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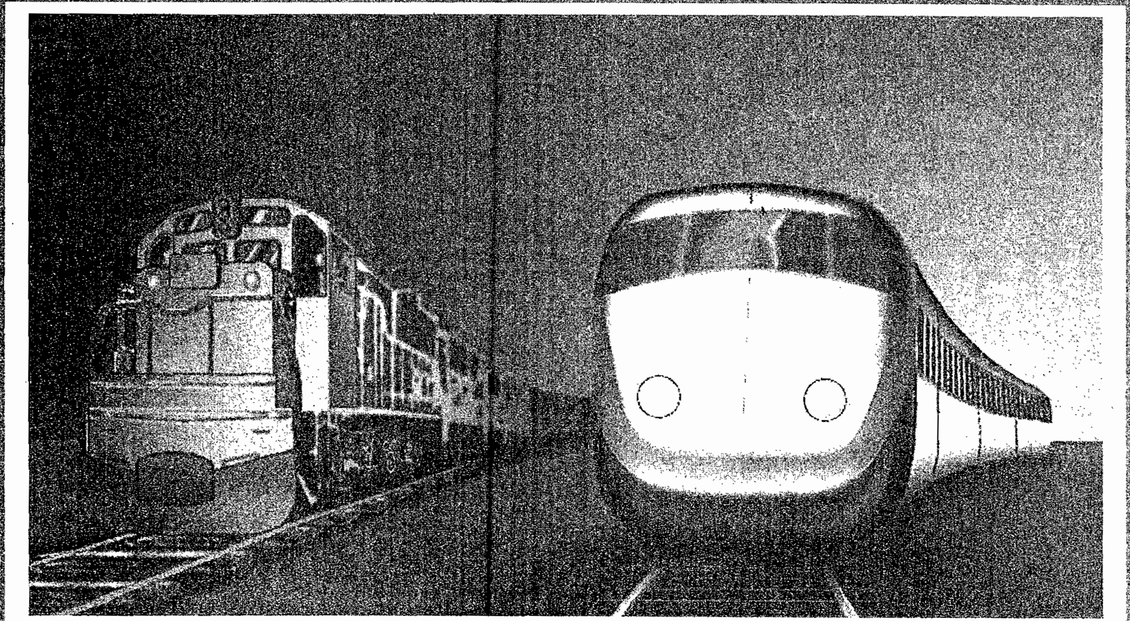
High Speed Passenger Trains in Freight Railroad Corridors: Operations and Safety Considerations

Arthur D Little, Inc.
and
Parsons Brinckerhoff Quade & Douglas, Inc.



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13. ABSTRACT *(Maximum* 200 ***words)***

This report presents the results of a study into some operations and technical issues likely to be encountered when planning for high-speed rail passenger service on corridors that presently carry freight or commuter traffic. The study starts with a review of corridors designated under Section 1010 of the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991, as potential future high-speed corridors. The review summarized operations and infrastructure features of the corridors, leading to definition of a hypothetical corridor representative of the Section 1010 corridors.

After a review of signal, train control and braking systems presently used in the United States and elsewhere, the study provides analyses of the safety and operations impacts of introducing high-speed rail service on the hypothetical corridor. The safety analysis established a safety performance target based on present intercity rail safety performance, and reviewed the need for and benefits from safety improvements for high speed operation. The operations analysis concentrated on the impacts on track capacity and train delays of introducing a high-speed rail service on three hypothetical existing corridors with different track layouts and signal systems.

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PREFACE

In recent years, there has been growing interest in implementing high-speed rail service in the United States. Because of the high cost of dedicated new lines, recent developments have focussed on providing higher speed passenger service on existing freight railroad corridors through incremental infrastructure improvements. The Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991 encouraged such development by making funds available for improvements on selected corridors.

However, operating higher speed passenger trains in a freight railroad comdor raises a number of questions of feasibility and safety. To address these questions, this report provides discussion and analysis on the operational feasibility of shared freight and passenger operations, and an analysis of safety performance of shared corridors. The study which led to the report is part of a comprehensive effort by the Federal Railroad Administration (FRA) to develop technical information on high-speed rail operations and safety issues necessary to support the regulation of high-speed rail safety and rail service planning activities.

The report was prepared by Arthur D. Little, Inc., together with Parsons Brinckerhoff Quade and Douglas, Inc., as subcontractor to Arthur D. Little, under Contract Number DTS-57-93-D-00036 with the John A. Volpe National Transportation Systems Center. The Federal Railroad Administration Office of Research and Development was the sponsor of the study.

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METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in) = 2.5 centimeters (cm)
1 foot (ft) = 3.0 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) = 2.6 square kilometers (km^2)
1 acre = 0.4 hectares (he) = 4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz) = 28 grams (gr)
1 pound (lb) = .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 millimeters (mm) = 0.04 inch (in)
1 centimeters (cm) = 0.4 inch (in)
1 meter (m) = 2.2 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)
1 hectares (he) = 10,000 square meters (m^2) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gr) = 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 milliliters (ml) = 0.03 fluid ounce (fl oz)
1 liter (l) = 2.1 pints (pt)
1 liter (l) = 1.06 quarts (qt)
1 liter (l) = 0.06 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)

TEMPERATURE (EXACT)

[(9/5)(y + 32)]°C = x°F

QUICK INCH-CENTIMETER LENGTH CONVERSION

INCHES 0 1 2 3 4 5 6 7 8 9 10

CENTIMETERS 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25

25, 40

QUICK FAHRENHEIT-CELCIUS 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 NBS Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50. SD Catalog No. C1310286.

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EXECUTIVE SUMMARY

In recent years, there has been growing interest in the United States in high-speed rail as a means of providing high quality public transportation service in intercity corridors of between 250 and 650 km (150 and 400 miles) in length. Because of the high cost of building dedicated new lines, recent interest has focussed on reducing journey times through incremental improvement to existing rail lines in key corridors.

To encourage the incremental approach to high speed rail service, Section 1010 of the Intermodal Surface Transportation Efficiency Act (ISTEA) created a process by which states could apply to the Secretary of Transportation for designation of high-speed corridors where they desire to make or continue to make incremental improvements in intercity rail passenger services. After designation under Section 1010, a corridor becomes eligible to receive Federal grants for grade crossing improvement or elimination, and other purposes.

Five corridors have been designated under Section 1010 of ISTEA:

- The Southeast corridor between Washington, DC, to Charlotte, NC
- The Florida corridor connecting Miami, Orlando, and Tampa
- The California corridor, connecting San Diego, Los Angeles, the Bay area, and Sacramento.
- The Pacific Northwest Corridor, between Eugene and Portland, OR, through Seattle, WA, to Vancouver, BC
- A group of corridors centered on Chicago, IL, connecting that city with St. Louis, MO; Detroit, MI; and Milwaukee, WI

In addition to the Section 1010 corridors, there is a continuing interest in incremental improvements to rail passenger service in two other intercity rail corridors:

- The Empire corridor from New York through Albany to Buffalo, NY
- The Northeast corridor from Boston, MA, through New York to Washington, DC

The purpose of this study is to examine some of the operations and technical issues likely to be encountered when attempting to introduce high-speed passenger service on corridors that presently carry freight or commuter service. More specifically, the study reviews the capabilities of the principal types of signal and train control systems and examines the relationships between these systems and the capacity of a rail line to accommodate different mixes of freight and passenger trains. In addition, the study provides an analysis of the safety performance achieved with present long-distance rail service, and safety improvements that may be needed to maintain adequate safety performance when higher-speed trains are introduced on an existing corridor. In the context of this study, the maximum speeds of interest are those that would be achievable on existing alignments, between 145 and 240 km/h (90 and 150 mph).

The study first reviews the characteristics of the designated ISTEA Section 1010 corridors listed above and identifies typical operations and infrastructure features.

These features are used to define a hypothetical corridor to be used for a parametric analysis of route capacity. Three cases having different operations and infrastructure characteristics were defined:

- *Case A:* Single track with passing sidings every 32 km (20 miles), presently carrying 6 daytime freight trains.

- *Case B:* Double track with Automatic Block Signalling (ABS) and interlockings every 24 km (15 miles), also carrying 6 daytime freight trains.

- *Case C:* Double track with Centralized Traffic Control (CTC) and interlockings every 16 km (10 miles), carrying up to 12 daytime freight trains.

In all cases, existing passenger train speeds are typically 130 km/h (79 mph) and there are numerous rail-highway grade crossings.

The capabilities of signal and train control systems and the interaction with the braking performance of passenger and freight trains are a primary factor in the ability of an existing line to accommodate higher speed passenger service. A review of these systems concluded that most existing ABS and CTC installations are adequate for passenger train speeds up to 130 km/h (79 mph). For higher speeds, the addition of automatic train control (ATC) or an equivalent system is mandatory under FRA regulations, and longer blocks or more signal aspects are required to accommodate the longer braking distances needed at higher speeds. Order-of-magnitude cost estimates for these signal and train control upgrades are provided in the report. Where speeds at the higher end of the range are under consideration, over 200 km/h (125 mph), it is likely that more advanced ATC systems will be required to provide positive speed control of all trains and enforce civil speed restrictions.

Present safety performance of long-distance passenger trains operating over predominantly freight railroad tracks was estimated from the data contained in the FRA's railroad accident/incident reporting system (RAIRS). Accident frequencies expressed as the expected number of trains in accidents per million train miles were calculated for three principal accident types: collisions between trains, derailments, and collisions with obstructions. The frequency of collisions at rail-highway grade crossings was quantified separately as the number of collisions per million crossing passes. The results of these calculations are:

Accident Scenario 1, Train-to-train collisions	0.043 per 10^6 train-km
Accident Scenario 2, Collisions with obstructions	0.147 per 10^6 train-km
Accident Scenario 3, Derailments	0.168 per 10^6 train-km
Accident Scenario 4, Grade crossing collision	0.91 per 10^6 crossing passes

Estimates of accident severity (damage and casualties) by accident type are also given in the report.

The FRA has stated that a higher speed rail passenger service should be at least as safe as present services. Thus, actions to reduce the frequency or severity of accidents must be taken to offset any adverse effects of higher speed. The principal adverse affect is the increasing severity of accidents with increasing speed. Also, depending on the details of high-speed train design and operation, there may be an increased frequency of some types of accidents, for example, due to a passenger train colliding with a defective or derailed freight train.

Estimates have been made of the beneficial impact of a number of accident prevention measures, including upgrades of signal and train control systems, track improvements, and various inspection and hazard detection improvements. The baseline for the estimates is a line with track meeting FRA track class 4 standards, and with ABS or CTC signalling but without train control. The results show that safety improvements of the general magnitude needed for operation at speeds between 175 and 240 km/h (110 and 150 mph) are achievable if the majority of the improvements analyzed are implemented in parallel.

The introduction of additional higher-speed passenger trains onto an existing freight corridor raises critical questions regarding the capacity of the corridor to support both freight and passenger services without causing unacceptable delays to either type of traffic. To investigate this issue, a computer model was used to simulate rail operations with different mixes of freight and passenger service on the three hypothetical corridor cases described above.

The results for each corridor case can be summarized as follows:

- The single track line with passing sidings (Case A) can barely support a two-hourly, 145 km/h (90 mph) passenger train service in each direction. Increasing the number of passenger or freight trains produces increasing delays, and additional or longer sidings would be needed for a satisfactory operation.

- The double track line with ABS (Case B) can support hourly passenger service in each direction at speeds up to 175 km/h (110 mph) and 6 daytime freight trains, but the freight train delays average over an hour for the 500-km (310 mile) journey and are of marginal acceptability.

  The double track line with CTC (Case C) can support hourly passenger service in each direction at any speed up to 240 km/h (150 mph) and 6 daytime freight trains with very minor delays. Additional trains could probably be accommodated with appropriate scheduling. Interestingly, delays declined as speed increased, probably because of reducing track occupancy time by the passenger trains.

The results of this study provide a preliminary indication of the capacity of a freight corridor to support higher speed passenger service and the types of investment likely to be needed to ensure safety and efficient operation. Site-specific analyses, together with appropriate organization and economic and environmental studies, will be needed to fully evaluate an actual corridor.

1. INTRODUCTION

1.1 BACKGROUND

Upgrading speeds on existing rail lines rather than building new, special-purpose very high-speed lines is known as incremental improvement. Interest in this subject is high with the 1991 passage of the Intermodal Surface Transportation Efficiency Act (ISTEA) [Ref. 1].

Section 1010 of ISTEA created a program whereby states could apply to the Secretary of Transportation for designation of high-speed corridors where they desire to make or continue incremental improvements in rail passenger service. Upon designation of the corridors, the applicant states become eligible to receive federal grants for grade crossing separation structures, for improvement of grade crossing warning systems, or other means of reducing hazards at grade crossings.

Many states have expressed interest in the incremental improvement of rail passenger services within their regions, and a number of studies have been performed of the feasibility of such improvements.

1.2 OBJECTIVE

The purpose of this report is to examine the operational and technical issues likely to be encountered when attempting to introduce high-speed passenger trains onto existing rail lines that support rail freight service and/or commuter rail service. In this context, high-speed does not refer to the 255-320 km/h (160-200 mph) (very high speed) trains such as the TGV or ICE, which would require their own specialized railroad infrastructure to operate on, but rather refers to speeds of 145-240 km/h (90 to 150 mph). Some analysts prefer to think of these as higher-speed trains rather than true high-speed trains. In any case, the chief differentiating factor is that the 145-240 km/h (90-150 mph) speed regime can often (but by no means always) be achieved within the confines of existing U.S. railroad rights-of-way, while the very high-speed trains almost always require both their own dedicated tracks and an alignment that has significantly less curvature than typical U.S. railroads, or even relatively highly developed lines like the Northeast Corridor line between Boston, MA, and Washington, DC.

It is a further objective that this report expand and update an earlier report on a similar subject prepared in 1975 for Federal Railroad Administration (FRA) [Ref. 2]. This and other reports referenced herein can be consulted for further information.

An additional objective of this effort is to illustrate the impact of mixed passenger-freight traffic on railroad operations in a hypothetical corridor having characteristics similar to some of the Section 1010 corridors.

1.3 CONTENTS

The remaining eight chapters of this report cover the following subject matter:

Chapter 2 introduces the Section 1010 corridors and describes their characteristics, particularly from the standpoint of factors influencing railroad operations. From observations concerning the 1010 corridors, several hypothetical railroad corridors are introduced.

Chapter 3 discusses the importance of braking in safe railroad operations, and the evolution of blocking as a means of providing for safe operations. Various block systems and block signal systems are described. A description of basic railroad track circuits is provided as well as a discussion of existing U.S. regulations concerning block signal systems. Foreign approaches are also discussed, along with implications for incremental corridor development.

Chapter 4 deals with systems for supplementing a train operator's ability to regulate safely the speed of a train. The systems in use in the U.S. are described within their historical context, and within the existing regulatory context. Foreign and advanced train control approaches are also discussed, together with implications for incremental corridor development and conceptual cost estimates.

Chapter 5 presents a safety analysis of passenger trains in freight railroad corridors. The general methodology is described, and six accident scenarios are proposed. Existing data on railway accidents is presented and analyzed within the context of the six accident scenarios.

Chapter 6 develops the consequences of increasing speeds on railway safety and proposes methods of preventing railway accidents in each of the six scenarios. An approach is presented to quantify the effectiveness of these prevention measures, and summaries are developed to show the net effect for the improved system.

Chapter 7 examines the issues of headway and capacity of a rail line. A simplified, micro-computer-based, stringline model is presented which can be utilized to illustrate and resolve the conflicts resulting from passenger-freight train interference. The model is used to illustrate the performance impacts on three hypothetical corridors from a number of different operations scenarios.

Chapter 8 presents a generalized Corridor Planning Methodology as a guide to undertaking an incremental improvement program in an existing railroad corridor. A planning process for such improvements is described, and the required engineering, operations, financial, and other studies required are outlined.

An Appendix contains data sheets summarizing available information on the 1010 corridors and related lines.

2. OPERATIONS CHARACTERISTICS

2.1 THE "1010" CORRIDORS

Section 1010 of ISTEA directed that $30 million be provided over six years for the elimination of highway-railroad grade crossings in no more than five rail corridors selected by the Secretary of Transportation. It requires that these corridors include rail lines where speeds of at least 145 km/h (90. mph) can be expected.

In 1992 the Department of Transportation (DOT) selected five corridors as eligible for the Section 1010 funding. The Department noted that two corridors — the Northeast Corridor (NEC) mainline and the New York State Empire Corridor — already were high speed corridors. These two existing corridors are not eligible for Section 1010 funding.

A brief narrative description of the five designated corridors, and the Empire and Northeast corridors, is presented below. (Unless noted otherwise, corridors are equipped with an automatic block signal (ABS) system, and no train control system is in use.) Further details are contained in the individual corridor route data sheets in the Appendix. A map of the 1010 corridors is shown in Figure 2-1.

2.1.1 Southeast Corridor

The Southeast corridor is presently the subject of a regional study of market demand. Applications were received from both Virginia (Washington, DC to Richmond, VA) and from North Carolina (Raleigh to Charlotte, NC) and it is these segments which are described here. The overall corridor designated is Washington to Charlotte via Richmond and Raleigh, with the Richmond-Raleigh alignment not defined at present.

The Washington to Richmond segment is 170 km (108 miles) long, double track, has limited curvature, and is presently cab-signal equipped. Passenger and commuter trains operate at up to 110 km/h (70 mph) today, with significant freight traffic at speeds of 65 - 95 km/h (40 to 60 mph).

The Raleigh to Charlotte segment is 275 km (173 miles) long, mostly single track, and has significant curvature. The portion of the railroad from Cary to Greensboro, NC is "dark" territory (has no block signal system installed) and has Arntrak 403(b) trains operating at 95 km/h (59 mph). The Greensboro-Charlottesegment has particularly heavy freight operations.

2.1.2 Florida Corridor

The overall Florida Corridor being developed by Florida Department of Transportation extends from Miami to Orlando and Tampa. The exact route alignments are still under study. The Section 1010 application focused on improvements in the Miami to West Palm Beach segment where the alignment is fixed. It is this segment that is described here and in the Appendix. This segment is 115 km (71 miles) long, single track, has limited curvature, and a centralized traffic control (CTC) system installed. Passenger and new Tri-Rail commuter trains between Miami and Fort Lauderdale operate at 125 km/h (79 mph). Limited freight service operates primarily in the nighttime hours. A funded program is now underway to double track approximately 35 percent of the line and install cab signals throughout.

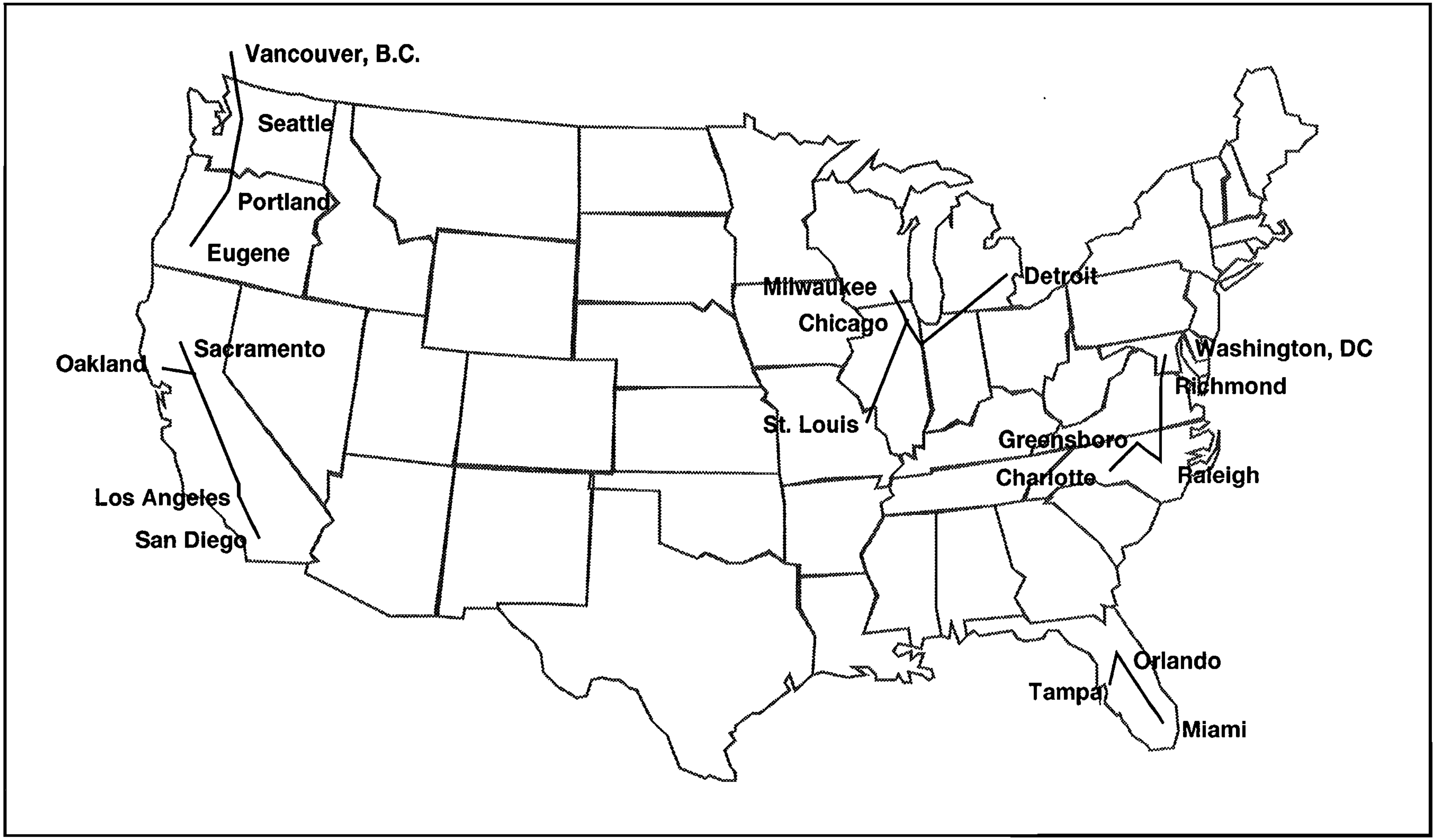


Figure 2-1. Section 1010 High Speed Rail Corridors

2.1.3 California Corridor

The California Corridor, as presented by Caltrans, consists of the Los Angeles-San Diego (LOSSAN) and Los Angeles-Bay Area/Sacramento (LOSBAS) sub-corridors. The overall route is 780 km (487 miles) long (excluding extensive bus connections, including between Los Angeles and Bakersfield), primarily single track, relatively light curvature, and a combination of ABS and CTC. Passenger and proposed commuter services operate on the LOSSAN segment at up to 145 km/h (90 mph) where an automatic trainstop system (ATS) is installed, and at up to 125 km/h (79 mph) at most other locations. There is at present no direct rail passenger service between Bakersfield and Los Angeles, requiring an Amtrak bus connection to be made. Significant freight service operates on the bulk of this route.

2.1.4 Pacific Northwest Corridor

The Pacific Northwest Corridor, as jointly conceived by the Oregon and Washington Departments of Transportation, extends from Eugene to Portland, OR, then continuing through Seattle and Everett, WA, and ending at Vancouver, BC, a total of 740 km (464 miles). The line is about half single, half double track, and is CTC operated at speeds between 65 and 125 km/h (40 and 79 rnph), with significant curvature. Heavy freight traffic is the rule on this corridor.

2.1.5 Chicago Hub Corridor

The designated Chicago Hub Section 1010 corridor consists of three segments which could form a regional rail system, extending from Chicago, IL, to Milwaukee, WI; Detroit, MI; and St. Louis, MO. The respective Departments of Transportation of Wisconsin, Michigan, and Illinois applied for and gained designation as a 1010 corridor.

The Chicago-Milwaukee segment is 140 km (86 miles) long, double track, is CTC operated, and has light curvature. Commuter and 16 daily passenger trains operate at up to 125 km/h (79 rnph). The line is heavily used by freight trains.

The Chicago-Detroit segment is 450 km (280 miles) long, primarily single track, is CTC operated, and has light curvature except between Detroit and Kalamazoo. Eight daily passenger trains operate at speeds up to 125 km/h (79 rnph). Daytime freight traffic is light, except on the Chicago-Porter, IN, segment, where it is very heavy at all times of the day.

The Chicago-St. Louis segment is 450 km (282 miles) long, primarily single track, predominately CTC operated, and has light curvature. Up to 8 passenger trains per day operate at 125 km/h (79 mph) maximum speeds. Freight traffic is light, particularly during daylight hours.

2.1.6 Empire Corridor (not a Section 1010 corridor)

The overall Empire Corridor is considered to extend from New York City to Niagara Falls, NY, via Albany and Buffalo, a distance of approximately 740 km (460 miles). Ten passenger trains per day operate over the portion of this line west of Schenectady, at maximum speeds of 125km/h (79 rnph). New York State's immediate priority for this rail line is the incremental improvement of the New York-Hoffmans, NY (Schenectady area) segment. The segment is 273 km (170 miles) long, mostly double or multiple track, and has light to moderate curvature. The segment is CTC operated and equipped throughout with a cab signal system. Portions of this line operate today at 175 km/h (110 mph) and 200 km/h (125 mph) is the next target. Sixteen passenger trains per day operate from Penn Station, New York, and extensive electrified commuter service from Grand Central Terminal, NY, operates on a 50-km (30-mile) segment of this line. The limited freight operations are primarily during the nighttime hours.

2.1.7 <u>Northeast Corridor (not a Section 1010 corridor)</u>

The southern half of the Northeast Corridor from Washington, DC, to New York, NY, has undergone extensive improvement under a federally-sponsored development program. Presently operating 34 Metroliner trains per day at speeds up to 200 km/h (125 mph) as well as up to 64 other intercity passenger trains and 240 commuter trains daily), this line is the U.S. benchmark in high-speed rail operations. This line is fully electrified and has no grade crossings. The corridor also carries some limited freight traffic.

The northern portion of the NEC from New York to Boston, MA, although also receiving improvements during the Northeast Corridor Improvement Project (NECIP), was not developed to as high a level as the New York-Washington portion. Amtrak plans to extend the electrification from New Haven, CT, to Boston. The New York-Boston corridor is 370 km (231 miles) in length, double or multiple track, is CTC operated, and has significant curvature along the Connecticut and Rhode Island shorelines. The line is fully cab signal equipped, has few remaining grade crossings, and operates at speeds up to 175 km/h (110 mph). Freight train traffic is limited on this segment, but frequent commuter trains, up to 200 per day, are operated between New York and New Haven.

2.2 CORRIDOR CHARACTERISTICS AND IMPLICATIONS

Table 2-1 presents a summary of the characteristics of the Section 1010 and other corridor segments. A more complete presentation of corridor characteristics is contained in the Appendix data sheets. The following discussion relates to the interpretation of data contained in Table 2-1 and the Appendix data sheets. The data shown are in some cases estimated, particularly concerning grade crossings, where private crossings may not be included in every case.

Trains/day figures are one-way figures, i.e., one round-trip counts as two trains.

Passenger Speed is the typical maximum speed in mph presently being operated on the segment, not throughout the segment. **Proposed Passenger Speed** is the initial target speed for the improvement program planned as of this writing, not the ultimate objective.

Daytime freight trains refer to through trains that would likely interfere with passenger service between approximately 7 am and 9 pm. Fully developed corridor passenger services could extend operating hours beyond those limits. Freight/Passenger train interference is discussed in chapter 7.

Grade Crossings are all highway crossings at grade (i.e., not grade separated), including public and private, with and without warning devices. (Although this is the intent, data may not reflect private crossings in every case.) Although no regulatory standard has been established at this writing, limiting the speed of passenger trains over grade crossings is clearly a formidable safety challenge. Detailed discussion of grade crossing safety issues, including elimination projects and warning means, is outside the scope of this study, but substantial attention has been given to this subject elsewhere [Refs. 4, 5, 6 and 7]. Precedent exists in the U.S. today to operate at 175 km/h (110 mph) speeds over grade crossings. Operation at speeds in excess of 175 km/h (110 mph) is beyond that authorized by the track safety standards and hence would require an FRA waiver. FRA may grant such a waiver if it "is in the public interest and consistent with railroad safety" (49 United States Code 20103(d) — recodified transportation statutes) [Ref. 8].

Table 2-1. Summary of Corridor Data*

Route	End Points	Number of Tracks	Route Length, Miles	Maximum Psgr. Trns/day	Commuter Service (trains/day)	Max Psgr. Train Speed, mph	Proposed Psgr. Train Speed, mph	Daytime Freight Trains	Freight Train Speed, mph	Siding Length, miles	Siding Spacing, miles	Total Grade Crossings	Grade Crossings/ Route Mile	Typical Curvature
Virginia	Washington-Richmond	2	108	18	yes (8/day)	70	90-95	12	40-60	NA	NA	64	.59	1°
N. Carolina	Raleigh-Charlotte	1	173	4	no	59-79	90	2-10	50	1-10	10-19	260	1.5	1°-4°
Florida	Miami-W. Palm Beach	1-2	71	8	yes (24/day)	79	90	0	60	[35% double track]		73	1.03	1° -2°
California	San Diego-Bay Area/ Sacramento	1	487	0-16	no	60-90	100	2-12	40-65	.9-1.6	5-9	428	.88	1°-3°
Oregon/ Washington	Eugene-Vancouver, BC	1-2	464	2-8	no	40-79	90	8-16	40-60	1-5	1.5-13	404	.87	2°-4°
Illinois	Chicago-St. Louis	1	282	4-8	yes	79	90	0-1	60	2	12-23	327	1.15	1°
Wisconsin	Chicago-Milwaukee	2-3	86	16	yes	70-79	90	7-8	50-60	NA	NA	111	1.31	.5°-1°
Michigan	Chicago-Detroit	1-2	280	8-16	yes	79	100	0-20	60	2-5	16-20	388	1.39	1°-2.5°
Empire	New York-Hoffmans	2-4	170	16	yes (up to 140/day)	70-110	125	0	50	NA	NA	37	.22	1°-2°
NEC	Washington/ New York	2-4	226	102	yes (up to 240/day)	125	150	0-4	30D 60N**	NA	NA	0	0	0.5°
NEC	New York-Boston	2-4	231	30	yes (up to 200/day)	110	150	0-2	30D 60N**	NA	NA	17	.07	1°-3°

*See explanation of data and column headings in Section 2.2

** D = Daytime N = Nighttime

Grade crossings/route mile gives an indication of the prevalence of these impediments to high-speed operation on a given segment. A national average is approximately one crossing/route mile. Figures lower than this suggest prior grade crossing elimination projects, making incremental HSR potentially less expensive to implement.

Signaling shows the prevalent type of signal system in the segment. Signal systems will be discussed in detail in chapters 3 and 4. (Shown in Appendix only.)

For rail line segments that are at least partially single track, **Percent Second Track/Siding** (shown in Appendix only) indicates, on average, the effective second track available for passing, while **Average Siding Length** and **Average Siding Spacing** estimate those parameters for the segment. As discussed in prior research reports [Refs. 2, 9, 10], siding spacing has an effect on route capacity. This effect will be further discussed and illustrated in chapter 7. Siding length is important, since if a siding is not long enough to hold a given freight train, it is useless operationally (as a location to hold a freight train and allow a passenger train to pass). If some sidings are short in comparison to operating freight train length, the effective distance between sidings is increased, directly reducing capacity.

Typical Curvature refers to the degrees of curvature frequently and regularly encountered on a rail line segment. Maximum curvature will be higher, and there will always be speed restrictions present as a result of atypical sharp curves. For a given allowable track superelevation and vehicle cant deficiency (unbalanced superelevation), degree of curvature is related to allowable operating speed by the following formula:

$$V_{max} = [(Ea + Eu)/.0007\ D_c]^{1/2}$$

where V_{max} = maximum speed [mph]
E_a = superelevation [inches]
E_u = unbalanced elevation [inches]
D_c = degree of curve [degrees].

Superelevation is limited to a maximum of 150 mm (6 inches) by Federal Track Safety Standards [Ref. 3], and unbalanced superelevation (cant deficiency) is limited to 75 mm (3 inches) unless a waiver of these values has been granted by FRA. Furthermore, many freight railroads have reduced superelevation in their curved track to a lower maximum level, frequently 100 mm (4 inches), which reduces the allowable speed on such curves. To increase curve speeds in general, the degree of curvature must be reduced to a value that is compatible with the desired speed using the above formula. The typical curvature values can be used to gauge how much of a problem route curvature is in achieving increased speeds.

Table 2-2 shows the effect of different curvature levels on maximum curve speed. Curvatures are shown in Table 2-2 for three conditions:

- 3" unbalanced superelevation corresponding to the FRA regulatory maximum.
- 5" unbalanced superelevation corresponding to a level that is generally considered comfortable with a modern high-performance suspension system.
- 9" unbalanced superelevation corresponding to the value approved by FRA for demonstration service of the X-2000 tilting body trainset in the NEC.

These values bracket the range of acceptable curvature with adequate passenger comfort under the range of conditions likely to be encountered.

Curve realignment projects are relatively expensive undertakings and, because of development or natural barriers immediately abutting the right-of-way, can not always be implemented practically. Tilting body trains can also be employed to increase curve speed to some degree without realignment in corridors where curvature is significant, provided that rolling stock design produces acceptable lateral/vertical (L N) force ratios under these conditions.

Table 2-2. Maximum Speed vs. Curvature Level (4" Superelevation)

Speed, mph	Degrees of Curvature (Radius, Feet)		
	3" Unbalance	5" Unbalance	9" Unbalance
90 **mph**	1.23° (4659)	1.59° (3604)	2.29" (2502)
110 **mph**	0.83" (6904)	1.06° (5392)	1.53" (3745)
125 **mph**	0.64" (8953)	0.82" (6936)	1.19° (4815)
150 **mph**	0.44° (13,023)	0.57" (10,053)	0.83" (6904)

2.3 DEVELOPMENT OF HYPOTHETICAL CORRIDOR

Rather than illustrating the impacts of train operations on a particular 1010 comdor, the safety and operations analysis methodologies are applied to a "hypothetical corridor" representing the 1010 comdors in the aggregate. In analyzing the data from the corridors (as represented in the Appendix data sheets and other available information), three typical cases seem appropriate for further analysis. These are briefly described below, in order of increasing complexity and cost, and are then used in the comdor efficiency analysis of chapter 7.

2.3.1 Case A: Single Track and Passing Sidings

Many of the 1010 corridors will have this structure for at least a portion of their extent. Typical values for base case evaluation will be sidings of 2.4 km (1.5 mile) length spaced every 32 km (20 miles), with operation under CTC rules. Hourly passenger trains (at maximum speeds of 145 km/h) (90 mph) will operate in each direction across the territory, in competition with light to moderate freight traffic of 3 daylight freight trains in each direction, randomly spaced throughout the 14-hour daylight period. Freight trains are assumed to have maximum speeds of 80 km/h (50 rnph).

2.3.2 Case B: Double Track ABS

This fairly common arrangement consists of a full double track, each signaled for movements with the current of traffic (i.e., in one designated direction). Interlockings are present every 24 km (15 miles), and these are assumed to be configured so that trains may meet and pass at these points. Between interlockings, however, trains must follow one behind another on the designated directional track under normal operating conditions. Passenger traffic is as in Case A above, except at 175 km/h (110 mph) maximum speed; base freight traffic is as in Case A.

2.3.3 Case C: Double Track CTC

This arrangement is not uncommon in highly utilized corridors, particularly if passenger service has always been a strong factor. Under the CTC scenario, trains may operate on signal indications in either direction on either track — there is no "current of traffic." Interlockings are assumed to be spaced every 16 km (10 miles), but these are simple universal crossovers not allowing passing within interlocking limits; rather, trains may pass on the links between interlockings. Passenger service is as outlined above, however, maximum speeds of 145, 175,200 and 240 km/h (90, 110, 125, and 150 mph) will be considered. Base freight service will be as in Case A, however, the ability to handle much higher volumes (up to 12 daylight trains/day) will be considered.

3. BRAKING AND BLOCK SIGNAL SYSTEMS

3.1 IMPORTANCE OF BRAKING

Safe train operation is based on the concept of adequate train separation. This in turn requires positive control of train velocity — the function of the braking system. Railway braking systems have been developed through the years into highly reliable equipment, and no shortage of hardware exists internationally to perform this important function. Braking rates may be increased through higher braking forces, but these rates are limited by considerations of passenger comfort and wheel-rail adhesion. Furthermore, the energy dissipation capacity of the braking components must be matched to the intended application. As speeds are increased, for a given braking rate, distance required to stop and energy dissipated rise as the square of the velocity. This square law relationship of stopping distance and maximum speed provides a challenge for a railroad system designer laying out a signal system for a line with operating equipment of different speed and braking characteristics, such as passenger and freight trains, as further discussed below.

3.2 TYPES OF BRAKING

The historical railway braking system has been the pneumatic or air brake system, consisting of friction braking between wheel treads and brake shoes, with braking effort supplied pneumatically. As passenger speeds increase, both the necessity of increasing the number of elements dissipating braking energy and the desire to remove large thermal energy loadings from the wheels have led to disk friction brakes, alone or in combination with tread brakes. Braking control can also be pneumatic (as with the conventional freight car braking system), or can be electric, or a combination of electric and pneumatic (as with many rail transit and passenger designs).

A further distinction can be made between the train air brakes (as described above), and the locomotive air brake (independent brake) which is generally fitted on locomotives.

The advent of diesel-electric propulsion permits the use of dynamic braking, and that of electric propulsion permits either dynamic or regenerative braking. Hydraulic and hydrodynamic braking systems or components have also been used, but much less widely. An additional form of braking is the track brake, which does not rely on wheel-rail adhesion but directly transmits truck forces to the track. Track brakes can be either electromagnetic (as in a non-contacting eddy current brake) or rely on more conventional friction contact principles.

Most modem vehicles incorporate several types of braking, such as friction and dynamic. Increasingly in passenger applications, these are integrated within a control apparatus where the blending between the different systems takes place automatically, simplifying the operators' tasks and tapering the application and release for smooth performance. The basic braking platform is generally the friction brake, with additional braking devices serving as "overlays" integrated by the braking control system.

Control of the braking system is ordinarily effected manually by the engineman (train operator or locomotive engineer), but automatic applications of the brakes may also be initiated if a train stop or train control safety device is installed. (Train control systems are discussed in chapter 4.) Automatic applications of the brakes by these devices are termed "penalty" applications and ordinarily result in retardation of the train by friction braking exclusively. Such a braking rate may be lower than that available from the combined braking systems, but not necessarily.

3.3 SAFE BRAKING DISTANCES

A train can stop in the minimum distance when a number of favorable conditions are met: the train operator uses the highest braking rate, the emergency braking rate; the wheel-rail adhesion is high, implying clean, dry rails; and restrictions on passenger comfort are disregarded. In practice, these conditions are not always present, and it would certainly be inappropriate to design a railway signal system around such best-case stop distances. The term safe braking distance refers to an idealized distance derived from conservative assumptions concerning the variables mentioned above. Safe braking distances are always verified by actual tests on specific equipment performed by the railroad carriers prior to initiating regular service.

Safe braking distances generally include allowances for the following conditions:

- Rather than the emergency rate, full service braking is generally used as this is the rate provided in a penalty application from trainstop or train control systems.

- The train is assumed to be fully loaded (passengers plus baggage in the case of a passenger train).

- A certain percentage of the trains' brake units are presumed to be inoperative; a derating of 20 to 25 percent is typically used.

- Allowances are made for the reaction times of the automatic safety systems, the braking system, and the engineman in applying the brakes.

As a result of these allowances, the safe braking distance for a train may be significantly greater than the best-case stop distance, thereby providing a significant margin of safety. In any event the safe braking distance at higher speeds becomes substantial, and this affects rail line capacity. Figure 3-1 shows the safe braking distance for Amtrak AEM-7 and Amfleet equipment as used in the NEC at up to 200 km/h (125 mph). The curves assume a 25 percent derating, and are shown with and without an 8-second total reaction time. From a speed of 200 km/h (125 mph), such a train has a safe braking distance of 3437 m (11,277 feet). The overall deceleration rate obtained is approximately 1.28 km/h/sec (0.8 mph/sec) (less than 0.04 g) which is quite consistent with passenger comfort and adhesion limits.

Figure 3-2 shows safe braking distances for a variety of passenger and freight equipment. Note that the freight safe braking distances are compatible with the passenger distances for the slower speeds at which the freight trains run.

3.4 BLOCK SIGNAL SYSTEM OVERVIEW

The necessity of adequate train separation has already been mentioned. It is conceivable to separate trains by time intervals. Indeed, even today a primary protection for freight trains in the absence of more sophisticated means involves dropping fusees (railroad flares which bum for a predetermined length of time). Operating rules require that a following train finding a burning fusee stop, extinguish it, and wait five minutes (or other predetermined interval) before dropping another fusee and proceeding.

Long ago the more flexible concept of distance separation came into general use with the division of a railroad operating temtory into **blocks,** lengths of track which could be "given to" only one train at a time. Authority to enter and occupy the block extends only to the block limit (the boundary of the next block in the direction of travel). Originally these blocks were many miles long. A number of ways of controlling block occupancy exist, and these are described in the next sections.

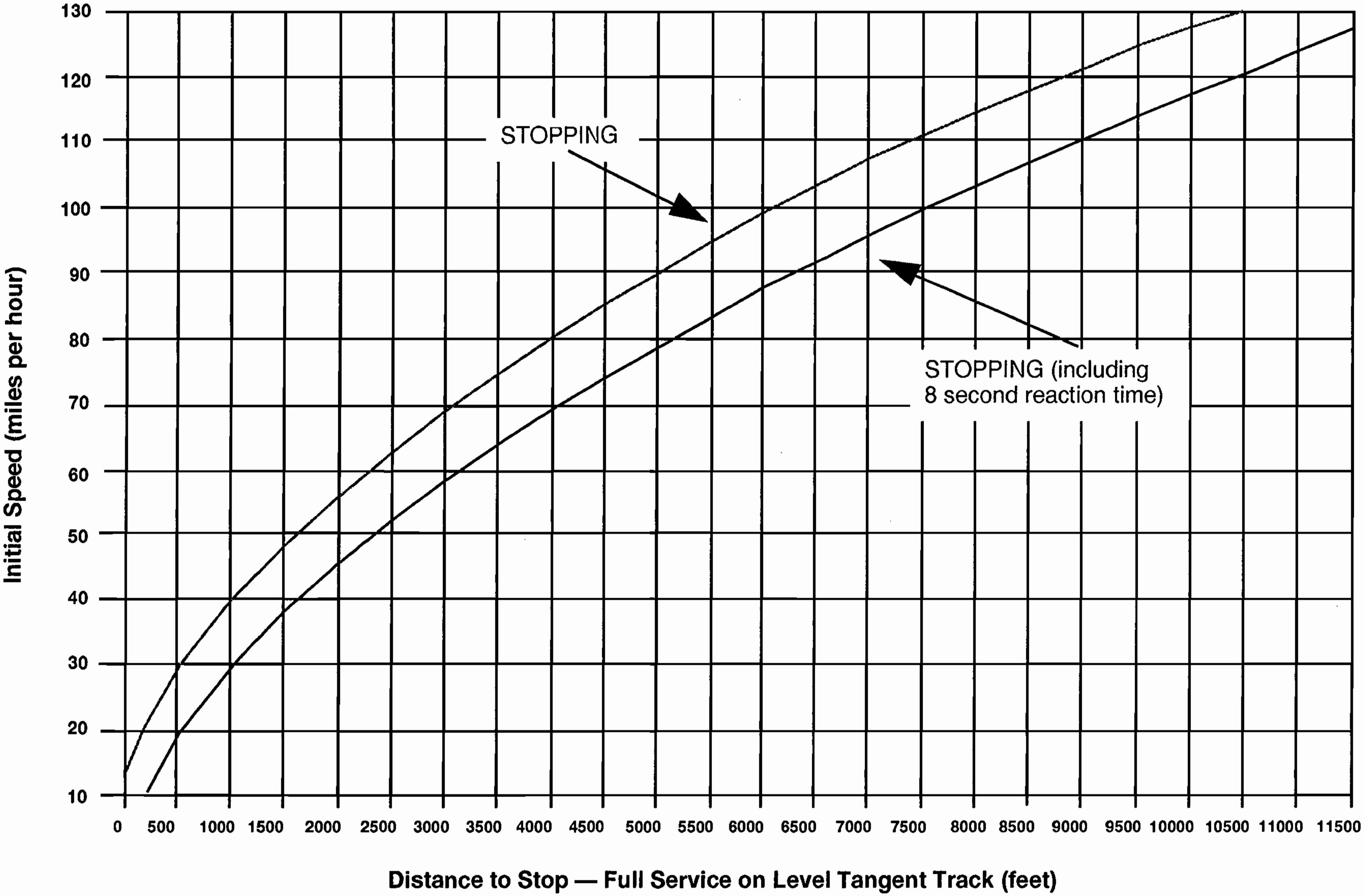


Figure 3-1. Safe Braking Distance, AEM-7 & Amfleet

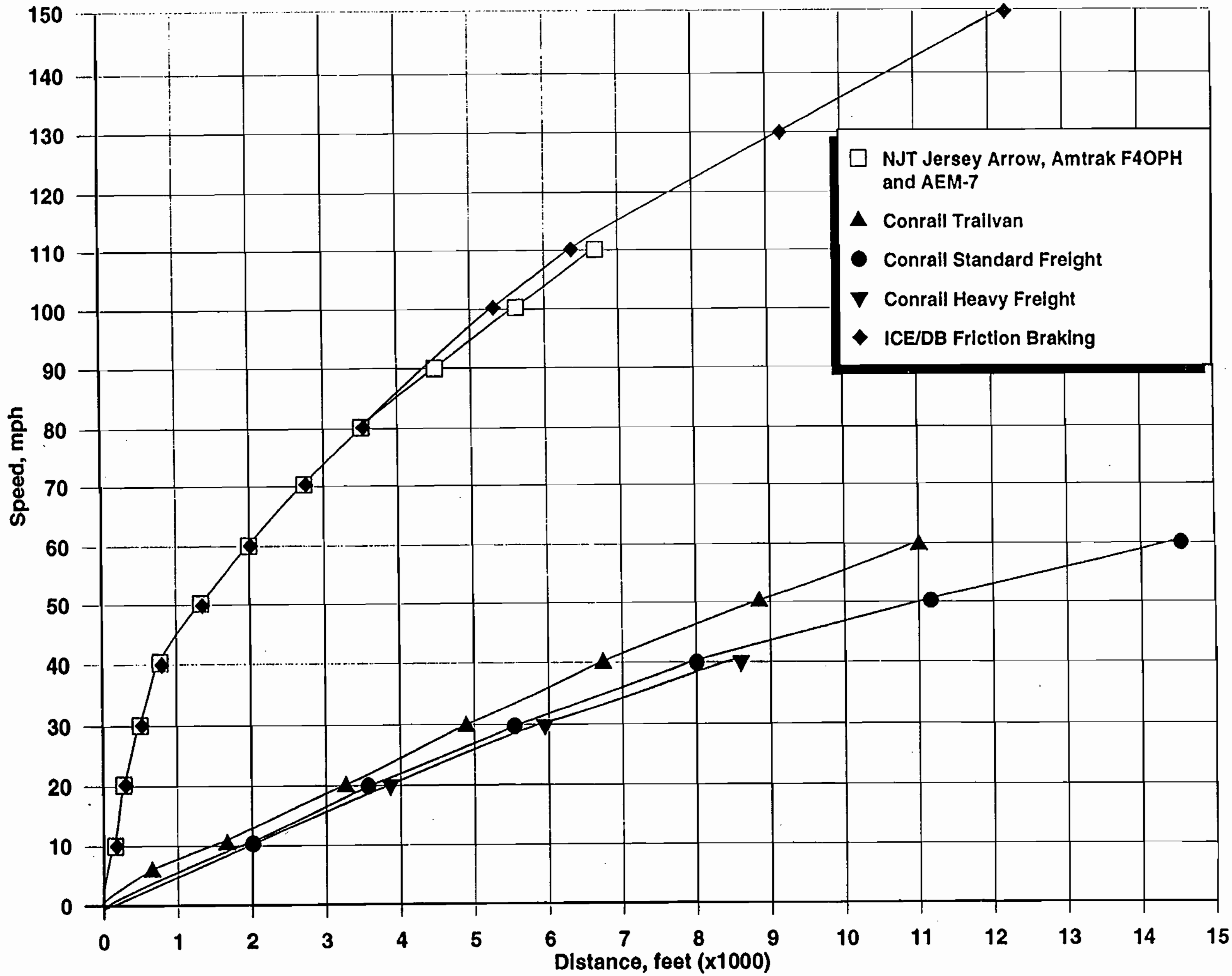


Figure 3-2. Safe Braking Distance, Passenger vs. Freight

3.5 TRAIN OPERATION AND DISPATCHING

With the railroad divided into blocks, a train dispatcher could determine train priorities, and plan meets and passes at convenient points on the line with relative safety, although of course this system is not immune to human error. The dispatcher would relay his instructions to block operators stationed in the field at the block limits, by telegraph and later by telephone, dictating train orders to hold a train or allow it to enter the next block. These train orders were then copied manually by the operator and delivered by him to the conductor and engineer of the affected trains. Supplemented by the operating rule book and timetable definitions and special instructions, this type of train order operation is still widely used around the world, although it is being replaced by numerous variants whereby dispatchers dictate train orders by radio directly to engineers and/or conductors. Clearly this arrangement becomes cumbersome when train densities become high. As of January 1993, approximately 40,960 km (25,600 track miles) were operated in the U.S. under this technique, approximately 16 percent of the total track mileage operated (all U.S. railroads) [Ref. 11].

3.6 TYPES OF BLOCK SIGNAL SYSTEMS

The addition of fixed signals installed at the block stations to transmit movement authority to trains greatly enhanced the efficiency of railroad operations. These signals are commonly of the semaphore, color light, searchlight, position light, or color-position light type, but whatever the form the information transmitted is the same. If the operator had no "special" messages to deliver to the train, he could simply clear the appropriate block signal and the train could pass through to the next block station, where the same procedure would repeat. This type of operation is referred to as a **manual block signal system** (MBS). The signal system, manually operated by the operator, provides movement authority to the train without the necessity of train orders at every block station.

The MBS system is relatively inexpensive to install and, for small railroads at least, to operate. **A** total of approximately 78,400 km (49,000 track miles, or 30 percent of the total U.S. network, were operated in this fashion in 1993. Many smaller railroads are entirely MBS or timetable/train order operated.

A drawback of this type of operation is its limited capacity or throughput. If a train requires 15 minutes to reach and clear the next block station in advance, then another passenger train (observing the absolute block rule) cannot enter the block during that period. It follows that the capacity of such an operation could not exceed four trains per hour, even with totally uni-directional flow. This long ago became unworkable in areas of high passenger train density.

The introduction of the **automatic block signal system** (ABS) revolutionized railroad operations, allowing greatly increased capacity, efficiency, and safety. In the ABS system, much shorter blocks are established, with fixed signals installed at each block location. The ABS system automatically detects the presence of a train (an occupied block) through the use of a **track circuit** (discussed below) and protects the train against following movements by causing the signals at entry to any occupied block to be at "stop." Further, the ABS system provides advance warning of the stop signal ahead (in "advance") by displaying one or more restrictive signals between the clear and stop signals.

The physical appearance of a signal as viewed approaching it (from the "rear" of the signal) is termed its **aspect.** Thus a stop signal could variously appear as a red light, a horizontal semaphore arm, or a horizontal pattern of position lights. The meaning of the aspect is known as its **indication;** the indication is the rule that the train operator responsibly must obey.

The simplest form of ABS is the three-aspect system, wherein there is one caution aspect between the clear (proceed) and stop aspects. Figure 3-3 shows a three-aspect, three-block, ABS system as an illustration. This illustration employs color light signal conventions:

G	=	Green	Name: Clear	Indication: Proceed
Y	=	Yellow	Name: Approach	Indication: Stop at next signal
R	=	Red	Name: Stop	Indication: Stop

Note that the following train (Train B) must be able to stop from its timetable-designated maximum authorized speed (MAS) within a single block (yellow, Block 3). This means that these blocks must be no less than "safe braking distance" in length (see above discussion of safe braking distance). More elaborate ABS systems provide multiple aspects, allowing the safe braking distance to be divided up into multiple, shorter segments of increasingly reduced operating speed. As the number of aspects increases, the block length decreases (other things being equal) and the system has the ability to operate trains spaced more closely together, thereby increasing effective capacity. (Capacity will be discussed further in chapter 7, Corridor Efficiency Considerations.)

Approximately 28,500 miles of track were ABS-operated in 1993, approximately 17 percent of the total track-mileage.

ABS systems effectively space trains safely once they have been dispatched on a route, but at locations where routes may change (i.e., trains may move from one track to another via turnouts and crossovers) a more complicated system known as interlocking is employed. The original interlocking machines were mechanical devices that interconnected the control mechanisms for the switches and signals so that routes had to be cleared in a predetermined sequence and "unsafe" moves (such as displaying proceed signals in both directions on a given route) could not be made. While the mechanical locking providing such protection gave interlockings their name, the same logical functions (and more) are now provided electromechanically (relay interlockings) or electronically (solid state vital electronics). Within the limits of an interlocking, all movements are authorized by signal indications. An interlocking may be locally controlled (from a "tower" or interlocking station), or it may be controlled remotely. The long-term trend has been away from towers and trackside telephone block circuits for control and communications, and towards remotely controlled interlockings and train-wayside radio, which are now virtually a standard on U.S. mainline railroads. While there are exceptions to the rule, today the expectation is that a major railroad mainline will have ABS signaling and relatively frequent interlockings. Operations on such a line ordinarily will be accomplished through signal indications supplemented by radio messages. In 1993, there were 2050 interlockings on U.S. railroads, consisting of 542 automatic interlockings, 440 attended interlockings, and 1068 remote interlockings. There are an additional 11,200 controlled points associated with traffic control systems (discussed below). These controlled points are a special case of remote interlockings.

Whatever the aspect given by an interlocking or automatic block signal, its indication is essentially a speed command, or can be reduced to a speed command. This is the speed signaling concept. Another form of signaling, route signaling, incorporates information as to upcoming track changes (diverging route, etc.) into its indications. Route changes can generally be inferred from the sequence of aspects in a speed signaling system. Route signaling lends itself less readily to speed enforcement and to automation, and speed signaling has become the dominant form in modem use.

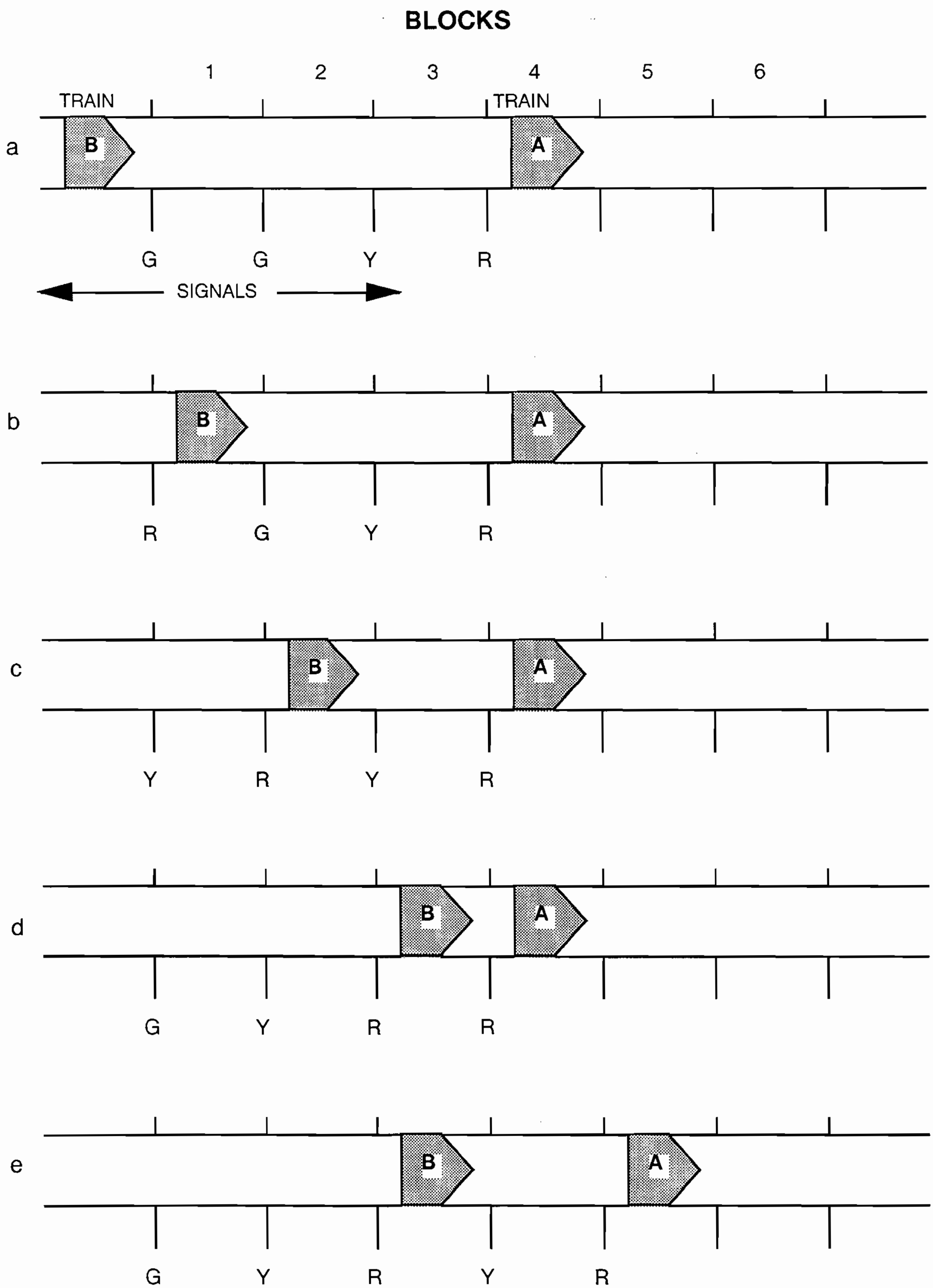


Figure 3-3. Three Aspect, Three Block Color Light ABS System

3.7 REVERSE TRAFFIC

The descriptions up to this point primarily have related to trains moving in a uni-directional motion on a track. If a track is signaled for movements in only one direction, that direction is the established current of traffic. A common arrangement is a double track rail line with one track signaled in each direction. Movements against the current of traffic (opposing movements), as for example in an emergency or when a track is out of service for maintenance, can only be made through train order operation.

If a track is signaled so that reverse movements can also be made, i.e., so that movements in both directions can be made on signal indications, the track is said to have reverse traffic capability, and the operation is defined under traffic control system (TCS) rules rather than ABS and Interlocking rules. A traffic control system wherein all interlockings and other manually-controlled points are remotely controlled from one central location is referred to as centralized traffic control. The term CTC is not defined within Federal regulations and its usage and application may vary within the industry. As of 1993, over 96,000 km (60,000 miles) of U.S. railroad track were operated as TCS, 37 percent of the total.

3.8 TRACK CIRCUITS

As previously mentioned, train detection in automatic block and traffic control systems is accomplished through the use of track circuits. In their simplest form, a track circuit consists of a power source (battery) at one end of the circuit, and a relay (track relay) at the opposite end of the circuit. The rails are the conductors of the circuit, connecting the battery and the relay in a series loop circuit. For this purpose, the rails are made electrically discontinuous (while remaining mechanically continuous) at the block boundaries by the use of insulated joints. The simple DC track circuit is illustrated in Figure 3-4.

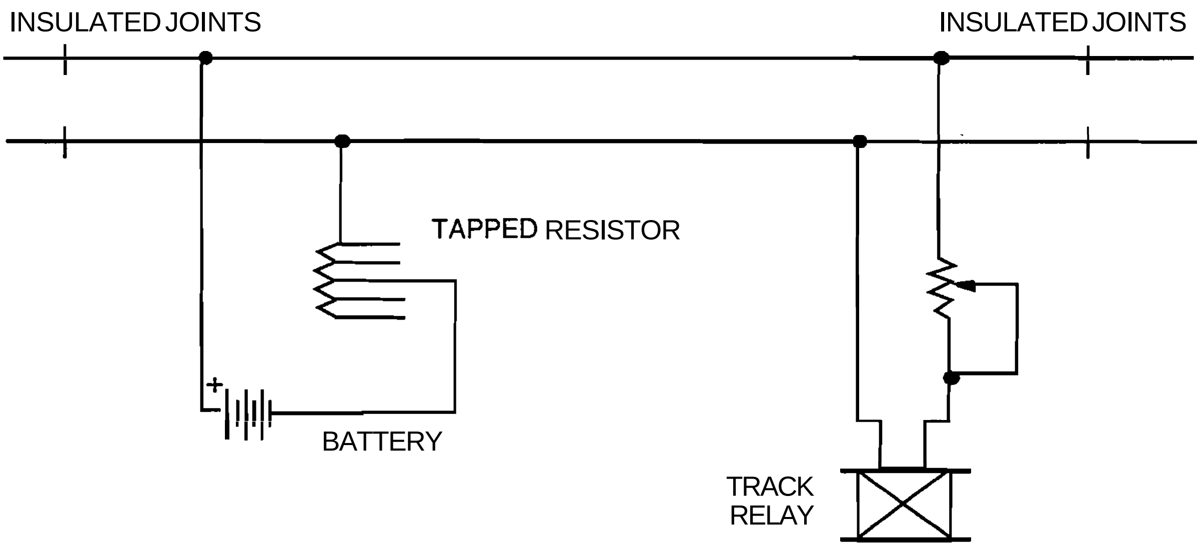


Figure 3-4. DC Track Circuit

The current from the battery flows through the rail to the track relay, and returns to the battery through the opposite rail. Since this is a normally-energized circuit (i.e., the relay is normally operated or "picked-up"), it operates on the **fail-safe** or closed loop principle. The presence of a train's wheelsets within the block will shunt the track circuit, causing the track relay to become de-energized or "drop." Note also that a failure of the battery, a failure of the relay coil, a broken rail, or other damaged intermediate loop wiring would cause the circuit to indicate "block occupied," thus producing a safe condition upon failure. The classical track relays were constructed with relatively massive armatures and were arranged to "gravity-drop" open if de-energized. Their contacts were made of carbon and specially designed to be "non-weldable" to prevent sticking in the picked-up position. This type of relay became known as a vital relay and such a track circuit as a vital circuit.

The aim of all signal engineering is to display safe and proper signal aspects under all conditions, and especially to reduce to a near-zero level the probability of displaying a "false-clear" indication (showing a block as clear when occupied or restricted), and instances of these are extremely rare. The overall ABS system consists of contact trees of track relays and repeater relays connected to signal relays to produce the appropriate aspects corresponding to blocks occupied in advance of the signal. Interlocking designs follow the same basic principles for train detection, but require additional devices and logic to accomplish approach locking and route locking, for example. Much of this logic can be performed by electronic means rather than with relay logic, and solid-state systems with high reliability, redundancy, and spike- and- surge-resistance have been introduced to perform this function successfully. The great majority of the installations present in the U.S. today remain of the relay type.

While the DC track circuit described is commonly in use, electrified railroads pose an additional set of requirements and significantly increase track circuit complexity and cost. In electrified systems, the two running rails also serve as return conductors for the propulsion power supply. As such, they are effectively connected in parallel which would shunt the simple DC track circuit. If DC propulsion is employed, AC track circuits at commercial frequency may be used with track inductors (impedance bonds) installed to parallel the rails for propulsion return purposes while keeping the track relay normally energized. If AC propulsion is employed, a higher, non-harmonic frequency may be used for the track circuit, or a phase-selective relay may be employed. **Audio frequency overlay** track circuits have been developed which can function without insulated joints. These have been widely used for crossing protection circuits and have been adapted for mainline use as well. Further description of track circuits can be found in a number of references [e.g., Refs. 12 and 13].

3.9 BLOCK SIGNAL SYSTEM REGULATIONS

Signal systems are regulated by the Federal Railroad Administration, and the requirements are contained in the ***Rules, Standards and Instructions Governing the Installation, Inspection, Maintenance, and Repair of Signal and Train Control Systems, Devices, and Appliances*** [Ref.14]. Insofar as operating impact is concerned, there are two principal provisions of the Rules which are pertinent to passenger train incremental improvement programs:

- Where passenger trains are to operate at 95 km/h (60 mph) or greater, a block signal system (or a qualifying manual block system) must be in effect providing absolute block protection.

- Where trains are to operate at 130 km/h (80 mph) or greater, an automatic cab signal system, automatic trainstop system, or automatic train control system must be installed. (These systems will be discussed in chapter 4.)

3.10 MOVING BLOCK CONCEPT

The systems described up to this point make use of fixed block limits and signal locations. The signal equipment is entirely along the wayside (right-of-way) and not on-board the train. The moving block concept does not have fixed block locations but instead requires interactive communication between equipment on trains and the wayside equipment in order to function. In that regard it is allied with train control systems which are discussed in chapter 4.

The moving block system has the principal advantage of improving the headway attainable over that provided by a fixed block signal system. With reference to the fixed block example of Figure 3-3d, Train B will receive a red signal when any portion of Train A is in block 4. The block layout and safe braking distance assume that the preceding train is in the most adverse (conservative) position in the block, i.e., at the end closest to the following train. As the first train proceeds, however, the signal governing the following train's passage will not improve until the preceding train has traveled to the far end of the block and no portion of the train remains in the block. This means that the second train will not receive an indication allowing it to proceed (Figure 3-3e) until the first train has traveled the block length plus a train length. The resulting **headway distance** or separation between trains is therefore the sum of safe braking distance, one additional block, and the train length. A moving block system will allow a headway distance equal to the safe braking distance and train length alone.

Moving block systems have been employed in transit applications in North America, but are not common in railroad applications at the present time. The existing SELTRAC system developed in Canada utilizes transponders, central and on-board computers, a multiply-redundant digital communications link, and a moving block approach. The system has a resolution of 6.25 meters (20 feet).

3.11 FOREIGN APPROACHES

Other means are available for detecting train presence besides track circuits. One approach which has been used successfully in Europe relies on wheel detectors at block boundaries. When a train is allowed to enter a block, its axle count is registered as it enters. When it leaves the block, it is counted again. If the number of wheel or axle pulses agrees, the train is considered to have left the block and it is cleared. This system is known as **check in-check out.** Although it has successful foreign experience, it has not been employed in the U.S. as a means of controlling a block signal system. This is probably because it offers a lesser degree of protection than track circuited systems (as against broken rails, for example).

3.12 IMPLICATIONS FOR HSR INCREMENTAL CORRIDOR DEVELOPMENT

- As a general rule, existing corridor signal systems will be ABS or TCS and will fulfill the FRA block signaling regulations for operation at speeds of 95 km/h (60 mph) or greater. This statement refers to type of signal system only, not to block length adequacy or train control requirements (discussed in chapter 4).

- "Off the shelf' braking systems available for application in corridor improvement programs will permit increased passenger train speeds within the physical limits incorporated into many existing block signal systems. The precise upper speed limit that can be achieved can only be determined through careful study of the specific corridor block layout and gradients, and by consideration of the braking characteristics of the specific equipment to be applied in the corridor.

- As a first approximation, however, it is not unreasonable to expect that where existing block lengths are 2130 m (7000 feet) or more in length, operation at up to 175 km/h (110 mph) may be possible whereas 145 km/h (90 mph) may be achievable with 1525 m (5000 foot) block spacing. These estimates are derived from Figure 3-2 and assume that Amtrak F40PH/Amfleet equipment (or better performing equipment) would be employed.

- The train control requirements (discussed in chapter 4) must be met independently.

4. TRAIN CONTROL SYSTEMS

4.1 ORIGIN OF U.S. TRAIN CONTROL SYSTEMS

A brief chronology of events in the early 1900s will serve to place train control systems in perspective. In 1906 Congress directed the Interstate Commerce Commission (ICC, the predecessor agency to FRA for rail safety regulation) to investigate and report on the use of and necessity for block signal systems and appliances for the automatic control of trains in the U.S. Between 1909 and 1920, a great number of train-train collisions occurred, resulting in:

16,565 head-on and rear end collisions
3,089 deaths
43,964 injuries
$26 million property damage

In 1920, Congress passed the Signal Inspection Act granting authority to the ICC to require any carrier subject to the Interstate Commerce Act to install **automatic trainstop** (ATS) or **automatic train control** (ATC) or other safety devices, subject to ICC specifications and requirements, *upon the whole or any part of its railroad.* In January 1922, the ICC ordered respondent carriers (certain major railroads) to install ATS or ATC on all locomotives on at least one full passenger locomotive division between geographic limits prescribed in the Order [Ref. 15]. (This initiated relatively widespread application of these devices, and **automatic cab signal** (ACS), not mentioned in the 1922 Order.) Finally, in 1947, the ICC Ordered ACS, ATS, or ATC be installed on any route where any trains were to operate at 130 km/h (80 mph) or more [Ref. 16]. In February, 1984, FRA revised the signal and train control regulations, deleting the above 1922 Order and making the 1947 Order a permanent part of the Code of Federal Regulations (CFR). In other substantive respects, the regulations remain the same.

Another code provision (49 CFR 236.566) requires that the lead locomotive or driving car of any train (freight or passenger) operating over territory equipped with ACS, ATS, or ATC shall also be equipped with "apparatus responsive to the roadway equipment installed" on such territory, and such apparatus shall be in operative condition. It should be noted that compliance with this provision does not require that every type of vehicle have the same system or same reaction to the roadway signals. For example, while a passenger train may have ACS and ATC equipment to respond to wayside coded track circuits, a freight train (or a different passenger train) may have ACS alone. It should be noted further that the requirements of this provision are subject to requests for relief (limited waiver of applicability) and that relief has frequently been granted.

A point of confusion exists in the discussion of these systems. The term *train control systems* is frequently used in a generic sense, as in the title of this chapter, to refer to any of the three types of systems defined in the regulations. *Automatic train control* refers specifically to the system so defined in the regulations. ATC systems are also known as **automatic speed control** systems since they can regulate a train's speed rather than merely bring it to a stop. This logical and clarifying name is not embodied in the regulations, however. Furthermore, these systems can be and frequently are used in combination with one another, and there is no standard as to the combined systems. Each component, if present, must meet the prescribed regulations.

4.2 WARNING VS. ENFORCEMENT

A key differentiator between different train control systems is their overall philosophy: some act as warning systems to alert the train engineer to a change in route conditions, whereas others enforce a lower train speed when a restrictive change occurs. The first type of system provides an increased level of information to the engineer, but leaves him in complete control of the train. The second type of system provides the increased level of information and permits the engineer to remain in control of the train, but takes over control of the train should the engineer fail to do so. This philosophical difference will become evident in discussing the various systems in use, and may result in different levels of train protection.

4.3 INTERMITTENT VS. CONTINUOUS SYSTEMS

All train control systems involve the interaction of wayside equipment (installed along the right-of-way) and on-board equipment (installed on locomotives, cab control cars, or multiple unit cars). Train control systems are said to be either of the intermittent or continuous type depending upon how information is transmitted from the wayside to the on-board equipment. **Intermittent** systems provide information on block conditions only upon entering the block. **Continuous** systems receive information at all times, and can therefore provide information to the engineer about changing block conditions after entering a block.

4.4 CAB SIGNAL SYSTEMS

Automatic cab signal systems of the intermittent type generally employ **inductors** at block boundaries to electro-magneticallytransmit block information to the train-borne equipment, which is displayed on a panel in the locomotive cab. The ACS system may have as few as two aspects (proceed and restricting), but three- and four-aspect cab signals are more common. In operation, as a train enters an unrestricted block the cab indicator display shows a clear indication. If the train enters a restricted block, the cab indicator displays the appropriate indication, and an audible indicator (whistle or horn) sounds in the cab. The engineer must depress an **acknowledging lever** or other device to silence the audible indicator, acknowledging the fact that he is aware of a more-restrictive aspect being displayed.

Continuous ACS systems operate with **coded track circuits.** These are variants of the conventional track circuits described above, in which the electrical current in the loop circuit is caused to vary at a low-frequency rate through interruption, polarity change, or modulation. This coding is performed by the wayside apparatus to correspond with the signal aspect which is displayed by the wayside signal. The ACS system receives this information through receiving coils mounted ahead of the first wheelset. The signals are then decoded by the on-board ACS equipment and displayed as described. Continuous ACS systems, unless combined with ATS or ATC, perform in the same manner described for intermittent ACS systems.

Since the cab signal replicates the information displayed by the wayside signal, and this information is available on a continuous basis in the locomotive cab, wayside signals are sometimes not installed or are retired from service when cab signals are in use, reducing maintenance cost.

Note that the ACS system is an open-loop system which does not interact with the train braking system. Its information is relayed to the engineer for action in controlling train speed and no further action is taken.

4.5 TRAIN STOP SYSTEMS

Train stop systems operate with the same wayside-to-train signals described under ACS, generated by either intermittent inductors or continuous coded track circuits. ATS systems also have an interface with the train braking system, generally through an electropneumatic valve which can vent the brake pipe at a service rate, causing a full service brake application. In operation, as a train enters an unrestricted block the ATS will not take action. If the train enters a restricted block, an audible indicator (whistle or horn) sounds in the cab. The engineer must depress an acknowledging lever to silence the audible indicator and to prevent an automatic application of the brakes, thereby acknowledging the fact that he is aware of a more-restrictive aspect being displayed. Because actuation of this lever will prevent an automatic application of the brakes, it is also referred to as a forestalling lever.

If the train receives a restrictive indication from the ATS system and the engineer does not take any action, a full service brake application will occur after a delay time of an 8 second maximum. The train will continue in a full service braking mode to a stop, whereupon the ATS device may be reset and the train can continue.

ATS systems are somewhere between warning and enforcement systems. Their enforcement is indirect in that acknowledgment of a restrictive indication will prevent further action from being taken, as in the ACS case, even,if the train continues to violate such a restriction for any reason.

4.6 SPEED CONTROL SYSTEMS

Full ATC systems are enforcement systems in that train speed is reduced directly by the system unless the train's speed is similarly reduced under the control of the engineman. These systems operate with continuous coded track circuits, and the track circuit code rates provided must correspond with the number of speed levels to be controlled. In addition to the hardware described above, ATC systems include an on-board speed generator to permit the system to control train speed on a closed-loop basis. Train speed is continuously compared with the speed permitted by the signal indication transmitted via the coded track circuit. Even operating under a non-restrictive signal indication, the Maximum Authorized Speed for the train is enforced; i.e., an overspeed condition will result in an audible indication and an automatic service brake application until the train speed is reduced to MAS (as determined by the setting of the on-board governor).

In operation, as a train enters an unrestricted block, the ATC will take no action. If the train enters a restricted block, an audible indicator (whistle, bell or horn) sounds in the cab. The engineer must (within 8 seconds) begin to reduce the speed of the train at a full service rate or an automatic application of the brakes will occur, bringing the train to a complete stop. The train will continue braking under the engineman's control until the speed of the train is reduced to the required reduced speed, at which time the audible indicator ceases to sound and the brakes may be released. In an ATC system, if the governing signal indication (or track circuit code rate) changes to a more favorable indication after a brake application has been initiated to comply with a prior speed reduction, the audible indication will cease and the brakes may be released if the actual speed of the train is less than the new, more favorable indication.

The actions described have historically been applicable to both passenger and freight vehicles equipped with ATC, and some freight lines operate in this manner today. Some freight carriers have petitioned for relief of the automatic full-service penalty applications from the ATC system, citing problems in train handling, particularly in undulating terrain. In response to these petitions, FRA has permitted the removal of ATC in some instances.

A recently developed device, the Locomotive Speed Limiter (LSL), has been introduced to solve the potential problem of too-aggressive penalty braking on long freight trains. LSL utilizes more gradual braking at a varying rate that still complies with the safe braking distance. It is this system that has been retrofitted to Conrail locomotives (and other non-equipped units) in the Northeast Corridor in the aftermath of the Chase, Maryland, collision.

ATC systems are frequently combined with cab signals. Once the complexity and expense of the ATC system is justified, the addition of the cab signal display device is a minor expense. As two examples of the use of ATC and cab signals, Figure 4-1 shows the present cab aspects, code rates, and speed control settings for the existing 4-aspect Northeast Comdor line system; and Figure 4-2 shows the proposed aspects, rates and settings for the new 9-aspect high-density system proposed for the Northeast Corridor line, incorporating future 240 km/h (150 mph) operation [Ref. 17].

100 HZ	180	120	75	--
Governor Settings (MPH)	125	45	30	20
Signal Aspect Displayed in Cab	L L	L L L L	L L	L L

Figure 4-1. NEC Existing Cab Aspects

100 HZ	180	180	270	120	270	120	75	75	--
250 HZ	180	--	270	120	--	--	75	--	
Governor Settings (MPH)	150	125	100	80	60	45	30	30	20
Signal Aspect Displayed in Cab	G G	G G	G G	G G F	G G F	Y Y G F	Y Y G	Y Y	R R L L
	150	125	100	80	60	45	30	30	20

G = Green
Y = Yellow
R = Red
L = Lunar White
F = Flashing

Figure 4-2. NEC Proposed Cab Aspects (High Density Interlocking System)

4.7 PRESENT APPLICATION OF TRAIN CONTROL SYSTEMS IN THE U.S.

Table 4-1 summarizes the present application of train control systems in the U.S. as of January 1993. The table is derived from information reported annually to the FRA by the rail carriers [Ref. 11]. The table shows the type of train control system, the number of carriers reporting installation of each system, the total track mileage equipped, and representative carriers using each type of system. In every case, the carriers listed account for at least 93 percent of the total miles of each type of system. A total of 15,750 km (9,843 track miles) is equipped with one or more train control systems, or 6.0 percent of the U.S. network.

Table 4-1. FRA-Reported Train Control Systems in Use, 1993

System Type	Number of Carriers	Total Track Miles	Major Users
ACS	5	3964	UP, CR
ATS	5	1780	ATSF,CNW
ACS/ATS	1	90	CCP
ACS/ATC	5	1554	CNW, LIRR, CSX
ACS/ATC/ATS	2	2455	NRPC, MNCR

4.8 ADVANCED TRAIN CONTROL SYSTEM (ATCS)

The Advanced Train Control System had its roots in CP Rail research projects dating back to 1980. By 1984, the Railway Association of Canada and the Association of American Railroads initiated a joint Advanced Train Control Systems Project [Ref. 18]. An operating requirements document was created and consultants were hired to perform systems engineering functions. The goals of the ATCS project consist of reducing the costs of performing all the traditional safety-oriented functions now performed by railroad signal and train control systems (including manual block and timetable/train order systems and the dispatching function), as well as adding a host of improved features of the type generally characterized as management information, seeking improved economic and market performance for the rail industry. The system is based on extensive use of 900-MHz digital communications systems between individual trains and trackside route change points and a central computer, and incorporates microcomputers in each train. Trackside locations (block boundaries) are equipped with passive transponders only, and satellite positioning technology could eliminate the need for these.

All of the ATCS systems rely ultimately on digital data transmission between central control and train, and large central computers. Since vital functions are being performed at the central control, error-free communications must be maintained between trains and central control for the system to function. In the absence of the radio link, all trains are brought to a halt. Following a break in the link, the system must be re-started. Multiple transmitters and parallel information processing have been utilized to achieve high reliability for these systems.

Various pilot projects have been successfully undertaken to prove the concept on a small scale. At the present time, the ATCS project locks the MIS-oriented and train detectionlmovement authority functions into one system, which may slow down the application of ATCS where there is a significant investment in route signaling equipment. It would seem evident that application of ATCS would be most attractive on dark territory (or a totally new railroad), and be most readily installed there, compared with the more highly developed infrastructure associated with existing CTC and ATC [Ref. 19]. Transition to ATCS on ATC lines may be many years in the future, as the ATCS system will presumably have to prove it provides equal safety operating in parallel with existing signaling systems before FRA will approve the discontinuance of the existing system. Two ATCS approaches presently being investigated in the U.S., among many types and levels of application, are the Advanced Railroad Electronics System (ARES) and the Hughes system.

4.8.1 ARES Svstern

ARES is a project of the Burlington Northern Railroad and Rockwell Electronics. It uses signals from the Navstar satellites provided for the Defense Department's Global Positioning System (GPS), achieving a resolution of about 30 m (97 feet). The base system can not differentiate between tracks in multiple-track territory, and additional conventional devices must be used in such territory. Augmented (differential) GPS may provide sufficient resolution to solve this problem. The signal is also lost in tunnels or under overpasses, causing intermittent outages and necessitating the re-establishing of communications and a new start-up for the service. Originally seen by the railroad as an attractive alternative in its many miles of unsignaled territory, the project is no longer under active development by Burlington Northern.

4.8.2 Hughes Svstem

Hughes Electronics has developed an advanced automatic train control application based on its military spread-spectrum ranging and position reporting technology using radio frequency communications. The system is called EPLRS — Enhanced Position Location Reporting System. The system is under test on Bay Area Rapid Transit (BART) as an overlay to the existing signal and train control system, with an ultimate goal of reducing headways. Each train head and tail end is equipped with an EPLRS radio, and additional units are located frequently along the right-of-way (ROW), forming a backbone communications network. The location of every train is reported from a minimum of three wayside locations, and this location is cross-checked by central control which determines safe speed for each train. Coded messages are then sent to each train from multiple wayside EPLRS units. Message coding provides additional redundancy.

4.9 FOREIGN SOLUTIONS

Foreign railroads utilize systems substantially similar to those described in Section 4.8. A number of railroads have been especially creative in developing overlay systems which provide for high-speed operation. French National Railways (SNCF) has for many years used a system which provides an intermittent indication of a "super clear" block condition, i.e., at least one block beyond the block being entered is also unrestricted. The overlay signal was originally transmitted by direct electrical contact with the train through "crocodiles" in the track, and other systems have been developed that perform this function inductively. This system was an early alternative to cab signaling, and widespread cab signaling and ATC has replaced its use on newer lines installed since 1981.

SNCF and CSEE-Transport developed and first used the TVM300 system on the TGV Southeast, and used it again on TGV Atlantique. These systems are intended for the operation of lines with high train densities. The system utilizes continuous track circuits without insulated joints, using frequency modulated signals in the audio range. The carrier frequency is modulated at 18 different frequency modulations, thus permitting 18 potential speed levels. The frequency modulation technique is compatible with unelectrified lines or lines electrified at any commercial frequency. Wayside signals are not employed, and full ATC is provided enforcing a total of five speeds in a stepped fashion. Advance warning of a speed restriction approaching occurs one block in advance of the first restriction. As implemented on the TGV Atlantique, this system permits four-minute headways at 300 km/h (186 mph).

The newest system, TVM430, is designed to achieve three-minute headways at 300 km/h (186mph), with capability of 350 km/h operations. Now the standard for new specialized lines, this system has been installed on the TGV Nord and Channel Tunnel links. It is similar to the TVM300 system, but uses four carrier frequencies in the audio range and an increased number of frequency modulations, permitting 27-bit messages to be sent to the train through the track circuits. Six bits are used for data integrity checks, three for operation (route), eight for permitted speed, six for distance to next section, and four for average gradient in the section. The system thus utilizes fixed block architecture, but on-board speed control is continuous (stepless, as opposed to stepped curve) resulting in a reduction of the length of each block from 2000-2100 m to 1500 m (6560-6888 ft to 4920 ft). Both systems utilize a four-block stopping distance. The TVM430 utilizes advanced data processing techniques to validate the integrity of the commands at several points in the transmission chain, and fail safety has been demonstrated. The large number of available speed commands makes it possible to enforce civil speed restrictions as well as traffic-related restrictions.

SNCF also has under development a track transponder-based system known as ASTREE which is directed at reducing headways, and German Federal Railways is developing the DIANE system. (The two projects taken together comprise the ARTEMIS system.) ASTREE follows the general approach of ATCS, but is not designed to the ATCS standard. It incorporates Doppler radar for on-board speed detection in an attempt to eliminate the speed updating problems encountered with wheel revolution counter or tacho-generator devices, which are confused by wheel slips and slides. ASTREE is still an experimental-stage system, and further development time will be needed before these systems are introduced on a large scale [Ref.20].

Deutche Bundesbahn (DB), the German Federal Railway, in conjunction with Siemens, has developed and applied the LZB system of high speed continuous automatic train control since its introduction in 1965. Several versions of LZB exist, and the most advanced system is employed on ICE lines. All LZB systems share the characteristic that the signal codes are transmitted to and from train and wayside not through the rails themselves but through a separate conductor loop. This loop can be up to 12623 m (41656 ft) in length, subdivided into up to 127 "short loops" as follows. The two legs that make up the short loop are located in the center of the track, and attached to one of the running rails. Every 100 m (328 ft), the two legs are transposed by crossing the position of the wires. Vehicle position is determined by counting the short loops. Each group of three short loops is fed by an amplifier unit, located every 600 m (1928 ft) along the wayside and feeding two short loop groups. These amplifiers are, in turn, fed by the wayside cable or "logical loop" which, is in turn, connected to a Central Line Unit (CLU) which can accommodate up to 16 logical loops (16-64 km (10 to 40 miles) of route).

The vehicle equipment consists of an antenna, central computer logic unit and interfaces with the on-board display panel, the propulsion/braking systems, and input data switches to describe the train length, maximum speed, and braking capabilities. In operation, the LZB system determines train position as follows: A train entering LZB territory passes over an entrance loop indicating code numbers for the logical loop being entered, and the short loop crossing. As the train enters the logical loop it retransmits its position (logical loop and crossing numbers) to the wayside. This process continues with the train giving the updated crossing number each 100 m (328 ft), and the CLU responding with a change in train address. Each CLU consists of a triple computer system using parallel processing—two outputs must match in order to transmit any signal and permit train movement. Wayside-to-train transmission is in the form of messages which provide information to the vehicle computer to calculate:

- Maximum permitted speed.
- Actual speed.
- Distance to next target (up to 10 km (6 miles)).
- Permitted speed at that target.
- Other information.

Train-to-wayside 41-bit messages include the following information:

- Location (loop code and crossing number update).
- Brake type.
- Actual speed.
- Administrative and status codes.

The key advantages of the LZB system are its ability for a large number of speed control gradations (every 2 km/h (1.25 mph)) resulting in a stepless deceleration curve, and a true moving block approach which maximizes the capacity of the rail line (i.e., short operational headways). The LZB system is also very flexible in adapting to new or different equipment types/braking rates, etc., since it does not rely on fixed block spacings.

4.10 UPGRADING TO HIGHER SPEEDS

Upgrading from conventional passenger train speeds to speeds higher than **79** mph requires installation of a train control system meeting the FRA requirements [49 CFR 236.0(d)]. As shown in chapter 2, very few miles of the 1010 comdor rail lines are presently equipped with such systems. As discussed in chapter 3, in many cases some increase in passenger train speeds can be achieved within the existing block layouts of these comdors. The amount of increase permitted and the location of the zones of increased speeds must be determined through a detailed study of the existing block layout and the braking characteristics of the proposed equipment.

Should the desired maximum speeds be greater than the existing block layout permits with regard to safe braking distance, then the block layout and/or signal system must be changed. One solution is to respace the signals, providing longer blocks and therefore greater braking distance. This solution has the disadvantage of increasing the headway distance and decreasing the capacity of the rail line. An alternate solution is to expand the number of signal aspects and shorten the individual block length somewhat; this approach has a lesser impact on headway and capacity, but is more costly. If the existing signal system is fairly new it may be possible to respace the signals while reusing the existing equipment. In other cases it will prove more prudent to replace the existing signal apparatus with new material. If ACS is to be provided universally, wayside automatic signals could be omitted at a cost savings.

To provide an order-of-magnitude estimate of the costs involved with adding a train control system to an existing corridor, the costs of retrofitting the hypothetical corridors (see Section 2.3) have been developed. The estimates are developed for two types of train control applications:

- Intermittent ATS.
- Continuous (coded track circuit) ACS/ATC.

Cab signals alone (without ATC) are not costed because no.significant cost savings are presented by this option.

For each of these applications, the estimates are developed for three levels of improvement that may be required, depending on the local circumstances:

- Level 1 is the total cost per mile for a simple retrofit of the wayside train control devices to the existing signal system.
- Level 2 is the total cost per mile for wayside train control retrofit and respacing of existing signals, assuming existing signal equipment can be reused.
- Level 3 is the total cost per mile for wayside train control devices installed together with a new signal system.

The estimates have been prepared for each of the corridor types described in chapter 2: Case A, Single track and passing sidings; Case B, Double track ABS with passing zones at interlockings; and Case C, Double track CTC. Each of these estimates assumes that the basic signal system is installed to the level stated in the description of these cases in chapter 2 . Costs are not included for any upgrade from one configuration to another that may be required to solve problems of train interference.

The estimates are for non-electrified rail lines; electrified lines may cause costs to be higher because of the need to prevent electrical interference between the train control system and electrification equipment. The estimates are for relatively uncongested corridors; highly congested conidors may increase costs as well. Estimates include construction costs and material costs plus a relatively modest 22 percent factor to cover design engineering, construction management/agency costs, and contingency. Table 4-2 shows the estimates on a per-mile basis in 1994 dollars. Costs for each locomotive or power unit to be equipped are also shown; these on-board costs are additional to the wayside costs. The train control estimates presented here are for conventional, off-the-shelf technology as currently employed on U.S. railroads. Costs for communications-based train control systems such as ATCS may differ when these systems are fully developed.

Table 4-2. Estimated Costs per Mile for Train Control Upgrades (see text)

System	Case A	Case B	Case C
ATS, intermittent			
Level 1	$ 21,300	$ 40,000	$ 67,000
Level 2	172,300	201,000	275,000
Level 3	291,300	461,000	532,000
Per Equipped Loco	27,500	27,500	27,500
ACS/ATC, continuous			
Level 1	$ 26,400	$ 50,000	$ 85,000
Level 2	177,400	219,000	302,000
Level 3	296,400	478,000	560,000
Per Equipped Loco	43,000	43,000	43,000

Note that the costs to equip the locomotive fleet with compatible train control equipment must be separately computed based on the fleet size appropriate for the application, including passenger and freight locomotives.

4.11 IMPLICATIONS FOR INCREMENTAL HSR DEVELOPMENT

- Some sort of train control system is required to advance beyond 125 km/h (79 mph) operating speeds. Any of the systems described in this chapter will satisfy the FRA requirements, with intermittent ATS being the least expensive system. As of the present time, speeds up to 175 km/h (110 mph) may be achieved within the FRA track regulations. Speeds higher than 175 km/h (110 mph) require a waiver or special approval on an application-by-application basis which amount to a conditional safety permit to operate at higher speeds than those now encompassed by the regulations. FRA may update its track safety standards to encompass operating speeds above 110 rnph in the relatively near future. It is likely that operations above 175 km/h (110 mph) would require a full ATC (universal speed control) system in place, with positive speed control of all trains in effect; i.e., no relief from the provisions of 49 CFR 236.566, and all trains being equipped at the highest train control level. This is now the requirement in the Northeast Corridor, operating at 200 km/h (125 rnph), following the Chase, Maryland, accident in 1987. At some point in the speed spectrum, positive speed control of civil restrictions as well as route restrictions may also become an FRA requirement.

- Moving block technologies will not be required for many incremental corridors where train densities are not extremely high and very short headways are not required. Their use will be in specialized applications approaching rail transit densities.

- Some sort of ATCS application in the long run will undoubtedly take over many of the functions performed by the more conventional signal and train control systems described here. In order to maintain broken-rail protection, track circuits will probably continue to be used in combination with ATCS on passenger lines. As the pace of development of ATCS applications has been relatively slow, as has the development of U.S. high-speed rail systems and the safety regulations they will operate under, it is prudent at this juncture to consider relatively conventional solutions to meet the train control requirements in implementing incremental HSR.

- The major drawbacks of train control systems are their significant initial cost and their reputation for high ongoing cost of maintenance. Systems, presently available, are of high reliability and require modest operating costs. To date, the high cost of train control has been considered a justifiable expenditure, required to meet the high safety performance expected of high-speed passenger rail systems. However, it is to be hoped that present development efforts on advanced train control systems will result in lower cost systems able to meet high-speed rail performance requirements.

5. SAFETY ANALYSIS OF PASSENGER TRAINS IN FREIGHT RAILROAD CORRIDORS

5.1 INTRODUCTION

When the operation of higher speed and more frequent passenger train services on freight railroad corridors is proposed, two principal concerns are raised:

- There is a risk of high-speed collisions and derailments, which could result in less-that-acceptable safety performance.
- There will be operations conflicts between passenger and freight trains, potentially leading to unacceptable delays to either or both classes of train.

This chapter and chapter 6 address the safety concerns, and analyze the options for achieving acceptable safety performance with mixed freight and passenger service. The accident risks faced by passenger trains operating in freight corridors are quantified, and estimates are developed for how these risks will change when a more frequent high-speed train service is introduced, and when additional safety measures such as improved signal and train control systems are implemented.

Higher speed passenger trains operating on freight railroad corridors are exposed to a variety of accident risks that can broadly be grouped as follows:

- Collisions between trains, usually caused by human error on the part of train crew or the dispatcher, but also occasionally by signal system defects or other plant or equipment defects.
- Collisions between a passenger train and an obstruction on the track, including collisions with a derailed or defective freight train on an adjacent track.
- Derailment of a passenger train caused by a track or equipment defect, or by a human error such as an incorrect switch setting or excessive speed.
- Collision of a passenger train with a highway user at a highway-railroad at-grade crossing.

In addition, there are two other accident situations which do not normally threaten the safety of the passenger train itself, but may be of significance when considering higher speed passenger operations on freight railroad corridors:

- Personal casualties resulting from passenger train operations, other than in train accidents.
- Freight train accidents that do not involve a passenger train, but which could disrupt or delay normal operations.

Before analyzing the need for safety improvements on rail freight corridors where high-speed passenger rail services are under consideration, it is necessary to quantify the safety performance of passenger trains on freight railroad corridors under current operating conditions. This information provides the basis for first estimating how safety performance could change with increasing train frequency and speed, and then determining the need for additional safety measures to maintain acceptable safety performance. This chapter describes the analysis to quantify the present safety performance of rail passenger services on freight railroad corridors.

5.2 GENERAL APPROACH

Accident frequency and severity information is developed for each of the six accident situations or scenarios listed in Section 5.1. Calculating safety performance by scenario provides a clear understanding of the nature of safety threats faced by passenger trains operating in freight railroad corridors, and the base data from which to estimate the change in safety performance with higher speed, and with the application of additional safety measures.

The safety performance of present Amtrak rail passenger services operating over freight railroad corridors was selected as the baseline for this study, as representative of present operating conditions on the Section 1010 corridors over which high-speed passenger services may be implemented in the future. Section 1010 corridors can be characterized as follows, based on the data presented in the Appendix:

- Normal maximum speed of 127 km/h (79 mph), reducing to 95 km/h (59 mph) in some locations, and lower speeds in station and terminal areas.

- Track quality mostly FRA track class 4, with some class 3, class 5, and class 6 (in the Northeast and Empire corridors).

- Almost all routes equipped with CTC or ABS.

- Track having a mix of welded and bolted joint rail on wood ties with cut spike rail-tie fastenings, with little use of concrete ties and elastic rail-tie fastening systems.

The analysis is concerned with safety performance on main-line track. Passenger train accidents on yard and siding tracks have not been analyzed, on the assumption that yard accident risks would not be affected in any systematic way by the introduction of high-speed train services.

The safety performance assessment utilized the accident data in the FRA Railroad Accident/Incident Reporting System (RAIRS), containing railroad and highway-railroad grade-crossing accidents and incidents, for the years 1986 through June 1993 [Refs. 21 and 22]. Since the frequency of passenger train accidents while operating on freight railroad tracks is relatively low, the analysis of historical accident data needed to cover as long a period as possible, while still remaining representative of present safety performance. The 7.5-year period, from 1986 to mid 1993, selected for analysis reflects this requirement. Since 1986, U.S. railroad accident rates have stayed approximately constant, but were generally higher in earlier years. Passenger train-kilometer data for this period on and off the Northeast Corridor were obtained from Amtrak. Freight train-kilometer data were obtained from the Analysis of Class I Railroads, published by the Association of American Railroads [Ref. 23]. Grade crossing inventory data were obtained from the Volpe National Transportation Systems Center.

These data were used to derive accident frequency and severity, as defined below, for each of the six accident scenarios for passenger trains operating on freight railroad corridors:

- Accident Frequency: the number of accidents occurring for a specified amount of exposure to the risk of an accident, such as the average number of accidents per million train-kilometers.

- Accident Severity: the average number of casualties per accident and/or the average property damage ($) per accident, as a function of train speed and other factors.

Descriptions of typical accident causes and consequences in each scenario are provided, obtained from the short accident descriptions given in the accident reports and the accident cause data contained in the FRA databases.

In addition, analysis results are presented graphically to illustrate specific trends and support hypotheses regarding the effect of speed and other parameters on accident frequency and severity.

5.3 DESCRIPTION OF ACCIDENT SCENARIOS

The six accident scenarios to which passenger trains operating in freight railroad corridors are exposed are described below. The scenarios enable the separate characterization of accidents that have distinctly different causes, severity of consequences, and applicable safety improvement actions.

5.3.1 Scenario 1: Train-to-Train Collisions

This scenario covers head-on and rear-end collisions between trains operating on the same track. Such collisions tend to be the most serious of train accidents, leading to severe consequences in terms of human casualties and property damage. The causes of train-to-train collisions are predominantly human error, for example a failure to obey signals and operating instructions, but occasionally are an equipment failure, for example of a signal or braking system. The primary improvement to reduce the incidence of train-to-train collisions is to install an ATC system to warn or override the train operator when signals or other instructions are not obeyed.

5.3.2 Scenario 2: Collision with an Obstruction

This scenario covers all collisions with obstructions other than with another train on the same track. Such obstructions can include debris on the track, maintenance and construction equipment, and an intrusion of vehicles from a derailed train on an adjacent track. Collisions in this scenario tend to be less severe than in the train-to-train scenario because the mass of the obstruction is less, or the collision is at an angle. The causes are very varied, and include severe weather, vandalism, equipment failure in the case of a derailed train on an adjacent track, and human error in the case of maintenance or construction equipment obstructing the track. Additional safety measures to reduce the incidence of obstruction collisions are similarly varied, and can include intrusion or obstruction detectors, barriers and fences, and train control enhancements, for example to reliably locate on-track maintenance equipment.

5.3.3 Scenario 3: Passenaer Train Derailment

In this scenario, a passenger train leaves the track without the involvement of another train or an obstruction on the track. The usual causes are a mechanical failure of a vehicle component such as a wheel or bearing, a failure of a track component, or human error in the form of excessive speed. The consequences of derailment accidents are highly variable, particularly depending on the immediate surroundings of the track at the derailment location. Additional safety measures to reduce the incidence of derailments include enhanced inspection and fault detection systems, and improved train control systems for overspeed accidents.

5.3.4 Scenario 4: Highwav-Railroad Grade Crossing Collision

This scenario covers all collisions between a train and a highway user at a highway-railroad grade crossing, irrespective of whether the collision results in significant damage or casualties on the train or not. The cause of highway-railroad grade crossing collisions is almost always a failure of the road user to obey warnings or exercise adequate caution at the crossing. However, restricted visibility of the railroad right-of-way, traffic congestion in the vicinity of the crossing, and an uneven highway surface can contribute to accident risk. The consequences of highway-railroad grade crossing collisions are severe for the road user but normally minor for the train. The exceptions are when the highway vehicle is a truck carrying a hazardous material, or when the highway vehicle is exceptionally heavy. Additional safety measures to reduce highway-railroad grade crossing collisions include improved warning systems and bamers, and systems to warn an approaching train of an obstructed crossing.

5.3.5 Scenario 5: Personal Casualties

This scenario is the first of two accident scenarios that do not involve an accident to passenger trains, but are of significance when planning higher speed passenger service on a freight railroad corridor. The scenario covers all personal injuries and fatalities directly attributable to passenger train operations, except those in highway-railroad grade crossing collisions. Such casualties include persons on the right-of-way that are hit by a moving passenger train, and passengers or train crew who become casualties in an event other than a train accident. By far the most prevalent type of accident in this scenario is a person struck by a moving train while trespassing on the railroad right-of-way. Additional safety measures to reduce personal casualties include security fencing at high-risk locations, and education programs in communities along passenger train routes.

5.3.6 Scenario 6: Freiaht Train Accident

This scenario is the second of two accident scenarios that do not involve an accident to a passenger train. An accident only involving freight equipment is not necessarily a threat to the safety of passenger operations. In most cases, a passenger train will be warned of a potential danger before reaching an accident location. Those cases where the passenger train is not warned, and a collision with derailed equipment occurs, are covered in Scenario **2.** However, such a derailment will typically block operations for several hours while the wreck is cleared, and severely disrupt normal passenger service even when there is no direct passenger train involvement. This disruption is a form of interference between freight and passenger service that may impact the quality of passenger service. The causes of **freight** train accidents are the full range of track defects, equipment defects, and human errors mentioned in the descriptions for accident scenarios 1 through 4. In most cases, the additional safety measures proposed to reduce the incidence of passenger train accidents will also reduce the incidence of freight train accidents on the same route.

5.4 ANALYSIS OF ACCIDENT DATA

This section describes the analyses performed for each accident scenario to quantify accident frequency and severity, and to characterize the operating environment in which the accidents occurred. The subsections for each scenario contain a description of the data sources used, as well as graphs and charts illustrating results.

5.4.1 Scenario 1: Train-to-Train Collisions

5.4.1.1 Data Analysis

The data for this scenario comprise the total number of freight-train to freight-train collisions, passenger-train to freight-train collisions, and passenger-train to passenger-train collisions (head-on or rear-end types only) that occurred on mainline track operated by freight railroads. Accidents on track operated by Amtrak and commuter railroads were excluded as potentially unrepresentative of the safety performance of passenger trains on a freight railroad corridor. Routes operated by Amtrak and commuter railroads, such as the Northeast corridor, are characterized by dense passenger traffic, a high-performance ATC system, and little freight traffic. These characteristics are very different from a freight railroad corridor.

The data gave the following breakdown of head-on and rear-end collisions on mainline track during the study period of 1986 to June 1993:

freight-train to freight-train collisions:	- All track classes	221
	- FRA Class 4	74
passenger-train collisions with a freight- or passenger-train		4

There are too few passenger train collisions to yield a meaningful value for accident frequency. Therefore, the freight train collision frequency for FRA track class 4 was used as the estimate for passenger train collision frequency. Since collisions are primarily a result of human error, rather than track or equipment failure, there should be no significant difference in accident frequency between freight and passenger trains. However, it is recognized that special care is normally exercised in operating passenger trains, which could result in a lower incidence of human error accidents than with freight trains under similar operating conditions. FRA track class 4 was selected because it most closely corresponds in signal system type and traffic density to routes used by passenger trains.

The collision data were broken down by FRA track class (1 to 6) and within each track class by traffic density in million gross tons per year (MGT/yr) and signal system grouping. The traffic density and signal system breakdowns are used to illustrate the operating environment on each track class.

Figure 5-1 shows the distribution of freight-train to freight-train collisions by track class. Approximately two-thirds of the collisions between freight trains occurred on track classes 3 and 4.

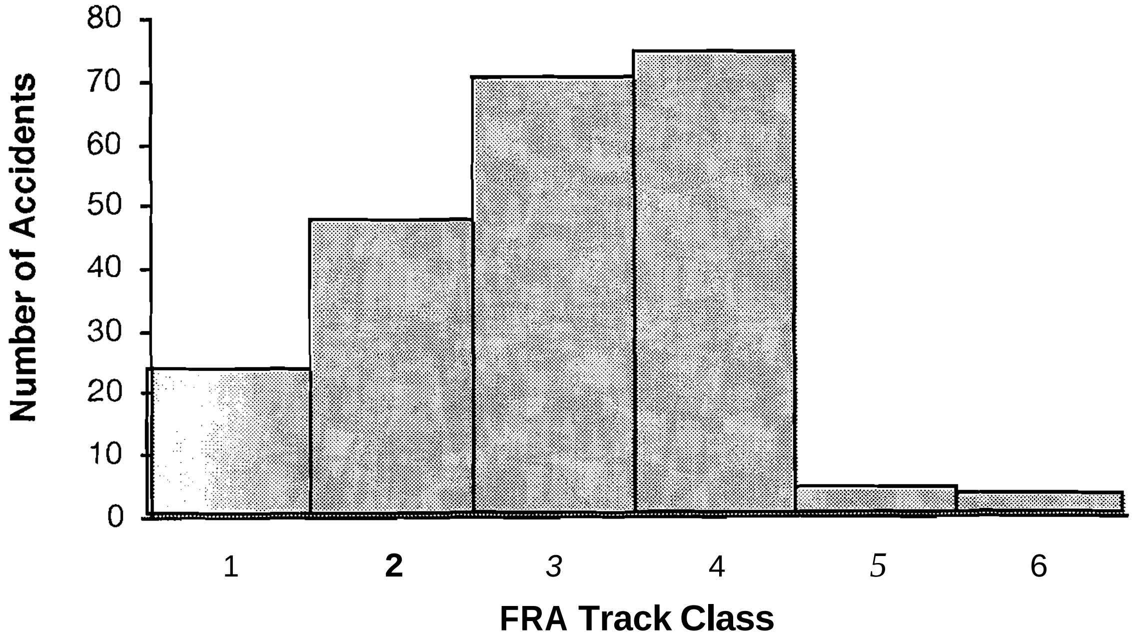


Figure 5-1. Distribution of Freight Train-to-Train Collisions by FRA Track Class

Five signal system groups represent the hierarchy of traffic control systems used on both freight and passenger routes. Accident counts were obtained by signal system type, providing an approximate indication of the types of train control systems used on each track class. The five signal and train control groups are as follows:

Group 1.	Cab signal, automatic train control, and automatic trainstop systems.
Group 2.	Centralized traffic control in combination with any other system not contained in group 1.
Group 3.	Automatic block signaling in combination with any other system not contained in groups 1 and 2.
Group 4.	Interlocking or manual block signals in combination with any other system not contained in groups 1, 2, and 3.
Group 5.	Any signal system not contained in groups 1, 2, 3, and 4.

Figure 5-2 shows the distribution of freight train collisions by signal system group within each track class. In collisions on track classes 1 and 2, the predominant signal system is group 5 (i.e., train orders, timetable, radio, and verbal permission), which have more human interaction and thus a higher risk of accidents. In the collisions on track classes 3 and 4, the predominant signal systems are groups 2 and 3 (e.g., CTC and ABS). The remaining one-third of the collisions on track classes 3 and 4 occurred on track equipped with groups 4 and 5 signal systems (e.g., manual block, interlocking, timetable, and train orders).

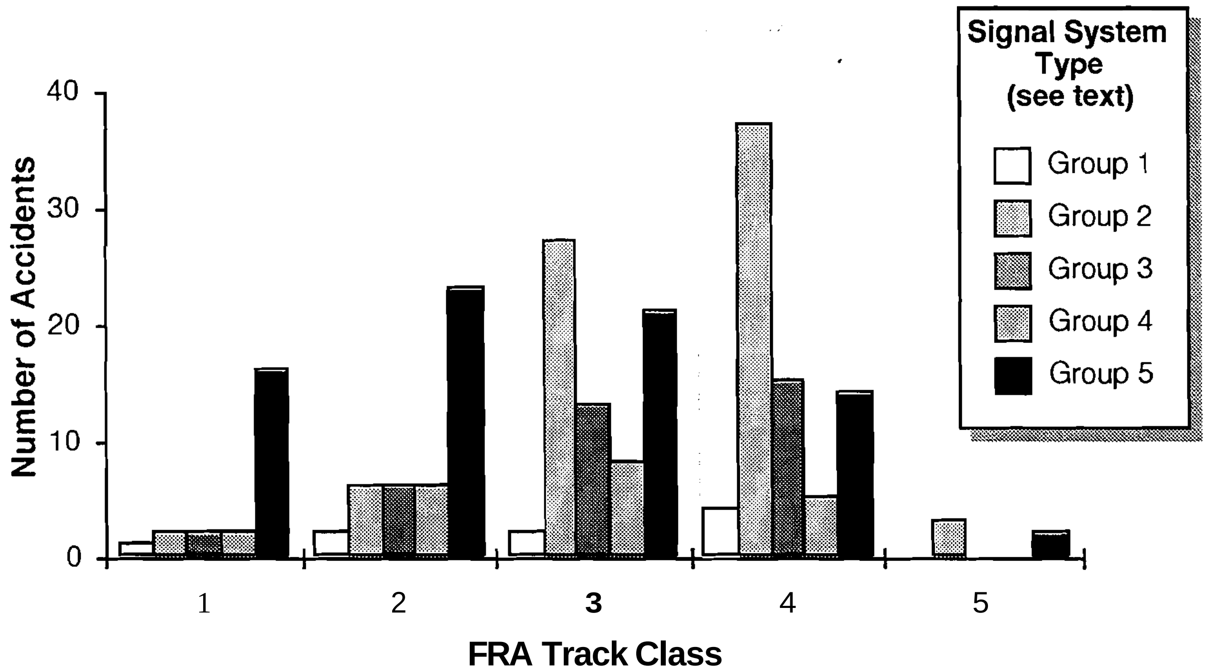


Figure 5-2. Distribution of Freight Train-to-Train Collisions by FRA Track Class and Signal System Type

Figure 5-3 shows the distribution of the freight train collisions by traffic density within each track class. In general, higher traffic density means a greater number of meets and passes, thereby increasing the risk of collision. However, the analysis shows no clear trend in accident distribution by traffic density or track class. Possibly, the higher risks at higher traffic densities and higher speeds are offset by the use of higher performance signaling and train control systems.

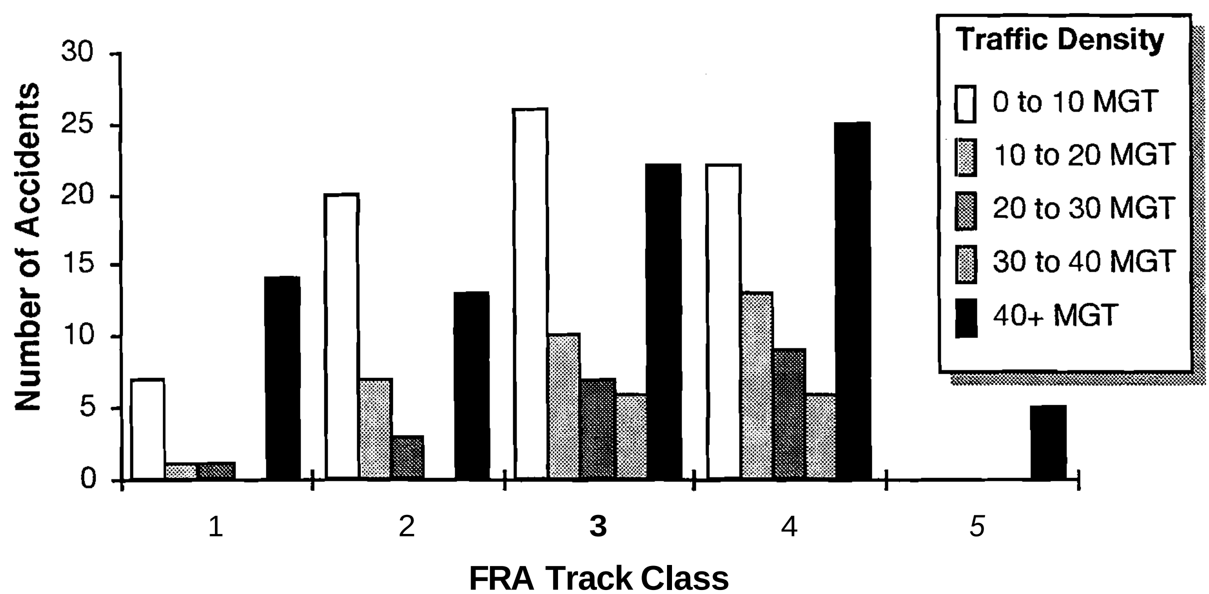


Figure 5-3. Distribution of Freight Train-to-Train Collisions by FRA Track Class and Traffic Density

5.4.1.2 Accident Frequency

Accident frequency is measured by the number of trains in collisions per million train-kilometers, for which an estimate of accident exposure as measured by the number of train-kilometers operated is required. Since the estimate is based on freight train collisions on FRA class 4 track, the exposure is the number of freight train-kilometers operated on class 4 track. During the 7.5 year study period, Class I freight railroads operated a total of 5294 million train-kilometers (3282 million train-miles) on mainline track, while Amtrak operated a total of 286 million train-kilometers (177 million train-miles) on freight railroad tracks (i.e. off the Northeast Corridor and commuter railroads).

There is no readily available source for the distribution of railroad traffic by track class. The best that can be done is to make an estimate from indirect or incomplete information. Two published sources give an estimated breakdown of freight train-kilometers by track class [Refs. 24 and 25]. Both indicate that the percentage of train-kilometers operated on class 4 track is between 65 and 70 percent. More recent unpublished information suggests a somewhat lower figure, in the region of 60 to 65 percent, would be representative of current conditions. Assuming that 65 percent of freight train-kilometers are on FRA class 4 track, the estimated frequencies for freight train collisions on FRA class 4 track is as follows:

Freight-train to freight-train collisions:	0.022 collisions/million train-km. (0.035 collisions/million train-miles)

Since two trains are involved in each collision, the frequency with which an individual train is in a collision is as follows:

Freight trains in collisions on FRA class 4 track:	0.043 collisions/million train-km (0.069 collisions/million train-miles)

The frequency of trains in collisions involving passenger trains can similarly be calculated from the passenger train-km operated and the number of collisions.

Collisions involving passenger trains on freight railroads:	0.014 collisions/million train-km (0.023 collisions/million train-miles)
Trains in collisions involving passenger trains on freight railroads:	0.028 collisions/million train-km (0.045 collisions/million train-miles)

Given the very small sample of only four passenger train collisions, there can be only limited confidence in these frequency values. The figures derived from freight train data is judged to be more reliable, and is used in subsequent analysis.

5.4.1.3 Accident Severity

The severity of freight-train to freight-train collisions, indicated by total property damage (equipment plus track) per accident, has been plotted by train speed range in Figure 5-4. This plot shows a trend of increasing average damage per accident with speed. The drop in average damage in the 51 - 60 mph speed range may be due to a lack of observations. Overall, the average property damage per accident for this scenario, which involves head-on and rear-end collisions, is much higher than the average damage per accident for other types of collisions, underscoring the severity of this type of accident. Of the two damage categories, equipment damage far exceeds the damage to the right-of-way.

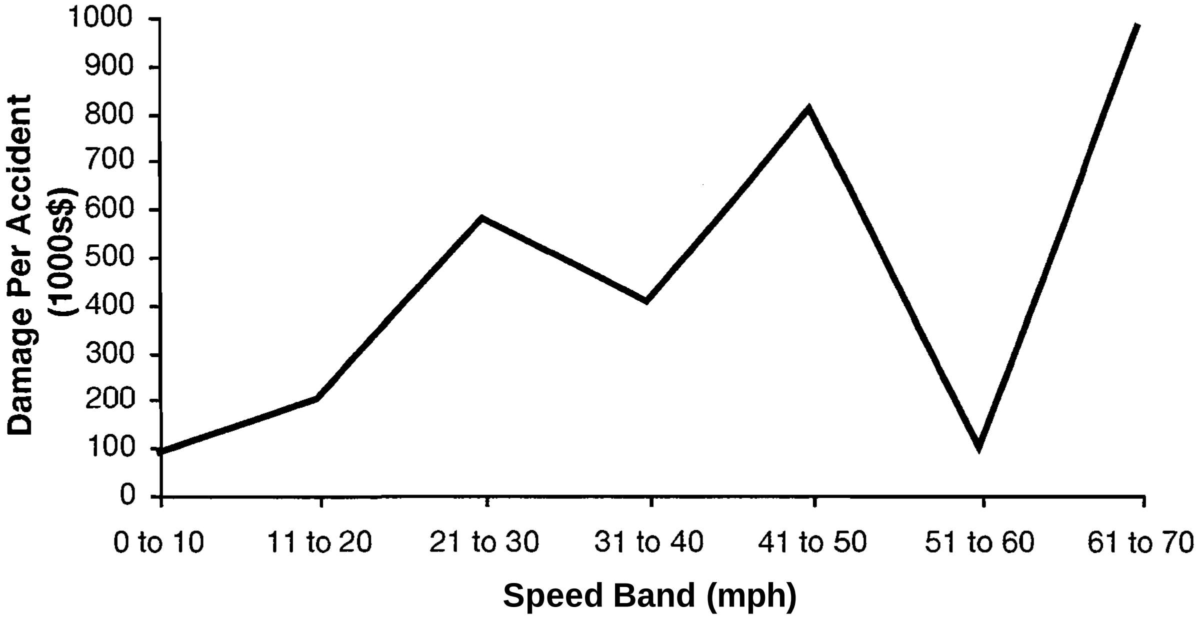


Figure 5-4. Total Property Damage/Accident in Freight Train-to-Train Collisions by Speed

The four passenger train collisions all occurred at low speed (32 km/h (20 mph) or less), and none caused extensive damage. All appeared to have occurred during switching movements and were caused by a human error in transmitting or observing operating instructions.

5.4.1.4 Accident Causes

The principal causes of freight train-to-train collisions on FRA class 4 track are failure to obey signals and operating instructions (approximately 30 percent), employee condition (25 percent), errors in brake operation (15 percent), excessive speed (10 percent), and various equipment failures (10 percent). Signal and communication system failures account for fewer than 5percent of collisions.

5.4.2 Scenario 2: Other Collisions

5.4.2.1 Data Analysis

The data for this scenario is contained in two files. The first file contained "other collisions" for freight trains occurring on mainline track throughout the U.S. rail system, including the Northeast Corridor. The second file contained "other collisions" for intercity passenger trains occumng on mainline track both on and off the Northeast Corridor. Both files cover the period 1986 to mid 1993, and were obtained from the FRA's RAIRS database.

Analysis of the data files yielded the following breakdown of "other collisions" (e.g., side, raking, broken train, and with obstructions) that occurred on mainline track during the study period:

Freight-train "other collisions," all track classes:	443
Freight-train "other collisions," FRA track class 4:	146
Passenger-train "other collisions" on freight railroads:	42

The distribution of "other collisions" by track class is shown in Figure 5-5 for freight trains, and Figure 5-6 for passenger trains. The vast majority (62 percent) of passenger train collisions occurred on Track class 4, the standard condition on the freight railroads that permits passenger train speeds up to 79 mph.

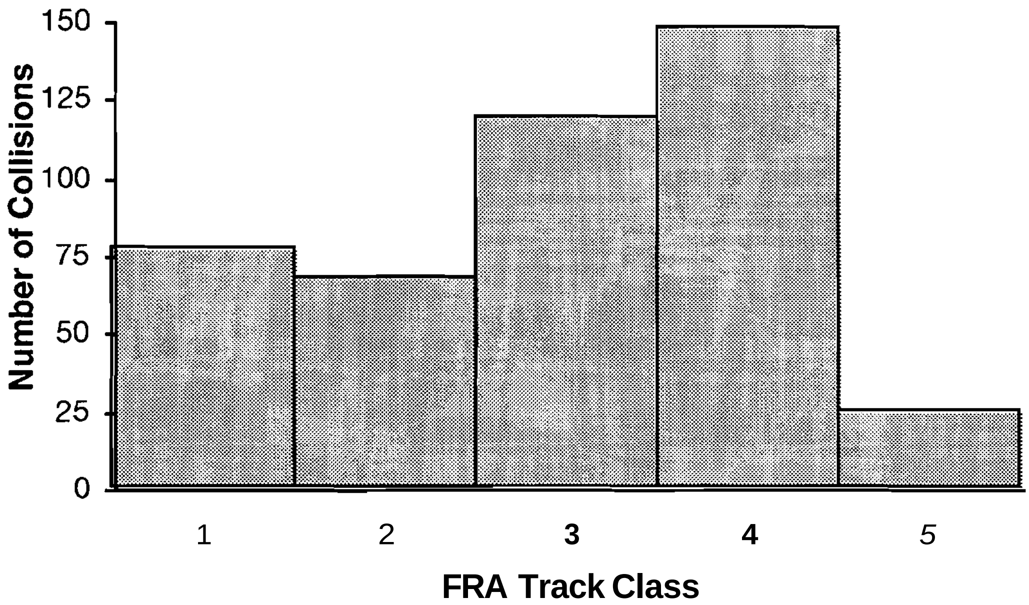


Figure 5-5. Distribution of Freight Train "Other Collisions" by FRA Track Class

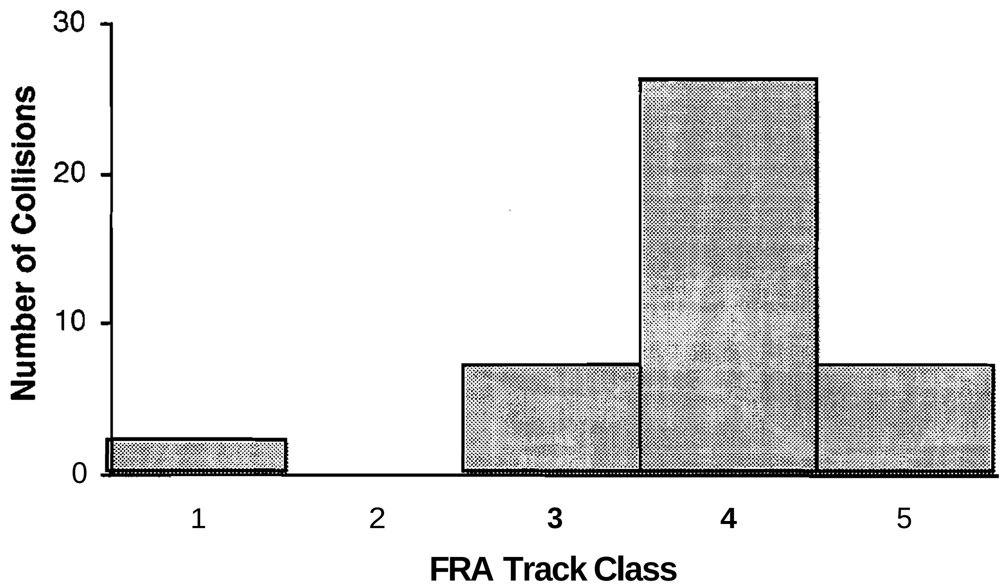


Figure 5-6. Distribution by FRA Track Class of Passenger Train "Other Collisions" on Freight Railroad Tracks

5.4.2.2 Accident Frequency

The frequency of "other collisions" for freight and passenger service was calculated from the number of accidents using the train-kilometer data given in section 5.4.1.2:

All freight train "other collisions":	0.084 accidents/million freight train-km.
Freight train "other collisions" on FRA Class 4 track:	0.068 accidents/million pass. train-km.
Passenger train "other collisions" on freight railroads:	0.147 accidents/million pass. train-km.

The higher incidence of passenger train "other collisions" is likely due to the typically higher speed of passenger trains; a given obstruction will cause more damage, and the event is more likely to be reportable as an accident to the FRA. Also passenger equipment repair costs are typically higher than for freight equipment, again making it more likely that a given collision is reportable as an accident.

5.4.2.3 Accident Severity

The severity of freight train "other collisions," measured by total property damage (equipment plus track) per accident, is plotted by train speed in Figure 5-7. The amount of damage increases as speed increases up to 50 mph but reduces at higher speed. The reason for the reduction in damage beyond 50 mph may be a distortion attributable to a smaller number of accidents in the higher speed groups, but also may be due to a change in the nature of accidents at higher speeds. Further study would be necessary to properly understand this effect.

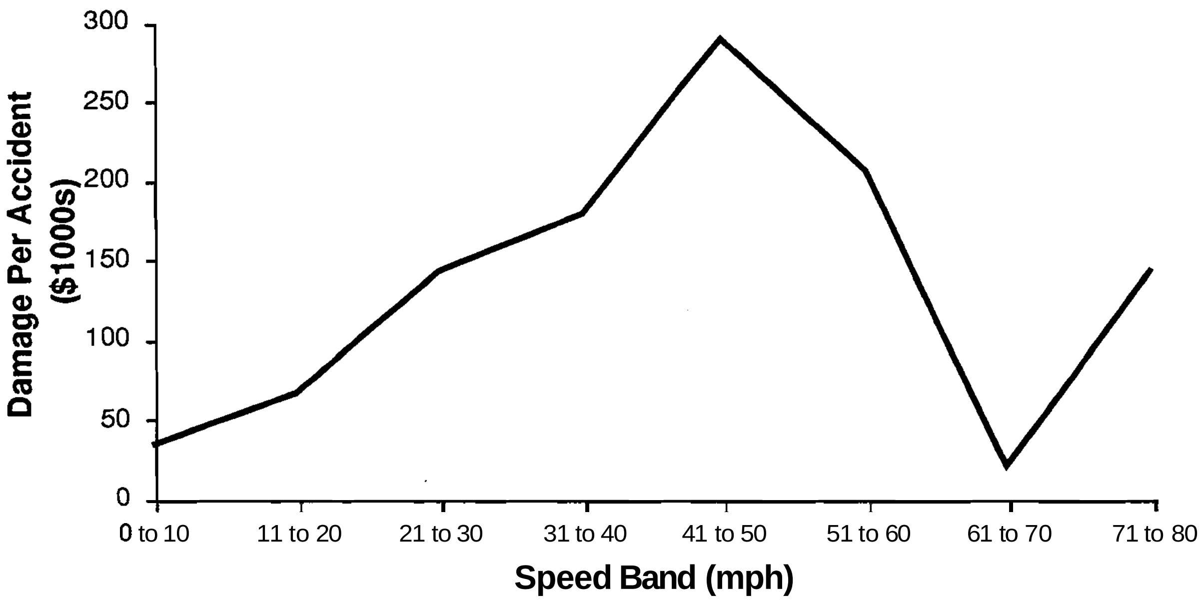


Figure 5-7. Variation of Property Damage by Speed for Freight Train "Other Collisions"

Figure 5-8 shows that average property damage per accident for passenger trains operating on freight railroads varies little with speed, except in the lowest speed range. One of the five accidents in the 0-10 mph range had $206,000 in damages, resulting in a high average value. One explanation for the lack of variation in damage with speed may be that higher-speed operations take place away from urban areas, where there are fewer yards, sidings, and switching activities to produce significant hazards.

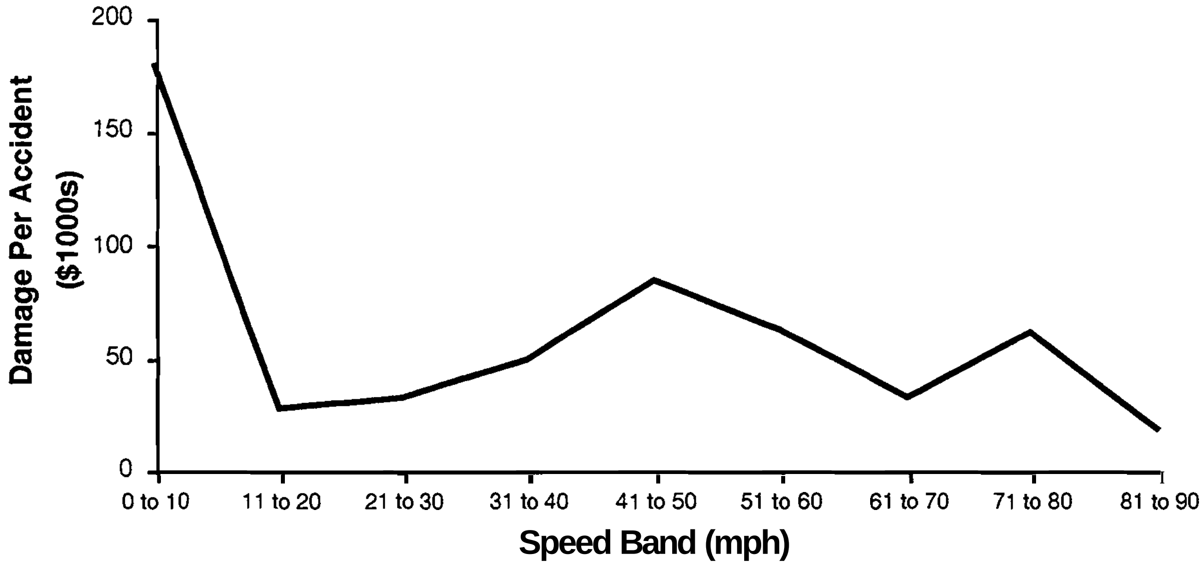


Figure 5-8. Variation in Property Damage by Speed for Passenger Train "Other Collisions"

5.4.2.4 Accident Causes

A sample of "other collisions" occurring on freight railroad tracks was reviewed to determine the distribution of accident descriptions. The sample contained only those accidents that occurred on FRA track class 4, where most Amtrak intercity trains operate on freight railroads. The results showed the following distribution of types of obstruction hit by a passenger train:

Debris on the track, including rockfalls, and objects placed by vandals	33%
Other equipment (trucks, forklift, etc.) fouling the mainline	25%
Maintenance-of-way equipment fouling the mainline	17%
Derailed or not-in-clear freight trains on adjacent track	17%
Freight car or other loose/shifted equipment that was fouling the mainline	8%

5.4.3 Scenario 3: Passenaer Train Derailments

5.4.3.1 Data Analysis

The data for this scenario contained Amtrak passenger train derailments that occurred on mainline track on freight railroad corridors. Commuter rail derailments were excluded. The analysis yielded 48 Amtrak passenger train derailments during the study period.

5.4.3.2 Accident Frequency

During the 7.5 year study period, Amtrak operated a total of 286 million train-kilometers (177.02 million train-miles) on freight railroad mainline tracks. Therefore, passenger train-derailment frequency on freight railroad track is estimated to be 0.168 derailments/million train-km.

A distribution of the 48 derailments by track class is shown in Figure 5-9. Since most Amtrak train-kilometers on freight railroads are accumulated on FRA track class 4 or higher, one would expect that most of the derailments would be on these track classes. However, about 40percent of the accidents occur on FRA track classes 1 and 2. Clearly, low-speed derailments on lower quality track are a feature of present passenger train operations on freight railroad track. A more detailed examination of the track class 1 and 2 accidents is provided in section 5.4.3.4.

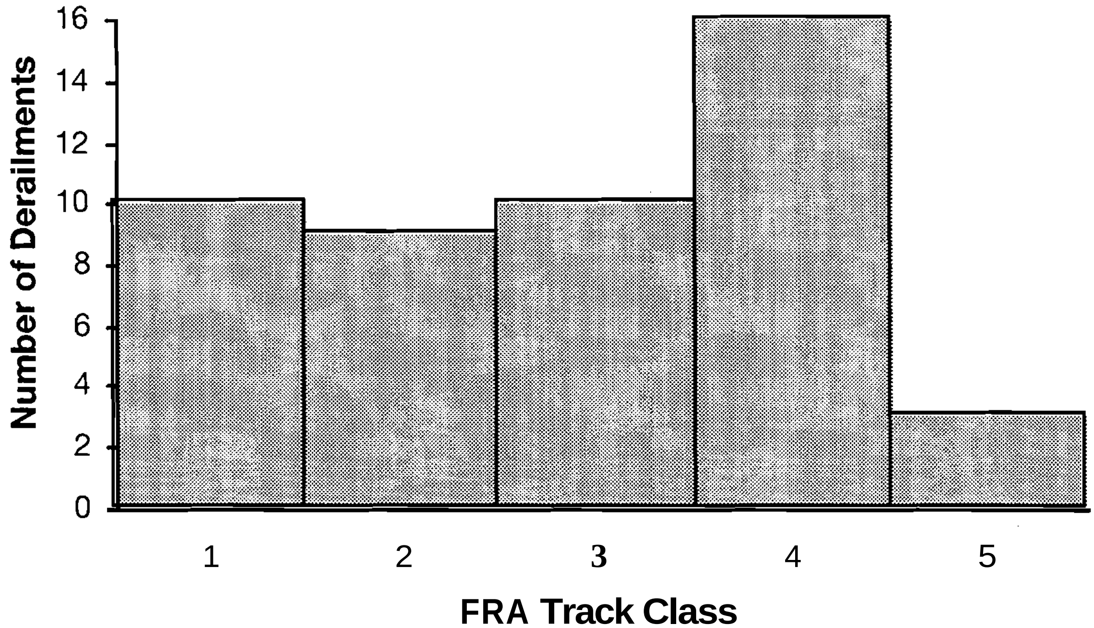


Figure 5-9. Distribution of Passenger Train Derailments on Freight Railroad Track by FRA Track Class

5.4.3.3 Accident Severity

The severity of Amtrak passenger train derailments was computed as the average property damage (equipment plus track) per accident, and plotted by train speed group as shown in Figure 5-10. The results showed a sharp increase in average cost at 40 mph, but no significant trend above and below this point.

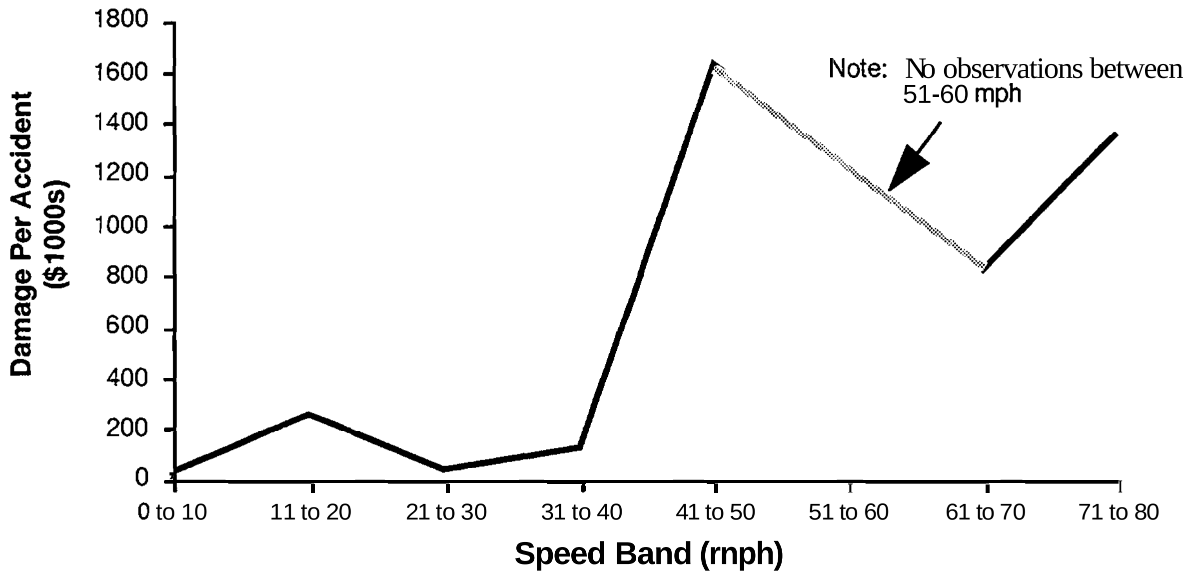


Figure 5-10. Variation of Property Damage by Speed for Passenger Train Derailments on Freight Railroads

5.4.3.4 Accident Causes

Of the 48 reported derailments over the 7.5 year study period, 19 occurred on track classes 1 and 2. The accident description and cause codes were examined to gain additional insight into the causes of these derailments. The descriptions of the low speed derailments indicated the following:

- 42 percent involved splitting the switch at crossovers due to worn/gapped points or excessive speed.
- 21 percent were due to other track-related defects, including wide gauge, broken rail, and rolled over rail.
- 21 percent involved reverse moves of the trainset over a switch to wye the train.
- 16 percent were due to other causes such as debris/equipment fouling the track, snow/ice buildup on switches, and train emergency braking at red signal.

The majority of these low-speed derailments (84 percent) were attributable to switch and track-related defects that are potentially preventable by improved track maintenance.

The causes of derailment accidents on the higher class tracks are approximately evenly distributed between track defects, equipment defects, human errors, and miscellaneous causes such as vandalism. The accidents also take place at higher speeds and are much more damaging.

5.4.4 Scenario 4: Hiahwav-Railroad Grade Crossina Collisions

5.4.4.1 Data Analysis

The data developed for this scenario were obtained from the highway-railroad portion of the RAIRS database, and covered passenger highway-railroad grade crossing collisions occurring on freight railroad mainline track that involved Amtrak intercity trains. Commuter trains were excluded. A subset of these grade crossing collisions also involved damage to railroad plant and equipment and passenger casualties above the reporting threshold, and, as such, was the subject of a rail equipment accidendincident report.

During the period of 1986 through June 1993, there were a total of 1,111 grade crossing accidents involving Amtrak intercity passenger trains operating on freight railroads. A total of 161 of these accidents resulted in damage to the plant and equipment above the reporting threshold, requiring a rail equipment accidendincident report to be filed.

5.4.4.2 Accident Frequency

The frequency of grade crossing collisions was calculated in terms of the number of collisions per million times a train passes over a grade crossing. In order to compute the accident exposure for this scenario, it was necessary to determine the average number of grade crossings per route-kilometer along corridors where Amtrak currently operates on freight railroads. The national average of grade crossings per mile from the DOT/FRA National Rail-Highway Grade Crossing Inventory, and from the 1010 corridor data was used to obtain the exposure estimate of 0.6 grade crossings per route-kilometer (1.0 grade crossings/route-mile). Multiplying by the total number of passenger train-kilometers operated on freight railroads during the study period yielded 177 million rail-highway grade crossing passes per year. The resulting accident frequencies were:

- 6.3 accidents per million grade crossing passes for all grade crossing accidents.
- 0.91 accidents per million grade crossing passes for accidents causing rail equipment and track damages exceeding the FRA reporting threshold.

Figures 5-11 and 5-12 show the distribution of the 1,111 grade crossing accidents and the 161 more-severe grade crossing accidents by speed group. As shown, the majority of the accidents in both cases involve passenger train speeds in the 65 to 130 km/h (40 to 80 mph) range with the highest number occurring in the 115 to 130 km/h (71 - 80 mph) group. The most common speed limit for Amtrak trains on freight railroad track is 127 km/h (79 mph). It can also be seen that the percentage of grade crossing accidents that cause sufficient damage to be reported as train accidents increases from less than 5 percent at speeds below 50 km/h (30 mph) to 25 percent between 115 to 130 km/h (71 to 80 mph).

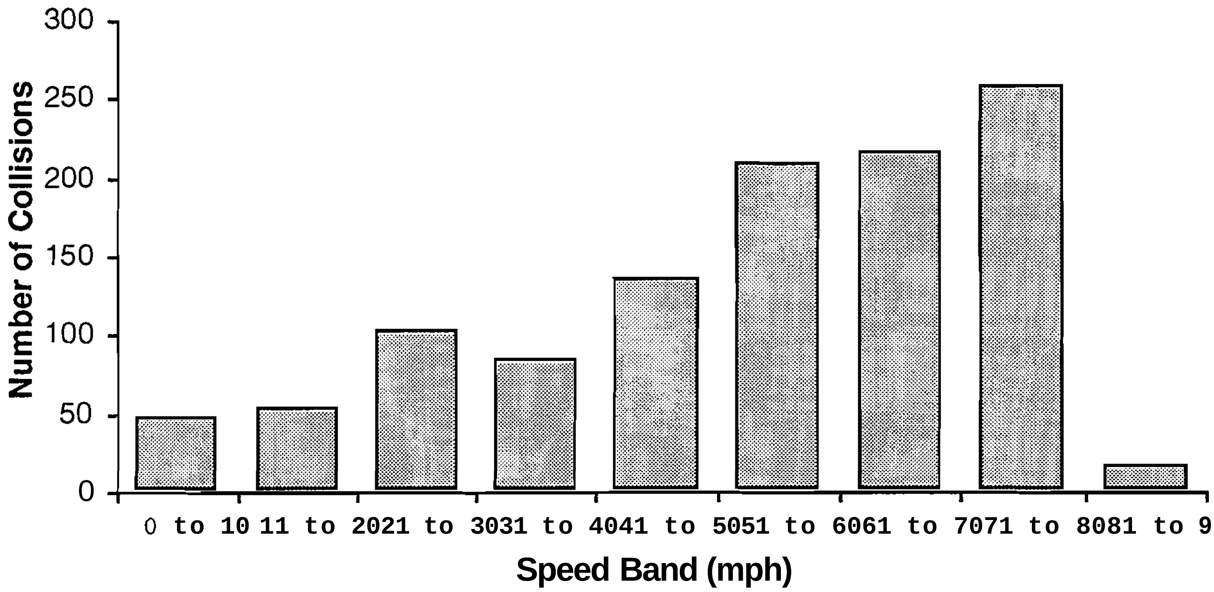


Figure 5-11. Total Amtrak At-Grade Highway-Railroad Crossing Collisions by Speed

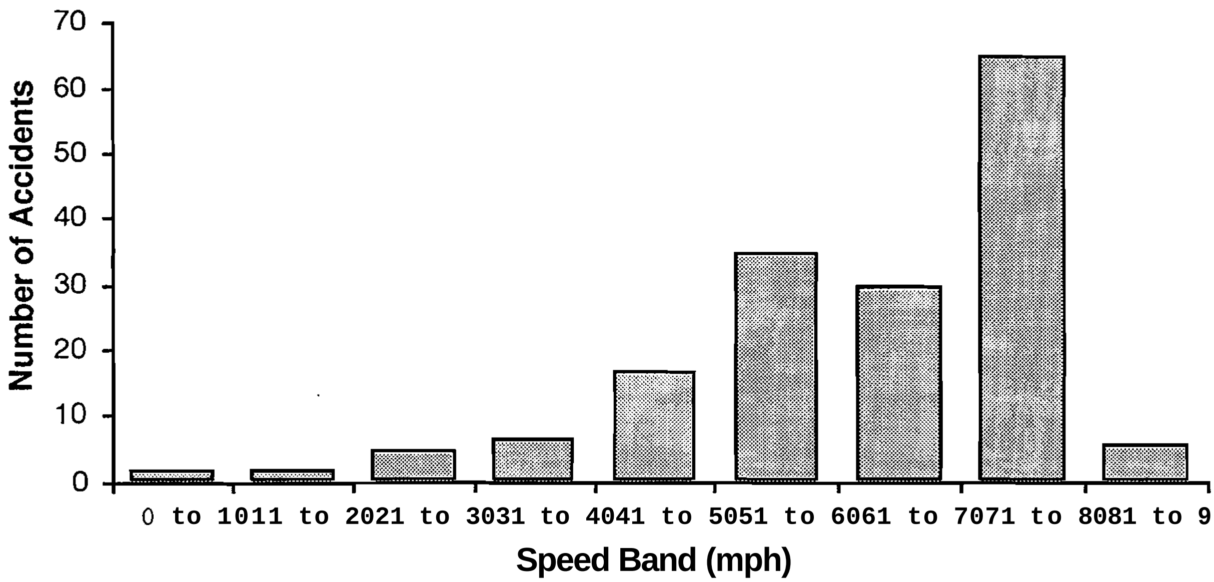


Figure 5-12. Amtrak Grade Crossing Collisions Reported as Train Accidents

5.4.4.3 Accident Severity

Figure 5-13 shows that the average number of casualties per accident increases with speed.

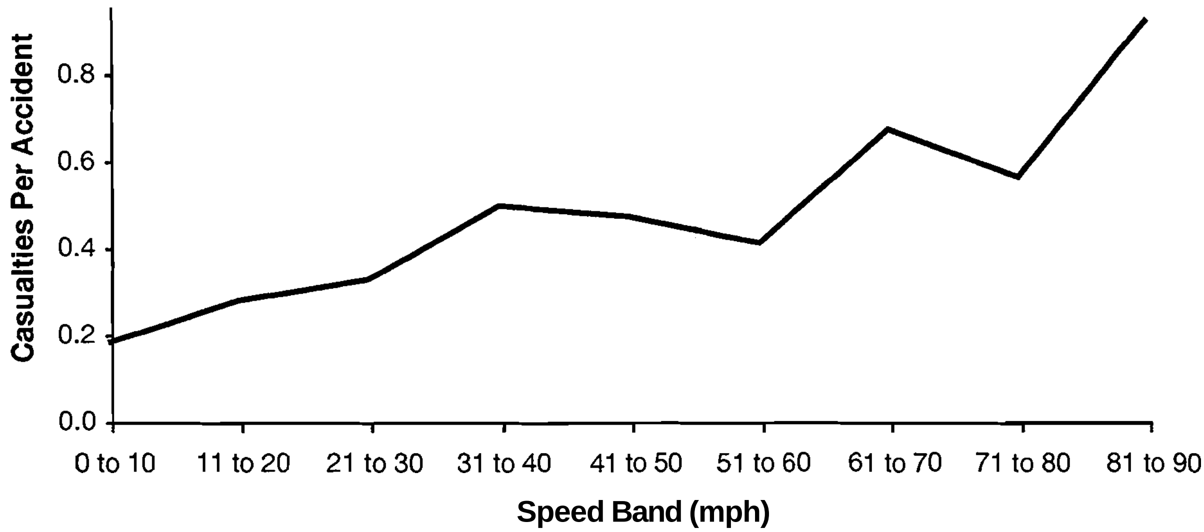


Figure 5-13. Highway Casualties in Highway-Railroad Grade Crossing Collisions by Speed

Figure 5-14 depicts the average total railroad property damage (rail equipment plus track) per accident by speed range, showing that property damages increases as speed increases. Since there were few accidents in some speed ranges, the results can be strongly influenced by one or two extreme cases. For instance, between 50 and 65 km/h (31 and 40 mph) there were only six accidents, but one accident caused $750,000 in property damage, resulting in a high average property damage of $213,482 per accident.

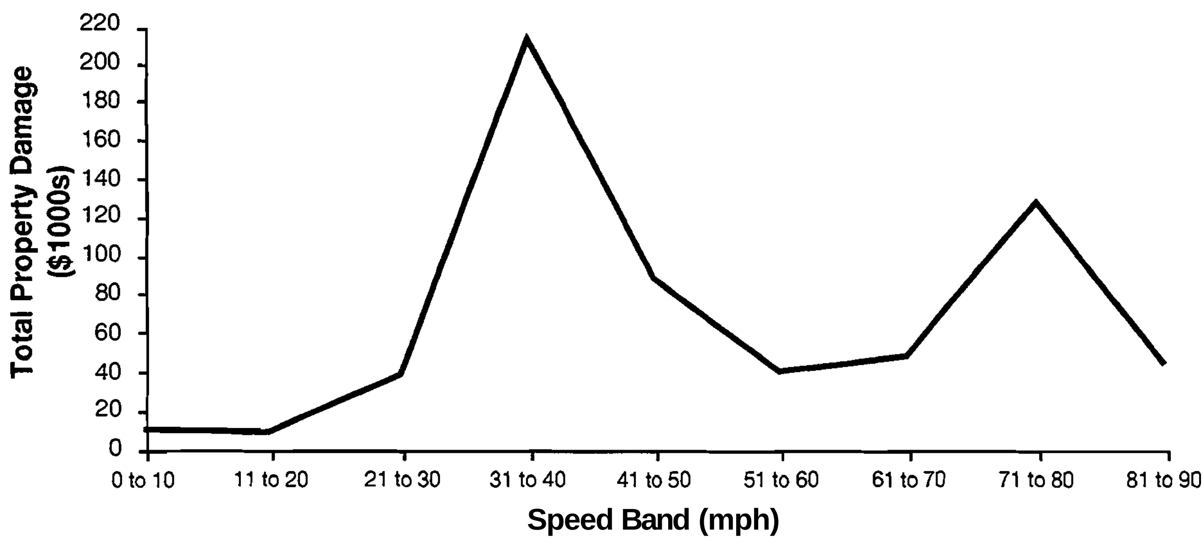


Figure 5-14. Average Railroad Property Damage in Reportable Highway-Railroad At-Grade Crossing Collisions

5.4.4.4 Accident Causes

A sample of 73 of the 161 grade crossing train-accident reports filed by Arntrak were randomly selected to examine the narrative description of the accident. Nearly two-thirds (66 percent) of these accidents were attributed to the driver of the highway vehicle failing to stop at the grade crossing and either being hit by the train or running into the side of the train, apparently at crossings that lacked automatic gates. Another 22 percent of these accidents were a result of a stalled, disabled, or abandoned vehicle fouling the crossing being hit by a passenger train. The remaining 12 percent of these accidents were attributed to the driver of the vehicle running around or through crossing gates in the down position.

5.4.5 Scenario 5: Personal Casualties

5.4.5.1 Data Analysis

The data for this scenario was developed from the injury and illness data in the RAIRS database, and includes only Amtrak passenger trains operating both on and off the Northeast Corridor. The data have not been segregated by type of railroad (passenger or freight) where the casualty occurred. The database included both injuries and fatalities, which were broken down into the following categories describing the type of person and accident:

- Passengers boarding, on-board, and de-boarding passenger trains.
- Employees on duty hit by moving passenger train equipment.
- Contractors hit by moving passenger train equipment.
- Non-trespassers hit by moving passenger train equipment.
- Trespassers hit by moving passenger train equipment.

Casualties having causes other than those listed above are not included. The results of analysis are shown in Table 5-1. The total number of injuries and fatalities occurring in the 7.5 year period for each category of person are given in the first two columns. The totals include casualties occumng in reportable train accidents as well as those incurred in other types of incidents. The third and fourth columns in Table 5-1 give casualty frequencies in terms of injuries and fatalities per million train-kilometers. For comparison, corresponding freight train casualty frequencies are given in columns five and six.

The comparison of the passenger and freight casualty frequencies shows nearly identical frequencies for employees on duty and contractor personnel. In both cases, these personnel receive safety training regarding working along or on the right-of-way, and usually are in radio contact with dispatchers about approaching trains. As indicated in the table, freight railroads report some passenger casualties, presumably arising from commuter services operated under contract, or excursion or dinner train operations.

The total number of reported passenger injuries on freight railroads for the 7.5 year period was 808 versus 1,397 for Arntrak intercity service. This value appears high, but it should be noted that the period reviewed contained a serious excursion train derailment (on the Norfolk and Western RR) with over 200 injuries.

Casualties to non-trespassers (e.g., bystanders not on railroad property, visitors to the railroad, and FRA inspectors) are only slightly higher for passenger train service relative to freight train service.

Table 5-1. Personal Casualties in Train Operations

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

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

The frequency of trespasser fatalities due to passenger train operation is nearly double that for freight trains. This is most likely due to the higher speed of approaching passenger trains which reduces the time that the trespasser has available to get out of the way of the train.

5.4.5.2 Accident Causes

An analysis of the occurrence codes in the RAIRS database yielded the following results for passenger casualties.

A breakdown of the 50 fatalities to Amtrak passengers is shown in Figure 5-15. Approximately three-quarters of the fatalities were in train accidents (collisions and derailments), with the remainder being due primarily to slipping, falling, or jumping from moving equipment.

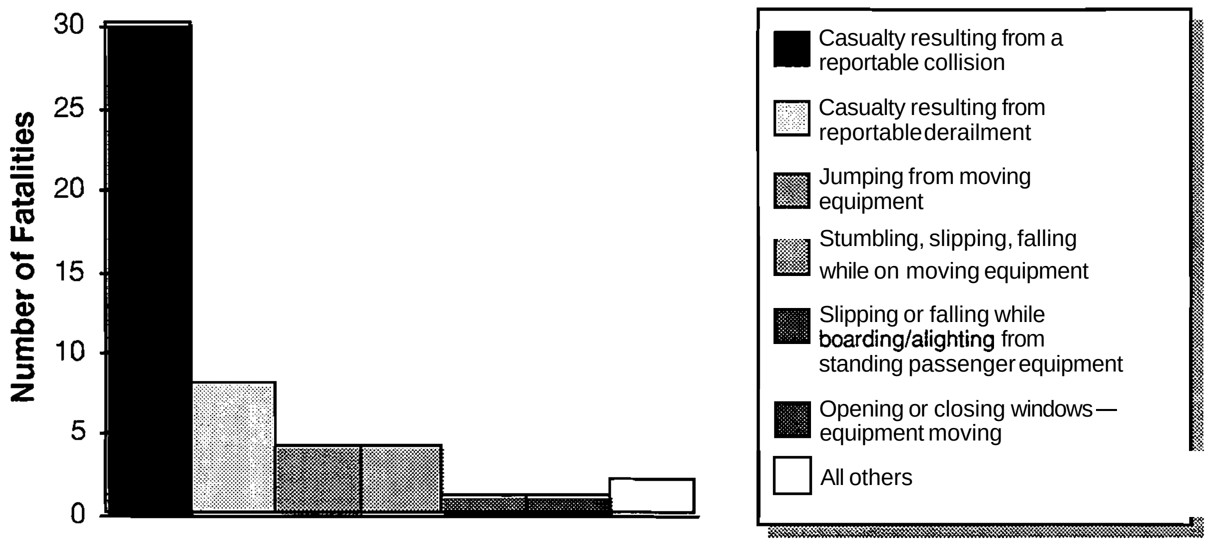


Figure 5-15. Causes of Passenger Fatalities in Amtrak Operations

Figure 5-16 gives the breakdown of the 1397 passenger injuries by cause. Slightly over half of the injuries occur in reportable train accidents. Of the remainder, about 20 percent involved doors and other interior equipment, and another 20 percent comprised various slipping and falling incidents.

All the other casualties listed in Table 5-1 are due to persons being struck by moving equipment in passenger train operations. Other casualty causes have not been examined.

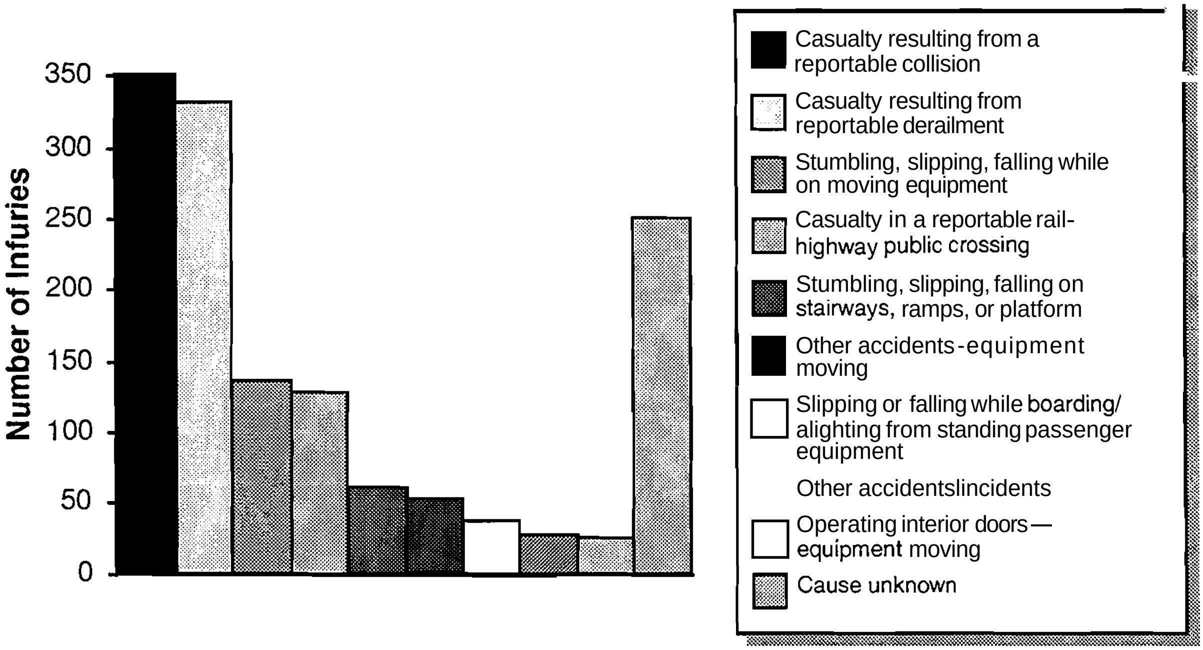


Figure 5-16. Causes of Passenger Injuries in Amtrak Operations

5.4.6 Scenario 6: All Freiaht Train Accidents

The data for this scenario were developed from the FRA RAIRS database, and include all types of freight train accidents occurring on mainline track.

This scenario was analyzed to indicate the delay potential due to freight train accidents temporarily blocking mainline track where passenger trains operate; and to estimate the risk of adjacent track encroachment accidents. The frequency measure used is the number of accidents per million freight train-kilometers by track class.

The analysis of the database yielded a total of 7581 accidents involving freight trains on mainline track during the study period. Figure 5-17 gives a distribution of these accidents by track class. Approximately 29 percent of the accidents occurred on track class 4. Total freight railroad train-kilometers for the 7.5 year study period were 5294 million (3282 million train-miles) and it is estimated that 65 percent of train-kilometers are operated on FRA class 4 track (from section 5.4.1.2). Thus, freight train accident frequency on class 4 track is approximately 0.7 accidents per million freight train kilometers. Approximate freight train accident frequencies have also been estimated in the same way for FRA track classes 2, 3, and 5 and are shown in Figure 5-18. The assumed distribution of freight train miles by FRA track class is 5 percent for class 2; 15 percent for class 3; and 15 percent for class 5. Train miles on class 1 track are assumed to be small, less than 1 percent. It must be emphasized that this distribution is based on sketchy data and must be regarded as indicative of only the order of magnitude of accident frequency variations.

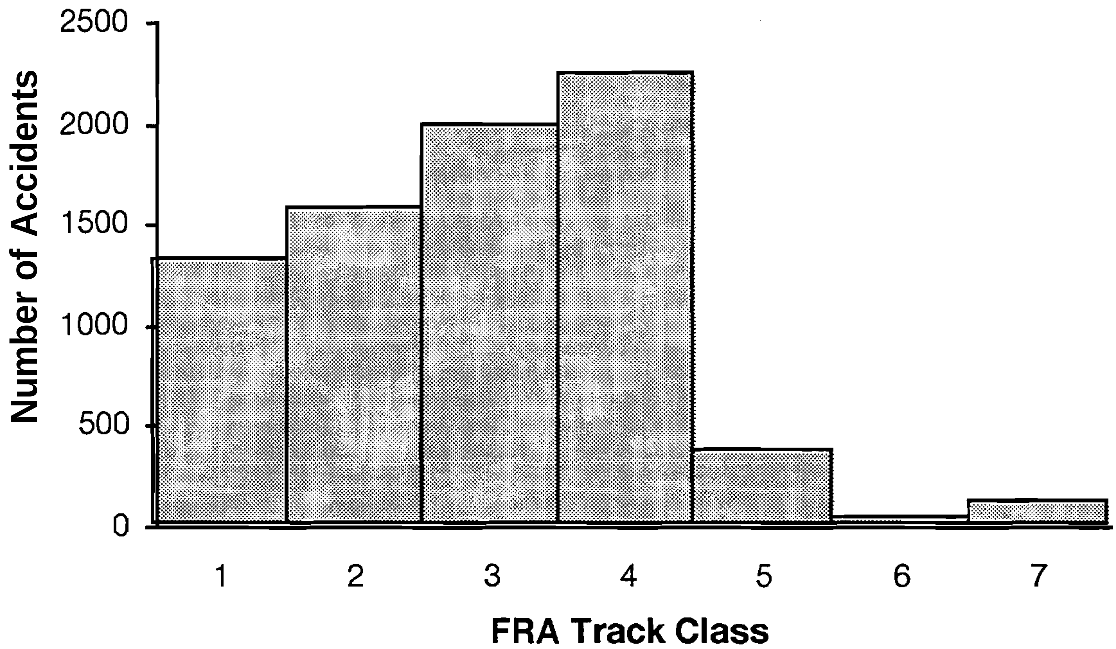


Figure 5-17. Distribution of Freight Train Accidents by FRA Track Class

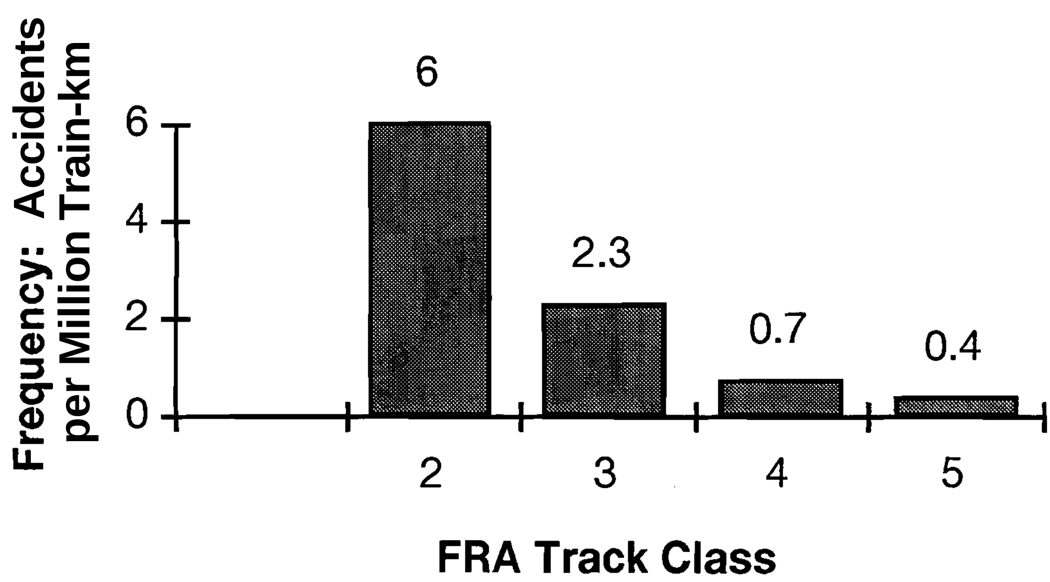


Figure 5-18. Estimated Freight Train Accident Frequency by FRA Track Class

5.5 SUMMARY OF ACCIDENT DATA

Table 5-2 summarizes the accident frequencies and severities for each of the six accident scenarios as discussed above. It is emphasized that these data are for long-distance passenger trains on freight railroad corridors under current operating and infrastructure conditions, as follows:

Typical maximum speed of 127 km/h (79 mph).
Track quality FRA class 4.
CTC or ABS signal system.
Welded or bolted joint rail fastened to wood ties by cut spikes.

With the exception of train-to-train collisions, all the data derive directly from the safety performance of Amtrak passenger trains operating on freight railroads. There were too few passenger train train-to-train collisions to yield meaningful accident data, so freight train collision data on FRA class 4 track are used as the best available source of an estimate.

It is also emphasized that these data are national averages over several years. The actual accident record in a specific corridor can vary significantly from the average as a function of local conditions, and could also vary substantially from year to year. In particular most passenger casualties, especially fatalities, occur in a few serious accidents. Casualty frequencies, therefore, are very dependent on whether the time period selected for analysis includes any very serious accidents.

To illustrate what kind of safety performance would be expected in a typical corridor under present infrastructure and operating conditions, total accident occurrence and railroad property damage in a one-year period have been calculated for the following corridor:

Length 500 km (310 miles).
Passenger service: 24 trains weekdays, and 20 trains weekends and holidays.
Freight service averaging 10 trains daily.
250 highway-railroad at-grade crossings.
Annual train-kilometers:
— Passenger: 4.2 million
— Freight: 1.75 million

Annual passenger-kilometers, assuming a train capacity of 350 seats and a 50 percent load factor, are 726 million (equivalent to 450 million passenger-miles).

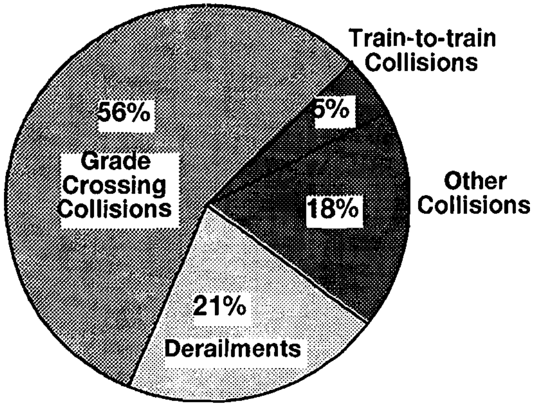
Accident frequencies from Table 5-2 have been applied to the total annual train miles given above to yield the estimate of accidents to passenger trains shown in Table 5-3 and the pie-charts in Figure 5-19.

The pie charts in Figure 5-19 show the distribution by scenario of accident numbers and damage to railroad plant and equipment. Overall, the estimated accident occurrence is for slightly over three reportable passenger train accidents and thirteen grade crossing collisions involving passenger trains per year. The estimated number of freight train accidents in one year is 1.2.

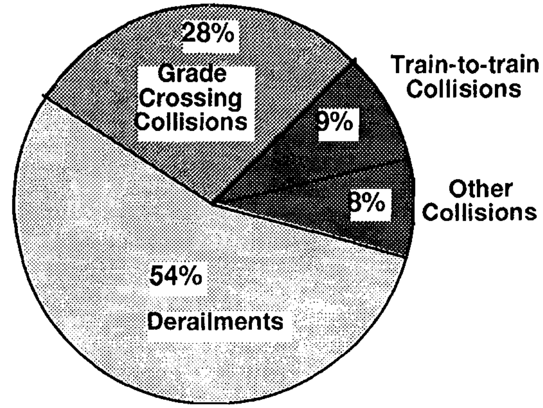
Table 5-2. Summary of Estimated Passenger Train Accident Frequencies and Severities on Freight Railroad Track

<table>
<tr><th>Train/Person Type</th><th>Accident/Incident Type</th><th colspan="2">Accident/Incident Frequency</th><th>Average Accident/Incident Severity</th></tr>
<tr><td rowspan="5">Passenger Train Accidents</td><td>Scenario 1: Train-to-Train Accidents</td><td colspan="2">*0.043 trains in collisions per million train-km</td><td>*$300,000 per train in collision</td></tr>
<tr><td>Scenario 2: Collisions with Obstructions</td><td colspan="2">0.147 collisions per million train-km</td><td>$80,000 per accident</td></tr>
<tr><td>Scenario 3: Derailments</td><td colspan="2">0.168 derailments per million train-km</td><td>$455,000 per derailment</td></tr>
<tr><td>Scenario 4: Rail-Highway Grade Crossing Collisions
All Collisions</td><td colspan="2">6.3 per million crossing passes</td><td>0.49 casualties per accident</td></tr>
<tr><td>Collisions Reportable as Train Accidents</td><td colspan="2">0.91 per million crossing passes</td><td>$86,000 per accident</td></tr>
<tr><td colspan="2">Train-movement personal casualties, except at rail-highway grade crossings</td><td>Injuries</td><td>Fatalities</td><td rowspan="5">Not Applicable</td></tr>
<tr><td colspan="2">Passengers (train accidents and other incidents)
Per million train-km</td><td>3.61</td><td>0.129</td></tr>
<tr><td colspan="2">Per billion passenger-km</td><td>19.6</td><td>0.7
(0.5 in train accidents)</td></tr>
<tr><td colspan="2">Employees/contractors/non-trespassers, per million train-km</td><td>0.23</td><td>0.064</td></tr>
<tr><td colspan="2">Trespassers, per million train-km</td><td>0.43</td><td>1.00</td></tr>
<tr><td colspan="2">All Freight Train Accidents on FRA Class 4 Track</td><td colspan="2">0.7 per million freight train km</td><td>Not Analyzed</td></tr>
</table>

*Derived from data for freight train collisions on FRA Class 4 track. Passenger train collisions too few to yield meaningful data.



Accident Distribution
Total 3.4 Accidents



Railroad Property Damage
Total $580 thousand

Basis

- Estimated Total FRA reportable passenger train accidents in one year on a hypothetical 500 km (310 mile) corridor
- Assumed service — 24 trains/day on workdays
20 trains/day on weekends and holidays

Figure 5-19. Distribution of Passenger Train Accidents and Damage Costs on Hypothetical Corridor

Table 5-3. Estimated Accidents in One Year on a Hypothetical Freight Railroad Corridor

Accident Scenario	Accidents per Year	Total Damage $1000s
Trains in Train-to-train collisions	0.18	53
Other collisions	0.61	49
Derailments	0.70	314
Grade crossing collisions - All collisions - Reportable as train accidents	 13.0 1.9	 ---- 162
Total, All Reportable Train Accidents	3.4	580

The estimated number of personal casualties attributable to passenger train operations in a one-year period are shown in Table 5-4, derived from the passenger train personal casualty frequencies given in Table 5-1. Casualties attributable to freight train operations are not included.

Table 5-4. Estimated Personal Casualties in One Year on a Hypothetical Freight Railroad Corridor Attributable to Passenger Train Operations

Type of Person	Injuries	Fatalities
Passengers (in both train and other types of accident)	15	0.5
Employees, contractors, non-trespassers	1.0	0.3
Trespassers	1.8	4.2
Highway users at grade crossing	5.0	1.3
Total, all Casualties	22.8	6.3

To put the estimated fatality figures into context, the fatality frequency per passenger kilometer derived from the figures in Table 5-4 can be coinpared with equivalent data from other modes of transportation, and other railroad accident studies. Using the passenger kilometer data estimate above, the implied fatality frequencies are approximately 0.7 per billion passenger-km from all causes, and 0.5 per billion passenger-km in train accidents. This result can be compared with a previous analysis of passenger train safety [Ref. 13] which quotes a frequency of 0.35 per billion passenger-km for U.S. intercity rail, using data from a different time period. Approximate fatality frequencies for other modes are 6 per billion passenger-km for motor vehicle occupants, 1 per million passenger-km for commuter air carriers, and 0.2 per billion passenger-km for large air carriers. European railroad fatality frequencies are in the range of 0.2 to 1.2 per billion passenger-km.

6. EVALUATION OF SAFETY IMPROVEMENTS

This chapter provides an analysis of the safety impacts of higher passenger train speeds on freight railroad corridors and the effectiveness of safety-related improvements in reducing the incidence of passenger train accidents.

6.1 SAFETY IMPACTS OF HIGHER SPEEDS

There are two potential impacts of higher speeds on passenger train safety performance: an increase in accident frequency and an increase in accident severity.

With regard to accident frequency, some types of accidents could occur more frequently when passenger train speed is increased without changing any of the signal and track installations on the route over which the train operates. For example, vehicle-track forces could increase, leading to more frequent track failures; or there could be more human errors due to the reduced time for operators to respond to signal indications and other instructions. However, higher speed trains are typically designed not to exert higher forces on the track than conventional trains, and have improved braking and other systems to ensure compatibility with the infrastructure over which they will operate. Therefore, any increase in accident frequency specifically due to increased speed is likely to be small.

There may be an increase in accident frequency due to increased traffic density on a corridor. The introduction of higher speed passenger trains is typically accompanied by an increase in the number of services operated each day. The larger number of passenger trains, in turn, means a relative increase in the number of meets and passes, and occasions when a passenger train passes a freight train on an adjacent track. Thus, the higher traffic density may bring a greater relative exposure to risks of train-to-train collisions and "other collisions," such as with a derailed freight train or a shifted load.

With regard to accident severity, there is no question that operating at higher speed increases the severity of any given accident. The accident severity data presented in chapter 5 is not very helpful for establishing a speed-severity relationship. There is no clear trend of higher damage as speed increases, possibly because the mix of accident risks to which trains are exposed alters as speed is increased.

An alternative approach to estimating the severity effects of speed is to assume that the damage in an accident is proportional to the energy dissipated in the accident. While accident dynamics are complex, a reasonable approximation might be that damage and the potential for casualties in train accidents are proportional to the square of speed of the passenger train. Using this hypothesis, the following reductions in train accident incidence would be needed to maintain an equivalent safety record at higher speeds, assuming a base case of 127 km/h (79 mph) operation:

Speed km/h (mph)	Reduction in Accidents
145 (90)	23 percent
175 (110)	48 percent
200 (125)	60 percent
240 (150)	72 percent

However, it is rarely possible to operate at maximum speed throughout a comdor: typically, maximum speed will be achievable over only 50 to 75 percent of a route because of curves and other factors, with the balance operated at lower speed. Also, improved crashworthiness which is normally a feature of high-speed train design, will serve to reduce the number of casualties in an accident. Another factor is that an accident record consisting of a smaller number of more severe accidents may be less publicly acceptable than one with a larger number of less severe accidents. This factor would tend to increase the need to reduce accident frequency, especially at the highest speeds between 200 and 240 km/h (125 and 150 rnph). Overall, a reduction in accident frequency of the order of 30 - 40 percent may be desirable for speeds of 175 km/h (110 mph) and of 60 - 80 percent for speeds exceeding 200 km/h (125 rnph).

It is emphasized that these estimates of desirable reductions in accident frequency are very approximate, and are presented with the idea of indicating the rough magnitude of improvement needed, rather than as an exact specification of safety requirements. The precise requirements for a specific corridor should be the subject of analysis using actual planned speeds and operating conditions.

6.2 IDENTIFICATION OF ACCIDENT PREVENTION MEASURES

The need to reduce the frequency of accidents with increasing speed means that additional safety measures must be implemented on any comdor over which higher speeds are planned. It is necessary to identify additional safety measures which are potentially applicable to a freight railroad comdor, and to estimate the benefit provided by each measure. This information can then be used to determine what improvements are needed to meet safety goals for a given passenger train operation.Some safe

y measures are mandated by current FRA safety regulations, such as the installation of automatic train control or an equivalent system where speeds exceed 127 km/h (79 rnph), and track upgrades o meet the requirements of the track safety standards. Other measures have been applied on the No theast Comdor between Washington and Boston for operations at 200 km/h (125 rnph), such as a enhanced ATC system and more frequent track inspections. Further sources of candidate safety me sures are practices adopted on foreign high-speed operations, such as those in France, Germany, nd Japan.This sect

on describes the additional safety measures, selected from a review of U.S. and international practice, for which the benefit in terms of a reduced frequency of accidents of each type are estimated. Seventeen improvements have been identified, some of which are mutually exclusive and others of which can be used in combination, as indicated in the notes below.

6. Sianal and Train Control Upgrades

Three levels of signal and control system upgrade have been defined, assuming the base case to be ABS or CTC. Improved signal and train control systems primarily reduce the number of human error accidents, especially errors by the train operator.

1. ***Minimum*** *FRA* ATC. A system having the minimum capabilities needed to comply with the FRA requirements for operations between 130 km/h (80 mph) and 175 km/h (110 rnph). As described in chapter 4, such systems include automatic train stop, automatic cab signals, and automatic train control. There is no requirement for all trains operating on the equipped route to have identical systems, but all must be able to respond to the wayside equipment. Waivers have been granted by the FRA to allow unequipped trains to operate in some routes.

2. ***Northeast Corridor ATC.*** An ATC system as currently installed on the Northeast Corridor between Boston and Washington. All trains operating on the corridor must be equipped with cab signals and continuous automatic speed control so that the safe speed for the signal indication cannot be exceeded. No exceptions are allowed.

3. ***Advanced ATC.*** An advanced ATC system such as that proposed for the Boston - New York segment of the Northeast Corridor. The principal differences with the present Northeast Corridor ATC are that permanent and temporary civil speed restrictions are enforced as well as signal indications, and an absolute stop is enforced at interlockings.

The three train control safety improvements are mutually exclusive. Only one of the three can be applied to a given route segment.

6.2.2 Defective Equipment Detectors

There are three types of defective equipment detectors commonly used in the railroad industry. The safety improvement consists in installing additional detectors in appropriate locations to reduce intervals between detectors. Reducing the intervals increases the chance that a defect will be detected and precautionary action taken before the it causes an accident.

4. ***Hot Bearing Detectors.*** Hot bearing and hot wheel detectors located at half the typical industry spacing of about 30 km (18 miles), and linked to the signal system to restrict the speed of a passenger train in the vicinity of a potentially defective train.

5. ***Dragging Equipment Detectors.*** Dragging equipment detectors located at half the typical industry spacing of about 30 km (18 miles), and linked to the signal system to restrict the speed of a passenger train in the vicinity of a potentially defective train.

6. ***Shifted Load Detectors.*** Oversize vehicle and shifted load detectors, located at classification yard exits and at other points where freight trains join the high-speed corridor from other lines, and at intervals along the corridor.

The defective equipment detector improvements can be applied in any combination.

6.2.3 Hazard Detectors and Barriers

One of the hazards to which high-speed trains are exposed is to collisions with obstructions fouling the high-speed line. In particular, vehicles operating on an adjacent railroad track or highway could intrude on the high-speed track after an accident. Hazard detectors could provide a warning of intrusion before the train reaches the location of the hazard, and a barrier could prevent the intrusion occurring in the first place. Further discussion of intrusion risks and risk reduction measures can be found in Reference 26. Specific safety measures to reduce the risk of such collisions are:

7. ***Intrusion Detectors.*** Intrusion detectors at points of potential risk, capable of detecting when a large object (e.g. a rail or highway vehicle) has intruded into the high-speed right-of-way. One way of providing such detectors is to adapt the conventional railroad slide-detector fences.

8. ***Intrusion Barriers.*** Physical intrusion barriers at points of high potential risk, capable of preventing a large object (e.g., a rail or highway vehicle) intruding into the high-speed right-of-way, and linked to the train control system.

9. ***Security Fencing.*** Security fencing at locations of known risk to discourage trespassers and vandals from gaining access to the right-of-way. This measure includes suitable fencing or barriers at highway overbridges to reduce the risk of objects being dropped on the high-speed right-of-way.

10. ***Weather Detectors.*** Detectors for potentially hazardous extreme weather events, and other environmental hazards such as earthquakes, linked to the control center responsible for the high-speed route.

The hazard detector and barrier improvements can be applied in any combination.

6.2.4 Track Qualitv and Inspection Improvements

Track quality upgrades result in improved track geometry and track strength. Geometry improvements reduce wheel-rail forces, which combined with an increase in track strength leads to a lower risk of derailment or failure of the track. More intensive track inspection reduces the chance that a defective track component will remain undetected and cause an accident.

11. ***Track Upgrade to Class 6+.*** Upgrade of track quality to at least FRA track class 6, plus the installation of concrete ties, elastic fasteners, and welded rail throughout. This level of improvement is normally considered desirable for speeds exceeding 175 km/h (110 mph), and can be beneficial for speeds in the range 145-175 km/h (90-110 mph).

12. ***Track Geometry Inspection.*** More frequent track geometry inspections using automated track geometry inspection car, e.g., monthly inspections as currently performed by Amtrak on the high-speed segments of the Northeast Corridor.

13. ***Rail Flaw Inspection.*** More frequent rail flaw inspections using an automated detector car, e.g., every 6 months instead of every 12 months as currently required by the FRA on track used by passenger trains.

14. ***Daily Inspection.*** Inspection of the entire route over which high speeds are operated from a hi-rail vehicle or equivalent, prior to the start of service each day. This improvement is similar to present practice on French National Railways high-speed routes.

15. ***On-Train Monitoring.*** Use of data from trains in regular service equipped with condition monitoring sensors, such as truck-mounted accelerometers. These data are obtained much more frequently than conventional track geometry measurements, and can provide timely warning of some defective track conditions as well as equipment defects.

6.2.5 Grade Crossing System Uparades

Two highway-railroad at-grade crossing improvements have been included in the analysis, aimed at preventing or detecting crossing obstruction by a road vehicle when a train is approaching:

16. ***Obstacle Detectors.*** Grade crossing obstacle detectors linked to the train control system, capable of detecting a stalled road vehicle on the crossing, and warning an approaching train of the obstruction at a sufficient distance from the crossing. This improvement is based on the system used in high-speed rail lines in Sweden.

17. Four-Quadrant Gates. The application of a full set of warning systems to all crossings, to include four-quadrant gates, flashing lights, and bells.

6.3 ANALYSIS OF ACCIDENT PREVENTION MEASURES

1 Analvsis Approach

The objective of the analysis is to estimate the effectiveness of each of the measures described in section 6.2 in reducing the frequency of train accidents on a freight railroad corridor over which high-speed passenger train service is under consideration. The steps in the analysis were as follows:

- Select base freight corridor track and signaling conditions from which the benefits of improvements are calculated. These base conditions were derived from those typical of the Section 1010 railroad freight corridors over which higher speed passenger services are under consideration and are:

  - FRA class 4 track, with conventional wood ties and rail-tie fastenings, and a mix of welded and jointed rail.

  - Automatic block or central traffic control signaling, but not any form of automatic trainstop, automatic train control, or cab signaling.

  - A mix of at-grade highway-railroad crossing warning systems typical of a busy freight railroad corridor.

- Develop a list of railroad accident cause groups, using the accident cause definitions specified in the FRA accident reporting instructions. Each cause group comprises individual causes which are affected in the same way by one of the accident reduction measures listed above. For example, all the different types of rail flaw accident causes can be grouped together because they are all affected in the same way by a change in detector car inspection frequency. A total of 40 accident cause groups have been defined, as listed in Table 6-1.

- Estimate the distribution of accidents in each cause group among the four train accident scenarios, as defined in chapter 5; train-to-train collisions, "other collisions," derailments, and grade crossing collisions. This distribution is also given on Table 6-1.

- For each accident scenario, estimate the distribution of passenger train accidents among the cause groups that apply to that scenario. The estimate was based in part on the information developed in chapter 5 on accident causes, and in part on the distribution of freight train accidents among the individual causes. Passenger train data could not be used exclusively, because the sample of accidents available for study was too small. Judgement was used to adjust the freight train distribution to reflect likely differences between freight and passenger train accident causality. For example, high longitudinal in-train forces are a significant cause of freight train accidents, but are a very minor factor in passenger train accidents.

Table 6-1. Relationship Between Accident Cause Groups and Accident Scenarios

Ref	Accident Cause Group	FRA Cause Codes	Percentage of Accidents in Each Cause Group Attributable to Each Accident Scenario			
			Train to Train Collisions	Other Collisions	Derailments	Grade Crossing Collisions
1	Roadbed Defects	T001 - T009			100%	
2	Track Geometry Defects, excl Buckled	T101 - T108, T110 - T199			100%	
3	Buckled Track	T109			100%	
4	Rail Failures	T202, T205 - T212 T218 - T222, T299			100%	
5	Welded Joint Failures	T203, T204			100%	
6	Bolted Joint Failures	T201, T213 - T217			100%	
7	Turnout Failures	T301 - T399			100%	
8	All Other Track	T401 - T499			100%	
9	Automatic Cab Signal and Train Control Defect	S001 - S004	80%	20%		
10	Block or Interlocking Signal/Equipment Failure	S005, S008 - S011	80%	20%		
11	Other Signal/ Communication Defect	S012 - S099	80%	20%		
12	Brake Rigging Dragging	E07C, E07L				
13	Undesired Emergency	E05C, E05L				
14	Other Brake Defects	E00 - E09 Excl E05, E07			100%	
15	Carbody Defects	E11C - E19C E20C - E29L			100%	
16	Coupler Defects	E30C - E39L		15%	85%	
17	Truck Defects	E40C - E49L			100%	
18	Overheated Bearings	E52C, E52L E53C, E53L			100%	
19	Other Axle, Bearing Defects	E51C, E51L E54C - E59L			100%	

Table 6-1. Relationship Between Accident Cause Groups and Accident Scenarios (continued)

Ref	Accident Cause Group	FRA Cause Codes	Percentage of Accidents in Each Cause Group Attributable to Each Accident Scenario			
			Train to Train Collisions	Other Collisions	Derailments	Grade Crossing Collisions
20	Cracked, Broken Wheels	E60C - E63L E6AC - E6AL			100%	
21	Other Wheel Defects	E64C - E68L E69C, E69L			100%	
22	All Other Equipment Defects (Loco, Car)	E70L - E99L		50%	50%	
23	Brake Operation (Incl Handbrakes)	H008 - H099	80%	20%		
24	Employee Condition (Incl Drink, Drugs)	H101 - H199	50%	25%	25%	
25	Fixed and Hand Signal Errors	H201 - H209 H217, H299	75%	25%		
26	Radio Communication Errors	H210 - H212	75%	25%		
27	Failure to Comply with Block, Interlocking Signals	H215, H216	80%	20%		
28	Switching Errors, Vehicles Not in Clear	H301 - H399	20%	30%	50%	
29	Failure to Observe Main Track Authority	H401 - H499	100%			
30	Train Make-up and Handling Errors	H501 - H599		30%	70%	
31	Failure to Control Speed	H601 - H699	50%		50%	
32	Use of Switches	H701 - H799	20%	20%	60%	
33	Cab Signals - Tampering, Failure to Comply	H821 - H899	100%			
34	Miscellaneous Human Factors	H991 - H999	50%	25%	25%	
35	Severe Environment (snow, ice, wind, flood)	M101 - M199		50%	50%	
36	Shifted, Oversize, Improper Load	M201 - M299		100%		
37	Rail/Highway Grade Crossing Collision	M301 - M399				100%
38	Lateral/Vertical Force Interaction	M405			100%	
39	Obstruction Fouling Track plus Vandalism	M402 - M404, M409 - M410, M501 - M504		100%		
40	Miscellaneous Causes	M401, M406, M505, M599		50%	50%	

For each accident scenario, estimate the reduction in accident frequency in each cause group produced by the implementation of each applicable safety improvement measure. The effectiveness of accident prevention measures in reducing the number of accidents were derived, in part, from a comparison of passenger train accidents on the Northeast Corridor with accidents on freight railroads, in part on the extensive research literature on railroad track and equipment failures and inspection techniques, and in part on the expert judgment of members of the project team. The expert judgments were obtained by asking selected team members to estimate the beneficial impact, if any, of each accident prevention measure on accident incidence for each of the 40 accident cause groups. The accident reduction estimates are then combined to provide an estimate of the overall reduction in accident frequency produced by each safety improvement measure for each accident scenario. It should be emphasized that the estimates of the benefits of each accident prevention measure obtained through this process are necessarily only approximate, and are for an "average" corridor. A detailed analysis of each measure, utilizing all available statistical and engineering data was beyond the scope of this study. Furthermore, actual corridors will differ in their exposure to accident risks, leading to differences in the benefits obtainable from the various improvement measures.

The following section describes the detailed estimates of benefits developed for each accident scenario and accident prevention measure.

6.3.2 Analvsis Results

6.3.2.1 Train-to-Train Collisions

The results for train-to-train collisions are shown in Table 6-2. The table shows the estimated percent reduction in collisions attributed to each major relevant cause group resulting from the implementation of each level of signal and control system upgrade. The reference number in the first column refers to the accident cause groups listed in Table 6-1. The fourth column gives the estimated distribution of train-to-train accidents among the cause groups. The distribution was based on FRA accident data, including freight train accident data with appropriate adjustments to reflect likely variations in accident causality, where insufficient passenger train data were available.

Estimates of the benefit from accident prevention measures are given in the three right-hand columns of Table 6-2 as a percent reduction in accidents in each cause group achievable by implementing each measure. The estimates reflect the collective judgement of the project team. To simplify the table, only major cause groups with over three percent of accidents in this scenario have been identified individually. Other relevant cause groups have been combined into an "all other" category. The bottom row in Table 6-2 gives the overall benefit from each measure, obtained by averaging the individual benefits weighted by the percent of accidents in each cause group.

The table suggests that a Northeast Corridor ATC system or an advanced ATC system (levels 2 or 3 as described in paragraph 6.2.1) is required to attain the magnitude of accident reduction needed for speeds in the range 200 to 250 km/h (125 to 140 mph). An adequate safety performance cannot be attained without the safe speed enforcement capabilities of these systems. For speeds up to 175 km/h (110 mph), an ATC system of the type normally installed in response to the current FRA regulations (i.e., with capabilities between levels 1 and 2 as described in paragraph 6.2.1) would likely meet safety requirements, provided all trains operating in the equipped territory are able to respond to the ATC equipment.

Table 6-2. Effectiveness of Accident Reduction Measures
Accident Scenario 1: Train-to-Train Collisions

Ref	Accident Cause Group	FRA Cause Codes	Percent of Accidents in Scenario	Effectiveness of Accident Reduction Measures (Percent Reduction in Accidents)		
				Minimum FRA ATC	Northeast Corridor ATC	Advanced ATC
23	Brake Operation (Incl Handbrakes)	H008 - H099	12	10	40	60
25	Fixed and Hand Signal Errors	H201 - H209 H217, H299	17	30	80	90
27	Failure to comply with Block, Interlocking Signals	H215, H216	22	30	80	90
28	Switching Errors, Vehicles not in clear	H301 - H399	10	30	60	80
29	Failure to observe main track authority	H401 - H499	12	30	80	90
31	Failure to Control Speed	H601 - H699	14	10	70	90
	All Other Relevant Cause Groups	(9, 10, 11, 24, 26, 32, 33, 34)	12	20	30	50
	Overall Benefit (Percent reduction in accidents)			24	68	81

6.3.2.2 Other Collisions

The results for "other collisions" are shown in Table 6-3. The estimates of reductions in the numbers of accidents are derived and presented in the same manner as in Table 6-2 for train-to-train collisions. The value for percent reduction in accidents for all measures combined shown in the right-hand column was obtained by assuming that the benefits were multiplicative. For example, the combined benefit of 2 measures that each produced a 20 percent reduction in accidents would be [1 - (0.8 x 0.8)] x 100 = 36 percent. Where 2 prevention measures are mutually exclusive, such as with the different levels of ATC, only the benefit from the most effective measure was counted.

It can be seen that no one type of accident prevention measure will provide the reduction in accident frequency needed to provide the required safety performance for high-speed passenger service. It is necessary to use improved signal systems and various detection and barrier systems, in combination, to approach the required performance levels for the highest speeds under consideration. With all the improvements in combination, safety performance just reaches that needed at speeds over 200 km/h (125 mph). The results suggest that additional risk-reducing measures may be needed, such as increasing the spacial separation between high-speed tracks and any activity likely to cause an accidental intrusion. Alternatively, higher risks for this scenario may be acceptable if offset by lower-than-required risks for other accident scenarios.

6.3.2.3 Derailments

The results for derailments are shown in Table 6-4. The estimates of reductions in the numbers of accidents are derived and presented in the same manner as in Tables 6-2 for train-to-train collisions and 6-3 for other collisions.

As with "other collisions," the causes of derailments are very diverse, thus several different accident reduction measures need to be applied in combination to meet high-speed safety requirements. Although track improvements are not the focus of this study, the principal cause of derailment is track failure, and higher track quality and more fiequent inspections are appropriate actions to reduce derailment accident occurrence to acceptable levels. The track quality and inspection practices analyzed are similar to those currently applied to the 200 km/h (125 mph) segments of the Northeast Corridor, and have been estimated to provide about a 90-percent reduction in track-caused accidents.

Similarly, a reduction of about 90 percent in human-error derailments, primarily overspeed situations, can be obtained by application of an advanced ATC system (level 3 as described in Section 6.2.1).

Improved track and on-train condition monitoring systems contribute to a reduction in equipment failure accidents. Overall, all accident reduction measures combined provide a reduction of about 70 percent in derailments, which is the order of magnitude needed for operation at the highest speeds, in the range 200-240 km/h (125-150 mph).

Table 6-3. Effectiveness of Accident Reduction Measures
Accident Scenario 2: Other Collisions

Ref	Accident Cause Group	FRA Cause Codes	Percent of Accidents in Scenario	Effectiveness of Accident Reduction Measures (Percent Reduction in Accidents)									
				Minimum FRA ATC	Northeast Corridor ATC	Advanced ATC	Outsize Load Detector	Weather Detector	Intrusion Detectors	Intrusion Barrier	Security Fencing	Daily Inspection	All Measures Combined
16	Coupler Defects	E30C - E39L	8	-	-	-	-	-	-	-	-	-	0
22	All Other Equipment Defects (Loco, Car)	E70L - E99L	12	-	-	-	30	-	-	-	-	-	30
28	Switching Errors, Vehicles not in clear	H301 - H399	14	30	60	80	-	-	-	-	-	-	80
35	Severe Environment (snow, ice, wind, flood)	M101 - M199	10					75	10	10			77
36	Shifted, Oversize, Improper Load	M201 - M299	14				50						50
39	Obstruction Fouling Track plus Vandalism	M402 - M404, M409 - M410, M501 - M504	25		30	30	15	15	50	70	30	30	97
	All Other Relevant Cause Groups	(23, 24, 25, 26, 27, 30, 32, 34 and 40)	17	25	70	80							
Overall Benefit (Percent Reduction in Accidents)				8	28	32	14	11	14	19	8	8	67

Ref	Accident Cause Group		tion in Accidents)			
			Track Upgrade to Class 6+	Security Fencing	On-Train Monitoring	All Measures Combined
2	Track Geometry Defects, excl Buckled	T T	70%		40%	96%
3	Buckled Track		70%		20%	88%
4	Rail Failures	T20 T21	70%		-	90%
5	Welded Joint Failures	T	20%		-	90%
6	Bolted Joint Failures	T20	70%		-	88%
7	Turnout Failures	T	70%		15%	93%
	Other Track Failures (Cause Groups		70%		10%	90%
18	Overheated Bearings	E E			40%	60%
20	Cracked, Broken Wheels	E6 E6	20%		-	32%
	All Other Equipment Defects (Loco, Car)	Ca 12-	20%		5%	56%
30	Train Makeup and Handling Error	H4			-	0
31	Failure to Control Speed	H6			-	90%
32	Use of Switches	H7			-	70%
34	Other Human Factors	Caus 26,			-	80%
38	Lateral/Vertical Force Interaction		70%		50%	97%
39	Obstruction Fouling Track plus Vandalism	M4 M4 M5		40%	-	71%
	Other Causes	(3			-	30%
Overall Benefit (Percent Reduction in Accidents)			40%	4%	12%	72%

6.3.2.4 Grade Crossing Collisions

A brief analysis is provided below of the potential benefits from applying the two improvement measures at highway-railroad grade crossings; obstacle detectors and active warning systems with four-quadrant gates. Detailed analysis of grade crossing safety on corridors where high-speed passenger services have been proposed is likely to be the subject of a separate study.

- *Obstacle detectors.* The review of Amtrak grade crossing accidents indicated that 22percent of the collisions involved the train striking a disabled or stalled highway vehicle on the crossing. In most cases this situation would be sensed by a detector systein and a stop command transmitted to the train through the automatic train control system. If the train was far enough away, it would stop before reaching the crossing. Thus, the effectiveness is a direct function of rail traffic density. At typical rail traffic densities of 2 or 3 trains per hour, overall effectiveness is likely to be of the order of 80 to 90 percent, allowing for detection reliability and the greater likelihood of a highway vehicle becoming stalled when a train is known to be approaching. On this basis, a detection system could prevent about 19 percent of rail-highway grade crossing collisions.

- *Provide 4-quadrant gates and active warning systems at all crossings.* A rough estimate of the benefit from this improvement measure was derived from the FRA Rail-Highway Crossing Accident/Incident Bulletin [Ref. 27] and a previous study of the effectiveness of warning devices at crossings [Ref. 28]. Assuming rail traffic level on the corridors of interest is 11 trains a day or higher, the estimates in Table 6-5 are obtained for the types of warning systems presently in place, the present accident record at those crossings, and the estimated benefits of the proposed improvements.

Table 6-5. Benefits of Applying Existing Warning Systems to all Crossings (Lights, Bells, 2-Quadrant Gates)

Existing Warning System	Installation (Percent)	Accidents (Percent)	Benefit of Improvement	Accident Distribution After Improvement
2-Quadrant Gates	37	40	-	40
Active Warning (lights, bells)	19	28	69% reduction	9
Passive (cross bucks)	44	32	83% reduction	5
Total	100	100		54

Thus, the application of all the improvements, except 4-quadrant gates, is an estimated reduction of 46 percent in crossing collisions. There are no data on the benefits to be derived from substituting 4-quadrant gates for 2-quadrant gates, but Amtrak accident records indicated that 12 percent of collisions were due to highway vehicles going around gates. Given that 40 percent of collisions occur at gated crossings, the maximum benefit of 4-quadrant gates would be a further reduction of the order of 25 percent in the accident rate at crossings with 2-quadrant gates. If actual improvement is 20 percent, the estimated overall benefit of this improvement is a reduction of 57 percent in crossing collisions.

Thus, the two grade-crossing improvements together could produce an overall reduction of the order of 65 percent in crossing collisions as shown in Table 6.6. This improvement is close to that needed for 175 km/h (110 mph) operation, but falls short of that needed for higher speeds. In practice, of course, a crossing improvement program will be needed that includes grade separations and crossing closings, and selectively applies other improvements, taking into account the situation of each crossing.

6.4 SUMMARY OF RESULTS

The results for all accident scenarios are summarized in Table 6-6, showing the benefit of each accident reduction measure to each accident scenario. The implementation of all measures in combination on a typical existing 127 km/h (79 mph) line produces the order of magnitude in accident reduction likely to be needed for operation at the highest speeds - over 200 km/h (125 mph). The implementation of at least some of the improvement will be necessary at lower speeds, between 130 km/h and 200 km/h (80-125 mph). It should be noted that many of the accident reduction measures analyzed have already been implemented in the Northeast Corridor, and, in any case, track upgrades and the installation of an ATC system are required under current FRA regulations for speeds of 130 km/h (80 mph) and above.

Table 6-6. Summary of Accident Reduction Measure Effectiveness

	Accident Reduction Measure	Percent Reduction in Accidents			
		Train-to-Train Collisions	Other Collisions	Derailments	Grade Crossing Collisions
1	Minimum FRA ATC	24	8	5	
2	Northeast Corridor ATC	68	28	12	
3	Advanced ATC	81	32	15	
4	Hot Bearing Detectors			4	
5	Dragging Equipment Detectors			2	
6	Shifted Load Detectors		14	2	
7	Intrusion Detectors		14		
8	Intrusion Barriers		19		
9	Security Fencing		8	4	
10	Weather Detectors		11	3	
11	Track Upgrade to Class 6+			40	
12	Track Geometry Inspection			15	
13	Rail Flaw Inspection			8	
14	Daily Inspection		8	17	
15	On Train Monitoring			12	
16	Grade Crossing Obstacle Detectors				19
17	Four-Quadrant Crossing Gates				57
	All Measures	81	67	72	65

7. CORRIDOR EFFICIENCY CONSIDERATIONS

Corridor efficiency refers to the ability of a rail line to handle traffic smoothly, without undue delay. Efficiency depends on the way the rail line is constructed (infrastructure), the way it is utilized (operations), and the traffic requirements placed upon it (demand). The dispatching function directs the operations of the rail line, and we will assume in this study that dispatching is done in an efficient and equitable manner. It is possible for conflicts to develop between freight and passenger train schedules and priorities, and this is a matter that must be addressed within the institutional arena of HSR incremental upgrading.

7.1 HEADWAY AND CAPACITY

Reference to reports earlier cited [Refs. 2, 9, 10, 13, and 17] may be made for further discussion of headways. Briefly, headway refers to the minimum interval between trains traveling in the same direction on a track, either in time or in distance. We have seen that trains must be spaced at least as far apart as the stopping distance of the following train, plus the safety factor distance and the reaction time distance. Safe braking distance assumes worst case location of trains in blocks, i.e., closest together. Headway calculations must assume the opposite, that the preceding train is at the far end of the block, because the signal aspect for the following train will not improve until the preceding train exits the block. This has the effect of adding an additional block length and the train length into the headway distance. The **unimpacted headway** assumes that trains will be operating on clear signals at all times, and, that in an approach to a signal, it will change to the clear aspect a sighting distance away, providing some response time for the engineman.

Using braking rates from the Northeast Comdor example of Figure 3-1, adding an additional block length, train length, and sight distance to the 3477m (11,300 feet) safe braking distance results in a headway distance of approximately 4570m (18,000 feet). At 200 km/h (125 mph), this means that 36 trains could pass a given point in a one-hour period; equivalently, the system has a theoretical capacity of 36 trains/hour and a theoretical minimum headway of 99 seconds, with a perfectly uniform and optimized block layout. Using more typical actual NEC block distances (which allow for freight operations as well as passenger) would reduce this to a theoretical capacity of 28 trains/hour and 125 second headways, but this still represents an idealized railroad.

Any actual railroad operation has many factors which will reduce headway and capacity from the idealized theoretical values, including uneven block spacing and grade effects, trains of different maximum speeds and lengths, civil speed restrictions (those not traffic- or route-dependent) present on the route, differences in train handling between enginemen, trains operating off schedule, and other random events. Capacity in the vicinity of even 20 trains/hour, nevertheless, provides for movement of a very large amount of traffic.

The presence of different train speeds greatly affects the **practical capacity** of the line. In the example cited above, inserting a short express freight train operating at 95 km/h (60 mph) into the traffic stream would reduce the throughput of the system from 28 trains/hour to 13 trains/hour, on a theoretical basis. The following passenger trains would suffer delays in following the express train at 95 km/h (60 mph). If the freight train was 5000 feet long, the capacity would drop to 11 trains/hour. The solution to these problems lies in scheduling slower freight trains out of passenger hours or away from passenger train schedules where possible, and in adding infrastructure to permit faster trains to overtake and pass slower trains. Many time-sensitive freight schedules exist on today's railroads (intermodal traffic, mail and parcel traffic, landbridge traffic, and perishable traffic, to name but a few), and it will not generally be possible to implement HSR improvements without the requirement to handle freight traffic, to some degree, during hours of passenger train operation.

7.2 STRINGLINE MODEL DEVELOPMENT

In order to demonstrate the range of impacts that freight-passenger interaction could produce under a variety of circumstances, and to provide a tool for use during corridor development, a simplified, microcomputer-based, manually-dispatched, rail operations model was developed and tested on the hypothetical corridors discussed in chapter 2. The simplified model is a link-and-node representation of a railway over which trains operate at assumed average speeds. Such a model does not directly model the effects of train acceleration and braking, differences in power/weight ratio on acceleration, individual speed restrictions, block layout and signal aspects, or train length effects. It does deal with these effects in an aggregate manner, however, through the use of average speeds which represent realistic overall reductions from maximum speed for illustrative purposes. More refined models incorporating site-specific details would be appropriate to use in actually designing a signalling system. The model used in this study is suitable for determining feasibility at the planning level.

The maximum passenger train speeds considered in this study are 145, 175,200, and 240 km/h (90, 110, 125, and 150 rnph). Based on Amtrak timetables in the Northeast Corridor for segments of the ROW where high speeds are routinely accomplished, the average speed achieved was assumed to be 80 percent of the maximum speed. Freight trains were assumed to have a 80 km/h (50 mph) maximum speed (which is a typical value, but does not represent the most expedited traffic), and the average speed was assumed to be 70 percent of the maximum, or 55 km/h (35 rnph). These factors account for all speed restrictions and accelerating and braking for them and in station areas. Passenger trains were scheduled to make four intermediate stops with a one-minute dwell time each, while freight trains were assumed to slow but make no stops. This assumption, and the relatively low average speed for freights, are conservative assumptions in that they are closer to worst case than best case.

Passenger trains were assumed to operate hourly in each direction across the approximately 500 krn (310 mile) corridors. While most incremental comdors would not be able to initially support such a dense passenger service, at certain times of the day (morning and late afternoon) hourly service is highly desirable and is operated in some incremental corridors today, and the requirement was set at this level to illustrate such peak service conditions. In this case as well, the cases analyzed are at the worst-case end of the scale.

Three daylight freight trains were assumed to operate in each direction on the comdor, scheduled in an irregular, quasi-random manner. The schedule tested called for westbound freights to depart at 5:20 am, 10:40 am, and 3:10 pm, and for eastbound freights to depart at 7:20 am, 12:05 pm, and 4:05 pm. All freight trains were assumed to be no longer than 2.4 km (1.5 miles).

Operating in the idealized, unimpacted manner described above, the freight trains would require 529 minutes [8 hours 49 minutes (8:49)] to complete their run, and the passenger trains would require the times shown below:

Passenger speed	=	145 km/h (90 mph) max	4:22
Passenger speed	=	175 km/h (110 mph) max	3:35
Passenger speed	=	200 km/h (125 mph) max	3:10
Passenger speed	=	240 km/h (150 mph) max	2:39

7.3 'TRAIN INTERFERENCE

7.3.1 Case A: Sinqle Track and Passina Sidings I145 km/h (90 mph) passenger speeds)

Figure 7-1 shows the track layout for a portion of this case, with 2.4 km (1.5 mile) length passing sidings spaced 32 km (20 miles) apart. Mileposts are shown at the top of the figure for siding entry, center, and exit. Segment identifications appear adjacent to the track diagram. Station names appear at the bottom of the figure. Figure 7-2 shows the "stringline" time-distance chart output for a sample run on this corridor for special conditions: 7 am-2 pm, 3 passenger trains/direction, 145 km/h (90 mph) maximum speed, no freights. In reading the stringline chart, time increases upward, and the slope of a line indicates speed. Vertical segments of the traces indicate trains not in motion, i.e., waiting for a meet. This can be seen, for example, at the siding at milepost 224 at 10:00 am when Train 5 (the westbound 9:00 am departure) waits for Train 2 to pass. This figure is provided to show clearly these meets on an expanded scale. The balance of the plots dealing with the actual traffic requirements show the entire 20-hour run period. In this run, total train delay was 76 minutes, average delay was 13 minutes, and individual train delay ranged from 3 to 18 minutes. Figure 7-3 shows a sample of the output delay report.

Figure 7-4 shows all the passenger trains (but still no freight trains) on this corridor. For this run, average passenger train delay was 21 minutes/train, and ranged from 3 to 44 minutes. Such a large delay range is hard to handle. A schedule pad can be inserted to account for a relatively narrow band of delays, but a range this wide indicates erratic performance at best. This is clearly a case where the passenger traffic alone provides significant interference, without any freight service being operated. The situation could possibly be improved by attempting to even out the number of times each train takes a delay to make a meet. Particularly in situations such as these, dispatching is an art as well as a science.

Figure 7-5 shows the same passenger traffic with one freight train (the 5:20 am westbound departure). The impacts are pronounced as can be seen in the chart. Average passenger delay increased by 85 percent to 39 minutes, with a range of 3 to 143 minutes; five passenger trains were delayed in excess of one hour. The freight train was delayed 96 minutes. It is likely that different dispatching could improve the passenger results at the expense of freight delay, but holding the freight in one of the passing sidings means that a passing maneuver between opposing passenger trains now takes place over a 64 km (40 mile) segment rather than a 32 km (20 mile) segment, and transit time alone for such a link is 34 minutes. Other solutions are clearing the freight off to an intermediate yard or switching siding, more frequent sidings, segments of double track to allow "running meets" or expanding the complexity of the passing siding to allow for 3-train meets (additional tracks or crossovers to provide several "pockets"). No attempt was made to run the full anticipated freight complement on this infrastructure. Case A clearly shows the limits of single track and passing siding operation for even modest freight requirements in addition to hourly passenger service.

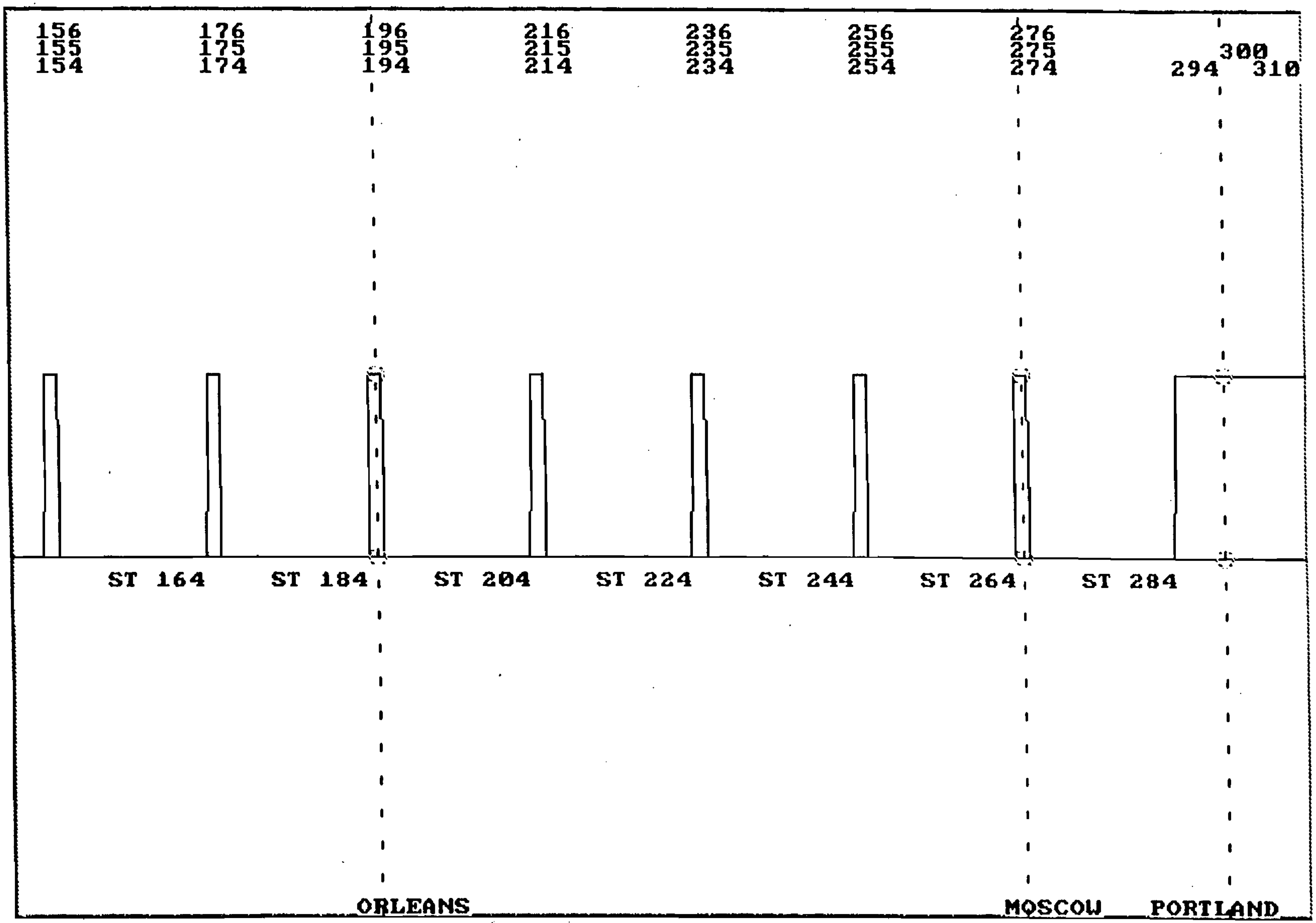


Figure 7-1. Case A: Track Layout (portion)

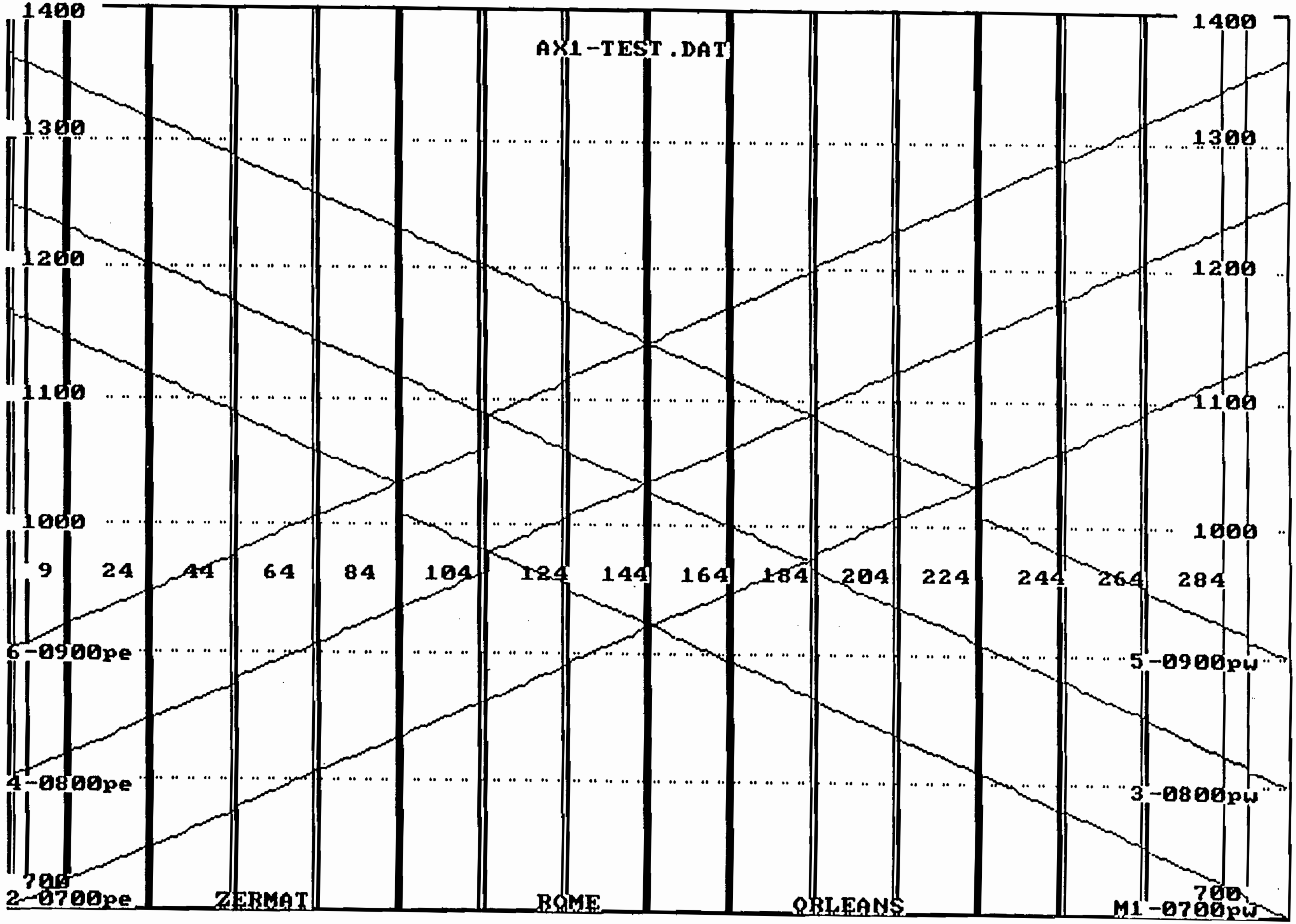


Figure 7-2. Case A: Sample Stringline

```
c:\fra\ax1-test.dat

1 0700pw Net Minutes delay  18
    Zero Intf run minutes 263  Arrival at  1123
    With intf run minutes 281  Arrival at  1141

2 0700pe Net Minutes delay  3
    Zero Intf run minutes 263  Arrival at  1123
    With intf run minutes 266  Arrival at  1126

3 0800pw Net Minutes delay  9
    Zero Intf run minutes 263  Arrival at  1223
    With intf run minutes 272  Arrival at  1232

4 0800pe Net Minutes delay  12
    Zero Intf run minutes 263  Arrival at  1223
    With intf run minutes 275  Arrival at  1235

5 0900pw Net Minutes delay  17
    Zero Intf run minutes 263  Arrival at  1323
    With intf run minutes 280  Arrival at  1340

6 0900pe Net Minutes delay  17
    Zero Intf run minutes 263  Arrival at  1323
    With intf run minutes 280  Arrival at  1340


  Total delay for all FREIGHT trains =    0
  Total delay for all PASSENGER trains =  76
Total delay for all trains =  76
```

Figure 7-3. Case A: Sample Delay Report

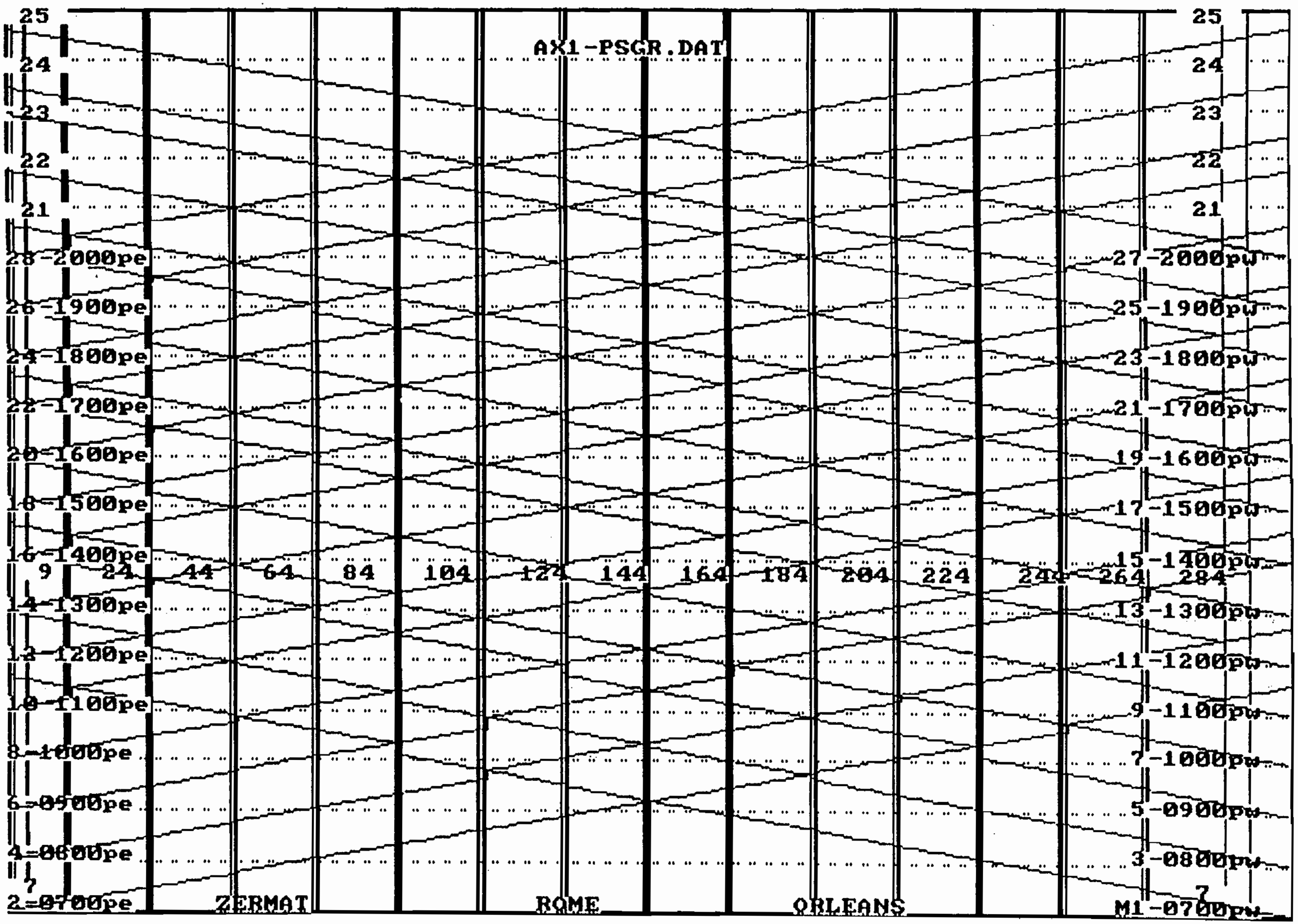


Figure 7-4. Case A: All Passenger Trains Stringline

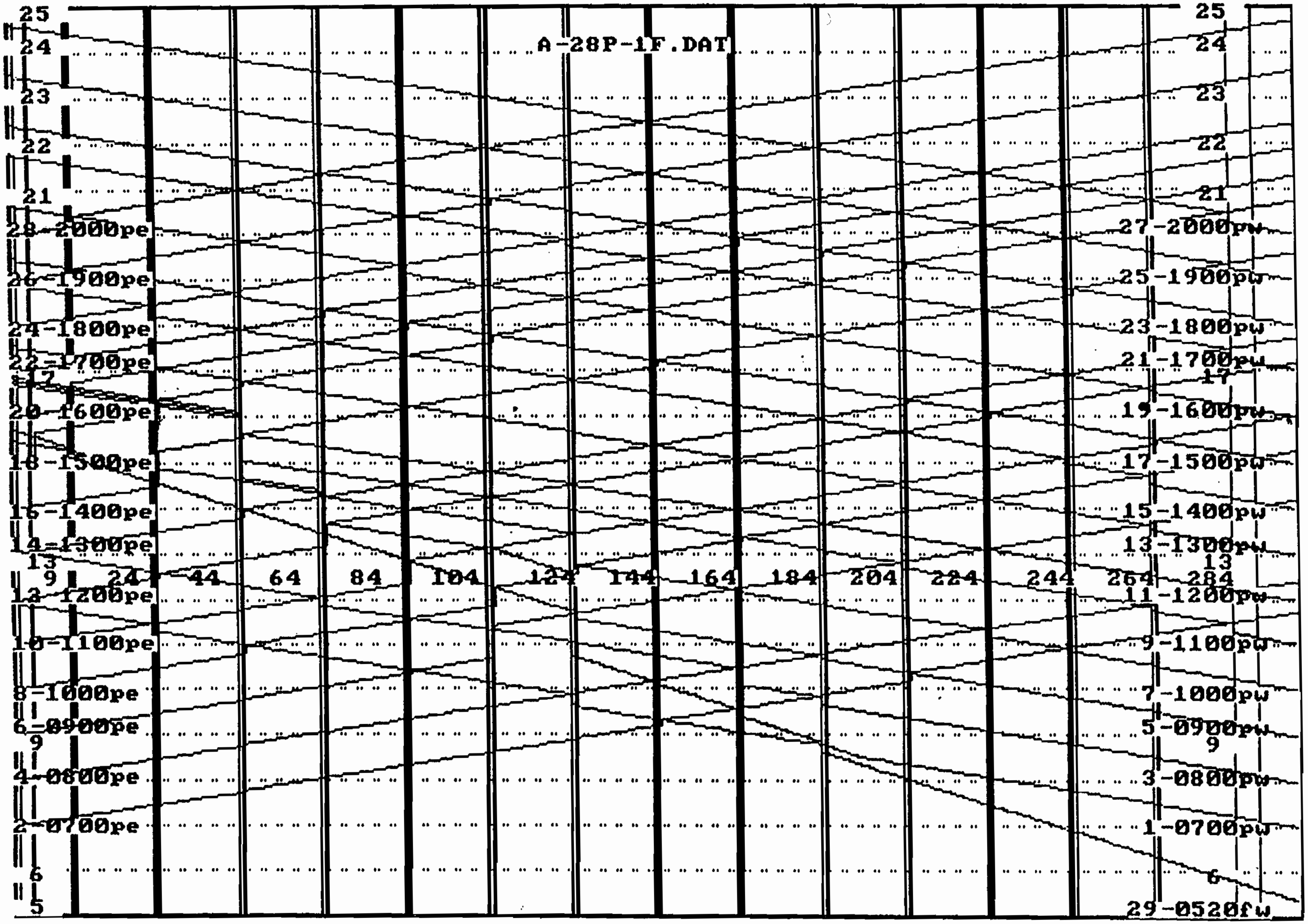


Figure 7-5. Case A: All Passenger Trains and One Freight Train

7.3.2 Case B: Double Track ABS (145 kmlh (90 mph) and 175 kmlh (110 mph) passenaer speeds1

Figure 7-6 shows a portion of Corridor B, featuring full double track and double interlockings every 24 km (15 miles). In this arrangement, trains may meet and pass every 24 km (15 miles), and have two uni-directional tracks between passing points. Figure 7-7 shows the train performance with the full complement of 28 passenger trains at 145 km/h (90 mph) maximum speed, and 6 freight trains; Figure 7-8 shows the same traffic with 175 km/h (110 mph) maximum passenger speed. The figures show clearly that this is a quite workable configuration to handle the traffic requirements efficiently. The delay statistics are interesting:

	Minutes of Delay	
	145 km/h (90 mph)	175 km/h (110 mph)
Freight delay	463	491
Passenger delay	177	145
Total delay	640	636
Freight delay/train	77	82
Passenger delay/train	6	5
Passenger delay range	6-15	3-16
Average delay/train	19	19

Total train delay does not increase in going from the 90-mph case to the 110-mph case. Freight delay has dropped from the **A** case (96 minutes), and passenger delay is low and relatively uniform. Slight schedule adjustments to freight departure times could reduce delays further. This is certainly an acceptable passenger operation, and freight performance may well be found acceptable in many instances.

7.3.3 Case C: Double Track CTC (90-150 mph passenaer speeds)

Figure 7-9 shows the track layout, featuring full reverse running on a double track railroad with crossovers every 16 km (10 miles). The same schedule of trains is operated as in Case B, with passenger train maximum speeds of 145,175,200, and 240 km/h (90,110, 125, and 150 mph). The train graph results are shown in Figures 7-10 through 7-13, and the delay statistics are summarized below:

	Minutes of Delay			
	145 km/h (90 mph)	175 km/h (110 mph)	200 km/h (125 mph)	240 km/h (150 mph)
Freight delay	247	71	83	41
Passenger delay	157	139	199	188
Total delay	404	210	282	229
Freight delayltrain	41	12	14	7
Freight delay range	21-53	1-23	4-32	1-14
Passenger delayltrain	6	5	7	7
Passenger delay range	5-17	3-17	6-13	5-17
Average delay/train	12	6	8	7

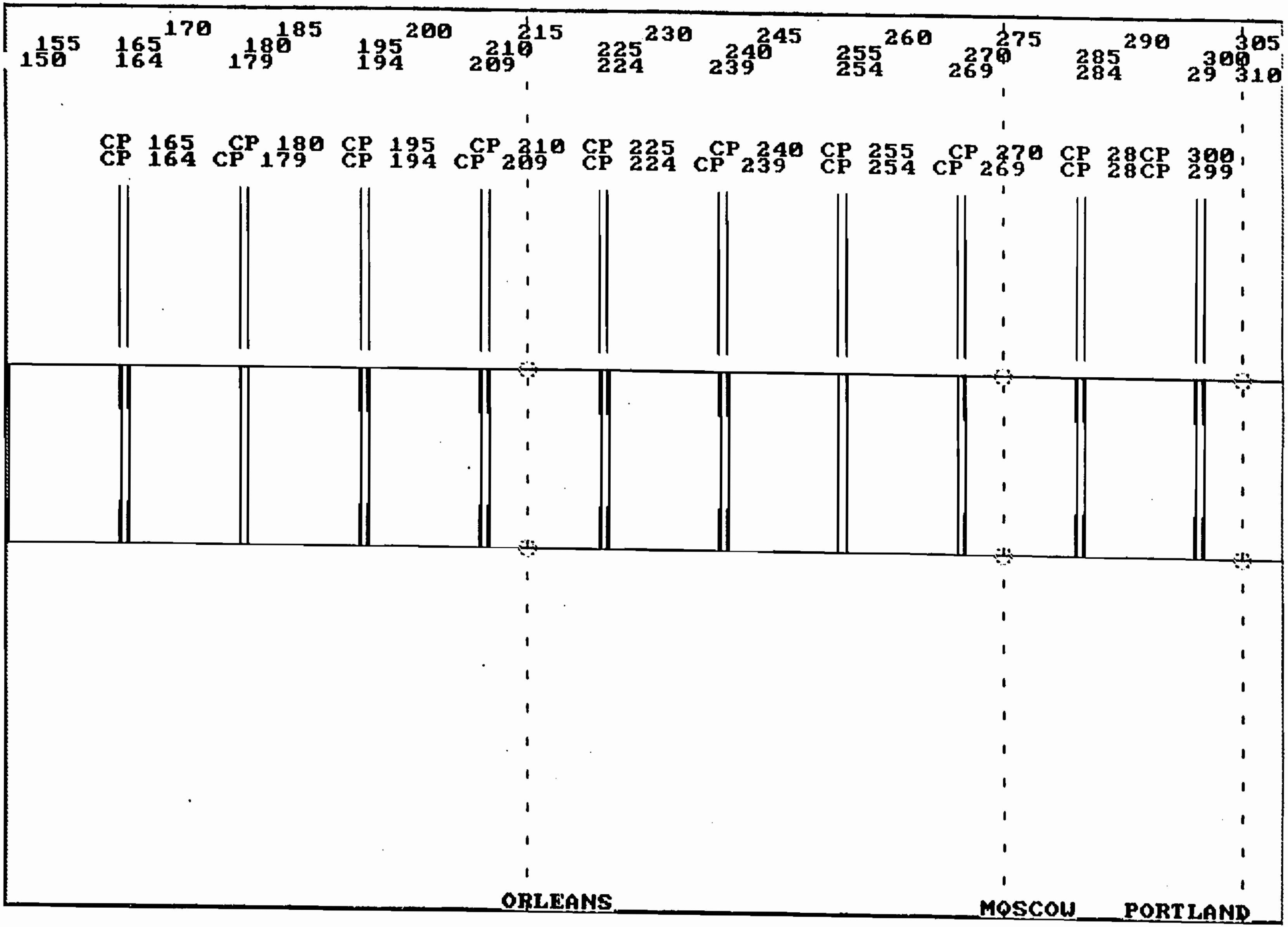


Figure 7-6. Case B: Track Layout (portion)

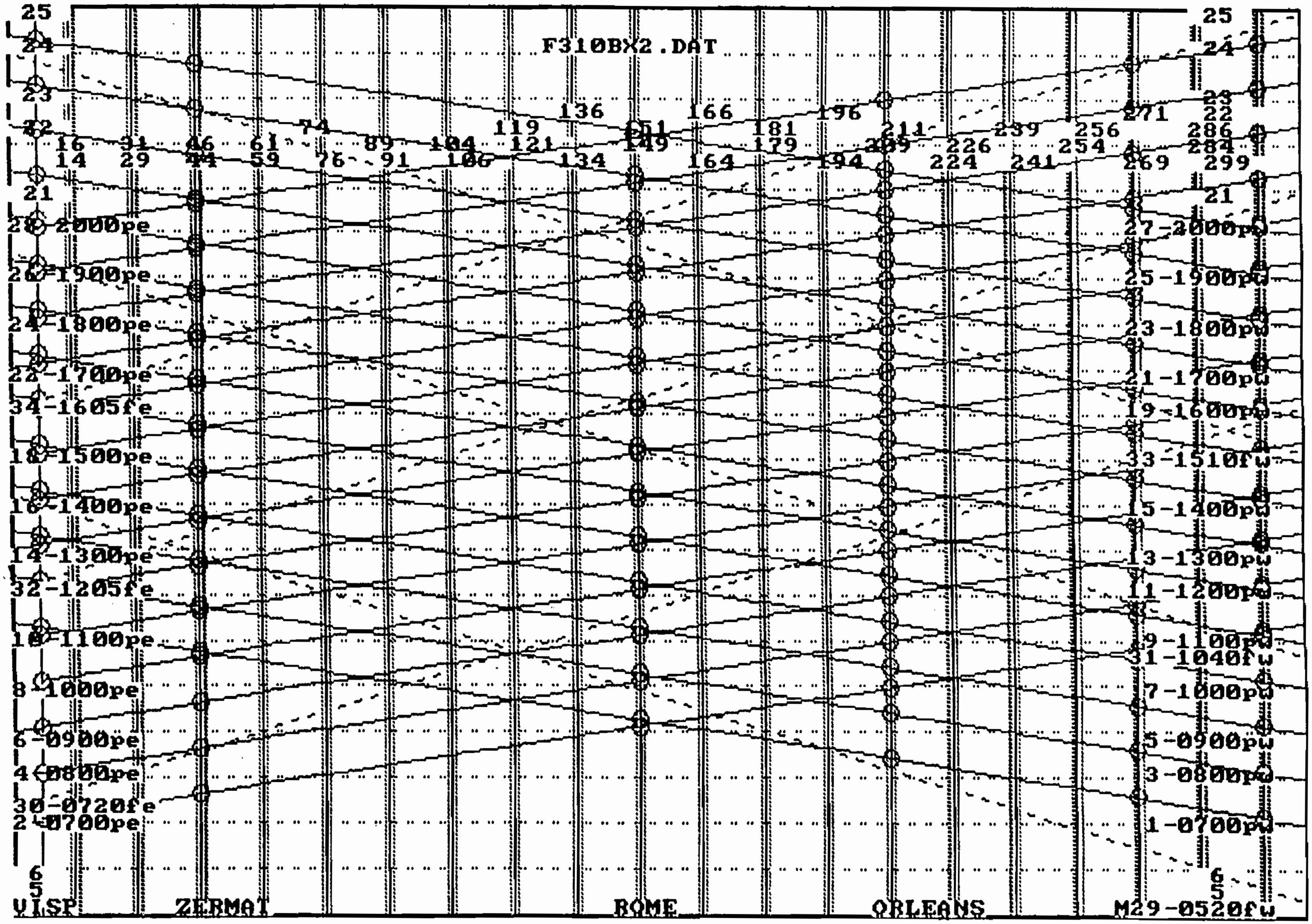


Figure 7-7. Case B: Stringline, 90-mph Passenger Train Speeds

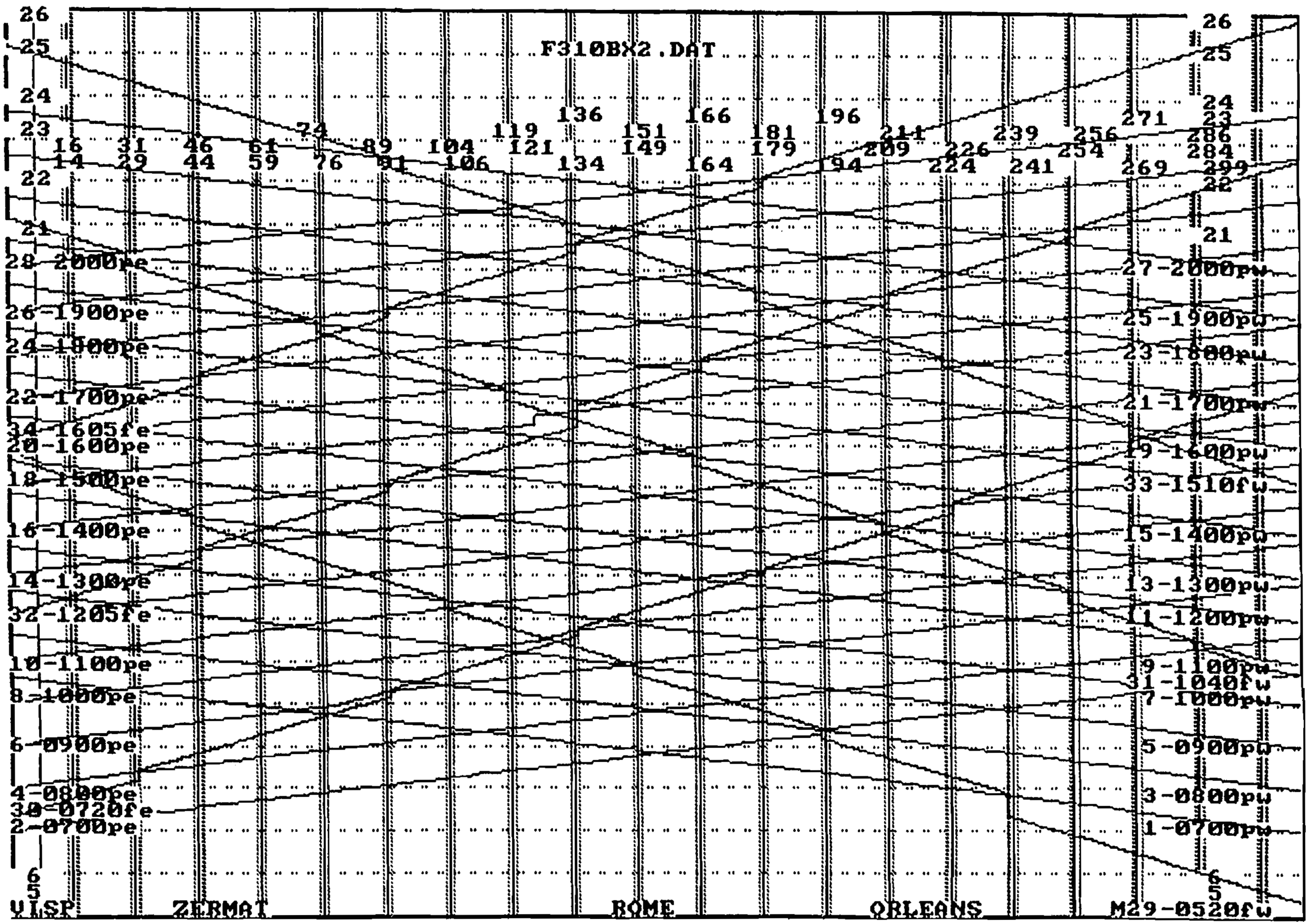


Figure 7-8. Case B: Stringline, 110-mph Passenger Train Speeds

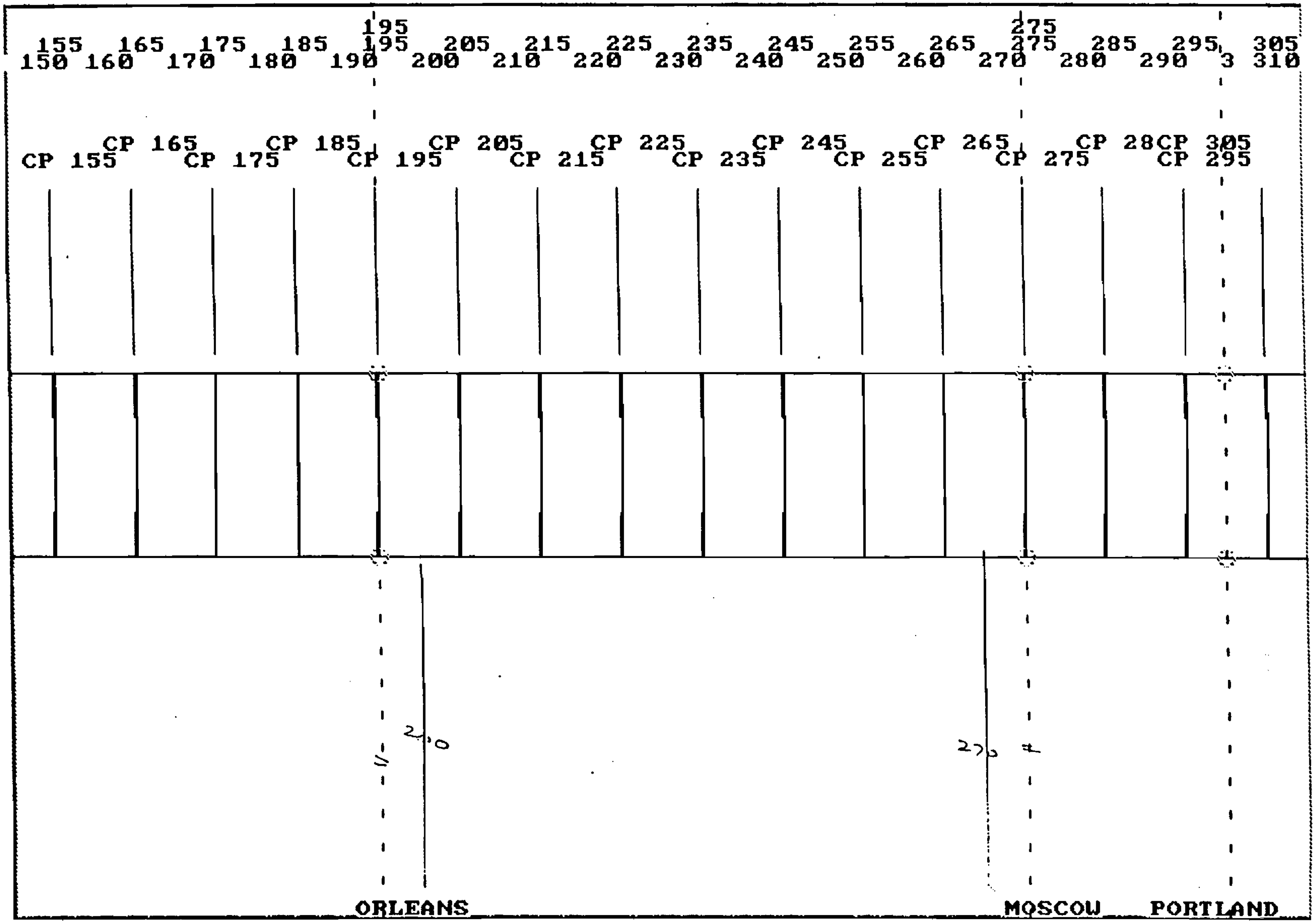


Figure 7-9. Case C: Track Layout

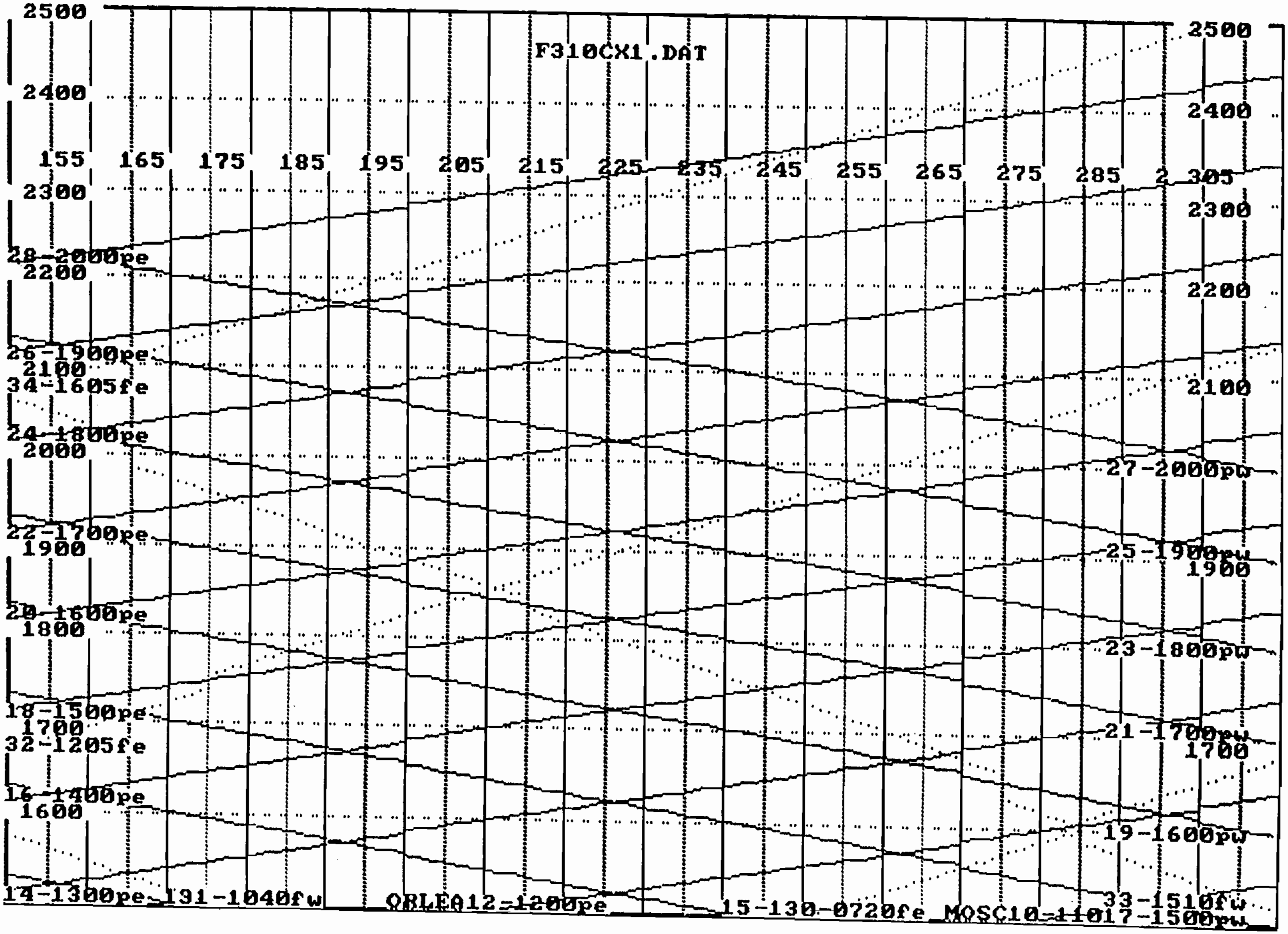


Figure 7-10. Case C: Stringline, 90-mph Passenger Train Speeds (expanded portion)

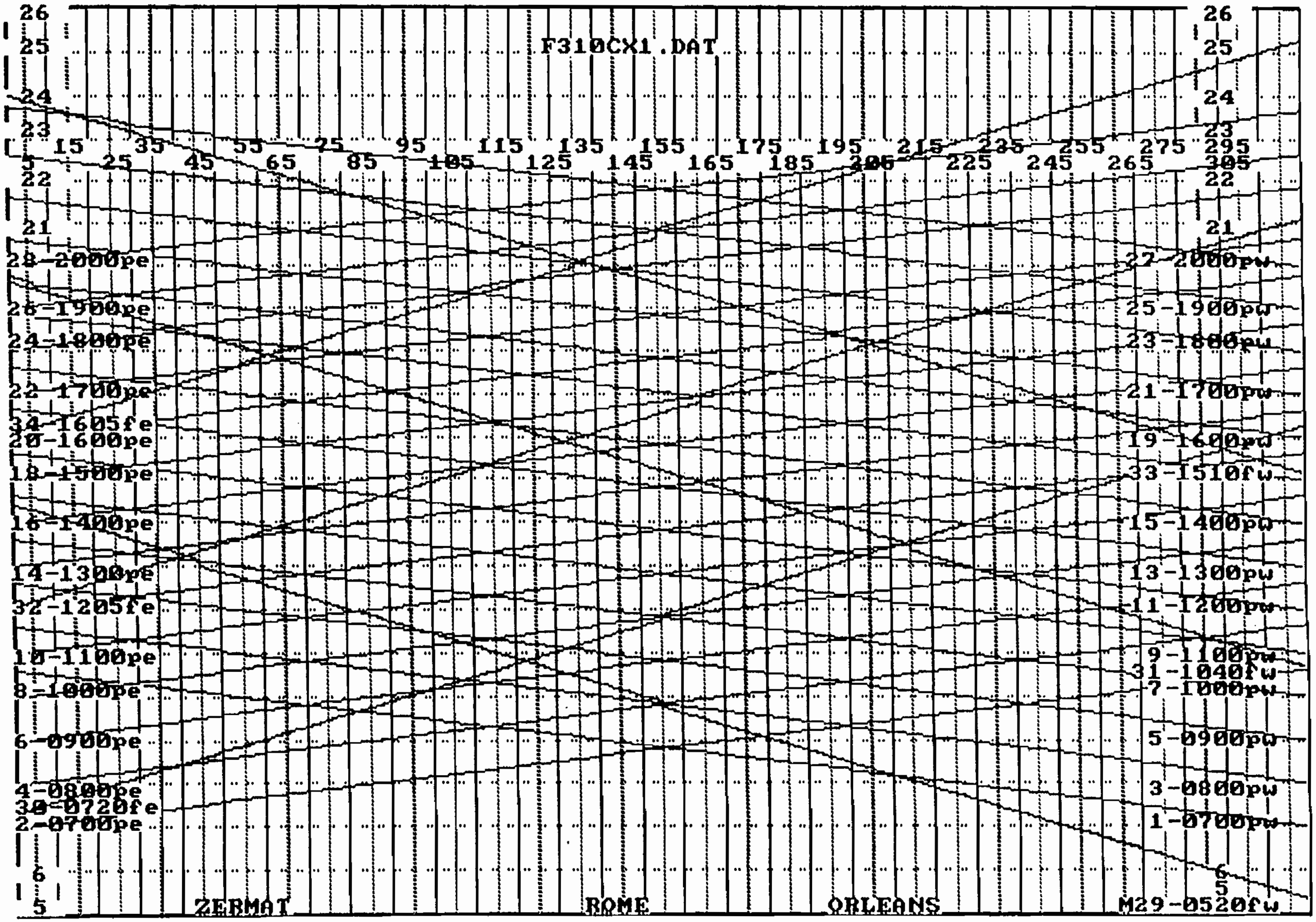


Figure 7-11. Case C: Stringline, 110-mph Passenger Train Speeds

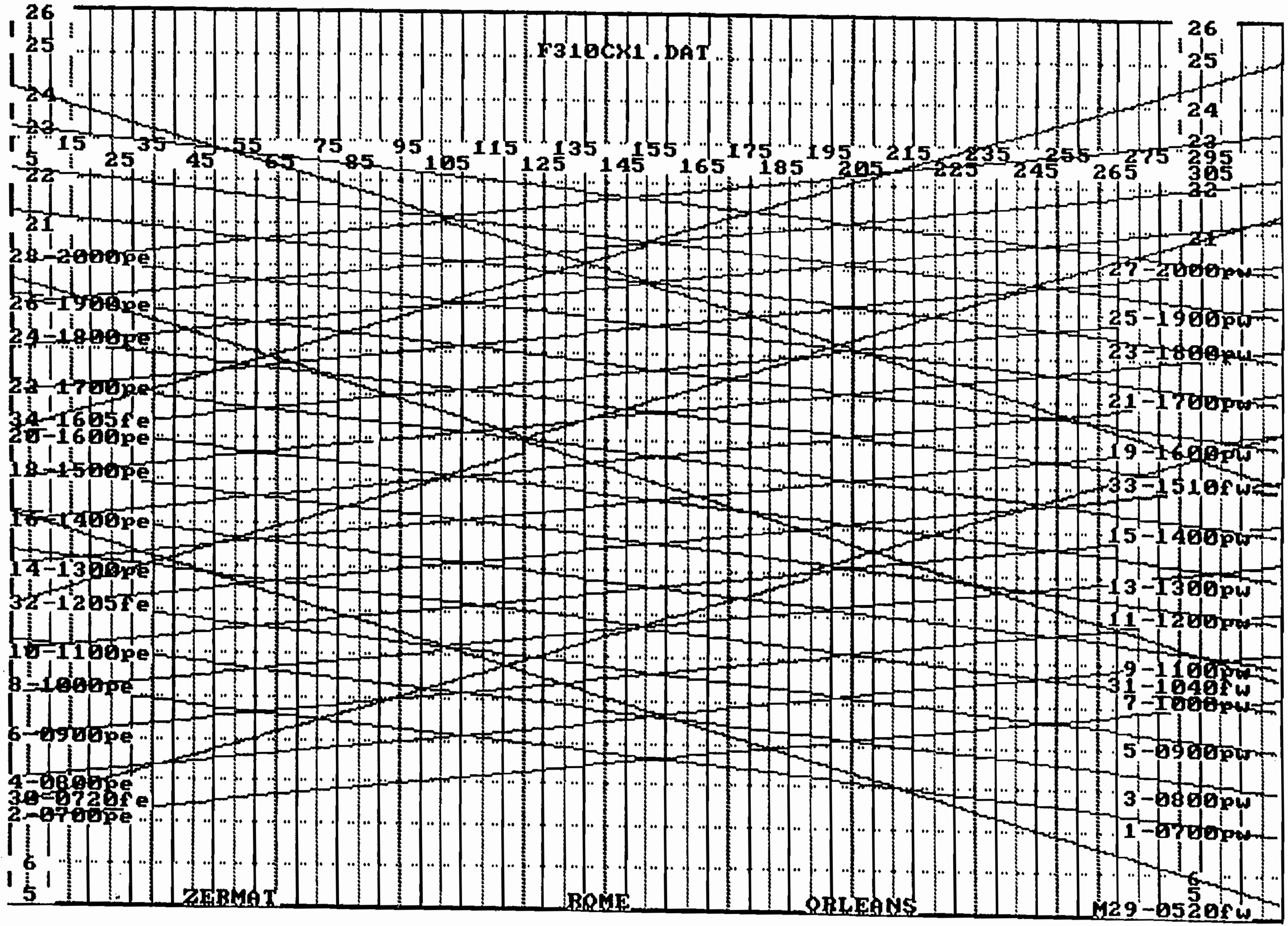


Figure 7-12. Case C: Stringline, 125-mph Passenger Train Speeds

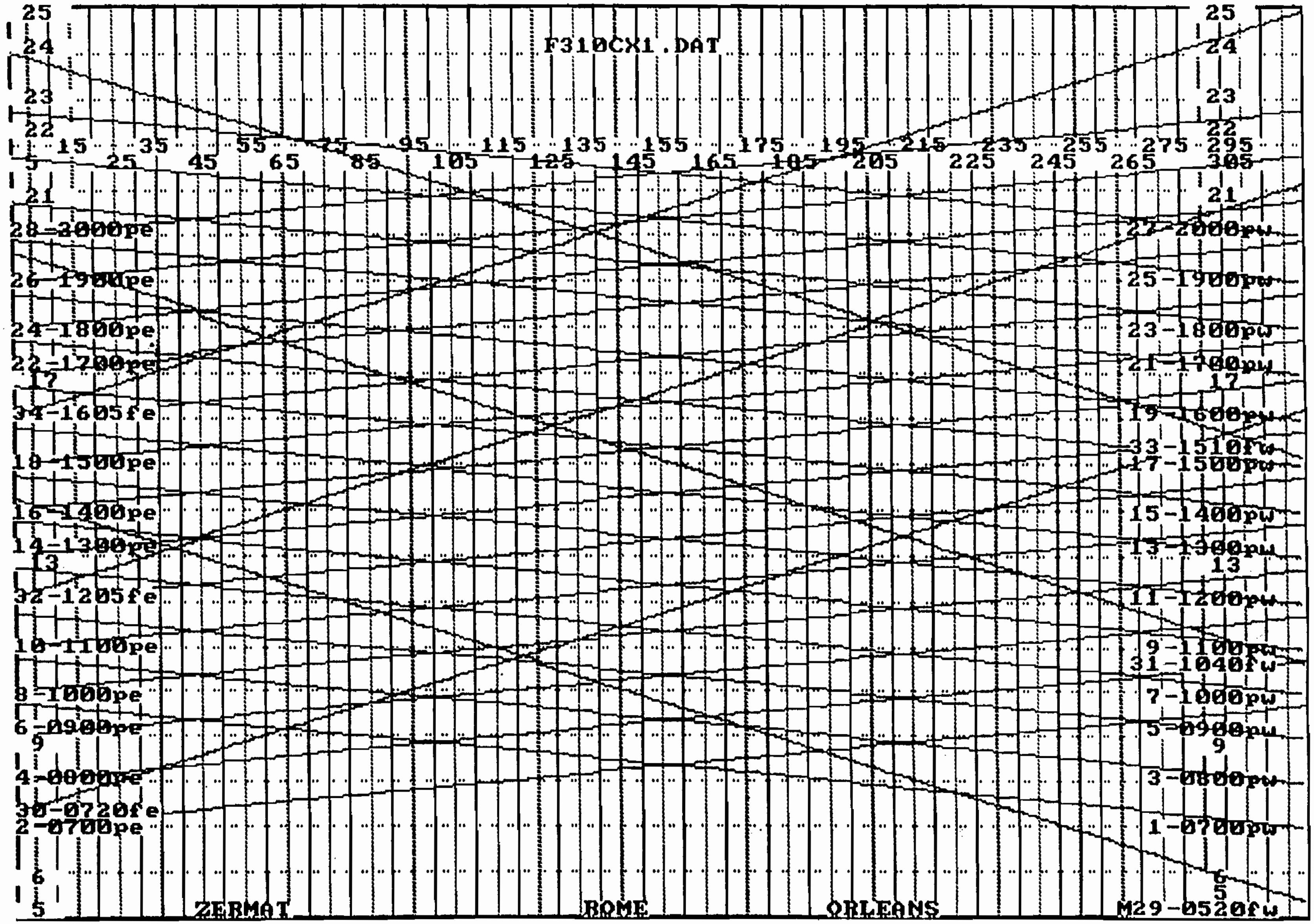


Figure 7-13. Case C: Stringline, 150-mph Passenger Train Speeds

These results are much improved over those of Case B, with average total delay falling from 19 minutes/train to as low as one-third that level. Freight delays have declined markedly. In fact, in the 240 km/h (150 mph) case, freight train delay performance is actually better than passenger train delay performance. This indicates that a redispatch could further improve the passenger train statistics and still permit a very acceptable freight performance.

With a dispatching model tool such as utilized in these illustrations of corridor efficiency considerations, adjustments can be made in starting times and other "what if' scenarios can be played out to optimize train performance. This is an essential component of HSR corridor development planning.

7.4 IMPLICATIONS FOR INCREMENTAL HSR CORRIDOR DEVELOPMENT

- The Case **A** examples illustrated above reveal the difficulties that single track corridors would face if frequent passenger and freight operations must both operate during the same time periods. While some service is obviously possible, there are limits to what can be achieved with such infrastructure. There is also the potential for significant schedule unreliability, which could adversely affect the marketability of service provided over such a corridor.

- Detailed studies should be performed on a site-specific basis to determine that the traffic requirements and the infrastructure proposed are in balance from the standpoint of acceptable delays to freight and passenger services.

- Studies should also address switching and local freight operations at any industries served by a rail line. These operations have not been addressed in this analysis, and can further increase the interference problems encountered.

8. CORRIDOR PLANNING METHODOLOGY

This chapter is intended to serve as a guide to the steps required to advance a rail corridor improvement project, particularly insofar as railroad operations are concerned. The setting for this particular study has been incremental rail improvements associated with the 1010 Corridor program, but the discussion will be generally applicable to all incremental improvement projects.

8.1 PLANNING PROCESS

The planning process to be used will naturally depend on the program sponsor and the sources of funds for the project. A private railroad carrier could undertake a corridor improvement project with its own funds, subject only to environmental reviews where new right-of-way is required. It is reasonable to expect that incremental improvement projects would be sponsored and funded primarily by public agencies, and so the public planning process is the applicable one. Several levels of analysis, review, and findings must be made, but the questions to be answered inevitably boil down to these:

- Will the proposed system work from a technical and operations standpoint?
- Will it work from a financial standpoint? If the operations must be supported by taxpayer financing, do the benefits merit the required expenditures of funds?
- Are any adverse environmental impacts acceptable and mitigated appropriately?

We will focus most directly on the first of these questions.

8.2 INSTITUTIONAL CONSIDERATIONS

It is important to identify the required players early in the game, particular the owners, operators, and sponsor/funders of the project. Often this means a state DOT, transportation commission or authority as lead agency and primary funder of the project; a railroad or railroads as owner of the right-of-way and the operating rail line, although some of these are state-owned; and the operating entities proposed to be involved — the freight rail carriers on the one hand, and Amtrak or another operator for the passenger service on the other. The engineering and operations departments of the carriers need to be involved throughout, and at different stages of the project other carrier departments (legal, insurance, etc.) must be involved.

The cooperation of the owning railroads is essential for a successful project. In the final analysis agreements must be reached between the parties mentioned above and reduced to contractual terms. It is helpful if project ground rules are agreed upon at the highest levels in the organization and communicated to all participants.

8.3 CONCEPTUAL PLANNING, ENGINEERING, AND OPERATIONS ANALYSIS

As mentioned above, the three major questions to be studied in an incremental improvement project center around technical/operations, financial, and environmental concerns. Because many disciplines are involved in making these evaluations, project development may not proceed in a totally linear fashion; it may be necessary to reiterate steps and adjust the program plan before it is optimum.

Nevertheless, in order to have a starting point as well as a target, it is suggested that a Project Concept be advanced at the outset. Alternatively, a first phase study can be employed to develop one.

.3 j Concept

The project concept must identify the route or routes to be used, the end-points of the corridor, the intermediate markets to be served (station stops), access to stations, and the level of service to be provided in the corridor. Station stops must be selected to build ridership where the market is strongest, but must be limited so as not to increase running time needlessly. Station access, station location, station parking, and security may be issues which affect the image and marketability of service in the community to be served. Level of service includes target trip times, train frequency (number of trains per day), and desired or preferred operating times. It may be most prudent to "aim high" in setting frequencies to allow for future growth in demand. However it may be necessary to reduce frequencies and associated infrastructure costs to permit the project to be funded, particularly if the project represents "new start" service. These adjustments would be made after ridership forecasting efforts are completed. Since accurate forecasting often requires survey design and data collection, it is a lengthy process. The project concept will serve as a "straw-man" until projected demand is available. The process can then reiterate to balance supply (frequencies) with demand.

In parallel with the project concept development, the project constraints must be identified. If budgetary limitations are clearly known, this should be recognized at the outset to save effort and planning expense. Railroad freight and switching requirements must be investigated, discussed, and documented. Access to railroad timetables, track charts, signal block layouts, clearance diagrams etc. must be secured.

8.3.2 Operations Analyses

In order to determine train running times, a Train Performance Calculator (TPC) is employed. This computer model can reveal the effects of improved train propulsion and braking performance, potentially increased speed on curves through tilt-train technology or better-performing suspension systems, and reduced curvature from realignment projects, to name several key examples. Eliminating slow speed areas that are not curvature-limited is another key improvement category to be addressed, particularly if the speed restriction is related to track conditions (which can be upgraded relatively simply) rather than some more embedded problem (e.g., a deteriorated movable bridge). Each project should be studied in isolation so that costs and benefits can be compared for each project.

After TPCs have been performed and a sufficiently rapid railroad has been proposed on paper, more detailed simulations must be performed to show the effects of freight/passenger interaction. These are analogous to the computer-generated stringline charts of chapter 7, but are more detailed, at least in the later stages of project development. The results of the simulations will suggest infrastructure additions (tracks, passing sidings, crossovers, and improved signaling) that would be required to permit the identified freight and passenger traffic level(s) to be achieved within a tolerable range of delays. The simulations would be repeated with improved infrastructure until the line appears to operate satisfactorily, with respect to standards agreed to in advance, or to the satisfaction of all parties.

8.3.3 Engineering and Cost Estimatinq

The operations analysis will have developed a list of potential improvement projects, and other improvements will be required by virtue of increased maximum speeds, e.g., signal and train control requirements, track class upgrading, etc. Each improvement must be described and sketched in sufficient detail to permit accurate construction cost estimation. The cost estimates should be developed project-by-project to allow the costs to be compared with the benefits (trip-time benefits and others) calculated in other tasks.

At the same time, a safety analysis of the project should be performed to identify risk areas and mitigation measures to be undertaken. Key areas of concern are grade crossings, train control systems, shifted load detection, hazardous materials provisions, and weather hazard detectors. As increased federal rail safety regulations in the high-speed rail arena are under discussion at this writing, close coordination with FRA is desirable, particularly where speeds are planned to exceed 175 km/h (110 mph) and waivers or special approvals are currently required.

8.4 OTHER STUDIES

Simultaneous with the engineering and operations studies described, studies should be undertaken to answer the question of financial feasibility and environmental impact. Generally, these studies should include:

- A study of demand for passenger transportation in the various corridor markets and a forecast of that demand over time. Compatible freight demand (parcels, mail, and other expedited high-value traffic) may also be studied as a means of enhancing revenue.
- A revenue forecast associated with the ridership forecast.
- An operations and maintenance cost estimate and a plan for the management of the operation, indicating responsibilities of all parties.
- A study of the economic benefits accruing to the HSR service.
- A financial analysis relating project cash inflows and outflows over the life of the project, including capital and operating/maintenance, fare revenues, other revenues, and any subsidies required.
- An environmental assessment of the proposed improvements including any mitigation requirements determined to be necessary. This study would have to satisfy state environmental regulations, and possibly federal environmental regulations as well.

As these studies are progressing, fine-tuning of the project's level of service may be required. Project improvements may have to be increased to handle environmental or safety concerns, or may need to be decreased to improve financial performance or to match demand forecasts. Following the fine-tuning adjustments and the equilibration of supply and demand, a final report would summarize all the analyses performed.

If the project receives funding approval, it would then enter the design phase where the detailed engineering design documents and environmental impact statement (if required) would be prepared. The project would then move forward into construction, commissioning, and operations.

If federal funding is involved in the project, the funding agency may require a particular evaluation process and a standardized methodology to be used. A high-speed rail project of significant scope would likely require a Major Investment Study, regulations for which are now being developed at U.S. DOT among the Federal Highway Administration, Federal Transit Administration, and FRA, as part of the rulemaking process.

APPENDIX - SECTION 1010 CORRIDORS DATA

The following tables provide data on each Section 1010 corridor or sub-comdor as listed below.

Table A1 Route Data Sheet:	New York (Empire Comdor)
Table A2 Route Data Sheet:	Virginia
Table A3 Route Data Sheet:	North Carolina
Table A4 Route Data Sheet:	Florida
Table A5 Route Data Sheet:	Illinois - Missouri
Table A6 Route Data Sheet:	Michigan - Illinois
Table A7 Route Data Sheet:	Wisconsin - Illinois
Table A8 Route Data Sheet:	California
Table A9 Route Data Sheet:	Oregon - Washington

TABLE A1 ROUTE DATA SHEET: **NEW YORK (EMPIRE CORRIDOR)**

City Pair: New York - Albany/Hoffmans

Segment	Mileage	Railroad	Number Tracks	Psgr Speed/ Signalling/ Dispatch Pt	Typical Curvature
1 New York-Spuytn Duyvil	10	Amtrak	1	70 CTC (New York)	2 deg.
2 Sp Dyv-Poughkeepsie	63	MNCR	4/2	79 CTC (New York)	1-2 deg.
3 Poughkeepsie-Stuyvesant	51	CR	2	110 CTC (Selkirk)	1-2 deg.
4 Stuyvesant-Hoffmans	46	Amtrak	1-2	110 CTC (Selkirk)	1-2 deg.
	170				

Proposed Passenger Train MAS: 125 mph (initially on Segment 4)

Freight Train Speeds: 50 mph

Present Traffic:

Passenger Trains/day: 16
Add'l. Commuter Service?: Yes; extensive electrified MNCR service on Segment 2
Freight Trains/day: 4
Daytime Freight Trains: 0

Total Grade Crossings: 37 **Grade Crossings/route mile:** 0.22

Single Track Biding Data: N/A
Percent Second Track/Siding:
Average Biding Length, mi:
Average Biding Spacing, mi:

Other Information:

- All 4 segments equipped with continuous cab signal system; all carriers operating with ATC equipped power units.

TABLE A2 ROUTE DATA SHEET: VIRGINIA

City Pair: Washington - Richmond

Segment	Mileage	Railroad	Number Tracks	Psgr Speed/ Signalling/ Dispatch Pt	Typical Curvature
Washington-Richmond	108	CSX	2	70 ABS (Jacksonville)	1 deg.

Proposed Passenger Train MAS: 90-95 mph

Freight Train Speeds: 40-60 mph

Present Traffic:
- **Passenger Trains/day:** 18
- **Add'l. Commuter Service?:** Yes; VRE, 8 trains/day
- **Freight Trains/day:** 15
- **Daytime Freight Trains:** 12

Total Grade Crossings: 64 **Grade Crossings/route mile:** 0.59

Single Track Siding Data: N/A
- **Percent Second Track/Siding:**
- **Average Siding Length, mi:**
- **Average Siding Spacing, mi:**

Other Information:
- Entire corridor is cab signal equipped.
- Route is former RF&P line.

TABLE A3 ROUTE DATA SHEET: **NORTH CAROLINA**

City Pair: Raleigh - Charlotte

Segment	Mileage	Railroad	Number Tracks	Psgr Speed/ signalling/ Dispatch Pt	Typical Curvature
1 Raleigh- Carey	6	NS/CSX	2	79 ABS (Greenville)	3-4 deg.
2 Carey-Greensboro	75	NS	1	59 dark	3-4 deg.
3 Greensboro-Charlotte	92	NS	1	79 CTC (Greenville)	1-2 deg.
	173				

Proposed Passenger Train MAS: 90 mph (135 mph in later phase)

	Segment 1	Segment 2	Segment 3
Freight Train Speeds:	49 mph	49 mph	50 mph
Present Traffic:			
Passenger Trains/day:	4	4	4
Add'l. Commuter Service?:	No	No	No
Freight Trains/day:	6	4	22
Daytime Freight Trains:	2	2	10
Single Track Siding Data:			
Percent Second Track/Siding:	NA	5%	50%
Average Siding Length, mi:	NA	1	10.0
Average Siding Spacing, mi:	NA	18.8	10.0

Total Grade crossings: 260 (all segments)
Grade Crossings/route mile: 1.50

Other Information:

- Raleigh-Carey operates in a paired track coordination arrangement using both CSX and NS tracks.
- Portions shown as NS are formally North Carolina RR (75% state-owned) and operated by NS under a 99-year lease expiring in 1994.

TABLE A4 ROUTE DATA SHEET: **FLORIDA**

City Pair: Miami - W. Palm Beach

Segment	Mileage	Railroad	Number Tracks	Psgr Speed/ Signalling/ Dispatch Pt	Typical Curvature
Miami-W. Palm Beach	71	SFRC	1	79 CTC (Jacksonville)	1-2 deg.

Proposed Passenger Train MAS: **90** mph

Freight Train Speeds: **60 mph**

Present Traffic:
- **Passenger Trains/day:** 8
- **Add'l. Commuter Service?:** Yes; TCCRA operates 24 trains/day
- **Freight Trains/day:** 4
- **Daytime Freight Trains:** 0

Total Grade crossings: 73 **Grade Crossings/route mile:** **1.03**

Single Track Siding Data:
- **Percent Second Track/Siding:** 35% after 1987 completion of presently-funded program
- **Average Siding Length, mi:**
- **Average Siding Spacing, mi:**

Other Information:

- Corridor will form a segment of larger Miami-Orlando-Tampa future HSR corridor under study. Under present improvement program, MIA-WPB will be **100%** cab-signalled and approximately 35% double tracked; future programs will implement 100% double track goal.

TABLE A5 ROUTE DATA SHEET: **ILLINOIS - MISSOURI**

City Pair: Chicago - St. Louis

Segment	Mileage	Railroad	Number Tracks	Psgr Speed/ Signalling/ Dispatch Pt	Typical Curvature
1 Chicago-S. Joliet	35	IC	2	79 CTC (Chicago)	1 deg.
2 S. Joliet-Mazonia	23	SPCSL	1	79 ABS (Denver)	1 deg.
3 Mazonia-St.Louis	224	SPCSL	1	79 CTC (Denver)	1 deg.
	282				

Proposed Passenger Train MAS: 90 mph (135 mph in later phase)

	Segment 1	Segment 2	Segment 3
Freight Train Speeds:	60 mph	60 mph	60 mph
Present Traffic:			
Passenger Trains/day:	4-8	4-8	4-8
Add'l. Commuter Service?:	Yes; Metra	No	No
Freight Trains/day:	3/wk	6-8	6-8
Daytime Freight Trains:	0	1	1
Single Track Siding Data:			
Percent Second Track/Siding:	NA	0%	17%
Average Siding Length, mi:	NA	0	2.0
Average Siding Spacing, mi:	NA	23.0	11.8

Total Grade Crossings: 327 (all segments)
Grade Crossings/route mile: 1.15

Other Information:

- Amtrak and TRRA control short multiple-track segments at Chicago (1.6 miles) and St. Louis (3.0 miles) terminii, respectively.
- SPCSL Route is former GM&O/ICG/ChgoMo&Wn line.

TABLE A6 ROUTE DATA SHEET: **MICHIGAN - ILLINOIS**

City Pair: Detroit - Chicago

Segment	Mileage	Railroad	Number Tracks	Psgr Speed/ signalling/ Dispatch Pt	Typical curvature
1 Detroit-Kalamazoo	142	CR	1-2	79 CTC (Dearborn)	2.5 deg.
2 Kalamazoo-Porter	97	Amtrak	1	79 CTC (Dearborn)	1 deg.
3 Porter-Chicago	41	CR	2	79 CTC (Chicago)	1 deg.
	280				

Proposed Passenger Train MAS: 100 mph

	Segment 1	Segment 2	Segment 3
Freight Train Speeds:	60 mph	60 mph	60 mph
Present Traffic:			
Passenger Trains/day:	8	8	20
Add'l. Commuter Service?:	No	No	Yes (Metra)
Freight Trains/day:	6	2	
Daytime Freight Trains:	1	0	

Total Grade Crossings: 388 (all segments)
Grade Crossings/route mile: 1.39 (all segment average)

Single Track Siding Data:			
Percent Second Track/Siding:	25%	13%	NA
Average Siding Length, mi:	5.1	2.1	NA
Average Siding Spacing, mi:	20.3	16.2	NA

Other Information:
- Corridor operates over GT rights in Battle Creek. Final 1.6 miles into Chicago Union Station is 3-track Amtrak ROW,.

TABLE A7 ROUTE DATA SHEET: **WISCONSIN - ILLINOIS**

City Pair: Chicago - Milwaukee

Segment	Mileage	Railroad	Number Tracks	Pegr Speed/ Signalling/ Dispatch Pt	Typical Curvature
Chicago-Rondout	33	Metra	2-3	70 CTC (Chicago)	1 deg.
Rondout-Milwaukee	53	SOO	2	79 CTC (Chicago)	0.5 deg.
	86				

Propoeed Passenger Train MAS: 90 mph

Freight Train Speeds: **50** mph manifest, 60 mph intermodal

Present Traffic:
- **Paeeenger Trains/day:** 16
- **Add'1. Commuter Service?**: Yes
- **Freight Trains/day:** 20-22
- **Daytime Freight Trains:** 7-8 (Noon-3pm departures)

Total Grade Crossings: 111 **Grade Crossings/route mile:** 1.31

Single Track Siding Data: N/A
- **Percent Second Track/Siding:**
- **Average Siding Length, mi:**
- **Average Siding Spacing, mi:**

Other Information:

TABLE A8 ROUTE DATA SHEET: **CALIFORNIA**

City Pair: San Diego/Los Angeles/Bay Area/Sacramento

	Segment	Mileage	Railroad	Number Tracks	Psgr Speed/ Signalling/ Dispatch Pt	Typical Curvature
1	San Diego-Fullerton	103	ATSF	1	90 CTC/ATS (Chicago)	
2	Fullerton-Los Angeles	25	ATSF	2	79/65 CTC (Chicago)	
3	Bakersfield-Stockton	234	ATSF	1	79 CTC (Chicago)	
4	stockton-Port Chicago	42	ATSF	1	79 ABS (Chicago)	
5	Port Chicago-Oakland	35	SP	2	60/40 ABS (Roseville)	
6	Stockton-Sacramento	48	SP	1	70 CTC/ABS (Roseville)	
		487				

Proposed Passenger Train MAS: 100 mph, LOSSAN (90 mph LOSBAS in later phase).

	Segment 1	Segment 2	Segment 3	Segment 4	Segment 5	Seument 6
Freight Train Speeds:	55 mph	55 mph	55 mph	55 mph	60/40 mph	65 mph
Present Traffic:						
Passenger Trains/day:	16	16	8	8	8+	0
Commuter Service?:	No	No	No	No	No	No
Freight Trains/day:			20		8-12	20-24
Daytime Freight Trains:					2	6-8
Single Track Siding Data:						
Percent Second Track/Siding:	22%	NA	22%	18%	NA	34%
Average Siding Length, mi:	1.0	NA	1.6	.94	NA	1.5
Average Siding Spacing, mi:	9.1	NA	7.3	5.25	NA	7.8
Total Grade Crossings:		85	231	24	42	46
Grade Crossings/route mile:		.66	.99	.57	1.2	.96

Other Information:

- ATS installed between E. Santa Ana and Sorrento, 73 miles of 90 mph territory.
- LA-Bakersfield has bus connection service but no rail passenger service; new direct rail line presently in planning and preliminary design.
- Stockton-Sacramento has bus connection service but no rail passenger service; Caltrans is now planning to introduce rail service to replace bus feeders.
- Commuter service on LOSSAN segments is scheduled for 1994, and commuter service on Capital segment is under study.
- Virtually all grade crossings in all segments are protected by active warning devices.

TABLE A9 ROUTE DATA SHEET: OREGON - WASHINGTON

City Pair: Eugene/Portland/Seattle/Vancouver

Segment	Mileage	Railroad	Number Tracks	Psgr Speed/ Signalling/ Dispatch Pt	Typical Curvature
1 Eugene-Portland	124	SP	1	70 CTC (Roseville)	2 deg.
2 Portland-Seattle	186	BN	2	75/79 CTC/ABS (Seattle)	3 deg.
3 Seattle-Everitt	32	BN	2	60 CTC/ABS (Seattle)	3-4 deg.
4 Everitt-Vancouver,BC	122	BN	1	60/40 CTC/ABS (Seattle)	3 deg.
	464				

Proposed Passenger Train MAS: 90 mph (125 mph in later phase)

	Segment 1	Segment 2	Segment 3	Segment 4
Freight Train Speeds:	60 mph	50/60 mph	50 mph	50/40 mph
Present Traffic:				
Passenger Trains/day:	2	6-8	2	0
Add'l. Commuter Service?:	No	No	No	No
Freight Trains/day:	20			
Daytime Freight Trains:	8'			
Total Grade Crossings:	205	72		127 (Segments 3 + 4)
Grade Crossings/route mile:	1.65	0.38		0.82
Single Track Siding Data:				
Percent Second Track/Siding:	20%	NA	79%	13%
Average Siding Length, mi:	1.4	NA	5.2	1.0
Average Siding Spacing, mi:	9.1	NA	1.4	13.3

Other Information:

- Access to Portland Union Station presently controlled by UP (Omaha). Project in planning to convert to regional control by SP or BN.
- Single track @ Nelson Bennett tunnel, Tacoma, 1.5 miles.
- Portion of ROW within Canada dispatched by Southern Railway of B.C.
- UP operates on rights between Portland and Tacoma, adding to already heavy freight density.
- Operation into CN terminal, Vancouver, BC is under Yard Limit rules (dark).

GLOSSARY

This glossary provides definitions and brief explanations of acronyms and terms used in this report.

AAR	Association of American Railroads, a North American railroad trade association
ABS	Automatic Block System, a form of railroad signaling in which the signals governing entry to a track block are controlled automatically by track circuits or other means to sense the occupancy of a block by a train
ACS	Automatic Cab Signals, a system that provides a display of signal indications in the cab, accompanied by an audible warning when a more restrictive signal aspect is displayed
ARTEMIS	A joint project of French and German railways to combine the features of their individual advanced train control s systems, ASTREE and DIANE
ASTREE	An advanced train control system under development by French National Railways
ATC	Automatic Train Control, a system of train control having the capability of automatically applying train brakes when signal indications, and in some systems, speed limits are not observed. Note that when used in the context of a mass transit system, ATC means a system that provides automatic train operation (ATO), as well at enforcement of speed limits and signal indications
ATCS	Advanced Train Control Systems, a project initiated by the AAR to develop functional and interface specifications for advanced signal and train control systems, including communications-based signal systems
ATS	Automatic Train Stop, a system to automatically apply train brakes when a more restrictive signal indication is received and is not acknowledged by the engineer
ATSF	Atcheson, Topeka and Santa Fe Railway, a major U.S. railroad
BARD	Bay Area Rapid Transit, a mass transit system in the San Francisco area
CCP	Chicago, Central and Pacific, a regional U.S. railroad
CFR	Code of Federal Regulations
CNW	Chicago and Northwestern Railroad, a major U.S. Railroad
CR	Consolidated Rail Corp., a major U.S. railroad
CP Rail	The railroad unit of the Canadian Pacific Co, and a major Canadian railroad
CSEE	A major French signal system manufacturer, which produces the TVM series of continuous automatic train control systems.
CSX	A major freight railroad in the U.S.

GLOSSARY (continued)

CTC	Centralized Traffic Control, a system of railroad operations control in which all train movements over a designated territory are supervised and controlled from one location
DB	Deutsche Bundesbahn, German Federal Railways. DB was restructured as a government-owned corporation, DBAG (Deutsche Bahn AG), effective January 1, 1994.
DIANE	An advanced train control system under development by German Railways (DBAG)
DOT	United States Department of Transportation
EPLRS	Enhanced Position Location Reporting System, a communications-basedsignal and train control system being jointly developed by BART, Hughes Electronics, and Morrison Knudsen
FRA	Federal Railroad Administration, an agency of the United States Department of Transportation
GP	Global Positioning System, a system of satellites developed by the U.S. Department of Defense, able to provide location anywhere on earth
ICC	Interstate Commerce Commission, a U.S. government agency responsible for the economic regulation of some forms of transportation, and formerly responsible for railroad safety regulations
ICE	Intercity Express, a high-speed passenger train system developed by German Federal Railways (DB).
ISTEA	Intermodal Surface Transportation Assistance Act of 1991
LIRR	Long Island Railroad, a commuter railroad in the New York area
LSL	Locomotive Speed Limiter, a system controlling brake applications on a freight locomotive operating under ATC in a way that avoids excessively heavy braking and the risk of high longitudinal forces in the train
LZB	ILinienzugbeinflussung, a system of continuous speed control used on the high-speed lines of German Railways (DBAG)
MAS	Maximum Authorized Speed applying in a track block for a given signal indication
MBS	Manual Block System, a system of railroad operation where permission to enter each track block is conveyed by manually operated signals

GLOSSARY (continued)

MGT	Million Gross Tons, a commonly-used measure of railroad traffic level (e.g., as in MGT/year)
MNCR	Metro North Commuter Railroad, a commuter railroad in the New York area
NEC	Northeast Corridor, the rail line carrying the principal passenger services between Washington, DC; New York, NY; and Boston, MA.
NECIP	Northeast Corridor Improvement Program, a continuing program to upgrade the infrastructure of the Northeast Corridor for higher speeds and greater safety.
NRPC	National Railroad Passenger Corporation (Amtrak), the operator of nationwide long-distance passenger rail services in the U.S.
RAIRS	Railroad Accident/Incident Reporting System, an FRA requirement, in which all railroads in the U.S. have to report accidents, injuries and occupational illnesses above a defined severity threshold. The reports are assembled in a database and are used for analysis of railroad safety performance.
ROW	Right-of-way
SELTRAC	A communications-based signal and train control system manufactured by Alcatel-SEL
SNCF	Societe National des Chemins de Fer, French National Railways
TCS	Traffic Control System, a signal system and accompanying operating rules designed to allow bi-directional running under the control of block signals
TGV	Train a Grand Vitesse, a high-speed passenger train system developed by French National Railways (SNCF).
TPC	Train Performance Calculator, a computer model which calculated train speeds and times over a defined route from data on maximum speeds, installed power, train weight, etc.
TRI-RAIL	A commuter rail service between Miami and Fort Lauderdale, FL.
TVM	An automatic block and ATC system manufactured by a French company, CSEE, and used on the high-speed lines of the SNCF.
UPRR	Union Pacific Railroad Corp.
U.S.	United States

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