U.S. Department of Transportation
Federal Railroad Administration

Positive Train Control Effectiveness - A Corridor Risk Assessment Model Approach

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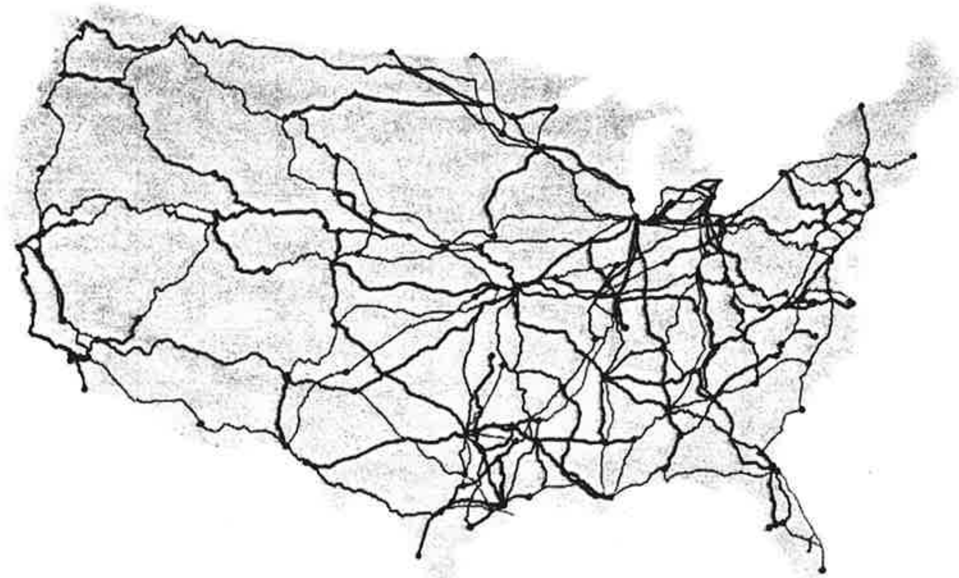

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13. ABSTRACT (Maximum 200 words)

Positive Train Control (PTC) systems have been found to have significant potential for risk reduction and increased efficiency in railroad operations by introducing redundancy into the control and operation of trains. Centralized oversight using digital data communication and satellite-based train position tracking allow for intervention into the operation of the train when needed, a capability that should provide safety enhancements in environments that have higher accident rates. At the request of the FRA, the U.S. Department of Transportation's Volpe National Transportation Systems Center (Volpe Center) determined in 1995 that it was feasible to attempt to identify potentially high-risk rail corridors. The Volpe Center developed a methodology based on identifying geographically related factors that seemed to contribute to risk. Subsequently, a model, employing a geographical information system (GIS) platform, was built and used to differentiate among rail corridors on the basis of risk. This model, the Corridor Risk Assessment Model (CRAM), was found to have several potential applications, including assisting the FRA in its evaluation of PTC deployment, identifying cost-effective improvements for high-speed rail corridors by determining risk impacts of higher train speeds and the risk reduction benefits of alternative safety improvements.

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METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in)	=	2.5 centimeters (cm)
1 foot (ft)	=	30 centimeters (cm)
1 yard (yd)	=	0.9 meter (m)
1 mile (mi)	=	1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2)	=	6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2)	=	0.09 square meter (m^2)
1 square yard (sq yd, yd^2)	=	0.8 square meter (m^2)
1 square mile (sq mi, mi^2)	=	2.6 square kilometers (km^2)
1 acre = 0.4 hectare (he)	=	4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz)	=	28 grams (gm)
1 pound (lb)	=	0.45 kilogram (kg)
1 short ton = 2,000 pounds (lb)	=	0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp)	=	5 milliliters (ml)
1 tablespoon (tbsp)	=	15 milliliters (ml)
1 fluid ounce (fl oz)	=	30 milliliters (ml)
1 cup (c)	=	0.24 liter (l)
1 pint (pt)	=	0.47 liter (l)
1 quart (qt)	=	0.96 liter (l)
1 gallon (gal)	=	3.8 liters (l)
1 cubic foot (cu ft, ft^3)	=	0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3)	=	0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

[(x-32)(5/9)] °F = y °C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm)	=	0.04 inch (in)
1 centimeter (cm)	=	0.4 inch (in)
1 meter (m)	=	3.3 feet (ft)
1 meter (m)	=	1.1 yards (yd)
1 kilometer (km)	=	0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2)	=	0.16 square inch (sq in, in^2)
1 square meter (m^2)	=	1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2)	=	0.4 square mile (sq mi, mi^2)
10,000 square meters (m^2)	=	1 hectare (ha) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gm)	=	0.036 ounce (oz)
1 kilogram (kg)	=	2.2 pounds (lb)
1 tonne (t)	=	1,000 kilograms (kg)
	=	1.1 short tons

VOLUME (APPROXIMATE)

1 milliliter (ml)	=	0.03 fluid ounce (fl oz)
1 liter (l)	=	2.1 pints (pt)
1 liter (l)	=	1.06 quarts (qt)
1 liter (l)	=	0.26 gallon (gal)
1 cubic meter (m^3)	=	36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3)	=	1.3 cubic yards (cu yd, yd^3)

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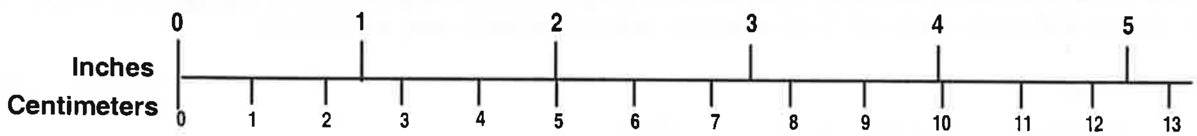

QUICK FAHRENHEIT - CELSIUS TEMPERATURE CONVERSION

°F	-40°	-22°	-4°	14°	32°	50°	68°	86°	104°	122°	140°	158°	176°	194°	212°
°C	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°

For more exact and or other conversion factors, see NIST Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50 SD Catalog No. C13 10286

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PREFACE

This report is among the more difficult and controversial ever undertaken for the Federal Railroad Administration (FRA). The FRA and the Positive Train Control (PTC) Working Group of the Railroad Safety Advisory Committee (RSAC) have joined the Volpe Center in investing significant effort to make the report as realistic and meaningful as possible. Ultimately, of course, the report is the professional product of the Volpe Center. In this preface, FRA offers its observations concerning the place the report occupies in the overall dialogue regarding PTC. In an appendix, the Volpe Center summarizes peer comments on the final report from members of the RSAC Working Group.

This report is a very useful document that describes the way in which the risk of PTC-preventable accidents is distributed over a large part of the national rail system. In addition, it derives a model that may be helpful in describing priorities for migration toward interoperable PTC across the national rail system. Finally, the study effort has resulted in the creation of geographically-linked databases and associated analytical expertise that are being used for a number of railroad safety purposes. Those purposes include the provision of benchmarks for use in risk assessment techniques under forthcoming performance standards for processor-based signal and train control systems.

FRA is aware that many factors affect the likelihood of collisions, overspeed derailments, and train incursions into roadway work zones. For instance, it is generally understood that safety requires conditions such as: sound operating rules; alert, well trained employees; appropriate workload (to avoid distraction from key duties, on the one hand, or boredom leading to complacency, on the other); and strong and positive expectations among employees and managers with respect to rules compliance. No database available to FRA clearly measures these conditions at the railroad system level, let alone at a corridor level, and these factors may vary from time to time; so it is a limitation of this report that it cannot consider directly what most experts in the field would consider many of the most influential variables.

However, this report deals with these human factor issues to the extent that physical and operating characteristics of the railroad may mitigate or potentiate hazards arising out of them. Importantly, the model can consider event *consequences* as a function of known variables (i.e., speed, passenger trains, and presence of population centers potentially affected by a hazardous materials release).

The report shows that track curvature and train volume are associated with the risk of a PTC-preventable accident on any segment during a fixed period of time. (This does not mean that predicted frequency necessarily rises on a normalized basis as traffic grows). The presence of wayside signals is associated with reduced risk, and use of traditional forms of train control is even more strongly associated with lower risk. Events involving passenger trains or release of hazardous materials may result in greater societal costs.

Predicted risk, defined as frequency times expected severity, is displayed on a corridor basis. This modeling technique, when refreshed with current data at the point investment decisions are being made, should be useful to railroads undertaking train control projects so that phased installation of wayside components needed for the system to function is not delayed on routes where the aggregate risk is relatively higher than other routes. In this regard, information concerning cumulative risk on corridors (e.g., per mile of track) is available from this model, even though results are not displayed in this report.

Although the model is internally validated to a rather high level of correlation (.7, where 1.0 is ideal), model predictions for a subsequent two-year period did not correlate well with actual outcomes. This result may have related to a "memory effect" in the system (as crew awareness increases for a time at least on segments where accidents occurred in the recent past) or the very short period used for comparison (involving a small number of data points), but the concern does suggest further caution with respect to any thought that immediate and dramatic results could be achieved by focusing only on predicted higher risk corridors. Further investigation using data from a longer period may (or may not) demonstrate greater correspondence between predicted and actual results.

This study was originally requested by the Office of Safety, FRA, with the anticipation that it might point the way for corridor-by-corridor implementation of PTC. That original purpose has been overtaken by intervening events. Study within the RSAC has affirmed that, at least under circumstances contemplated by that body, it is not possible to deploy PTC in a cost effective manner, considering only safety benefits, by "cherry picking" individual rail corridors. As the data developed for this study show, while there are differences among corridors with respect to potential for risk mitigation, and although it is possible to predict to some extent how it will be distributed geographically in the future, there are not clear "pockets" of very high risk on corridors that together account for the majority of system risk. Even if that were the case, issues of practicality would arise.

Contemporary communications-based train control systems will become economic as allied business systems that can be built on the communications infrastructure are embraced by railroad strategic plans. A majority of the cost of PTC systems will likely be on board locomotives, and most of the economic benefits will be captured only as communications, control, and information system functions extend throughout the rail network (potentiating sound asset management and enhancing service quality). Certain classes of locomotives are being held captive on specific routes. However, a majority of locomotives are used to move freight throughout the national rail network rather than being tied to individual territories. Accordingly, the scale of PTC implementation should be conceived as a migration to a nationally-compatible system, rather than a patchwork of disconnected corridors.

Although this report does not point to a single strategy for implementing PTC, it does add another tool to the toolset we will need to promote sensible deployment of this potentially life-saving technology.

Grady C. Cothen, Jr.
Deputy Associate Administrator for
Safety Standards

Steven R. Ditmeyer
Director, Office of Research
and Development

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1. INTRODUCTION

Positive Train Control (PTC) systems have significant potential for risk reduction and increased efficiency in railroad operations. Studies of PTC conducted by the railroads, the Federal Railroad Administration (FRA), and others since the 1980s identified specific functions that would reduce the frequency and severity of railroad accidents. One of the constraints faced by this and other studies in defining the exact magnitude of this reduction has been establishing a definition of PTC. A strict definition of PTC is difficult to formulate due to the potential for a wide variety of implementations with different operational characteristics; however, FRA describes PTC systems as "...a family of functions that can be supported by communications-based train control systems and similar advanced technologies. PTC functions include the safety functions, generally denoted by the term Positive Train Separation (PTS) as well as other functions useful to the business of railroading." The Railroad Safety Advisory Committee (RSAC) defines the core PTC features as the ability to:

> "a. Prevent train-to-train collisions (positive train separation).
>
> b. Enforce speed restrictions, including civil engineering restrictions (curves, bridges, etc.) and temporary slow orders.
>
> c. Provide protection for roadway workers and their equipment operating under specific authorities"[1]

PTC can increase safety by introducing redundancy into the control and operation of trains. Centralized oversight through technologies such as digital data communication and satellite-based train position tracking provide the capacity for intervention into the operation of the train when necessary. This oversight and intervention capability should provide safety enhancements in environments that have higher accident risk.[2] The preventable accidents are most often those involving operator errors and track problems that can be detected by the PTC system and therefore prevented through the intervention of the central oversight controller (either a dispatcher or software component).

Although the potential of PTC systems to improve railroad operations and enhance safety significantly has been recognized since the 1980s, FRA has not recommended a regulatory requirement. In its 1994 Report to Congress, the FRA concluded that "...while a universal PTC requirement could not at present be warranted on the basis of cost and safety benefits alone, the benefits of PTC may justify the costs in certain corridors with certain characteristics, including

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[1] RSAC 1999. Implementation of Positive Train Control Systems, Report of the Railroad Safety Advisory Committee to the Federal Railroad Administrator.

[2] This general concept of scaling safety systems based upon risk is already incorporated into FRA regulations. See 49 CFR §236.0.

the presence of passenger trains, hazardous materials or higher levels of congestion...FRA will continue to support PTC research, development, and implementation in a number of ways.[3] The FRA determined at that time to undertake certain actions to invest in the development of PTC, including initiating development of a risk analysis model to guide determination of priorities (among major freight rail corridors) for application of PTC technology."[4]

At the FRA's request, the U.S. Department of Transportation's Volpe National Transportation Systems Center (Volpe Center) determined in 1995 that it was feasible to attempt to identify potentially high-risk rail corridors. The Volpe Center developed a methodology based on the identification of geographically related factors that seemed to contribute to risk. Subsequently, a model, employing a geographical information system (GIS) platform, was built and used to differentiate among rail corridors on the basis of risk. This model had several potential applications, including assisting the FRA in its evaluation of PTC deployment.

The Volpe Center developed its first GIS-based tool by integrating data gathered from existing databases. The databases included information, such as the FRA's GIS data, track and accident data, U.S. census data and shipment data based upon the Interstate Commerce Commission's waybill sample now maintained by the Surface Transportation Board.

The first version of this model, produced in 1996, was based upon the FRA's definition of PTC functionality and extant prototype systems. Operational rail corridors were proposed by the FRA and defined using the GIS. These inputs were in turn used in the analytical model that described risk of PTC-preventable accidents based upon geographical characteristics. The preliminary results and conclusions were presented to the FRA and the Railroad Safety Advisory Committee (RSAC)[5] in June 1997.

When the RSAC PTC Working Group was formed in September of 1997, this effort was offered to the group by the FRA as a possible tool to assist in their risk analysis. The Implementation Task Force of this working group was briefed on the background and status of this analysis effort, referred to as the Corridor Risk Assessment Model (CRAM).

During late 1997 and into 1998 the task force and individual railroads provided input and direction to the project. Task force contributions and resulting modifications to the modeling effort were made in several areas. These areas included: 1) the definition of PTC functions; 2) the selection of PTC-preventable accidents; 3) the data to be used as the basis for exposure measure including total train-miles and million gross tons of traffic for each railroad; and 4) the definition of operational corridors.

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[3] FRA 1994. Report to Congress Communications and Train Control, p. v.

[4] Ibid., p. 78.

[5] RSAC is a Federal Advisory Committee established to provide consensus-based recommendations to the FRA concerning railroad safety issues.

A team formed of members of the Data/Implementation Task Force referred to as the Accident Review Team (ART) addressed the PTC definitions and identification of preventable accidents. The ART identified accident causes and specific accidents that could be used as input into the regression analysis for predictive purposes. Exposure data, in the form of traffic flows, and the definition of operational corridors were contributed by the American Association of Railroads (AAR) and participating railroads. Some railroads had provided these data as part of public processes (such as merger and acquisition applications) and others regularly publish traffic flow data. These data on freight and intercity passenger traffic were integrated into the GIS. American Public Transportation Association (APTA) members provided some commuter rail data. Additional information on network flows was acquired from other published sources (such as train schedules).

1.1 PTC FUNCTIONS

The ART approached the PTC accident analysis by first defining a categorical framework which established PTC design functionality and capabilities. Four categories were defined which represented a broad range of PTC systems and their likely impacts upon safety. In addition, the ART recognized that the effectiveness of PTC systems in safety improvement depended upon the infrastructure and operational characteristics of the environment in which they were implemented. Therefore, PTC system effectiveness was evaluated both in terms of the functionality of the system and the control system and the existing signal system and traffic control at the time of the accident.

PTC levels were based upon the functionality of train-control projects such as the BNSF TrainGuard™ System Project, the Union Pacific Railroad (UP)/Burlington Northern Santa Fe (BNSF) Positive Train Separation (PTS) Pilot Project, and the Amtrak/Michigan DOT Michigan Line Incremental Train Control System (ITCS) Project). The design specifications originally proposed for the UP/Illinois Department of Transportation (IDOT) St. Louis Line Project now referred to as the IDOT of the North American Positive Train Control Program, which were based on the Advanced Train Control Systems Specifications (ATCS) were also used to define PTC levels.

For the 1999 RSAC Report to the Administrator, the Data and Implementation Task Force defined the four design concepts in operational terms:

"The four design concepts are hierarchical, in that each superior design incorporates all of the functions of the previous concept(s), and may either add functionality or scope (coverage) or both. The design concepts, from the least functionality/scope, to the most, are as follows.

1.1.1. PTC LEVEL 1

This is the first level PTC design concept to address the core functions as identified by the PTC RSAC.

PTC Level 1 will:

- Prevent train to train collisions (i.e., positive train separation).

- Enforce speed restrictions, including civil engineering and temporary restrictions imposed by slow orders.

- Protect roadway workers and their equipment operating under specific authorities from train movements.

This level of PTC is based on providing specific location information on nearby trains and roadway crews to the lead locomotive of a train. On-board enforcement is indicated on either the failure of the engine crew to acknowledge a warning of a nearby train, or roadway worker crew, or exceeding permanent or temporary speed restrictions.

Most of these systems will use a radio frequency (RF) link to provide information to the lead locomotive of a train.

1.1.2 PTC LEVEL 2

The next level PTC design will depend on the issuance of specific movement authorities and the reporting of train and roadway crew locations to the authority issuer. In addition to the functionality of PTC Level 1, Level 2 will:

Include a computer-aided dispatch (CAD) system designed to prevent the issuance of overlapping authorities, and provide for the issuance and enforcement of additional speed limits and restrictions.

Provide a digital communications link between the CAD system and the locomotives.

1.1.3 PTC LEVEL 3

In addition to the capabilities of PTC Level 1 and 2, PTC Level 3 will:

Incorporate devices, such as Wayside Interface Units (WIUs), that monitor each mainline wayside switch, signal, and protective device currently installed in traffic controlled territory, to reduce risk of operating over unsafe track. If new switches are required during implementation of a Level 3 system, these switches will be tied into a wayside local area network (WLAN).

Provide WIUs in non-signaled territory that monitor switch and protective devices.

1.1.4 PTC LEVEL 4

This is the highest level PTC design concept, and is largely based on the level 40 Advanced Train Control Systems (ATCS) specifications. In addition to providing the functionalities of PTC Levels 1, 2 and 3, Level 4 will:

Monitor each mainline signal, switch, and protective device with WIUs. This may require the installation of devices on currently installed switches and protective devices.

Use additional protective devices, e.g., slide fences, anemometers, high water, dragging equipment, hot box detectors, etc.

Add track circuits, track continuity circuits or other risk reduction approaches for broken rail detection.

Provide track forces terminals (e.g., laptops or other technology with data link) for roadway machinery to reduce the risk of accidents involving track forces outside their authority limits."[6]

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[6] RSAC 1999, p. 16-17.

2. ACCIDENT DATA

A review of the requirements for reporting accidents identified 63 causal factors of accidents that are potentially PTC preventable. The RSAC PTC Working Group assigned the ART to identify the PTC-preventable accidents in which those causal factors were present. The ART reviewed a large accident database of candidate PTC Preventable Accidents (PPAs), and a judgment was made on whether each accident was a PPA or not. These judgments were based on the generalized capabilities of the four PTC concept levels discussed in Chapter 2. The ART was composed of representatives from railroad management, labor, and FRA with many years of experience in railroad operations, signal and train control systems, and research and development. In some cases, members of the ART were on site at the time of the accident investigation.

The accident data available for analysis in the study period included all reported accidents between 1988 and 1997 in the FRA Railroad Accident/Incident Database called the "Rail Accident Incident Reporting System" (RAIRS). Railroads are required to file monthly accident/incident reports with the FRA Office of Safety in accordance with 49 CFR 225. The reporting threshold that determines which accidents must be reported is $5,200 in 1987, and is adjusted annually for inflation. The current threshold dollar value is $6,600.[7]

The ART reviewed accidents from a data set of about 6,400 accidents. This data set was compiled from over 22,000 accidents reported to the FRA from 1988 through 1997. The 6,400-member accident data set was reviewed in detail and the results of that review are shown in this report. Table 1 provides a summary of the breakdown of accidents reported in RAIRS and included in this study.

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[7] FRA 1999 Accident Incident Bulletin.

Table 1. Total Accidents in Study Period

	1988-1995	1996-1997
Total Accidents in Study Period	22,594	5,140
Total Geographically Located Accidents (non-yard)	10,726	1,499
Accidents Reviewed by ART	4,800	1,600
PTC Preventable Accidents Selected	819	131

In its review of many reports, the ART encountered data fields that were in conflict, or contained missing, insufficient, or incomplete information. When necessary, further information was obtained from other sources. In every case, a final decision on the classification of an accident was achieved by consensus.

The determination that an accident was a PPA, a non-PPA, or some other category resulted in a notation being made in the database under the appropriate PTC level. Notations included accidents that might be preventable by that category of PTC; those that may/will have the cost of the accident mitigated by a category of PTC; those involving a track machine collision with another track machine that is not preventable with current technology but may be preventable with future technology; or accidents involving collisions between trains and track equipment outside the limits of the track equipment's authority. Various levels of preventability were assigned by the ART and employed in the final modeling four PTC levels.

An attempt was made to assign a geographic location to every accident record. About 50 percent of all reported accidents in RAIRS occurred in yards, and therefore were not considered to be potentially preventable by PTC. These accidents, as well as those that could not be located geographically, were eliminated from the analysis. Finally, only those accidents that were considered PTC preventable, based upon the inputs from the ART, and for which complete data were available, were included in the analysis. This led to the exclusion of grade crossing accidents and most equipment-failure related events.

It should be understood that Table 1 does not represent the universe of PTC-preventable accidents that occurred in calendar years 1988 to 1997. It represents all of the accidents that could be identified by using the accident cause code as a preliminary method of identifying a potential PPA. Additional accidents could be PPAs but were assigned to cause codes that were not reviewed by the accident review team.[8] The initial selection of cause codes served to reduce the volume of accident data to be reviewed by the ART and is representative of railroad accidents during the analysis period.

Accident consequences were used to describe the risk attributable to PPAs (historically) and to construct an estimate of the likely severity of future PPAs. A summary of the PPAs, their consequences, and their PTC system level appears in Table 2. Generally, accidents in the PPA group were either collisions or derailments, although a few accidents involving equipment or signal malfunctions were also included, such as a 1993 accident that resulted from a weld failure causing one injury, and a 1988 accident, the result of an improperly displayed fixed signal, that resulted in one fatality and two injuries.[9]

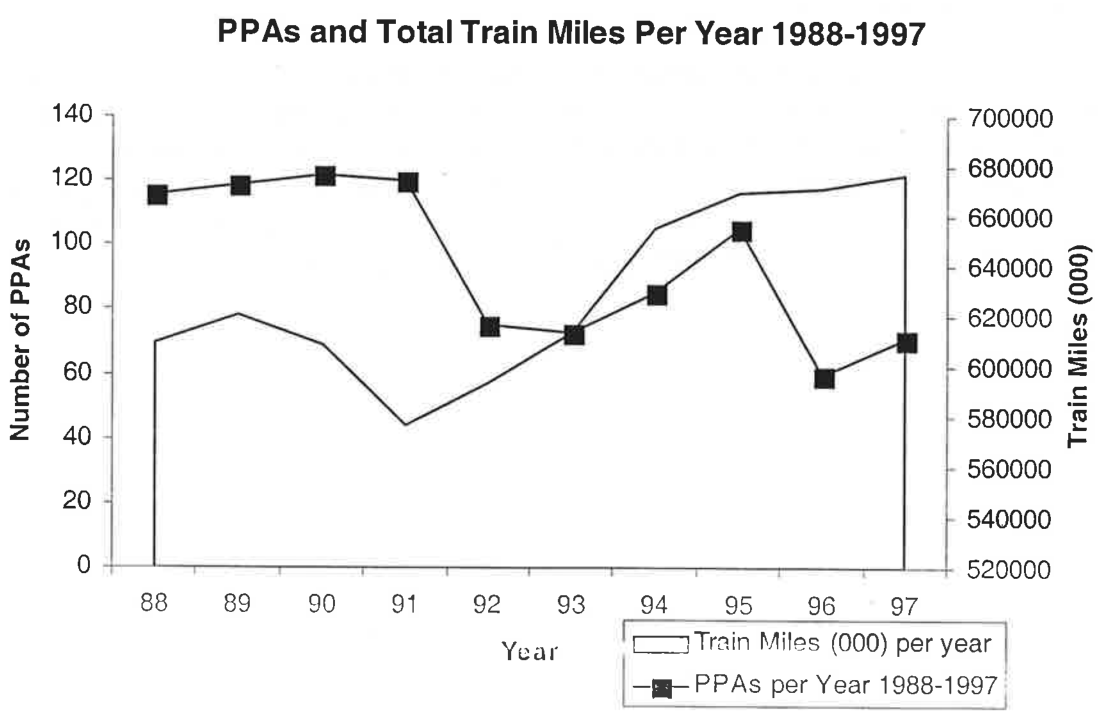

Figure 1. PPAs and Train-Miles Per Year 1988-1997

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[8] ART team members, including FRA staff, used their personal knowledge and FRA/NTSB investigation files to seek out accident records for major events. Relatively few events with serious consequences are believed to have been overlooked.

[9] USDOT FRA Railroad Accident Incident Reporting System Database 1999 Accidents # 9301CSX19303005 (cause code T002), and #99-1ATSF310188105 (cause code S005).

The trend in accident occurrence over time indicates that there were more PPAs annually in 1988-1991 than in the subsequent years. This may be due to earlier safety interventions that occurred as a result of each of these incidents, or the trend may be related to other factors, such as the volume of train traffic that occurred during that time period.

Figure 1 illustrates the frequency of PPAs per year [10] (read off of the left-hand axis) compared to the number of train-miles per year[11] (values shown on the right Y axis). The graphic shows that the number of PPAs per year decreased from 1988 to 1992, and increased again in a cyclic manner, as did the total train-miles during the period. This is a basic indication that the frequency of this type of accident is related to the total train volume. However, the trend in PPAs does not completely mimic the trend in train volume, as the difference between 1995 and 1996 illustrates. Other factors obviously affect the frequency of PPAs and those factors, along with changes in train volume, were investigated in this study.

Just as all years are not alike, neither are all PPAs. The distribution in severity is wider than the deviation in frequency from year to year, as is described in Table 2. Since the ART defined several levels of PTC systems for evaluation and rated accidents according to the likelihood that they are PTC preventable in all or only certain circumstances, a distribution of accidents and consequences were created. In Table 2 the accidents assigned to each category (both those rated as completely preventable, or only partially preventable under certain circumstances) are described.

[10]USDOT FRA Railroad Accident Incident Reporting System Database.

[11] USDOT FRA Accident Incident Bulletin, 1999 and 1993.

Trends in the derailment category indicate relatively infrequent low-consequences events, whose greatest potential hazard is in the possible release of hazardous chemicals and subsequent evacuation. Seventeen of 420 derailments resulted in evacuations; the average number of people evacuated was approximately 420 per incident. Two incidents resulted in over 1,000 evacuations. One derailment, included in the group of accidents thought to be possibly preventable by the highest level of PTC system, accounted for 47 fatalities.[12] This accident is not consistent with the general trend of the consequences of PTC-preventable derailments being less than collisions, but it identifies a source of risk. The historical data can only answer part of that question. To understand the total risk potential for the United States that might be addressed by PTC, a more formal assessment of the hazards other than through the use of this model is required.

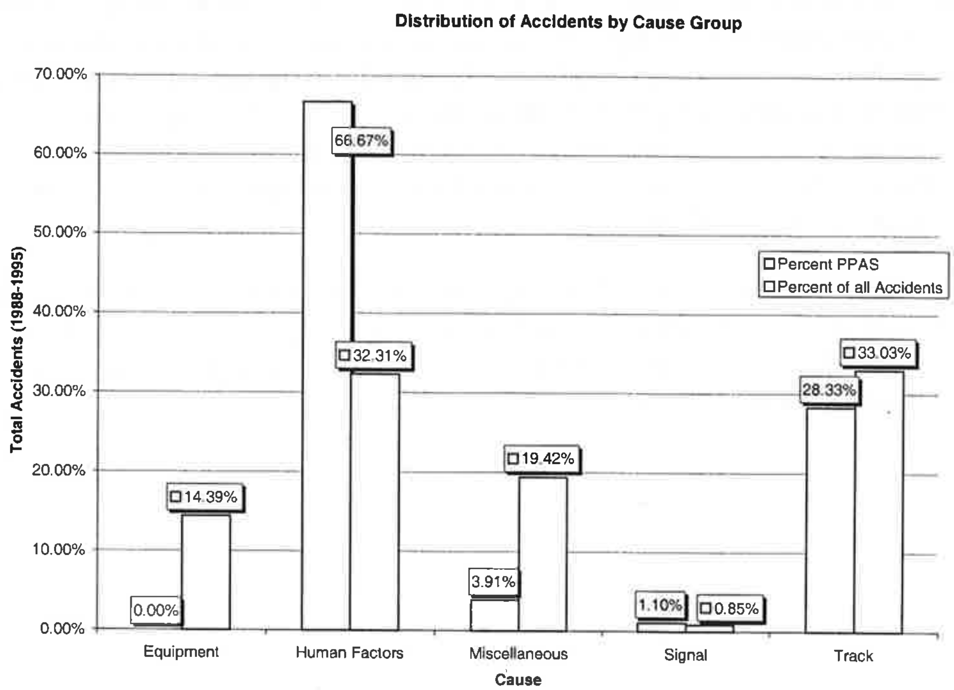


Figure 2. PPA and Non-PPAs by Cause Group

[12] This derailment was not included in the corridor analysis because its likelihood of preventability was considered "low." The conditions that led to its high severity are not treated in the model (presence of a body of water capable of floating a commercial tow at a railroad bridge), and its consequences were unusual with respect to the rest of the PPA database, making it of questionable relevance with respect to the distribution of risk geographically in this particular context. The accident was considered in the RSAC report as aggregate costs and benefits were described.

One significant difference between the PPA data and the balance of accidents during the same time period is their attributed cause. Human factors-related causes account for 32 percent of all other non-yard accidents, while they account for 67 percent of PPAs. Of the non-PPAs 33 percent and 15 percent are attributed to track or equipment failures, respectively, while in the PPA dataset those numbers are 28 and 0 percent, respectively.

The accidents thought to be preventable by PTC are primarily in the category of human factors accidents, with the exception of a few track-related scenarios that are highly dependent upon the availability of the track equipment necessary to successfully implement specific PTC designs.

There is significant divergence between the PPA and the non-PPA data in terms of the distribution of severity as well. The vast majority (88 percent) of severe accidents, one in which there was at least one fatality, are reported in RAIRS in one of the "miscellaneous" cause codes. These are general cause codes used to represent a variety of generic causes within each of the major cause groups (human factors, equipment, track, etc.). Even though the initial screening of accidents that could be preventable by PTC systems did not include the miscellaneous group their high frequency of severe accidents suggested that they should be evaluated. As a result of the ART's evaluation, several severe accidents fell into these categories that were considered to be PPAs; these accidents accounted for 14 fatalities.

PPAs represented many of the accidents involving fatalities during the time period. Of the 525 fatalities that occurred in non-yard accidents, not at grade crossings, 105 occurred in accidents that were thought to be PTC preventable at level 4 (24 percent). A complete comparison of PPA and non-PPA accidents appears in Table 4.

Table 3. PPA Consequences (1987-1995) Mainline Accidents Only

	PPA	Non-PPA	Total	PPA	Non-PPA
Human Factors					
Fatalities	42	16	58	72.41%	27.59%
Injuries	662	532	1194	55.44%	44.56%
Dollar Damages (million)	146.7	269.3	416	35.27%	64.73%
Evacuatees	6614	12933	19547	33.84%	66.16%
Miscellaneous					
Fatalities	14	443	457	3.06%	96.94%
Injuries	35	2294	2329	1.50%	98.50%
Dollar Damages (million)	231.7	331.6	355	6.53%	93.47%
Evacuatees	170	10902	11072	1.54%	98.46%
Signal			0		
Fatalities	1	0	1	100.00%	0.00%
Injuries	7	12	19	36.84%	63.16%
Dollar Damages (million)	2.6	4.4	6.9	37.04%	62.96%
Evacuatees	0	0			
Track					
Fatalities	1	1	2	50.00%	50.00%
Injuries	16	282	298	5.37%	94.63%
Dollar Damages (million)	36.1	407.03	443	8.14%	91.86%
Evacuatees	385	33608	33993	1.13%	98.87%
Equipment					
Fatalities	0	7	7	0.00%	100.00%
Injuries	0	217	217	0.00%	100.00%
Dollar Damages (million)	0	313	313	0.00%	100.00%
Evacuatees	0	13042	13042	0.00%	100.00%

3. GEOGRAPHIC DATA

This analysis focused on identifying specific corridors that might benefit from PTC implementation. That objective necessitated the development of a geographically specific database to support the comparative analysis of risk on a location-by-location basis. The purpose of the Geographic Information System (GIS) is to facilitate the analysis of rail-specific characteristics in the prediction of risk and distinction of risk between corridors. Without a complete description of the rail network upon which the accident model is based, the PTC accident occurrence rate could not have been estimated. This network provided the basis for the accident rate calculation, which is the probability portion of the risk analysis, and was crucial to the completion of the project.

The physical description of the rail network was accomplished by creating a composite database reflecting, as completely as possible, all of the national Class I railroads in the United States. This database includes geographic location of track (including horizontal and vertical curves), grade crossings, switches, and other features of the network such as speed limits.

3.1 DATABASES AND GIS PLATFORM

An important goal of this project was to produce a complete rail database for the continental United States that is geographically accurate and contains useful attributes such as track ownership, track rights, and status. It was also required to be suitable for network analysis and for building an associated route system to locate linear-referenced features such as speed limits, curvature, and grade changes since these features relate to the frequency of accident occurrence.

3.2 AGGREGATION OF RAIL DATABASES

Many different databases containing information relating to railroads have been provided to the Volpe Center. Drawing from the strengths of each source, a composite geographically-based rail database and a representation of a 1:100,000-scale rail network were constructed incorporating data from a variety of sources. The input data included the FRA 1:2,000,000 scale rail database, derived from the United States Geographic Survey (USGS) 1:2,000,000 scale digital line graphs (DLGs); the Oak Ridge National Laboratory (ORNL) 1:100,000 scale database derived from the USGS 1:100,000 scale DLGs; the VNTSC 1:2,000,000 scale database derived from the USGS 1:100,000 scale DLGs; and a VNTSC 1:100,000 scale database which was also derived from the USGS 1:100,000 database with significant corrections made from a previous rail survey.

3.2.1 GEOGRAPHICAL ACCURACY

Geographical accuracy is important for many different components of this task. Accuracy has a direct impact on the quality all of the computed statistics (grade, curvature, and population exposure) considered in other parts of this report. In addition, the closer it matches the actual physical infrastructure, the easier it is to accurately locate physical features in the rail database.

The original FRA database used for analysis was created using 1:2,000,000 scale DLGs. This is sufficient for abstract network analysis, but is not suitable for detailed examinations of individual sites (e.g., accident locations), since the underlying map product (1970 National Atlas) was designed for national coverage. Assuming the National Map Accuracy Standard (90 percent of the features must be within .02 inches on the map of their correct locations), features should be within 3333 feet of their true locations. Unfortunately, it is not clear if the 1:2,000,000 scale DLGs even meet this accuracy, since their published background data omits this information.

A vast improvement in the geographical detail can be obtained by utilizing the 1:100,000 scale DLGs. They are based on the topographical maps of the same scale and are appropriate for analyzing individual regions of the country (down to a region approximately the same size as a county). Their accuracy is approximately 167 feet. The coverage is complete for the purposes of this project since the DLGs are available for all the states, except Alaska. Both the ORNL and VNTSC 1:100,000 scale databases were based on this product. The FRA 1:100,000scale database was based on TIGER/Line from the U.S. Census, which uses the same DLG geography in rural areas. Unfortunately, it uses the older files in urban areas, which are missing many shape points and have no published accuracy, since they were created solely for census enumeration.

Further improvement is possible using the 1:24,000 scale DLGs, which are the best produced by USGS. The underlying topographical maps have an accuracy of approximately 40 feet. Unfortunately, the digital coverage was available at the time of the construction of this database for only 20 percent of the country. It has been important to use the currently available coverage as a reference layer and for later studies of subregions of the rail database.

For this project, the 1:100,000 scale DLG-based databases were the logical foundation for the final conflated network, since they contain significant geographical detail and the most complete coverage is available.

This database is a “fixed” link rail database that incorporates all of the location-specific data from the various input data sets including railroad ownership, position of stations, and other railroad attributes. In addition, these databases include information that is linear-referenced, meaning that the data provide a description of some characteristic of the link (beginning at a milepost and ending on the same route at another milepost). This linear-referenced data describes such characteristics as the maximum allowable speed on the link, the curvature, if any, and other attributes that apply to track links. These linear-referenced attributes were attached (by using common geographic data) to the 1:100,000 network and characteristics of each link were calculated using this association.

Some of the data refer to specific points, that is, geographic locations that can be described in terms of a route and milepost, or latitude and longitude. These include the presence of a grade crossing or switch. These attributes came from the survey data as well as from the ORNL 1:100,000 database, and were similarly attached to the individual links through a geographically based association.

3.2.2 NETWORK CONFLATION

Conflation is the process of merging geography from multiple databases. The general problem of conflating databases from the radically different sources with no common attribute is very complicated and difficult to automate, given the difficulty of matching features between the sources. Some features may be present in one database and not in the other, causing the topologies of the databases to differ greatly. In addition, the geographical locations of features will usually differ. Conflation involves creating associations between nodes and between links in different databases to facilitate the transfer of attributes.

A good illustration of this problem would be the task of conflating between raw 1:2,000,000 and 1:100,000 scale rail DLG databases without any additional linkage information. The vast difference in scale and lack of many attributes would preclude any automated process of producing the correct associations.

The FRA 1:2,000,000-scale database was associated with the corresponding Volpe database based on the same DLG source and their common attributes. The simple conflation between like-scale databases required matching links and subdividing the Volpe links to create any nodes, which were missing in one but present in the other database. Missing portions of track were also merged into the Volpe database. At the conclusion of the process each node and link of the Volpe database was labeled with its corresponding FRA 1:2 million unique identifier.

This association, along with the Volpe association, is then used to transfer the attributes to a 1:100,000-scale database (initially the Volpe database). A similar simple conflation was used between the ORNL and the new Volpe database since they are both based on the same DLG source.

3.2.3 NETWORK SEGMENTATION

A procedure was designed to segment the VNTSC 1:100,000-rail network into uniformly defined Route Operational Segments (ROS) for the analysis. It was necessary to create a uniform definition of segments to enable the analysis of each link, since variability in segment definitions could yield questionable results. This method defined segments in terms of control points, as denoted by the presence of an interlocking switch. Further segmentation occurred if additional track (or reduction in the number of tracks) or type of traffic (from freight or passenger only to another type) occurred within the link. The resulting database has approximately 8,000 segments, representing about 120,000 miles of track.

In addition, descriptions of rail-specific attributes were assigned to each link. These attributes were subsequently used in the analysis of the historical pattern of accidents and the development of a predictive model of accident occurrences:

Switches: the number of switches of each class counted for each segment, classified by the type of track from which they exited or entered.

Number of tracks: the number of tracks, which is constant throughout the link due to the segmentation.

Curvature: the minimum and maximum curvature and numbers of curves starting and ending on the link were computed.

Grade: the minimum and maximum grade and a weighted sum of the average grades for all segments were computed.

Maximum speed: the maximum freight speed for each link.

Signaling system: the number of point signals on the link, the first primary signal system observed, and a flag indicating whether this was in effect for the whole link.

Traffic Control system (Auto, Signalized, or Dark): the number of point controls on the link, the first primary control system observed, and a flag indicating whether this was in effect for the whole link.

Population: the number of individuals living within ¼, ½, 1, 2, 5, and 10 miles of the link, calculated using the U.S. Census TIGER database using a census block centroid method. By this method, if the centroid of the census block lies within the specified aggregation distance the total population for that block is added to the aggregation.

3.2.4 TRAIN VOLUME DATA

One of the most crucial inputs into the analysis is the annual volume of traffic on each segment. Data from a variety of sources were again merged to create two estimates of these volumes. In the initial version of the model, the Surface Transportation Board Waybill Sample was used to estimate total train traffic flows. A full description of the waybill sample appears in Appendix A. The PTC Implementation Working Group decided, due to limitations with the waybill sample in accurately describing train volumes and the desire to have a more detailed estimate of true train traffic, to substitute actual train counts or traffic density estimates for all segments of the rail network where they were available. This was accomplished by conflating data provided to the Volpe Center by the railroads or the FRA to specific locations on the GIS, and assigning the flows between stations to match those reported by the individual railroads.

During the time period between 1995 and 1997, several major railroad mergers and acquisitions took place. The Surface Transportation Board reviews and must approve such transactions. As part of their applications, railroads must submit data relevant to the competitive and

During the time period between 1995 and 1997, several major railroad mergers and acquisitions took place. The Surface Transportation Board reviews and must approve such transactions. As part of their applications, railroads must submit data relevant to the competitive and environmental impacts of their proposals. Beginning with the acquisition of Conrail, FRA has also requested (and STB has required), preparation of Safety Integration Plans. In response, the UP/SP (now UP), BN and Santa Fe (now BNSF) Norfolk Southern, Control and CSX (now NS, CSX and joint territory Control) having all proposed mergers or acquisitions of some sort during this time period, provided extraordinarily detailed information to FRA on the exact train volumes between stations, the type of traffic, and the volume of hazardous materials for those segments affected by their proposals.

These data are publicly available and were made available to the Volpe Center through the railroads' cooperation and via existing FRA databases. Other published data sources were also included in the analysis, where railroads provided specific information on their annual tonnage.

Finally, some data were provided by the other railroads on segments not covered by mergers and for which no publicly available data were available. These data were incorporated into the database as well.

For each segment on the network, where possible, flow is provided in one or more of these forms: annual trains per year, annual tons per year, or trains/mile per year. These data were resolved to a common metric (trains per year) for the analysis using a methodology based upon a linear regression model.

In some cases, railroads provided data both on the total gross tons per year on segments of the network along with the number of trains that traversed those segments per day. In those cases it was possible to fit a linear regression model using the number of trains per day as the dependent variable, and annual gross tons as the independent variable. Given this relationship the resulting formula was used to create an estimate of the number of trains per day for segments for which these data were not reported, and convert the gross tons data into a common metric (trains per year) for all segments.

The linear regression model fit to this data resulted in a highly reliable model. The goodness-of-fit statistic (R-square) resulted in a value of 0.87. The "adjusted" R-square was likewise very high (0.875) indicating that the model provides a good linear fit of train counts to gross tons.

The final form of the model converts million gross tons to trains per year using the function

Trains per year = ((mgt * .412501) + 2.2382)* 250.

This model was therefore applied to translating the available data into a uniform measure of train volume; trains per year.

3.2.5 PASSENGER TRAIN AND COMMUTER RAIL VOLUMES

In addition to the train data provided by the freight railroads, data on passenger train volumes, including number of cars and passengers, were assigned to the network. The passenger rail market has been segregated into two different groups for purposes of quantification and analysis. The segmentation is intercity rail passengers, defined by National Railroad Passenger Corporation (Amtrak), and regional/commuter passenger rail as defined by the Federal Transit Administration (FTA) in the National Transit Database.

3.2.5.1 National Passenger Rail Corporation (Amtrak)

Data collection efforts differed significantly for the two types of passenger rail carriers. The Amtrak marketing department provided annual passenger information on train routes and between stations. Amtrak owns, co-owns, or has track-use rights on many routes traversing the country. Each route was coded into the GIS and the passenger volume for each route between each station then added to the existing route. This information was added to the base network. Amtrak initially provided information for the month of June 1996. Subsequently, they provided information for a full year of Amtrak train movements (1995).

3.2.5.2 Commuter Rail

The data collection was much more difficult for the regional/commuter rail networks. Unlike intercity passenger rail, there is no central source for passenger information based on volume for travel between stations. Each of the 14 operating commuter rail companies and a larger group of city transit rail operators which reports to the FTA's National Transit Database (formerly Section 15), has their own method of reporting and counting passengers. The most recent passenger data was collected between 1992 and 1995 depending on the rail service provider involved.

The information fell into several major groups, with each operator providing their own variation. Operators provided a list of stations and either bi-directional or single direction boarding and alighting counts for each of their stations. Generally, a good assumption is that passengers make a round trip every day; therefore, a single direction passenger count is representative of traffic in both directions. Single direction passengers are assumed to offset each other when data are aggregated annually.

Commuter rail operators also provided passenger information by providing "between" station counts. Volpe did not receive documentation on the methods used to collect this information, however, the onboard counts are probably reliable since conductors or other railroad personnel report them. Commuter operators accumulated data for 1 week, 1 month, or 1 year time periods.

Since the ultimate objective was not only to reflect passenger counts but also passenger trains per year, the published schedules were used to count the number of trains between stations on a weekly basis. These data were then used to create an annual train count for each year and the data were subsequently accumulated with the intercity passenger and freight traffic for each segment of the network. A description of the Volpe Rail Network appears in Table 4.

Table 4. Summary of Volpe Rail Network Characteristics (79,000 Links)

	Automatic Train Control	Signalized Train Control (Not Auto)	Dark Territory	Unknown Control Method
VID (Unique Arc-Level Records)	4,706	44,662	31,132	3,518
PPA Accidents	57	427	231	98
Miles (measured at ARC level)	5,585	74,500	63,559	2,657
Average Maximum Speed	44	43	27	9
Number of Tracks (per link)	2	1	1	0.4
Number of Switches (per link)	1	1	1	0.4
Number of Curves (per link)	1	2	2	0.4
Average Curvature (in degrees)	42	65	74	20.7
Average Million Gross Tons Freight Per Year (per link)	58	34	7	12.9
Average Percent of Tonnage Hazmat (per link)	3%	4%	3%	5%
Average Number of Freight Trains Per Year (per link)	8,895	5,586	1,255	2,110
Average Number of Commuter Rail Trains per Year (per link)	6,506	298	57	392
Average Number of Amtrak Trains per Year (per link)	5,124	360	14	135
Total Derailments	371	4,280	2,007	158
Total Collisions	80	590	236	26

It is important to note that the 79,000-segment rail network described in Table 4 is not a complete representation of the full national rail network. A significant portion of territory in Wisconsin, Minnesota, New York, and Vermont was not characterized either because the segments were low-volume territory or were passenger rail corridors alone. The Wisconsin Central and Long Island Railroad are the notable portions of the rail network not included in the database used to construct the rail network. In spite of this omission, only 2,400 miles of territory not on short-lines were completely unavailable for analysis at the VRAIL level. When these segments were aggregated into Route Operational Segments (ROS) they were characterized when possible, but if other data were also missing the effect was to make the segment unusable (see Table 5).

Table 5. ROS Network Characteristics

	Automatic Train Control	Signalized Train Control (Not Auto)	Dark Territory	Unknown
S_ID (Unique Arc-Level Records)	355	3,731	3,224	771
PPA Accidents	56	434	218	17
Miles (measured at ROS level)	4,412	64,331	58,130	3392
Length Weighted Average Maximum Speed	43	39	25	6
Number of Tracks (per ROS segment)	2	1	1	0.3
Number of Switches (per ROS segment)	2	2	2	0.3
Number of Curves (per ROS segment)	2	2	3	0.5
Length Weighted Average Curvature (in degrees) (per ROS segment)	35	32	41	5.3
Average Million Gross Tons Freight Per Year (per ROS segment)	17	14	2	7.2
Average Percent of Tonnage Hazmat (per ROS segment)	4%	4%	3%	5%
Average Number of Freight Trains Per Year (per ROS segment)	8,775	5,641	1,313	1,301
Average Number of Passenger Trains Per Year (per ROS segment)	10,882	585	66	377
Total Derailments	369	4,308	1,850	289
Total Collisions	79	602	213	38

Table 5 summarizes the effect after the ROS were created, in terms of the total segments that could not be characterized and included in the final analysis. About 3,400 miles of track could not be included because the train control method was unknown or some other important factor could not be characterized. It was from this level, the ROS group, that corridors were defined.

3.3 PPAS AND METHODS OF OPERATION

Among the most important variables in predicting risk on the rail network is the type of signal system and control method employed. Signal systems and methods of operation determine the possible speed, traffic mix, and traffic density on the railroad. They are distinct in their reliability and vulnerability. While signal systems are highly reliable, they are vulnerable to, among other things, weather and human error. Similarly, dispatching systems can result in errors of traffic assignment with deadly consequences. As the level of train control increases, implied by the method of operation, the safety of the network should also increase. Most locations in the U.S. employ a system of signal control that automatically assigns a right-of-way clearance based upon track occupancy. Some segments employ cab-signal systems that display signal aspects to the cab crew inside of the locomotive. Neither of these types of systems can automatically stop a train. Only a few systems are capable of enforcement of braking requirements, and those principally in the event of train-to train conflicts due to a crew's failure to comply with a signal indication. Other conflicts, such as those between trains and maintenance of way equipment, or train-to-train collisions caused by excessive speed, overtakes, etc., are not preventable by the Automatic Train Control methods currently in existence. The ART found nearly 20 PPAs that occurred in territory that was under ATC, the highest method of operation. Due to the counterintuitive result of finding so many PPAs in this method of operation, a special analysis of this topic was undertaken.

Methods of operation were assigned to segments (as described in Table 5) according to the percentage of the total mileage in each segment defined by the GIS as in one of several signal and control methods of operation. There are, in total, 13 methods of operation that were originally described by the GIS database as to the signal or control method for each individual location. As the data were aggregated from approximately [illegible] links to [illegible] segments, the information captured at the detailed level also had to be aggregated. These data were accumulated by making two groupings; first, by taking the individual control method data (which consists of 13 possible control methods) and collapsing those into one of four categories (including unknown), and then by calculating the percent of the total miles in each segment classified into one of those four categories. The categorizations shown in Table 6 are based upon these two types of aggregations.

Another source of data on the method of operation also exists, however. That data comes from the accident record itself, which also records up to 13 different methods. The method captured on the accident record (due to its point specificity) often fails to correspond directly with the method of operation shown as the percentage of each of the four categories described in Table 6. PPAs were attributed to these aggregated segments, and therefore the specific method of operation for the geographic "point" at which the incident occurred is obscured. The PPA data reflect the percent of the miles of that ROS on which the accident occurred, control were under auto, cab-signal/abs, remote control or dark territory mileage percentages, respectively. The method of operation is a critical input into understanding the frequency and severity of PPAs, however, and without point-specific data it can be argued that our understanding of the relationship is less than adequate. For that reason, a separate analysis of the distribution of PPAs by method of operation was conducted.

While the GIS network data provide information as of 1990 on the method of operation for most of the network, an additional source of data on this point also exists. This information is provided by the railroad on the accident report and reflects all of the methods of operation on the segment at the time of the incident. A facsimile of this report appears in Figure (inserted)). The copy in this report reflects the current accident report form (in some cases earlier versions were in use when data were collected for this analysis). Using this report form, railroad officials identify the method (or methods) of operation in effect at specific a location at the time of the accident. Multiple methods of operation are often reported on this form.

Using this form and information provided from the GIS, a table of "equivalent" groupings of methods of operation to be used in this analysis were developed. In some cases the correspondence is also governed by whether the methods of operation are functionally (or legally) equivalent to one another.

DEPARTMENT OF TRANSPORTATION
FEDERAL RAILROAD ADMINISTRATION (FRA)

RAIL EQUIPMENT ACCIDENT/INCIDENT REPORT

OMB Approval No. 2130-0500

1. Name of Reporting Railroad	1a. Alphabetic Code	1b. Railroad Accident/Incident No
2. Name of Other Railroad Involved in Train Accident/Incident	2a. Alphabetic Code	2b. Railroad Accident/Incident No.
3. Name of Railroad Responsible for Track Maintenance *(single entry)*	3a. Alphabetic Code	3b. Railroad Accident/Incident No.
4. U. S. DOT-AAR Grade Crossing Identification Number	5. Date of Accident/Incident month day year	6. Time of Accident/Incident AM PM

7. Type of Accident/Incident *(single entry in code box)*: 1. Derailment 2. Head on collision 3. Rear end collision 4. Side collision 5. Raking collision 6. Broken train collision 7. Hwy-rail crossing 8. RR grade crossing 9. Obstruction 10. Explosion-detonation 11. Fire/violent rupture 12. Other impacts 13. Other *(describe in narrative)* — Code

8. Cars Carrying HAZMAT	9. HAZMAT Cars Damaged/Derailed	10. Cars Releasing HAZMAT	11. People Evacuated	12. Division
13. Nearest City/Town	14. Milepost *(to nearest tenth)*	15. State Abbr. — Code	16. County	

17. Temperature (F) *(specify if minus)* °F

18. Visibility *(single entry)*: 1. Dawn 2. Day 3. Dusk 4. Dark — Code

19. Weather *(single entry)*: 1. Clear 2. Cloudy 3. Rain 4. Fog 5. Sleet 6. Snow — Code

20. Type of Track: 1. Main 2. Yard 3. Siding 4. Industry — Code

21. Track Name/Number

22. FRA Track Class (1-6, X) — Code

23. Annual Track Density *(gross tons in millions)*

24. Time Table Direction: 1. North 2. South 3. East 4. West — Code

25. Type of Equipment Consist *(single entry)*: 1. Freight train 2. Passenger train 3. Commuter train 4. Work train 5. Single car 6. Cut of cars 7. Yard/switching 8. Light loco(s). 9. Maint./inspect. car — Code

26. Was Equipment Attended? 1. Yes 2. No — Code

27. Train Number/Symbol

28. Speed *(recorded speed, if available)* R - Recorded E - Estimated — MPH — Code

29. Trailing Tons *(gross tonnage, excluding power units)*

30. Method(s) of Operation *(enter code(s) that apply)*: a. ATCS b. Auto train control c. Auto train stop d. Cab signals e. Traffic control f. Interlocking g. Automatic block h. Current of traffic i. Time table/train orders j. Track warrant control k. Direct traffic control l. Yard limits m. Special instructions n. Other than main track rules o. Other *(specify in narrative)* — Code(s)

31. Principal Car/Unit	a. Initial and Number	b. Position in Train	c. Loaded *(yes/no)*
(1) First Involved *(derailed, struck, etc.)*			
(2) Causing *(if mechanical, cause reported)*			

32. If any railroad employees tested for drug or alcohol impairment, enter codes from reporting manual. — Code(s)

33. Was this consist transporting passengers? (y/n)

34. Locomotive Units	a. Head End	Mid Train b. Manual	Mid Train c. Remote	Rear End d. Manual	Rear End e. Remote
(1) Total in Train					
(2) Total Derailed					

35. Cars	Loaded a. Freight	Loaded b. Pass.	Empty c. Freight	Empty d. Pass.	e. Caboose
(1) Total in Equipment Consist					
(2) Total Derailed					

36. Equipment Damage This Consist	37. Track, Signal, Way, & Structure Damage	38. Primary Cause Code	39. Contributing Cause Code

Number of Crew Members

40. Engineers/Operators	41. Firemen	42. Conductors	43. Brakemen

Length of Time on Duty

44. Engineer/Operator	45. Conductor
Hrs: Mins:	Hrs: Mins:

Casualties to:	46. Railroad Employees	47. Train Passengers	48. Others	49. Special Study Block
Fatal				
Nonfatal				

50. Narrative Description *(Be specific, and continue on separate sheet if necessary)*

51. Typed/Printed Name & Title of Preparer	52. Signature	53. Date

FORM FRA F 6180.54

Table 6 shows the correspondence between the network definitions of train control method and the accident report data.

Table 6. Network and Accident Record Control Method Codes

Network Codes	Accident Record Code
None	Yard
AUTO	Auto Train Control Auto Train Stop Cab Signal
SIGNAL	Manual Block Interlocking Automatic Block Traffic Control
DARK	Time Table Radio Verbal Permission Train Orders

The data represented in Figure 3. PPA Accidents by Control Method 1988-1995 Using Accident Record Data reflect the assignment of PPAs to a method of operation based upon information reported on the FRA's accident report (not the GIS). Sorted by frequency, the data illustrate that the highest number of incidents were assigned to dark territory.

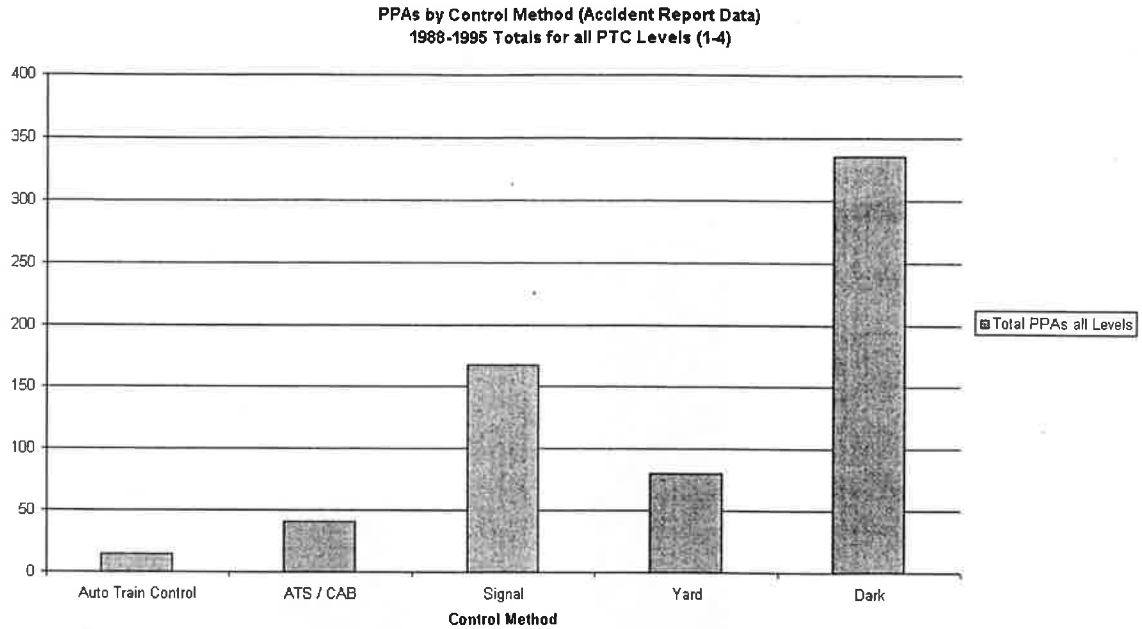


Figure 3. PPA Accidents by Control Method 1988-1995 Using Accident Record Data

There are some differences in the frequency of accidents by type of territory using the GIS method of operation assignments. One major differences is that in the GIS the data on YARD rules is sparse, since most of it is not coded. Instead, these accidents were reflected as having occurred in "unknown" territory. Using the FRA's accident report data, at PTC level 1, 168 of 326 accidents occurred in dark territory for which data were reported. Figure 4. PPAs by Control Method Using Network Data illustrates the distribution of PPAs of all PTC Levels based upon network data. In most instances the distribution of accidents in each category is very similar.

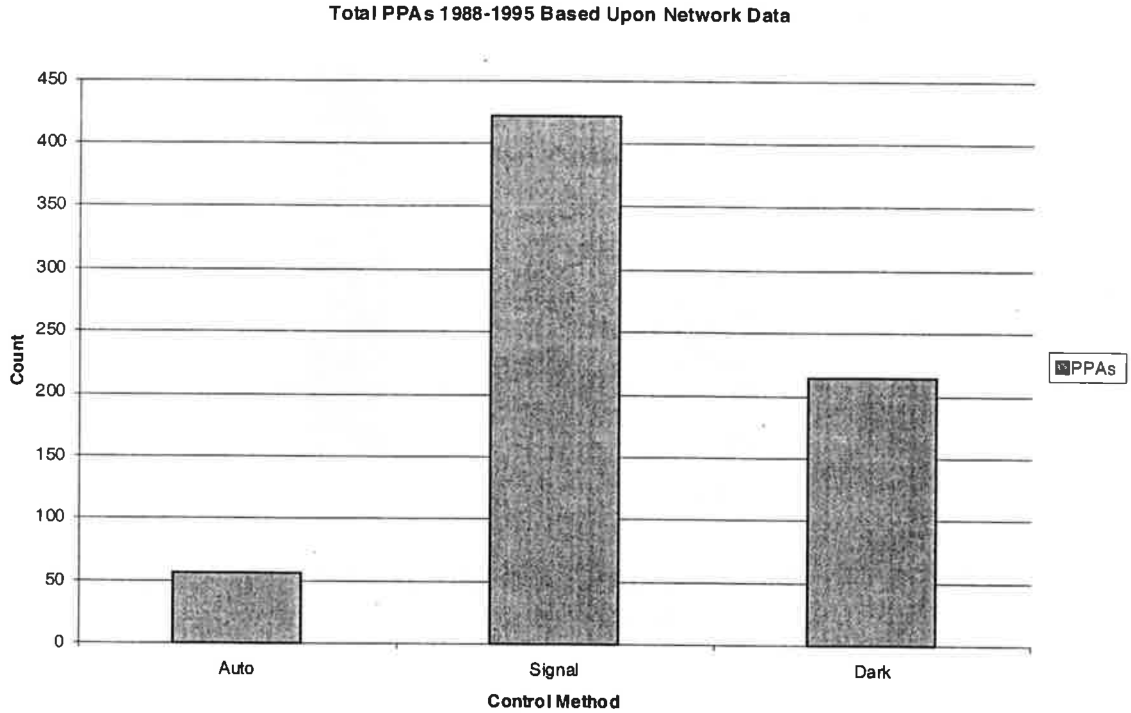


Figure 4. PPAs by Control Method Using Network Data

Another method of interpreting this data lies within the context of the accidents per unit of exposure to each method of operation. Exposure can be measured in several ways all of which will result in a different interpretation of the accident "rate." One method is to measure exposure in terms of the number of route or track-miles under a particular method of operation. Another measure might be the total number of trains or number of tons hauled under the various methods. Still another estimate of exposure expresses both the distance and the volume of traffic by constructing a measure such as train-miles or ton-miles. Each of these measures has been examined as a possible method of normalizing the accident frequency for this study. The effect of normalization by train-mile is illustrated in Figure 5.

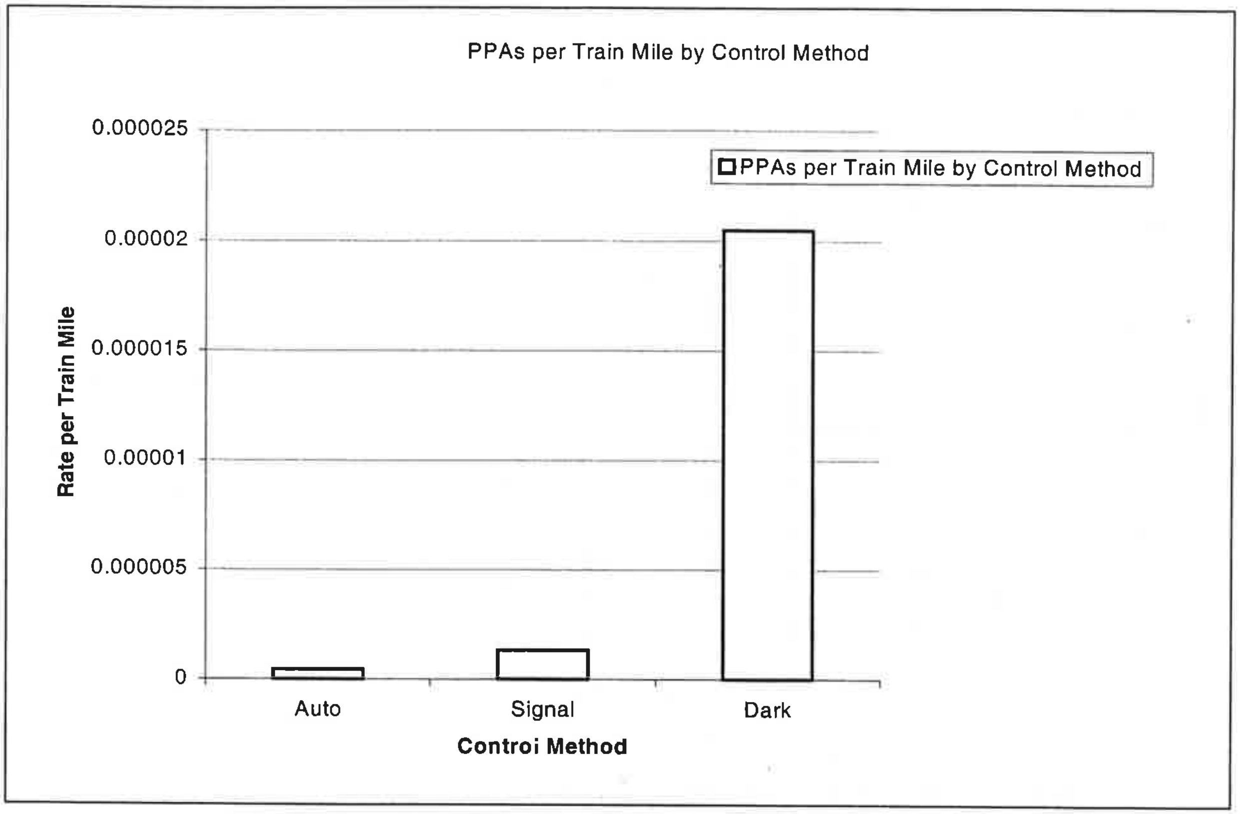


Figure 5. PPAs by Control Method per Train-Mile

The actual difference in the number of PPAs in each of the categories of method of operation is less significant than the normalized difference. Figure 6. PPA Costs by Train Control Method Costs Using Economic Team Cost Assignment Methodology illustrates the effect of normalizing the 8-year PPA frequency against the total number of train-miles in each of those categories of method of operation. From this perspective, dark territory (operated only by voice communications or paper train-orders) has a significantly higher accident rate per train-mile than the other two categories. The exposure measure chosen for comparison of the results or input values may have a significant impact on their meaning, hence the result of the analysis. It is, therefore, important to look at several methods of normalization before coming to conclusions about the relative risks.

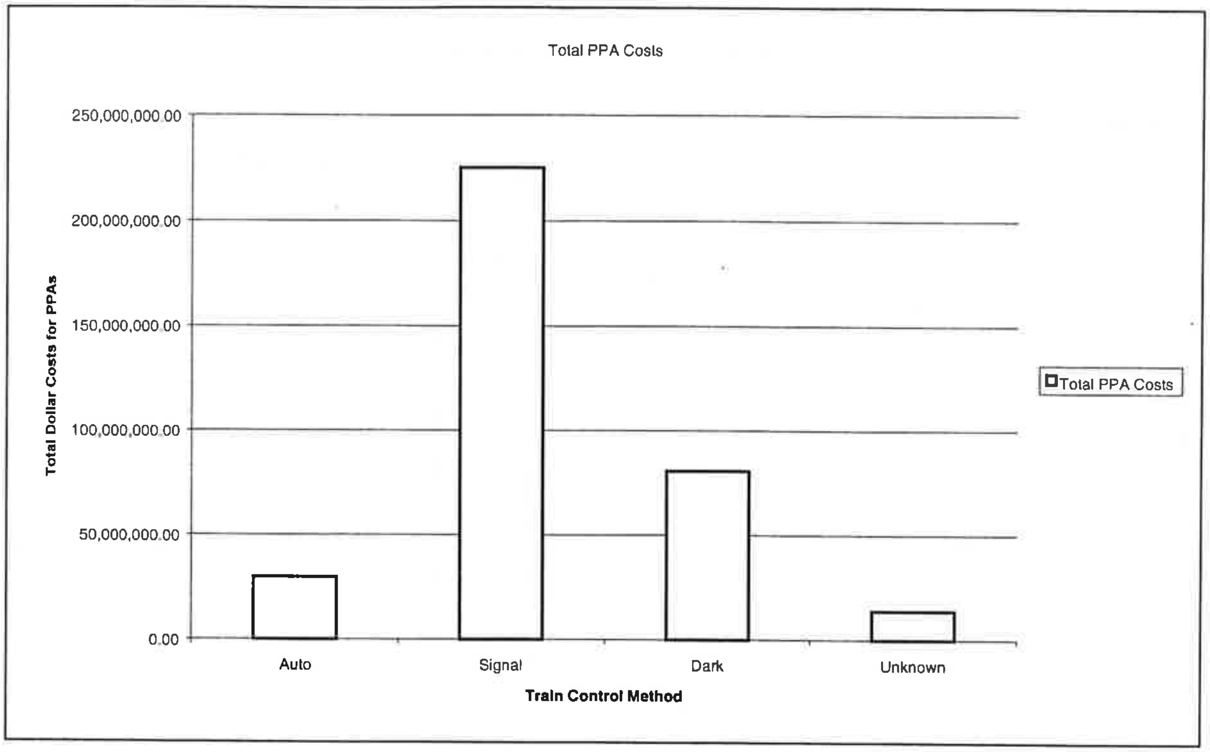


Figure 6. PPA Costs by Train Control Method Costs Using Economic Team Cost Assignment Methodology

Figure 6 illustrates another method of expressing the frequency of PPAs; by weighting their outcomes in terms of accident severity. Each of the PPAs in the three known train control methods represented in Figure 7 (and those in the unknown category) have been assigned a severity measure based upon the cost of the accident. This cost assignment strategy was developed by the RSAC Implementation Task Force to allow for a universal comparison of the outcomes of train accidents under consideration in this study. (See Appendix B). This method is employed in the CRAM to evaluate the historical effects of accidents and to predict the severity of the consequences of future accidents. Here it is simply employed to allow for a "risk-" based comparison of the frequency of accidents and their severity. The non-normalized total accident costs in signal territory were higher than the other three categories.

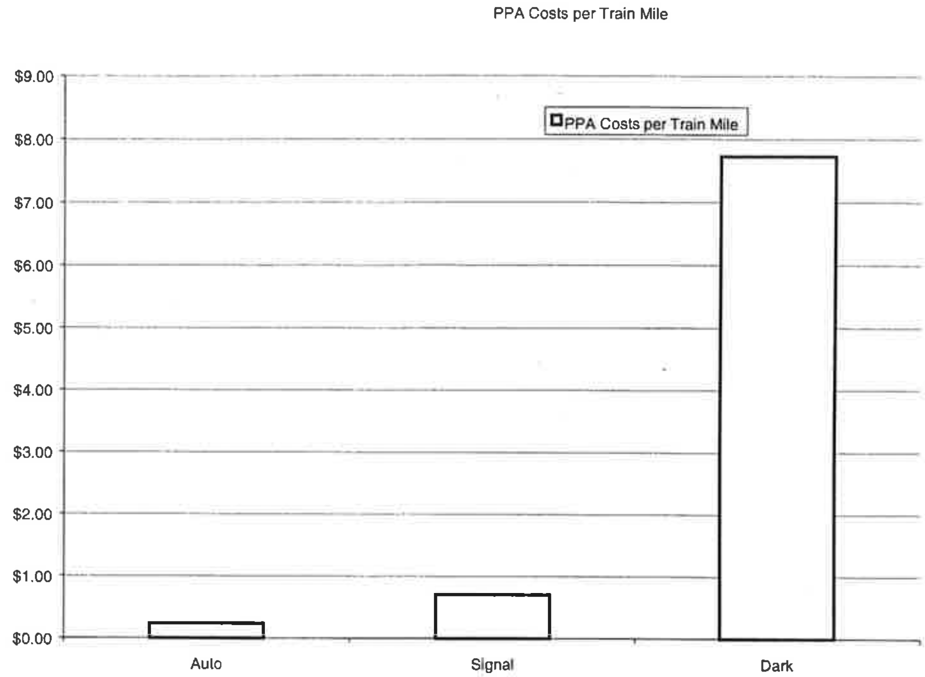


Figure 7. PPA Costs per Train-Mile by Train Control Method

The normalized PTC risk (PTC accident costs divided by total train-miles in each method of operation) again indicates that although the highest costs were in the signal train-control method, the highest risk per train-mile was in dark territory during the 8-year-study period. If this rate is indicative of future trends, traffic in dark territory will experience the highest costs of PTC-preventable accidents per train-mile.

4. CORRIDORS

Corridors are logical geographic segments that represent typical point-to-point shipping lanes in the United States. Corridor definitions were initially provided by the FRA to Volpe; later these definitions were reviewed and modified by the railroads. Corridor definitions are specific to origin and destination points and reflect the typical shipping lane, although they may exclude short-line or terminal segments that exist around major cities.

The identification of corridors had two steps. First, the definition of the endpoints and the route between those points were provided by the railroad. Second, each corridor's component "segments" was identified within the GIS as part of the corridor. Since all of the analysis is conducted at the "segment" level, definition of the corridor is actually an aggregation of these specific segments into a subgroup. Those subgroups sometimes have overlapping segments, and therefore corridors may share many common elements, including PPAs.

In the final version of the model, 183 corridors were analyzed. The corridors selected for study are disparate in length, volume of traffic, type of traffic and method of control. They represent the normal operational corridors for many of the major rail shipping lanes in the country, however different those lanes may be.

4.1 ANALYSIS OF CORRIDOR DIFFERENCES

Corridors represent roughly half of the total ROS Segments analyzed in this study. Of the total 8,081 ROS segments in the database, 3,394 were assigned to corridors representing 57,139 route-miles of U.S. railroad. Freight and passenger train counts per year were summed to reflect the total traffic volume on segments and corridors. The total freight trains per year on corridors in this analysis were approximately 26 million. Passenger trains totaled approximately 3.8 million per year. On average, corridors saw 7,395 freight trains per year and 888 passenger trains per year. Corridor speeds were represented by both the highest maximum speed on any ROS segment and also by the length weighted average speed for segments. The average maximum speed was 39 mph on all corridors, and the average length weighted average speed approximately 35 miles per hour. Finally, train control methods represented by rail GIS data that described the control method for various locations around the network were assigned on a percentage basis for each of the ROS segments. In total there were 3,456 miles of track assigned to automatic train control territory (including cab signaling), 47,667 miles assigned to signal territory and 5,880 miles in dark territory. However, most of the territory assigned to corridors was single-track territory.

Table 7 shows that there is significant variability in the number of tracks, speeds and volume on the corridors. Figure 8 illustrates the total mileage variation between corridors, sorted by the percentage of the total corridor mileage that is considered "dark" territory.

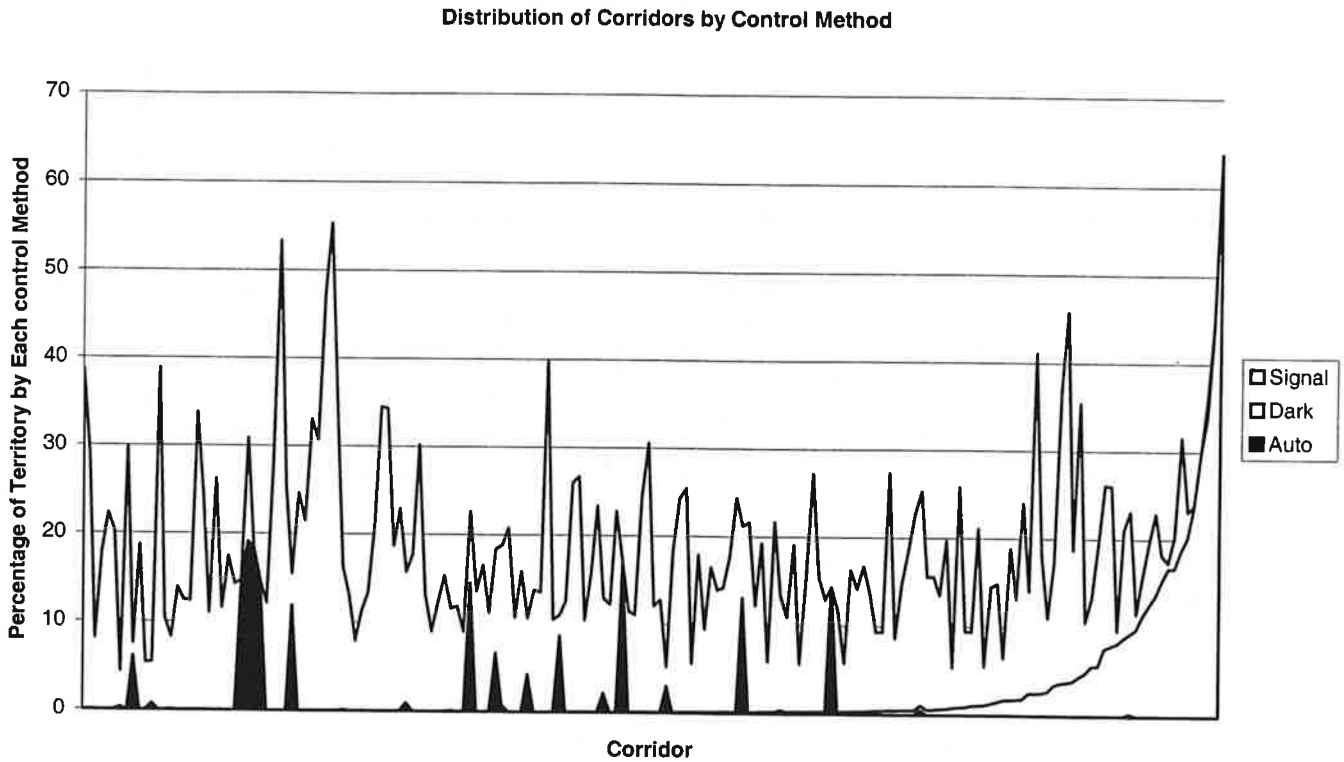


Figure 8. Distribution of Corridor Territory by Control Method

Figure 8 illustrates that the method of operation on most corridors in this study is by signal indication; not automatic train control, (including cab signaling) or dark territory. In Figure 8 the shaded areas refer to the percentage of territory on each corridor that are operated under each of these three control methods (according to the Volpe Center's database).

The 180 corridors described in this study averaged 342 miles in length, however, they ranged from 61 to 1,836 miles. Likewise, they varied significantly in the total traffic and the type of traffic, either freight, passenger, or mixed. Corridors varied by orders of magnitude in the number of freight trains reported for each ROS segment of which it was composed. Table 7 illustrates the diversity of these values. Corridors with no passenger trains, or very few freight trains, which experienced any PPAs would, due to their low total traffic level, appear to be of much higher risk per train-mile than would higher volume corridors experiencing the same number of accidents.

Since there is so much variation among the attributes of the corridors, which were likely to have an effect on the occurrence of PPAs, such as, the length and total volume of traffic on the corridor, it was necessary to examine multiple ways of comparing corridors with regard to their PPA risk.

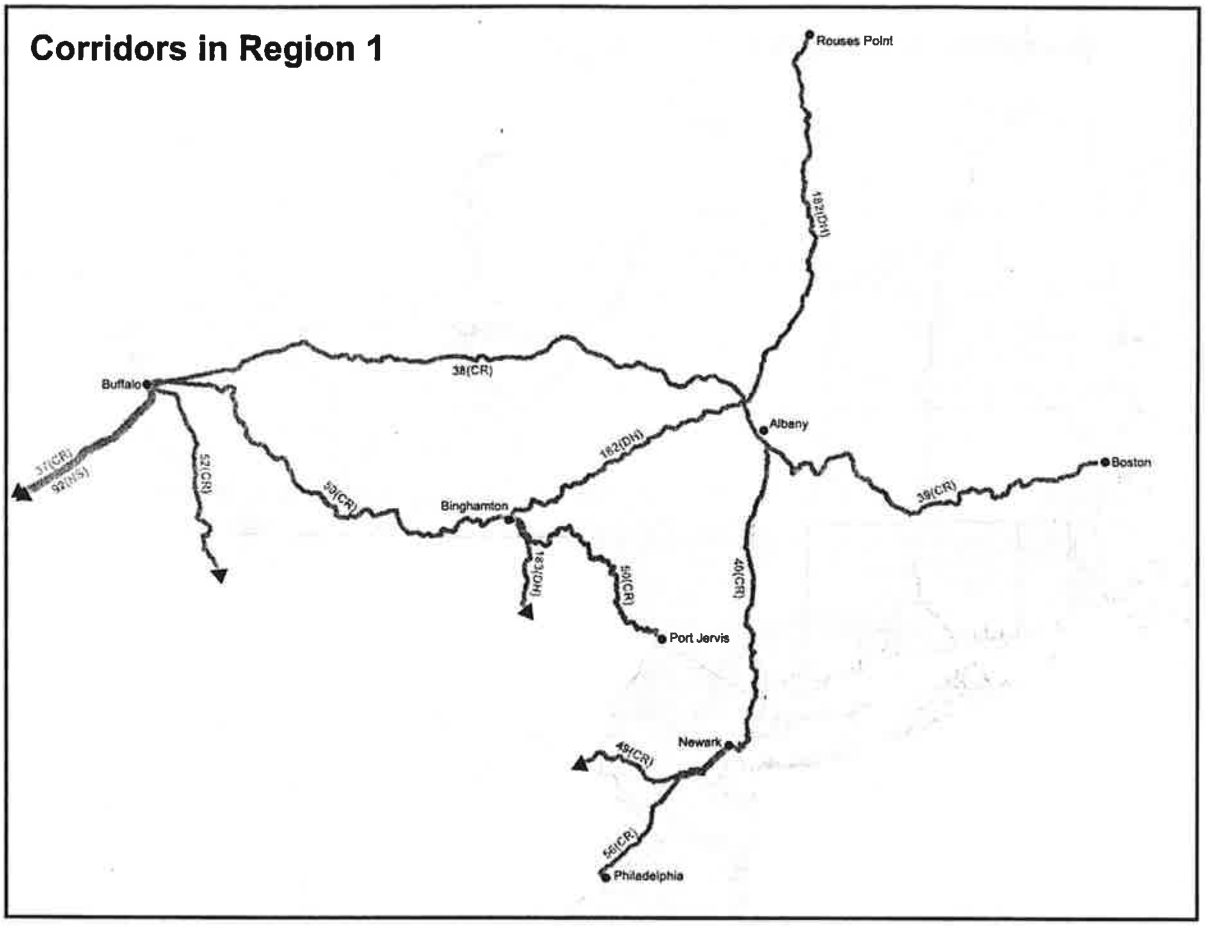
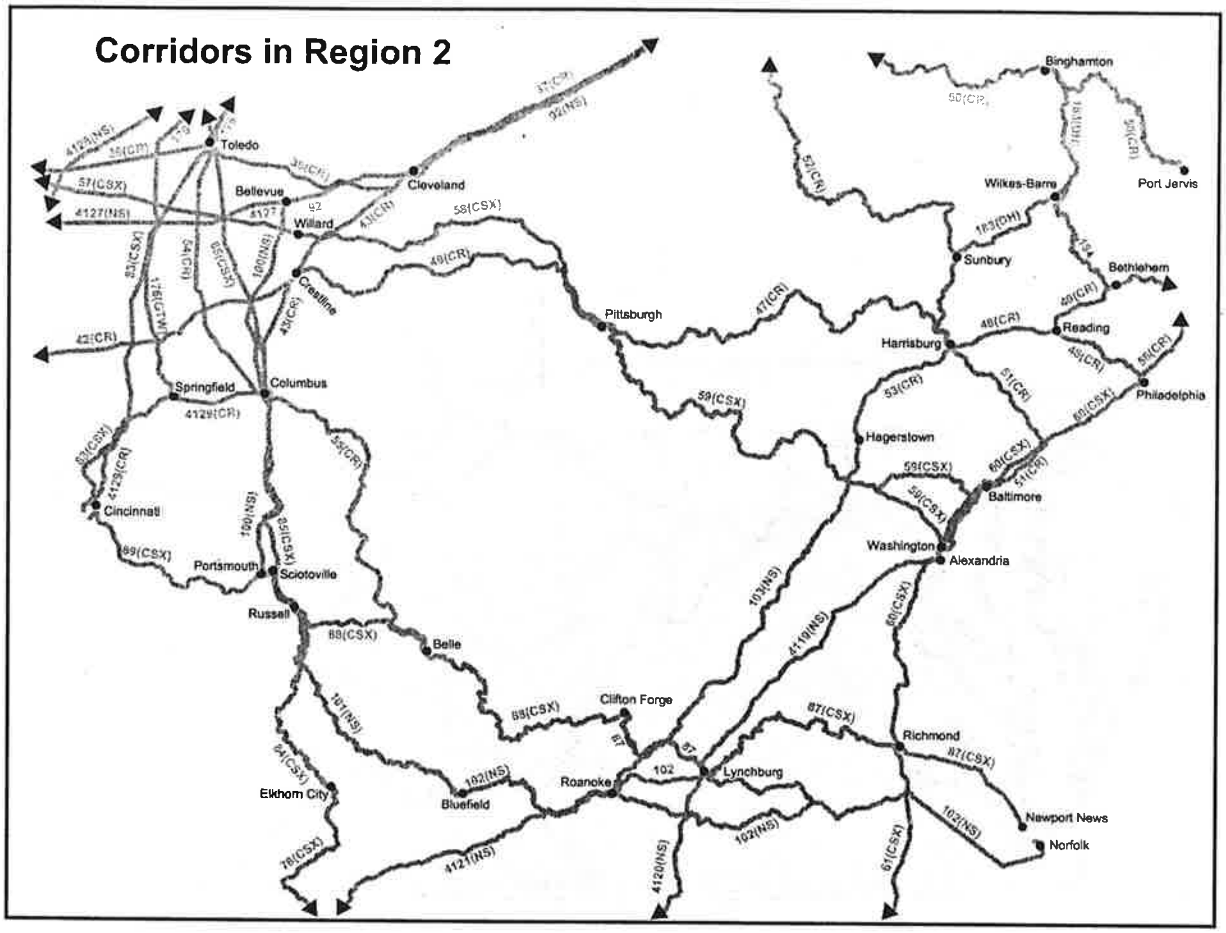
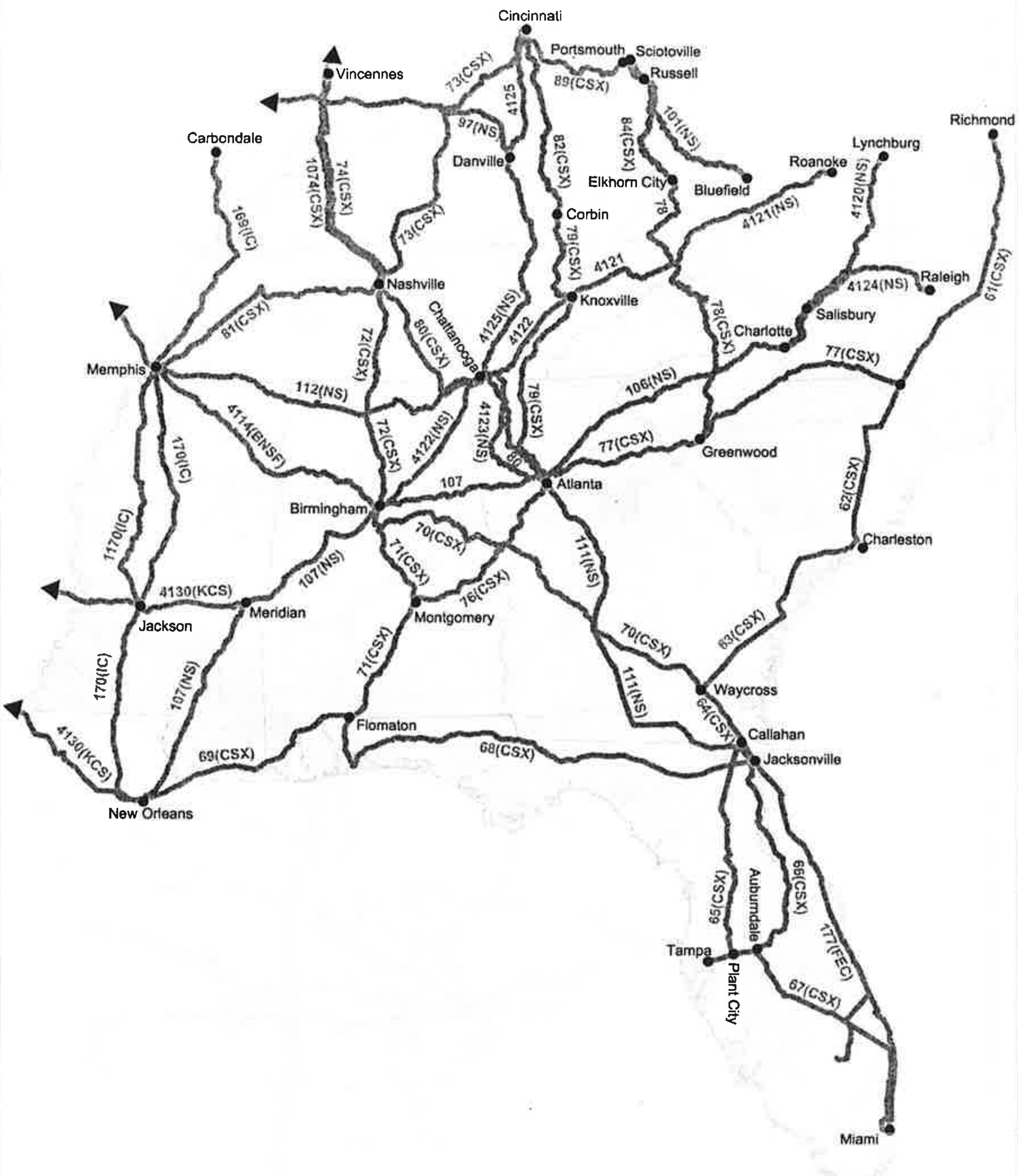


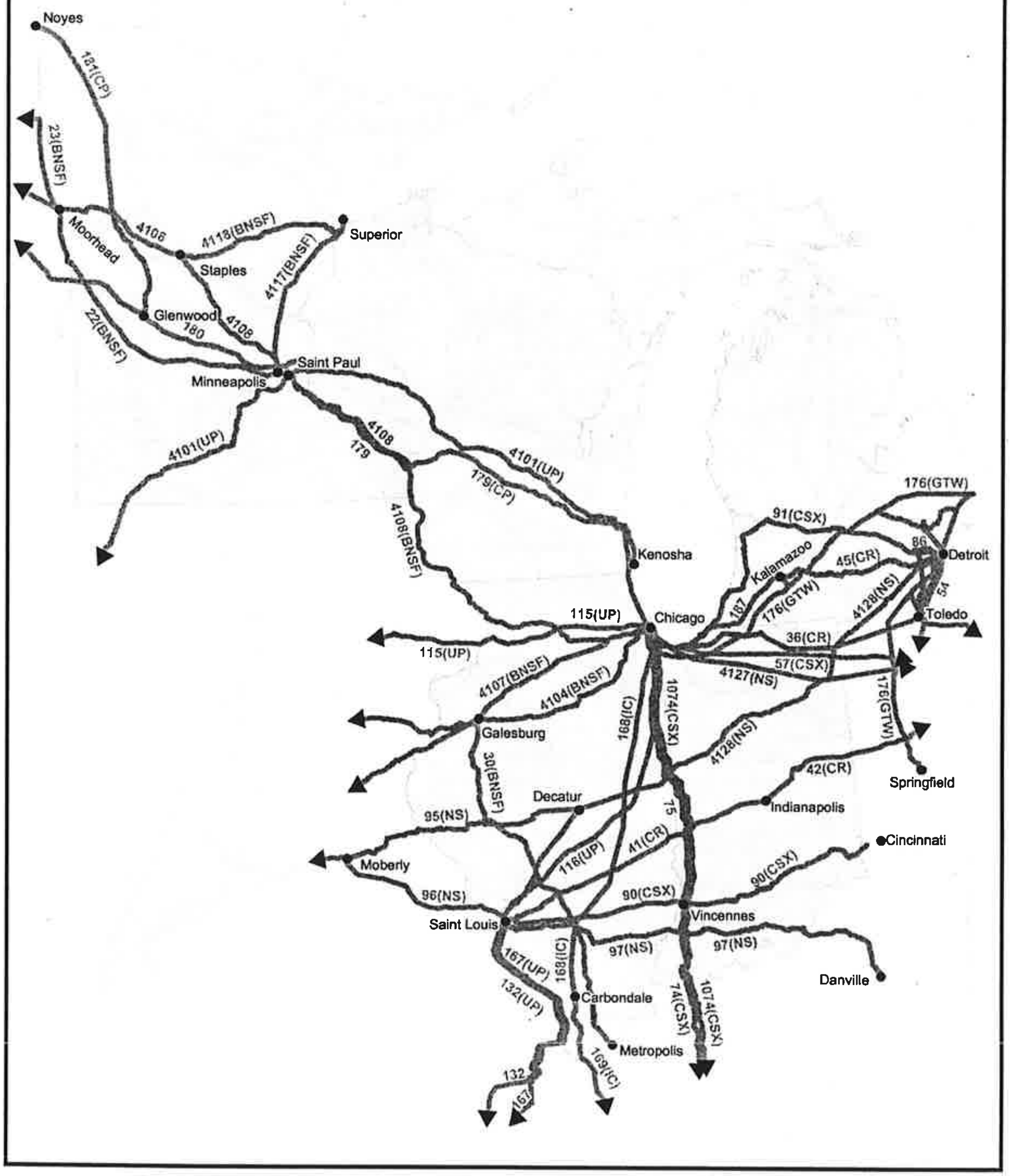
Figure 9. Corridor Maps


Corridors in Region 2
Toledo
Bellevue
Willard
Cleveland
Crestline
Columbus
Springfield
Cincinnati
Portsmouth
Sciotoville
Russell
Belle
Elkhorn City
Bluefield
Roanoke
Clifton Forge
Lynchburg
Pittsburgh
Binghamton
Port Jervis
Wilkes-Barre
Sunbury
Bethlehem
Harrisburg
Reading
Philadelphia
Hagerstown
Baltimore
Washington
Alexandria
Richmond
Newport News
Norfolk

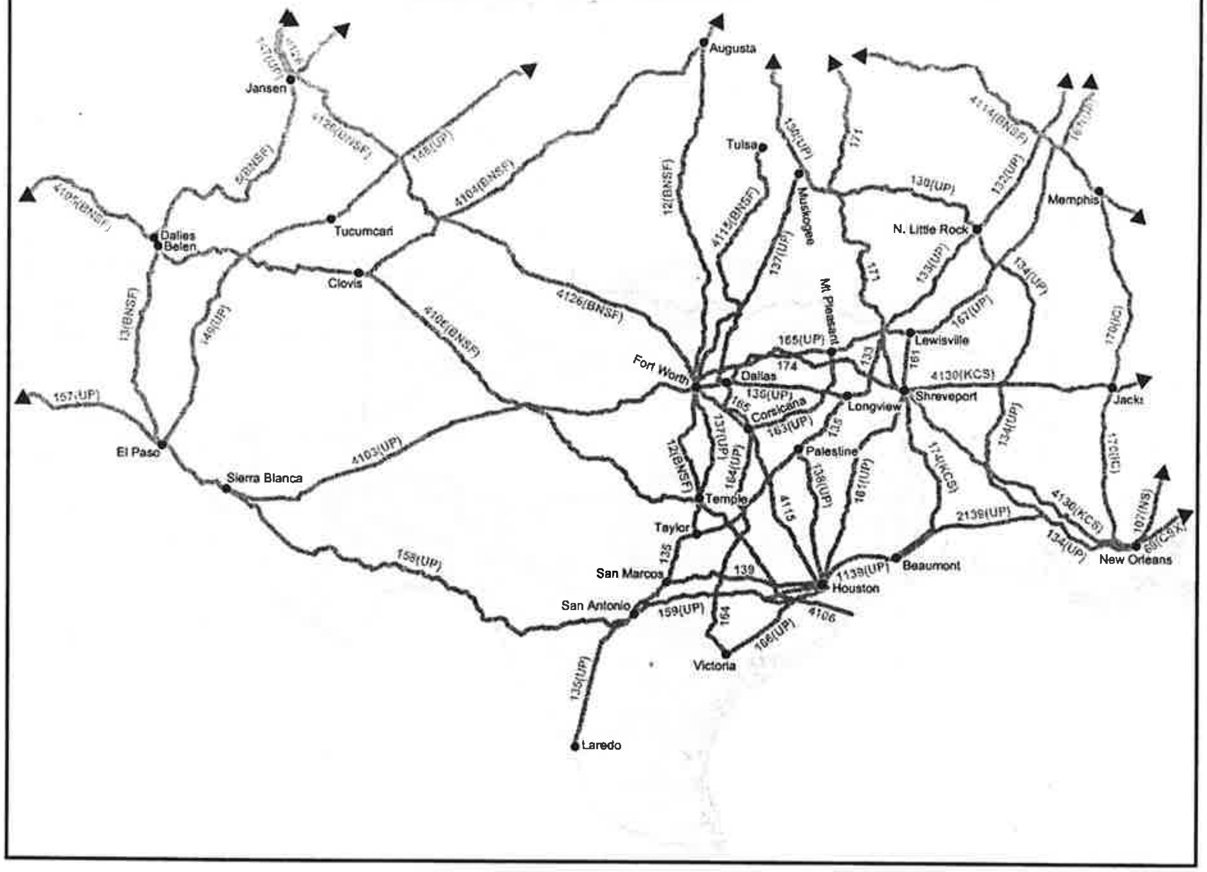
Corridors in Region 3



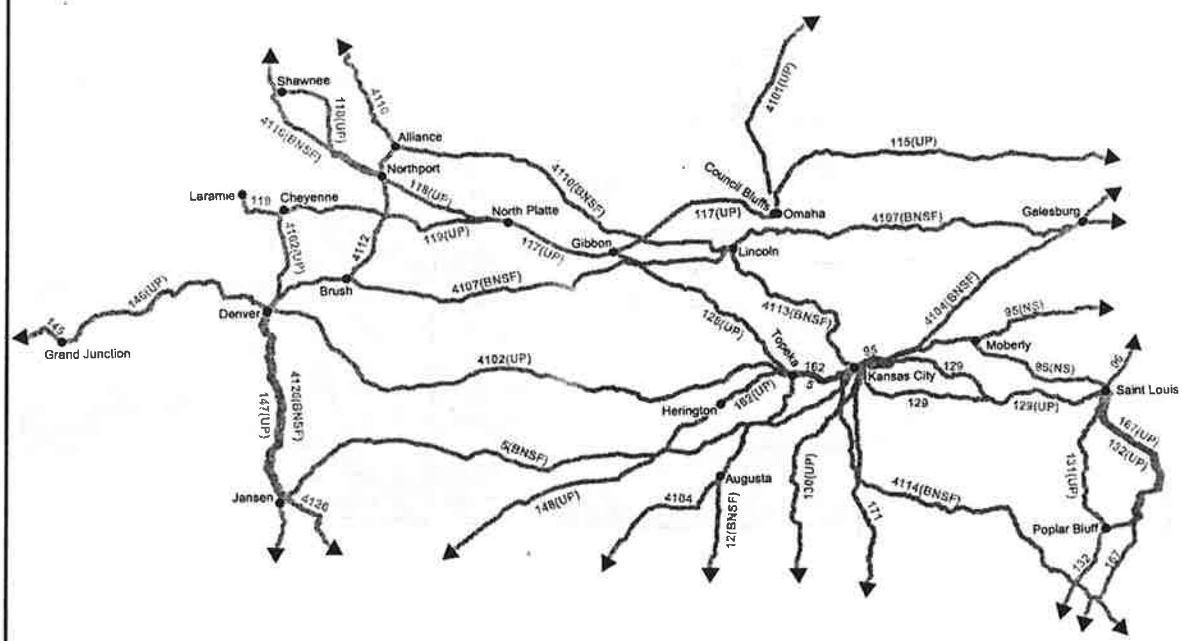
Corridors in Region 4

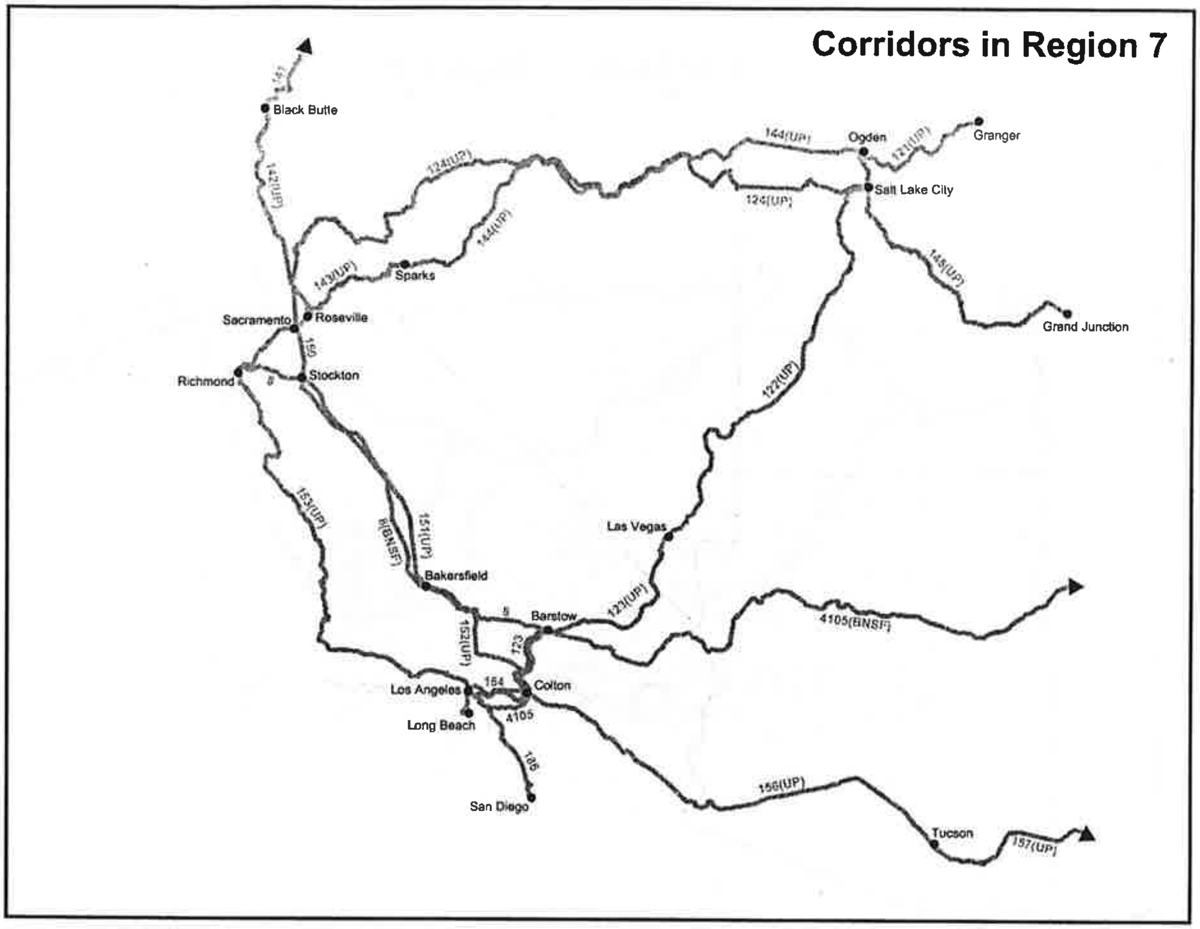


Corridors in Region 5



Corridors in Region 6




Corridors in Region 7
Black Butte
142(UP)
124(UP)
144(UP)
143(UP)
Sparks
Sacramento
Roseville
150
Richmond
8
Stockton
144(UP)
Ogden
121(UP)
Granger
124(UP)
Salt Lake City
145(UP)
Grand Junction
122(UP)
153(UP)
8(BNSF)
151(UP)
Las Vegas
Bakersfield
5
Barstow
123(UP)
4105(BNSF)
152(UP)
123
Los Angeles
154
Colton
Long Beach
4105
186
San Diego
156(UP)
Tucson
157(UP)

Corridors in Region 8

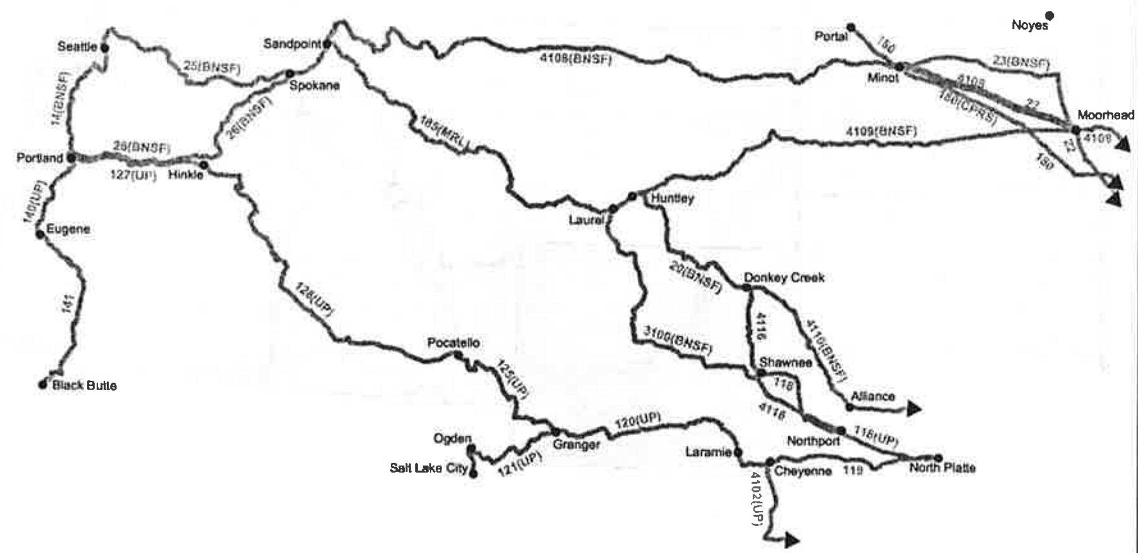


Table 7 Definition Key	
Corridor Number	Corridor ID Number (Internally Assigned)
Owner	Railroad Owner
Endpoint	From Location, City, State
Endpoint	To Location, City, State
Total PPAs	Number of PPAs Assigned to Corridor
Corridor Length (Miles)	Length (endpoint to endpoint)
Average Maximum Speed	Average Freight Maximum Speed by ROS for Corridor
Average Number of Tracks	Average Reported Number of Tracks by ROS for Corridor
Average Percentage Hazmat Per Year	Average Percent Hazmat Freight by ROS for Corridor
Average Number of Freight Trains per Year	Average Freight Trains by Corridor
Average Number of Passenger Trains per Year	Average Passenger Trains (Amtrak and Commuter)
Length Weighted Average Speed Mean	Average of Speed Multiplied by Mileage Under That Speed Limit for Corridor
Length Weighted Average Curvature Mean	Average of Degrees of Curvature by Mileage Under that Curvature by ROS for Corridor
Average Curves per Mile	Average Number of Curves Per Mile per ROS for Corridor

5. HISTORICAL PATTERNS

Distinguishing among corridors based upon risk was addressed by using two methods. The first method examined the historical pattern of accidents by corridor and described these accidents in terms of their overall consequences. By comparing all corridors with each accident "weighted" by its consequences it was possible to determine whether any corridor presented a higher historical PPA risk than any other.

This method of historical consequences comparison was accomplished by calculating the total consequences for all accidents, which were then used to produce the corridor rankings. A comparison of all corridors based on the total calculated historical benefits was used to determine whether there were actual significant "differences" among corridors, and to determine which corridors might warrant more thorough investigation.

5.1 BENEFIT ASSIGNMENT METHOD

Implementing PTC is expected to result in quantifiable benefits. These benefits might be in the form of avoided fatalities and injuries to railroad employees or passengers, or they may take the form of avoided costs due to track or equipment damage in accidents. The estimate of the costs of previous accidents, which expresses the value of all of these benefits, can be used to forecast the value of PTC implementation in the future.

The risk avoided by PTC is therefore expressed, for this analysis, in terms of both the expected reduction in accident probability as a result of PTC and the resulting avoided costs due to these prevented accidents. Again, the analysis benefited from the participation of the RSAC/ PTC Implementation Task Force in developing a method to assign costs to historical accident experience, and provide a method for forecasting the cost avoidance due to PTC implementation. This methodology is discussed in detail in Appendix B, the Report of the Railroad Safety Advisory Committee to the Federal Railroad Administrator – Implementation of Positive Train Control Systems, September 8, 1999 Section V-C, p 71-89, and Appendix D (referred to as the "RSAC Report").

These accident costs were converted into operational values for application in the PTC study. The methodology by which these costs were assigned is based upon the assigned values from the accident costs report (Appendix B) and data made available through RAIRS on accident outcomes. Each individual PTC preventable accident in the dataset was evaluated using the same formula that assigns a dollar value to the costs of the accident and thereby creates a potential safety benefit for accident avoidance.

5.2 PPA ASSIGNMENT TO CORRIDORS

All PPAs with a valid geographical location were assigned to corridors for this analysis. Although 813 (of the total 818 PPAs identified by the ART) were assigned to valid geographic locations and were eligible for the analysis, only 445 were actually assigned to network locations that were also included in the identified corridors. In some cases, more than one corridor includes the same location, most often when terminus points occur in yards or on shared track around major cities.

Table 8. PPA Consequence Descriptions (PPAs located on Corridors)

Number of PPAs	Fatalities (not railroad employees)	Fatalities (railroad employees)	Injured (not railroad employees)	Injured (railroad employees)	Reported Track Damages (M$s)	Reported Equipment Damages (M$)	Evacuations	Hazards materials cars releases
445	7	38	48	297	$11	$80	1,285	539

Table 9. Cost Factors for Accident Valuation

The total cost of an accident is the weighted sum:	
$2,700,000	per number of fatalities in freight and passenger train accident
$100,000	per the number of employee injuries in freight and passenger trains
$55,000	per the number of non-employee (passenger) injuries in freight or passenger trains
$500	Per the number of individuals evacuated in an accident
$250,000	per hazmat release
$ 6,500	per freight cars where loss of lading occurs
$250	per hour of delay of a freight train
$148.44	per hour of passenger train delay
$750	per derailed freight locomotive or
$75,000	per derailed passenger train locomotive +
$2500	per derailment (for emergency response and rerailing) +
$s reported	reported Track and Equipment damage.

To systematically compare corridors with respect to their historical accident experience, the cost of each accident was determined, using a cost assignment methodology. A full description of this cost assignment methodology appears in the Economics Section of the RSAC Report (Section V. -C, p. 69). Using this methodology, costs were assigned to each PTC-preventable accident, using the scale $2.7 million per fatality, $100,000 per employee injury, $55,000 per passenger injury and $500 per evacuation. Dollar damages to track and equipment were included as reported on the RAIRS accident reports. To reflect additional unreported costs for repairs, delays and equipment damage other raw damage, hazard cleanup, etc., specific costs were assigned to the cost of accident emergency response, rerailing derailed equipment, and the loss of hazardous materials. Using these numbers the average PPA cost $1.10 million, ranging from the lowest accident cost of $10,266.00 to the highest of $8.581 million). The result of the historical cost assignment is illustrated in Figure 10.

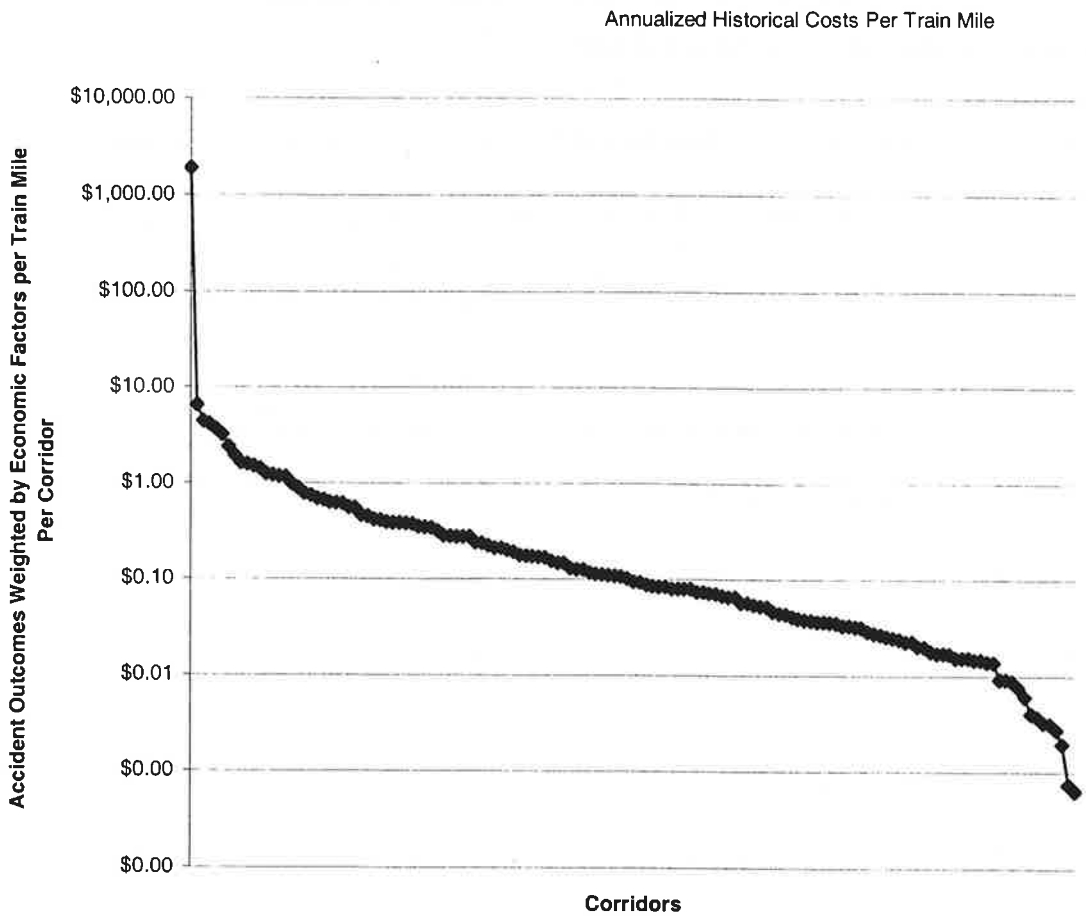


Figure 10. Historical Costs of PPAs by Corridors in Dollars per Train-Mile

The historical costs of PTC-preventable accidents are concentrated at a handful of locations experiencing catastrophic PPAs. However, that concentration does not necessarily imply that future PPA costs will be concentrated at the same locations. To predict future PPA locations, one must employ a model that relates network and link characteristics (e.g., curvature, train volume, etc.) to PPA experience. That is what this analysis does.

The contribution of these differences to the determination of risk for each corridor, the total benefits, as calculated using the weighting function described above, were calculated for each. At that point these benefits were divided by two different measures of exposure, total corridor length, and total train-miles (the number of trains reported to have flowed on the corridor in 1 year multiplied by the length).

Based upon this analysis, corridors were sorted from the highest ratio of benefits per mile and benefits per car mile and compared. The results of these comparisons appear in Table 10 and are shown for the top 20 corridors in the following illustrations.

Table 10 Definition Key	
Corridor ID Number	Corridor ID Number (Internally Assigned)
Total PPAs	Number of PPAs Assigned to Corridor
Total Historical Costs	Calculated PPA Costs Based Upon Economic Team Cost Assignment Method
Annualized Historical Costs	Total Historical Costs Divided by 8-year Time Period
Annualized Historical Costs per mile	Annualized Historical Costs Divided by Total Miles on Corridor
Annualized Historical Costs Per Train-Mile	Annualized Historical Costs Divided by Total Train-Miles on Corridor
Annualized Historical Costs Per Train	Annualized Historical Costs Divided by Total Trains on Corridor
Historical Rank Total Annualized Historical Costs	Rank (Highest to Lowest) based upon Annualized Historical Costs
Historical Rank per Mile	Rank (Highest to Lowest) based upon Annualized Historical Costs per Mile
Historical Rank Per Train-Mile	Rank (Highest to Lowest) based upon Annualized Historical Costs per Train-Mile
Total Fatality Costs	Costs per Fatality based upon Economic Team Report (2.7 million per)
Total Railroad Employee Injuries Costs	Cost per Injury ($100,000)
Total Non-Railroad Injury Costs	Cost per Non-railroad employee injury $55,000
Total Derailments	Total Estimated Derailment Costs
Total Loss of Lading	Economic Costs for Loss of Lading
Total Other Freight Costs	Other Freight Costs
Total Delay Costs	Delay costs to travelers
Total Equipment Costs	Damaged equipment costs
Total Track Related Costs	Track damage costs

Table 10. Historical Costs of PPAs on Corridors (Sorted by Historical Rank per Train-Mile)

Historical Corridor Costs and Rankings (Annualized) Per Mile and Per Train-Mile										Costs for PPAs Assigned to Corridor							
Corridor ID Number	Total PPAs	Total Historical Costs	Annualized Historical Costs	Annualized Historical Costs per mile	Annualized Historical Costs Per Train-Mile	Historical Rank Total Annualized Historical Costs	Historical Rank per Mile	Historical Rank Per Train-Mile	Total Fatality Costs	Total RR Injuries Costs	Total Non-Railroad Injury Costs	Total Derailments	Total Loss of Lading	Total Other Freight Costs	Total Delay Costs	Total Equipment Costs	Total Track Related Costs
5	3	$54,198	$6,775	$77	$0.04	119	127	102	0		0	2,800	0	6,000	998	24,400	14,000
8	11	$865,939	$108,242	$2,412	$0.56	47	31	26	0		0	31,100	78,000	22,000	3,739	252,300	41,800
12	4	$142,476	$17,809	$87	$0.01	100	125	129	0		0	10,600	6,500	8,000	3,202	23,400	72,274
13	1	$225,486	$28,186	$388	$0.37	87	92	36	0	0	0	6,700	26,000	2,000	86	108,700	30,000
14	5	$182,629	$22,829	$114	$0.01	96	121	131	0		0	75,000	0	10,000	5,499	82,130	0
20	1	$19,789	$2,474	$758	$0.03	132	62	106	0	0	0	0	0	2,000	1,989	10,200	3,600
22	1	$146	$0	$0	$0.00	0	0	0	0	0	0	0	0	2,000	0	0	0
23	1	$190,290	$23,786	$1,886	$1.27	94	43	13	0	100,000	0	3,700	26,000	2,000	90	50,500	6,000
25	1	$996,456	$124,557	$808	$0.21	44	61	50	0	400,000	0	2,500	0	2,000	291	523,500	65,415
26	4	$1,000,482	$125,060	$370	$0.05	43	94	92	0		0	80,200	58,500	8,000	3,367	239,915	2,500
30	5	$1,147,855	$143,482	$1,497	$0.21	37	49	49	0		0	9,400	0	10,000	2,455	623,000	293,000
36	1	$24,625	$3,078	$2,043	$0.08	130	39	77	0	0	0	0	0	2,000	2,025	0	18,600
37	4	$162,135	$20,267	$71	$0.00	97	129	135	0		0	17,200	0	8,000	6,185	11,400	10,600
38	2	$10,730	$1,341	$12	$0.00	137	139	140	0		0	0	0	4,000	2,330	400	0

Historical Corridor Costs and Rankings (Annualized) Per Mile and Per Train-Mile										Costs for PPAs Assigned to Corridor							
Corridor ID Number	Total PPAs	Total Historical Costs	Annualized Historical Costs	Annualized Historical Costs per mile	Annualized Historical Costs Per Train-Mile	Historical Rank Total Annualized Historical Costs	Historical Rank per Mile	Historical Rank Per Train-Mile	Total Fatality Costs	Total RR Injuries Costs	Total Non-Railroad Injury Costs	Total Derailments	Total Loss of Lading	Total Other Freight Costs	Total Delay Costs	Total Equipment Costs	Total Track Related Costs
39	1	$526,383	$65,798	$742	$0.08	64	63	80	0	100,000	110,000	0	0	2,000	727	201,656	0
40	2	$50,394	$6,299	$51	$0.01	120	134	133	0		0	0	0	4,000	4,656	37,738	0
41	1	$8,504,365	$1,063,046	$62,495	$4.47	7	2	3	8100000	300,000	0	6,700	91,000	2,000	1,165	0	0
42	0	$0	$0	$0	$0.00	0	0	0	0							0	0
43	1	$240,941	$30,118	$2,373	$0.45	85	32	29	0	200,000	0	4,000	32,500	2,000	441	0	0
45	0	$0	$0	$0	$0.00	0	0	0	0							0	0
46	5	$475,542	$59,443	$618	$0.04	67	72	94	0		0	11,100	32,500	10,000	5,062	174,687	30,693
47	2	$11,657,553	$1,457,194	$11,959	$0.62	6	7	25	0		0	11,500	195,000	4,000	2,948	403,605	35,000
48	1	$294,406	$36,801	$1,801	$0.20	81	45	51	0	200,000	0	3,700	6,500	2,000	756	28,500	49,450
49	0	$0	$0	$0	$0.00	0	0	0	0							0	0
50	1	$26,380	$3,298	$81	$0.02	129	126	118	0	0	0	0	0	2,000	380	22,000	0
51	5	$947,041	$118,380	$3,430	$0.15	45	23	59	0		0	12,500	162,500	10,000	3,291	433,250	14,000
52	4	$689,712	$86,214	$708	$0.35	54	65	38	0		0	27,100	227,500	8,000	548	340,064	75,500
53	0	$0	$0	$0	$0.00	0	0	0	0							0	0
54	0	$0	$0	$0	$0.00	0	0	0	0							0	0

Historical Corridor Costs and Rankings (Annualized) Per Mile and Per Train-Mile										Costs for PPAs Assigned to Corridor							
Corridor ID Number	Total PPAs	Total Historical Costs	Annualized Historical Costs	Annualized Historical Costs per mile	Annualized Historical Costs Per Train-Mile	Historical Rank Total Annualized Historical Costs	Historical Rank per Mile	Historical Rank Per Train-Mile	Total Fatality Costs	Total RR Injuries Costs	Total Non-Railroad Injury Costs	Total Derailments	Total Loss of Lading	Total Other Freight Costs	Total Delay Costs	Total Equipment Costs	Total Track Related Costs
55	3	$774,695	$96,837	$522	$0.15	51	82	60	0		0	21,000	260,000	6,000	1,053	419,788	60,854
56	0	$0	$0	$0	$0.00	0	0	0	0							0	0
57	3	$50,213	$6,277	$386	$0.04	121	93	95	0		0	0	0	6,000	3,213	14,000	21,000
58	0	$0	$0	$0	$0.00	0	0	0	0							0	0
59	5	$345,506	$43,188	$177	$0.03	76	112	104	0		0	12,700	58,500	10,000	2,406	109,150	37,500
60	2	$36,028	$4,504	$92	$0.01	126	124	132	0		0	5,600	0	4,000	2,028	20,200	200
61	4	$3,135,446	$391,931	$2,878	$0.28	19	26	45	0		0	93,300	214,500	8,000	3,646	2,520,000	188,000
62	1	$106,393	$13,299	$347	$0.06	105	96	89	0	100,000	0	0	0	2,000	393	2,000	0
63	1	$217,308	$27,163	$533	$0.07	90	78	83	0	0	0	4,900	52,000	2,000	508	86,900	69,000
64	0	$0	$0	$0	$0.00	0	0	0	0							0	0
65	0	$0	$0	$0	$0.00	0	0	0	0							0	0
66	1	$2,409,618	$301,202	$6,637	$1.63	23	12	9	0	500,000	715,000	75,000	0	2,000	618	1,115,000	0
67	1	$324,875	$40,609	$363	$0.05	77	95	93	0	0	0	6,700	0	2,000	275	300,900	13,000
68	4	$608,147	$76,018	$449	$0.10	61	85	70	0		0	23,500	149,500	8,000	1,398	386,749	29,500
69	1	$68,416	$8,552	$200	$0.02	112	109	117	0	0	0	3,100	6,500	2,000	816	54,000	0

Historical Corridor Costs and Rankings (Annualized) Per Mile and Per Train-Mile										Costs for PPAs Assigned to Corridor							
Corridor ID Number	Total PPAs	Total Historical Costs	Annualized Historical Costs	Annualized Historical Costs per mile	Annualized Historical Costs Per Train-Mile	Historical Rank Total Annualized Historical Costs	Historical Rank per Mile	Historical Rank Per Train-Mile	Total Fatality Costs	Total RR Injuries Costs	Total Non-Railroad Injury Costs	Total Derailments	Total Loss of Lading	Total Other Freight Costs	Total Delay Costs	Total Equipment Costs	Total Track Related Costs
70	3	$2,168,554	$271,069	$2,166	$0.38	25	36	35	0		0	7,600	19,500	6,000	1,654	520,300	3,000
71	2	$1,273,579	$159,197	$678	$0.12	31	68	64	0		0	5,600	13,000	4,000	979	196,000	0
72	2	$1,717,094	$214,637	$2,589	$0.32	27	28	40	0		0	27,200	279,500	4,000	1,344	877,300	70,000
73	0	$0	$0	$0	$0.00	0	0	0	0							0	0
74	2	$0	$0	$0	$0.00	0	0	0	0		0	0	0	4,000	0	0	0
75	8	$219,421	$27,428	$1,095	$0.19	89	53	52	0		0	6,500	32,500	16,000	5,971	29,500	112,200
76	1	$152,082	$19,010	$529	$0.08	99	79	75	0	0	0	4,300	0	2,000	532	143,250	0
77	1	$4,024,090	$503,011	$11,468	$1.95	15	8	8	0	0	165,000	19,900	357,500	2,000	490	1,665,000	22,200
78	5	$3,280,121	$410,015	$1,936	$0.34	17	41	39	0		0	26,800	364,000	10,000	2,174	2,616,647	46,000
79	1	$5,080	$635	$33	$0.00	141	135	136	0	0	0	0	0	2,000	830	250	0
80	4	$2,320,120	$290,015	$928	$0.13	24	57	61	0		0	22,000	260,000	8,000	2,314	1,739,806	80,000
81	0	$0	$0	$0	$0.00	0	0	0	0							0	0
82	3	$309,787	$38,723	$263	$0.04	79	104	99	0		0	12,000	91,000	6,000	1,937	180,350	12,500
83	0	$0	$0	$0	$0.00	0	0	0	0							0	0
84	0	$0	$0	$0	$0.00	0	0	0	0							0	0

Corridor ID Number	Total PPAs	Total Historical Costs	Annualized Historical Costs	Annualized Historical Costs per mile	Annualized Historical Costs Per Train-Mile	Historical Rank Total Annualized Historical Costs	Historical Rank per Mile	Historical Rank Per Train-Mile	Total Fatality Costs	Total RR Injuries Costs	Total Non-Railroad Injury Costs	Total Derailments	Total Loss of Lading	Total Other Freight Costs	Total Delay Costs	Total Equipment Costs	Total Track Related Costs
		Historical Corridor Costs and Rankings (Annualized) Per Mile and Per Train-Mile								Costs for PPAs Assigned to Corridor							
85	1	$316,456	$39,557	$1,025	$0.24	78	54	46	0	300,000	0	0	0	2,000	356	12,100	0
86	0	$0	$0	$0	$0.00	0	0	0	0							0	0
87	4	$2,834,392	$354,299	$1,660	$0.46	21	47	28	0		0	11,200	26,000	8,000	1,192	380,000	0
88	2	$459,896	$57,487	$3,515	$0.90	70	22	18	0		0	2,800	0	4,000	596	146,000	1,000
89	0	$0	$0	$0	$0.00	0	0	0	0							0	0
90	1	$615,429	$76,929	$1,975	$0.38	60	40	33	0	200,000	0	2,500	0	2,000	429	407,000	0
91	1	$22,220	$2,778	$2,108	$0.28	131	37	41	0	0	0	3,400	0	2,000	620	14,200	0
92	0	$0	$0	$0	$0.00	0	0	0	0							0	0
95	1	$222,907	$27,863	$3,286	$0.42	88	24	30	0	200,000	0	2,500	0	2,000	657	15,000	0
96	1	$49,560	$6,195	$57	$0.02	123	132	123	0	0	0	4,000	32,500	2,000	310	6,750	2,000
97	0	$0	$0	$0	$0.00	0	0	0	0							0	0
100	0	$0	$0	$0	$0.00	0	0	0	0							0	0
101	5	$483,183	$60,398	$217	$0.02	66	107	114	0		0	9,300	39,000	10,000	4,033	381,300	22,800
102	1	$215,286	$26,911	$2,361	$0.15	91	33	58	0	200,000	0	0	0	2,000	1,286	10,000	0
103	1	$74,088	$9,261	$297	$0.07	111	103	82	0	0	0	3,400	13,000	2,000	338	43,350	10,000

Corridor ID Number	Total PPAs	Total Historical Costs	Annualized Historical Costs	Annualized Historical Costs per mile	Annualized Historical Costs Per Train-Mile	Historical Rank Total Annualized Historical Costs	Historical Rank per Mile	Historical Rank Per Train-Mile	Total Fatality Costs	Total RR Injuries Costs	Total Non-Railroad Injury Costs	Total Derailments	Total Loss of Lading	Total Other Freight Costs	Total Delay Costs	Total Equipment Costs	Total Track Related Costs
Historical Corridor Costs and Rankings (Annualized) Per Mile and Per Train-Mile									Costs for PPAs Assigned to Corridor								
106	1	$16,514	$2,064	$1,901	$0.28	133	42	44	0	0	0	0	0	2,000	514	12,000	0
107	1	$146	$0	$0	$0.00	0	0	0	0	0	0	0	0	2,000	0	0	0
111	2	$104,695	$13,087	$579	$0.11	106	76	69	0		0	4,000	6,500	4,000	995	71,000	14,200
112	0	$0	$0	$0	$0.00	0	0	0	0							0	0
115	8	$1,266,449	$158,306	$871	$0.04	32	59	98	0		0	8,700	0	16,000	13,609	410,640	750
116	2	$808,130	$101,016	$1,858	$0.17	49	44	55	0		0	13,100	97,500	4,000	1,782	409,900	177,848
117	4	$1,030,474	$128,809	$2,476	$0.11	39	30	66	0		0	5,300	6,500	8,000	6,334	47,000	48,590
118	1	$146	$0	$0	$0.00	0	0	0	0	0	0	0	0	2,000	0	0	0
119	3	$6,053,278	$756,660	$16,374	$0.64	11	6	23	0		0	18,600	240,500	6,000	7,228	2,739,150	133,550
120	2	$102,318	$12,790	$338	$0.01	107	97	127	0		0	6,500	6,500	4,000	3,968	72,850	4,500
121	1	$13,714	$1,714	$57	$0.00	135	131	138	0	0	0	0	0	2,000	1,714	8,000	0
122	3	$4,188,109	$523,514	$2,059	$0.28	14	38	42	0		0	11,400	71,500	6,000	1,717	1,017,242	69,000
123	9	$266,195	$33,274	$3,565	$0.24	82	21	47	0		0	10,300	19,500	18,000	6,595	81,800	112,000
124	2	$159,607	$19,951	$59	$0.02	98	130	122	0		0	3,100	0	4,000	607	47,900	0
125	2	$690,385	$86,298	$529	$0.06	53	80	86	0		0	12,500	123,500	4,000	1,635	484,150	60,600

Historical Corridor Costs and Rankings (Annualized) Per Mile and Per Train-Mile										Costs for PPAs Assigned to Corridor								
Corridor ID Number	Total PPAs	Total Historical Costs	Annualized Historical Costs	Annualized Historical Costs per mile	Annualized Historical Costs Per Train-Mile	Historical Rank Total Annualized Historical Costs	Historical Rank per Mile	Historical Rank Per Train-Mile	Total Fatality Costs	Total RR Injuries Costs	Total Non-Railroad Injury Costs	Total Derailments	Total Loss of Lading	Total Other Freight Costs	Total Delay Costs	Total Equipment Costs	Total Track Related Costs
126	8	$1,211,619	$151,452	$404	$0.04	35	90	96	0		0	19,700	123,500	16,000	5,698	439,806	89,415
127	2	$195,057	$24,382	$255	$0.03	93	105	109	0		0	5,900	19,500	4,000	1,113	4,000	53,544
128	5	$750,955	$93,869	$1,005	$0.07	52	56	84	0		0	14,400	84,500	10,000	6,000	300,800	124,505
129	3	$251,713	$31,464	$135	$0.02	84	118	113	0		0	3,700	0	6,000	1,488	28,200	206,325
130	3	$1,018,646	$127,331	$1,020	$0.22	40	55	48	0		0	12,900	104,000	6,000	1,335	561,861	124,300
131	1	$139,397	$17,425	$200	$0.17	101	110	57	0	100,000	0	0	0	2,000	76	35,321	0
132	7	$620,163	$77,520	$330	$0.04	59	100	101	0		0	26,400	208,000	14,000	4,763	81,000	272,000
133	4	$1,551,789	$193,974	$1,533	$0.18	29	48	53	220000		220,000	10,900	0	8,000	2,779	188,000	592,610
134	2	$90,802	$11,350	$335	$0.06	109	98	87	0		0	5,600	13,000	4,000	952	37,500	25,000
135	1	$56,967	$7,121	$98	$0.02	116	123	115	0	0	0	4,000	32,500	2,000	367	14,600	1,500
136	1	$50,106	$6,263	$683	$0.05	122	67	90	0	0	0	3,700	13,000	2,000	1,024	26,382	2,000
137	4	$7,330,118	$916,265	$10,134	$3.20	8	9	6	0		0	84,600	39,000	8,000	972	842,198	139,848
138	0	$0	$0	$0	$0.00	0	0	0	0							0	0
139	3	$1,003,951	$125,494	$1,258	$0.55	42	50	27	0		0	11,700	91,000	6,000	594	500,954	84,703
140	3	$0	$0	$120	$0.02	108	120	120	0		0	6,800	39,000	6,000	1,413	24,400	13,000

Corridor ID Number	Total PPAs	Total Historical Costs	Annualized Historical Costs	Annualized Historical Costs per mile	Annualized Historical Costs Per Train-Mile	Historical Rank Total Annualized Historical Costs	Historical Rank per Mile	Historical Rank Per Train-Mile	Total Fatality Costs	Total RR Injuries Costs	Total Non-Railroad Injury Costs	Total Derailments	Total Loss of Lading	Total Other Freight Costs	Total Delay Costs	Total Equipment Costs	Total Track Related Costs
		Historical Corridor Costs and Rankings (Annualized) Per Mile and Per Train-Mile								Costs for PPAs Assigned to Corridor							
141	0	$0	$0	$0	$0.00	0	0	0	0							0	0
142	3	$346,500	$43,312	$198	$0.02	75	111	112	0		0	8,000	65,000	6,000	1,816	224,426	32,258
143	2	$1,204,961	$150,620	$19,875	$2.40	36	5	7	0		0	9,100	143,000	4,000	1,311	598,550	95,000
144	3	$4,945,387	$618,173	$2,633	$0.39	12	27	32	0		0	24,800	429,000	6,000	1,333	3,498,254	580,000
145	4	$944,944	$118,118	$872	$0.17	46	58	54	0		0	5,800	71,500	8,000	2,144	544,500	105,000
146	2	$13,499,198	$1,687,400	$6,861	$1.17	5	11	16	0		0	11,000	65,000	4,000	858	2,025,840	184,000
147	2	$185,108	$23,139	$431	$0.03	95	87	108	0		0	7,400	52,000	4,000	2,508	115,200	0
148	1	$5,475	$684	$5	$0.00	140	141	141	0	0	0	0	0	2,000	675	800	0
149	0	$0	$0	$0	$0.00	0	0	0	0							0	0
150	2	$0	$0	$0	$0.00	0	0	0	0		0	0	0	4,000	0	0	0
151	2	$44,887	$5,611	$134	$0.03	124	119	111	0		0	0	0	4,000	887	0	36,000
152	6	$677,533	$84,692	$409	$0.05	56	88	91	0		0	5,900	19,500	12,000	4,383	159,000	64,000
153	6	$475,254	$59,407	$699	$0.08	68	66	78	0		0	81,800	0	12,000	3,024	50,430	116,000
154	4	$54,970	$6,871	$403	$0.02	118	91	119	0		0	0	0	8,000	7,570	9,500	21,900
156	6	$134,557	$16,820	$27	$0.00	103	136	139	0		0	0	0	12,000	6,657	32,400	71,500

Historical Corridor Costs and Rankings (Annualized) Per Mile and Per Train-Mile										Costs for PPAs Assigned to Corridor								
Corridor ID Number	Total PPAs	Total Historical Costs	Annualized Historical Costs	Annualized Historical Costs per mile	Annualized Historical Costs Per Train-Mile	Historical Rank Total Annualized Historical Costs	Historical Rank per Mile	Historical Rank Per Train-Mile	Total Fatality Costs	Total RR Injuries Costs	Total Non-Railroad Injury Costs	Total Derailments	Total Loss of Lading	Total Other Freight Costs	Total Delay Costs	Total Equipment Costs	Total Track Related Costs
157	5	$1,604,028	$200,504	$648	$0.04	28	70	97	0		0	17,200	0	10,000	6,673	1,124,984	32,921
158	2	$13,839,851	$1,729,981	$8,679	$1.51	4	10	11	0		0	6,500	32,500	4,000	854	2,899,019	87,728
159	5	$205,061	$25,633	$224	$0.04	92	106	103	0		0	10,800	52,000	10,000	2,021	87,840	32,400
161	0	$0	$0	$0	$0.00	0	0	0	0							0	0
162	1	$1,004,699	$125,587	$2,550	$0.11	41	29	68	0	200,000	0	12,100	26,000	2,000	1,961	710,138	49,000
163	1	$4,075	$509	$14	$0.02	143	138	124	0	0	0	0	0	2,000	75	0	0
164	1	$642,984	$80,373	$2,895	$4.20	58	25	4	0	0	0	6,400	0	2,000	57	607,527	22,000
165	3	$498,214	$62,277	$2,296	$0.98	65	34	17	0		0	11,100	71,500	6,000	1,964	36,300	63,100
166	1	$33,347	$4,168	$175	$0.08	127	113	74	0	0	0	3,400	13,000	2,000	147	1,300	11,500
167	9	$368,610	$46,076	$136	$0.01	73	116	125	0		0	8,400	19,500	18,000	8,152	247,898	48,660
168	2	$135,964	$16,995	$486	$0.09	102	84	72	0		0	6,800	32,500	4,000	664	64,000	24,000
169	3	$2,970,397	$371,300	$5,272	$1.43	20	16	12	0		0	2,500	0	6,000	997	250,000	3,400
170	1	$146	$0	$0	$0.00	0	0	0	0	0	0	0	0	2,000	0	0	0
171	5	$422,246	$52,781	$151	$0.04	71	115	100	0		0	9,500	97,500	10,000	1,823	287,444	5,229
174	0	$0	$0	$0	$0.00	0	0	0	0							0	0

Corridor ID Number	Total PPAs	Total Historical Costs	Annualized Historical Costs	Annualized Historical Costs per mile	Annualized Historical Costs Per Train-Mile	Historical Rank Total Annualized Historical Costs	Historical Rank per Mile	Historical Rank Per Train-Mile	Total Fatality Costs	Total RR Injuries Costs	Total Non-Railroad Injury Costs	Total Derailments	Total Loss of Lading	Total Other Freight Costs	Total Delay Costs	Total Equipment Costs	Total Track Related Costs
		Historical Corridor Costs and Rankings (Annualized) Per Mile and Per Train-Mile								Costs for PPAs Assigned to Corridor							
175	1	$4,522	$565	$105	$0.02	142	122	121	0	0	0	0	0	2,000	522	0	0
176	5	$462,118	$57,765	$445	$0.13	69	86	62	0		0	16,000	110,500	10,000	3,086	247,600	64,932
177	0	$0	$0	$0	$0.00	0	0	0	0							0	0
179	5	$677,058	$84,632	$608	$0.07	57	74	81	0		0	16,600	130,000	10,000	4,158	83,800	221,000
180	2	$679,404	$84,925	$852	$0.35	55	60	37	110000		110,000	0	0	4,000	404	451,000	0
181	1	$64,658	$8,082	$5,153	$1.18	113	17	15	0	0	0	4,000	32,500	2,000	363	22,720	1,075
182	1	$55,208	$6,901	$54	$0.03	117	133	110	0	0	0	4,600	0	2,000	108	45,000	1,500
183	0	$0	$0	$0	$0.00	0	0	0	0							0	0
184	1	$28,679	$3,585	$315	$0.28	128	101	43	0	0	0	0	0	2,000	95	0	24,584
185	8	$2,636,183	$329,523	$648	$0.08	22	71	79	0		0	20,400	143,000	16,000	5,533	1,840,000	90,000
186	2	$60,165	$7,521	$1,150	$0.09	115	51	71	0		0	0	0	4,000	12,165	0	40,000
187	0	$0	$0	$0	$0.00	0	0	0	0							0	0
1074	5	$540,798	$67,600	$305	$0.03	63	102	105	0		0	13,800	58,500	10,000	3,928	168,100	175,720
1139	2	$120,150	$15,019	$204	$0.69	104	108	21	0		0	7,700	32,500	4,000	630	50,570	20,000
1170	5	$14,697,787	$1,837,223	$4,405	$0.78	3	18	19	0		0	18,400	0	10,000	2,111	2,051,276	0

Corridor ID Number	Total PPAs	Total Historical Costs	Annualized Historical Costs	Annualized Historical Costs per mile	Annualized Historical Costs Per Train-Mile	Historical Rank Total Annualized Historical Costs	Historical Rank per Mile	Historical Rank Per Train-Mile	Total Fatality Costs	Total RR Injuries Costs	Total Non-Railroad Injury Costs	Total Derailments	Total Loss of Lading	Total Other Freight Costs	Total Delay Costs	Total Equipment Costs	Total Track Related Costs
		Historical Corridor Costs and Rankings (Annualized) Per Mile and Per Train-Mile								Costs for PPAs Assigned to Corridor							
2139	0	$0	$0	$0	$0.00	0	0	0	0							0	0
3100	2	$1,257,907	$157,238	$724	$0.41	33	64	31	0		0	13,100	65,000	4,000	307	578,750	73,000
4101	0	$0	$0	$0	$0.00	0	0	0	0							0	0
4102	2	$0	$0	$615	$0.11	86	73	67	0		0	5,000	0	4,000	880	205,000	7,400
4103	1	$16,446	$2,056	$17	$0.00	134	137	134	0	0	0	3,100	0	2,000	346	9,000	0
4104	7	$855,248	$106,906	$523	$0.02	48	81	116	0		0	12,300	6,500	14,000	14,146	342,500	51,052
4105	23	$56,821,096	$7,102,637	$6,289	$0.38	1	13	34	0		0	90,200	721,500	46,000	26,735		1,386,87
4106	4	$369,980	$46,247	$331	$0.09	72	99	73	0		0	14,800	71,500	8,000	1,810	188,120	74,000
4107	10	$1,110,763	$138,845	$659	$0.07	38	69	85	0		0	15,100	6,500	20,000	6,783	398,630	143,000
4108	18	$7,301,467	$912,683	$559	$0.08	9	77	76	0		0	48,000	370,500	36,000	10,250	4,603,717	894,000
4109	6	$3,875,112	$484,389	$1,132	$0.17	16	52	56	0		0	21,100	162,500	12,000	3,353	431,259	31,400
4110	11	$1,213,105	$151,638	$155	$0.01	34	114	130	0		0	36,000	253,500	22,000	14,705	576,400	186,250
4112	0	$0	$0	$0	$0.00	0	0	0	0							0	0
4113	3	$89,616	$11,202	$136	$0.01	110	117	126	0		0	2,800	0	6,000	2,416	69,700	2,700
4114	5	$1,454,296	$181,787	$596	$0.12	30	75	63	0		0	13,900	26,000	10,000	1,946	545,200	45,000

Historical Corridor Costs and Rankings (Annualized) Per Mile and Per Train-Mile									Costs for PPAs Assigned to Corridor								
Corridor ID Number	Total PPAs	Total Historical Costs	Annualized Historical Costs	Annualized Historical Costs per mile	Annualized Historical Costs Per Train-Mile	Historical Rank Total Annualized Historical Costs	Historical Rank per Mile	Historical Rank Per Train-Mile	Total Fatality Costs	Total RR Injuries Costs	Total Non-Railroad Injury Costs	Total Derailments	Total Loss of Lading	Total Other Freight Costs	Total Delay Costs	Total Equipment Costs	Total Track Related Costs
4115	3	$3,255,522	$406,940	$2,284	$1.22	18	35	14	0		0	15,200	208,000	6,000	477	1,251,445	1,165,40
4116	8	$6,235,411	$779,426	$1,735	$0.11	10	46	65	0		0	18,600	78,000	16,000	9,273	5,088,538	0
4117	2	$12,434	$1,554	$12	$0.00	136	140	137	0		0	0	0	4,000	634	0	3,800
4118	1	$297,854	$37,232	$4,052	$0.74	80	19	20	0	200,000	0	3,400	19,500	2,000	454	38,500	32,000
4119	0	$0	$0	$0	$0.00	0	0	0	0							0	0
4120	0	$0	$0	$0	$0.00	0	0	0	0							0	0
4121	1	$1,953,099	$244,137	$20,395	$6.50	26	4	2	0	500,000	0	4,900	52,000	2,000	262	1,390,437	0
4122	1	$41,561	$5,195	$76	$0.01	125	128	128	0	0	0	3,400	19,500	2,000	461	10,000	4,200
4123	4	$365,639	$45,705	$404	$0.03	74	89	107	0		0	3,100	13,000	8,000	4,539	22,800	4,700
4124	0	$0	$0	$0	$0.00	0	0	0	0							0	0
4125	1	$63,073	$7,884	$5,779	$0.62	114	14	24	0	0	0	4,900	39,000	2,000	773	6,400	8,000
4126	15	$4,837,582	$604,698	$492	$0.06	13	83	88	0		0	63,100	663,000	30,000	11,882	2,517,600	1,110,00
4127	1	$22,278,500	$2,784,813	$1,511,171	$1,908.60	2	1	1	18,900,000	1,600,000	1,375,000	0	0	2,000	0	399,500	0
4128	1	$782,601	$97,825	$5,601	$0.67	50	15	22	0	600,000	0	3,400	19,500	2,000	701	148,500	5,000
4129	1	$254,844	$31,856	$23,699	$3.71	83	3	5	0	0	0	6,100	78,000	2,000	532	145,358	20,854

Historical Corridor Costs and Rankings (Annualized) Per Mile and Per Train-Mile										Costs for PPAs Assigned to Corridor							
Corridor ID Number	Total PPAs	Total Historical Costs	Annualized Historical Costs	Annualized Historical Costs per mile	Annualized Historical Costs Per Train-Mile	Historical Rank Total Annualized Historical Costs	Historical Rank per Mile	Historical Rank Per Train-Mile	Total Fatality Costs	Total RR Injuries Costs	Total Non-Railroad Injury Costs	Total Derailments	Total Loss of Lading	Total Other Freight Costs	Total Delay Costs	Total Equipment Costs	Total Track Related Costs
4130	2	$590,433	$73,804	$3,772	$1.58	62	20	10	0		0	11,900	149,500	4,000	333	399,000	21,700

Historical Corridor Rankings

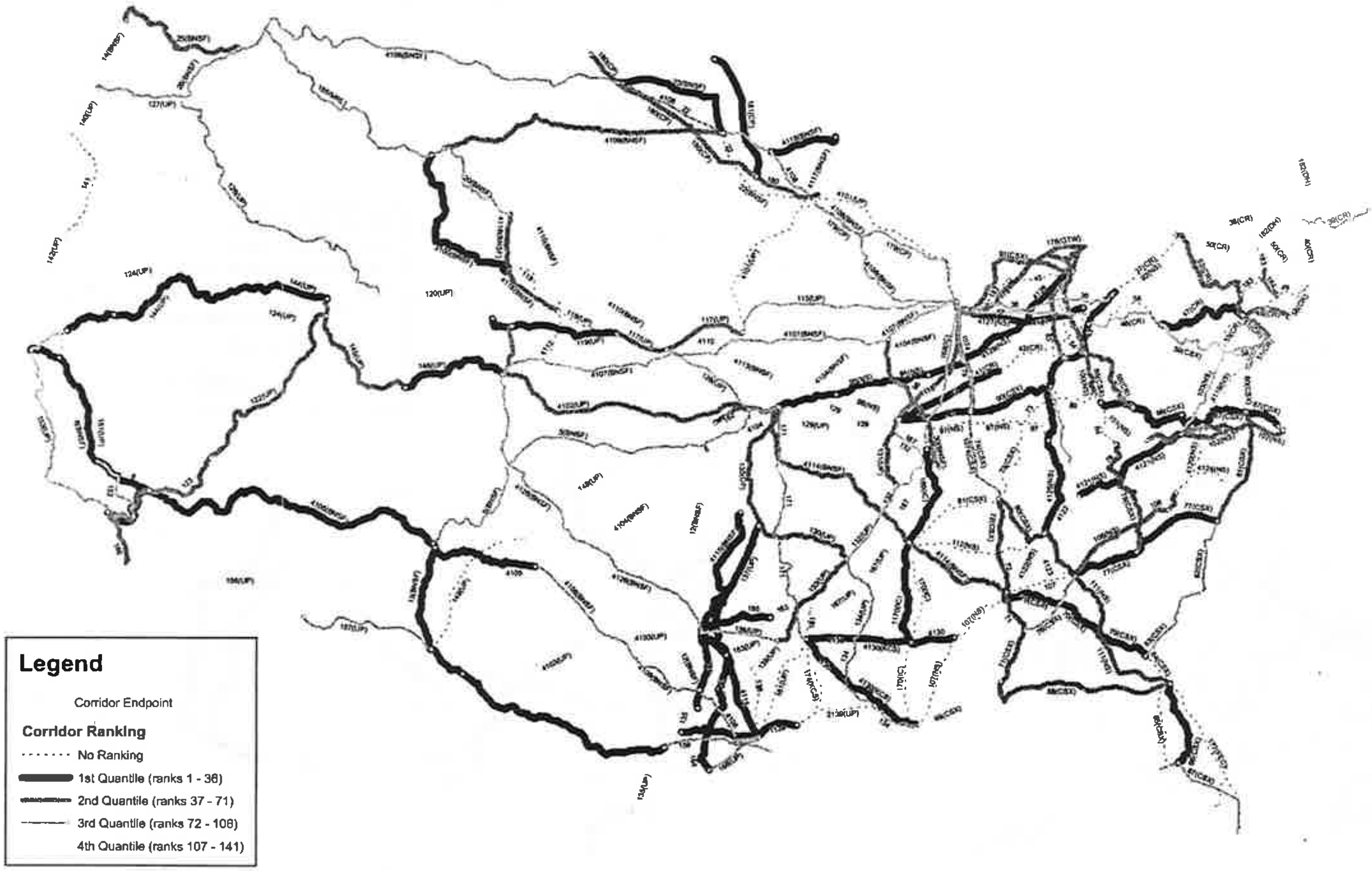


Figure 11. Historical Corridor Rankings

Predicted Corridor Rankings

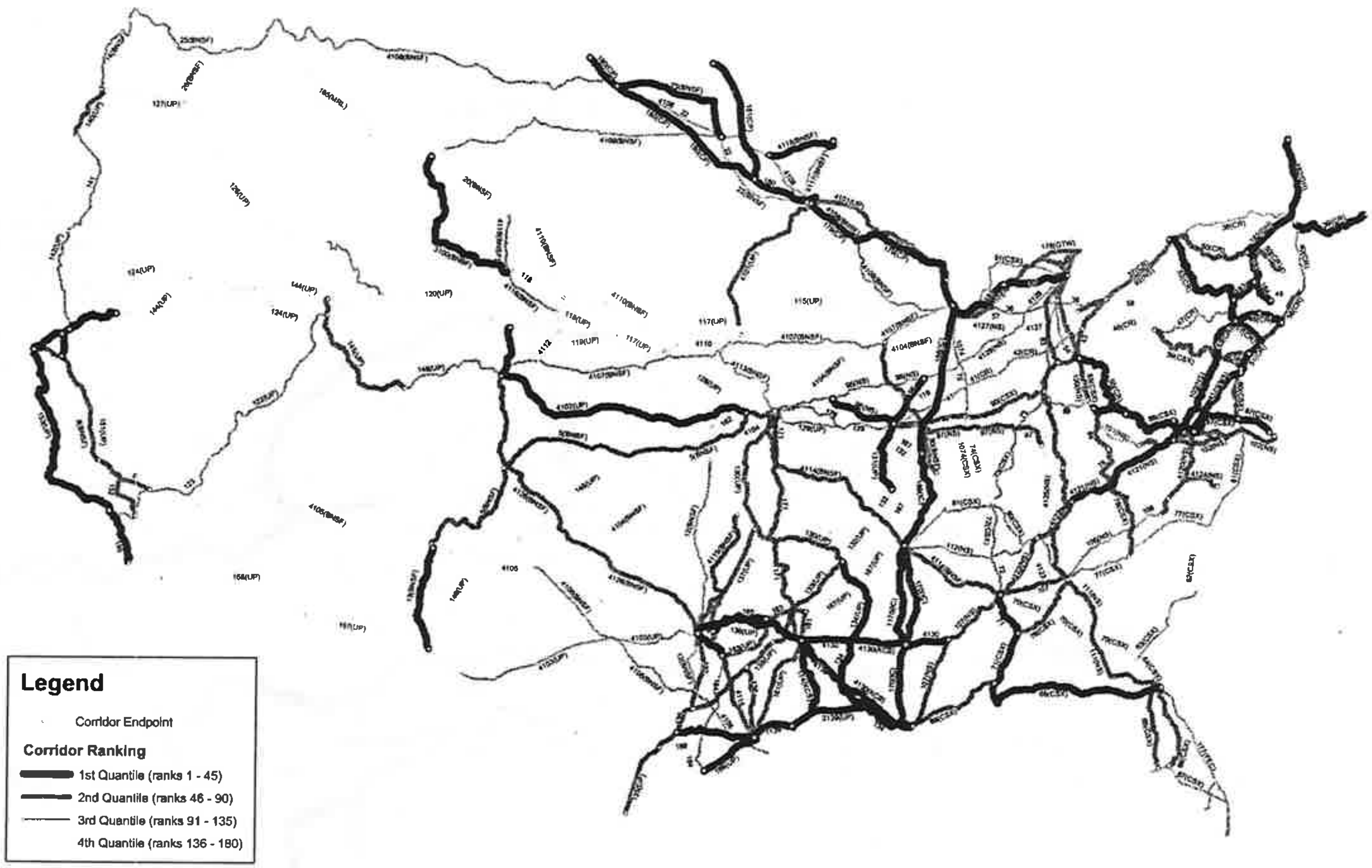


Figure 12. Predicted Corridor Rankings

6. ANALYSIS OF THE PPAS ON THE OVERALL NETWORK

The historical perspective on the pattern of PPAs illustrated both that there might be significant differences among corridors and that certain factors, such as corridor length and volume, might contribute to explaining these differences.

Since only 57,000 miles of the total network were assigned to corridors in this analysis, it was important to consider how the overall PPA risk behaves on the whole network, not just the track that was assigned to corridors.

To do this, a separate analysis of all PPAs on all locations was performed. This analysis involved the development of a regression model, which sought to relate link-specific characteristics to the occurrence of PPAs. By analyzing PPAs on the whole network, not only track assigned to corridors, a more robust model of PPA risk was developed.

Corridors themselves vary with respect to volume, control method, speed, curvature, grade, and other track and operational characteristics, as do segments. In fact, segments are like very small corridors, and the large number of segments available for this analysis (about 8,000) enhances the predictive generalizations both about segments and corridors. The application of the forecasting model reinforces the historically based conclusions about risk. If the forecasting model relating PPAs to location specific variables identifies "corridors" and not "random locations" as the centers of risk, then the determination as to whether some corridors were riskier than others is possible.

The first task in the construction of the forecast was to accurately assign PPAs to specific locations on the GIS network and to characterize the network with respect to the most "important" explanatory variables for PPA occurrence.

6.1 MODEL DEVELOPMENT

A regression analysis is generally used to understand how different factors describing a system relate to one another. Since this analysis focused on the identifying locations where PTC-preventable accident risk was significant enough to warrant implementation, the methodology was designed to identify characteristics of various locations that may to contribute to risk. Quantifying the contribution to risk of factors such as method of operation, speed limits, track curvatures, the number of tracks and characteristics of the volume of passenger and freight traffic on the network was used to develop a tool to distinguish between corridors based upon PTC-preventable accident risk.

Models were estimated using a regression methodology that allows the dependent variable to be the number of PPAs that occurred at a location. The independent variables used to understand the frequency of these accidents were the total trains per year at the location, the curvature, switches, number of tracks, type of control method, and speed at the location. Models were estimated for all four PTC levels. Model results can be used to create an estimate for any location where there is complete data on these independent variables provided the conditions represented by the model remain the same.

One of the most important components of the analysis is the input data. In this analysis, the critical variables, namely, the selection of PPAs, the freight-flow data, and the passenger flow data, were provided by the railroads and representatives of rail labor unions. Network variables that describe track characteristics, control methods and speed, were collected from published railroad descriptions, track charts, schedules, etc. Some PPAs occurred where freight or passenger flow had not been provided by the railroad. However, the railroads did provide that data on accident reports to the FRA at the time that those accidents occurred. In these cases, track density reported by the railroads on the RAIRS report were used in the analysis.

6.2 ESTIMATION OF ACCIDENT CONSEQUENCES

As a best approximation of future risk, historical consequences of accidents can be used to describe the likely consequences of future accidents. To enable a simple comparison among corridors, a single unit with which to express risk was created by quantifying the historical consequences of accidents in dollars, and using that historical experience as a predictor of future accident risk. Dollars are used to express the government's estimate of society's willingness to pay to avoid fatalities, injuries, track and equipment damages and evacuations, and the costs or societal value assigned to emergency response, delays, and other effects of accidents.

6.3 MODEL SPECIFICATION

The PPA accident model was developed using a regression technique known as Poisson regression that describes the relationship between location-specific factors and the occurrence of PPAs. Poisson regression is used to estimate a model in a way that is similar to a linear regression model in cases where the concern of the analysis can be described as an event or collection of events (such as accidents). Most importantly, the analysis applies to events that occur over time.

The events in this analysis are defined as the number of PPAs that have occurred in each location during the eight-year analysis period. It is assumed that these events are Poisson-distributed, not normally distributed, events. This means that tests of normality, as would apply to a *normal* or *Gaussian* distribution, are not applicable to these events. Therefore, the estimation methodology must reflect the underlying assumptions of the *Poisson* distribution.

The modeling objective is to design a function that provides a consistent estimate of the average number of accidents per year. The model is constructed assuming that the average number of occurrences per time period has both a random and a systematic component. Further, we assume that the random component behaves in a manner that is consistent with a Poisson process and that we can describe the systematic component of this process by identifying common factors surrounding the accident occurrences. Since this analysis is focused on identifying locations that have a potentially higher risk experience, this analysis has sought to describe the common geographic factors to all accidents, based upon the best available data describing the locations at which those accidents occurred.

The major feature of this model that is different from any standard linear model is that the dependent variable is a discrete variable (i.e., the accident count per year). The independent variables in this analysis, in a way similar to the linear regression counterpart, can be continuous, discreet, or transformed variables (such as the natural log of a value). The explanatory variables have been selected to allow us to identify how location-specific variables might have contributed to the occurrence rate of PPAs, even though we are aware that some random component of this process still exists.

6.4 REGRESSION TECHNIQUE

In order to make the notation clear, in this section we restrict all analysis (and related data) to a given type of accident (whether PTC-related, grade-crossing, derailment, equipment failure, etc.) and to a specific "segment" in the rail network. Because of its underlying "memoryless" property, the time between accidents is often assumed to be a random variable T years) with probability density function (pdf)

(1) $$f_T(t|\lambda) = \lambda e^{-\lambda t},$$

the familiar "negative exponential density function." The parameter λ, the occurrence "rate" of the accidents, has dimension [#/year].

As a consequence of equation (1), the number of accidents, N, in any time interval τ (years) is a random variable with Poisson probability mass function (pmf)

(2) $$p_N(n|\lambda,\tau) = [(\lambda\tau)^n/n!]e^{-\lambda\tau}$$

The use of equations (1) and (2) in some sense define the "accidentalness" of the phenomena under investigation, since if these distributions were any different, it could be argued that the events they describe are not, in fact, completely random but rather in some way predictable—and therefore potentially preventable—occurrences. In other words, if equations (1) and (2) hold, then intervention might be able to decrease λ, the accident rate, but the times at which subsequent accidents would occur would still be as "unpredictable."

More important:

a) these distributions are completely specified when the value of λ is known (or estimated);

b) the probability that no accident occurs on a link, in time period τ, is -- from equation (2):

$$p_N(0|\lambda,\tau) = e^{-\lambda\tau} \ (\cong 1-\lambda\tau \text{ for } \lambda\tau<<1) ;$$

c) the accident rate λ_c of a corridor made up of many segments can be represented by the sum of the segment rates, and thus the number of corridor accidents in a time interval of length t is Poisson with rate $\lambda_c t$.

Regression assumptions

The problem at hand, then, is to relate the rate λ to causal factors inherent in a segment (traffic density, length, control method, etc.) so that we can "estimate" a value of λ for any link, given its factors. In particular, the assumption is made that λ depends upon a set of r link factors, expressed in terms of k non-negative variables, $x_1, x_2, ..., x_k$ (below we discuss how the k variable values x_i -- traditionally called "independent variables" in the language of regression analysis -- relate to a link's r factors).

Unless some previous modeling has suggested otherwise, there are many ways to present a formal relation between λ and the x_i. For example, a linear regression approach might assume that

(3) $$\lambda = \alpha_0 + \alpha_1 x_1 + \alpha_2 x_2 + ... + \alpha_k x_k = \alpha_0 + \Sigma\alpha_i x_i$$

where the sum is over i=1, 2, ..., k.

Or, a *non*-linear regression with interaction terms could also be posited, so that

(4) $$\lambda = \alpha_0 + \Sigma\alpha_i x_i + \Sigma\Sigma\alpha_{ij} x_i x_j.$$

In this case the coefficients a_0, α_i and α_{ij} must be estimated (k^2+k+1 terms in all), which -- even for reasonably small k -- often produces problems in data availability.

In any case, once a functional form (i.e., "model") for the dependence of λ on the variables is parametrically specified, (as, for example, in equation (3) or (4)) we can write:

(5) $$\lambda = \lambda(x|a)$$

where (using **boldface** to indicate a vector)

(6) $$\mathbf{x} = (x_1, x_2, ..., x_k)$$

(7) $\mathbf{a} = (a_1, a_2, ..., a_m)$; m = number of parameters in the model.

Note that $m=k+1$ for the model of equation (3), and $m=k^2+k+1$ in the model of equation (4).

Then, estimates of $\mathbf{\hat{a}}_i$ (the component of the parameter m-vector $\hat{a}$) can be made.

In particular, given a data set for W segments containing, for each link w (w=1,2, ... W):

- values of $\mathbf{x}_w$, the variable vector for the w^{th} link
- the number of accidents n_w on link w in a period of length τ_w;

standard maximum likelihood (or Bayesian) methods can be used to find $\hat{a}$ and the associated confidence intervals. Using these, an estimate of a link's λ can then be made, given its x_w values. Note that it is not necessary, in this dataset, to:

a) restrict the accident data on a link to be either 0 or 1;

b) have the same exposure time t on each link.

For example, to obtain the vector of maximum likelihood estimates $\mathbf{\hat{a}}$, we find (using standard statistical packages) the vector **a** that maximizes the likelihood function

(8) $$f(a) = \Pi_{w=1,W} \{ p_N(n_w \mid \lambda(x_w|a), \tau_j)) \}$$

The associated confidence intervals, etc. should also be available from the package.

Logarithmic transformation of λ

One difficulty with using equations (3) or (4) is the fact that the resulting estimation might produce values such that, for some segments, the estimate of λ becomes negative -- clearly an undesirable effect. For this reason, an alternative to equation (3) is adopted: the *natural logarithm* of λ is assumed to be a linear additive function of the factors. Thus

(9) $$ln(\lambda) = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_k x_k = \beta_0 + \Sigma\beta_i x_i$$

or, equivalently

(10) $$\lambda(x|a) = \exp\{\beta_0 + \Sigma\beta_i x_i\} = \exp(\beta_0)\exp(\beta_1 x_1)\exp(\beta_2 x_2) \ldots \exp(\beta_k x_k)$$

$$= a_{k+1}\, a_1^{x1}\, a_2^{x2}\, a_3^{x3} \ldots a_k^{xk}$$

where

(11) $$a_i = \exp(\beta_i) \quad i=1, 2, \ldots, k; \qquad a_{k+1} = \exp(\beta_0).$$

6.5 MODEL SELECTION

The process of model selection involves model estimation, validation, and re-estimation. In the construction of the final model, eight regressions were estimated to reflect the different datasets that result from the framework implied by the PTC preventable criteria. Accidents have been rated as to their preventability by each of the four levels of PTC, and also the degree of their preventability (either complete or partial). As a result, we are confronted with eight possible datasets, four levels of PTC combined with the two degrees of preventability for each. To reflect these differences a separate regression analysis was constructed for each dataset. Regressions were estimated for all PTC preventable accidents, excluding grade crossing accidents, where the dependent variable expressed the number of PTC preventable accidents weighted by exposure:

N / (length (miles)) for each link;

The exponential equation contains any of the variables that were selected by the forward stepwise regression. The criteria for entry was significance at the 0.05 level. The procedure continues to include variables, one at a time, until no other variables meet the criteria. Using only derailments and collisions either with trains or roadway worker equipment, models were estimated for all PTC accidents, using the control method as a variable in the regression. The performance of the model was evaluated strictly on its ability to predict the correct number of accidents in the dataset upon which it was estimated. Inclusion of additional explanatory variables continued until the final model produced the best performance. The independent variables reflect the frequency of accidents on any ROS segment, and the independent variables were allowed to include any of the following: the natural log of the total number of trains on the link (the sum of passenger and freight trains), the square of the natural log of the number of trains on the link, a variable (equal to 0 or 1) for whether the total number of parallel tracks was one or greater than one (multitrak), a variable equal to the total number of switches on the link divided by the length of the ROS segment (switper), a variable indicating what the highest maximum speed for the location was, a variable that indicated what percent of the length of the link was under control method; Auto Train Stop, Cab Signaling, CTC, or Dark Territory, and a variable indicating whether there were any curvatures recorded for the link.

One method of calibrating the PPA specific model was to first estimate the model on all geographically located accidents. This was done looking specifically at collision and derailment accidents independently. Models were estimated using these two datasets to understand which variables were likely to have a significant explanatory value in predicting the accident rate, and to understand the direction of their effects (either positive or negative).

Table 11 shows the results of these two regressions on 955 collisions and 6,742 derailments respectively. The Chi-Square statistic of significance for each variable is shown in this table, along with the significance value and the odds ratio.

Table 11. Results of Logistic Regression Analysis Using All Geolocated Collisions and Derailments 1988-1997

ANALYSIS OF MAXIMUM LIKELIHOOD ESTIMATE 955 COLLISIONS

VARIABLE	PARAMETER ESTIMATE	STANDARD ERROR	CHI-SQUARE	PR>CHISQ
INTERCEPT	-13.6671	0.1743	6150.0426	<.0001
LOG2TURNS	0.0409	0.00255	258.2076	<.0001
MULTTRAK	0.8178	0.0797	105.1924	<.0001
PTRNRAT	0.7978	0.1350	34.9381	<.0001
SWITPER	0.0457	0.00618	54.8650	<.0001
ANYCURVE	-0.3335	0.0687	23.5562	<.0001

ANALYSIS OF MAXIMUM LIKELIHOOD ESTIMATE 6742 DERAILMENTS

VARIABLE	PARAMETER ESTIMATE	STANDARD ERROR	CHI-SQUARE	PR>CHISQ
INTERCEPT	-12.9217	0.5531	545.8899	<.0001
LOGTRNS	0.4790	0.1372	12.1934	0.0005
LOG2TRNS	-0.00180	0.00841	0.0458	0.8306
MULTTRAK	0.5098	0.0303	282.9690	<.0001
PTRNRAT	0.2221	0.0639	12.0924	0.0005
SWITPER	0.0559	0.00324	297.5831	<.0001

VARIABLE	PARAMETER ESTIMATE	STANDARD ERROR	CHI-SQUARE	PR>CHISQ
CRVPMILE	-0.0162	0.00567	8.1236	0.0044
ANYCURVE	0.1753	0.0258	46.0603	<.0001
LWA CURV	0.00309	0.000308	100.7694	<.0001
AUTOPCT	-0.6565	0.0722	82.6099	<.0001
SGNLPCT	-0.1812	0.0378	22.9857	<.0001

Using these models it is possible to construct forecasts of the predicted number of derailments and collisions for each corridor described in the historical analysis. Successful models should be able to predict the actual number of accidents that happened during the time period. Figures 14 and 15 illustrate the relationship between the predicted number of derailments and collisions and the actual number of each on corridors during the 1988-1995 time period.

The trend lines in each graph show the general tendency of the models. Both models are relatively successful at predicting the number of accidents when the total expected numbers are in the lower range; underprediction is a problem in the derailment model in higher frequencies, while overprediction is a problem for the collision model in the same ranges. These results are for use as a comparative baseline for the PPA models only, and are not employed for any other purpose in this study. However, they are helpful in identifying the likely variables that will be of predictive value in the PPA models.

7. RESULTS

The analysis sought to evaluate how all four different PTC levels might have affected risk on all of the predefined corridors. Since some accidents were thought to be "completely" preventable, and others had qualities that suggested that there was uncertainty as to their complete preventability, it was desirable to reflect this in the analysis as well. Of the available options for comparing these different accident categories, the most straightforward is to estimate the same model on all datasets. Given four PTC levels and two types (preventable and "maybe preventable") as noted previously, eight regressions were required.

In each case, the model makes the best possible association of the independent variables with the number of accidents that have occurred on each segment for which those variables have been described. In this analysis there are 8,001 geographical segments that have been characterized with respect to the important explanatory variables (train counts, speed, etc.). The model provides an estimate of the number of accidents that may happen on each segment based upon the accident experience for the entire network, and the similarities between the locations where accidents have occurred.

These results must be interpreted as the collection of the most influential factors in the determination of the occurrence of these PTC preventable accidents of those variables that were included in the model.

Table 12 (Regression Results) shows the resulting parameters for each regression based upon these datasets presented. In Column 1, the name of the variable appears. Column 2 refers to All PTC preventable accidents (including maybes) at level 4. This is the largest dataset (678). The regression parameters for variables that were significant in the stepwise regression can be read looking down that column. Likewise each successive dataset appears in the following columns.

Table 12. Regression Results All PTC Levels (1-4) Yes and Maybe

PARAMETER	PREVENTABLE & MAYBE PREVENTABLE				PREVENTABLE ONLY			
	PTC LEVEL 4	PTC LEVEL 3	PTC LEVEL 2	PTC LEVEL 1	PTC LEVEL 4	PTC LEVEL 3	PTC LEVEL 2	PTC LEVEL 1
N	703	489	439	357	510	462	420	284
INTERCEPT	10.1235	-14.4750	-14.8204	-14.8760	-14.3738	-14.5593	-14.9573	-15.1584
LOG TRAINS	-0.7751	NS	NS	NS	NS	NS	NS	NS
LOG TRAINS SQUARED	0.0835	0.0440	0.0450	0.0435	0.0434	0.0453	0.0475	0.0458
MULTITRAK	NS	NS	NS	NS	NS	NS	NS	NS
PTNRAT	NS	NS	0.4131	NS	NS	NS	NS	NS
SWITCHES PER MILE	NS	NS	NS	NS	NS	NS	NS	NS
CURVES PER MILE	0.0457	0.0484	0.0482	0.0497	0.0483	0.0482	0.0483	0.0390
ANYCURVE	NS	NS	NS	NS	NS	NS	NS	NS
LWAVCURVE	0.00316	0.00387	0.00457	0.00462	0.00386	0.00408	0.00458	0.00440
AUTOPCT	-0.4100	NS	NS	NS	NS	NS	NS	NS
SIGPCT	-0.3703	NS	NS	NS	NS	NS	NS	NS
LWASPEED	-0.0220	-0.0220	-0.0193	-0.01932	-0.0222	-0.0239	-0.0208	-0.0220

7.1 MODEL VALIDATION

Several methods of evaluating the performance of all of the regression models have been employed in this analysis. The primary method is by application of the Chi-square statistic for the estimate of the significance of the models. These statistics are all significant at the p=.00001 level, and are the criteria by which the decision on the validity of the regression model is judged. In addition, since the regression creates a predicted number of accidents for the estimation period, another measure of its performance is its ability to recreate the number of accidents it used as input. Table 13 lists the Chi-square statistics for each regression (including the relevant number of degrees of freedom), the number of actual (input) PPAs used for the model, and the predicted based upon the application of the model to the identical input data. In all cases the model produced the same number of input accidents (within about 3.5 percent).

Table 13. Actual and Predicted PPAs for Each Model

Model Chi-Square Statistic	Actual PPAs	Predicted PPAs based On Model	Percent Difference
473.877 w 7DF	766	744	2.8%
528.991 w/ 5 DF	539	521	3.34%
550.387 w/ 5 DF	485	468	3.5%
394.083 w/ 5 DF	389	380	2.31%
541.965 w/ 5 DF	557	542	2.7%
538.306 w/ 5 DF	506	492	2.77%
525.893 w/ 5 DF	462	446	3.46%
310.591 w/ 5 DF	310	302	2.58%
	Average		2.9%

Correlation Tables

Comparing the predicted number of accidents to the actual number of PTC-preventable accidents during the time period of estimation, and also comparing the predicted number of PTC-preventable accidents to those that occurred in the years following the estimation period provide a method of validating (a) the accuracy of the model and (b) its ability to provide a reliable forecast. Table 14 shows the correlation of the actual number of accidents used in the estimation period with the predicted number of accidents for each ROS segment in the analysis. In addition, a correlation between the actual number of PTC preventable accidents during the 1996-1997 period and the predicted number are also shown. The table shows the predicted numbers based upon each of the 8 regression models described above, and compares the predicted to actual numbers for each of those regressions (e.g., fewer accidents were included in PTC Level 3 than in PTC Level 4, therefore the number of accidents in the correlation analyses are fewer).

Table 14. Correlation of Predicted and Actual PPAs 1988-1995 and 1996-97

	PPAs 96-97	PTC4 ALL	PTC3 ALL	PTC2 ALL	PTC1 ALL	PTC4 YES only	PTC3 YES only	PTC2 YES only	PTC1 YES only
M^	0.174	0.4454	0.44	0.445	0.417	0.4408	0.43624	0.4402	0.4205
PPA 96-97		0.0411	0.02728	0.02813	0.0291	0.0411	0.0273	0.0281	0.0291

The best linear correlation between the actual number of PPAs on the ROS segments and the predicted number is about 0.45. Correlations with the model based upon the 1988-1995 data and the actual accidents in 1996 and 1997 were highly uncorrelated.

7.2 CORRELATION OF PREDICTED AND ACTUAL PPAS 1988-1995 ON CORRIDORS

The correlation statistics in Table 14 describe the performance of the regression model in creating a forecast of the number of accidents per ROS that occurred historically. The model is estimated at the ROS level and therefore the initial test of its reliability is also at that level. However, the regression model is applied to the aggregate ROS data at the corridor level, therefore an additional statistic, one which can describe the ability of the model to predict the number of PPA accidents that will happen at the corridor level, is more useful. If the model is successful the forecasts of the number of accidents on corridors (based upon the aggregated forecasts from their ROS segments) should correlate with the historical frequency of accidents on the corridor.

The Pearson Product Moment is the most commonly used statistic for describing the strength of the linear relationship between two variables. The relationship between the actual and predicted PPAs by corridor (illustrated in Figure 13) has a Person correlation coefficient of 0.695 at 0.0001 significance. This indicates the actual number of PPAs is predicted by the model at about 0.7 multiplied by the estimated number from the model.

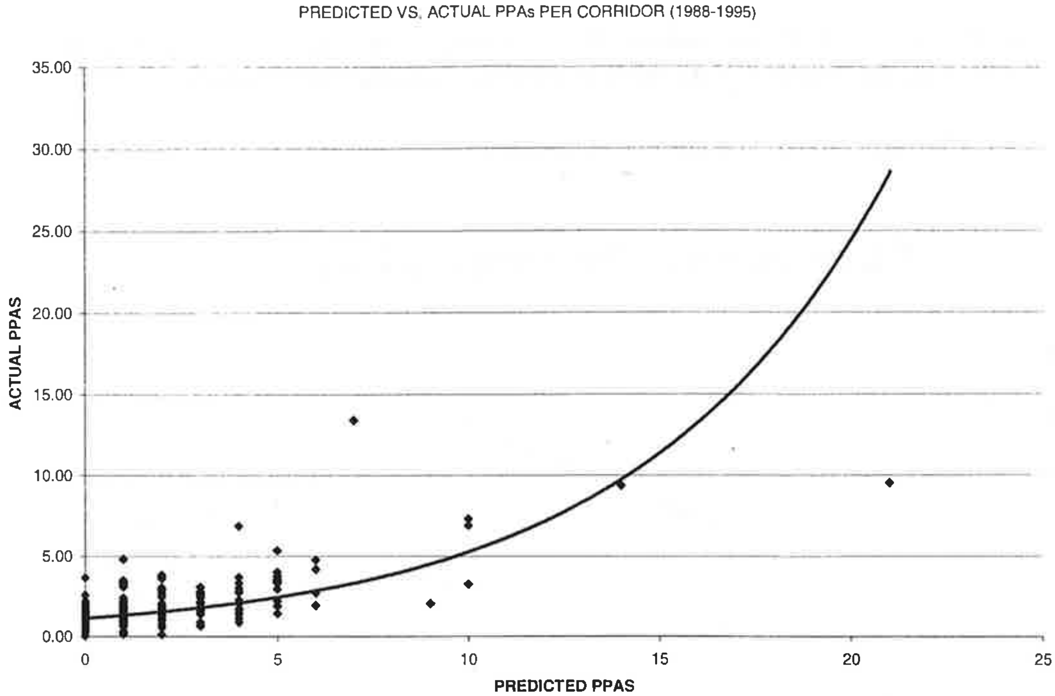


Figure 13. Actual and Predicted PPAs by Corridor

The square of the Pearson Correlation Coefficient is coefficient of determination, which is the percent reduction obtained in the total squared error in a regression model by using the regression equation (instead of the average value of all of the data) to forecast the historical data. Squaring the Pearson correlation coefficient provides an estimate of the coefficient of determination for the model (although there is no constant in the simple model presented in this illustration.

Since the relationship between predicted an actual is best approximated as an exponential figure (see the trend line in Figure 13), and the correlation only measures linearity, it obscures the true fit of the model to the given data. Taken in concert with the other two measures of model performance, however, this statistic affirms that the model is relatively successful in predicting the linear portion of accident frequencies on corridors.

7.3 MODEL VALIDATION USING THE NATURAL HISTOGRAM

This section describes a graphical technique, called the natural histogram, for evaluating the performance of the Poisson regression model. This technique is a special case of monotone regression. Let the number of accidents (of a given type) on a link be A_i and the length of the link be X_i. Then the observed average number of accidents per mile on a collection of segments is $\Sigma A_i/\Sigma X_i$ where both summations are over segments in the given collection.

The natural histogram facilitates a comparison of observed accidents per mile vs. predicted accidents per mile. It identifies collections of segments as those which belong to intervals in predicted numbers of accidents and identifies these intervals to be such that:

1. The average number of accidents per mile on the segments in any interval is less than the corresponding number on any interval with greater predicted number of accidents.

2. No interval can be disaggregated without losing property #1.

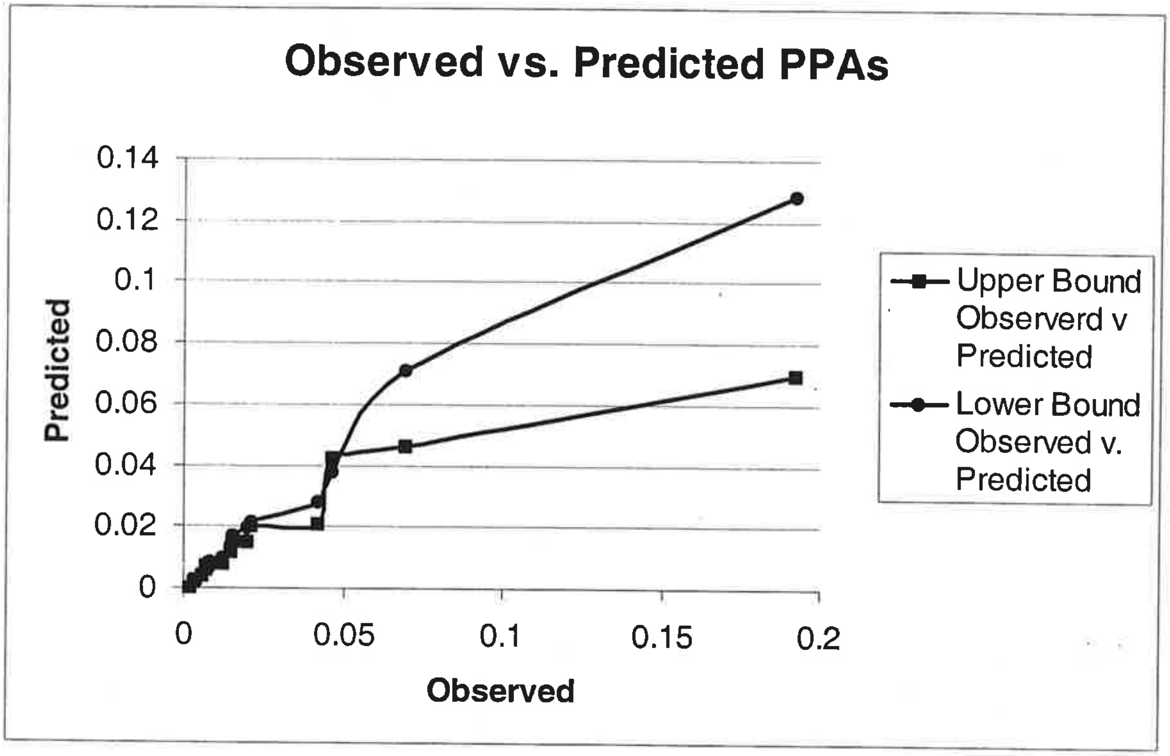


Figure 14. Natural Histogram Illustrating Observed Vs. Predicted Accidents 1988-1995

Figure 15 exhibits a natural histogram representation of actual average numbers of accidents per mile versus predicted numbers. The actual averages are the observed number of accidents in an interval divided by the total length of track in the interval. The interval in each case contains just those segments, which have predicted numbers of accidents per mile in a given range. For each observed value there are two predicted values, the "high" value and the "low" value (i.e., the predicted value at either end of the interval). Alternatively, one can take there to be a high and low observed value for each predicted value. If the observed value were to lie between the upper and lower predicted values in each case an excellent fit would be indicated. If the predicted high and low values tend to differ from each other by about as much as they differ from the observed (as appears to be the case here), then we might say there is no obviously significant difference.

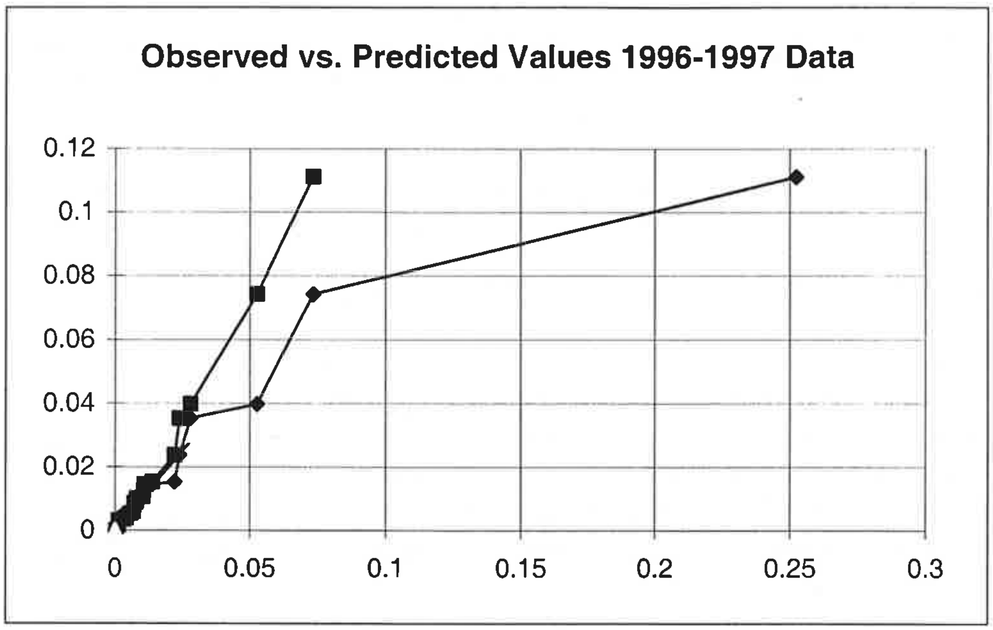


Figure 15. Natural Histogram for 1996-1997 Data and Predicted Accidents

Figure 14. Natural Histogram Illustrating Observed Vs. Predicted Accidents 1988-1995 shows satisfactory agreement between observed and predicted. When the predicted number of accidents per mile ranges from about .003 to about .02 it appears that actual and predicted agree as well as could be expected given the statistical character of the data. When the predicted number of accidents is greater than .02 it appears that the observed is greater than the predicted but the difference is not statistically significant. This can be demonstrated using a Chi-square test. The predicted and observed numbers of accidents on segments with predicted accidents rates below and above .02 per mile are shown in the following table.

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An alternative method of considering the corridor rankings presented in Table 18 is to first classify corridors according to their distinguishing characteristics, for instance, total train volume and miles, and then sort those corridors by category to compare similar corridors.

Based upon a comparison of the predicted dollar benefits per train-mile and the total corridor train-miles (see Figure 17), the choice of corridors for further investigation for PTC implementation may be recommended. Clearly, investment in PTC on very low volume corridors may have a very high return per train-mile, but the cost per train-mile is likely to be prohibitively high. This means that implementation of PTC on these corridors would be an unlikely initial choice for most railroads. Instead, the likely choice for implementation of PTC is a rail corridor (or corridors) that both enjoy high traffic volume and exhibit high risk, i.e., corridors that have about average train-miles and above average expected dollar benefits per train-mile. These corridors are found in the top 50 (in Figure 17) with above average values for total corridor train-miles. Corridors # 24, 153, 4108, 5,59, 106 and 48 fall into both the high rank and high train-mile categories.

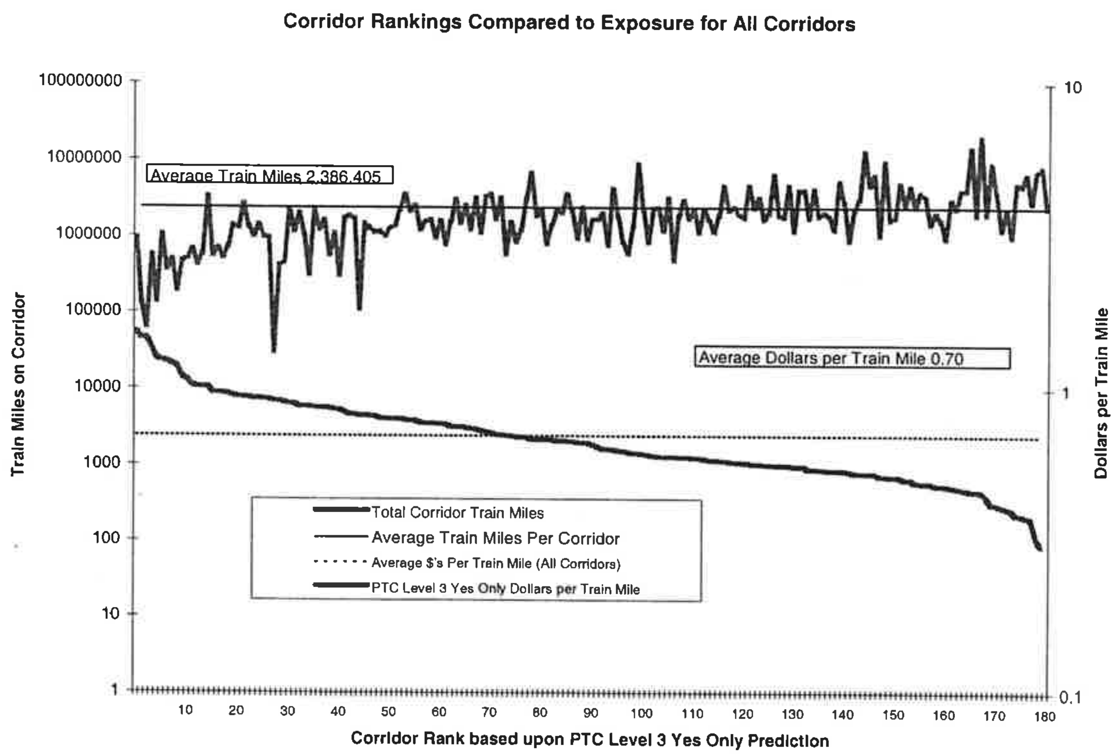

Figure 17. Comparison Corridor Train-Miles and $'s Per Train-Mile Rank

8. CONCLUSIONS

The point of this analysis was first to determine whether there was a methodology that could distinguish among geographic locations based upon risk. The objectives were to develop a comprehensive model of the rail network, including accidents, rail and operational features, and population characteristics. Using that platform it was the further mission of this analysis to use it to identify potentially fruitful locations for PTC system deployment.

The model was developed to enhance the policy maker's ability to compare and contrast the risks posed by accidents (both those that are PTC preventable and others) and to create an estimate of the potential benefit of implementation of various policies. Since the model has no economic or logistical component, it is not a complete planning tool - i.e., it can only act as a pointer to locations that may potentially benefit. Further analyses will be required to develop a true estimate of the net benefits of PTC implementation.

The analysis shows that we are able to make geographically based risk distinctions, and it allows us to compare extremely different localities because of our application of a uniform exposure measure – train-miles. Further refinements of this exposure measure (such as night or daytime train-miles, grade crossings per mile, etc.) will enhance our understanding of risk at each location.

In addition, the analysis pointed out that of the corridors studied the highest predictor of risk was the volume of traffic (as expressed by the log squared of the total trains per year). The train control method was less important in prediction of the accidents of interest in this dataset than other factors.

It is interesting to note that since we have a snapshot it is difficult to understand some of the parameters. It is counterintuitive to think that accidents decrease with speed limit increases as suggested by the parameter on length weight average speed. However, we might reverse the description of this variable and say that we have imposed lower speed limits where accident risk is higher; if we had the luxury of looking at a time-series model we would notice that speed limit changes have taken place over time where risk factors were present. This highlights one of the limitations of the model in that it is not a time-series model and cannot account for trends.

Whatever its limitations, the model and its results should be taken as an input into the complex decision making process required to evaluate the myriad of PTC technologies and potential strategies for implementation. It is possible to adapt the tool to the individual needs of analysts and decision makers as they ask deeper and more specific questions regarding alternative technological innovations.

Further research might help draw out the analytical distinctions and inform policy discussions regarding differences between freight and passenger trains in both the historical accident data and the estimates of PTC preventable accidents. This research would clarify at least the following three distinguishing characteristics between freight and passenger train circumstances in the context of PPAs: 1) passenger and freight trains operate differently with respect to speeds, programmed stops, and service braking characteristics; 2) passenger trains are more likely to be concentrated on highly maintained and multiple track, and on lines with cab signals; and 3) passenger train accident consequences are sometimes greater because of injuries and casualties to passengers (in addition to train crews and/or bystanders). Implications of these differences could be analyzed in the historical information and reflected in estimates of future PTC economics.

Appendix A - Surface Transportation Board's (Formerly Interstate Commerce Commission)/FRA's Freight Commodity Waybill Sample

The Surface Transportation Board's (STB) (formerly the Interstate Commerce Commission) waybill sample is the only statistically valid data base for industry-wide rail traffic patterns and flows making it a highly sought and unique source of data for preparing rail analyses. The waybill sample identifies originating and terminating freight stations, the names of all railroads participating in the movement, the point of all railroad interchanges, the number of cars, the car types, the movement weight in tons, the commodity and the freight revenue. There are many users of these data; among them is the FRA, which publishes an annual report, Territorial Distribution (TD1), which aggregates waybill sample data to show commodity distribution in the United States.

The names of the shipper and consignee are not included in the data and are not included in the overall analyses for this study. However, other data in the sample such as the origin and destination Freight Station Accounting Code (FSAC) may permit the identification of a shipper and consignee. Thus, the data in this raw form can disclose each railroad's significant customers and also the rate (including confidential contract rates) at which it transports the traffic.

Since all hazardous material 7-digit Standard Transportation Commodity Code (STCC) are "tagged" with the two digit "49" code, it is possible to identify all hazardous material waybill shipments. Because the waybill sample is considered to be a representative sample of all rail shipments, it is permissible to "project" the sample data to obtain an estimate of all hazardous material shipment terminations and the railroads handling these shipments in the United States.

Using this database, an estimate of volume provided by the sample of waybills was attached to the database. The FRA 2 million link direction was used to correctly assign the directional flows (west to east or east to west). The result of this process is that each link has an estimate of total freight volume and cars, and a measure of the total volume that was hazardous materials, by certain classes. The direction of the flow was also calculated.

5.2.1 Waybill Sampling Rate and Inflation Factors

The Code of Federal Regulation 49 C.F.R. § 1244 requires that railroads submit waybill sample information to the STB if, in any of the 3 proceeding years, they terminated on their lines at least:

4,500 revenue carloads, or

5 percent of the revenue carloads in any one state.

These railroads may file waybill sample information by using either: (1) authenticated copies of a sample of audited revenue waybills (the manual system), or (2) a computer tape containing specified information from a sample of waybills (the computerized system) Code 49 C.F.R. § 1244.2 (f) states: "In order to determine the number of carloads terminated in each state, railroads not otherwise submitting waybill information must report annually the number of carloads terminated by state for the last calendar year. These reports shall be submitted by March 1 of the year following the report year." (This requirement suggests that all railroads report the number of carloads terminating by state). Prior to 1990 many railroad still reported data in hardcopy form. However, currently nearly all reporting railroads submit their data in an electronic form (as illustrated in Table 5). Since sampling rates vary depending upon the number of loads reported per waybill, different inflation factors are required to convert waybill sample data into estimated total flows for each carload per waybill substrata. These factors are also reported in Table 6. Inflated data are provided with the processed waybill flows for each year, and are the data used for the flows on the Volpe 1:100k database.

Table 18. Waybill Sampling and Inflation Rates

	CARLOADS PER WAYBILL	Sampling Rate
MRI*	1 - 2	1 / 40
MRI	3-15	1 / 12
MRI	16 - 60	1 / 4
MRI	61 - 100	1 / 3
MRI	>100	1 / 2
Hardcopy	1 - 5	1 / 100
Hardcopy	6 - 25	1 / 10
Hardcopy	>25	1 / 5

*Total Hardcopy waybills = 4282 Total MRI waybills = 494054, 99.14% of the sample is submitted in Machine Readable Input (MRI)

Appendix B – Economic Benefits Assignment Method

Economics of Positive Train Control

No cogent public policy regarding Positive Train Control can be formulated until we know what the tradeoffs are. What benefits will PTC gain for us, and what will these benefits cost? The Implementation Task Force needed to review studies, such as the Corridor Risk Assessment Model, regarding where PTC may be needed. The Implementation Task Force has also heard competing theories regarding what business benefits may be derived from PTC. To resolve these issues, the Implementation Task Force assembled an Economics Team, and empowered them to study these issues and make consensus recommendations.

The Economics Team included members of management, labor, commuter railroads, and FRA. It was fortunate that one member of management, one representative of labor, and one representative of FRA on the Economics Team had been members of the Accident Review Team, which earlier had analyzed accident reports to determine which accidents were PTC-preventable.

PTC Benefits: Accidents Costs Avoided

The Team's first task was to assign costs to the accidents designated as PTC-preventable by the Accident Review Team. These costs were to be used as inputs for the Corridor Risk Assessment Model. The Corridor Risk Assessment Model measures the likelihood of certain occurrences, using a probabilistic model. It then assigns costs to these consequences in order to distinguish and prioritize among corridors. It may also be possible to estimate the expected consequences of these occurrences in a model using consequences as a dependent variable. In order to use either model we need to know the unit costs of various occurrences, such as fatalities, injuries, property damage, and evacuations, the avoidance of which provides the direct safety benefits of PTC. It is desirable to estimate other costs, but the FRA accident report does not contain data on them. An example of such a cost is environmental clean up. The Economics Team tried to limit the data on which its estimates relied to data on the Accident Reports, or otherwise in the CRAM database. The Economics Team was able to fashion several such estimates, and to provide some thought on others.

Fatalities

The first element on which the Economics Team reached consensus was on the willingness-to-pay to avoid a fatality, which the Team estimated at $2,700,000 per fatality. This number represents what society has been shown to be willing to pay for safety devices which will in the future avoid a fatality, and is a standard number used by all DOT agencies.

Injuries

The Economics Team also agreed to accept a value of $100,000 per employee injury avoided due to train accidents. The team considered the Accidental Injury Severity (AIS) scale, which DOT uses for comparisons of injury costs. This would imply an average injury on the low side of the interval between moderate and severe injuries, and uses a round number. There isn't much precision in this estimate.

Data from four commuter railroads indicates that their average payout per injury claim was about $35,000. This represents settlements and judgments. While the judgments probably reflect loss per claimant where the railroad was found liable for the injury to the claimant, there may have been injuries where the claimant was not successful. The settlements reflect the expected value of suits had they gone to trial, and reflect a reduction from the actual claim, which is the risk that a claimant might lose were the case to go to judgment. From an economic standpoint that is liable for an injury is not relevant to the question of the societal loss caused by an injury. Further, the loss to society also includes the costs of administering and pursuing claims. Thus the fees paid to claimants' attorneys, and the costs of defending and administering claims are also societal costs of an accident. If the average claimant received $35,000 it is not unreasonable to assume that the societal cost of an average passenger injury in real economic terms was roughly 50% greater, or about $55,000, a figure accepted as a consensus estimate by the Economics Team.

Equipment Damage

The Economics Team attempted to distinguish between the costs of equipment damage reported on the accident report and the actual loss to society of that damage. The Federal Railroad Safety Regulations require that the railroads report the depreciated book value of the equipment damaged if the equipment is destroyed. Otherwise, the railroads must report the estimated costs of repairs. The depreciated book value can be a poor estimate of the societal value of a car. A much better estimate is provided by concepts such as Economic Limit of Repair (ELOR).

Several major freight railroads utilize a concept and methodology called Economic Limit of Repair (ELOR) or Maximum Allowable Expenditure for Repair (MAER) to determine the value of existing equipment, particularly equipment being considered for repair or upgrade. Where estimated repair costs exceed the ELOR or MAER, the equipment is typically scrapped or placed in a heavy bad order status rather than repaired. The ELOR methodology typically considers contribution to revenue, replacement cost, salvage value, service life, repair life, and repair cost.

FRA incident reporting requirements dictate that equipment damage costs be the repair estimates for damaged cars to be repaired and depreciated book value for destroyed cars. However, the PTC Economic Team agrees that the ELOR or MAER values provide a more appropriate and accurate estimate of the pre-accident economic value of destroyed equipment than does the depreciated book value. Some railroads cooperated with the Economics Team to develop an analysis comparing the actual repair costs to the FRA reported values for repaired cars and MAER values to FRA reported values for destroyed cars. The study showed that the MAER values were very close, on the average, to the equipment damage numbers reported to FRA. There were some numbers much higher or lower, but the high and low values appear to offset each other, so the Team agreed to accept the value reported to FRA as the best estimate of actual damage.

The Economics Team also could not discern a difference between the reported costs of damage to passenger equipment and the societal cost of the damage. The Team agreed that the best estimator of passenger equipment damage is the reported damage. Passenger equipment is often insured for replacement value, so sometimes damaged equipment is over reported as the cost of replacement equipment. Other times the equipment is reported as the depreciated value of the equipment. There just does not seem to be a pattern that would enable us to use a scaling factor.

Track and Right-of Way Damage

It appears that actual damage reported for track and right-of-way damage is fairly accurate, and reflects societal costs. It may be underreported in some cases, but in other cases it may be over reported as older track and right-of-way may be repaired to better than pre-accident condition. This appears to the Economics Team to balance out over time, and not to be correlated with any reported characteristics. For purposes of this study the Economics Team agrees to use the reported damage to track and wayside.

Damage Off the Right-of-Way

Some damage may occur to property not on the right-of-way, for example when an over speed train derails, damaging a building owned by someone other than the railroad. The Economics Team estimated this damage at $2,000 per PTC-preventable accident.[13] Such damage is rare, and cannot easily be attributed to an accident based on any characteristics reported on the accident report form.

Hazardous Materials Cleanup

If an accident involves a release of hazardous materials, there may be a cost to clean up the hazardous material and remediate (restore) the environment. Based on data from actual settlements and judgments the Economics Team estimated the cost of cleanup and remediation at $250,000 per hazardous material car releasing. The Team considered using a single cost per incident in which hazardous material was released, but thought that it would be at least as good to base the estimated cost on cars releasing to provide some measure of the severity of the accident. This measure is still far from perfect, as some accidents involving single car releases may have resulted in far more costly clean-ups than some multi-car releases, yet it is the best measure the Team could agree upon.

Evacuations

Accidents may lead to evacuations, either because of real or perceived threats to safety from hazardous materials. The Team estimated the societal cost of an evacuation from data on 77 evacuations on which we had data on the duration of an evacuation. These accidents were not necessarily PTC preventable (most were not) and occurred between 1993 and 1997. We estimated the value of time at $11.70 per hour, plus 30%, or $15.21 per hour. We added 30% to reflect the involuntary nature of the costs imposed. Unfortunately, one accident, at Weyauwega, Wisconsin, on March 4, 1996, dominated the costs. The Weyauwega evacuation lasted 426 hours, while the next longest lasted 43 hours. The average cost per evacuation was $986 with the Weyauwega evacuation, and $267 without. The Weyauwega evacuation was clearly an outlier,

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[13] Yard and highway-rail grade crossing accidents are excluded from any definition of PTC preventable accident considered here.

but nevertheless relevant, so the Economics Team compromised on an estimate of $500 per evacuation.

Loss of Lading

If there is an accident involving a loaded freight car, there may be a loss to society as a result of loss or damage to lading. In this case railroad payments to shippers are probably very close to the societal cost of lading loss and damage, which based on AAR data is roughly $6,500 per loaded freight car derailed, a figure the Team agreed upon.

Wreck Clearing

If locomotives or cars are derailed or destroyed, the railroad would need to remove them from the right of way. This cost includes the cost of mobilizing a crane or rerailing equipment to the accident site and the cost of employing that equipment. The Team estimated that the cost of mobilizing equipment to an accident site is $2,500 per incident where cars or locomotives are derailed. Once the equipment is there the Team estimated that it would cost $750 to rerail, wreck or transport a freight locomotive that had derailed, and $300 to rerail, wreck or transport a derailed freight car.

Rerailing passenger equipment can be far more costly. The equipment is more expensive, and may be less robust than freight equipment. It needs to be handled with more care. The sites of passenger accidents are more likely to be in urban areas where the right of way is constrained, as in tunnels and sunken routes under streets. Further, the NTSB is far more likely to investigate a passenger train accident, so there may be significant costs while the rerailing/wrecking equipment sits near the accident site, awaiting NTSB's permission to clear the accident. Four commuter railroads' data suggests that the cost per incident of clearing equipment is roughly $75,000 per accident in which passenger cars or locomotives are derailed. The Team agrees with this estimate.

Delays

If a train is derailed it will block the track it is on, and may block adjacent tracks. The Team estimated that the average blockage would last two hours, so if the average affected freight train arrived randomly, the average train delay would be one hour, for freight trains, and fifteen minutes for passenger trains, which are likely to be switched around a delay, and would affect the trains that would pass over an average segment of rail in two hours. The Team estimated the average cost per hour of freight train delay at $250 per hour. Thus the estimated cost of a delay would be freight trains per day divided by twelve (the expected number of trains in two hours), times one (the average expected delay) times the cost per hour of a delay ($250).

The Team estimated the cost of passenger train delays, based on 285 passengers per train (a national average), an average duration of blockage of 2 hours (which implies passenger trains per day/12 are affected), an average per train delay of 15 minutes, and an average value of passenger time of $25 per hour. This relatively high per hour value of time is related to the income of train passengers. Many commuter lines have average passenger household incomes in excess of $75,000 per year. This works out to $148.44 times passenger trains per day.