunning a home signal at stop protecting the secondary train (traveling at a lower speed) that it is following on the same track. Such an overrun may be the result of (i) the primary train operator's failure to comply with the displayed restrictive signal, (ii) a train control system's unsafe failure, or (iii) insufficient braking. As a result, the structure of the fault-tree for rear-end collisions will be the same as for head-on collisions, as discussed in Section 3.5. Again, the key factor affected by PTC will be the probability of no braking initiated at a restrictive signal.

PTC will reduce the risk of rear-end collisions by automatically complying with the first restrictive signal (provided the primary train has sufficient braking capability). There might be a possibility for further reducing the risk in certain situations by having the secondary train accelerate, but this may result in an unsafe condition for the secondary train. Therefore, it will be assumed that the secondary train always travels at a constant speed

Again, PTC will not eliminate all collisions since a braking failure may prevent it from stopping the primary train before the collision.

3.8.2.2 Metric for Exposure

The number of opportunities for a rear-end collision is clearly linked to the number of overtakes in the segment under consideration. Consequently, the number of overtakes between two given train types is used to measure the exposure to rear-end collision risk. In multi-track territory, it is also necessary to estimate the probability that two following trains will be routed on the same track. As in the case of head-on collisions, this probability will be assumed to be in the order of 2%, but can always be adjusted according to any segment's physical and operating characteristics.

In order to derive an estimate of the number of overtakes of type *j* trains by a type *i* train, let the notations be the same as in Section 3.7.1.2. Note that a type *i* train will potentially overtake type *j* trains only if $Si > Sj$, since all trains are assumed to travel at constant speeds. Given this condition, a type *i* train departing at time *t* will overtake all type *j* trains that depart in the time window $\left(t - \frac{D}{S_j} + \frac{D}{S_i}, t\right)$. There are exactly $\int_{t-\frac{D}{S_j}-\frac{D}{S_i}}^{t} n_j(u) \cdot du$ such type *j* trains. With the uniform departure rate assumption, the number of overtakes of type *j* trains by type *i* trains during the period of analysis of duration *T* will be:

$$O_{ij} = \max\left\{0, k \cdot T \cdot n_i \cdot n_j \cdot D \cdot \left(\frac{1}{S_j} - \frac{1}{S_i}\right)\right\}$$

Where $k=2$ when *j* corresponds to commuter service and $k=1$ otherwise.

Likewise, the average number of overtakes of type j trains by a type *i* train can be formally derived as:

$$\frac{O_{ij}}{T \cdot n_i} = \max\left\{0, k \cdot n_j \cdot D \cdot \left(\frac{1}{S_j} - \frac{1}{S_i}\right)\right\}$$

Finally, the number of following interlocking movements (*FIM*) involving a type *i* train being routed behind a type *j* train on the same track is given by:

$$FIM_{ij} = p_{seg} \cdot O_{ij}$$

Where *pseg* is the probability that any two trains following each other are routed on the same track (*pseg* = 2% for multi-track and 1 for single track).

3.8.2.3 Modeling of an Accident Situation

A primary train encounters the first restrictive signal indicating the presence of a secondary train ahead of it. Given that the base-case ABS is a four-aspect system, this means that the rear of the secondary train is located at a distance between two and three blocks ahead of the primary train. It will therefore be assumed that the separation between the two trains will be at the average value of 2.5 blocks, given a uniform probability distribution for the location of the secondary train.

At each block traversed, the primary train will either initiate/continue braking or continue at its previous speed. The conditional probability (given the state at the previous block) of either situation occurring at the entrance of each block is given by the fault-tree. Given a braking state and initial speed, the complete trajectory of the primary train can thus be determined. Given that the secondary train will continue its course at a constant speed, it can be determined whether a collision occurs, and if so, at which closing speed.

3.8.2.4 Estimation of Rear-End Collision Risk

Given the block before the home signal when the primary train initiates braking and its braking state, the impact speed (if any) is determined as discussed above. Thus, for each of those fifteen possible situations, a value of the risk can be derived using the casualty and fatality ratios. Knowing the probability of occurrence of each situation enables calculating an average value of the rear-end collision risk for each pair of train types (*i,j*). Multiplying by the metric and summing over all possible train type pairs will yield a measure of the total rear-end collision risk in the segment under consideration.

3.8.3 Collision with Maintenance-of-Way (MOW) Equipment

3.8.3.1 Scope of the Analysis

A collision with MOW equipment will be the result of a train overrunning a home signal at stop protecting MOW vehicles and personnel. In this sense this accident scenario is equivalent to a head-on collision with a secondary train at stop. The fault-tree for this accident will therefore be the same as for train to train collisions. Again, the home signal overrun might result either from operator's failure to comply with the restrictive signal(s), train control system (ABS and PTC if any) failure, or braking failure.

3.8.3.2 Metric for Exposure

The basic metric for this scenario must provide a measure of the number of times a train is routed around a track between a pair of interlockings where MOW forces are present. Clearly such a metric will depend on both the number of hours of track maintenance and the traffic volume. Therefore, the amount of required maintenance hours in a given segment need to be estimated. In [23], Robert and Martland estimate this parameter for heavy haul rail lines (a 30 MGT and an 80 MGT single track line). Noting that hours of maintenance increase less than linearly with MGT and using data from this study, a simple linear relationship between hours of required maintenance (*H*) and the square root of MGT can be estimated as follows:

$$H = a + b \cdot \sqrt{MGT}$$

Where *a* represents a fixed number of hours, and *b* a variable component depending on the intensity of traffic.

Calibration with data from [23] yields:

$$H = 0.006 + 0.001 \cdot \sqrt{MGT} \quad \text{(hrs/track-km/day)}$$

Let *D* be the segment length and *H0* be the number of working hours per day for a single maintenance gang. Thus $\frac{H}{H_0} \cdot D$ is an estimate of the number of maintenance gangs present in the segment during a single day. Therefore, the number of encounters between MOW equipment and trains of type *i* during a single day will be estimated by:

$$MOW_i = \frac{H}{H_0} \cdot D \cdot n_i \cdot T$$

Where $n_i.T$ is the number of type *i* trains per day in the segment.

3.8.3.3 Modeling of an Accident Situation

This scenario is simply treated as a particular instance of head-on collisions, with MOW equipment playing the role of a standing secondary train.

3.8.3.4 Estimation of Risk of Collision with MOW Equipment

Different types of maintenance activities will require different MOW equipment and gang sizes. The consequences of an accident involving MOW equipment depends primarily on the size of the work gang and the type of equipment on the track, and secondarily on the train type. Therefore, the estimation of accident risk is done for a "typical" maintenance activity, involving a gang of size $G = 10$ people and MOW equipment that will make the oncoming train derail if the collision impact speed is larger than $Vcrit$. $Vcrit$ ranges from 5 to 15 meters per second, varying linearly with the percentage of track located in curves.

3.8.4 Derailment Due to Track Fault

3.8.4.1 Scope of the Analysis

This scenario is concerned with accidents due to a broken rail. In [8], Chapman and Martland provide estimates of the occurrence of rail defects in general and of in-service defects in particular.

A PTC system will not affect the number of broken rails, but it may be able to reduce the risk due to derailments for two main reasons:

- In signaled territory, if the rail brakes when an approaching train is in an adjacent signal block, then the signal system will give a restrictive indication, but the engineer may see the signal too late to stop in time and avoid the break (e.g. because of reduced visibility). A PTC system could provide an earlier warning and automatically commence breaking sooner. By braking sooner, some derailments will be avoided and others will occur at lower speeds, thereby reducing their consequences.

- If PTC allows some new method for detecting broken rails, then the derailment rate in non-signaled territory would drop to the rate in signaled territory (with PTC).

In the following, only the first factor is considered to be applicable, since the detection of broken rails is not strictly an attribute of a train control *per se*. Currently, the only known methods for automated detection of broken rail involve some sort of track circuits (as discussed at the June 18, 1998 meeting of the Association of American Railroad's Railway Technology Working Committee), so it is not yet clear whether or how an advanced PTC could provide superior detection system for broken rails. In addition, only signaled territory is considered, with a four-aspect wayside ABS as the base case.

3.8.4.2 Metric for Exposure

It is assumed that the number of in-service rail defects per kilometer per year is a constant r. For a single train running along the segment the number of rail defects encountered by the train will be $r.D$, where D is the segment length.

3.8.4.3 Modeling of Accident Situation

A train comes by at a constant speed $V0$. At $t=0$, it encounters a restrictive signal due to a broken rail that is located at some distance d ahead of it. At $t=T$ (we will assume $T=0$ for PTC systems) the train starts braking with a constant deceleration rate a.

Depending on d, $V0$ and T, the train may or may not stop before it encounters the broken rail. If not, it is hypothesized that it will derail if the "impact" speed is larger than some critical value $Vcrit$, which varies linearly with the proportion of curved track.

Kinematics equations yield the following result: There will be a derailment if and only if

$$d \le V_0 \cdot T + \frac{V_0^2 - V_{cnt}^2}{2a} \qquad \text{(given that } V_0 \ge V_{cnt}\text{)}$$

Given the above condition, the derailment speed will be:

$$V^* = \sqrt{V_0^2 - 2 \cdot a \cdot (d - V_0 \cdot T)} \qquad \text{if } d \ge V_0 \cdot T$$

$$V^* = V_0 \qquad \text{if } d \le V_0 \cdot T .$$

3.8.4.4 Accident Frequency

Assuming that d is uniformly distributed between 0 and D, the total segment length, the probability of a derailment for a single encounter of a rail defect will be:

$$\Pr(derail) = \frac{V_0 \cdot T + \frac{V_0^2 - V_{cnt}^2}{2a}}{D}$$

Using the metric $r.D$, the frequency of derailments is derived as:

$$E(derail) = r \cdot \left(V_0 \cdot T + \frac{V_0^2 - V_{cnt}^2}{2a} \right)$$

Therefore the absolute reduction in accident frequency achieved with a PTC system thanks to earlier application of brakes will be:

$$r \cdot V_0 \cdot T$$

3.8.4.5 Accident Severity and Consequences

From the above formulae, the probability distribution function of the derailment speed V^*, $f(V^*)$, is determined. Note that there is a non-zero probability that $V^*=V0$, the initial speed. Therefore, $f(V^*)$ will consist of: (i) a continuous part for Vcrit<V*<V0 ; and (ii) a discrete part for $V=V0$ (which corresponds to the case where derailment occurs before any braking action is initiated).

The total consequences can be formally calculated as:

$$E(cons) = \int_{V_{crit}}^{V_0} cons(V^*) \cdot f(V^*) \cdot dV^* + cons(V_0) \cdot \Pr(V^* = V_0)$$

Setting $T=0$ yields the consequences under PTC.

3.8.5. Grade-Crossing Collisions

PTC offers three opportunities for improving grade crossing safety:

1. Communications link with protection devices
2. Communications link with priority vehicles
3. Reduced costs of protecting crossings

If the train can communicate to the WIU controlling the protection device (warning bells or gates), then the WIU can provide a constant lead time for the warning. This would reduce the likelihood that drivers would ignore warnings in expectation of very long waiting time. If the WIU can communicate to the train, then it could require the train to slow down if the warning device is not working properly. If there is an obstacle detector at the crossing, then the WIU could communicate directly to the train in the event of a stalled car or other obstacle blocking the crossing.

Communications linkage between railway and vehicles is a topic that has been discussed the context of Intelligent Transportation Systems (ITS) as well as in the context of railway control. The most likely applications would involve some sort of communications with priority vehicles, which might be school buses, other buses, or large trucks that frequently use a grade crossings and conceivably could be the cause of a catastrophic grade crossing accident. One approach would be to have an indirect communication link via the WIU. For example, a Vehicle Proximity Alert System (VPAS) would be able to notify the train is a priority vehicle is hung up on the crossing. The train could also broadcast directly to priority vehicles, which could provide additional warning, especially at unprotected crossings. It is unclear what kinds of systems might emerge, but it is clear that there is a possibility for some improvement in grade crossing safety through linkages between ITS and train control systems Implementation of such systems will be difficult because, in addition to technological issues, there may be legal issues concerning liability in the event of equipment failure.

A third area of potential benefit might be that the availability of a digital communications link will reduce the costs of protecting crossings with gates or other warning devices. If so, then more crossings could be protected for the same budget, and the expected number of crossing accidents would decline.

It is beyond the scope of the current research to examine the potential technologies for improving grade crossing safety. However, even a cursory analysis is sufficient to show that grade crossing safety is worth considering in more detail. The magnitude of the problem is evident from the FRA accident statistics ("Highway-Rail Crossing Accident/Incident and Inventory Bulletin", No. 19, August 1997).

Equal warning times: there are approximately 800 accidents per year in which a moving automobile is struck by a train. A 1-10% reduction might be achievable if warning times were equalized and if very long warning times were eliminated. This would be 8-80 accidents per year.

Malfunctioning devices: as there were only 9 accidents in 1996 involving malfunctioning devices, the safety potential would be only 5-10 accidents per year even if the technology were highly successful.

Improved linkages to obstacle detectors: there are approximately 70 accidents per year involving stalled vehicles at crossings with gates. Based upon experience in Japan, where obstacle detectors are common, 70-90% of this type of accident are typically eliminated after obstacle detectors are installed. However, obstacle detectors are expensive and the incremental benefit from having better communications with the train would be small; the success of the detectors would be somewhat higher, perhaps 75-95%, i.e. a 5% improvement or less than a half-dozen accidents per year even in obstacle detectors were widely installed.

Communications with priority vehicles: here the potential is greater, as there is a potential for directly influencing the behavior of the drivers of the highway vehicles. There are approximately 400 accidents per year involving large trucks and buses. Conceivably, 25-75% of these (100-300 accidents) could be eliminated through a widely implemented "priority vehicle" program.

In the aggregate, there could be the potential to eliminate 140 to 450 grade crossing accidents annually. Assuming that the average consequences of these accidents is $350,000 (which would be the case if there were about 1 fatality for every 10 accidents), the annual reduction in risk would be on the order of $50 to 150 million. The safety benefits from this one area could therefore be as great or greater than other safety benefits of PTC, which have been estimated to be on the order of $50 to $100 million annually.

Since grade crossing accidents are so different from the typical PTC preventable accidents, we did not include them within the same spreadsheet model. Instead, we adapted the DOT model so that it could be readily applied to a large number of crossings with diverse types of traffic, rail and highway infrastructure, and protection. The model and itds applications are discussed in Appendices B and C.

3.9 Potential Applications of the Model

The model provides a variety of potential uses with respect to the risk assessment of train control systems. Importantly, it provides a framework that lends itself to integrating results from more detailed studies on specific aspects or parameters that are part of the model. Among the potential applications are the following:

- Comparative assessment of the relative merit of many different risk reduction strategies;
- Analysis of the incremental benefits of advanced train control systems;
- Analysis of the incremental risk associated with adding traffic on a line for a particular service;
- Identification of the most important causes of accidents and risk for different corridors;
- Identification of the features of PTC that contribute the most to risk reduction.

The following chapter provides an illustration of the potential use of the model. First, sensitivity analyses on several key parameters are performed for a particular accident scenario (head-on collision). Second, the model is applied to an example corridor with varying characteristics.

Chapter 4
Effects of Train Control on Risk: Sensitivity Analysis

4.1 Introduction

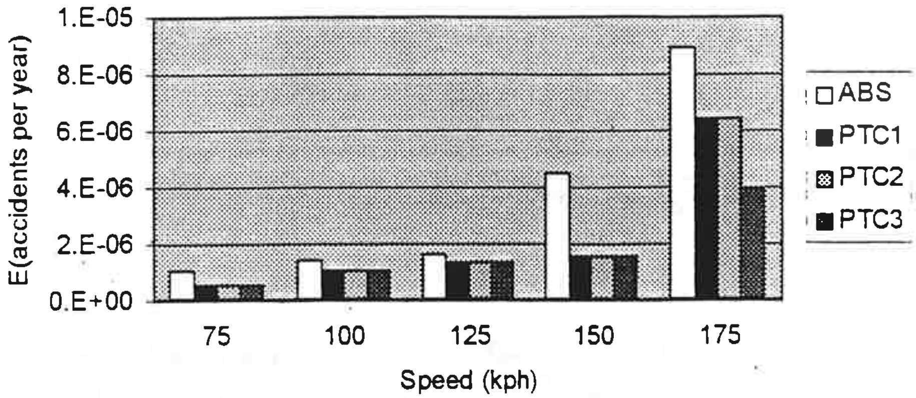
This section provides an illustration of the use of the model for sensitivity analyses for a particular accident scenario, namely head-on collisions. We examine the effects on the risks associated with head-one collisions due to four important operating parameters: speed, freight traffic volume, passenger traffic volume, and block length.

4.2 Sensitivity to Speed

The example segment is a passenger-service-only line, 100-km long, with 5 passenger trains per day and double track, uniform blocks of 1,500m; and fairly flat and straight terrain. First, the impact of speed on accident frequency is examined.

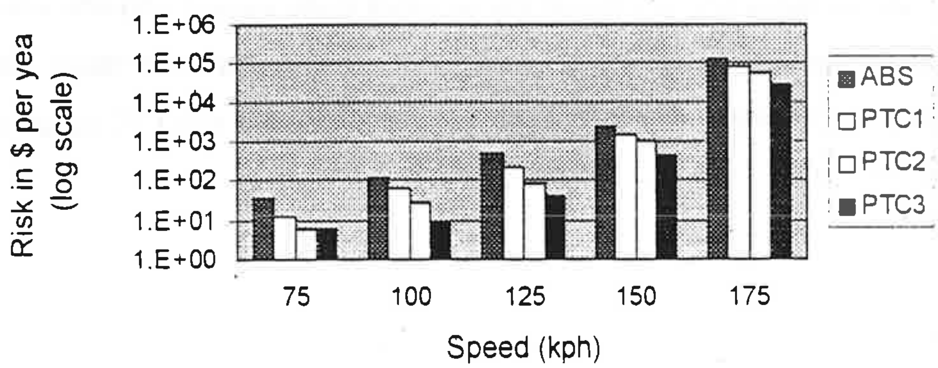
As evidenced in Figure 4.1, head-on collision frequency increases more than linearly with speed. All else being equal, a signal overrun at a higher speed is clearly more likely to result in a collision than one at a lower speed. In addition, the accident reduction of the more advanced PTC systems is more marked for higher speeds. Indeed, the higher the speed, the more critical it is to have an automatic braking and warning (for the secondary train) system for collision avoidance. Therefore at higher speeds the performance of PTC, primarily in terms of the time lag necessary to alert the secondary train, becomes increasingly determinant.

Figure 4.1 Head-On Collision Frequency vs Speed



The following chart shows the total risk as a function of speed on the same segment. The risk is plotted on a logarithmic scale. This shows a clear, more-than-linear, relationship between speed and total risk for head-on collisions. This relationship is even more marked than for accident frequency as consequences increase more than linearly with impact collision speed. The risk reduction achieved with the most advanced system (PTC3) is on the order of 80-90% while for the least advanced (PTC1) it is in the range of 35-50%. This suggests that there may be significant differences in the performance of PTC systems according to their specification.

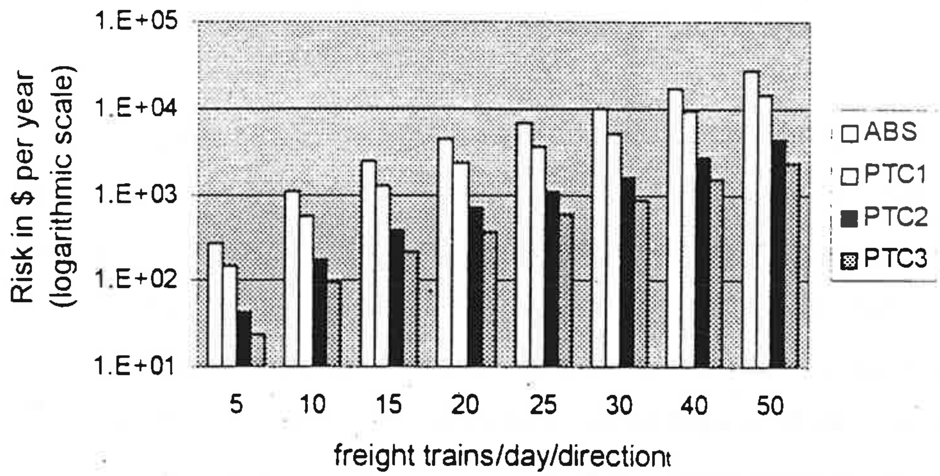
Figure 4.2: Head-On Collision Risk for a Segment vs. Speed



4.3 Sensitivity to Freight Traffic Volume

In this section a single-track, 100-km long segment is considered, with only freight service. The block length is uniform at 2,000 meters and the maximum authorized speed (MAS) is 100 kph. Figure 4.3 shows the relationship between head-on collision risk and the number of freight trains per day running on the line.

Figure 4.3: Head-On Collision Risk vs Traffic Volume
Freight Trains on Single Track Segment



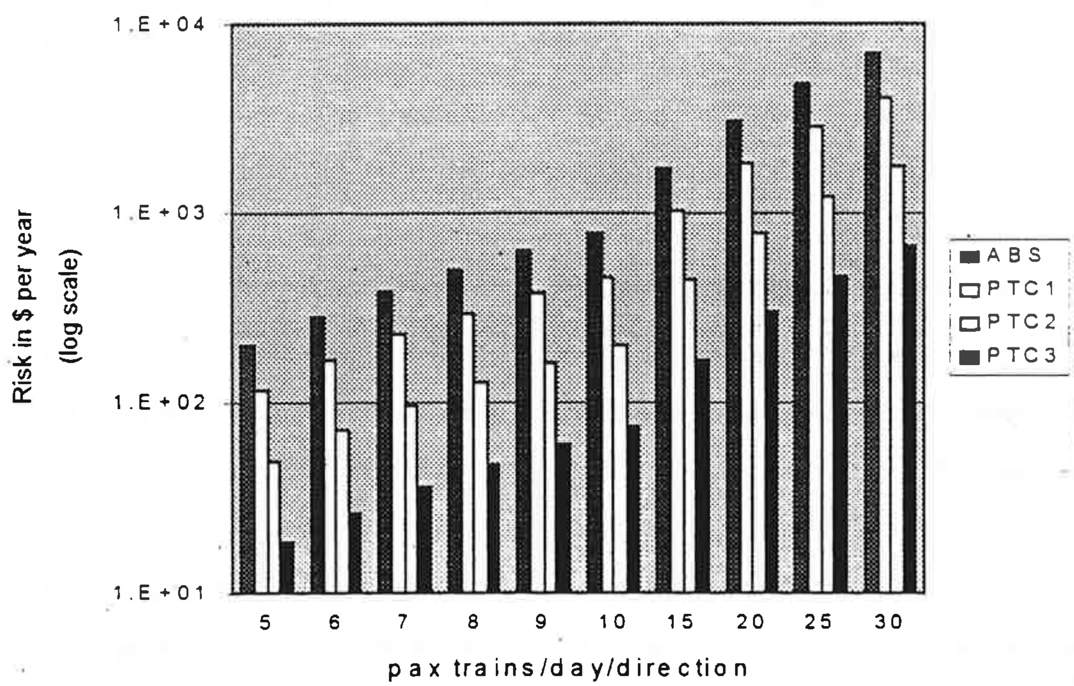
Again, as evidenced by the logarithmic scaled used, the risk varies more than linearly with traffic volume. This is understandable since the number of accident opportunities (here the number of meets between freight trains) varies as the squared of traffic volume. Therefore, all else being equal, more traveled routes will naturally be riskier than routes or segments with little traffic. Here the risk reduction achieved with PTC ranges from around 50% (PTC1) to more than 90% (PTC3).

4.4 Sensitivity to Passenger Train Volume

To illustrate the impact of passenger service traffic volume a double-track, 100-km long segment is considered. Block length is assumed to be 1,500m, and the maximum authorized speed is 100 kph.

Figure 4.4 shows the result of the sensitivity analysis with head-on collision risk plotted on a logarithmic scale.

Figure 4.4: Head-On Collision Risk vs Traffic Volume
Passenger Trains on Double Track Segment



Again, for the same reasons discussed in the previous section, risk increases more than linearly with the number of passenger trains per day.

Interestingly, the two previous figures show that the absolute value of the risk is not higher in the passenger service segment than in the previous freight-only segment (under any of the control systems). The occupancy of passenger trains is a couple of orders of magnitude higher than that of freight trains (200 occupants on average as compared to only 3 for freight trains). This should cause, all other things being equal, the consequences for a head-on collision between passenger trains to be much higher than for one between freight trains. However, there are at least two factors that counterbalance this effect. First, in a single-track line, the probability for two opposing trains to be routed on the same track is equal to one. This happens in a double-track line under special circumstances (if one track is closed for maintenance or occupied by a third train). Second, in a head-on collision between two freight trains, the occupants are all in the first car involved in the impact.[4] Therefore, the "damage transfer function" described in Section 3.7.3 does not apply for freight trains in a head-on collision and the crew members are much more at risk than the "average" occupant of a passenger trains.

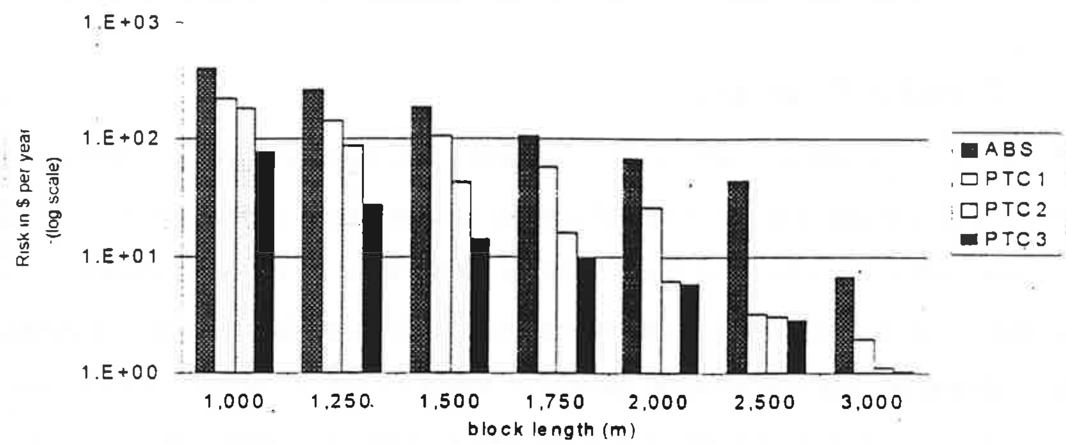
On the other hand, the previous argument also indicates that adding passenger train to a freight-only line in single-track territory could significantly increase the risk.

4.5 Sensitivity to Block Length

The last parameter to be examined in this sensitivity analysis is block length. This parameter should be of importance since it is critical in determining an appropriate separation between trains and ensuring a sufficient "buffer" to brake safely in the event of a partial failure of the braking system or improper use thereof. Figure 4.5 shows the result of the sensitivity of head-on collision risk to block length on the same double-track segment as before (with 5 passenger trains per day in each direction running at an MAS of 100 kph).

[4] This would hold for only one of the freight trains in the event of a side collision at a rail crossing.

Figure 4.5: Head-On Collision Risk vs Block Length



As expected, the results show that total head-on collision risk decreases sharply when block length increases, as separation between trains and available braking distances become greater. This also illustrates the underlying trade-off between safety and capacity as block lengths are reduced. However, an advanced PTC system (such as PTC3) seems to achieve a significant reduction in risk (around 90% for shorter blocks) as compared to the base-case ABS, and can assist in maintaining an acceptable level of risk.

Chapter 5
Effects of Train Control on Risk: Corridor Analysis

5.1 Corridor Description

We chose to examine a hypothetical rather than a real corridor. With a hypothetical corridor, it is possible to use a limited number of segments to cover a diverse set of traffic volume, traffic mix, and route characteristics. What is lost in realism is gained in flexibility: more time can be spent on sensitivity analysis and less time in data collection and calibration. Our hypothetical corridor is similar to the 183 actual corridors analyzed in the RSAC report, which had an average length of 482 miles and a maximum length of 1,922 miles [RSAC, 1999, p. 52].

The hypothetical corridor is loosely modeled on the route from New York City to Chicago. It is 1200 miles long, with heavy passenger operations at each end, 4-6 daily Amtrak trains across the entire route, and 50-75 annual million gross tons (MGT) of freight trains per mile of track. There are both single- and double-track segments, and the terrain varies from flat through rolling hills, to very difficult, with sharp curves and grades. Using typical train and car characteristics, we translated annual MGT into average trains per day as required by the model. We established varying speeds for freight and passenger trains, with top speeds of 120 km/hour (75 mph) for passenger trains and 60 km/hour (37.5 mph) for freight. These speeds are intended to reflect the average operating speed over the segment, rather than the maximum speed that trains might actually achieve at some point along the segment. Based upon the traffic volume, we estimated the maintenance requirements and work windows using techniques developed for the AAR's heavy axle load analysis.

5.2 Levels of Train Control

We considered three levels of train control that are similar but not identical to what we have used in earlier chapters (Exhibit 5.1). PTC1 is a bare-bones system that responds to signal overruns with full emergency braking; it will also warn the crew and then stop the train if it exceeds speed limits. This system relies on uploading current information about speed limits and temporary slow orders from a diskette (or other means) at the start of each trip. This unsophisticated system affords protection against signal overruns and overspeed accidents, but responds slowly and clumsily to dangerous situations and does not use the digital communications link for further safety improvements.

PTC2 is intended to represent the type of PTC systems that have been widely discussed and tested in recent years by the railway industry. This system provides a stronger communications link between headquarters and the train, so that temporary slow orders, information about hazards, and authorities granted to MOW crews can be sent to the train. The system is also assumed to be quicker in informing opposing trains that there is a problem, which will allow them either to stop in time to prevent an accident or to slow down and reduce the severity of the accident.

Exhibit 5.1
Train Control Assumptions Used in the Corridor Analysis

Train Control Feature	PTC1	PTC2	PTC3
Safety Critical	No	Yes	Yes
Replace Signals	No	No	Yes
Authority Enforcement	Upon Exceeding	Upon Exceeding	Before Exceeding
Speed Enforcement & Intervention	Maybe Full service braking	Yes Speed Control	Yes Speed Control
Broken rail protection	No	No	Yes
Crossing protection			
Basic	No	Yes	Yes
Advanced	No	No	Yes

The on-board systems are also more sophisticated. The on-board computer continually updates braking distances and will control the trains speed so that it does not exceed either its operating authorities or the speed limits. The train will broadcast its location and speed so that grade crossing protection devices can provide equal warning times when lowering gates or flashing lights. This system, like PTC1, still relies upon the existing signal system to provide broken rail protection.

PTC3 is a more advanced system with features that can be imagined but that are not currently available. For safety, the most important changes are the provision of linkages to a new system for detecting broken rails and alerting trains. Such a system, which does not now exist, would prevent some derailments by giving most approaching trains a more immediate warning than is possible from track circuits, i.e. the train will respond even before the crew sees the next signal and even if it is already within the block where the rail is broken. For grade crossing protection, the PTC3 system is assumed to have direct communication with selected fleets of trucks and buses that commonly use crossings. This is another technology that is possible, but does not yet exist. If implemented, a portion of the most dangerous grade crossing accidents could be prevented by warning the highway vehicle of the approaching train or by warning the approaching train if the highway vehicle is stuck on the track.

5.3 Base Case Results

The base case results are shown in Exhibit 5.2. The risks are based upon the expected casualties, weighted at $2.7 million per expected fatality and $100,000 per expected injury. The risks for this corridor are $1.09 per train-km ($1.74 per train-mile) or $25 million per year. On a route-km basis, the risks are $6,300 per route-km ($10,000 per route-mile). The RSAC analysis of corridor risk, which covered similar risks, estimated that only about 10 of the 183 corridors were this risky. As we desired, the hypothetical corridor is in fact a high risk corridor. Exhibit 5.2 breaks out the risks by the major accident types. The most important category is head-on collisions, which account for one third of the accidents and two thirds of the total risk per year. Broken rails are predicted to be a much more common cause of derailments than going too fast through a temporary or permanent slow order. Rear-end collisions are not predicted to be an important element of risk.

Exhibit 5.2
Base Case Results for the Hypothetical Corridor

Accident Type	Accidents per MTK	Consequences/ Accident	Risk/Train-km	Total Risk/Year
Derailment		$6.2 million		
Track Fault	0.051		$0.33	$7.6 million
Temporary Slow Order	0.006		$0.03	$0.7 million
Permanent Slow Order	<0.001		$0.00	$0.007 million
Collision		$22.2 million		
Head-on	0.032		$0.69	$16.1 million
Rear-end	<0.001		$0.00	~ $0
Total	0.09		$1.09	$25.1 million

The results for three levels of train control are shown in Exhibit 5.3. The PTC systems are effective in reducing both the accident rate and the risk. The accident rate declines to 80% of the base level with PTC1 and to 45% of the base level for PTC2. The risk declines even more, because the PTC systems can reduce train speeds and therefore consequences even when they cannot eliminate accidents. The risk declines to half the base case for PTC1 to less than 20% for PTC3. These reductions are achieved because the PTC systems reduce the frequency and severity of head-on collisions and eliminate most of the overspeed derailments. PTC2 is more effective than PTC1 because it provides more timely feedback to both the train that is about to overrun a signal and to approaching trains. PTC3 is more effective than PTC2 in part because of even more timely communications, but also because there is a linkage to a new (as yet unknown) technology that will alert the train if a rail breaks. Of these three systems, PTC2 is most similar to the communications-based train control systems under serious consideration at the turn of the century. This exhibit shows that the PTC systems with different capabilities could have significantly different levels of effectiveness.

Exhibit 5.3
Effects of Train Control Systems on Accidents/MTK and Corridor Risk ($million/year)

Accident Type	Base Case	PTC1	PTC2	PTC3
Head-on Collision	$16.10	$6.60	$3.17	$2.13
Track-fault Derailment	$7.60	$6.70	$5.08	$1.91
Temporary Slow Order Derailment	$0.70	$0.07	$0.07	$0.07
Total Risk	$25.10	$13.91	$8.85	$4.62
Per Cent	100%	51%	32%	17%
Accidents/MTK	$0.09	$0.07	$0.06	$0.04
Per Cent	100%	80%	67%	45%
Consequences per accident	$12.02	$7.63	$5.83	$4.52
Per Cent	100%	63%	48%	38%

5.4 Sensitivity Analysis for the Corridor

We conducted sensitivity analyses to consider the effects of what we expected to be the most significant factors affecting risk (Exhibit 5.4). The amount of passenger traffic is the most important factor considered. Eliminating the passenger traffic reduces the annual train km from 23.15 million in the base case to 15.33 million, a reduction of 34%, but the risks decline to just 6% of the base. Doubling the passenger traffic increases annual train-km by a third (to 30.98 million), but the risk more than doubles. Accidents involving passenger trains can potentially result in dozens of fatalities and injuries, so that the expected consequences are much higher than for accidents only involving freight trains.

Risk does not vary proportionately with traffic volume. Derailment risks are about the same, while collision risks increase with the square of traffic. Track fault derailments are expected to be proportional to the number of broken rails, which in turn are expected to be governed by track inspection, maintenance and rail replacement policies. If rail is replaced when defects exceed N per mile per year (which is independent of traffic volume), then the expected number of broken rails per year (and the related derailments) will be constant. This result occurs because rail replacement balances the benefits of deferring rail replacement for another year with the annual costs associated with rail defects, including rail inspection, replacement of defects and the small probability of a derailment if the rail breaks. The probability of a defect eventually increases to the point may at which it makes sense to replace the rail [Roney, et al., 1982]. For mainline track the maximum expected number of defects per year is commonly stated as 2 to 3 per mile, independent of tonnage [e.g. Martland, et al., 1990]. Collisions, on the other hand, are expected to increase in proportion to the square of the number of trains, so that these potentially catastrophic accidents will increase more than proportionately with traffic volume. This is why the risk increases by 39% under ABS when traffic only increases by 25%.

Exhibit 5.4
Results of Sensitivity Analysis

Scenario	Annual Risk	% of Base
Passenger Traffic		
None	$1.52 million	6%
Doubled	$63.89 million	254%
Traffic Volume		
25% of base	$8.82 million	35%
50%	$12.14 million	38%
75%	$17.57 million	70%
125%	$34.87 million	139%
# of Tracks		
Double	$14.28 million	57%
Single (rural)	$37.49 million	149%
Train Speed		
10 km/hr less	$16.44 million	65%
10 km/hr more	$40.25 million	160%

The number of tracks is important because the risk of collision is much greater on single than on double track. Even though having double tracks will increase the probability of broken rails (because there are more rails that might break), the risk falls to 57% of the base ABS case if the entire route is double-tracked. If all of the rural route is single-tracked, the broken rail accidents are expected to decline, but the collisions increase and the overall risk rises to 149% of the ABS base case.

Train speed is important, because this affects the time required for a train to stop. Under the PTC systems, there are still collisions because of problems with brake systems. With faster speeds, it will take longer for both the train approaching the signal and the opposing train to stop in the event of a signal overrun related to brake problems. The exhibit shows that modest changes in trains speed (+/- 10 km/hr, i.e. +/- 6 mph) will have significant effects on risk. PTC systems will be slightly more effective at higher speeds. In actual operations, the sensitivity to speed would likely be mitigated by using better equipment, more frequent inspections, better track and more experienced engineers for the higher speed operations.

Exhibit 5.5 shows results of the sensitivity analysis for the three PTC systems. The second column shows the change in base case (ABS) risk for each of the sensitivity scenarios. These percentages, which are the same as shown in Exhibit 5.4, serve as a comparison for the changes in risk under the three PTC strategies. The percentages shown in the three PTC columns are related to the base case under the specified control system. Hence, the percentages for the base case are 100% for PTC1, PTC2, and PTC3.

Now consider the scenario in which passenger traffic is doubled. Under ABS, the risks rise to 254% of the base case (i.e. from $25 million per year to about $64 million per year, an increase of nearly $40 million per year). The percentage changes in risk are a bit different for the three PTC systems. Under PTC2, for example, risks rise to 203% (from $8.2 to $16.6 million per year) of the base risk if passenger traffic is doubled. Since the risk increases less for PTC2 system than for the ABS system, the benefits of PTC2 are increasing more than proportionately with the increase in risk under the base case system. In this case, PTC2, which has 32% of the modeled risks for the base case, has only 26% of the risks if passenger traffic doubles. Thus there are two reasons that PTC system will have greater benefits as passenger traffic increases: a) corridor risk increases faster than the proportion of passenger traffic and b) the ability of PTC to reduce risk also increases.

Exhibit 5.5
Results of Sensitivity Analysis

Scenario	Base Case (ABS)	PTC1.	PTC2	PTC3
Base	$25.1 million/yr.	$12.8 million	$8.2 million	$4.3 million
Base	100%	100%	100%	100%
Passenger Traffic				
None	6%	8%	9%	4%
Doubled	254%	238%	203%	221%
Traffic Volume				
25%	35%	51%	60%	45%
50%	38%	61%	68%	56%
75%	70%	77%	81%	74%
125%	139%	118%	124%	134%
# of Tracks				
Double	57%	76%	92%	88%
Single (rural)	149%	135%	123%	125%
Train Speed				
10 km/hr less	65%	71%	74%	75%
10 km/hr more	160%	154%	155%	149%

As noted above in the discussion of Exhibit 5.4, the frequency of collisions increases with traffic density while the frequency of derailments decreases. Since the PTC systems are more effective at reducing collision risks than they are at reducing risks related to broken rails, the benefits of PTC are higher as traffic density increases. For example, under the base case (ABS) train control system, the risk increases 39% when the traffic increases 25%. The risks increase more slowly for each of the PTC systems.

The potential benefits of PTC also vary with the amount of double-track. All three systems will be slightly more effective in single- than in double-track situations. The same is true for train speed. If trains go faster, it takes longer to stop and the probability of accidents will increase if block length, train density, and engineer performance remain the same. If trains go more slowly, then there will be fewer collisions and overspeed derailments. The benefits of the PTC system will therefore be greater if train speed increases.

Appendix A has a more detailed discussion of the corridor study. It includes the inputs used to describe the 50 segments as well as many exhibits showing accident frequency and risk by type of accident and segment. Both accident frequency and risk per MTK vary by an order of magnitude from the least to the most risky segment. The benefits of the three levels of PTC systems are clearly evident all along the corridor..

Chapter 6
Use of the Risk Model in Technology Mapping

6.1 Overview of Technology Scanning and Technology Mapping

Technology mapping is a process for relating specific changes in technological capabilities to specific changes in system performance. The term implies that is possible to "map" particular technological characteristics into particular improvements in performance. We have used this concept in rail research at MIT to relate track technology to constraints on train operations (especially axle loads) and to track and train operating costs. We have found that it is possible and quite useful to compare and contrast the potential benefits of generic types of technology improvement before becoming too bogged down in specific technological studies. For example, we were able to show that achieving a higher loading density for a freight train provides similar operating benefits to what could be achieved simply by increasing axle loads (Chapman, Robert *et al.*, 1997). Hence, seeking better equipment design (e.g. higher, shorter cars) is an alternative that should be considered in evaluating research results from the Association of American Railroads research on heavy axle loads.

The same concept applies to safety research. In this report, we have shown that it is possible to estimate the safety benefits of an as yet unknown technologies (e.g. PTC3 in the corridor studies). Technology mapping - using parametric analysis - provides a way to consider quite different approaches to improving safety, e.g. PTC, improved grade crossings, or better training for engineers. This chapter provides an overview of technology mapping that is drawn from prior MT research.

Technology mapping is part of technology scanning, which is an organized effort to identifying new and emerging technologies that are potentially important to an industry, its competitors and its customers. Technology scanning can be approached in terms of technologies, system constraints, or customer requirements. The technological approach is the most straightforward: what are the new technologies and how can we benefit by using them? The benefit of this approach is that certain rapidly evolving technologies will certainly have numerous advocates and are likely to have many benefits for a broad range of applications. The danger of this approach is that the particular technologies that are most well-known may not address the most critical problems; having the best "technology" may not really do much to improve performance.

The supply-driven approach begins with the problems and constraints affecting a system, then seeks technologies to deal with those constraints. This approach is more difficult, since the real problems and constraints are not necessarily well understood. However, this approach may lead to technologies that will be very helpful in dealing with the problems that are identified. This approach will be very good for finding incremental improvements in an established system, because the technological constraints are likely to be well known.

The customer-driven approach is the most abstract, for it considers the problems from the customer's perspective. In transportation systems, the customer is not really concerned with the engineering constraints of the system (e.g. axle load limits or the ability to send information to a train), but with the performance provided by the system - speed, reliability, safety, and cost.

Each of these approaches must take into account the competitive effects of technologies that can affect the demand for a company's core services. A balanced technology scanning program should consider all of these perspectives.

The three approaches to technology scanning require access to three distinctly different kinds of knowledge. The supply-driven approach requires a detailed technical understanding of the limits and capabilities of the existing system and a methodology for predicting how new technologies or technological capabilities would affect system operations and system performance. The technology-driven approach requires awareness of the evolving areas of technology and access to knowledge in specific areas that are believed to be of greatest interest. The customer-driven approach requires an understanding of the way that changes in rail equipment and service affect the transportation choices made by passengers and shippers, taking into account the effects of technological advances on the other transportation options available to these customers.

In general, technological developments can affect all areas of performance. However, any particular development is likely to have a greater effect on different aspects of performance, such as cost, service, safety, capacity, or loss & damage. It is possible to "map" the effects of a particular technology onto potential benefits in each area of performance, a process that can be called "technology mapping". Exhibit 1 shows how technology mapping fits into the broader set of technology scanning activities.

Exhibit 6.1
Technology Scanning Activities

General Search for Technologies

Conduct a very broad review of new and emerging technologies that might be beneficial to the industry

Technology Mapping

Conduct structured investigations into the performance capabilities of the system and identify the points of leverage for technological developments related to cost, reliability, safety, or capacity (for both rail and competing modes)

Rail Systems Modeling

Develop and maintain a set of models that can be used to evaluate technological improvements as they affect specific aspects of rail systems performance

Customer Requirements Analysis

Investigate the requirements of selected groups of customers and identify new ways of doing business; estimate the benefits to customers that will result from improvements in cost, speed, reliability, safety or capacity

Analysis of Specific Technologies

Examine the potential for specific technologies identified as having potential for improving system performance

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The most general activity is the search for new and emerging technologies that might have some relevance to the industry. This search is of necessity somewhat unstructured, as it is not initially clear what technologies will be available or what relevance they will have for the industry. This general search typically would involve people with varied backgrounds and different working contexts, so that the search is truly broad.

The three intermediate activities provide ways to narrow the technology scan from the "general search for technologies" to the "analysis of specific technologies". Technology mapping is the most general of these activities, since it predicts the effects of hypothetical technological changes in order to find the most important technological constraints on rail performance. If our concern is safety, then technology mapping would relate system risks to changes in the effectiveness of grade crossing protection, rail defect detection, broken rail detection, enforcement of train speeds, or positive train separation. Note that this mapping exercise can be carried out with or without specific reference to actual technologies; we can compare the benefits of a 10% reduction in broken rails with the benefits of a 2% reduction in signal overruns without knowing how these improvements are to be obtained.

Rail systems modeling is a more detailed activity. The objective here is to estimate the effects of particular technological improvements on performance. In looking at train control, we have looked at some of the details of train deceleration and information availability. In looking at grade crossing safety, we have used models calibrated to show the effects of train speed, rail and highway traffic volumes, type of protection and other factors on the probability of an accident.

Customer requirements analysis is another detailed activity, but almost completely apart from the engineering analysis. How will a particular group of customers respond to potential changes in price, service, safety or capacity? What constraints, if any, limit the amount of services that will be purchased by these customers? How important are improvements in equipment design as opposed to improvements in trip times and reliability? At some level, the answers to these questions are what will drive successful technological strategies.

At the most detailed level, there is a need for specific research and tests to demonstrate that a particular technology is indeed suited for the industry. However, research and testing at a detailed level is of necessity expensive and highly focused; it is therefore important to take care in deciding which technologies should be advanced to this stage of technology scanning.

In summary, technology scanning involves five distinct activities ranging from the very general to the very specific. An effective technology scanning program will require some means of narrowing the scan, of selecting particular technologies for detailed analysis and testing. Technology mapping, rail systems modeling, and customer requirements analysis are three research activities that can be used to focus the technology scan on the most promising activities.

Technology mapping is a technique that has been used in various industries to link technological improvements to changes in system performance and capabilities. For transportation applications, see the studies conducted by the National Commission on Intermodal Productivity, Industry Canada, and the Port Authority of New York and New Jersey. The ARES benefits analysis was, in many respects, a very detailed study that mapped the effects of train control technology onto system performance in terms of service, cost, and safety. ARES was designed by Burlington Northern and Rockwell International during the 1980s; an extensive benefits analysis was carried out by BN to determine whether or not to invest in ARES. Unlike the current study of train control, which considers only safety improvements, the ARES benefits analysis focused on the business benefits including better meet/pass planning, improved control over line and terminal operations, and the revenue potential of improved customer service. The ARES benefits analysis mapped the effects of an advanced train control system onto changes in line and terminal operations, which were mapped into changes in service capabilities and ultimately into estimates of the changes in demand. It was an excellent example of technology mapping, as it incorporated rail systems analysis, knowledge of technology, and awareness of customer requirements.

6.2 Summary

A formal process for technology mapping can be very helpful in finding ways to use technology to improve system performance. What is needed is a framework for mapping the effects of technological change first into improved performance and then into customer benefits. Such a mapping technique will provide a valuable tool for technology scanning, because it will provide a way to focus future scanning efforts on areas that are likely to have significant payoffs.

Technology mapping has four major elements:

1. Calibrate a Base Case: document the actual performance (cost, service, safety, or capacity) of a representative portion of the rail system

2. Develop High-Level Models of System Performance: develop and calibrate models that can predict performance for particular types of services as a function of technological capabilities (e.g. the risk models described in earlier chapters of this report)

3. Capture the Effects of New Technologies: include inputs within the high-level models that capture the desired/anticipated results of deploying new technologies (e.g. improved crossing protection or advance train control)

4. Engineering Economic Models: given the predicted changes in performance as the technological assumptions vary, calculate the expected costs and benefits (using results from the Customer Requirements Analysis); use sensitivity analysis to show what ranges of capabilities and costs are applicable to various kinds of operations

This whole approach is very similar to the corridor analyses performed as part of this research. We predicted selected risks of rail operations over a typical route at sufficient detail to provide realistic performance data and to capture the major safety issues for different segments of the rail industry. We have used our results to identify "technology opportunities", i.e. the parameters that are likely to be most influential on the competitive or safety characteristics of various segments of the industry.

Chapter 7
Incorporating Human Factors in a Risk Model

7.1 Introduction

When we began our research concerning the differences in risk associated with different levels of train control, we anticipated that we would be much more interested in technology than in human factors. Nevertheless, human factors are embedded within the approach that we have described in this report. The model compares the risks for various levels of train control to the risks of a base case. In the base case, the frequency of accidents is calculated as a function of route, train, and traffic characteristics along with certain key parameters that reflect base line safety. What needs to be emphasized is that the risks calculated for the base case are highly related to assumptions concerning human factors.

7.2 Model Parameters Reflecting Human Factors and Collision Risks

For example, in the analysis of signal overruns or authority violation, the model uses a probability distribution of braking rates that reflects human factors as well as the technology of braking. The lowest braking rate corresponds to a situation where the brakes are not applied at all; the highest braking rate corresponds to full emergency braking; three intermediate braking levels have increasingly limited braking rates. Exhibit 7.1 shows the probabilities used in the model. The probability that the train is in full emergency braking is 0.001 lower for manual than for automatic operation, while the probability of being in a reduced braking state is 0.001 higher. This small change reflects the "potential inadequate use of the brakes by the operator for various reasons, including drug or alcohol impairment in addition to equipment failure". We obtained these probability estimates from a prior study (Kokkins, Snyder, et al., appendix B).

Table 7.1: Braking States Used in the Model Base Case

Braking State	Probability (operator braking)	Probability (automatic braking)	Deceleration Rate (m/s^2)
0	2.01×10^{-8}	2×10^{-8}	Varies with speed
1	2.52×10^{-7}	1×10^{-7}	0.2
2	1.28×10^{-5}	6.9×10^{-7}	0.3
3	1.13×10^{-2}	1×10^{-2}	0.5
4	0.99	0.99	0.7

Source: Lahrech, Feb. 1999, p. 34

Using these braking states, the model uses kinematics to determine when and where the train will stop. Whether or not there is a collision depends upon the location, speed, and response of the nearest trains. Here there is another parameter that includes some consideration of human factors, namely the "Authority Violation Warning Time". This parameter varies from 60 seconds in the base case (ABS territory) to 0 seconds in the most advanced PTC case, in which the warning is sent directly to nearby trains as soon as a violation is made (or is anticipated). This parameter relates primarily to the communications delays inherent in the technologies of the train control system, but it could also be varied to allow more or less time for the dispatcher to relay a message quickly and for the engineer of nearby trains to respond.

The model estimates accident probabilities as the product of two factors: the probability of an accident per unit of exposure and the number of units of exposure. For collisions, the number of train meets is the metric for exposure, and the probability of an accident is based upon a fault tree analysis. Two human factors variables are included in the fault tree. The probability that the engineer is inattentive or incapacitated (2 x 10-7 and 4.5 x 10-14 respectively, based on prior work by Kokkins & Snyder). Either of these factors could be modified to represent different levels of human error.

7.3 Human Factors in Rail Defect Detection

Broken rails resulting from unidentified internal defects can cause train derailments. The number and rate of growth of defects is proportional to the tonnage on the line; where cleaner, harder rail steel is used, the number of defects declines. Most defects do not cause safety problems, because they are found and replaced before they are large enough to cause a broken rail. Most broken rails do not result in accidents becuase the breaks are identified either by signal system or by visual inspection; also, it is quite possible for trains to pass over some broken rails without derailing. In railroad engineering studies, only a small percentage (less than 1%) of broken rails are assumed to result in accidents.

The technology and frequency of inspection determine the likelihood that defects will be found before the rail breaks. To some extent, therefore, the probability of derailments can be reduced by more frequent inspections, which is an element of railroad planning and control systems.

The model assumes that the exposure to broken rails per kilometer per year is a constant r. This parameter can be defined for each track segment. Hence it is possible to adjust r to reflect changes in the frequency or reliability of track inspection as well as to reflect changes in the quality of the rail or traffic levels.

7.4 Summary and Conclusions Concerning Human Factors

This very brief review supports three general conclusions. First, human factors are an important element in railroad safety, as they account for a third of all railroad accidents. Second, research is underway to provide a scientific basis for actions to improve the ability of engineers and dispatchers to make safe decisions. Third; efforts that address human factors can have significant benefits; based upon results achieved in grade crossing safety and in reducing drugs and alcohol abuse, it may be possible to reduce accidents caused by human factors by 10 to 20% (note that these benefits would accrue across most categories of accidents, not just those that are PTS preventable).

It is beyond the scope of this research project to examine the potential safety improvements from any specific human factors program. We will therefore simply stress the importance of human factors, including such things as safety management programs, selection of employees, supervision, and workload. As shown by experience with grade crossing safety and by studies in various aspects of transportation systems, human factors can have a profound effect on transportation safety. Risks can go up or down by 20-50% depending upon how people are selected and trained, how operations are supervised, and how workloads are assigned. A major role of train control systems (broadly defined) must be to anticipate human errors and to prevent them

Chapter 8
Summary, Conclusions and Recommendations

8.1 Summary

The risks of rail line operations can be measured as the expected annual consequences of accidents. Risk is therefore the product of two major factors, the probability of an accident and the expected consequences if there is an accident. Both of these factors, especially the probability of an accident, are affected by the type of train control system that is in place.

The train control system can be considered to include such elements as the training and experience of the work force as well as the hardware and software associated with train dispatching and signal systems. In addition to the adoption of better signal systems or PTC technology, development of better operating rules, better selection and training of train crews and dispatchers, provision for adequate rest, safety-conscious supervision, and enforcement of safety regulations can all be considered options for improving the train control systems and reducing rail transportation risk.

A spreadsheet model has been developed that estimates risk as a function of train control, traffic, and route characteristics for different accident classes and scenarios. Results show that the risk can vary significantly, up to several orders of magnitude, as a function the typical range of variation in these parameters. PTC systems can reduce the risks of certain types of accidents by 90%, or more; they do not eliminate the risks, because PTC systems do not affect the possibility of mechanical failures, e.g. failures in the braking system of the train.

Traffic volume and traffic mix are extremely important factors related to risk. The number of passenger trains is very critical, for accidents involving these trains could have catastrophic consequences. Since risk measures expected consequences, the addition of a pair of passenger trains can double the risk on a medium density freight corridor. Likewise, trains carrying hazardous materials are much riskier than trains without such loads.

Traffic volume is also an important factor, although one that may be difficult to detect in a purely statistical study. The U.S. rail industry encompasses a tremendous range of operating conditions, ranging from low-speed operation over light density lines in dark territory to high-speed, high density operations over very well maintained lines with centralized traffic control. Also, risk exposure tends to increase with the number of trains, whereas line density tends to be measured in terms of gross tonnage. As traffic volumes increase in terms of annual tonnage, railroads tend to operate heavier trains, and they tend to provide better track in order to be able to operate at higher speeds; railroads also are very concerned about safety for the higher density lines. Statistical records of accidents per million train-miles may therefore show little or no relationship between traffic density and risk. However, when all other factors are held constant, risks are predicted to rise more than linearly with traffic volume. For example, the number of train meets, and therefore the risk exposure for collisions, will increase with the square of the number of trains.

The model includes parameters that can be used to illustrate the effects of changes in the human factors of the train control system. For instance, manning levels are known to influence fatigue factors, which in turn have a significant impact on the probability of overrunning a signal or simply being inattentive. The model does not indicate how fatigue relates to the probability of a signal overrun, but it could take such information from other studies and estimate the effects on risk for a particular corridor.

The organizational structure of the railway and its staff capability are also relevant in the realm of risk reduction. For instance, programs that lead to a reduction in drug and alcohol abuse would reduce the probability of inadequate use of the brakes, which could be reflected by changing one of the inputs to the model (cf. Section 3.3.2).

In addition to these human factors, train control system hardware and software do have an influence on risk reduction. PTC failure rates and, more importantly, quality and rapidity of communication are critical for collision avoidance and risk reduction. Also, the way PTC is operated may be of prime importance. If a system is set to intervene only upon authority violation or excessive speed, it might lose some of its risk reduction potential. Indeed, an "intelligent" system that would indicate to the operator the presence of a potential hazardous condition and take appropriate action in case the operator does not respond to the warning would clearly prove more effective in reducing risk. The way the information is conveyed to the operator is in this sense critical, and so is the interaction between the latter and the train control system.

8.2 Other Factors Pertinent to Corridor Risk Reduction

8.2.1 Partial Protection

It is possible to imagine technologies other than PTC that either provide partial protection or that address some of the underlying causes of derailments and collisions. Overspeed protection requires an on-board system with a GPS or other positioning system, a computer that can calculate train trajectories and braking requirements, and data concerning the location of permanent and or temporary slow orders. Such a system could be implemented one train at a time, as it is not linked to dispatching or the signal system. With some added software and a digital link to the dispatcher, this system could be used by individual trains to enforce its own authority limits. This would protect equipped trains from errors made by their own train crews, even it could not protect then from errors made by the crews of opposing, unequipped trains.

8.2.2 Root Causes of Accidents

A different approach would be to address the root causes of accidents. For example, some signal overruns could be prevented by systems that test engineer alertness and stop the train if the engineer does not respond. Another approach would be to provide systems that could detect deterioration in braking effectiveness or improper train handling in time to prevent dangerous braking conditions.

8.2.3 Equipment Design

For passenger trains, design is clearly a key concern. High-speed train sets are designed to withstand large forces and impacts while minimizing danger to passengers. For these train sets, the assumptions concerning casualty and mortality rates could be lower than those used in our analysis.

8.2.4 Comparison with Prior Studies of PTC Safety Benefits

The analytical framework used in this study complements prior studies of the safety benefits of PTC. A probabilistic risk-based analysis gives a better estimate of the potential safety benefits of a system than does an analysis of the costs of recent accidents. The historical approach is limited by the choice of a time period and the set of accidents that actually occurred within that time period. The risk-based approach considers the possibility of catastrophic accidents, which are very rare but may contribute more than half of the total risk. For example, in a study of the East Japan Railroad, the expected number of fatalities was nearly 4 times greater than the average number of fatalities during the preceding 10 years [Horiuchi and Fukuyama [1997].

A parametric, engineering-based approach also provides capabilities for sensitivity analysis that are not available with a more aggregate statistical approach. An analytic model can give a causal basis for calculating the frequency and severity of accidents as the details of traffic, track, and operating conditions change. Statistical analysis can be used to estimate how traffic volume and other factors affect risk, but generally not at the detailed level that is possible with an engineering analysis.

8.2.5 Comparison with Other Modes

While this report has focused on the risks of using railroads, it is important to remember that the risks would likely be much higher if the rail traffic were shifted to other modes. Commuting by train is much safer than commuting by car, and rail is also safer than highway transportation for freight. In 1998, when there were 5,374 fatalities involving large truck crashes in the U.S., the large truck fatality crash rate was 2.8 per 100 million vehicle miles [Schulz, 2000]. In the base case, there are approximately 20 million net tons per year moving across the 1200-mile corridor. If a quarter of this freight shifted to trucks with an average payload of 20 tons, 300 million truck-miles would be added to the highways. At the national average fatality rate, the expected number of fatalities would be about 8 per year, compared to less than 1 per year for the entire "freight-only" case.

8.3 Conclusions

1. **Corridor differences:** the risks addressed by PTC systems can vary by a factor of at least 100 across different mainline corridors. The most important factors are the proportion of passenger trains, the total number of trains per day, train speed, and the amount of double track. A few corridors with heavy freight and passenger traffic moving over a route with substantial single track sections will account for a substantial portion of the total system benefit. In other words, the risks addressed by PTC systems may be concentrated on small portions of the total network.

2. **Causality**: the risks addressed by PTC do not all vary in proportion to train volume:

- Collisions: the risks associated with collisions increase with the square of the number of trains, but are vastly reduced if trains are running on double track.
- Overspeed Derailments: the risks associated with overspeed derailments may in fact be proportional to the number of trains, as these risks depend upon human error, i.e. failing to observe speed limits or slow orders.
- Broken Rail Derailments: risks associated with broken rail derailments do not increase with train volume (and the risks per train will actually decline as the number of trains increases).

3. **Effectiveness of Positive Train Control:** PTC systems should be able to eliminate most of the accidents related to human errors in overrunning signals, running too fast through curves, or failing to obey slow orders. PTC systems can also reduce the consequences of some accidents by slowing down trains before the point of impact or derailment. A 50-70% reduction in risk appears to be achievable, with greater reductions coming as the coverage and the timeliness of the train control increases. However, some of these accidents will still be expected as a result from equipment failure or improper application of the brakes. The potential benefits of PTC will be greater for corridors where there are more passenger trains, more traffic volume, more single track or faster trains.

4. **Broken Rail Detection:** if PTC can be linked to a new system for the detection of broken rails, then some of the accidents related to broken rails can be avoided. Since some of these accidents occur under, or close in front of a train, it will not be possible to prevent all of these accidents.

5. **Grade Crossing Accidents:** if PTC can be linked to grade crossing protection devices, it may be possible to prevent a small portion of grade crossing accidents. A small reduction in grade crossing accidents - especially if these are the accidents involving buses and heavy trucks - may be as important as all of the other potential safety benefits of PTC.

6. **Passenger Trains**: the risk to a passenger train is an order of magnitude greater than the risk to a freight train because of the higher potential for loss of life. Therefore, adding a few passenger trains to a freight corridor can easily increase the total risk by a factor of 2 or much more. On the highest risk corridors, most of the risk may in fact relate to passenger operations.

8.4 Recommendations

1. **Enhanced Control for Priority Trains.** Given the much higher level of risks associated with certain types of trains (e.g. passenger or haz mat trains), control systems that provide some benefits for individual high-risk trains should be pursued.

2. **Accidents Involving Hazardous Materials.** Hazmat accidents could conceivably be much more catastrophic even than a high-speed collision of two passenger trains. The historical accident costs cited in this study do include some consequences involving hazardous materials as part of the average consequences of accidents: some of the accidents in the data base included evacuations and other costs associated with hazmat spills, but there were no catastrophic hazmat incidents. The results in this study therefore reflect the trains, hazmat traffic, and hazmat consequences of the PPAs identified by the RSAC process.

3. **Use of Broader Risk Measures in Evaluating PTC Systems.** It would be informative to use both historical and risk-based methods to investigate the potential of PTC systems to reduce risk, taking into account projections for the growth of passenger and freight traffic over major rail corridors.

4. **Enhance the Risk Assessment Methodology.** This research has demonstrated the effectiveness of a methodology for relating incremental changes in train control to incremental changes in risk. There are three types of improvements to the methodology that could be pursued:

- Examine additional types of train control systems
- Enhance the capabilities and ease of use of the model
- Develop better models for the underlying probabilities and expected consequences

5. **Apply the Model in Additional Corridor Studies.** Apply the model to an actual corridor, in cooperation with the railroads and public agencies involved. This could be undertaken at various levels of detail, depending upon the types of accidents that would be examined, the desired precision of the results, and the range of train control systems that would be analyzed. The model could also be used for a more aggregate analysis of a set of corridors, e.g. corridors deemed to be most suitable for PTC.

6. **Use the Model for Technology Mapping.** Technology mapping is a process that relates technological capabilities to the performance of a system, where performance could be cost, capacity, safety, or service quality. Technology mapping requires a model that relates the key technological parameters to the key performance indices. Given the model, it is then possible to run sensitivity analyses to determine which technological parameters have the greatest influence on performance under different sets of conditions. Since the model does not require the technologies to exist, it is possible to use the model to explore which technological options have the most promise.

The risk models developed in this study could be used as the core of a technology mapping exercise related to the risks of railroad line operations. There are many studies underway to look at the effects of specific technologies on rail risk. The extensive work on Positive Train Control, for instance, has produced various options for achieving the well-defined goals of PTC. However, PTC is but one way to reduce the risks of rail line operations that could be examined from a technology mapping perspective.

7. **Human Factors and Rail Risk.** Human factors are clearly an important element in transportation risk. While the models developed have been designed with inputs that can be used to represent human factors, they rely on other studies to determine how to change these inputs. Additional research would help to integrate human factors more effectively into this modeling framework.

Some specific opportunities include the following:

- Work with experts in the human-machine interface of locomotive cabs to identify the parameters that most affect the performance of the train crew and to estimate various values for these parameters to reflect the range of conditions that might be encountered in typical train operations.
- Use recent studies of the effects of fatigue on transportation operating employees to develop a way to incorporate the effects of fatigue and of strategies for dealing with fatigue into the model. For example, some U.S. railroads allow engineers to take a nap while on duty. The relationship between hours of service, fatigue, and safety is a concern in the air and trucking industries as well as in the rail industry.

8. **PTC and Grade Crossings.** The preliminary analysis in this study has suggested that PTC, in combination with ITS for highway vehicles, could achieve modest improvements in grade crossing safety that could have a greater reduction in rail transportation risk than can be gained from the ability of PTC to eliminate nearly all train collisions related to authority violation. We therefore

recommend a more in-depth consideration of the relationship between different elements of PTC and ITS and the potential for reducing grade crossing risks.

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Appendix A

Collision and Derailment Risks on the Hypothetical Corridor

1. Corridor Description

As described in the report, the 1200-mile hypothetical corridor is loosely modeled on the corridor from New York City to Chicago. There are heavy commuter operations at each end of the corridor, Amtrak operations along the entire length of the corridor, and heavy freight operations along most, but not all of the corridor. The traffic volume is 23.15 MTK (Million Train Kilometers) for the whole corridor, an average of 53 trains per day. The corridor includes 50 segments, which are described in Exhibit 1. (Note: all exhibits are at the end of the appendix)

Block Length

Block length is determined by the number of tracks and the type of segment. We set the block length to 1000m for segments with commuter rail, 3000m for single-track segments and 2000m for multiple track segments.

Terrain Definitions

Four categories of terrain are used in the model, as defined in Exhibit 2. As the terrain gets more difficult, an increasing percentage of tracks are in curves, on bridges or elevated structures, and in tunnels or cuts. These characteristics affect the amount of track maintenance required as well as the expected consequences of an accident.

Train Characteristics

For each type of train, four categories of data are needed: maximum speed restriction, trains per day per direction, daily operating hours and trainload. Speed and trainload are related to braking distance and estimated consequences of an accident, trains per day and operating hours relate to the number of train meets that will be observed. Maximum Train Speed is divided into 4 Categories, as shown in Exhibit 3.

Intercity passenger train characteristics are based upon Amtrak's timetable for the Empire Corridor. The number of passenger trains ranges from 14 to 20 trains/day/direction in urban areas, and from 4 to 8 trains/day/direction in rural areas. We assume that the trainload is 200 passengers in urban areas, 150 passengers in suburban areas, and 100 passengers in rural areas. The operating hours are also based on the real timetable. Depending on the segment, passenger trains operate 9 to 22 hours per day.

For commuter trains, we assume there are 60 to 100 trains/day/direction in urban areas, and 10 to 40 trains/day/direction in suburban areas near major cities. There are no commuter trains in rural areas or small towns. The trainload is 200 passengers in urban areas, and 150 passengers in suburban areas. Commuter trains are assumed to operate 3 hours in the morning and 3 hours in the evening, for a total of 6 hours/day.

For freight trains, we used typical train consists based on prior work by Chapman and Martland (1997) to relate annual MGT (Million Gross Tons) to trains per day per direction. We used a mix of coal, grain, general merchandise, automobile, and intermodal trains, which is shown in Exhibit 4. We assume that annual MGT is 0 to 5 in urban areas, 10 to 30 in suburban areas, and 40 to 75 in rural areas. The operating hours varied from 4 to 14 hours per day depending upon MGT.

Permanent Speed Restriction

Permanent speed restrictions are required to prevent over speed derailments on curves. The sharper the curve, the slower the maximum safe speed. The relationship between number of permanent speed restriction and curve condition is shown in Exhibit 5.

The model allows 3 levels of speed restriction, which were applied in proportion to curvature. The restricted speed for PSR1, PSR2, PSR3 is 40, 30, 20 km/hour, respectively. The formulas for calculating the number of permanent speed restrictions are:

Number of Permanent Speed Restriction
= (Permanent Speed Restriction/Mile) * (Segment Length)
Number of Permanent Speed Restriction 1
= (Number of Permanent Speed Restriction) * (Percent of 2 degree curves)
Number of Permanent Speed Restriction 2
= (Number of Permanent Speed Restriction) * (Percent of 4 degree curves)
Number of Permanent Speed Restriction 3
= (Number of Permanent Speed Restriction) * (Percent of 6+8 degree curves)

Temporary Slow Orders

Temporary slow orders are imposed when track conditions cannot support the normal maximum speed. For mainline track, slow orders are commonly imposed after certain types of major maintenance and renewal activities. We assume that temporary slow orders are imposed for 10 days after 25% of work windows. The number of work windows/year was estimated using HALTRACK, a railroad track maintenance model developed for analyzing the effects of track and traffic characteristics on track investment and maintenance costs. The results are shown in Exhibit 6. For a detailed discussion of this methodology, see ROMPS (1993).

The formula for calculating the number of slow orders is:

Number of Slow Orders
= (Work Windows / year / 100 miles) * (Segment length / 100) * 25% * 10 / 365

We have three types of slow orders with different maximum speed restriction. The total number of slow orders is distributed to each type by terrain conditions. The method is similar to that in permanent speed restriction. The restricted speed for TSO1, TSO2. TSO3 is 25. 20, 15 km/hour, respectively.

Route Description

The route starts with 5 miles of triple track with 20 passenger trains and 100 commuter trains per day operating over flat and rolling terrain. Over the next 60 miles (segments 2-9), the frequency of passenger and commuter trains declines to 8 and 10 respectively. while the number of daily freight trains increases to 8.

Continuing west for 215 miles (segments 10-17) on what is now a single-track route, there are no more commuter trains, while the freight traffic increases to 50 MGT (million gross tons per mile per year), with 20 heavy freight trains per day. In the middle of the route (segments 18-20), there is a 170-mile stretch of double track with 8 Amtrak and nearly 30 freight trains per day and 75 MGT annually. Throughout this long middle stretch, there are segments of difficult and very difficult terrain interspersed among longer sections of flat or rolling terrain. In the more difficult terrain, more track work is needed, there are more speed-restricted curves, and the potential consequences of accidents are increased.

Segments 21-27 offer a 280-mile rural stretch of single track with 50 MGT of freight traffic and 4 daily Amtrak trains. For this stretch, the track is older, so that maintenance activity is greater. There are a couple of more stretches of double track: segments 28, 29, 30 and 35, representing the routes through towns, and segment 36, a 100-mile stretch with 60 MGT and 10 Amtrak trains. As the route approaches Chicago end it becomes multiple track, the commuter traffic starts to build up and the freight traffic drops to 30 MGT (segments 37-50).

2. Base Case Analysis

Corridor Results

Exhibit 7 shows the base case results with details of collisions and derailments for the whole corridor. The number of accidents per MTK (Million Train Kilometers) is 0.090 for the whole corridor under ABS. The accident rate drops to 0.073, 0.060 and 0.041 under PTC1, PTC2 and PTC3. The risk is $1.09 per train per kilometer under ABS and drops to $0.55, $0.35 and $0.18 per train per kilometer for the PTC systems. These results show a clear reduction in both accident frequency and risk.

The number of collisions/MTK did not vary much from ABS to PTC systems, but the risk decreased substantially as PTC was able to reduce train speeds at impact. Most of the derailments were prevented by PTC3; the risk of derailment in PTC3 is much lower than that in other train control systems as well.

For each train control system. Exhibit 8 shows the risk per accident for collisions. derailments and total accidents. It appears that PTC can prevent "expensive" accidents especially the "expensive" collisions. The average collision cost is $22.2 million/accident in ABS. while it is $9.5. $5.3 and $3.9 million/accident in PTC1. PTC2 and PTC3. respectively. The average derailment cost did not varied greatly. It is $6.2 to $6.3 million/accident in ABS, PTC1, PTC2. and it is $5.8 million/accident inPTC3.

Exhibit 9 shows the more detailed summary results for the corridor. In the first section of Exhibit 9-A. the first 6 rows show the number of accidents for each accident scenario (head-on collision, rear-end collision, maintenance of way collision, permanent speed restriction derailment, temporary slow order derailment, and derailment due to track fault). The following two rows show the subtotal of collisions and derailments. then the last row shows total modeled accidents. The second section shows the percentage of all accidents for each scenario. The third section shows the accident and risk reduction rate for PTC systems compared to the ABS base case. Exhibit 9-B shows the annual risk/MTK. percentage of all consequence and reduction rate for each accident scenario and total risk.

With the ABS system. derailment is the main type of accident. comprising 64% of total accidents and 33% of total consequences; collisions are about 36% of the total accidents and 67% of the consequences. Under PTC3. collision is the main type of accident. accounting for 67% of total accidents and 57% of the consequences.

Although PTC3 only prevents 17% of the ABS collisions. it reduces the risk by 86%. The reductions in accident frequency are 20%, 33% and 55% for PTC1. PTC2. PTC3. respectively. The risk reduction rates for the three levels of PTC system are 49%. 68% and 83%. All of the PTC systems are effective in preventing accident and reducing risks.

Segment Results

Exhibits 10-16 graph accident frequency and risk. by segment. for each type of accident. In each exhibit. part A shows the expected number of accidents per MTK. while part B shows the risk. which is measured as the expected consequences per MTK. Both measures vary significantly along the corridor. Please note that the charts are on different scales in order to show the changes from segment to segment. As already noted. track fault derailments and head-on collisions are the major accidents, comprising about 93% of the total accidents in the ABS system. Derailments due to temporary slow orders and MOW collisions are of secondary importance. The accidents and risk due to permanent speed restriction and rear-end collision can almost be omitted compared with other types of accidents.

Exhibit 17 shows the same information in tabular form for each of the 50 segments. Exhibit 17-A shows summary statistics for all modeled accidents. Exhibits 17-B to 17-G give results for each accident scenario. In each sheet of Exhibit 17. the first part gives the number of accidents for ABS and the PTC systems. The second part shows PTC effectiveness, which is shown as the accident reduction rate (number of reduced accidents over number of ABS accidents). The third part shows the risk for each train control system, and the fourth part shows PTC effectiveness of risk reduction. The last two parts show accident frequency and risk/MTK.

Exhibit 18 summarizes accidents and risk for major sections of the corridor. The first four segments are located in inner city or suburban areas with multiple tracks. Most of the trains operated in these 25 miles are passenger trains and commuter trains, as there are 60 to 100 commuter trains and 14 to 20 intercity passenger trains operated per day per direction. Few freight trains run over these segments. The accident frequency and risk/MTK are higher than average since the train volume is much higher than the average of 26.4 trains/day/direction for the corridor). The risk is low because there are fewer collisions in multi-track segments and because the consequences are lower if the terrain is either flat or rolling and train speed is moderate. The accident reduction rate is from 10% to 50% for different PTC systems. Since many commuter trains operate in these 25 miles, more injuries and fatalities would happen for the same number of accidents compared with freight corridor, so that the risk was high as well.

The accident frequency is higher in segments 5 to 9, which have single track. These 40 miles are mainly for passenger and commuter trains. The accident frequency and risk/MTK are both much higher than average, especially for the ABS system. The consequences are higher because most of these segments have higher speed and some of them are in rolling or difficult terrain condition.

From segment 19 to segment 36, freight traffic is heavy, while passenger traffic drops to 4/day/direction. Both the accident frequency and risk/MTK are below average for the corridor. The effectiveness of PTC3 is the same as that in segments 5 to 9, but PTC1 and PTC2 are more effective in these freight dominated segments. There are some segments with significantly higher probability of accidents. Segment 30 is a double track route through difficult terrain, resulting in more track fault derailments and collisions. However, with few passenger trains, the consequences of derailments are not very costly, so that the risk stays at $1 /mile. Segment 36 is a high-speed segment, where single track with rolling terrain increases the expected number of derailments due to slow orders.

Starting from segment 37, commuter trains appear again. From segment 37 to segment 50, more and more commuter trains were operated, as the route gets closer to the city. There are also more passenger trains, while freight trains begin to decrease. The number of accidents and risk stay at an average level through this route. Segments 40 to 43 have single track over flat and rolling terrain, with passenger trains increasing to nearly half the total trains. The train frequency is 10 to 20 trains per day in each direction. With high speed, high volume traffic on a single-track route, both accident frequency and risks increase.

Result Compared with Other Research or Statistics

Exhibit 19 compares accident frequency for the hypothetical corridor to the results presented in a study conducted for Railroad Safety Advisory Committee (RSAC). The results are similar for the two studies. In our corridor analysis, there are 0.090 accidents per million-train kilometers for the hypothetical corridor under ABS. The RSAC study identified 665 PPA (PTC Preventable Accidents) under ABS for the years 1988 to 1995, which accounted for 3% of the 21775 non-yard accidents **[1]**. During this period there were 3.77 accidents per million train-miles **[2]**. Then there are 0.072 PPA per million-train kilometers (3% * 3.77 /1.609).

There are some difference between the scenarios in our model and the historical analysis in the RSAC report, which may explain the disparity of results. Accidents considered in our model are only part of the PPAs considered in the RSAC report. We include collisions and derailments in the model, which are about 75% of the total PPA. The other 25% of the PPA reflect a diverse set of causes, and the accidents are not included in our model. For example, we do not consider the accidents caused by wind or rock slides in our "Derail" scenario, nor do we consider collisions with obstructions other than trains or maintenance equipment in our "Collision" scenario.

Risk in our model is measured as the expected consequence of accidents, summed over all the accident categories that are affected by train control systems. In 1998, loss and damage, injuries and insurance was $1,080 million for class I railroads, which operated 119,813 route miles and 759.92 MTK (Million Train Kilometers) **[2]**. Our 1200-mile corridor with 23.15 MTK train density, therefore has 1% of the class I railroad route-miles and 3% of train density, and it might be expected to have 1%~3% of the risks, i.e. $10.80~$32.40 million. Our result of $25.14 million is in the high end of the range, which is not surprising, since our corridor is a composite high volume corridor with many passenger trains and commuter trains.

We can also compare our results to Amtrak's experience. Exhibit 20 shows that A.D.Little (1994) documented the average consequences of Amtrak accidents for the period 1986 to mid 1993 **[3]**. During this period, the casualty frequency per Million Train-km was 0.14 fatalities and 3.965 injuries. This indicates a risk of $0.775 million/MTK. (weighting fatalities by $2,700,000 and injuries by $100,000). The modeled risk is $1.086 million/MTK for the hypothetical corridor, where passenger train speeds (60~120 km/h) and freight train speeds (30~60 km/h) may be higher than average, which would increase the risks.

The accidents involving passenger trains cost much more than those involving only freight trains. **Exhibit 21** estimates the risks for PPA. We assume that a fatality costs $2.7 million, one passenger injury costs $0.055 million, one employee injury costs $0.1 million, and each evacuation costs $500. The total cost per accident is the sum of fatality and injury cost, as well as track and equipment damages. (If the hazardous materials cleanup, evacuations, loss of lading, wreck clearing and delays were considered, the result would be higher.) The result shows that the cost of PPAs involved with passenger trains varied from $1.1 to $3.5 million per accident, and the cost of PPAs involved with freight trains is varied from $0.5 to $0.6 million per accident. Passenger train PPA costs about $1.8 million more than freight train PPA.

For the hypothetical corridor, the risk per accident for PTC systems ranges from $4.5 million to $7.6 million, which is in the range of $10.266 to $8.6 million per accident indicated in the RSAC report. The overall risk shown in our model results is higher than the average level shown in Exhibit 21, because the hypothetical corridor has a large share of passenger trains and commuter trains.

3. Sensitivity Analyses

The results for a single corridor are not enough to predict the most effective way of using PTC systems. We therefore conducted sensitivity analyses for traffic density, train speed, train composition and number of tracks. We believed these to be the most important determinants of corridor risk.

Train Composition

Train composition is clearly a key risk factor for two reasons: Accidents involving passenger trains have much higher expected consequences, and passenger traffic is growing on many routes. We examined two scenarios related to passenger traffic. In the first scenario, we eliminated all of the passenger trains in order to get a freight-only transportation corridor. In the other scenario, we doubled the passenger traffic and to get a "heavy load" passenger transportation corridor.

Exhibit 22 shows the results as accidents and risk for the base case corridor, freight-only corridor and double passenger traffic corridor. Part A focuses on the accident frequency along the route, which is described as the expected number of accidents per million train kilometers in the section "E (# accidents/MTK)". The next section "Percentage of Base Case" compares the results of the new scenarios to the base case. For example, for the freight-only corridor, there are 0.009 accidents/MTK under ABS; correspondingly, for the base case, there are 0.041 accidents/MTK under ABS; the ratio therefore is 0.009/0.041 = 22%. If the ratio in this section is less than 100%, it means the corridor scenario has fewer accidents than the Base Case. The next section "Reduction" shows the PTC effectiveness as reduction rate of PTC systems to ABS. For example, for the freight-only corridor, there are 0.067 accidents under ABS and 0.050 under PTC1; the reduction rate therefore is (0.067-0.050)/0.067 = 26%. The larger the reduction, the more effective the train control system. The last section "MTK" gives the millions train-km per year for this scenario. Finally, the graph on the right side gives a clearer view of the results in the first section.

Part B shows the number of accidents for the whole corridor. It gives another measure to estimate the safety and PTC effectiveness. The number in the section "E (# accidents)" can be obtained from the first and last section in part A. (e.g. For the Base Case, the number of accidents in the whole corridor is 0.090 *23.15 = 2.091) The result shows that PTC systems are more effective in reducing accident frequency in freight-only corridors, because the reduction rate for the freight-only corridor (26% to 87%) is higher than for the base case (20% to 55%) or the double passenger corridor (18% to 44%), especially under PTC 3.

Part C shows the risk/MTK, which is described as the economic consequences of risk per million train kilometers in the section "E (Consequences $/MTK)". Similar to part A, "Percentage of Base Case" gives the ratio of risk frequency of new scenarios to the base case under the same train control system. If the ratio in this section is less than 100%, it means that the corridor scenario has lower risk than the Base Case. The next section "Reduction" shows the PTC effectiveness as reduction rate of PTC systems to ABS. The larger the reduction rate, the more effective the train control system.

Part D shows the risk as economic consequences for the whole corridor. The numbers in the section "E (Consequences $)" can be obtained from the first and last section in part C. The risk reduction rate shows that PTC1 and PTC2 systems are more effective for passenger corridors (52% to 74%) than for the base case (49% to 68%) and freight corridors.(36% to 54%). PTC3 system is most effective for freight corridors in terms of both accident and risk.

Traffic Density

Traffic density is another import factor to consider in estimating corridor risk. Some risks increase with traffic density, and traffic density varies greatly across the network. We therefore varied traffic density to see its influence on accident frequency and risk. Since the base case corridor is already a heavy density corridor, we looked at lower as well as higher traffic densities. In each case, we made the same percentage change in commuter, intercity, passenger, and freight trains.

Part A in Exhibit 13 shows the number of accidents/MTK is increasing when traffic density is decreasing. Under the ABS system, accident frequency rises from 98% to 139% of the base case as when the traffic drops from 125% to 50% of the base case. However, when the traffic density drops to 25% of the base case, the accident frequency jumps to 244% of the base case. This means that the risk is increasing rapidly when the traffic density is low. From the "Percentage" section, we see that under PTC1 and PTC2 systems, the accident frequency is also sensitive to traffic density; while under PTC3 system, the traffic density does not influence the accident frequency as much as in other train control systems. According to the "Reduction" section, the effectiveness of PTC1 and PTC2 do not change much with the traffic density; the effectiveness of PTC3 increased smoothly when traffic density decreases.

Part B shows that the number of accidents for the whole corridor increases if more trains are operated on the same corridor. The "Percentage" section indicates the number of total accidents is sensitive to traffic density under PTC3 system, which changes from 37% to 138% of base case when the traffic density increases from 25% to 125% of base case.

Part C shows the risk/MTK. In the "Percentage" section, we see the best traffic density range is different for ABS and PTC systems. The lowest risk/MTK occurred when traffic density is 75% of base case under ABS, and when traffic density is 125% under PTC systems. The "Reduction" section indicates increasing PTC effectiveness when traffic density is also increasing.

In Part D, the risk of the whole corridor is increasing when the traffic density is increasing. Among different train control systems, the risk under ABS is most sensitive to traffic density and the risk under PTC2 is least sensitive.

Train Speed

As speed increases, the capacity of the corridor increase, without dramatic or costly infrastructure improvements. However, as speed increases, both accident frequency and accident consequences increase. We therefore increased or decreased the maximum speed allowed for each segment by 10km/h.

Exhibit 24 shows that PTC systems will enhance the operation of higher speed rail corridor operations. In part A, the results shows when the speed is decreased 10km/hr, the number of accidents drops slightly to 92% of base under ABS. But when the speed is increased by 10 km/h, the number of accidents jumps to140% of the base case. Similar results are shown for the PTC systems.

Because the MTK does not change when train speed is changed, the results in sections "Percentage" and "Reduction" sections are same for part A and part B. According to the "Reduction" section the effectiveness of PTC systems increases when the trains run faster. Part C and D show the risk/MTK and risk for the whole corridor increase when the maximum train speed is increasing.

Track

From the base case analysis, we know that the number of tracks is important for expected collision frequency. One of the major types of accident—head on collisions—is much more likely on single-track segments. Derailments due to track fault are also influenced by the number of tracks, since there would be more track defects in multi-track routes. Therefore, we considered two options to the base case: to a double track corridor and a corridor where all rural area are operated over single track.

Part A of Exhibit 25 shows the accidents frequency decreased to 92% of the base case for double-track scenario, but increased to 117% of the base case for rural single-track scenario under ABS. The accidents frequency is more sensitive to the number of tracks under the PTC systems.

The "Reduction" section in Part B shows the effectiveness of PTC3 (46% for single track, 55% for base case and 67% for double track) is more sensitive than PTC1 (17%, 20% and 25%) and PTC2 (29%, 33% and 39%). PTC systems are more effective for single track (67% under PTC3) than double track (46% under PTC3) since they can prevent many head-on collision and collisions cost more than derailments.

Part C and D show that risk is more sensitive to the number of tracks. Compared to accident frequency changes in part A (92% and 117%) under ABS, the risk changes are much larger in part C (57% and 149%). PTC systems are more effective for double track according to risk measurement.

Summary of the Sensitivity Analysis

The model was used to estimate the sensitivity of accident frequency and risk to corridor characteristics. Exhibit 26 shows lower traffic density, higher speed, more single-track or more passenger trains increase the accident frequency per 1000 train-km. The accident frequency is more sensitive to the changes of traffic density and train speed than to the other two factors. When the maximum train speed is increased by 10km/hr, the effect on accident frequency is greater than for doubling the passenger traffic density or assuming single-track for the rural areas. If the traffic density were lower than 50% of the base case traffic, the accident frequency would increase greatly. The accident frequency is more sensitive to train mix and train speed under PTC systems, while it is more sensitive to traffic density and the number of tracks under ABS systems.

Exhibit 27 shows the results of corridor risk for all of the sensitivity analyses. Train mix is the most important factor to influence the risk. Operating without any passenger trains has the lowest risks, while doubling the passenger trains increases risks dramatically. Higher speed, higher traffic density more single track would increase the annual corridor risk as well. The corridor risk is more sensitive to traffic density and the number of tracks under ABS systems than under PTC systems.

Exhibit 28 shows the effectiveness of PTC systems defined as annual risk reduction rate compared with ABS. The results indicate that PTC systems are more effective in corridors with higher traffic density, higher speed, and more single-track route. PTC3's effectiveness is stable and it is in the range of 74% to 90% for all scenarios.

In sum, PTC system can prevent collisions and derailments effectively to reduce the risks of rail transportation. Passenger corridors, high speed and high traffic density corridors benefit greatly from PTC systems. For freight corridors, the risk is much lower than for intercity passenger corridors. Although PTC systems can be effective in reducing freight risks, the absolute reduction in risk for freight routes will be much lower than the reductions that can be obtained on passenger routes.

List of Exhibits for Appendix A

Exhibit 1 Hypothetical Corridor Segments Description

					Passenger Trains				Commuter Trains				Freight Trains						
Segment ID	# of Tracks	Segment Length (km)	Block Length (m)	Pr(2 trains are routed on same track)	Passenger Max Speed	train/day /dir	hours op per day	train load	Commuter Max Speed	train/day /dir	hours op. per day	train load	Freight Max Speed	train/day /dir	hours op per day	train load	Terrain Condition	Land Use	Max Speed Restriction Category
1	3	8	1000	0.02	80	20	18	200	60	100	6	200	40	0	4	0	flat	Inner City	3
2	2	8	1000	0.02	80	16	18	200	60	100	6	200	40	2	4	2	rolling	Suburban	3
3	2	16	1000	0.02	100	16	16	200	70	60	6	200	50	4	4	5	flat	Outer Suburban	2
4	2	8	1000	0.02	100	14	16	200	70	60	6	200	50	4	4	5	rolling	Outer Suburban	2
5	1	16	3000	1	120	14	16	150	80	20	6	150	60	5.3	6	10	flat	Rural	1
6	1	8	3000	1	120	14	18	150	80	20	6	150	60	5.3	6	10	rolling	Rural	1
7	1	16	3000	1	120	14	18	150	80	10	6	150	60	9.3	6	20	flat	Rural	1
8	1	8	3000	1	120	14	18	150	80	10	6	150	60	9.3	6	20	rolling	City	1
9	1	16	3000	1	120	8	18	150	80	10	6	150	60	14	8	30	flat	City	1
10	1	8	3000	1	120	8	18	100	80	0	6	0	60	14	8	30	rolling	Rural	1
11	1	8	3000	1	100	8	18	100	70	0	6	0	50	14	8	30	difficult	Rural	2
12	1	32	3000	1	120	6	20	100	80	0	6	0	60	17	10	40	flat	Rural	1
13	1	16	3000	1	120	6	20	100	80	0	6	0	60	17	10	40	rolling	Rural	1
14	1	8	3000	1	100	4	20	100	70	0	6	0	50	17	10	40	difficult	Rural	2
15	1	161	3000	1	120	4	21	100	80	0	6	0	60	20.4	12	50	flat	Rural	1
16	1	80	3000	1	120	4	21	100	80	0	6	0	60	20.4	12	50	rolling	Rural	1
17	1	32	3000	1	100	8	21	100	70	0	6	0	50	20.4	12	50	difficult	Rural	2
18	2	161	2000	0.02	120	8	22	100	80	0	6	0	60	29.6	14	75	flat	Rural	1
19	2	80	2000	0.02	120	8	22	100	80	0	6	0	60	29.6	14	75	rolling	Rural	1
20	2	32	2000	0.02	100	4	22	100	70	0	6	0	50	29.6	14	75	difficult	Rural	2
21	1	161	3000	1	100	4	15	100	70	0	6	0	50	20.4	12	50	flat	Rural	2
22	1	80	3000	1	100	4	15	100	70	0	6	0	50	20.4	12	50	rolling	Rural	2
23	1	16	3000	1	80	4	15	100	60	0	6	0	40	20.4	12	50	difficult	Rural	3
24	1	80	3000	1	100	4	12	100	70	0	6	0	50	20.4	12	50	flat	Rural	2
25	1	64	3000	1	100	4	12	100	70	0	6	0	50	20.4	12	50	rolling	Rural	2
26	1	32	3000	1	80	4	12	100	60	0	6	0	40	20.4	12	50	difficult	Rural	3
27	1	16	3000	1	60	4	11	100	50	0	6	0	30	20.4	12	50	very difficult	Rural	4
28	2	32	2000	0.02	100	4	11	100	70	0	6	0	50	20.4	12	50	flat	Town	2
29	2	16	2000	0.02	100	4	11	100	70	0	6	0	50	20.4	12	50	rolling	Town	2
30	2	8	2000	0.02	80	6	14	100	60	0	6	0	40	20.4	12	50	difficult	Town	3
31	1	80	3000	1	100	6	14	100	70	0	6	0	50	24.3	12	60	flat	Rural	2
32	1	32	3000	1	100	6	14	100	70	0	6	0	50	24.3	12	60	rolling	Rural	2
33	1	16	3000	1	80.	6	13	100	60	0	6	0	40	24.3	12	60	difficult	Rural	3
34	2	32	2000	0.02	100	8	13	100	70	0	6	0	50	24.3	12	60	flat	Town	2
35	2	161	2000	0.02	100	8	13	100	70	0	6	0	50	24.3	12	60	flat	Rural	2
36	1	161	3000	1	100	10	16	100	70	0	6	0	50	24.3	12	60	rolling	Rural	2
37	2	32	2000	0.02	100	10	16	150	70	8	6	150	50	24.3	12	60	flat	City	2
38	2	32	2000	0.02	100	10	16	150	70	8	6	150	50	24.3	12	60	flat	City	2
39	2	32	2000	0.02	100	10	21	150	70	12	6	150	50	20.4	12	50	flat	Rural	2
40	1	32	3000	1	100	10	21	150	70	12	6	150	50	20.4	12	50	flat	Rural	2
41	1	16	3000	1	100	16	21	150	70	12	6	150	50	20.4	12	50	rolling	Rural	2
42	1	8	3000	1	100	16	22	150	70	16	6	150	50	20.4	12	50	flat	Suburban	2
43	1	8	3000	1	100	16	22	150	70	16	6	150	50	20.4	12	50	rolling	Suburban	2
44	2	8	1000	0.02	100	16	18	150	70	24	6	150	50	17	10	40	flat	Suburban	2
45	2	8	1000	0.02	100	16	18	150	70	30	6	150	50	17	10	40	flat	Suburban	2
46	2	8	1000	0.02	100	16	18	150	70	30	6	150	50	14	8	30	flat	Urban	2
47	2	8	1000	0.02	100	16	19	150	70	36	6	150	50	14	8	30	flat	Urban	2
48	2	8	1000	0.02	80	16	19	150	60	36	6	150	40	14	8	30	rolling	Urban	3
49	2	8	1000	0.02	80	16	19	150	60	40	6	150	40	14	8	30	flat	Urban	3
50	2	8	1000	0.02	80	16	9	150	60	40	6	150	40	14	8	30	flat	Urban	3
Sum		1930.8		28.44															
Average	1.46	38.616	2340	0.5688	100.4	9.68	17.02	127	70.2	14.2	6	73	50.2	17.732	10.16	42.34			

Exhibit 2 Terrain Definitions

	Flat	Rolling	Difficult	Very Difficult
% Curves	10%	20%	35%	50%
% Elevated	2%	5%	10%	20%
% Tunnel/cut	0%	5%	10%	40%

Exhibit 3 Categories of Train Speed (Unit: km/hour)

Category	Passenger	Commuter	Freight
1	120	80	60
2	100	70	50
3	80	60	40
4	60	50	30

Exhibit 4 Traffic Mix and Gross Tonnage

MGT	5	10	20	30	40	50	60	70	80	90	100
Trains/day	4	5.3	9.3	14	17	20.4	24.3	28	31.3	29.2	30.7
Coal	0%	0%	5%	3%	15%	27%	31%	36%	40%	43%	46%
Grain	0%	0%	0%	3%	15%	12%	10%	9%	12%	14%	13%
Intermodal	0%	0%	27%	36%	29%	24%	28%	27%	24%	22%	20%
Gen. Mer.	100%	100%	54%	54%	29%	24%	21%	20%	16%	13%	15%
Autos	0%	0%	14%	5%	12%	12%	10%	9%	8%	7%	7%

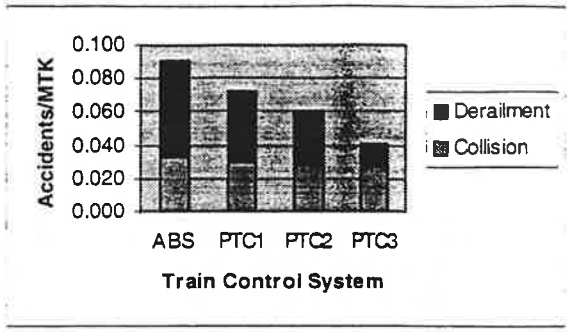
Exhibit 5 Number of Permanent Speed Restriction and Terrain Condition

Terrain Condition		Flat	Rolling	Difficult	Very Difficult
Permanent Speed Restriction/Mile	Rural	0.01	0.02	0.03	0.05
	Urban	0.05	0.05	0.05	0.05
Average Curve Length (miles)		0.2	0.4	0.6	0.8
2 degree curves		100%	70%	50%	30%
4 degree curves		0	20%	30%	20%
6 degree curves		0	10%	15%	30%
8 degree curves		0	0	5%	20%

Exhibit 6 Work Windows and MGT

MGT	10	20	30	40	50	60	70	75
Work Windows/year/100 miles	40	55	67	88	98	114	127	134

Exhibit 7 Results Summary of the Base Case



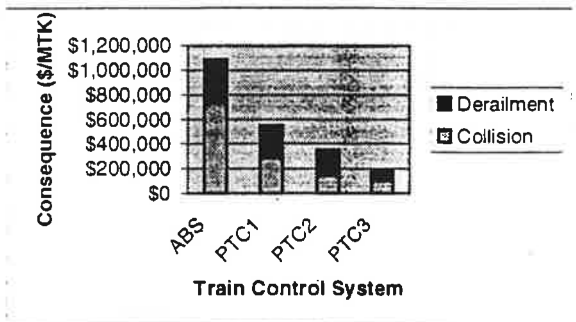


Exhibit 8 Average Accident Cost for the Base Case

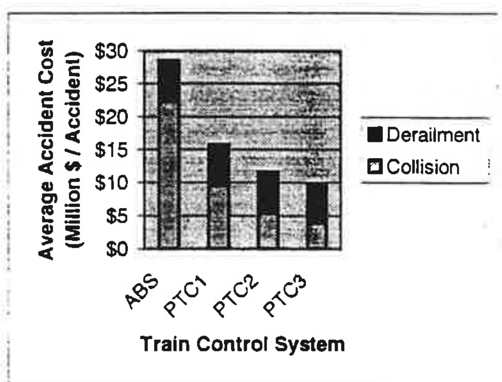


Exhibit 9 Detailed Results of the Base Case

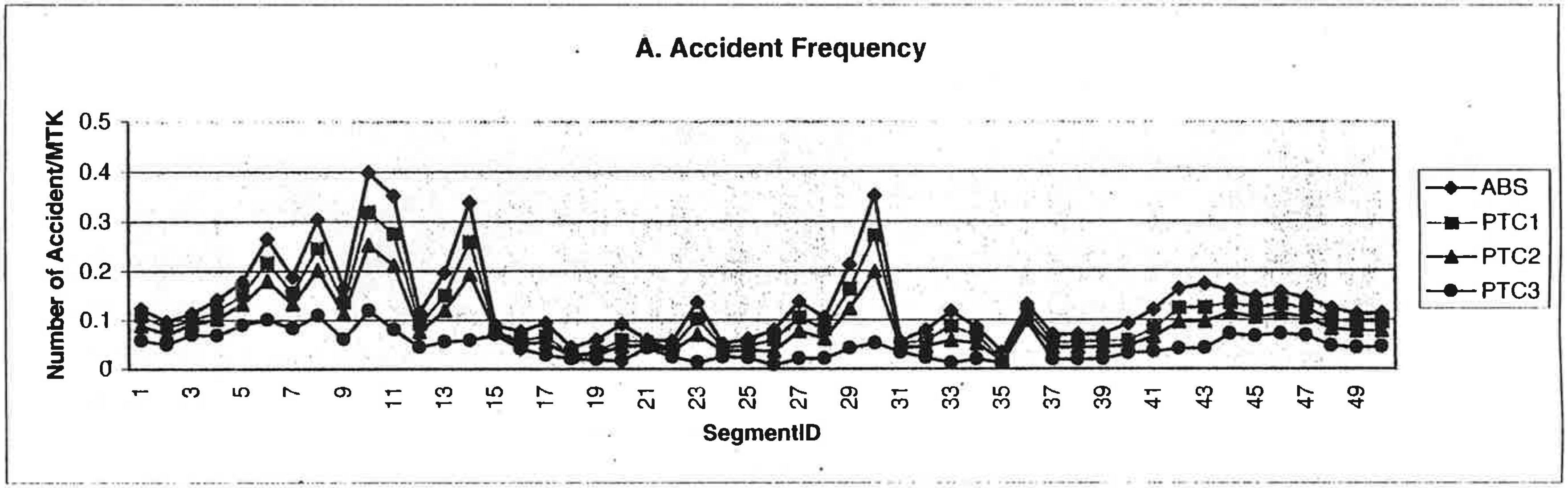
A. Accident Frequency

Accident type	E(# accidents/MTK)				Percentage of all accidents				Reduction Rate		
	ABS	PTC1	PTC2	PTC3	ABS	PTC1	PTC2	PTC3	PTC1	PTC2	PTC3
Head-On	0.032	0.030	0.027	0.027	35%	41%	45%	66%	7%	15%	17%
Rear-End	0.000	0.000	0.000	0.000	0%	0%	0%	0%	-	-	-
MOW	0.001	0.000	0.000	0.000	1%	1%	1%	1%	24%	26%	26%
Track Fault	0.051	0.042	0.032	0.013	57%	58%	53%	32%	19%	37%	75%
Temp SO	0.006	0.001	0.001	0.001	7%	1%	1%	1%	91%	91%	91%
Perm SR	0.000	0.000	0.000	0.000	0%	0%	0%	0%	77%	77%	77%
Collision	0.033	0.030	0.028	0.027	36%	42%	46%	67%	8%	16%	17%
Derailment	0.058	0.042	0.033	0.014	64%	58%	54%	33%	26%	43%	76%
All Accidents	0.090	0.073	0.060	0.041					20%	33%	55%

B. Risks

Accident type	E($/MTK)				Percentage of all consequence				Reduction Rate		
	ABS	PTC1	PTC2	PTC3	ABS	PTC1	PTC2	PTC3	PTC1	PTC2	PTC3
Head-On	$694,831	$261,737	$126,159	$84,889	64%	47%	36%	46%	62%	82%	88%
Rear-End	$0	$0	$0	$0	0%	0%	0%	0%	-	-	-
MOW	$31,788	$23,788	$20,939	$20,398	3%	4%	6%	11%	25%	34%	36%
Track Fault	$328,560	$265,399	$202,238	$75,917	30%	48%	57%	41%	19%	38%	77%
Temp SO	$30,434	$2,605	$2,605	$2,605	3%	0%	1%	1%	91%	91%	91%
Perm SR	$289	$77	$77	$77	0%	0%	0%	0%	73%	73%	73%
Collision	$726,619	$285,525	$147,098	$105,287	67%	52%	42%	57%	61%	80%	86%
Derailment	$359,282	$268,080	$204,919	$78,598	33%	48%	58%	43%	25%	43%	78%
All Accidents	$1,085,901	$553,606	$352,017	$183,885					49%	68%	83%

Exhibit 10. All Modeled Accidents



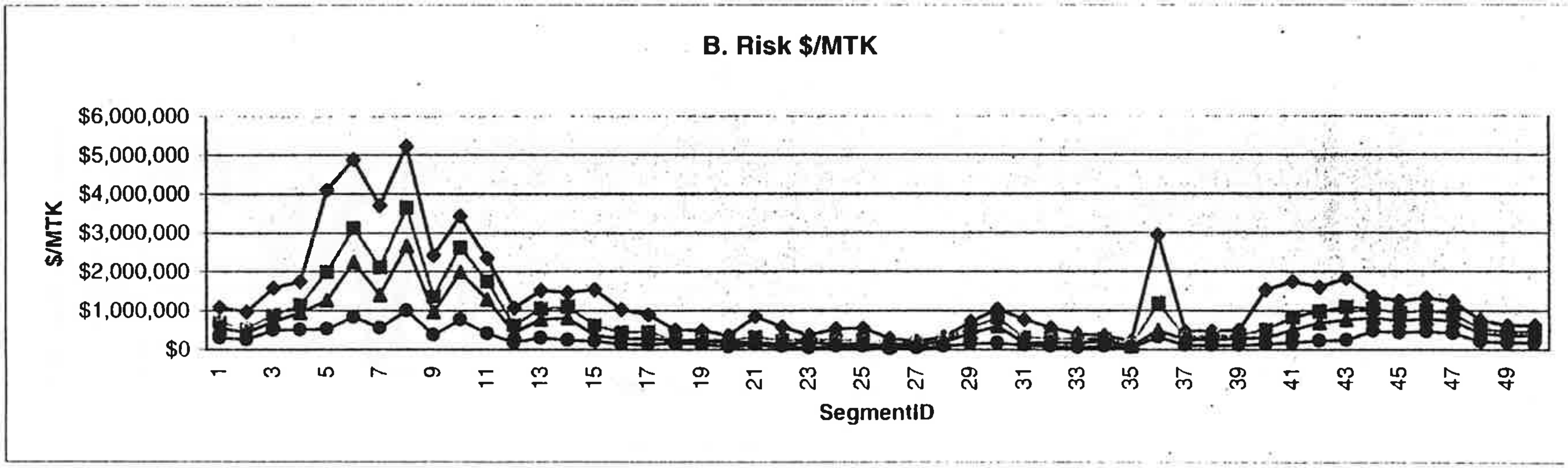
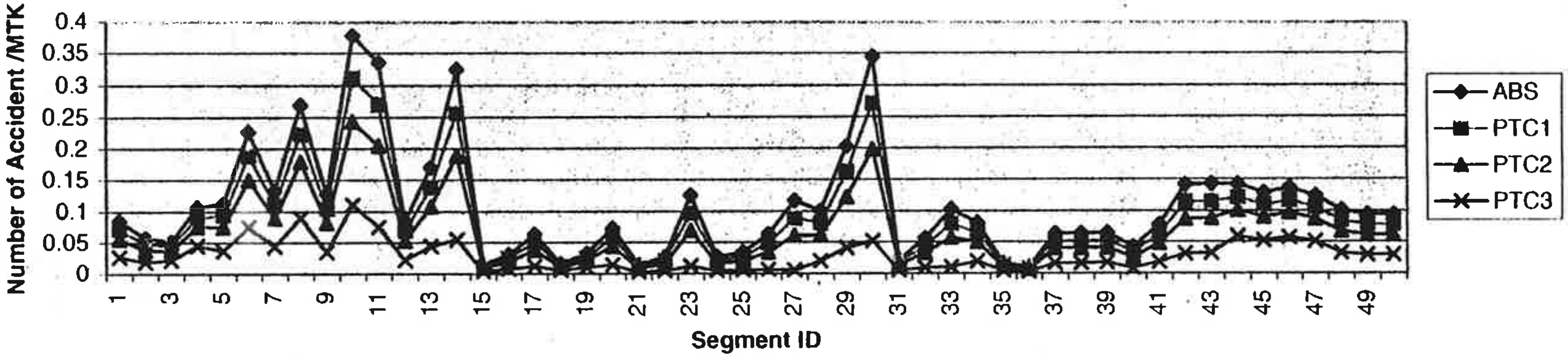


Exhibit 11. Derailments due to Track Fault

A. Accident Frequency



B. Risk $/MTK

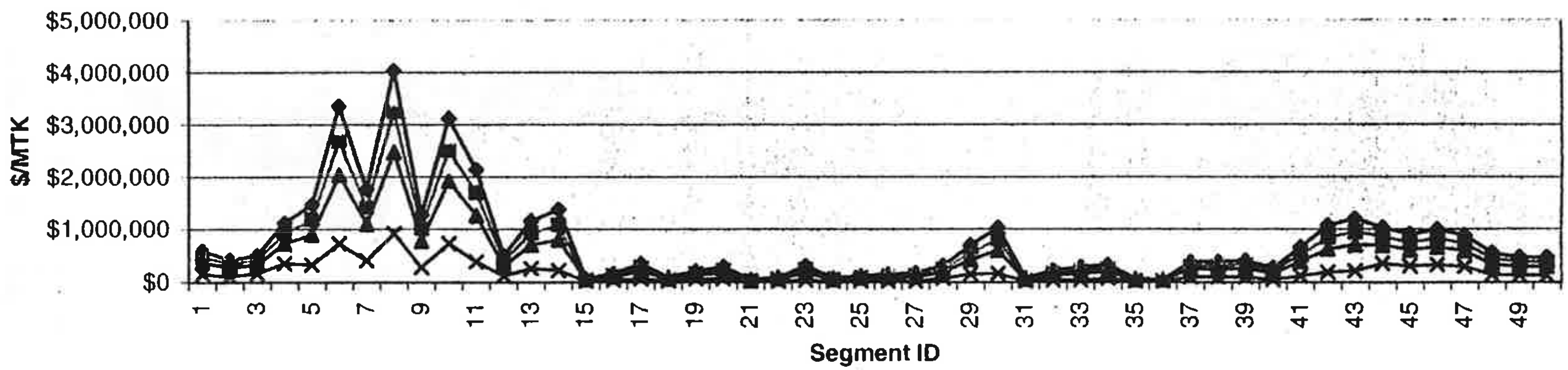


Exhibit 12. Head-on Collisions

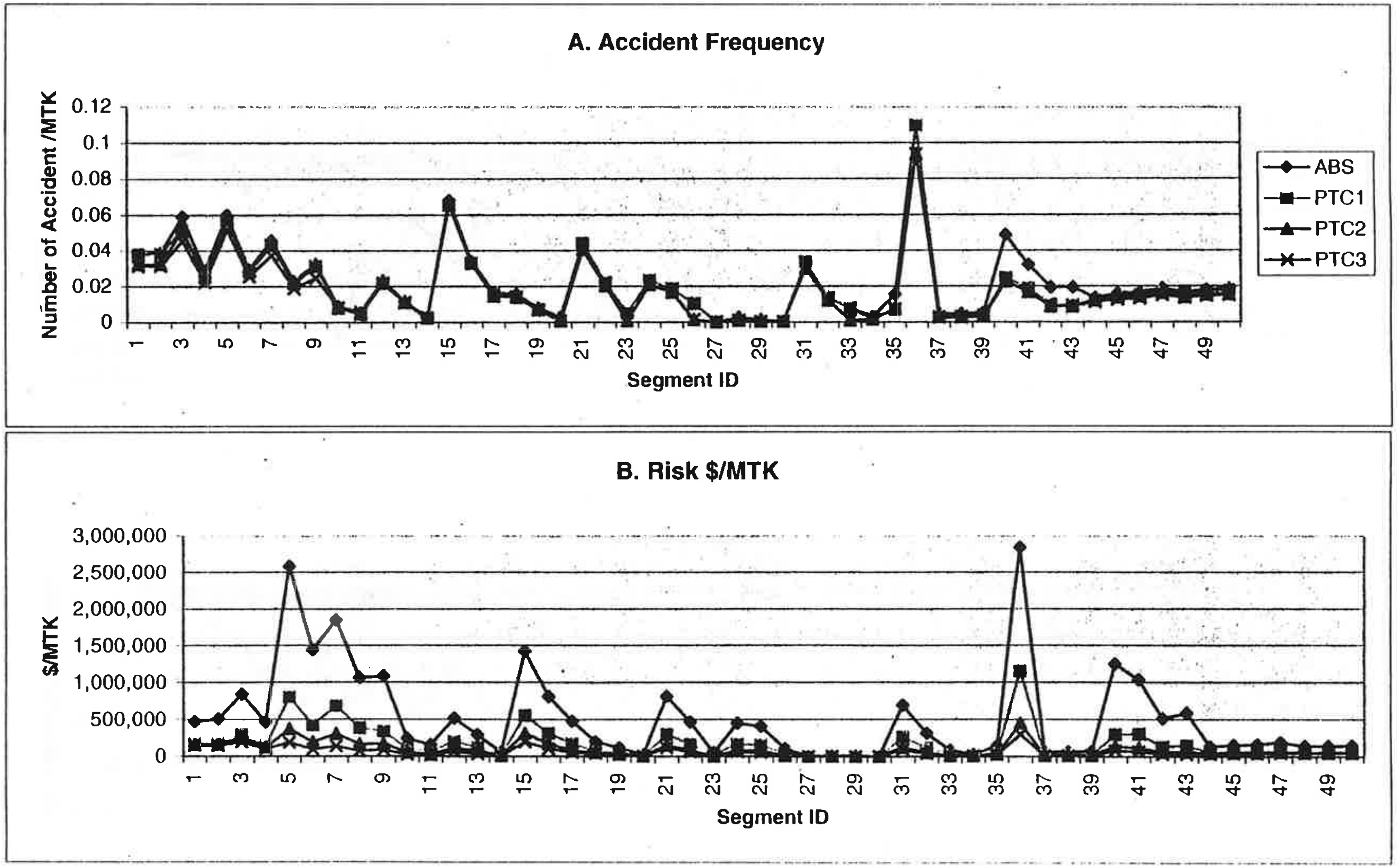
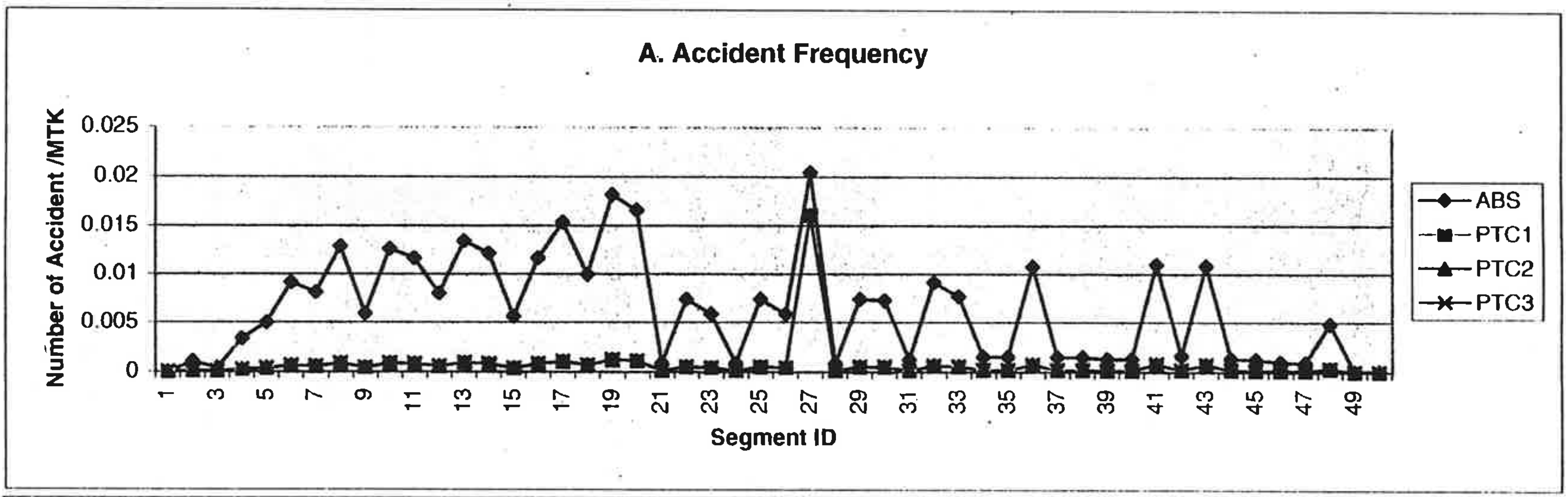


Exhibit 13. Derailments due to Slow Orders



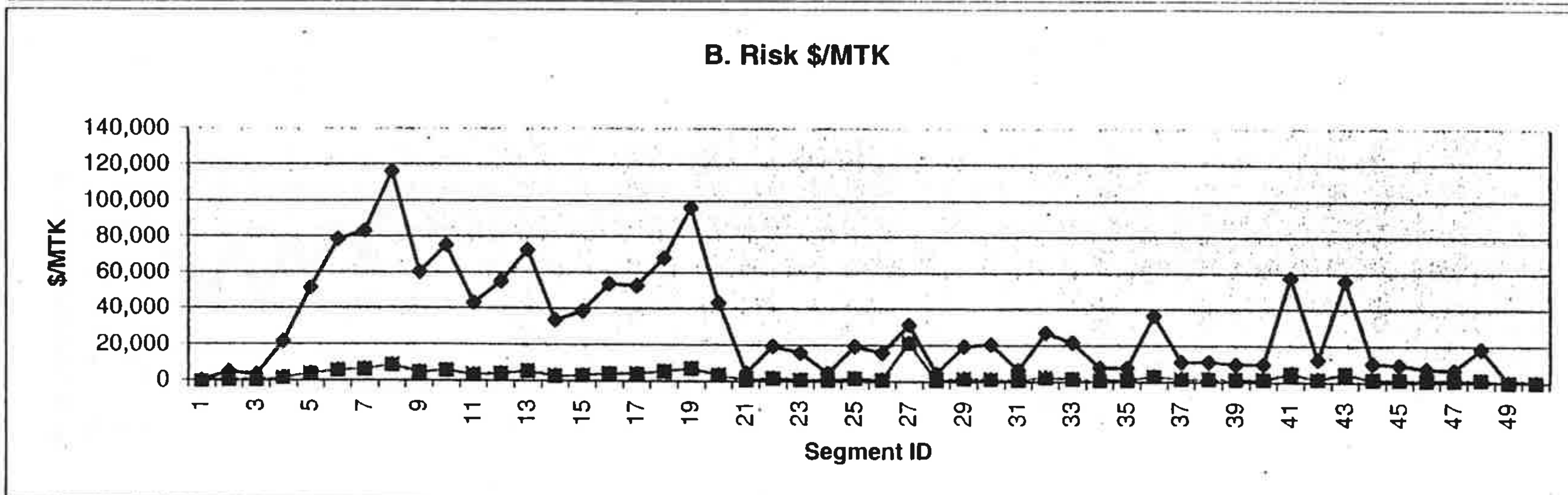
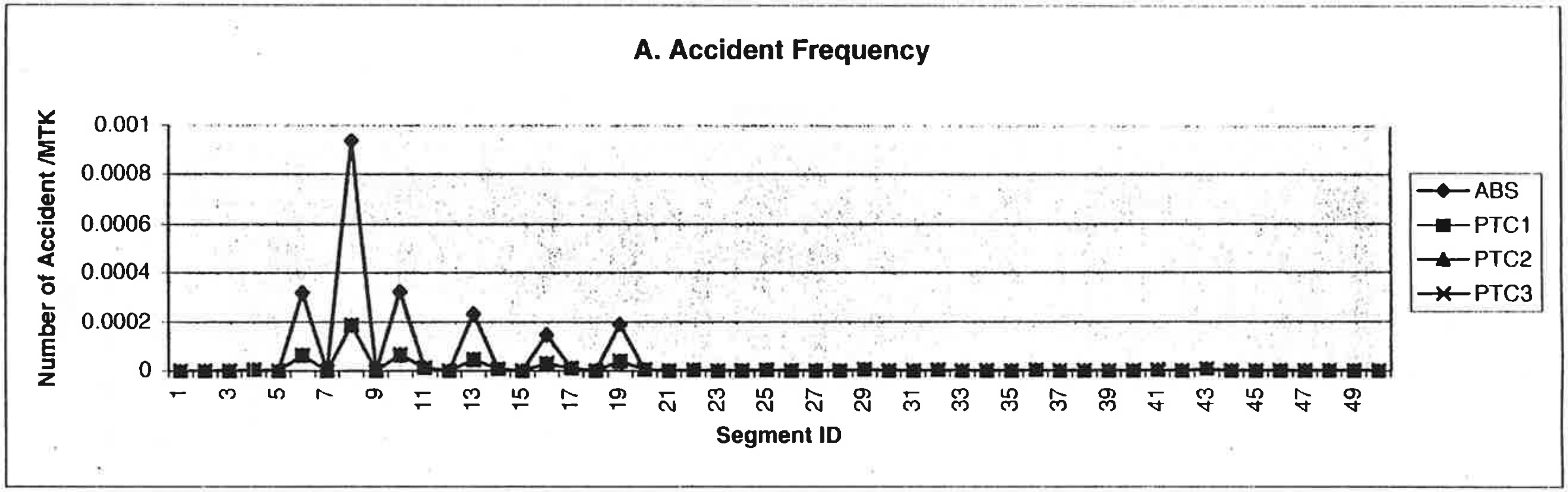


Exhibit 14. Derailments due to Permanent Speed Restriction



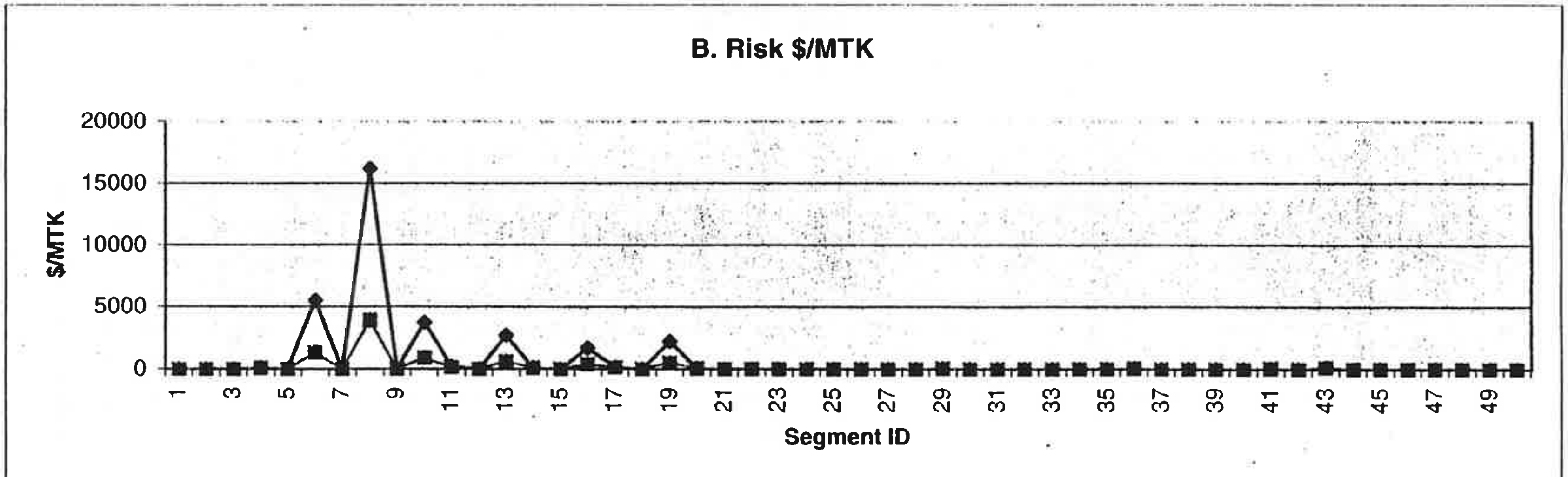


Exhibit 15. MOW Collisions

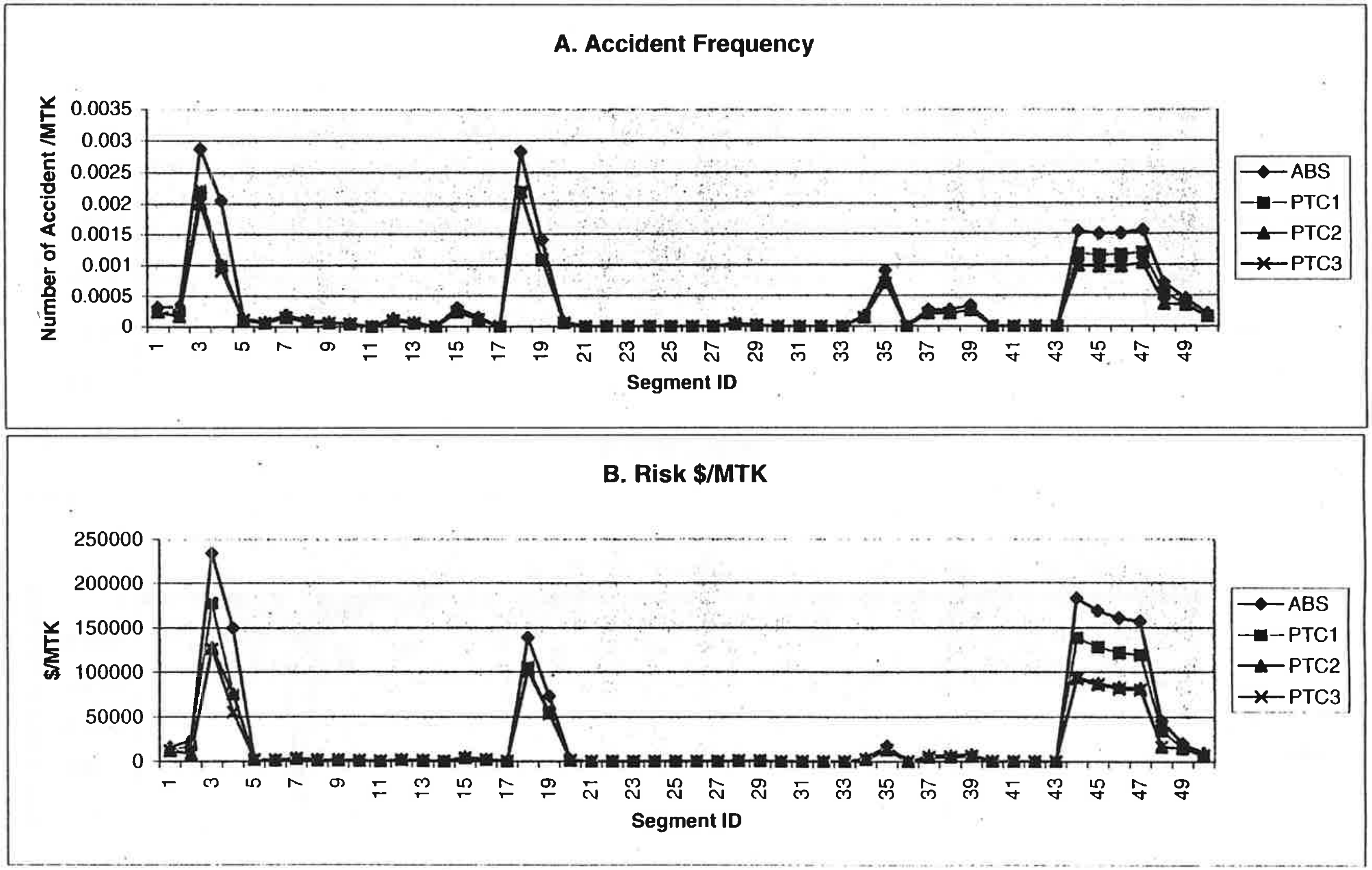
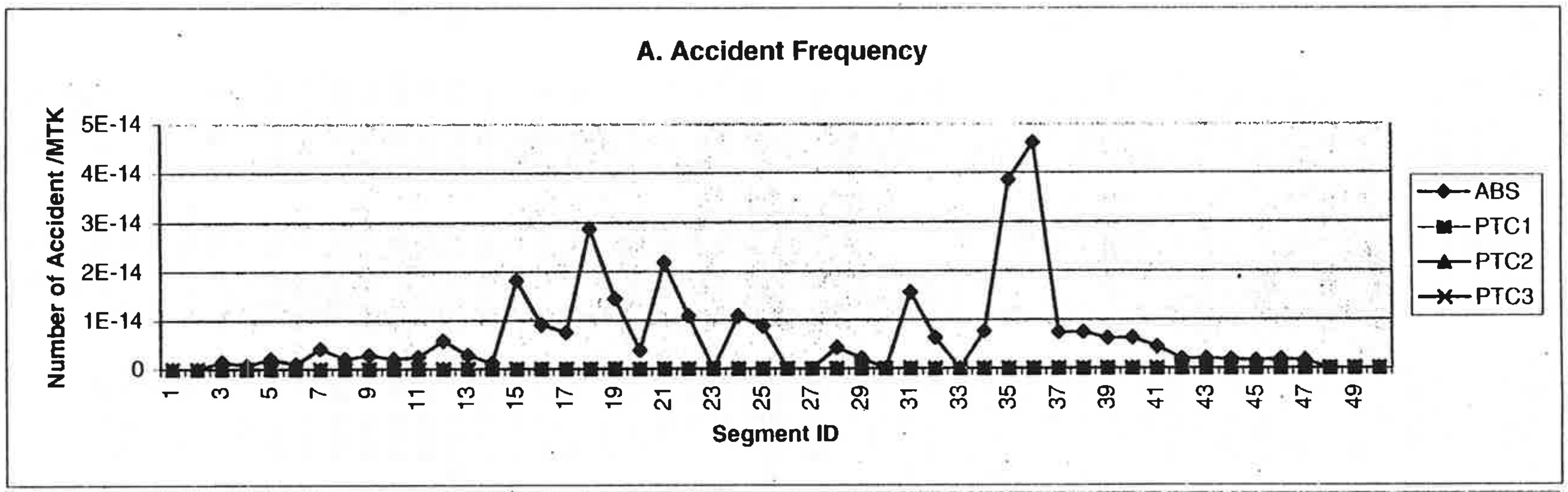


Exhibit 16. Rear-End Collisions



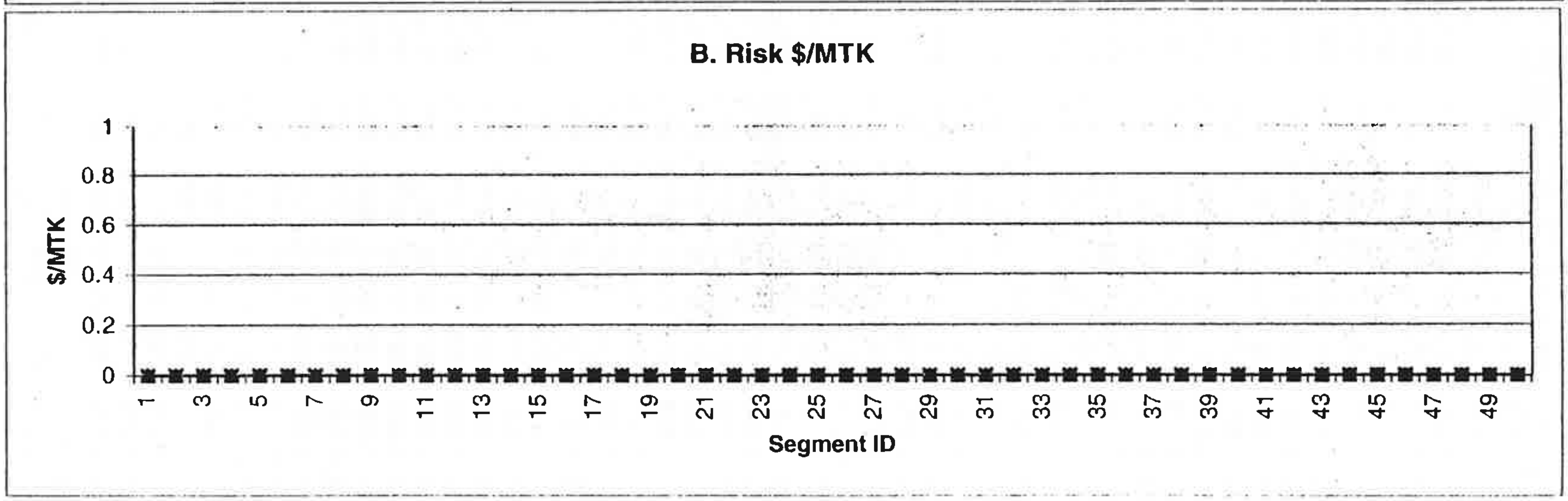


Exhibit 17-A Results for Segments (Total Accidents)

	Number of Accidents				Reduction Rate			Risk			
Segment ID	I_ABS	PTC1	PTC2	PTC3	PTC1	PTC2	PTC3	E2_ABS	E2_PTC1	E2_PTC2	E2_PTC3
1	0.043	0.038	0.031	0.021	12%	28%	53%	$385.398	$246,378	$192,797	$107,716
2	0.034	0.030	0.024	0.017	11%	28%	49%	$334.162	$193,661	$149,239	$88.828
3	0.054	0.046	0.042	0.032	14%	21%	39%	$746,026	$422,358	$334,257	$228.183
4	0.032	0.027	0.023	0.016	16%	28%	52%	$399,988	$263,839	$213,876	$115,841
5	0.041	0.035	0.031	0.021	15%	25%	50%	$948,655	$461,085	$294,144	$119.109
6	0.031	0.025	0.021	0.012	18%	32%	62%	$562.841	$361,286	$258,157	$95.595
7	0.037	0.030	0.026	0.016	17%	29%	56%	$724.527	$415,119	$274,512	$108.051
8	0.030	0.024	0.020	0.011	19%	34%	64%	$511.462	$357,304	$259.618	$97.615
9	0.031	0.026	0.021	0.011	18%	32%	64%	$453.513	$256.670	$178,669	$69.751
10	0.026	0.021	0.016	0.008	20%	37%	70%	$222.165	$170.055	$127,858	$48.957
11	0.023	0.018	0.014	0.005	22%	40%	77%	$151.274	$114,174	$83.261	$26,144
12	0.031	0.025	0.020	0.012	21%	35%	62%	$290.130	$169,761	$115,490	$49,132
13	0.026	0.020	0.016	0.008	23%	39%	72%	$205.520	$142.593	$104.375	$40.127
14	0.021	0.016	0.012	0.004	23%	43%	83%	$90.425	$68,414	$50,104	$14,614
15	0.127	0.112	0.108	0.099	12%	15%	22%	$2,194.985	$891.240	$522,879	$306,570
16	0.055	0.042	0.037	0.029	24%	31%	47%	$738.835	$319,267	$196.135	$100.677
17	0.031	0.022	0.018	0.009	29%	44%	71%	$296,604	$155,537	$94.287	$37.347
18	0.097	0.066	0.060	0.047	32%	38%	51%	$1,109,467	$571,408	$478,646	$368.979
19	0.065	0.039	0.033	0.021	40%	49%	68%	$548,367	$302.946	$244,578	$149.641
20	0.036	0.024	0.018	0.006	35%	51%	83%	$143.228	$95,597	$71,494	$23.934
21	0.084	0.079	0.069	0.061	6%	18%	28%	$1,228,664	$480,418	$249,809	$177,167
22	0.041	0.032	0.026	0.018	22%	36%	56%	$412.926	$173,952	$96,615	$55,039
23	0.020	0.015	0.010	0.002	25%	49%	91%	$53,860	$37,722	$25,166	$5,240
24	0.037	0.032	0.026	0.018	13%	29%	52%	$383.887	$171,982	$92,640	$53,015
25	0.034	0.026	0.021	0.013	24%	39%	63%	$312.854	$142.394	$78,705	$40,104
26	0.023	0.017	0.010	0.002	25%	55%	91%	$79,967	$48,223	$26,528	$6,195
27	0.020	0.015	0.011	0.003	24%	44%	85%	$30,190	$22.731	$16,690	$4,608
28	0.030	0.023	0.018	0.006	22%	41%	80%	$95,505	$73,667	$55,520	$20.016
29	0.030	0.023	0.018	0.006	23%	42%	80%	$103,594	$80,590	$60,845	$21,586
30	0.027	0.021	0.015	0.004	23%	44%	85%	$81,334	$63,080	$46,391	$13,079
31	0.051	0.046	0.038	0.030	10%	25%	41%	$691,729	$295,726	$152,142	$94,372
32	0.028	0.021	0.016	0.008	26%	43%	72%	$201.429	$106,040	$65,485	$27,141
33	0.021	0.016	0.010	0.002	26%	51%	90%	$72,032	$48,049	$30,423	$6,652
34	0.032	0.025	0.019	0.008	22%	40%	76%	$138.541	$104,819	$79,177	$30.559
35	0.065	0.041	0.034	0.022	37%	47%	66%	$438,687	$220,988	$154,981	$89.611
36	0.263	0.239	0.202	0.194	9%	23%	26%	$5,908,744	$2,420,132	$979,202	$633,970
37	0.035	0.027	0.021	0.009	21%	39%	73%	$235,725	$172,078	$129,703	$52,154
38	0.035	0.027	0.021	0.009	21%	39%	73%	$235,725	$172,078	$129,703	$52,154
39	0.035	0.028	0.022	0.010	20%	38%	72%	$252,301	$182.900	$138,310	$55,726
40	0.046	0.029	0.024	0.015	37%	48%	66%	$764,363	$260,006	$147,048	$64.508
41	0.034	0.023	0.018	0.010	32%	46%	71%	$498.296	$235,855	$143,690	$52,424
42	0.025	0.019	0.015	0.006	24%	41%	75%	$245.251	$151,290	$105,365	$34,286
43	0.027	0.019	0.015	0.006	27%	44%	76%	$282.394	$169,699	$117,676	$37.809
44	0.027	0.023	0.019	0.012	15%	29%	55%	$227.111	$176.438	$138,147	$79.455
45	0.027	0.023	0.019	0.012	15%	28%	55%	$230.623	$175.855	$137.602	$79.380
46	0.027	0.023	0.020	0.013	15%	28%	54%	$233.719	$179,102	$140,537	$80,274
47	0.028	0.024	0.020	0.013	15%	28%	54%	$239.489	$179.853	$141,028	$81.261
48	0.024	0.019	0.016	0.009	18%	34%	63%	$146,398	$105,061	$79,581	$39,317
49	0.023	0.019	0.016	0.009	15%	32%	61%	$130.017	$94,711	$74,378	$37.454
50	0.023	0.020	0.016	0.009	15%	32%	61%	$129.848	$94,221	$73,247	$36.249

Risk Reduction Rate			Accident /MTK				Risk /MTK			
_PTC1	_PTC2	_PTC3	e_ABS	PTC1	PTC2	PTC3	Risk_ABS	Risk_PTC1	Risk_PTC2	Risk_PTC3
36%	50%	72%	0.123	0.109	0.088	0.059	$1,093,729	$699,200	$547,141	$305,689
42%	55%	73%	0.097	0.086	0.070	0.050	$964,399	$558,910	$430,708	$256,360
43%	55%	69%	0.114	0.099	0.090	0.069	$1,587,870	$898,962	$711,445	$485,673
34%	47%	71%	0.141	0.118	0.102	0.068	$1,746,361	$1,151,930	$933,787	$505,766
51%	69%	87%	0.178	0.152	0.133	0.089	$4,110,238	$1,997,743	$1,274,439	$516,063
36%	54%	83%	0.266	0.218	0.180	0.101	$4,877,243	$3,130,684	$2,237,033	$828,373
43%	62%	85%	0.188	0.155	0.133	0.082	$3,704,774	$2,122,653	$1,403,682	$552,505
30%	49%	81%	0.305	0.247	0.202	0.109	$5,230,588	$3,654,050	$2,655,048	$998,286
43%	61%	85%	0.165	0.136	0.113	0.060	$2,413,187	$1,365,765	$950,715	$371,153
23%	42%	78%	0.400	0.320	0.253	0.120	$3,439,009	$2,632,379	$1,979,192	$757,831
25%	45%	83%	0.353	0.277	0.211	0.080	$2,341,648	$1,767,360	$1,288,344	$404,705
41%	60%	83%	0.116	0.091	0.075	0.044	$1,073,956	$628,395	$427,502	$181,367
31%	49%	80%	0.196	0.151	0.119	0.056	$1,521,519	$1,055,651	$772,718	$297,073
24%	45%	84%	0.339	0.260	0.193	0.058	$1,466,396	$1,109,452	$812,528	$236,985
59%	76%	86%	0.089	0.078	0.075	0.069	$1,531,767	$621,951	$364,891	$214,009
57%	73%	86%	0.076	0.058	0.052	0.040	$1,031,190	$445,600	$273,745	$140,514
48%	68%	87%	0.094	0.067	0.053	0.028	$889,159	$466,269	$282,654	$111,959
48%	57%	67%	0.044	0.030	0.027	0.021	$502,432	$258,767	$216,759	$167,096
45%	55%	73%	0.059	0.035	0.030	0.019	$496,666	$274,384	$221,519	$135,532
33%	50%	83%	0.092	0.060	0.045	0.016	$362,919	$242,230	$181,155	$60,645
61%	80%	86%	0.059	0.055	0.048	0.043	$857,421	$335,259	$174,329	$123,636
58%	77%	87%	0.057	0.044	0.036	0.025	$576,320	$242,784	$134,846	$76,817
30%	53%	90%	0.136	0.102	0.069	0.012	$375,865	$263,243	$175,622	$36,569
55%	76%	86%	0.051	0.045	0.036	0.025	$535,790	$240,034	$129,298	$73,993
54%	75%	87%	0.060	0.046	0.037	0.022	$545,812	$248,424	$137,311	$69,967
40%	67%	92%	0.079	0.059	0.036	0.007	$279,025	$168,261	$92,563	$21,614
25%	45%	85%	0.137	0.104	0.077	0.021	$210,677	$158,629	$116,472	$32,157
23%	42%	79%	0.104	0.081	0.061	0.021	$333,242	$257,044	$193,724	$69,842
22%	41%	79%	0.212	0.164	0.123	0.042	$722,926	$562,395	$424,605	$150,638
22%	43%	84%	0.352	0.272	0.199	0.052	$1,049,174	$813,707	$598,422	$168,710
57%	78%	86%	0.057	0.051	0.043	0.034	$777,454	$332,375	$170,997	$106,067
47%	67%	87%	0.079	0.058	0.045	0.022	$565,979	$297,953	$184,002	$76,261
33%	58%	91%	0.117	0.087	0.058	0.012	$404,797	$270,018	$170,969	$37,382
24%	43%	78%	0.085	0.067	0.051	0.020	$365,173	$276,286	$208,697	$80,547
50%	65%	80%	0.034	0.021	0.018	0.012	$231,262	$116,497	$81,701	$47,240
59%	83%	89%	0.131	0.118	0.100	0.096	$2,933,271	$1,201,423	$486,104	$314,721
27%	45%	78%	0.070	0.055	0.043	0.019	$474,445	$346,342	$261,055	$104,971
27%	45%	78%	0.070	0.055	0.043	0.019	$474,445	$346,342	$261,055	$104,971
28%	45%	78%	0.071	0.057	0.044	0.020	$506,611	$367,256	$277,721	$111,896
66%	81%	92%	0.092	0.058	0.048	0.031	$1,534,811	$522,081	$295,266	$129,530
53%	71%	89%	0.120	0.082	0.065	0.035	$1,753,046	$829,756	$505,511	$184,431
38%	57%	86%	0.162	0.124	0.095	0.040	$1,593,898	$983,243	$684,775	$222,824
40%	58%	87%	0.172	0.125	0.097	0.042	$1,838,543	$1,102,882	$764,782	$245,724
22%	39%	65%	0.159	0.135	0.113	0.071	$1,356,891	$1,054,141	$825,366	$474,711
24%	40%	66%	0.146	0.124	0.105	0.066	$1,246,645	$950,594	$743,817	$429,095
23%	40%	66%	0.155	0.133	0.112	0.071	$1,326,552	$1,016,555	$797,667	$455,623
25%	41%	66%	0.144	0.123	0.104	0.067	$1,235,727	$928,016	$727,681	$419,295
28%	46%	73%	0.123	0.100	0.081	0.046	$755,390	$542,100	$410,628	$202,872
27%	43%	71%	0.112	0.095	0.077	0.043	$632,532	$460,771	$361,848	$182,213
27%	44%	72%	0.112	0.095	0.077	0.044	$631,712	$458,385	$356,346	$176,349

Exhibit 17-B Results for Segments (Derailments due to Track Fault)

	Number of Accidents				Reduction Rate			Risk			
Segment ID	1_ABS	PTC1	PTC2	PTC3	PTC1	PTC2	PTC3	E2_ABS	E2_PTC1	E2_PTC2	E2_PTC3
1	0.030	0.025	0.020	0.010	17%	34%	68%	$212,802	$173,066	$133,330	$53,858
2	0.020	0.016	0.013	0.006	17%	34%	68%	$147,424	$119,768	$92,113	$36,801
3	0.024	0.021	0.017	0.010	15%	29%	58%	$238,223	$197,832	$157,440	$76,656
4	0.024	0.021	0.017	0.010	14%	29%	58%	$255,069	$211,411	$167,752	$80,434
5	0.026	0.022	0.017	0.008	17%	34%	67%	$340,110	$273,912	$207,714	$75,318
6	0.026	0.022	0.017	0.009	17%	34%	67%	$386,373	$310,787	$235,201	$84,029
7	0.026	0.022	0.017	0.009	17%	34%	67%	$346,025	$279,518	$213,011	$79,996
8	0.026	0.022	0.018	0.009	17%	33%	67%	$394,404	$318,175	$241,946	$89,488
9	0.024	0.020	0.015	0.007	18%	36%	72%	$237,946	$191,537	$145,129	$52,312
10	0.024	0.020	0.016	0.007	18%	35%	71%	$201,414	$162,813	$124,212	$47,011
11	0.022	0.017	0.013	0.005	19%	39%	78%	$138,127	$109,845	$81,563	$24,999
12	0.023	0.019	0.014	0.006	19%	37%	75%	$136,795	$110,378	$83,962	$31,129
13	0.023	0.019	0.014	0.006	19%	37%	74%	$155,608	$125,427	$95,247	$34,386
14	0.020	0.016	0.012	0.003	21%	42%	83%	$84,743	$67,065	$49,387	$14,030
15	0.022	0.017	0.013	0.005	20%	39%	79%	$100,984	$81,018	$61,052	$21,119
16	0.022	0.017	0.013	0.005	20%	39%	78%	$114,053	$91,445	$68,837	$23,621
17	0.021	0.017	0.013	0.004	20%	40%	80%	$118,697	$94,085	$69,473	$20,249
18	0.034	0.028	0.022	0.010	17%	35%	70%	$206,030	$168,388	$130,746	$55,461
19	0.035	0.029	0.023	0.011	17%	35%	69%	$232,186	$189,643	$147,101	$62,015
20	0.029	0.023	0.017	0.006	20%	40%	81%	$115,873	$92,248	$68,622	$21,371
21	0.019	0.015	0.011	0.003	21%	43%	85%	$59,816	$47,253	$34,690	$9,564
22	0.020	0.015	0.011	0.003	21%	42%	85%	$66,475	$52,503	$38,531	$10,586
23	0.018	0.014	0.010	0.002	23%	45%	91%	$44,530	$34,618	$24,705	$4,881
24	0.019	0.015	0.011	0.003	21%	43%	85%	$59,816	$47,253	$34,690	$9,564
25	0.020	0.015	0.011	0.003	21%	42%	85%	$66,475	$52,503	$38,531	$10,586
26	0.018	0.014	0.010	0.002	23%	45%	91%	$44,530	$34,618	$24,705	$4,881
27	0.017	0.013	0.009	0.001	24%	48%	96%	$25,751	$19,710	$13,669	$1,586
28	0.029	0.023	0.017	0.006	20%	40%	80%	$89,669	$72,034	$54,398	$19,127
29	0.029	0.023	0.018	0.006	20%	40%	80%	$99,558	$79,962	$60,366	$21,173
30	0.027	0.021	0.015	0.004	21%	43%	85%	$79,523	$62,873	$46,223	$12,923
31	0.020	0.016	0.011	0.003	21%	42%	84%	$71,158	$56,238	$41,318	$11,477
32	0.020	0.016	0.012	0.003	21%	42%	84%	$79,128	$62,522	$45,916	$12,703
33	0.018	0.014	0.010	0.002	22%	45%	90%	$52,872	$41,119	$29,365	$5,859
34	0.030	0.025	0.019	0.007	19%	38%	77%	$123,600	$99,640	$75,680	$27,759
35	0.030	0.025	0.019	0.007	19%	38%	77%	$123,600	$99,640	$75,680	$27,759
36	0.021	0.017	0.012	0.004	20%	40%	81%	$102,565	$81,348	$60,132	$17,699
37	0.031	0.026	0.020	0.008	19%	38%	75%	$195,449	$157,768	$120,087	$44,725
38	0.031	0.026	0.020	0.008	19%	38%	75%	$195,449	$157,768	$120,087	$44,725
39	0.032	0.026	0.020	0.008	19%	37%	74%	$207,315	$167,337	$127,359	$47,402
40	0.021	0.017	0.013	0.004	20%	40%	80%	$137,393	$108,970	$80,547	$23,701
41	0.022	0.018	0.013	0.005	19%	39%	77%	$186,556	$148,214	$109,872	$33,188
42	0.022	0.018	0.013	0.005	19%	39%	78%	$164,126	$130,396	$96,665	$29,204
43	0.022	0.018	0.013	0.005	19%	39%	77%	$183,799	$145,890	$107,981	$32,163
44	0.024	0.020	0.017	0.010	15%	29%	59%	$172,040	$143,637	$115,234	$58,428
45	0.024	0.020	0.017	0.010	15%	30%	59%	$168,224	$140,251	$112,278	$56,332
46	0.024	0.021	0.017	0.010	15%	29%	58%	$174,915	$145,905	$116,895	$58,875
47	0.024	0.020	0.017	0.010	15%	29%	59%	$171,012	$142,467	$113,922	$56,833
48	0.020	0.016	0.013	0.006	17%	34%	68%	$106,058	$86,598	$67,139	$28,219
49	0.019	0.016	0.013	0.006	17%	35%	69%	$96,643	$78,868	$61,094	$25,546
50	0.019	0.016	0.013	0.006	17%	35%	69%	$96,643	$78,868	$61,094	$25,546

Risk Reduction Rate			Accident /MTK				Risk /MTK			
_PTC1	_PTC2	_PTC3	e_ABS	_PTC1	_PTC2	_PTC3	Risk_ABS	Risk_PTC1	Risk_PTC2	Risk_PTC3
19%	37%	75%	0.085	0.070	0.056	0.027	$603,915	$491,147	$378,380	$152,844
19%	38%	75%	0.057	0.048	0.038	0.018	$425.468	$345,653	$265,839	$106.210
17%	34%	68%	0.052	0.044	0.037	0.022	$507,044	$421,073	$335,101	$163.158
17%	34%	68%	0.106	0.091	0.076	0.045	$1,113,640	$923,025	$732,409	$351,177
19%	39%	78%	0.113	0.094	0.075	0.037	$1,473,592	$1,186,777	$899,961	$326,330
20%	39%	78%	0.227	0.189	0.151	0.075	$3.348,078	$2,693,095	$2,038,113	$728,148
19%	38%	77%	0.134	0.111	0.089	0.044	$1,769,354	$1,429.277	$1,089.201	$409,048
19%	39%	77%	0.269	0.224	0.179	0.089	$4.033,468	$3.253,894	$2,474,320	$915.172
20%	39%	78%	0.127	0.104	0.081	0.035	$1,266.134	$1,019.189	$772,245	$278.356
19%	38%	77%	0.378	0.311	0.244	0.111	$3,117,794	$2,520,271	$1,922,748	$727.702
20%	41%	82%	0.336	0.270	0.205	0.074	$2,138.150	$1,700,355	$1,262,560	$386,970
19%	39%	77%	0.085	0.069	0.053	0.021	$506,363	$408,579	$310,796	$115.228
19%	39%	78%	0.170	0.139	0.107	0.044	$1,152,005	$928,571	$705,136	$258,267
21%	42%	83%	0.325	0.257	0.189	0.054	$1,374,257	$1,087,574	$800,892	$227,527
20%	40%	79%	0.015	0.012	0.009	0.003	$70,472	$56.538	$42,605	$14.738
20%	40%	79%	0.030	0.024	0.018	0.007	$159,183	$127,629	$96,076	$32.968
21%	41%	83%	0.063	0.050	0.037	0.012	$355,829	$282.047	$208.265	$60.701
18%	37%	73%	0.016	0.013	0.010	0.005	$93,303	$76,256	$59.209	$25,116
18%	37%	73%	0.031	0.026	0.021	0.010	$210.296	$171,764	$133.232	$56,168
20%	41%	82%	0.073	0.058	0.043	0.014	$293.606	$233,742	$173.878	$54.151
21%	42%	84%	0.014	0.011	0.008	0.002	$41,742	$32.975	$24,208	$6,674
21%	42%	84%	0.027	0.022	0.016	0.004	$92,779	$73,278	$53,777	$14,776
22%	45%	89%	0.125	0.097	0.068	0.012	$310,749	$241,578	$172,407	$34.065
21%	42%	84%	0.027	0.021	0.016	0.004	$83,485	$65,951	$48,416	$13,348
21%	42%	84%	0.034	0.027	0.020	0.005	$115,973	$91,597	$67,221	$18,469
22%	45%	89%	0.063	0.048	0.034	0.006	$155,375	$120,789	$86,203	$17,032
23%	47%	94%	0.116	0.088	0.060	0.005	$179,701	$137,544	$95,386	$11,071
20%	39%	79%	0.101	0.080	0.060	0.020	$312,878	$251,344	$189,809	$66,740
20%	39%	79%	0.203	0.163	0.122	0.041	$694,767	$558,014	$421,261	$147,755
21%	42%	84%	0.345	0.271	0.198	0.051	$1,025,813	$811,034	$596,255	$166,698
21%	42%	84%	0.022	0.018	0.013	0.003	$79,977	$63,207	$46,438	$12,899
21%	42%	84%	0.056	0.044	0.033	0.009	$222,335	$175,675	$129,015	$35,694
22%	44%	89%	0.102	0.079	0.056	0.010	$297,122	$231,073	$165,023	$32.924
19%	39%	78%	0.080	0.065	0.049	0.019	$325,790	$262.635	$199,479	$73,169
19%	39%	78%	0.016	0.013	0.010	0.004	$65,158	$52,527	$39,896	$14,634
21%	41%	83%	0.010	0.008	0.006	0.002	$50.916	$40,384	$29,851	$8,786
19%	39%	77%	0.063	0.051	0.040	0.016	$393,381	$317,540	$24-.700	$90,019
19%	39%	77%	0.063	0.051	0.040	0.016	$393,381	$317,540	$241,700	$90,019
19%	39%	77%	0.064	0.052	0.041	0.017	$416,281	$336.007	$255,732	$95,182
21%	41%	83%	0.042	0.034	0.025	0.008	$275,879	$218,807	$161,735	$47.591
21%	41%	82%	0.077	0.062	0.047	0.018	$656.319	$521,428	$386,538	$116.756
21%	41%	82%	0.142	0.114	0.086	0.031	$1,066,664	$847,447	$628,230	$189,797
21%	41%	83%	0.142	0.115	0.087	0.032	$1,194.520	$948.147	$701,774	$209,028
17%	33%	66%	0.142	0.121	0.100	0.059	$1.027,863	$858,168	$688,473	$349,083
17%	33%	67%	0.128	0.109	0.090	0.052	$909,344	$758,134	$606,924	$304.505
17%	33%	66%	0.137	0.117	0.097	0.057	$992.792	$828,134	$663,477	$334,162
17%	33%	67%	0.123	0.105	0.087	0.051	$882,395	$735,108	$587,822	$293,249
18%	37%	73%	0.101	0.084	0.066	0.032	$547,243	$446,834	$346,425	$145.607
18%	37%	74%	0.094	0.077	0.061	0.029	$470,167	$383.695	$297,224	$124,281
18%	37%	74%	0.094	0.077	0.061	0.029	$470.167	$383,695	$297,224	$124,281

Exhibit 17-C Results for Segments (Head-on Collisions)

	Number of Accidents				Reduction Rate			Risk			
Segment ID	f_ABS	PTC1	PTC2	PTC3	PTC1	PTC2	PTC3	E2_ABS	E2_PTC1	E2_PTC2	E2_PTC3
1	0.014	0.013	0.011	0.011	0%	16%	19%	$167,079	$69,097	$55,300	$49.738
2	0.013	0.013	0.011	0.011	1%	17%	19%	$176,910	$67,537	$54,082	$49.018
3	0.028	0.024	0.024	0.021	12%	13%	23%	$396,148	$140,606	$116.590	$92.283
4	0.007	0.006	0.006	0.005	12%	13%	23%	$105,587	$34,463	$28,475	$22.421
5	0.014	0.013	0.013	0.012	4%	4%	13%	$596,157	$185,855	$85,116	$42,481
6	0.003	0.003	0.003	0.003	3%	3%	13%	$166,644	$49.569	$22,028	$10.640
7	0.009	0.008	0.008	0.007	5%	5%	18%	$361.563	$133,835	$59.742	$26.301
8	0.002	0.002	0.002	0.002	5%	5%	18%	$103,945	$37,784	$16,329	$6.785
9	0.006	0.006	0.006	0.005	3%	3%	24%	$203.966	$64.062	$32,472	$16.373
10	0.001	0.001	0.001	0.001	7%	7%	7%	$15.616	$6.794	$3,198	$1.499
11	0.000	0.000	0.000	0.000	0%	13%	13%	$10,357	$4,107	$1,477	$924
12	0.006	0.006	0.006	0.006	5%	5%	5%	$138.004	$57.866	$30,016	$16.494
13	0.002	0.001	0.001	0.001	5%	5%	5%	$39,622	$16,259	$8.224	$4.338
14	0.000	0.000	0.000	0.000	0%	7%	7%	$3,619	$1.190	$558	$424
15	0.097	0.094	0.094	0.094	3%	3%	3%	$2.032.146	$800.814	$452,477	$276.257
16	0.024	0.023	0.023	0.023	3%	3%	3%	$583,326	$223,364	$122.855	$72.628
17	0.005	0.005	0.005	0.005	0%	12%	12%	$160,286	$60.087	$23,450	$15.734
18	0.034	0.031	0.031	0.031	10%	10%	11%	$447,257	$159.456	$108.517	$78.120
19	0.009	0.008	0.008	0.008	10%	10%	11%	$126.741	$43,660	$29,046	$20.346
20	0.001	0.000	0.000	0.000	75%	76%	76%	$9,463	$1,545	$1.074	$772
21	0.063	0.063	0.058	0.058	0%	9%	9%	$1.162,567	$432,292	$214,246	$166.730
22	0.016	0.016	0.014	0.014	0%	9%	9%	$332,687	$120,329	$56.965	$43.332
23	0.001	0.001	0.000	0.000	0%	91%	91%	$7,119	$2,944	$300	$198
24	0.017	0.017	0.015	0.015	0%	10%	10%	$320,930	$124,292	$57,514	$43.015
25	0.011	0.011	0.009	0.009	0%	10%	10%	$235,368	$88,995	$39,279	$28.622
26	0.003	0.003	0.000	0.000	0%	88%	88%	$31,014	$13.285	$1,502	$992
27	0.000	0.000	0.000	0.000	100%	100%	100%	$0	$0	$0	$0
28	0.001	0.000	0.000	0.000	66%	67%	67%	$4.339	$1,275	$765	$534
29	0.000	0.000	0.000	0.000	66%	67%	67%	$1,216	$352	$204	$139
30	0.000	0.000	0.000	0.000	7%	7%	7%	$209	$92	$53	$41
31	0.030	0.030	0.027	0.027	0%	11%	11%	$615,092	$238,726	$110,063	$82,133
32	0.005	0.005	0.004	0.004	0%	11%	11%	$112,782	$42,744	$18,795	$13.663
33	0.001	0.001	0.000	0.000	0%	87%	87%	$15,320	$6,652	$780	$515
34	0.001	0.001	0.001	0.001	52%	54%	54%	$10,736	$3,791	$2.120	$1.433
35	0.029	0.014	0.014	0.014	52%	54%	54%	$268,396	$94,780	$53,009	$35.824
36	0.221	0.221	0.188	0.188	0%	15%	15%	$5,732.722	$2,332,727	$913,013	$610,215
37	0.002	0.002	0.001	0.001	31%	41%	45%	$31,503	$11,041	$6.376	$4.216
38	0.002	0.002	0.001	0.001	31%	41%	45%	$31,503	$11,041	$6.376	$4.216
39	0.002	0.002	0.002	0.001	23%	33%	42%	$36.340	$11,915	$7,336	$4.741
40	0.024	0.012	0.011	0.011	50%	54%	54%	$622,227	$150,372	$65.837	$40.143
41	0.009	0.005	0.005	0.005	41%	48%	48%	$295.362	$86,292	$32,469	$17.887
42	0.003	0.001	0.001	0.001	49%	54%	54%	$79.230	$20.630	$8,436	$4,817
43	0.003	0.001	0.001	0.001	49%	54%	54%	$90,476	$23,093	$8,979	$4.930
44	0.002	0.002	0.002	0.002	9%	12%	18%	$22.767	$9.325	$6,923	$5,321
45	0.003	0.003	0.003	0.002	10%	13%	19%	$29.483	$11.663	$8,922	$6.934
46	0.003	0.003	0.003	0.002	10%	12%	19%	$29.269	$11,571	$8.837	$6.355
47	0.004	0.003	0.003	0.003	10%	13%	20%	$36,758	$14,100	$11,074	$8,676
48	0.003	0.003	0.003	0.003	5%	15%	18%	$27.969	$11,462	$9.023	$7.717
49	0.004	0.003	0.003	0.003	5%	15%	19%	$29,276	$12,736	$10,212	$8.870
50	0.004	0.004	0.003	0.003	5%	15%	18%	$31.234	$13,871	$10,688	$9.255

Risk Reduction Rate			Accident /MTK				Risk /MTK			
_PTC1	_PTC2	_PTC3	_ABS	_PTC1	_PTC2	_PTC3	Risk_ABS	Risk_PTC1	Risk_PTC2	Risk_PTC3
59%	67%	70%	0.038	0.038	0.032	0.031	$474,157	$196,091	$156,937	$141,152
62%	69%	72%	0.039	0.038	0.032	0.031	$510,567	$194,912	$156,081	$141,466
65%	71%	77%	0.059	0.052	0.051	0.045	$843,176	$299,271	$248,154	$196,419
67%	73%	79%	0.029	0.026	0.025	0.022	$460,998	$150,464	$124,321	$97,893
69%	86%	93%	0.060	0.057	0.057	0.052	$2,582,970	$805,253	$368,784	$184,058
70%	87%	94%	0.029	0.028	0.028	0.026	$1,444,033	$429,538	$190,881	$92,197
63%	83%	93%	0.046	0.043	0.043	0.037	$1,848,802	$684,348	$305,482	$134,488
64%	84%	93%	0.023	0.022	0.022	0.019	$1,063,016	$386,403	$166,991	$69,393
69%	84%	92%	0.032	0.031	0.031	0.025	$1,085,322	$340,881	$172,788	$87,125
56%	80%	90%	0.009	0.008	0.008	0.008	$241,725	$105,162	$49,505	$23,196
60%	86%	91%	0.006	0.006	0.005	0.005	$160,324	$63,579	$22,859	$14,310
58%	78%	88%	0.023	0.022	0.022	0.022	$510,841	$214,200	$111,107	$61,056
59%	79%	89%	0.011	0.011	0.011	0.011	$293,331	$120,371	$60,881	$32,114
67%	85%	88%	0.002	0.002	0.002	0.002	$58,691	$19,292	$9,051	$6,873
61%	78%	86%	0.068	0.066	0.066	0.066	$1,418,130	$558,847	$315,761	$192,785
62%	79%	88%	0.034	0.033	0.033	0.033	$814,146	$311,748	$171,469	$101,367
63%	85%	90%	0.016	0.016	0.014	0.014	$480,507	$180,130	$70,297	$47,166
64%	76%	83%	0.016	0.014	0.014	0.014	$202,545	$72,211	$49,143	$35,377
66%	77%	84%	0.008	0.007	0.007	0.007	$114,791	$39,543	$26,307	$18,428
84%	89%	92%	0.003	0.001	0.001	0.001	$23,979	$3,914	$2,722	$1,957
63%	82%	86%	0.044	0.044	0.040	0.040	$811,296	$301,674	$149,512	$116,352
64%	83%	87%	0.022	0.022	0.020	0.020	$464,331	$167,943	$79,506	$60,479
59%	96%	97%	0.005	0.005	0.000	0.000	$49,681	$20,546	$2,096	$1,385
61%	82%	87%	0.023	0.023	0.021	0.021	$447,922	$173,474	$80,272	$60,036
62%	83%	88%	0.018	0.018	0.017	0.017	$410,628	$155,263	$68,526	$49,934
57%	95%	97%	0.010	0.010	0.001	0.001	$108,216	$46,353	$5,241	$3,463
100%	100%	100%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
71%	82%	88%	0.002	0.001	0.001	0.001	$15,141	$4,448	$2,670	$1,864
71%	83%	89%	0.001	0.000	0.000	0.000	$8,485	$2,459	$1,426	$969
56%	75%	80%	0.000	0.000	0.000	0.000	$2,700	$1,188	$682	$528
61%	82%	87%	0.034	0.034	0.030	0.030	$691,319	$268,311	$123,703	$92,311
62%	83%	88%	0.014	0.014	0.012	0.012	$316,898	$120,102	$52,811	$38,390
57%	95%	97%	0.008	0.008	0.001	0.001	$86,092	$37,382	$4,383	$2,896
65%	80%	87%	0.003	0.002	0.001	0.001	$28,298	$9,993	$5,589	$3,777
65%	80%	87%	0.016	0.008	0.007	0.007	$141,490	$49,965	$27,944	$18,885
59%	84%	89%	0.109	0.109	0.094	0.094	$2,845,888	$1,158,033	$453,246	$302,928
65%	80%	87%	0.005	0.003	0.003	0.003	$63,406	$22,223	$12,833	$8,485
65%	80%	87%	0.005	0.003	0.003	0.003	$63,406	$22,223	$12,833	$8,485
67%	80%	87%	0.005	0.004	0.003	0.003	$72,970	$23,925	$14,731	$9,520
76%	89%	94%	0.049	0.025	0.023	0.023	$1,249,408	$301,941	$132,198	$80,606
71%	89%	94%	0.032	0.019	0.017	0.017	$1,039,106	$303,582	$114,228	$62,929
74%	89%	94%	0.019	0.010	0.009	0.009	$514,918	$134,074	$54,823	$31,305
74%	90%	95%	0.019	0.010	0.009	0.009	$588,008	$150,079	$58,353	$32,040
59%	70%	77%	0.013	0.012	0.012	0.011	$136,022	$55,714	$41,363	$31,789
60%	70%	76%	0.016	0.014	0.014	0.013	$159,373	$63,044	$48,228	$37,480
60%	70%	77%	0.016	0.015	0.014	0.013	$166,127	$65,676	$50,157	$38,905
62%	70%	76%	0.019	0.017	0.016	0.015	$189,667	$72,754	$57,138	$44,766
59%	68%	72%	0.016	0.016	0.014	0.013	$144,317	$59,143	$46,556	$39,817
56%	65%	70%	0.018	0.017	0.015	0.014	$142,429	$61,958	$49,680	$43,155
56%	66%	70%	0.018	0.017	0.016	0.015	$151,955	$67,483	$51,998	$45,023

Exhibit 17-D Results for Segments (Derailments due to Slow Orders)

	Number of Accidents				Reduction Rate			Risk			
Segment ID	_ABS	_PTC1	_PTC2	_PTC3	PTC1	PTC2	PTC3	E2_ABS	E2_PTC1	E2_PTC2	E2_PTC3
1	0.000	0.000	0.000	0.000	76%	76%	76%	$7	$2	$2	$2
2	0.000	0.000	0.000	0.000	93%	93%	93%	$1,670	$123	$123	$123
3	0.000	0.000	0.000	0.000	88%	88%	88%	$1,572	$223	$223	$223
4	0.001	0.000	0.000	0.000	93%	93%	93%	$4,939	$388	$388	$388
5	0.001	0.000	0.000	0.000	93%	93%	93%	$11,859	$914	$914	$914
6	0.001	0.000	0.000	0.000	93%	93%	93%	$9,038	$660	$660	$660
7	0.002	0.000	0.000	0.000	93%	93%	93%	$16,251	$1,238	$1,238	$1,238
8	0.001	0.000	0.000	0.000	93%	93%	93%	$11,353	$830	$830	$830
9	0.001	0.000	0.000	0.000	93%	93%	93%	$11,342	$871	$871	$871
10	0.001	0.000	0.000	0.000	93%	93%	93%	$4,846	$354	$354	$354
11	0.001	0.000	0.000	0.000	93%	93%	93%	$2,778	$211	$211	$211
12	0.002	0.000	0.000	0.000	93%	93%	93%	$14,808	$1,116	$1,116	$1,116
13	0.002	0.000	0.000	0.000	93%	93%	93%	$9,794	$716	$716	$716
14	0.001	0.000	0.000	0.000	93%	93%	93%	$2,057	$154	$154	$154
15	0.008	0.001	0.001	0.001	93%	93%	93%	$54,975	$4,144	$4,144	$4,144
16	0.008	0.001	0.001	0.001	93%	93%	93%	$38,481	$2,817	$2,817	$2,817
17	0.005	0.000	0.000	0.000	93%	93%	93%	$17,575	$1,323	$1,323	$1,323
18	0.022	0.001	0.001	0.001	93%	93%	93%	$150,342	$11,334	$11,334	$11,334
19	0.020	0.001	0.001	0.001	93%	93%	93%	$106,156	$7,771	$7,771	$7,771
20	0.007	0.000	0.000	0.000	93%	93%	93%	$17,173	$1,253	$1,253	$1,253
21	0.001	0.000	0.000	0.000	89%	89%	89%	$6,281	$873	$873	$873
22	0.005	0.000	0.000	0.000	93%	93%	93%	$13,751	$1,108	$1,108	$1,108
23	0.001	0.000	0.000	0.000	93%	93%	93%	$2,212	$160	$160	$160
24	0.001	0.000	0.000	0.000	89%	89%	89%	$3,140	$437	$437	$437
25	0.004	0.000	0.000	0.000	93%	93%	93%	$11,001	$886	$886	$886
26	0.002	0.000	0.000	0.000	93%	93%	93%	$4,423	$321	$321	$321
27	0.003	0.002	0.002	0.002	21%	21%	21%	$4,439	$3,022	$3,022	$3,022
28	0.000	0.000	0.000	0.000	89%	89%	89%	$1,256	$175	$175	$175
29	0.001	0.000	0.000	0.000	93%	93%	93%	$2,750	$222	$222	$222
30	0.001	0.000	0.000	0.000	93%	93%	93%	$1,602	$115	$115	$115
31	0.001	0.000	0.000	0.000	89%	89%	89%	$5,480	$762	$762	$762
32	0.003	0.000	0.000	0.000	93%	93%	93%	$9,511	$767	$767	$767
33	0.001	0.000	0.000	0.000	93%	93%	93%	$3,840	$278	$278	$278
34	0.001	0.000	0.000	0.000	89%	89%	89%	$2,922	$406	$406	$406
35	0.003	0.000	0.000	0.000	89%	89%	89%	$14,612	$2,032	$2,032	$2,032
36	0.022	0.002	0.002	0.002	93%	93%	93%	$73,392	$5,995	$5,995	$5,995
37	0.001	0.000	0.000	0.000	89%	89%	89%	$5,505	$769	$769	$769
38	0.001	0.000	0.000	0.000	89%	89%	89%	$5,505	$769	$769	$769
39	0.001	0.000	0.000	0.000	89%	89%	89%	$4,743	$664	$664	$664
40	0.001	0.000	0.000	0.000	89%	89%	89%	$4,743	$664	$664	$664
41	0.003	0.000	0.000	0.000	93%	93%	93%	$16,363	$1,334	$1,334	$1,334
42	0.000	0.000	0.000	0.000	89%	89%	89%	$1,895	$265	$265	$265
43	0.002	0.000	0.000	0.000	93%	93%	93%	$8,599	$698	$698	$698
44	0.000	0.000	0.000	0.000	89%	89%	89%	$1,707	$239	$239	$239
45	0.000	0.000	0.000	0.000	89%	89%	89%	$1,710	$240	$240	$240
46	0.000	0.000	0.000	0.000	89%	89%	89%	$1,302	$183	$183	$183
47	0.000	0.000	0.000	0.000	89%	89%	89%	$1,305	$184	$184	$184
48	0.001	0.000	0.000	0.000	93%	93%	93%	$3,549	$260	$260	$260
49	0.000	0.000	0.000	0.000	76%	76%	76%	$57	$18	$18	$18
50	0.000	0.000	0.000	0.000	76%	76%	76%	$57	$18	$18	$18

Risk Reduction Rate			Accident /MTK				Risk /MTK			
_PTC1	_PTC2	_PTC3	e_ABS	_PTC1	_PTC2	_PTC3	Risk_ABS	Risk_PTC1	Risk_PTC2	Risk_PTC3
70%	70%	70%	0.000	0.000	0.000	0.000	$21	$6	$6	$6
93%	93%	93%	0.001	0.000	0.000	0.000	$4,820	$354	$354	$354
86%	86%	86%	0.000	0.000	0.000	0.000	$3,346	$474	$474	$474
92%	92%	92%	0.003	0.000	0.000	0.000	$21,566	$1,692	$1,692	$1,692
92%	92%	92%	0.005	0.000	0.000	0.000	$51,383	$3,959	$3,959	$3,959
93%	93%	93%	0.009	0.001	0.001	0.001	$78,318	$5,720	$5,720	$5,720
92%	92%	92%	0.008	0.001	0.001	0.001	$83,095	$6,333	$6,333	$6,333
93%	93%	93%	0.013	0.001	0.001	0.001	$116,102	$8,484	$8,484	$8,484
92%	92%	92%	0.006	0.000	0.000	0.000	$60,350	$4,637	$4,637	$4,637
93%	93%	93%	0.013	0.001	0.001	0.001	$75,019	$5,487	$5,487	$5,487
92%	92%	92%	0.012	0.001	0.001	0.001	$42,998	$3,264	$3,264	$3,264
92%	92%	92%	0.008	0.001	0.001	0.001	$54,813	$4,132	$4,132	$4,132
93%	93%	93%	0.013	0.001	0.001	0.001	$72,506	$5,304	$5,304	$5,304
93%	93%	93%	0.012	0.001	0.001	0.001	$33,356	$2,501	$2,501	$2,501
92%	92%	92%	0.006	0.000	0.000	0.000	$38,364	$2,892	$2,892	$2,892
93%	93%	93%	0.012	0.001	0.001	0.001	$53,708	$3,931	$3,931	$3,931
92%	92%	92%	0.015	0.001	0.001	0.001	$52,687	$3,967	$3,967	$3,967
92%	92%	92%	0.010	0.001	0.001	0.001	$68,084	$5,133	$5,133	$5,133
93%	93%	93%	0.018	0.001	0.001	0.001	$96,148	$7,038	$7,038	$7,038
93%	93%	93%	0.017	0.001	0.001	0.001	$43,513	$3,175	$3,175	$3,175
86%	86%	86%	0.001	0.000	0.000	0.000	$4,383	$609	$609	$609
92%	92%	92%	0.007	0.000	0.000	0.000	$19,193	$1,546	$1,546	$1,546
93%	93%	93%	0.006	0.000	0.000	0.000	$15,435	$1,119	$1,119	$1,119
86%	86%	86%	0.001	0.000	0.000	0.000	$4,383	$609	$609	$609
92%	92%	92%	0.007	0.000	0.000	0.000	$19,193	$1,546	$1,546	$1,546
93%	93%	93%	0.006	0.000	0.000	0.000	$15,435	$1,119	$1,119	$1,119
32%	32%	32%	0.020	0.016	0.016	0.016	$30,976	$21,086	$21,086	$21,086
86%	86%	86%	0.001	0.000	0.000	0.000	$4,383	$609	$609	$609
92%	92%	92%	0.007	0.000	0.000	0.000	$19,193	$1,546	$1,546	$1,546
93%	93%	93%	0.007	0.001	0.001	0.001	$20,661	$1,484	$1,484	$1,484
86%	86%	86%	0.001	0.000	0.000	0.000	$6,159	$856	$856	$856
92%	92%	92%	0.009	0.001	0.001	0.001	$26,724	$2,156	$2,156	$2,156
93%	93%	93%	0.008	0.001	0.001	0.001	$21,582	$1,563	$1,563	$1,563
86%	86%	86%	0.002	0.000	0.000	0.000	$7,703	$1,071	$1,071	$1,071
86%	86%	86%	0.002	0.000	0.000	0.000	$7,703	$1,071	$1,071	$1,071
92%	92%	92%	0.011	0.001	0.001	0.001	$36,434	$2,976	$2,976	$2,976
86%	86%	86%	0.001	0.000	0.000	0.000	$11,080	$1,547	$1,547	$1,547
86%	86%	86%	0.001	0.000	0.000	0.000	$11,080	$1,547	$1,547	$1,547
86%	86%	86%	0.001	0.000	0.000	0.000	$9,524	$1,333	$1,333	$1,333
86%	86%	86%	0.001	0.000	0.000	0.000	$9,524	$1,333	$1,333	$1,333
92%	92%	92%	0.011	0.001	0.001	0.001	$57,565	$4,695	$4,694	$4,695
86%	86%	86%	0.002	0.000	0.000	0.000	$12,316	$1,722	$1,722	$1,722
92%	92%	92%	0.011	0.001	0.001	0.001	$55,886	$4,536	$4,536	$4,536
86%	86%	86%	0.001	0.000	0.000	0.000	$10,196	$1,429	$1,429	$1,429
86%	86%	86%	0.001	0.000	0.000	0.000	$9,246	$1,298	$1,298	$1,298
86%	86%	86%	0.001	0.000	0.000	0.000	$7,391	$1,038	$1,038	$1,038
86%	86%	86%	0.001	0.000	0.000	0.000	$6,734	$948	$948	$948
93%	93%	93%	0.005	0.000	0.000	0.000	$18,311	$1,340	$1,340	$1,340
69%	69%	69%	0.000	0.000	0.000	0.000	$278	$86	$86	$86
69%	69%	69%	0.000	0.000	0.000	0.000	$278	$86	$86	$86

Exhibit 17-E Results for Segments (Derailments due to Permanent Speed Restrictions)

	Number of Accidents				Reduction Rate			Risk			
Segment ID	_ABS	_PTC1	_PTC2	_PTC3	_PTC1	_PTC2	_PTC3	E2_ABS	E2_PTC1	E2_PTC2	E2_PTC3
1	0.000	0.000	0.000	0.000	22%	22%	22%	$0	$0	$0	$0
2	0.000	0.000	0.000	0.000	13%	13%	13%	$0	$0	$0	$0
3	0.000	0.000	0.000	0.000	39%	39%	39%	$0	$0	$0	$0
4	0.000	0.000	0.000	0.000	11%	11%	11%	$23	$21	$21	$21
5	0.000	0.000	0.000	0.000	42%	42%	42%	$0	$0	$0	$0
6	0.000	0.000	0.000	0.000	80%	80%	80%	$633	$152	$152	$152
7	0.000	0.000	0.000	0.000	42%	42%	42%	$0	$0	$0	$0
8	0.000	0.000	0.000	0.000	80%	80%	80%	$1,583	$380	$380	$380
9	0.000	0.000	0.000	0.000	42%	42%	42%	$0	$0	$0	$0
10	0.000	0.000	0.000	0.000	80%	80%	80%	$241	$58	$58	$58
11	0.000	0.000	0.000	0.000	12%	12%	12%	$11	$10	$10	$10
12	0.000	0.000	0.000	0.000	42%	42%	42%	$0	$0	$0	$0
13	0.000	0.000	0.000	0.000	80%	80%	80%	$362	$87	$87	$87
14	0.000	0.000	0.000	0.000	12%	12%	12%	$6	$5	$5	$5
15	0.000	0.000	0.000	0.000	42%	42%	42%	$0	$0	$0	$0
16	0.000	0.000	0.000	0.000	80%	80%	80%	$1,206	$289	$289	$289
17	0.000	0.000	0.000	0.000	12%	12%	12%	$45	$42	$42	$42
18	0.000	0.000	0.000	0.000	42%	42%	42%	$0	$0	$0	$0
19	0.000	0.000	0.000	0.000	80%	80%	80%	$2.412	$579	$579	$579
20	0.000	0.000	0.000	0.000	12%	12%	12%	$23	$21	$21	$21
21	0.000	0.000	0.000	0.000	39%	39%	39%	$0	$0	$0	$0
22	0.000	0.000	0.000	0.000	11%	11%	11%	$13	$12	$12	$12
23	0.000	0.000	0.000	0.000	15%	15%	15%	$0	$0	$0	$0
24	0.000	0.000	0.000	0.000	39%	39%	39%	$0	$0	$0	$0
25	0.000	0.000	0.000	0.000	11%	11%	11%	$11	$10	$10	$10
26	0.000	0.000	0.000	0.000	15%	15%	15%	$0	$0	$0	$0
27	0.000	0.000	0.000	0.000	31%	31%	31%	$0	$0	$0	$0
28	0.000	0.000	0.000	0.000	39%	39%	39%	$0	$0	$0	$0
29	0.000	0.000	0.000	0.000	11%	11%	11%	$7	$6	$6	$6
30	0.000	0.000	0.000	0.000	15%	15%	15%	$0	$0	$0	$0
31	0.000	0.000	0.000	0.000	39%	39%	39%	$0	$0	$0	$0
32	0.000	0.000	0.000	0.000	11%	11%	11%	$8	$7	$7	$7
33	0.000	0.000	0.000	0.000	15%	15%	15%	$0	$0	$0	$0
34	0.000	0.000	0.000	0.000	39%	39%	39%	$0	$0	$0	$0
35	0.000	0.000	0.000	0.000	39%	39%	39%	$0	$0	$0	$0
36	0.000	0.000	0.000	0.000	11%	11%	11%	$66	$61	$61	$61
37	0.000	0.000	0.000	0.000	39%	39%	39%	$0	$0	$0	$0
38	0.000	0.000	0.000	0.000	39%	39%	39%	$0	$0	$0	$0
39	0.000	0.000	0.000	0.000	39%	39%	39%	$0	$0	$0	$0
40	0.000	0.000	0.000	0.000	39%	39%	39%	$0	$0	$0	$0
41	0.000	0.000	0.000	0.000	11%	11%	11%	$16	$15	$15	$15
42	0.000	0.000	0.000	0.000	39%	39%	39%	$0	$0	$0	$0
43	0.000	0.000	0.000	0.000	11%	11%	11%	$20	$18	$18	$18
44	0.000	0.000	0.000	0.000	39%	39%	39%	$0	$0	$0	$0
45	0.000	0.000	0.000	0.000	39%	39%	39%	$0	$0	$0	$0
46	0.000	0.000	0.000	0.000	39%	39%	39%	$0	$0	$0	$0
47	0.000	0.000	0.000	0.000	39%	39%	39%	$0	$0	$0	$0
48	0.000	0.000	0.000	0.000	13%	13%	13%	$0	$0	$0	$0
49	0.000	0.000	0.000	0.000	22%	22%	22%	$0	$0	$0	$0
50	0.000	0.000	0.000	0.000	22%	22%	22%	$0	$0	$0	$0

Risk Reduction Rate			Accident /MTK				Risk /MTK			
_PTC1	_PTC2	_PTC3	e_ABS	_PTC1	_PTC2	_PTC3	Risk_ABS	Risk_PTC1	Risk_PTC2	Risk_PTC3
25%	25%	25%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
10%	10%	10%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
38%	38%	38%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
8%	8%	8%	0.000	0.000	0.000	0.000	$101	$93	$93	$93
34%	34%	34%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
76%	76%	76%	0.000	0.000	0.000	0.000	$5,487	$1,317	$1,317	$1,317
34%	34%	34%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
76%	76%	76%	0.001	0.000	0.000	0.000	$16.190	$3,884	$3.884	$3.884
34%	34%	34%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
76%	76%	76%	0.000	0.000	0.000	0.000	$3,734	$896	$896	$896
8%	8%	8%	0.000	0.000	0.000	0.000	$176	$161	$161	$161
34%	34%	34%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
76%	76%	76%	0.000	0.000	0.000	0.000	$2.679	$643	$643	$643
8%	8%	8%	0.000	0.000	0.000	0.000	$92	$85	$85	$85
34%	34%	34%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
76%	76%	76%	0.000	0.000	0.000	0.000	$1,683	$404	$404	$404
8%	8%	8%	0.000	0.000	0.000	0.000	$136	$125	$125	$125
34%	34%	34%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
76%	76%	76%	0.000	0.000	0.000	0.000	$2,185	$524	$524	$524
8%	8%	8%	0.000	0.000	0.000	0.000	$58	$53	$53	$53
38%	38%	38%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
8%	8%	8%	0.000	0.000	0.000	0.000	$18	$17	$17	$17
11%	11%	11%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
38%	38%	38%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
8%	8%	8%	0.000	0.000	0.000	0.000	$18	$17	$17	$17
11%	11%	11%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
28%	28%	28%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
38%	38%	38%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
8%	8%	8%	0.000	0.000	0.000	0.000	$46	$43	$43	$43
11%	11%	11%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
38%	38%	38%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
8%	8%	8%	0.000	0.000	0.000	0.000	$22	$21	$21	$21
11%	11%	11%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
38%	38%	38%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
38%	38%	38%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
8%	8%	8%	0.000	0.000	0.000	0.000	$33	$30	$30	$30
38%	38%	38%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
38%	38%	38%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
38%	38%	38%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
38%	38%	38%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
8%	8%	8%	0.000	0.000	0.000	0.000	$56	$52	$52	$52
38%	38%	38%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
8%	8%	8%	0.000	0.000	0.000	0.000	$129	$119	$119	$119
38%	38%	38%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
38%	38%	38%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
38%	38%	38%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
38%	38%	38%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
10%	10%	10%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
25%	25%	25%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
25%	25%	25%	0.000	0.000	0.000	0.000	$0	$0	$0	$0

Exhibit 17-F Results for Segments (MOW Collisions)

	Number of Accidents				Reduction Rate			Risk			
Segment ID	_ABS	PTC1	PTC2	PTC3	PTC1	PTC2	PTC3	E2_ABS	E2_PTC1	E2_PTC2	E2_PTC3
1	0.000	0.000	0.000	0.000	23%	23%	23%	$5,510	$4.213	$4,164	$4.118
2	0.000	0.000	0.000	0.000	23%	48%	48%	$8,158	$6.234	$2,922	$2.887
3	0.001	0.001	0.001	0.001	23%	30%	30%	$110,082	$83.697	$60,005	$59,021
4	0.000	0.000	0.000	0.000	51%	51%	55%	$34,369	$17,557	$17,240	$12,577
5	0.000	0.000	0.000	0.000	23%	23%	23%	$529	$405	$400	$396
6	0.000	0.000	0.000	0.000	23%	23%	23%	$153	$117	$116	$114
7	0.000	0.000	0.000	0.000	23%	23%	23%	$689	$527	$521	$516
8	0.000	0.000	0.000	0.000	23%	23%	23%	$177	$135	$134	$132
9	0.000	0.000	0.000	0.000	23%	23%	23%	$260	$199	$197	$194
10	0.000	0.000	0.000	0.000	23%	23%	23%	$48	$36	$36	$36
11	0.000	0.000	0.000	0.000	100%	100%	100%	$0	$0	$0	$0
12	0.000	0.000	0.000	0.000	23%	23%	23%	$524	$401	$396	$392
13	0.000	0.000	0.000	0.000	23%	23%	23%	$135	$103	$102	$101
14	0.000	0.000	0.000	0.000	100%	100%	100%	$0	$0	$0	$0
15	0.000	0.000	0.000	0.000	23%	23%	23%	$6.880	$5.264	$5,206	$5.149
16	0.000	0.000	0.000	0.000	23%	23%	23%	$1.769	$1.353	$1,337	$1.321
17	0.000	0.000	0.000	0.000	100%	100%	100%	$0	$0	$0	$0
18	0.006	0.005	0.005	0.005	23%	23%	23%	$305.838	$232.230	$228.049	$224,064
19	0.002	0.001	0.001	0.001	23%	23%	23%	$80.872	$61.293	$60,082	$58,930
20	0.000	0.000	0.000	0.000	23%	23%	23%	$696	$531	$524	$517
21	0.000	0.000	0.000	0.000	100%	100%	100%	$0	$0	$0	$0
22	0.000	0.000	0.000	0.000	100%	100%	100%	$0	$0	$0	$0
23	0.000	0.000	0.000	0.000	100%	100%	100%	$0	$0	$0	$0
24	0.000	0.000	0.000	0.000	100%	100%	100%	$0	$0	$0	$0
25	0.000	0.000	0.000	0.000	100%	100%	100%	$0	$0	$0	$0
26	0.000	0.000	0.000	0.000	100%	100%	100%	$0	$0	$0	$0
27	0.000	0.000	0.000	0.000	100%	100%	100%	$0	$0	$0	$0
28	0.000	0.000	0.000	0.000	23%	23%	23%	$241	$184	$182	$180
29	0.000	0.000	0.000	0.000	23%	23%	23%	$62	$48	$47	$47
30	0.000	0.000	0.000	0.000	100%	100%	100%	$0	$0	$0	$0
31	0.000	0.000	0.000	0.000	100%	100%	100%	$0	$0	$0	$0
32	0.000	0.000	0.000	0.000	100%	100%	100%	$0	$0	$0	$0
33	0.000	0.000	0.000	0.000	100%	100%	100%	$0	$0	$0	$0
34	0.000	0.000	0.000	0.000	23%	23%	23%	$1.283	$981	$970	$960
35	0.002	0.001	0.001	0.001	23%	23%	23%	$32,079	$24.535	$24,261	$23,995
36	0.000	0.000	0.000	0.000	100%	100%	100%	$0	$0	$0	$0
37	0.000	0.000	0.000	0.000	23%	23%	23%	$3.268	$2.500	$2,472	$2,445
38	0.000	0.000	0.000	0.000	23%	23%	23%	$3.268	$2,500	$2,472	$2,445
39	0.000	0.000	0.000	0.000	23%	23%	23%	$3,902	$2,984	$2,951	$2,919
40	0.000	0.000	0.000	0.000	100%	100%	100%	$0	$0	$0	$0
41	0.000	0.000	0.000	0.000	100%	100%	100%	$0	$0	$0	$0
42	0.000	0.000	0.000	0.000	100%	100%	100%	$0	$0	$0	$0
43	0.000	0.000	0.000	0.000	100%	100%	100%	$0	$0	$0	$0
44	0.000	0.000	0.000	0.000	23%	36%	36%	$30,598	$23,237	$15,750	$15,467
45	0.000	0.000	0.000	0.000	23%	35%	35%	$31,205	$23,701	$16.162	$15,875
46	0.000	0.000	0.000	0.000	23%	35%	35%	$28.232	$21.443	$14.623	$14,362
47	0.000	0.000	0.000	0.000	23%	34%	34%	$30,414	$23,103	$15,848	$15,569
48	0.000	0.000	0.000	0.000	23%	48%	48%	$8.822	$6,741	$3,160	$3,122
49	0.000	0.000	0.000	0.000	23%	23%	23%	$4.041	$3.090	$3,054	$3,020
50	0.000	0.000	0.000	0.000	23%	23%	23%	$1,914	$1,463	$1,447	$1,430

Risk Reduction Rate			Accident /MTK				Risk /MTK			
_PTC1	_PTC2	_PTC3	e_ABS	_PTC1	_PTC2	_PTC3	Risk_ABS	Risk_PTC1	Risk_PTC2	Risk_PTC3
24%	24%	25%	0.000	0.000	0.000	0.000	$15,637	$11,956	$11,818	$11,686
24%	64%	65%	0.000	0.000	0.000	0.000	$23,544	$17,991	$8,434	$8.331
24%	45%	46%	0.003	0.002	0.002	0.002	$234,304	$178,144	$127,716	$125.622
49%	50%	63%	0.002	0.001	0.001	0.001	$150,056	$76,655	$75,271	$54,910
23%	24%	25%	0.000	0.000	0.000	0.000	$2.293	$1,754	$1.735	$1,716
24%	24%	25%	0.000	0.000	0.000	0.000	$1,327	$1,014	$1,002	$991
23%	24%	25%	0.000	0.000	0.000	0.000	$3,523	$2,696	$2,666	$2,637
24%	24%	25%	0.000	0.000	0.000	0.000	$1,812	$1,385	$1,369	$1,353
23%	24%	25%	0.000	0.000	0.000	0.000	$1,382	$1,058	$1,046	$1.035
24%	24%	25%	0.000	0.000	0.000	0.000	$737	$563	$557	$550
100%	100%	100%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
23%	24%	25%	0.000	0.000	0.000	0.000	$1,939	$1.483	$1,467	$1,451
24%	24%	25%	0.000	0.000	0.000	0.000	$997	$762	$753	$745
100%	100%	100%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
23%	24%	25%	0.000	0.000	0.000	0.000	$4,801	$3,673	$3,633	$3.593
24%	24%	25%	0.000	0.000	0.000	0.000	$2.469	$1,888	$1.866	$1,844
100%	100%	100%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
24%	25%	27%	0.003	0.002	0.002	0.002	$138,501	$105,167	$103.274	$101,469
24%	26%	27%	0.001	0.001	0.001	0.001	$73,247	$55.514	$54,417	$53.374
24%	25%	26%	0.000	0.000	0.000	0.000	$1,764	$1,345	$1,327	$1,309
100%	100%	100%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
100%	100%	100%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
100%	100%	100%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
100%	100%	100%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
100%	100%	100%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
100%	100%	100%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
100%	100%	100%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
24%	24%	25%	0.000	0.000	0.000	0.000	$840	$642	$635	$628
24%	25%	25%	0.000	0.000	0.000	0.000	$435	$333	$329	$325
100%	100%	100%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
100%	100%	100%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
100%	100%	100%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
100%	100%	100%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
24%	24%	25%	0.000	0.000	0.000	0.000	$3,382	$2,587	$2,558	$2,530
24%	24%	25%	0.001	0.001	0.001	0.001	$16,911	$12,934	$12,790	$12,649
100%	100%	100%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
24%	24%	25%	0.000	0.000	0.000	0.000	$6,578	$5,032	$4,975	$4,921
24%	24%	25%	0.000	0.000	0.000	0.000	$6,578	$5,032	$4,975	$4.921
24%	24%	25%	0.000	0.000	0.000	0.000	$7,835	$5,992	$5,925	$5,861
100%	100%	100%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
100%	100%	100%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
100%	100%	100%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
100%	100%	100%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
24%	49%	49%	0.002	0.001	0.001	0.001	$182,310	$138,831	$94,101	$92,410
24%	48%	49%	0.002	0.001	0.001	0.001	$168,682	$128.117	$87.366	$85,811
24%	48%	49%	0.002	0.001	0.001	0.001	$160,243	$121,707	$82.995	$81,518
24%	48%	49%	0.002	0.001	0.001	0.001	$156,932	$119,207	$81,774	$80.332
24%	64%	65%	0.001	0.001	0.000	0.000	$45,520	$34,783	$16,306	$16,107
24%	24%	25%	0.000	0.000	0.000	0.000	$19.659	$15,031	$14,858	$14,691
24%	24%	25%	0.000	0.000	0.000	0.000	$9,312	$7,120	$7,038	$6,959

Exhibit 17-G Results for Segments (Rear-end Collisions)

	Number of Accidents				Reduction Rate			Risk			
Segment ID	_ABS	PTC1	PTC2	PTC3	PTC1	PTC2	PTC3	E2_ABS	E2_PTC1	E2_PTC2	E2_PTC3
1	0.000	0.000	0.000	0.000	0%	0%	0%	$0	$0	$0	$0
2	0.000	0.000	0.000	0.000	0%	0%	0%	$0	$0	$0	$0
3	0.000	0.000	0.000	0.000	100%	100%	100%	$0	$0	$0	$0
4	0.000	0.000	0.000	0.000	100%	100%	100%	$0	$0	$0	$0
5	0.000	0.000	0.000	0.000	100%	100%	100%	$0	$0	$0	$0
6	0.000	0.000	0.000	0.000	100%	100%	100%	$0	$0	$0	$0
7	0.000	0.000	0.000	0.000	100%	100%	100%	$0	$0	$0	$0
8	0.000	0.000	0.000	0.000	100%	100%	100%	$0	$0	$0	$0
9	0.000	0.000	0.000	0.000	100%	100%	100%	$0	$0	$0	$0
10	0.000	0.000	0.000	0.000	100%	100%	100%	$0	$0	$0	$0
11	0.000	0.000	0.000	0.000	100%	100%	100%	$0	$0	$0	$0
12	0.000	0.000	0.000	0.000	100%	100%	100%	$0	$0	$0	$0
13	0.000	0.000	0.000	0.000	100%	100%	100%	$0	$0	$0	$0
14	0.000	0.000	0.000	0.000	100%	100%	100%	$0	$0	$0	$0
15	0.000	0.000	0.000	0.000	100%	100%	100%	$0	$0	$0	$0
16	0.000	0.000	0.000	0.000	100%	100%	100%	$0	$0	$0	$0
17	0.000	0.000	0.000	0.000	100%	100%	100%	$0	$0	$0	$0
18	0.000	0.000	0.000	0.000	100%	100%	100%	$0	$0	$0	$0
19	0.000	0.000	0.000	0.000	100%	100%	100%	$0	$0	$0	$0
20	0.000	0.000	0.000	0.000	100%	100%	100%	$0	$0	$0	$0
21	0.000	0.000	0.000	0.000	100%	100%	100%	$0	$0	$0	$0
22	0.000	0.000	0.000	0.000	100%	100%	100%	$0	$0	$0	$0
23	0.000	0.000	0.000	0.000	0%	0%	0%	$0	$0	$0	$0
24	0.000	0.000	0.000	0.000	100%	100%	100%	$0	$0	$0	$0
25	0.000	0.000	0.000	0.000	100%	100%	100%	$0	$0	$0	$0
26	0.000	0.000	0.000	0.000	0%	0%	0%	$0	$0	$0	$0
27	0.000	0.000	0.000	0.000	0%	0%	0%	$0	$0	$0	$0
28	0.000	0.000	0.000	0.000	100%	100%	100%	$0	$0	$0	$0
29	0.000	0.000	0.000	0.000	100%	100%	100%	$0	$0	$0	$0
30	0.000	0.000	0.000	0.000	0%	0%	0%	$0	$0	$0	$0
31	0.000	0.000	0.000	0.000	100%	100%	100%	$0	$0	$0	$0
32	0.000	0.000	0.000	0.000	100%	100%	100%	$0	$0	$0	$0
33	0.000	0.000	0.000	0.000	0%	0%	0%	$0	$0	$0	$0
34	0.000	0.000	0.000	0.000	100%	100%	100%	$0	$0	$0	$0
35	0.000	0.000	0.000	0.000	100%	100%	100%	$0	$0	$0	$0
36	0.000	0.000	0.000	0.000	100%	100%	100%	$0	$0	$0	$0
37	0.000	0.000	0.000	0.000	100%	100%	100%	$0	$0	$0	$0
38	0.000	0.000	0.000	0.000	100%	100%	100%	$0	$0	$0	$0
39	0.000	0.000	0.000	0.000	100%	100%	100%	$0	$0	$0	$0
40	0.000	0.000	0.000	0.000	100%	100%	100%	$0	$0	$0	$0
41	0.000	0.000	0.000	0.000	100%	100%	100%	$0	$0	$0	$0
42	0.000	0.000	0.000	0.000	100%	100%	100%	$0	$0	$0	$0
43	0.000	0.000	0.000	0.000	100%	100%	100%	$0	$0	$0	$0
44	0.000	0.000	0.000	0.000	100%	100%	100%	$0	$0	$0	$0
45	0.000	0.000	0.000	0.000	100%	100%	100%	$0	$0	$0	$0
46	0.000	0.000	0.000	0.000	100%	100%	100%	$0	$0	$0	$0
47	0.000	0.000	0.000	0.000	100%	100%	100%	$0	$0	$0	$0
48	0.000	0.000	0.000	0.000	0%	0%	0%	$0	$0	$0	$0
49	0.000	0.000	0.000	0.000	0%	0%	0%	$0	$0	$0	$0
50	0.000	0.000	0.000	0.000	0%	0%	0%	$0	$0	$0	$0

Risk Reduction Rate			Accident /MTK				Risk /MTK			
_PTC1	_PTC2	_PTC3	e_ABS	_PTC1	_PTC2	_PTC3	Risk_ABS	Risk_PTC1	Risk_PTC2	Risk_PTC3
0%	0%	0%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
0%	0%	0%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
100%	100%	100%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
100%	100%	100%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
100%	100%	100%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
100%	100%	100%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
100%	100%	100%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
100%	100%	100%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
100%	100%	100%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
100%	100%	100%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
100%	100%	100%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
100%	100%	100%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
100%	100%	100%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
100%	100%	100%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
100%	100%	100%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
100%	100%	100%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
100%	100%	100%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
100%	100%	100%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
100%	100%	100%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
100%	100%	100%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
100%	100%	100%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
100%	100%	100%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
0%	0%	0%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
100%	100%	100%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
100%	100%	100%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
0%	0%	0%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
0%	0%	0%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
100%	100%	100%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
100%	100%	100%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
0%	0%	0%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
100%	100%	100%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
100%	100%	100%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
0%	0%	0%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
100%	100%	100%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
100%	100%	100%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
100%	100%	100%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
100%	100%	100%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
100%	100%	100%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
100%	100%	100%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
100%	100%	100%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
100%	100%	100%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
100%	100%	100%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
100%	100%	100%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
100%	100%	100%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
100%	100%	100%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
100%	100%	100%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
100%	100%	100%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
0%	0%	0%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
0%	0%	0%	0.000	0.000	0.000	0.000	$0	$0	$0	$0
0%	0%	0%	0.000	0.000	0.000	0.000	$0	$0	$0	$0

Exhibit 18 Base Case Segment Results Summary

Segments	E(# Accidents/MTK) ABS	PTC1	PTC2	PTC3	Reduction Rate PTC1	PTC2	PTC3	MTK
1~4	0.117	0.101	0.087	0.062	13%	26%	47%	1.40
5~9	0.205	0.169	0.143	0.085	17%	30%	59%	0.83
10~36	0.079	0.063	0.053	0.038	20%	33%	52%	17.02
37~50	0.106	0.083	0.067	0.037	22%	37%	66%	3.91

Segments	Risk ($/MTK) ABS	PTC1	PTC2	PTC3	Reduction Rate PTC1	PTC2	PTC3	MTK
1~4	$1,334,710	$805,756	$636,863	$386,745	40%	52%	71%	1.40
5~9	$3,868,349	$2,237,459	$1,528,852	$592,304	42%	60%	85%	0.83
10~36	$953,281	$440,156	$252.609	$143,629	54%	74%	85%	17.02
37~50	$985,365	$600,963	$433,878	$200,168	39%	56%	80%	3.91

Exhibit 19 Accident Frequency Comparison

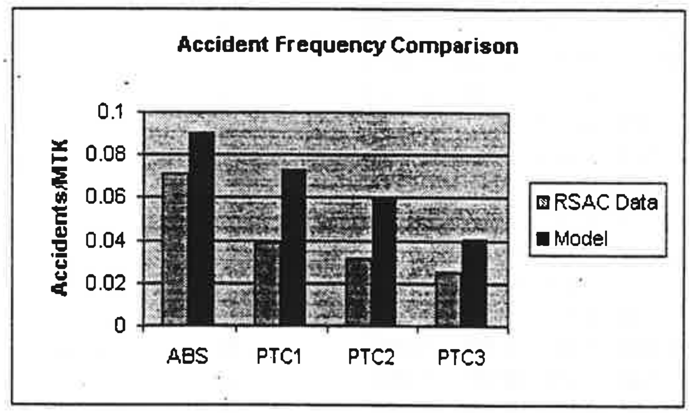


Exhibit 20 Personal casualties in Train Operations

Table 5-1. Personal Casualties in Train Operations

Category of Person	Amtrak Passenger Train Casualties 1986 - mid 1993		Casualty Frequency per Million Train-km			
			Amtrak Passenger Train Operations		Casualties Reported by Freight Railroads	
	Injuries	Fatalities	Injuries	Fatalities	Injuries	Fatalities
Passengers	1397	50	3.61	0.129	N/A*	N/A*
Employees	70	2	0.181	0.005	0.174	0.006
Contractors	3	2	0.008	0.005	0.006	0.003
Non-Trespassers	16	21	0.041	0.054	0.025	0.012
Trespassers	165	387	0.426	1.00	0.51	0.55

N/A*: Under FRA accident reporting procedures, casualties in passenger train accidents on freight railroads, other than in Amtrak operations, are reportable by the freight railroad. There were five fatalities and 808 injuries reported by freight railroads in the period analyzed, occurring in commuter and excursion train operations. Casualty frequency could not be calculated because corresponding train-km data were not available.

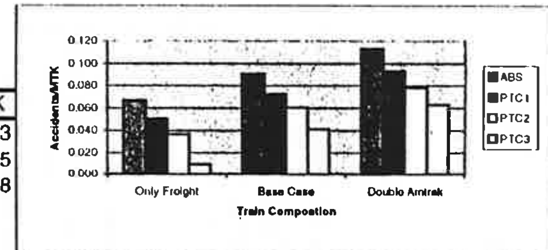
Exhibit 21 Consequences per PPA

Train Type	Risk	Fatalities	Passenger Injuries	Employee Injuries	Track Damages	Equipment Damages	Total Costs
Passenger	High	0.9483	3.3621	2.0517	$32,107	$493,515	$3,476,118
	Low	0.1509	1.9245	1.9434	$19,885	$323,356	$1,050,859
Freight	High	0.0938	0.2285	0.7031	$26,949	$265,906	$628,993
	Low	0.0657	0.1564	0.5125	$26,313	$222,633	$486,188

Exhibit 22 Trains Compostion Sensitivity

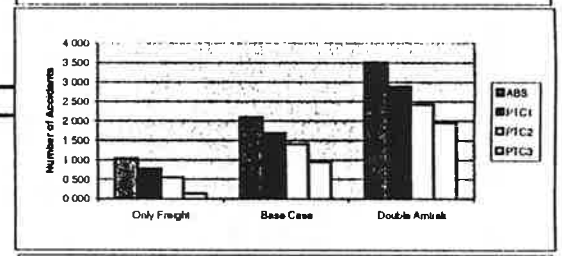
A. Accident Frequency (#/MTK)

	E(# accidents/MTK)				Percentage of Base Case				Reduction			
Train Composti	ABS	PTC1	PTC2	PTC3	ABS	PTC1	PTC2	PTC3	PTC1	PTC2	PTC3	MTK
Only Freight	0.067	0.050	0.036	0.009	74%	69%	60%	22%	26%	46%	87%	15.33
Base Case	0.090	0.073	0.060	0.041	100%	100%	100%	100%	20%	33%	55%	23.15
Double Amtrak	0.113	0.093	0.078	0.063	125%	128%	130%	154%	18%	31%	44%	30.98



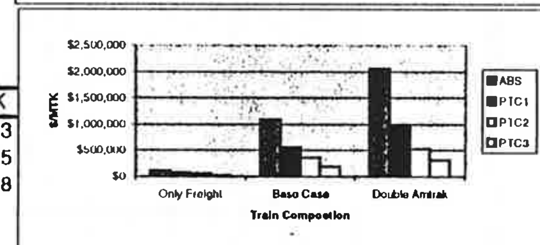
B. Number of Accidents

	E(# accidents)				Percentage of Base Case				Reduction		
Train Composti	ABS	PTC1	PTC2	PTC3	ABS	PTC1	PTC2	PTC3	PTC1	PTC2	PTC3
Only Freight	1.028	0.765	0.556	0.137	49%	46%	40%	15%	26%	46%	87%
Base Case	2.091	1.681	1.398	0.943	100%	100%	100%	100%	20%	33%	55%
Double Amtrak	3.495	2.880	2.424	1.942	167%	171%	173%	206%	18%	31%	44%



C. Risk ($/MTK)

	E(consequences$/MTK)				Percentage of Base Case				Reduction			
Train Composti	ABS	PTC1	PTC2	PTC3	ABS	PTC1	PTC2	PTC3	PTC1	PTC2	PTC3	MTK
Only Freight	$99,450	$63,552	$45,772	$10,283	9%	11%	13%	6%	36%	54%	90%	15.33
Base Case	$1,085,901	$553,606	$352,017	$183,885	100%	100%	100%	100%	49%	68%	83%	23.15
Double Amtrak	$2,061,955	$983,676	$534,521	$304,168	190%	178%	152%	165%	52%	74%	85%	30.98



D. Risk ($)

	E(consequences$)				Percentage of Base Case				Reduction		
Train Composti	ABS	PTC1	PTC2	PTC3	ABS	PTC1	PTC2	PTC3	PTC1	PTC2	PTC3
Only Freight	$1,524,154	$973,982	$701,487	$157,592	6%	8%	9%	4%	36%	54%	90%
Base Case	$25,143,278	$12,818,351	$8,150,714	$4,257,718	100%	100%	100%	100%	49%	68%	83%
Double Amtrak	$63,885,141	$30,477,048	$16,560,976	$9,423,989	254%	238%	203%	221%	52%	74%	85%

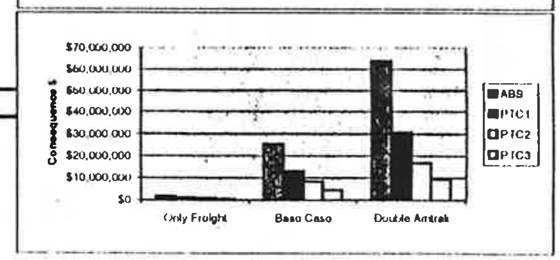
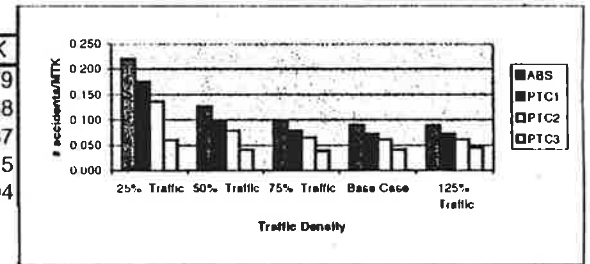


Exhibit 23 Traffic Density Sensitivity

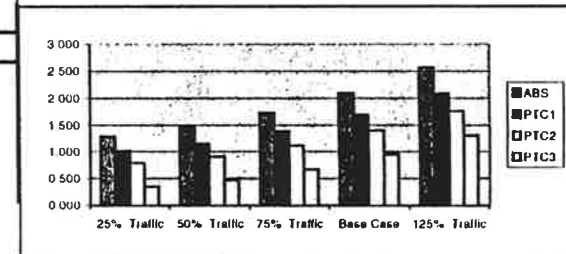
A. Accident Frequency (#/MTK)

	E(# accidents/MTK)				Percentage of Base Case				Reduction			
Traffic	ABS	PTC1	PTC2	PTC3	ABS	PTC1	PTC2	PTC3	PTC1	PTC2	PTC3	MTK
25% Traffic	0.220	0.175	0.136	0.059	244%	242%	226%	146%	20%	38%	73%	5.79
50% Traffic	0.125	0.099	0.079	0.040	139%	137%	130%	99%	21%	37%	68%	11.58
75% Traffic	0.099	0.079	0.064	0.038	110%	109%	106%	94%	20%	35%	61%	17.37
Base Case	0.090	0.073	0.060	0.041	100%	100%	100%	100%	20%	33%	55%	23.15
125% Traffic	0.088	0.072	0.061	0.045	98%	99%	101%	110%	19%	31%	49%	28.94



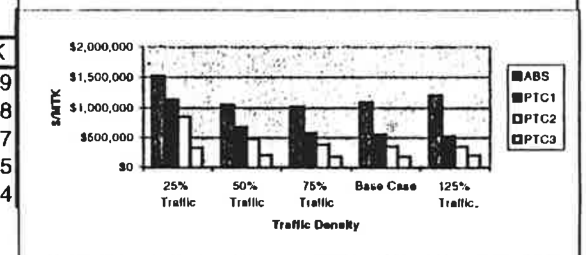
B. Number of Accidents

	E(# accidents)				Percentage of Base Case				Reduction		
Traffic	ABS	PTC1	PTC2	PTC3	ABS	PTC1	PTC2	PTC3	PTC1	PTC2	PTC3
25% Traffic	1.274	1.015	0.789	0.344	61%	60%	56%	37%	20%	38%	73%
50% Traffic	1.451	1.149	0.912	0.465	69%	68%	65%	49%	21%	37%	68%
75% Traffic	1.724	1.371	1.115	0.664	82%	82%	80%	70%	20%	35%	61%
Base Case	2.091	1.681	1.398	0.943	100%	100%	100%	100%	20%	33%	55%
125% Traffic	2.554	2.078	1.761	1.300	122%	124%	126%	138%	19%	31%	49%



C. Risk ($/MTK)

	E(consequences$/MTK)				Percentage of Base Case				Reduction			
Traffic	ABS	PTC1	PTC2	PTC3	ABS	PTC1	PTC2	PTC3	PTC1	PTC2	PTC3	MTK
25% Traffic	$1,524,256	$1,133,888	$846,835	$331,134	140%	205%	241%	180%	26%	44%	78%	5.79
50% Traffic	$1,048,387	$674,168	$478,862	$205,359	97%	122%	136%	112%	36%	54%	80%	11.58
75% Traffic	$1,011,869	$569,267	$381,390	$181,634	93%	103%	108%	99%	44%	62%	82%	17.37
Base Case	$1,085,901	$553,606	$352,017	$183,885	100%	100%	100%	100%	49%	68%	83%	23.15
125% Traffic	$1,204,629	$523,468	$350,202	$196,836	111%	95%	99%	107%	57%	71%	84%	28.94



D. Risk ($)

	E(consequences$)				Percentage of Base Case				Reduction		
Traffic	ABS	PTC1	PTC2	PTC3	ABS	PTC1	PTC2	PTC3	PTC1	PTC2	PTC3
25% Traffic	$8,823,272	$6,563,597	$4,901,966	$1,916,794	35%	51%	60%	45%	26%	44%	78%
50% Traffic	$12,137,328	$7,804,940	$5,543,862	$2,377,468	48%	61%	68%	56%	36%	54%	80%
75% Traffic	$17,571,842	$9,885,741	$6,623,118	$3,154,204	70%	77%	81%	74%	44%	62%	82%
Base Case	$25,143,278	$12,818,351	$8,150,714	$4,257,718	100%	100%	100%	100%	49%	68%	83%
125% Traffic	$34,865,436	$15,150,680	$10,135,856	$5,696,990	139%	118%	124%	134%	57%	71%	84%

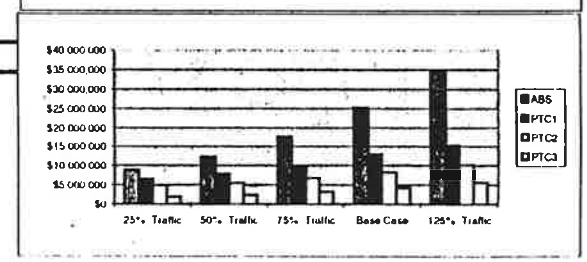
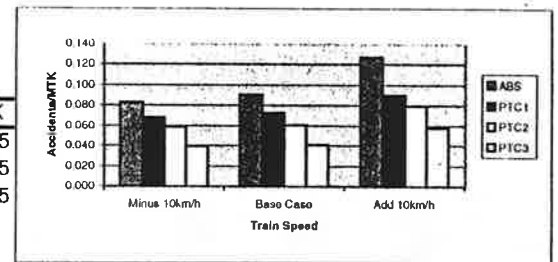


Exhibit 24 Train Speed Sensitivity

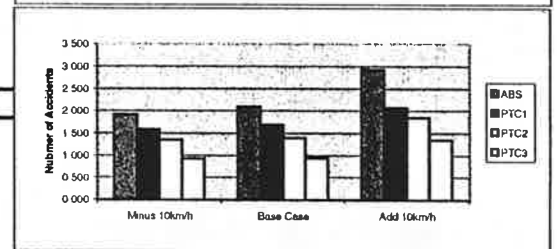
A. Accident Frequency (#/MTK)

Train Speed	E(# accidents/MTK) ABS	PTC1	PTC2	PTC3	Percentage of Base Case ABS	PTC1	PTC2	PTC3	Reduction PTC1	PTC2	PTC3	MTK
Minus 10km/h	0.083	0.068	0.058	0.040	92%	94%	97%	97%	18%	29%	52%	23.15
Base Case	0.090	0.073	0.060	0.041	100%	100%	100%	100%	20%	33%	55%	23.15
Add 10km/h	0.126	0.090	0.080	0.058	140%	124%	132%	142%	29%	37%	54%	23.15



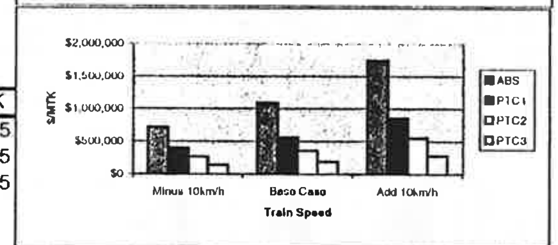
B. Number of Accidents

Train Speed	E(# accidents) ABS	PTC1	PTC2	PTC3	Percentage of Base Case ABS	PTC1	PTC2	PTC3	Reduction PTC1	PTC2	PTC3
Minus 10km/h	1.920	1.583	1.354	0.916	92%	94%	97%	97%	18%	29%	52%
Base Case	2.091	1.681	1.398	0.943	100%	100%	100%	100%	20%	33%	55%
Add 10km/h	2.926	2.080	1.844	1.343	140%	124%	132%	142%	29%	37%	54%



C. Risk ($/MTK)

Train Speed	E(consequences$/MTK) ABS	PTC1	PTC2	PTC3	Percentage of Base Case ABS	PTC1	PTC2	PTC3	Reduction PTC1	PTC2	PTC3	MTK
Minus 10km/h	$709,859	$391,953	$260,718	$137,060	65%	71%	74%	75%	45%	63%	81%	23.15
Base Case	$1,085,901	$553,606	$352,017	$183,885	100%	100%	100%	100%	49%	68%	83%	23.15
Add 10km/h	$1,738,336	$853,034	$546,125	$274,169	160%	154%	155%	149%	51%	69%	84%	23.15



D. Risk ($)

Train Speed	E(consequences$) ABS	PTC1	PTC2	PTC3	Percentage of Base Case ABS	PTC1	PTC2	PTC3	Reduction PTC1	PTC2	PTC3
Minus 10km/h	$16,436,285	$9,075,408	$6,036,749	$3,173,521	65%	71%	74%	75%	45%	63%	81%
Base Case	$25,143,278	$12,818,351	$8,150,714	$4,257,718	100%	100%	100%	100%	49%	68%	83%
Add 10km/h	$40,249,946	$19,751,414	$12,645,152	$6,348,182	160%	154%	155%	149%	51%	69%	84%

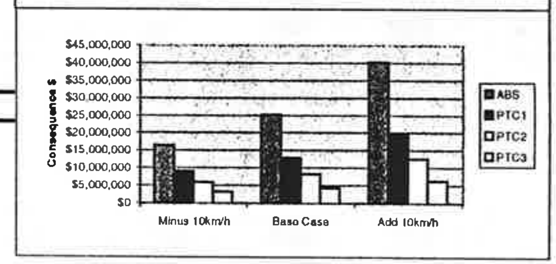
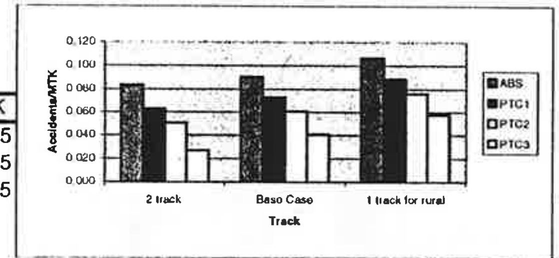


Exhibit 25 Track Sensitivity

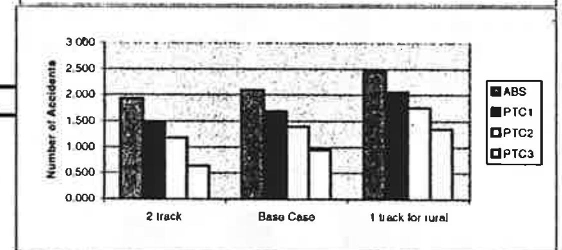
A. Accident Frequency (#/MTK)

# of Tracks	E(# accidents/MTK) ABS	PTC1	PTC2	PTC3	Percentage of Base Case ABS	PTC1	PTC2	PTC3	Reduction PTC1	PTC2	PTC3	MTK
2 track	0.083	0.063	0.051	0.027	92%	86%	84%	67%	25%	39%	67%	23.15
Base Case	0.090	0.073	0.060	0.041	100%	100%	100%	100%	20%	33%	55%	23.15
1 track for rural	0.106	0.088	0.076	0.058	117%	122%	126%	142%	17%	29%	46%	23.15



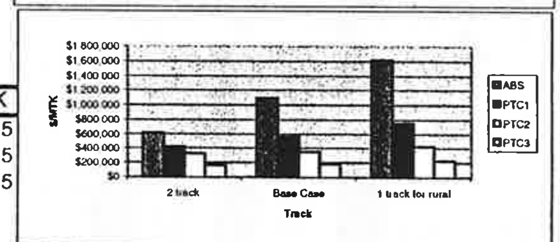
B. Number of Accidents

# of Tracks	E(# accidents) ABS	PTC1	PTC2	PTC3	Percentage of Base Case ABS	PTC1	PTC2	PTC3	Reduction PTC1	PTC2	PTC3
2 track	1.927	1.453	1.175	0.631	92%	86%	84%	67%	25%	39%	67%
Base Case	2.091	1.681	1.398	0.943	100%	100%	100%	100%	20%	33%	55%
1 track for rural	2.456	2.049	1.755	1.338	117%	122%	126%	142%	17%	29%	46%



C. Risk ($/MTK)

# of Tracks	E(consequences$/MTK) ABS	PTC1	PTC2	PTC3	Percentage of Base Case ABS	PTC1	PTC2	PTC3	Reduction PTC1	PTC2	PTC3	MTK
2 track	$616,911	$419,533	$325,180	$162,525	57%	76%	92%	88%	32%	47%	74%	23.15
Base Case	$1,085,901	$553,606	$352,017	$183,885	100%	100%	100%	100%	49%	68%	83%	23.15
1 track for rural	$1,618,976	$747,555	$432,359	$229,189	149%	135%	123%	125%	54%	73%	86%	23.15



D. Risk ($)

# of Tracks	E(consequences$) ABS	PTC1	PTC2	PTC3	Percentage of Base Case ABS	PTC1	PTC2	PTC3	Reduction PTC1	PTC2	PTC3
2 track	$14,284,136	$9,713,995	$7,529,325	$3,763,141	57%	76%	92%	88%	32%	47%	74%
Base Case	$25,143,278	$12,818,351	$8,150,714	$4,257,718	100%	100%	100%	100%	49%	68%	83%
1 track for rural	$37,486,251	$17,309,100	$10,010,963	$5,306,709	149%	135%	123%	125%	54%	73%	86%

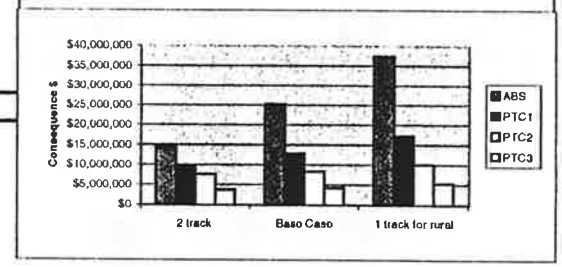


Exhibit 26 Accident Frequency Sensitivity Analysis

Character Description		Train Control System			
		ABS	PTC1	PTC2	PTC3
	Base Case	0.090	0.073	0.060	0.041
Train Compostion	Only Freight	0.067	0.050	0.036	0.009
	Double Amtrak	0.113	0.093	0.078	0.063
Traffic Density	25% Traffic	0.220	0.175	0.136	0.059
	50% Traffic	0.125	0.099	0.079	0.040
	75% Traffic	0.099	0.079	0.064	0.038
	125% Traffic	0.088	0.072	0.061	0.045
Train Speed	Minus 10km/h	0.083	0.068	0.058	0.040
	Add 10km/h	0.126	0.090	0.080	0.058
Number of Tracks	Double track	0.083	0.063	0.051	0.027
	Single track for rural	0.106	0.088	0.076	0.058

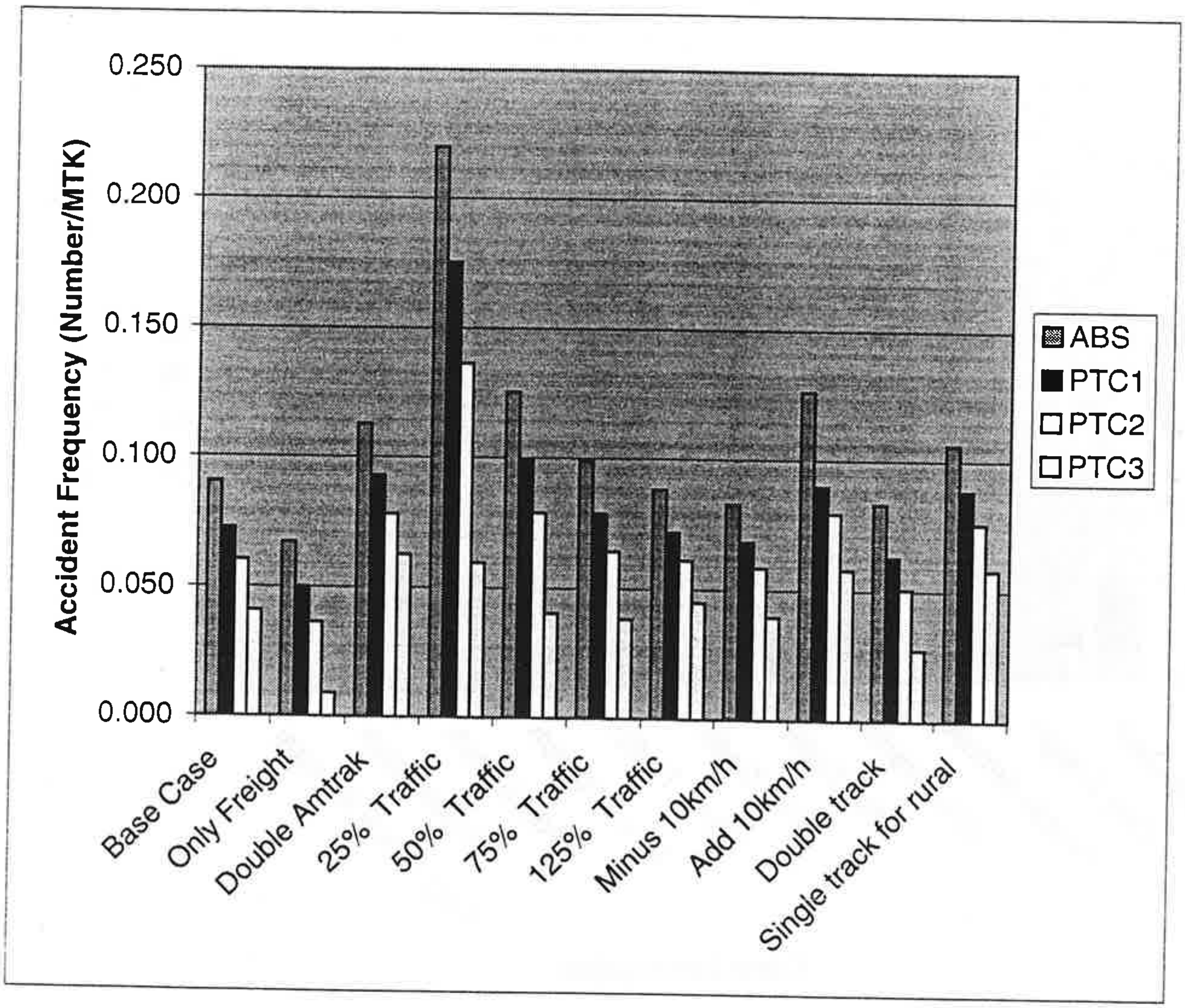


Exhibit 27 Annual Risk Sensitivity Analysis

Character Description		Train Control System: ABS	PTC1	PTC2	PTC3
	Base Case	$25,143,278	$12,818,351	$8,150,714	$4,257,718
Train Compostion	Only Freight	$1,524,154	$973,982	$701,487	$157,592
	Double Amtrak	$63,885,141	$30,477,048	$16,560,976	$9,423,989
Traffic Density	25% Traffic	$8,823,272	$6,563,597	$4,901,966	$1,916,794
	50% Traffic	$12,137,328	$7,804,940	$5,543,862	$2,377,468
	75% Traffic	$17,571,842	$9,885,741	$6,623,118	$3,154,204
	125% Traffic	$34,865,436	$15,150,680	$10,135,856	$5,696,990
Train Speed	Minus 10km/h	$16,436,285	$9,075,408	$6,036,749	$3,173,521
	Add 10km/h	$40,249,946	$19,751,414	$12,645,152	$6,348,182
Number of Tracks	Double track	$14,284,136	$9,713,995	$7,529,325	$3,763,141
	Single track for rural	$37,486,251	$17,309,100	$10,010,963	$5,306,709

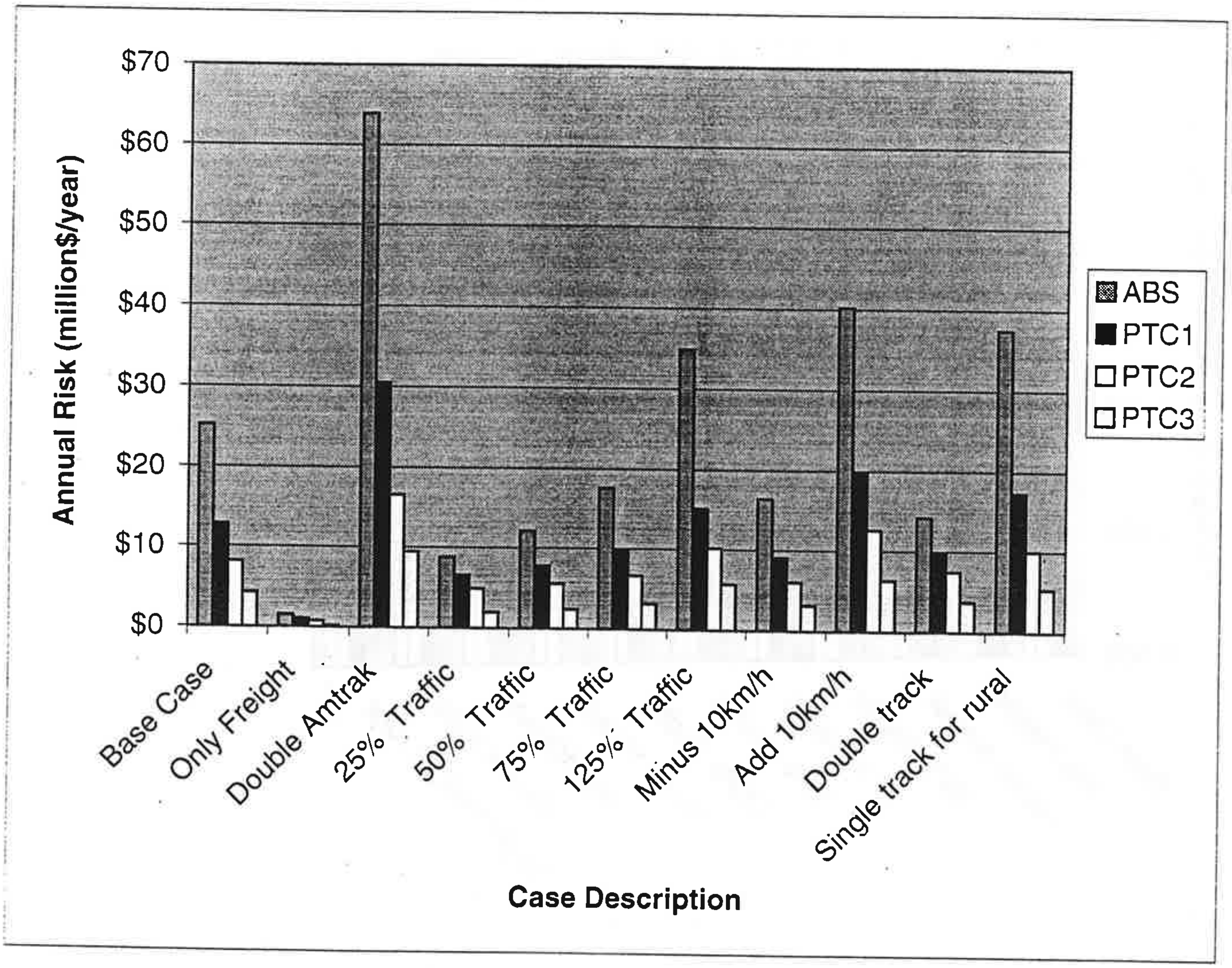
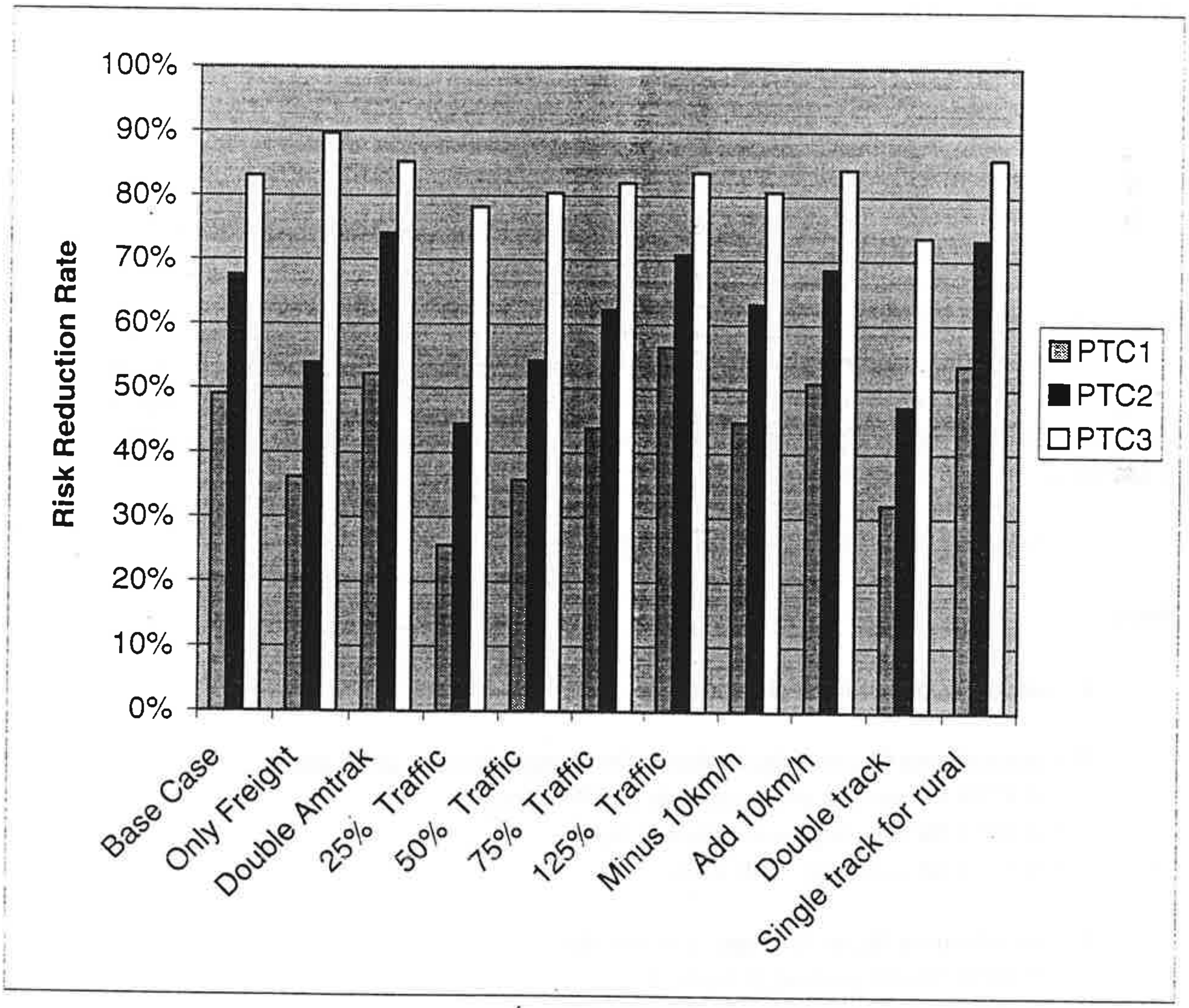


Exhibit 28 PTC Effectiveness of Annual Risk Comparison

Character Description		Train Control System		
		PTC1	PTC2	PTC3
	Base Case	49%	68%	83%
Train Compostion	Only Freight	36%	54%	90%
	Double Amtrak	52%	74%	85%
Traffic Density	25% Traffic	26%	44%	78%
	50% Traffic	36%	54%	80%
	75% Traffic	44%	62%	82%
	125% Traffic	57%	71%	84%
Train Speed	Minus 10km/h	45%	63%	81%
	Add 10km/h	51%	69%	84%
Number of Tracks	Double track	32%	47%	74%
	Single track for rural	54%	73%	86%



Appendix B
Train Control and Grade Crossing Risks

B.1 Introduction

Our analysis of grade crossings is based upon the same hypothetical corridor considered in the previous chapter. We first selected a diverse set of grade crossings to represent the range of crossings that would be found along a major rail corridor in the United States. We then predicted the risks associated with these crossings, given the rail traffic and operating characteristics assumed earlier. Sensitivity analysis illustrated the importance of key factors, e.g. type of protection, train speed, and rail and highway traffic volumes. Finally, we estimated the ranges of benefits that might be expected from improvements in the train control system.

B.2 The DOT Model of Grade Crossing Risks

Out grade crossing model is structured to facilitate assessment of strategies to reduce the risks associated with grade crossing accidents for a corridor where there are hundreds of grade crossings. At the core of the model are the relationships developed by DOT [Farr, 1987], which are described in the literature review.

The DOT model is based upon regressions of accident data; it is designed to predict the number of accidents at a particular crossing based upon the characteristics of the crossing, the highway traffic, and the rail traffic. Separate equations were calibrated for crossings with gates, flashing lights, or only passive protection. Each equation predicts the number of accidents per year (a) at a crossing:

$$a = NF \times K \times EI \times MT \times DT \times HP \times MS \times HL$$

where

a = accidents per years at the crossing

N = normalizing factor (which adjusts for changes in rates over time)
= 0.8239 for passive protection (as of 1992 update)
= 0.6935 for crossings with flashing lights
= 0.6714 for crossings with gates

K = initialization factor for type of protection
= 0.0006938 for passive protection
= 0.003351 for crossings with flashing lights
= 0.0005745 for crossings with gates

EI = exposure index based on product of highway and train train traffic

MT = factor for number of main tracks
DT = factor for number of trains/day in daylight
HP = highway pavement factor
MS = factor for maximum timetable speed
HL = factor for number of highway lanes

Each of the factors is given by a more complicated expression. The exposure index EI is the product of the highway traffic and the train traffic raised to a power that varies with the type of protection:

$$EI = ((\text{daily highway vehicles x daily trains} + 0.2)/0.2)^{ei}$$

where the exponent ei equals 0.37 for passive, 0.4106 for flashing lights, adn 0.2942 for gates. [Note: the use of 0.2 in two places in this expression (and in the following expression for daylight trains) means that this expression will equal 1 if either highway traffic or train traffic equals zero. This is a great help in the regression analysis, since the natural log of zero is undefined.]

The factor for daylight trains is similar:

$$DT = ((d+0.2)/0.2)^{dt}$$

where the exponent dt equals 0.178 for passive, 0.1131 for flashing lights, and 0.1781 for gates.

The other factors all have an exponential form:

$$MT = e^{a \text{ x main tracks}}$$

$$HP = e^{b \text{ x (hp - 1)}}$$

$$MS = e^{c \text{ x max speed}}$$

$$HL = e^{d \text{ x (highway lanes - 1)}}$$

Each of these factors applies to only one or two of the crossing protection categories. For example, the main tracks factor equals 1 for passive protection (i.e. a = 0 in the above equation), so that the number of main tracks does not affect the predicted number of accidents at a crossing with only passive protection. The exponent a is 0.1917 for flashing lights and 0.1512 for gates, so the factor MT is 1.21 for flashing lights and 1.16 for gates.

Highway pavement and maximum speed affect only passive crossings; the number of highway lanes only affects the crossings with active protection.

Table B.1
Coefficients in DOT Grade Crossing Accident Model

Factor	Passive	Flashing Lights	Gates
Normalizing factor	0.8239	0.6935	0:6714
Initialization factor	0.0006938	0.003351	0.0000574
EI exponent (ei)	0.37	0.4106	0.2942
MT exponent (a)	0	0.1917	0.15
DT exponent	0.178	0.1131	0.18
HP exponent (b)	-0.5966	0	0
MS exponent (c)	0.0077	0	0
HL exponent (d)	0	0.1826	0.142

While we could have adopted the same approach for our study, it would have been cumbersome to develop the data for hundreds of crossings and even more difficult to conduct sensitivity analyses or to examine multiple options for protection devices. We therefore developed a spreadsheet that would make it easier to deal with a large number of crossings.

The basic approach was to set up a structure for defining a reasonable (but limited) number of typical crossings. The user defines 12 typical crossings for each of four categories of crossing, where each category is either public or private crossings and each has its own type of protection. The model then calculates the accident probabilities for each of these crossings. The user can represent many different corridors either by selecting a different mix of these typical crossings or by defining different sets of typical crossings. Since rail traffic is such a critical variable for rail corridor analysis, the number of trains per day is a key structural variable: the user can define 10 new categories of train traffic and all of the typical crossings are updated for these new traffic categoris.

Thus, the model calculates the accidents per year for 480 typical situations: 4 categories of crossing protection & ownership, 12 typical crossings per category, and 10 categories of daily train traffic. To get the accidents for a corridor, the results are weighted by the number of crossings in each of these 480 categories. The results can be shown in terms of total accidents or accidents per million trains.

Appendix C "Details of the Grade Crossing Model" provides more details on the structure of the model.

B.3 Effects of PTC

In Chapter 3, there is a brief discussion of the potential benefits of improved train control on crossing safety. Ranges of potential improvement were estimated as follows:

- Equal warning times: 1-10% reduction if warning times were equalized and very long times were eliminated (8-80 fewer accidents per year, as there are approximately 800 accidents per year in which a moving automobile is struck by a train).

- Malfunctioning devices: elimination of all of these accidents would be a reduction of 5-10 accidents per year.

- Improved communication with obstacle detectors: there are only about 70 accidents per year involving vehicles stalled at gated crossings. Installing obstacle detectors could eliminate 70-90% of these, based upon evidence from Japan; the incremental benefits from better communication with the train would be small, a reduction of fewer than 5 accidents per year.

- Communications with priority vehicles: there are approximately 400 accidents per year involving large trucks and buses. Conceivably 25-75% of these could be eliminated through some sort of technology involving direct communication among these vehicles and the trains and/or the crossing protection devices.

For the corridor analysis, we first estimated a base case, which provides an estimate of the number of annual accidents for the corridor. We then assumed that these accidents were typical of the national accidents, so that the improvements in the four areas mentioned above would be proportional to the ratio of corridor to total national accidents. This is an approximate calculation, so we used round numbers for the analysis:

- Annual grade crossing accidents in the United States: 4000

- Annual accidents involving autos hit by trains: 800 (20%), with a 1-10% reduction in accident frequency hypothesized assuming improved train control technology

- Annual accidents involving malfunctioning equipment: 10 (0.25%), with 50-100% reduction in accident frequency

Annual accidents involving stalled vehicles: 80 (2%), with a 5% reduction in accident frequency due to better train control (and installation of obstacle detectors at all gated crossings)

Annual accidents involving large vehicles: 400 (10%) with a 25-75% reduction in accident frequency hypothesized.

These assumptions can be summarized as shown in Table B.2, where the percentages shown above are put into a table. The first column shows the percentage of accidents of that type; the second and third columns show the percentage of the 4000 accidents assumed for the base case that will happen with the minimum and maximum reductions cited above. The fourth row gives a total for the four categories of accidents and the fifth row shows the reduction in accidents. This rough analysis indicates that there may be a 3 to 12% reduction in grade crossing accidents from the application of technologies utilizing a digital radio link to the locomotives.

In the corridor analysis, we therefore calculated the annual number of accidents and considered a 3-12% reduction to be feasible if the train control and crossing protection systems were upgraded as described above.

Table B.2
Potential Reductcions in Grade Crossing Accidents

Category	Base Percentage	With Minimum Improvement	With Maximum Improvement
Equal warning	20%	19.8%	18%
Malfunction warning	0.25%	0.13	0%
Obstacle detection	2%	1.9%	0%
Large vehicle communication	10%	7.5%	2.5%
Total, for these accidents	32.25%	29.3%	20.5%
Potential Reduction	0%	3%	12%

B.4 Grade Crossing Accidents on the Hypothetical Corridor

We then created a base case for estimating the frequency of grade crossing accidents for the corridor case study. For the 661 grade crossings on the 1200 mile corridor, the expected number of accidents per year is 31.5, which is 4.32 per million train crossings. The corridor, which encompasses 0.7% of the nation's rail route mileage, is therefore predicted to have about 0.8% of the nation's grade crossing accidents (of which there were 3865 in 1997). Although there are fewer crossings per mile for the corridor than for the national system, there is more rail traffic, and the two factors almost balance.

The accident distribution is as follows:

Public, gated:	3.8 accidents at 147 crossings (2.2/million trains)
Public, flashing lights:	6.8 accidents at 143 crossings (4.2/million trains)
Passive protection:	20.0 accidents at 304 crossings (6.2/million trains)
Gated, private:	0.9 accidents at 66 crossings (1.2/million trains)

The grade crossings were defined to reflect a variety of highway situations and to be consistent with the corridor definitions in terms of tracks, trains and land use.

In the previous section, we argued that train control improvements could lead to a 3 to 12% reduction in accidents. For this corridor, that would be a reduction of 1 to 4 accidents per year. The average consequences for a grade crossing accident are on the order of $350,000; this figure includes loss of the highway vehicle, minor damage to the train and the expected value of injuries and fatalities. The most serious consequences of these accidents are the fatalities. In 1998, there were 0.12 fatalities per accident; using $2.7 million per fatality, as is done in the RSAC process, this gives an expected value of $324,000 for fatalities alone. Using this estimate of consequences, the annual benefits would be $350,000 to $1.4 million. A higher number could be justified, however, because the greatest reduction involves large trucks and buses where there is a possibility of catastrophic accident. When considering these numbers, bear in mind a) that the primary enabling train control technology is the digital radio link and b) that there would have to be considerable investment in crossing protection and in vehicle systems to achieve these savings.

B.5 Crossings in the Hypothetical Corridor

The description of the hypothetical corridor shows the number of grade crossings per mile and the total number of crossings for each segment (exhibit 1). The number of crossings per mile increased from 0 (in the city center) to 0.5 for most of the route, with a few segments with 1, 1.5 or 2 crossings per mile. For the entire route, there are 661 crossings, or 0.55 per mile. Since this is a high density corridor, the number of crossings was kept below the national average, which is more than 1 crossing per mile.

The crossing model is structured to deal with 10 sets of crossings that are defined in terms of the number of trains/day. For the hypothetical corridor, there were more than 10 distinct levels of train volumes, and it was necessary to combine segments where traffic volumes were similar. After sorting the segments by train volume (Exhibit 2), we grouped them into 9 categories and used an average traffic volume for each category:

1. "24 trains per day" includes segments with 22, 23, and 24.4 trains per day
2. "31 trains per day" includes segments with 30.3, 31.3, 32, or 32.3 trains per day
3. "37.5 trains per day" includes segments with 37.3 or 37.6 trains per day
4. "42.4 trains per day" includes segments with 43.3 or 42.4 trains per day
5. "52.4 trains per day" includes segments with 52.4 trains per day
6. "60 trains per day" includes segments with 57, 60, or 63 trains per day
7. "68 trains per day" includes segments with 66, 68, or 70 trains per day
8. '80 trains per day" includes segments with 80 trains per day
9. "120 trains per day" includes segments with 118 or 120 trains per day

We did not try to distinguish among types of train (freight, commuter, or Amtrak) in setting up these classifications. The number of crossings in each category was determined by summing up the crossings for the relevant segments (Exhibit 3). This exhibit also shows two other factors that are important for the crossing model: number of tracks and land use. The number of tracks is a factor in predicting accident frequency in the crossing model. The land use was used as a surrogate for highway traffic and the type of crossing protection. For example, in rural area, we assumed that highway traffic volumes were generally lower than in towns or in cities and that the percentage of passive crossings was higher.

To facilitate sensitivity analysis, we did not want to create a file with the characteristics for 661 individual crossings. Instead, we wanted to have a mix of crossings that would be representative of the conditions that would be likely to exist along a route such as the hypothetical corridor. That way, we would be able to calculate accident frequencies for representative crossings and apply the results to multiple crossings. Thus, there were two major questions in defining the characteristics of the crossings:

1. What is the set of typical crossings?
2. How many crossings correspond to each typical crossing?

The first question had already been addressed in structuring the crossing model (described above), which includes definitions of 48 crossings, 12 for each of four categories of protection (gated public, public with flashing lights, passive, and gated private). We used these same definitions for the base case analysis (Exhibit 4). For example, the type of public gated crossing is GP5000-2, which stands for "Gated Public, 5000 highway vehicles/day, double track" and has the attributes shown in the first line of the table. The first 6 crossings have declining highway traffic for double track; the last 6 crossings have the same characteristics for single track. The first crossing under "Flashing Lights" is called FL500-2-2, which stands for "Flashing lights, 500 vehicles per day, double track, 2 lanes". The other crossings have declining traffic for various combinations of tracks and lanes. Likewise, crossings are defined for passive and gated, private crossings in Exhibits 4c and 4d.

The second question required a multi-step analysis. First, for each of three types of land use (rural, town/suburban, or urban/city) we defined a typical distribution of the percentage of crossings across the 12 typical crossings defined for gated public, for public with flashing lights, and for passive protection. These assumptions are shown in Exhibit 5 as the first three columns of percentages in each section of the exhibit. For example, at the top of the exhibit, 2% of the rural crossings fall into the first category, which is shown above on Exhibit 4 as GP5000-2. If the land use is "Town", then 10% of the crossings fall into this first category; if the land use is "City", then 15% of the crossings fall into this category. Note that the columns add to 200% for Gated Public and Flashing Lights calculations. The assumption is that a segment will have some percentage of crossings where there is single track and some where there is double track. The actual number of crossings will be the product of the following factors:

1. Number of crossings in 'N trains/day' category
2. Percentage of crossings with this type of protection
3. Percentage of crossings with this number of tracks
4. Percentage of crossings in this category for this land use

This exhibit copies a portion of the spreadsheet that is used to estimate the number of crossings of each type. The land use and the number of tracks were given in the segment definitions and average percentages were calculated for the 9 segments, as shown above. Given the land use and the number of tracks, the model calculates the percentage of crossings in each of the crossing types, which can be used to calculate the number of crossings in each category. This may seem a bit cumbersome, but it provides a way to describe the set of crossings and a convenient basis for sensitivity analysis. The results are shown in Exhibit 6, which gives the number of crossings in each category (because of the use of probabilities, these numbers are not integers).

The crossing model will then calculate the expected number of accidents, the accidents per million train crossings, and other statistics (Exhibit 7). The results are given for each of the 48 types of crossings for each of the 8 categories of trains per day (note: there were no crossings on the segments with more than 80 trains per day), then summarized by type of protection.

B.6 Benefits of PTC

The next step in the analysis is to predict the effects of improved train control systems on accident frequency. This is done in the final two sections of Exhibit 7:

a. PTC Effects (accidents with PTC as fraction of accidents without PTC): these inputs show the expected reduction in accidents related to the PTC system being considered. To illustrate the concept, the exhibit assumes that the PTC system will prevent 2% of the accidents at the public crossings based upon some (unspecified) improvement in communications. For example, a system might allow more consistent warning times, since the train could send its speed and an estimated time of arrival to the crossing device. The system could also provide some warning to certain highway vehicles (e.g. school buses or heavy trucks, which could cause a catastrophic accident) equipped with a special receiver. For private crossings, a greater reduction in accidents (to 70% of the base case) is indicated, because it would be easier to identify the vehicles that use the crossing and it would be easier to adopt some sort of train-to-vehicle communications. Another possibility would be to have obstacle detectors that could communicate directly with oncoming trains if the crossing is blocked by a stalled or disabled vehicle.

b. The reduced accident rates are translated into a reduced number of accidents in the final segment of the exhibit. In this case, there is a 2.8% reduction in overall accidents, which is equivalent to about 1 accident less per year.

VNTSC Project: Risk & Train Control
Hypothetical Corridor
C.D. Martland
March 14, 2000

#	Land Use	Length	Trains/day Amtrak	Commuter	Freight	Total	Frt MGT/yr	Terrain	Tracks	Track Condition	Max Speed Category	Xing/mile	Crossings
11	Rural	5	8	0	14	22	30	difficult	1	modern	2	0.5	2.5
10	Rural	5	8	0	14	22	30	rolling	1	modern	1	1	5
14	Rural	5	6	0	17	23	40	difficult	1	modern	2	0.5	2.5
12	Rural	20	6	0	17	23	40	flat	1	modern	1	0.5	10
13	Rural	10	6	0	17	23	40	rolling	1	modern	1	0.5	5
17	Rural	20	4	0	20.4	24.4	50	difficult	1	modern	2	0.5	10
26	Rural	20	4	0	20.4	24.4	50	difficult	1	old	3	0.5	10
23	Rural	10	4	0	20.4	24.4	50	difficult	1	old	3	0.5	5
21	Rural	100	4	0	20.4	24.4	50	flat	1	old	2	0.5	50
15	Rural	100	4	0	20.4	24.4	50	flat	1	modern	1	0.5	50
24	Rural	50	4	0	20.4	24.4	50	flat	1	old	2	0.5	25
16	Rural	50	4	0	20.4	24.4	50	rolling	1	modern	1	0.5	25
22	Rural	50	4	0	20.4	24.4	50	rolling	1	old	2	0.5	25
25	Rural	40	4	0	20.4	24.4	50	rolling	1	old	2	0.5	20
27	Rural	10	4	0	20.4	24.4	50	very difficult	1	old	4	0.5	5
30	Town	5	4	0	20.4	24.4	50	difficult	2	new	3	1	5
28	Town	20	4	0	20.4	24.4	50	flat	2	old	2	1	20
29	Town	10	4	0	20.4	24.4	50	rolling	2	old	2	2	20
33	Rural	10	6	0	24.3	30.3	60	difficult	1	new	3	0.5	5
31	Rural	50	6	0	24.3	30.3	60	flat	1	new	2	0.5	25
32	Rural	20	6	0	24.3	30.3	60	rolling	1	new	2	0.5	10
34	Town	20	6	0	24.3	30.3	60	flat	2	new	2	0.5	10
8	City	5	12	10	9.3	31.3	20	rolling	1	modern	1	1.5	7.5
7	Rural	10	12	10	9.3	31.3	20	flat	1	modern	1	0.5	5
9	City	10	8	10	14	32	30	flat	1	modern	1	1.5	15
35	Rural	100	8	0	24.3	32.3	60	flat	2	new	2	1	100
36	Rural	100	8	0	24.3	32.3	60	rolling	1	new	2	0.5	50
5	Rural	10	12	20	5.3	37.3	10	flat	1	modern	1	0.5	5
6	Rural	5	12	20	5.3	37.3	10	rolling	1	modern	1	0.5	2.5
20	Rural	20	8	0	29.6	37.6	75	difficult	2	modern	2	0.5	10
18	Rural	100	8	0	29.6	37.6	75	flat	2	modern	1	0.5	50

Exhibit B-1 Description of Hypothetical Corridor, Including Number of Grade Crossings per Segment

19	Rural	50	8	0	29.6	37.6	75	rolling	2	modern	1	0.5	25
37	City	20	10	8	24.3	42.3	60	flat	2	steady state	2	0	0
38	City	20	10	8	24.3	42.3	60	flat	2	steady state	2	0	0
40	Rural	20	10	12	20.4	42.4	50	flat	1	steady state	2	0.5	10
39	Rural	20	10	12	20.4	42.4	50	flat	2	steady state	2	0.5	10
41	Rural	10	10	12	20.4	42.4	50	rolling	1	steady state	2	0.5	5
42	Suburban	5	16	16	20.4	52.4	50	flat	1	steady state	2	0.5	2.5
43	Suburban	5	16	16	20.4	52.4	50	rolling	1	steady state	2	0.5	2.5
44	Suburban	5	16	24	17	57	40	flat	2	steady state	2	0.5	2.5
46	Urban	5	16	30	14	60	30	flat	2	steady state	2	0.4	2
45	Suburban	5	16	30	17	63	40	flat	2	steady state	2	0.5	2.5
47	Urban	5	16	36	14	66	30	flat	2	steady state	2	0.3	1.5
48	Urban	5	16	36	14	66	30	rolling	2	steady state	3	0.3	1.5
49	Urban	5	16	40	14	70	30	flat	2	steady state	3	0.2	1
50	Urban	5	16	40	14	70	30	flat	2	steady state	3	0.2	1
3	Outer subur	10	16	60	4	80	5	flat	2	modern	2	0.2	2
4	Outer subur	5	16	60	4	80	5	rolling	2	modern	2	0.4	2
2	Suburban	5	16	100	2	118	2	rolling	2	modern	3	0	0
1	Inner city	5	20	100	0	120	0	flat	3	modern	3	0	0
	Total	1200											661

Exhibit B-1 (Continued)

#	Land Use	Crossing Trains/day	Frt MGT/yr	Terrain	Tracks	Max Speed Category	Crossings
11	Rural	24	30	difficult	1	2	2.5
14	Rural	24	40	difficult	1	2	2.5
17	Rural	24	50	difficult	1	2	10
26	Rural	24	50	difficult	1	3	10
23	Rural	24	50	difficult	1	3	5
12	Rural	24	40	flat	1	1	10
15	Rural	24	50	flat	1	1	50
24	Rural	24	50	flat	1	2	25
21	Rural	24	50	flat	1	2	50
10	Rural	24	30	rolling	1	1	5
13	Rural	24	40	rolling	1	1	5
16	Rural	24	50	rolling	1	1	25
22	Rural	24	50	rolling	1	2	25
25	Rural	24	50	rolling	1	2	20
27	Rural	24	50	very difficult	1	4	5
30	Town	24	50	difficult	2	3	5
28	Town	24	50	flat	2	2	20
29	Town	24	50	rolling	2	2	20
9	City	31	30	flat	1	1	15
8	City	31	20	rolling	1	1	7.5
33	Rural	31	60	difficult	1	3	5
7	Rural	31	20	flat	1	1	5
31	Rural	31	60	flat	1	2	25
35	Rural	31	60	flat	2	2	100
32	Rural	31	60	rolling	1	2	10
36	Rural	31	60	rolling	1	2	50
34	Town	31	60	flat	2	2	10
20	Rural	37.5	75	difficult	2	2	10
5	Rural	37.5	10	flat	1	1	5
18	Rural	37.5	75	flat	2	1	50
6	Rural	37.5	10	rolling	1	1	2.5
19	Rural	37.5	75	rolling	2	1	25
37	City	42.4	60	flat	2	2	0
38	City	42.4	60	flat	2	2	0
40	Rural	42.4	50	flat	1	2	10
39	Rural	42.4	50	flat	2	2	10
41	Rural	42.4	50	rolling	1	2	5
42	Suburban	52.4	50	flat	1	2	2.5
43	Suburban	52.4	50	rolling	1	2	2.5
44	Suburban	60	40	flat	2	2	2.5
45	Suburban	60	40	flat	2	2	2.5
46	Urban	60	30	flat	2	2	2
49	Urban	68	30	flat	2	3	1
47	Urban	68	30	flat	2	2	1.5
50	Urban	68	30	flat	2	3	1
48	Urban	68	30	rolling	2	3	1.5
3	Outer subur	80	5	flat	2	2	2
4	Outer subur	80	5	rolling	2	2	2
1	Inner city	120	0	flat	3	3	0
2	Suburban	120	2	rolling	2	3	0
	Total						661

Exhibit B-2 Segments Sorted by Daily Train Volume

#	Land Use	Crossing Trains/day	Terrain	Tracks	Max Speed Category	Crossings
11	Rural	24	difficult	1	2	2.5
14	Rural	24	difficult	1	2	2.5
17	Rural	24	difficult	1	2	10
26	Rural	24	difficult	1	3	10
23	Rural	24	difficult	1	3	5
12	Rural	24	flat	1	1	10
15	Rural	24	flat	1	1	50
24	Rural	24	flat	1	2	25
21	Rural	24	flat	1	2	50
10	Rural	24	rolling	1	1	5
13	Rural	24	rolling	1	1	5
16	Rural	24	rolling	1	1	25
22	Rural	24	rolling	1	2	25
25	Rural	24	rolling	1	2	20
27	Rural	24	very difficult	1	4	5
30	Town	24	difficult	2	3	5
28	Town	24	flat	2	2	20
29	Town	24	rolling	2	2	20
% Double track				15%		295
Land Use	Rural		84.7%	Town	15.3%	
9	City	31	flat	1	1	15
8	City	31	rolling	1	1	7.5
33	Rural	31	difficult	1	3	5
7	Rural	31	flat	1	1	5
31	Rural	31	flat	1	2	25
35	Rural	31	flat	2	2	100
32	Rural	31	rolling	1	2	10
36	Rural	31	rolling	1	2	50
34	Town	31	flat	2	2	10
% Double track				48%		227.5
Land use	Rural		85.7%	Town	4.4%	City 10%
20	Rural	37.5	difficult	2	2	10
5	Rural	37.5	flat	1	1	5
18	Rural	37.5	flat	2	1	50
6	Rural	37.5	rolling	1	1	2.5
19	Rural	37.5	rolling	2	1	25
% Double track				92%		92.5
Land use	Rural		100%			
37	City	42.4	flat	2	2	0
38	City	42.4	flat	2	2	0
40	Rural	42.4	flat		2	10
39	Rural	42.4	flat		2	10

Exhibit B-3 Segments Sorted by Land Use and Daily Train Volume

41 Rural		42.4	rolling	1	2	5
% Double track				40%		25
Land Use	Rural		100%			
42 Town		52.4	flat	1	2	2.5
43 Town		52.4	rolling	1	2	2.5
% Double track				0%		5
Land use	Town		100%			
44 Town		60	flat	2	2	2.5
45 Town		60	flat	2	2	2.5
46 Urban		60	flat	2	2	2
% Double track				100%		7
Land use	Town		71.4%	Urban	28.6%	
49 Urban		68	flat	2	3	1
47 Urban		68	flat	2	2	1.5
50 Urban		68	flat	2	3	1
48 Urban		68	rolling	2	3	1.5
% Double track				100%		5
Land use	Urban		100%			
3 Town		80	flat	2	2	2
4 Town		80	rolling	2	2	2
% Double track				100%		4
1 Urban		120	flat	3	3	0
2 Town		120	rolling	2	3	0
% Double track				100%		0
Land use			NA			
Total						661

Exhibit B-3 (Continued)

Corridor Study
Grade Crossing Data

Enter the data for up to 12 crossings in the following four categories: gated public, flashing lights - private, passive, and gated private crossings. Note that the model has four sets of coefficients that correspond to each of these categories.

Crossing Type: **Gated Public**

Trains per day: 5
% Trains in Day: 0.67

	Crossing	Acc. /year	Cars/day	Trains/day	Main tracks	Day trains	Paved	Max speed	Lanes
1	GP5000-2	0.0317	5000	5	2	3.35	1	80	2
2	GP1000-2	0.0198	1000	5	2	3.35	1	80	2
3	GP500-2	0.0161	500	5	2	3.35	1	80	2
4	GP200-2	0.0123	200	5	2	3.35	2	80	2
5	GP50-2	0.0082	50	5	2	3.35	1	80	2
6	GP10-2	0.0051	10	5	2	3.35	1	80	2
7	GP5000-1	0.0273	5000	5	1	3.35	1	80	2
8	GP1000-1	0.0170	1000	5	1	3.35	2	80	2
9	GP500-1	0.0138	500	5	1	3.35	1	80	2
10	GP200-1	0.0106	200	5	1	3.35	1	80	2
11	GP50-1	0.0070	50	5	1	3.35	1	80	2
12	GP10-1	0.0044	10	5	1	3.35	2	80	2
		0.173							

Exhibit B-4a Data for Gated Public Crossings

Crossing Type: **Flashing Lights, Private**

	Crossing	Acc. /year	Cars/day	Trains/day	Main tracks	Day trains	Paved	Max speed	Lanes
1	FL500-2-2	0.0273	500	5	2	3.35	1	80	2
2	FL100-2-2	0.0141	100	5	2	3.35	1	80	2
3	FL50-2-2	0.0106	50	5	2	3.35	1	80	2
4	FL20-2-2	0.0073	20	5	2	3.35	1	80	2
5	FL500-1-2	0.0225	500	5	1	3.35	1	80	2
6	FL100-1-2	0.0116	100	5	1	3.35	1	80	2
7	FL50-1-2	0.0087	50	5	1	3.35	1	80	2
8	FL20-1-2	0.0060	20	5	1	3.35	1	80	2
9	FL500-1-4	0.0324	500	5	1	3.35	1	80	2
10	FL100-1-4	0.0223	200	5	1	3.35	1	80	4
11	FL50-1-4	0.0126	50	5	1	3.35	1	80	4
12	FL20-1-4	0.0087	20	5	1	3.35	1	80	4
		0.1840							

Exhibit B-4b Data for Crossings with Flashing Lights

Crossing Type: **Passive Crossings**

	Crossing		Cars/day	Trains/day	Main tracks	Day trains	Paved	Max speed	Lanes
1	P500-P	0.0494	500	5	2	3.35	1	60	2
2	P200-P	0.0352	200	5	2	3.35	1	60	2
3	P50-P	0.0211	50	5	2	3.35	1	60	2
4	P10-P	0.0116	10	5	2	3.35	1	60	2
5	P1-P	0.0050	1	5	2	3.35	1	60	2
6	P500-U	0.0272	500	5	1	3.35	2	60	2
7	P200-U	0.0194	200	5	1	3.35	2	60	2
8	P50-U	0.0116	50	5	1	3.35	2	60	2
9	P10-U	0.0064	10	5	1	3.35	2	60	2
10	P1-U	0.0028	1	5	1	3.35	2	60	2
11	P500-P-4	0.0392	500	5	2	3.35	1	30	2
12	P200-P-4	0.0279	200	5	2	3.35	1	30	2
	Total	0.2567							

Exhibit B-4c Data for Crossings with Only Passive Protection

Crossing Type: **Gated Private Crossings**

	Crossing		Cars/day	Trains/day	Main tracks	Day trains	Paved	Max speed	Lanes
1	PRI50-P	0.0070	50	5	1	3.35	1	80	2
2	PRI25-P	0.0057	25	5	1	3.35	1	80	2
3	PRI2-P	0.0027	2	5	1	3.35	1	80	2
4	PRI50-U	0.0070	50	5	1	3.35	2	80	2
5	PRI25-U	0.0057	25	5	1	3.35	2	80	2
6	PRI2-U	0.0027	2	5	1	3.35	2	80	2
7	PRI50-2-P	0.0082	50	5	2	3.35	1	80	2
8	PRI25-2-P	0.0067	25	5	2	3.35	1	80	2
9	PRI2-2-P	0.0032	2	5	2	3.35	1	80	2
10	PRI50-2-U	0.0082	50	5	2	3.35	2	80	2
11	PRI25-2-U	0.0067	25	5	2	3.35	2	80	2
12	PRI2-2-U	0.0032	2	5	2	3.35	2	80	2
	Total	0.0671							

Exhibit B-4d Data for Gated Private Crossings

Gated, Public

	Rural	Town	City	Rural	Town	City
% double	40%	0%	0%			
% landuse	100%	0%	0%			
	Rural	Town	City	Rural	Town	City
	2%	10%	15%	0.800%	0.000%	0.000%
	8%	15%	20%	3.200%	0.000%	0.000%
	15%	30%	35%	6.000%	0.000%	0.000%
	20%	30%	20%	8.000%	0.000%	0.000%
	25%	10%	5%	10.000%	0.000%	0.000%
	30%	5%	5%	12.000%	0.000%	0.000%
	2%	10%	15%	1.200%	0.000%	0.000%
	8%	15%	20%	4.800%	0.000%	0.000%
	15%	30%	35%	9.000%	0.000%	0.000%
	20%	30%	20%	12.000%	0.000%	0.000%
	25%	10%	5%	15.000%	0.000%	0.000%
	30%	5%	5%	18.000%	0.000%	0.000%
	200.00%	200.00%	200.00%		100%	

Flashing Lights

	Rural	Town	City	Rural	Town	City
% double	51%	100%	0%			
% landuse	86%	4%	10%			
	Rural	Town	City	Rural	Town	City
	40%	50%	60%	17.579%	2.150%	0.000%
	30%	30%	35%	13.185%	1.290%	0.000%
	20%	15%	5%	8.790%	0.645%	0.000%
	10%	5%	0%	4.395%	0.215%	0.000%
	15%	20%	20%	6.263%	0.000%	2.000%
	15%	15%	15%	6.263%	0.000%	1.500%
	15%	10%	5%	6.263%	0.000%	0.500%
	15%	5%	5%	6.263%	0.000%	0.500%
	20%	30%	45%	8.350%	0.000%	4.500%
	20%	10%	10%	8.350%	0.000%	1.000%
	0%	5%	0%	0.000%	0.000%	0.000%
	0%	5%	0%	0.000%	0.000%	0.000%
	200.00%	200.00%	200.00%		100%	

Passive

	Rural	Town	City	Rural	Town	City
% double	0%	100%	0%			
% landuse	0%	100%	0%			
	Rural	Town	City	Rural	Town	City
	5%	0%	0%	2.197%	0.000%	0.000%
	5%	0%	0%	2.197%	0.000%	0.000%
	5%	15%	20%	2.197%	0.645%	0.000%
	5%	20%	20%	2.197%	0.860%	0.000%
	5%	20%	20%	2.088%	0.000%	2.000%
	5%	5%	0%	2.088%	0.000%	0.000%
	5%	5%	0%	2.088%	0.000%	0.000%
	5%	5%	0%	2.088%	0.000%	0.000%
	20%	10%	20%	8.350%	0.000%	2.000%
	30%	10%	20%	12.525%	0.000%	2.000%
	5%	5%	0%	2.088%	0.000%	0.000%
	5%	5%	0%	2.088%	0.000%	0.000%
	100.00%	100.00%	100.00%		50%	

Exhibit B-5 % Double Track and % of Crossings in Rural, Town or City Environment (plus various intermediate calculations from the model)

Number of crossings in each category

Crossing Descriptions:

Total Number: 661

Type:	Corridor Base											
Gated Public	20%	0 2000	0 2200	0 2400	0 2600	0 2800	0 3200	0 6500	0 7000	0 9000	0 9000	467%
Flashing Lights	20%	0 2000	0 2200	0 2400	0 2600	0 2800	0 3200	0 2000	0 2000	0 0000	0 0000	192%
Passive	50%	0 5000	0 4600	0 4200	0 3800	0 3400	0 2600	0 0500	0 0000	0 0000	0 0000	241%
Gated Private	10%	0 1000	0 1000	0 1000	0 1000	0 1000	0 1000	0 1000	0 1000	0 1000	0 1000	100%
Percent by # trains/day		1 0000	1 0000	1 0000	1 0000	1 0000	1.0000	1 0000	1.0000	1 0000	1 0000	
Number, by # trains/day		295 0000	227 5000	92 5000	25 0000	5 0000	7 0000	5 0000	4 0000	0 0000	0	661 0000

Crossing Type: Gated, Public

Trains per day		24	31	37 5	42 4	52 4	60	68	80	100	120	Total
1 GP5000-2	0 80%	0 89	0 70	0 41	0 05	0 00	0 26	0 49	0 28	0 00	0 00	3 1
2 GP1000 2	3 20%	1 33	2 26	1 63	0 21	0 00	0 37	0 65	0 42	0 00	0 00	6 9
3 GP500 2	6 00%	2 66	4 28	3 06	0 39	0 00	0 70	1 14	0 84	0 00	0 00	13 1
4 GP200 2	8 00%	2 66	5 50	4 08	0 52	0 00	0 61	0 65	0 84	0 00	0 00	14 9
5 GP50 2	10 00%	0 89	6 28	5 11	0 65	0 00	0 19	0 16	0 28	0 00	0 00	13 6
6 GP10-2	12 00%	0 44	7 39	6 13	0 78	0 00	0 11	0 16	0 14	0 00	0 00	15 1
7 GP5000-1	1 20%	1 00	1 12	0 04	0 08	0 14	0 00	0 00	0 00	0 00	0 00	2 4
8 GP1000 1	4 80%	4 01	2 49	0 14	0 31	0 21	0 00	0 00	0 00	0 00	0 00	7 2
9 GP500 1	9 00%	7 52	4 55	0 27	0 59	0 42	0 00	0 00	0 00	0 00	0 00	13 3
10 GP200 1	12 00%	10 03	4 73	0 36	0 78	0 42	0 00	0 00	0 00	0 00	0 00	16 3
11 GP50 1	15 00%	12 54	4 91	0 44	0 98	0 14	0 00	0 00	0 00	0 00	0 00	19 0
12 GP10 1	18 00%	15 05	5 84	0 53	1 17	0 07	0 00	0 00	0 00	0 00	0 00	22 7
Total	100 00%	59 00	50 05	22 20	6 50	1 40	2 24	3 25	2 80	0 00	0 00	147 4
Total trains		0 52	0 57	0 30	0 10	0 03	0 05	0 08	0 08	0 00	0 00	1 73

Crossing Type: Flashing Lights

Crossing												Total
1 FL500 2 2	20%	4 5135	9 8746	8 1696	1 0400	0 0000	0 0000	0 6000	0 4000	0 0000	0 0000	24 6
2 FL100 2 2	14%	2 7081	7 2445	6 1272	0 7800	0 0000	0 0000	0 3500	0 2400	0 0000	0 0000	17 4
3 FL50 2 2	9%	1 3541	4 7221	4 0848	0 5200	0 0000	0 0000	0 0500	0 1200	0 0000	0 0000	10 9
4 FL20 2 2	5%	0 4514	2 3072	2 0424	0 2600	0 0000	0 0000	0 0000	0 0400	0 0000	0 0000	5 1
5 FL500-1-2	8%	7 4960	4 1355	0 2664	0 5850	0 2800	0 4480	0 0000	0 0000	0 0000	0 0000	13 2
6 FL100-1-2	8%	7 4960	3 8852	0 2664	0 5850	0 2100	0 3360	0 0000	0 0000	0 0000	0 0000	12 8
7 FL50 1 2	7%	7 4960	3 3847	0 2664	0 5850	0 1400	0 1920	0 0000	0 0000	0 0000	0 0000	12 1
8 FL20 1 2	7%	7 4960	3 3847	0 2664	0 5850	0 0700	0 1120	0 0000	0 0000	0 0000	0 0000	11 9
9 FL500 1 4	13%	9 9946	6 4316	0 3552	0 7800	0 4200	0 7681	0 0000	0 0000	0 0000	0 0000	18 7
10 FL100 1 4	9%	9 9946	4 6798	0 3552	0 7800	0 1400	0 2240	0 0000	0 0000	0 0000	0 0000	16 2
11 FL50 1 4	0%	0 0000	0 0000	0 0000	0 0000	0 0700	0 0800	0 0000	0 0000	0 0000	0 0000	0 1
12 FL20 1 4	0%	0 0000	0 0000	0.0000	0 0000	0 0700	0 0800	0 0000	0 0000	0 0000	0 0000	0 1
	100 00%	59 0000	50 0500	22 2000	6 5000	1 4000	2 2400	1 0000	0 8000	0 0000	0 0000	143 19
		0 517	0 566	0 304	0 101	0 027	0 049	0 025	0 023	0 000	0 000	1 612

Exhibit B-6 Number of Crossings in Each Category, Gated Public Crossings

Crossing Type: Passive

Crossing												Total
1 P500 P	20%	29 5000	20 9300	7 7700	1 9000	0 3400	0 3640	0 0500	0 0000	0 0000	0 0000	60 9
2 P200 P	15%	22 1250	15 6975	5 8275	1 4250	0 2550	0 2730	0 0375	0 0000	0 0000	0 0000	45 6
3 P50 P	15%	22 1250	15 6975	5 8275	1 4250	0 2550	0 2730	0 0375	0 0000	0 0000	0 0000	45 6
4 P10 P	15%	22 1250	15 6975	5 8275	1 4250	0 2550	0 2730	0 0375	0 0000	0 0000	0 0000	45 6
5 P1 P	10%	14 7500	10 4650	3 8850	0 9500	0 1700	0 1820	0 0250	0 0000	0 0000	0 0000	30 4
6 P500 U	2%	2 9500	2 0930	0 7770	0 1900	0 0340	0 0364	0 0050	0 0000	0 0000	0 0000	6 1
7 P200 U	2%	2 9500	2 0930	0 7770	0 1900	0 0340	0 0364	0 0050	0 0000	0 0000	0 0000	6 1
8 P50 U	2%	2 9500	2 0930	0 7770	0 1900	0 0340	0 0364	0 0050	0 0000	0 0000	0 0000	6 1
9 P10 U	4%	5 9000	4 1860	1 5540	0 3800	0 0680	0 0728	0 0100	0 0000	0 0000	0 0000	12 2
10 P1 U	5%	7 3750	5 2325	1 9425	0 4750	0 0850	0 0910	0 0125	0 0000	0 0000	0 0000	15 2
11 P500 P 4	5%	7 3750	5 2325	1 9425	0 4750	0 0850	0 0910	0 0125	0 0000	0 0000	0 0000	15 2
12 P200 P 4	5%	7 3750	5 2325	1 9425	0 4750	0 0850	0 0910	0 0125	0 0000	0 0000	0 0000	15 2
Total	100 00%	147 5000	104 6500	38 8500	9 5000	1 7000	1 8200	0 2500	0 0000	0 0000	0 0000	304 27
Total trains		1 292	1 184	0 532	0 147	0 033	0 040	0 006	0 000	0 000	0 000	3 234

Crossing Type: Gated Private

Crossing												Total
1 PRI50 P	20%	5 9000	4 5500	1 8500	0 5000	0 1000	0 1400	0 1000	0 0800	0 0000	0 0000	13 2
2 PRI25 P	10%	2 9500	2 2750	0 9250	0 2500	0 0500	0 0700	0 0500	0 0400	0 0000	0 0000	6 6
3 PRI2 P	10%	2 9500	2 2750	0 9250	0 2500	0 0500	0 0700	0 0500	0 0400	0 0000	0 0000	6 6
4 PRI50 U	5%	1 4750	1 1375	0 4625	0 1250	0 0250	0 0350	0 0250	0 0200	0 0000	0 0000	3 3
5 PRI25 U	5%	1 4750	1 1375	0 4625	0 1250	0 0250	0 0350	0 0250	0 0200	0 0000	0 0000	3 3
6 PRI2 U	5%	1 4750	1 1375	0 4625	0 1250	0 0250	0 0350	0 0250	0 0200	0 0000	0 0000	3 3
7 PRI50 2 P	10%	2 9500	2 2750	0 9250	0 2500	0 0500	0 0700	0 0500	0 0400	0 0000	0 0000	6 6
8 PRI25 2 P	10%	2 9500	2 2750	0 9250	0 2500	0 0500	0 0700	0 0500	0 0400	0 0000	0 0000	6 6
9 PRI2 2 P	10%	2 9500	2 2750	0 9250	0 2500	0 0500	0 0700	0 0500	0 0400	0 0000	0 0000	6 6
10 PRI50 2 U	5%	1 4750	1 1375	0 4625	0 1250	0 0250	0 0350	0 0250	0 0200	0 0000	0 0000	3 3
11 PRI25 2 U	5%	1 4750	1 1375	0 4625	0 1250	0 0250	0 0350	0 0250	0 0200	0 0000	0 0000	3 3
12 PRI2 2 U	5%	1 4750	1 1375	0 4625	0 1250	0 0250	0 0350	0 0250	0 0200	0 0000	0 0000	3 3
Total	100 00%	29 5000	22 7500	9 2500	2 5000	0 5000	0 7000	0 5000	0 4000	0 0000	0 0000	66 1
Total trains		0 258	0 257	0 127	0 039	0 010	0 015	0 012	0 012	0 000	0 000	0 730

Grand Total	295	228	93	25	5	7	5	4	0	0	661
Million Trains per year	2 58	2 57	1 27	0 39	0 10	0 15	0 12	0 12	0 00	0 00	7 30

Exhibit B-6 (Continued)

Total Accidents per year for each type of crossing, by train volume

Crossing Type: Gated, Public

												Total
1	GP5000-2	0.0584	0.0521	0.0333	0.0045	0.0000	0.0260	0.0525	0.0326	0.0000	0.0000	0.26
2	GP1000-2	0.0546	0.1049	0.0828	0.0112	0.0000	0.0233	0.0436	0.0304	0.0000	0.0000	0.35
3	GP500-2	0.0890	0.1620	0.1267	0.0171	0.0000	0.0363	0.0623	0.0496	0.0000	0.0000	0.54
4	GP200-2	0.0680	0.1587	0.1290	0.0174	0.0000	0.0240	0.0272	0.0379	0.0000	0.0000	0.46
5	GP50-2	0.0151	0.1206	0.1072	0.0145	0.0000	0.0050	0.0045	0.0084	0.0000	0.0000	0.28
6	GP10-2	0.0047	0.0883	0.0802	0.0108	0.0000	0.0018	0.0028	0.0026	0.0000	0.0000	0.19
7	GP5000-1	0.0569	0.0719	0.0025	0.0058	0.0115	0.0000	0.0000	0.0000	0.0000	0.0000	0.15
8	GP1000-1	0.1418	0.0993	0.0062	0.0144	0.0107	0.0000	0.0000	0.0000	0.0000	0.0000	0.27
9	GP500-1	0.2168	0.1478	0.0095	0.0220	0.0175	0.0000	0.0000	0.0000	0.0000	0.0000	0.41
10	GP200-1	0.2207	0.1174	0.0096	0.0224	0.0133	0.0000	0.0000	0.0000	0.0000	0.0000	0.38
11	GP50-1	0.1835	0.0810	0.0080	0.0187	0.0030	0.0000	0.0000	0.0000	0.0000	0.0000	0.29
12	GP10-1	0.1372	0.0601	0.0060	0.0139	0.0009	0.0000	0.0000	0.0000	0.0000	0.0000	0.22
		1.2465	1.2641	0.6010	0.1727	0.0569	0.1164	0.1929	0.1616	0.0000	0.0000	3.81

Crossing Type: Flashing Lights

	Crossing											Total
		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.00
1	FL500-2-2	0.2783	0.6960	0.6361	0.0863	0.0000	0.0000	0.0638	0.0463	0.0000	0.0000	1.81
2	FL100-2-2	0.0862	0.2637	0.2464	0.0334	0.0000	0.0000	0.0192	0.0143	0.0000	0.0000	0.66
3	FL50-2-2	0.0324	0.1293	0.1236	0.0168	0.0000	0.0000	0.0021	0.0054	0.0000	0.0000	0.31
4	FL20-2-2	0.0074	0.0434	0.0424	0.0058	0.0000	0.0000	0.0000	0.0012	0.0000	0.0000	0.10
5	FL500-1-2	0.3816	0.2406	0.0171	0.0401	0.0214	0.0368	0.0000	0.0000	0.0000	0.0000	0.74
6	FL100-1-2	0.1971	0.1168	0.0088	0.0207	0.0083	0.0143	0.0000	0.0000	0.0000	0.0000	0.37
7	FL50-1-2	0.1483	0.0765	0.0067	0.0156	0.0042	0.0061	0.0000	0.0000	0.0000	0.0000	0.26
8	FL20-1-2	0.1018	0.0525	0.0046	0.0107	0.0014	0.0025	0.0000	0.0000	0.0000	0.0000	0.17
9	FL500-1-4	0.7331	0.5392	0.0329	0.0770	0.0463	0.0910	0.0000	0.0000	0.0000	0.0000	1.52
10	FL100-1-4	0.5032	0.2693	0.0226	0.0529	0.0106	0.0182	0.0000	0.0000	0.0000	0.0000	0.88
11	FL50-1-4	0.0000	0.0000	0.0000	0.0000	0.0030	0.0037	0.0000	0.0000	0.0000	0.0000	0.01
12	FL20-1-4	0.0000	0.0000	0.0000	0.0000	0.0021	0.0025	0.0000	0.0000	0.0000	0.0000	0.00
		2.4694	2.4275	1.1411	0.3593	0.0973	0.1750	0.0851	0.0673	0.0000	0.0000	6.82

Exhibit B-7a Total Accidents Per Year

Total Accidents per year for each type of crossing, by train volume

Crossing Type: Passive

	Crossing											Total
1	P500-P	3.4022	2.7745	1.1425	0.2987	0.0600	0.0691	0.0102	0.0000	0.0000	0.0000	7.76
2	P200-P	1.8180	1.4826	0.6105	0.1596	0.0321	0.0369	0.0054	0.0000	0.0000	0.0000	4.15
3	P50-P	1.0886	0.8877	0.3655	0.0956	0.0192	0.0221	0.0033	0.0000	0.0000	0.0000	2.48
4	P10-P	0.6003	0.4895	0.2015	0.0527	0.0106	0.0122	0.0018	0.0000	0.0000	0.0000	1.37
5	P1-P	0.1712	0.1395	0.0574	0.0150	0.0030	0.0035	0.0005	0.0000	0.0000	0.0000	0.39
6	P500-U	0.1874	0.1528	0.0629	0.0164	0.0033	0.0038	0.0006	0.0000	0.0000	0.0000	0.43
7	P200-U	0.1335	0.1089	0.0448	0.0117	0.0024	0.0027	0.0004	0.0000	0.0000	0.0000	0.30
8	P50-U	0.0799	0.0652	0.0268	0.0070	0.0014	0.0016	0.0002	0.0000	0.0000	0.0000	0.18
9	P10-U	0.0881	0.0719	0.0296	0.0077	0.0016	0.0018	0.0003	0.0000	0.0000	0.0000	0.20
10	P1-U	0.0471	0.0384	0.0158	0.0041	0.0008	0.0010	0.0001	0.0000	0.0000	0.0000	0.11
11	P500-P-4	0.6751	0.5506	0.2267	0.0593	0.0119	0.0137	0.0020	0.0000	0.0000	0.0000	1.54
12	P200-P-4	0.4810	0.3923	0.1615	0.0422	0.0085	0.0098	0.0014	0.0000	0.0000	0.0000	1.10
	Total	8.7724	7.1537	2.9457	0.7701	0.1547	0.1783	0.0262	0.0000	0.0000	0.0000	20.00

Crossing Type: Gated Private

	Crossing											Total
1	PRI50-P	0.0864	0.0751	0.0334	0.0096	0.0021	0.0032	0.0024	0.0021	0.0000	0.0000	0.21
2	PRI25-P	0.0352	0.0306	0.0136	0.0039	0.0009	0.0013	0.0010	0.0008	0.0000	0.0000	0.09
3	PRI2-P	0.0168	0.0146	0.0065	0.0019	0.0004	0.0006	0.0005	0.0004	0.0000	0.0000	0.04
4	PRI50-U	0.0216	0.0188	0.0084	0.0024	0.0005	0.0008	0.0006	0.0005	0.0000	0.0000	0.05
5	PRI25-U	0.0176	0.0153	0.0068	0.0020	0.0004	0.0006	0.0005	0.0004	0.0000	0.0000	0.04
6	PRI2-U	0.0084	0.0073	0.0032	0.0009	0.0002	0.0003	0.0002	0.0002	0.0000	0.0000	0.02
7	PRI50-2-P	0.0502	0.0437	0.0194	0.0056	0.0012	0.0018	0.0014	0.0012	0.0000	0.0000	0.12
8	PRI25-2-P	0.0410	0.0356	0.0158	0.0045	0.0010	0.0015	0.0011	0.0010	0.0000	0.0000	0.10
9	PRI2-2-P	0.0195	0.0170	0.0075	0.0022	0.0005	0.0007	0.0005	0.0005	0.0000	0.0000	0.05
10	PRI50-2-U	0.0251	0.0218	0.0097	0.0028	0.0006	0.0009	0.0007	0.0006	0.0000	0.0000	0.06
11	PRI25-2-U	0.0205	0.0178	0.0079	0.0023	0.0005	0.0007	0.0006	0.0005	0.0000	0.0000	0.05
12	PRI2-2-U	0.0098	0.0085	0.0038	0.0011	0.0002	0.0004	0.0003	0.0002	0.0000	0.0000	0.02
	Total	0.3520	0.3061	0.1361	0.0390	0.0086	0.0129	0.0097	0.0084	0.0000	0.0000	0.87

Exhibit B-7b Total Accidents Per Year

Corridor Base Case

	24	31	38	42	52	60	68	80	100	120	Total
	Accidents/year (by number of daily trains per crossing)										
Total Accidents	24	31	38	42	52	60	68	80	100	120	Total
Public Gated	1.25	1.26	0.60	0.17	0.06	0.12	0.19	0.16	0.00	0.00	3.81
Flashing Lights	2.47	2.43	1.14	0.36	0.10	0.18	0.09	0.07	0.00	0.00	6.82
Passive	8.77	7.15	2.95	0.77	0.15	0.18	0.03	0.00	0.00	0.00	20.00
Private Gated	0.35	0.31	0.14	0.04	0.01	0.01	0.01	0.01	0.00	0.00	0.87
Grand Total	12.84	11.15	4.82	1.34	0.32	0.48	0.31	0.24	0.00	0.00	31.51
	Accidents/million trains (by number of daily trains per crossing)										
Total Accidents/Million Trains	24	31	38	42	52	60	68	80	100	120	Total
Public Gated	2.41	2.23	1.98	1.72	2.12	2.37	2.39	1.98			2.21
Flashing Lights	4.78	4.29	3.76	3.57	3.64	3.57	3.43	2.88			4.23
Passive	6.79	6.04	5.54	5.24	4.76	4.47	4.23				6.19
Private Gated	1.36	1.19	1.08	1.01	0.90	0.84	0.78	0.72			1.20
Grand Total	4.97	4.33	3.81	3.47	3.32	3.15	2.53	2.03			4.32
PTC Effects (accidents with PTC as fraction of accidents without PTC)											
Public Gated	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	
Flashing Lights	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	
Passive	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	
Private Gated	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	
Accidents with PTC											
Public Gated	1.22	1.24	0.59	0.17	0.06	0.11	0.19	0.16	0.00	0.00	3.74
Flashing Lights	2.42	2.38	1.12	0.35	0.10	0.17	0.08	0.07	0.00	0.00	6.69
Passive	8.60	7.01	2.89	0.75	0.15	0.17	0.03	0.00	0.00	0.00	19.60
Private Gated	0.25	0.21	0.10	0.03	0.01	0.01	0.01	0.01	0.00	0.00	0.61
Grand Total	12.48	10.84	4.69	1.30	0.31	0.47	0.30	0.23	0.00	0.00	30.63
Accidents/million trains	4.83	4.21	3.70	3.37	3.23	3.06	2.46	1.97			4.20
% Improvement	2.8%	2.8%	2.8%	2.8%	2.8%	2.7%	2.9%	3.0%			2.8%

Exhibit B-7c Total Accidents Per Year Summary Statistics