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of Transportation
**Federal Railroad
Administration**

An Assessment of High-Speed Rail Safety Issues and Research Needs

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Office of Research and
Development
Washington DC 20590

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16. Abstract

Proposals are currently being developed for high-speed wheel-on-rail passenger train service in several intercity corridors in the United States. These proposals involve the application of foreign high-speed train technology, and operation at speeds exceeding 125 mph. This report provides an assessment of safety issues associated with high-speed rail passenger systems, and identifies where further research may be needed to ensure the safe operation of such systems in the United States railroad environment.

The approach taken in this assessment was to first identify and describe the key safety-related features of all high-speed rail systems that may be applied in the United States. Then all safety issues associated with passenger rail systems are identified, and pertinent safety-related regulations, standards and practices applicable in the U.S. and on foreign systems are discussed. Each discussion concludes with a recommendation regarding the need for research into the safety issue.

The principal issues on which research appears desirable include passenger car structural strength requirements, novel brake system performance, security of the right-of-way against obstructions, and high-speed signalling and train control systems.

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METRIC / ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

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

AREA (APPROXIMATE)

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

$[(x - 32)(5/9)]\ ^\circ F = y\ ^\circ C$

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

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

AREA (APPROXIMATE)

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

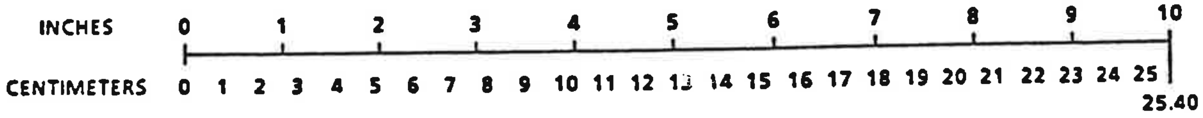
VOLUME (APPROXIMATE)

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

TEMPERATURE (EXACT)

$[(9/5)\,y + 32]\ ^\circ C = x\ ^\circ F$

QUICK INCH-CENTIMETER LENGTH CONVERSION



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. C13 10 286.

METRIC CONVERSION FACTORS

Length

1 inch	25.4 mm
1 ft	304.8 mm
1 yard	0.9144 m
1 mile	1.609 km

Area

1 in^2	645.16 mm^2
1 ft^2	0.0929 m^2
1 yd^2	0.8361 m^2
1 acre	0.4046 ha
1 mile^2	2.590 km^2

Volume

1 in^3	16387 mm^3
1 ft^3	0.0283 m^2
1 US gall	3.637 l

Velocity

1 ft/sec	0.3048 m/sec
1 mile/h	0.447 m/sec 1.6093 km/h

Density

1 lb/in^3	2.768 x 10^4 kg/m^3
1 lb/ft^3	16.019 kg/m^2

Force

1 lb force	4.448 N

Pressure

1 lbf/in^2	6.894 kN/m^2

Energy

1 ft-lbf	1.354 J
1 Btu	1.055 kJ

Power

1 hp	0.7457 kW

Temperature

1°F	5/9° K

Mass

1 lb	0.4536 kg
1 US ton	0.9072 tonnes (metric tons)

ABBREVIATIONS

Many abbreviations are in common use for railroad organizations and high-speed rail systems and their components. This list provides a convenient reference for those used frequently in this report.

AAR	Association of American Railroads
ABS	Ausbaustrecken. Existing lines of German Federal Railways rebuilt for high speed operation, usually at 125 mph
AREA	American Railway Engineering Association
ATC	Automatic Train Control--systems which provide some degree of automatic initiation of braking if signal indications are not obeyed by train operator
ATO	Automatic Train Operation—a system of automatic control of train movements from start-to-stop. Customarily applied to rail rapid transit operations
ATCS	Advanced Train Control Systems—a specific project of the AAR to develop train control systems with enhanced capabilities
ATP	Automatic Train Protection—usually a comprehensive system of supervision of train operator actions. Will initiate braking if speed limits or signal indications are not obeyed
AWS	Automatic Warning System—cab signalling system used on British Rail
CONEG	Coalition of Northeastern Governors
CWR	Continuous Welded Rail
DB	Deutche Bundesbahn—German Federal Railways
DIN	Deutches Institut for Normung—German National Standards Institute

EMI	Electro-Magnetic Interference—usually used in connection with the interference with signal control circuits caused by high power electric traction systems
FCC	Federal Communications Commission (United States)
FRA	Federal Railroad Administration of the United States Department of Transportation
FS	Ferrovie dello Stato—Italian State Railways
HSR	High-Speed Rail
HST	High-Speed Train—British Rail high-speed diesel-electric trainset
ICE	Inter-City Express or Inter-City Experimental—a high-speed train-set developed for German Federal Railways
ISO	International Standards Organization
JNR	Japanese National Railways—organization formerly responsible for rail services in Japan. Was reorganized as the Japan Railways (JR) Group on April 1, 1987, comprising several regional railways, a freight business and a Shinkansen holding company
JR	Japan Railways—see JNR
LGV	Ligne a Grand Vitesse—French newly-built high-speed lines. See also TGV
LRC	Light Rapid Comfortable. A high-speed diesel-electric train-set developed in Canada
L/V	Lateral/Vertical. Usually refers to force ratios applied to the rail by a wheel
LZB	Linienzugbeeinflussung—German Federal Railways system of automatic train control
MU	Multiple Unit. A train on which all or most passenger cars are individually powered and no separate locomotive is used

NBS	Neubaustrecken—German Federal Railway newly-built high-speed lines
NEC	Northeast Corridor (United States). The Boston-Washington Rail Corridor
NFPA	National Fire Protection Association (United States)
PSE	Paris Sud-Est. The high-speed line from Paris to Lyon on French National Railways
RENFE	Rede Nacional de los Ferrocarriles Espanoles—Spanish National Railways
SBB	Schweizerische Bundesbahnen—Swiss Federal Railways
SJ	Statens Jarnvagar—Swedish State Railways
SNCF	Societe Nationale des Chemin de Fer Francais—French National Railways
TGV	Train a Grand Vitesse—French High Speed Train. Also used to refer to complete high-speed train system
UMTA	Urban Mass Transportation Administration of the U.S. Department of Transportation
US	United States

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PART I

INTRODUCTION AND OVERVIEW OF HIGH SPEED RAIL SAFETY ISSUES

I.1 BACKGROUND AND INTRODUCTION

I.1.1 Background to the Study

One of the primary responsibilities of the Federal Railroad Administration (FRA) is to ensure the safe conduct of railway operations in the United States. It carries out this responsibility via the FRA safety regulations, and selected research and development to improve understanding of rail safety problems and to develop improved railroad plant, equipment and operational practices. In performing this role, it pays particular attention to the conduct of rail passenger services, in view of the large number of members of the public at risk. Through maintenance of this oversight, and the operational and safety practices used by the passenger rail industry, an excellent safety performance has been achieved, comparable with other common carrier passenger transportation modes.

With one exception, all this experience has been gained in rail operation at what can be termed conventional speeds — up to 110 mph — the maximum normally permitted under present FRA regulations. Even operations at this speed are limited: most passenger trains operate at 90 mph or less. The exception is Amtrak's Washington-New York line on which speeds of 125 mph are authorized over selected portions under a waiver to the regulations granted by the FRA Office of Safety.

There has long been interest in the United States in high speed rail (HSR) services operating at speeds in excess of 125 mph on dedicated track. Considerable research was carried out in the late 1960s and early 1970s under the High Speed Ground Transportation Act of 1965. However, these efforts lapsed in the early 1970s as a result of constrained economic circumstances, and the disappointing results from early attempts to build high speed trains.

Demand for intercity passenger transportation grew sharply in the 1980s with economic growth and deregulation of the airline industry. This has brought with it a revival of interest in high speed rail, as the air and highway modes become more congested, and investment in transportation infrastructure becomes inescapable. Interest has been further fueled by the success of the "Train a Grand Vitesse" (TGV) in France which entered service in 1981, initially at 260 km/h (162 mph) and later at 270 km/h (168 mph). This was the first major step-up in passenger rail speed since the opening of the first Japanese Shinkansen line at 210 km/h (131 mph) in 1964. Shinkansen maximum speeds were also increased to 240 km/h in the 1980s. As a result of this interest, serious proposals are being developed for a number of U.S. intercity corridors. The most currently active proposals are in Florida, linking Miami, Orlando and Tampa; in Texas between Dallas, Houston and Austin; and between Los Angeles and Las Vegas. One or more of these and other systems may be technically and economically feasible, and may be built and put into service in the foreseeable future.

These services are planned to operate at or over 125 mph, and will incorporate equipment and technology developed outside the United States. This may be built to a variety of technical standards which often differ from those applicable to conventional railroad equipment and infrastructure in the United States. Experience in the operation and maintenance of this equipment in the United States is very limited. Apart from the Washington-New York operation, there is also no experience of operating at speeds of 125 mph and higher with any type of equipment. As a result of this lack of experience, knowledge concerning safety-related construction, operating and performance conditions is unavailable or incomplete, and critical safety issues and acceptable operating procedures for high speed rail in the United States have not been defined and analyzed.

In view of this situation, the Federal Railroad Administration commissioned Arthur D. Little to assemble and review safety-related information associated with the high-speed rail systems under consideration for installation in U.S. corridors. The output of this review will serve as a valuable resource in determining future research needs related to high-speed rail safety. Such research will be aimed at ensuring that all critical safety issues are adequately studied, and any problems are resolved prior to the installation and operation of a high-speed rail system. This report presents the results of this review. This study has been confined to conventional wheel-on-rail systems. Unconventional systems such as magnetic levitation have not been included, but may be studied separately by the FRA should this be warranted.

I.1.2 Objectives and Scope of Study

The objectives of this study were to provide the Federal Railroad Administration, Office of Research and Development with the following information:

- A general description and operating characteristics of high-speed rail systems likely to be installed in the United States.
- An assessment of safety issues and concerns associated with the types of high speed rail systems likely to be installed in the United States.
- A final report summarizing the findings from this review, and making recommendations regarding where safety research is most critically needed.

The objectives have been achieved via a comprehensive assessment and review of safety issues and regulations, standards and practices, both in the United States and internationally, associated with each issue. The reviews focus particularly on the safe operation of the system, and the safety impacts on passengers, operating personnel and the public at large. The assessments and reviews were confined to conventional wheel on rail systems, and both electrified and non-electrified systems were included. The study is also confined to safety issues which are directly affected by the speed of operation of passenger trains in normal service. This definition includes almost all commonly understood rail safety issues, but excludes the following activities which are not directly affected by speed of operation:

- Safety during railroad construction testing and commissioning activities, except where this is carried out in close proximity to an operating line.
- Safety in maintenance shops.
- The safety of activities in stations and terminals, except in close proximity to trains.

In more detail, the scope of work comprised the following steps:

1. A preliminary description was prepared of all railroad systems (existing and in development) which may be incorporated into proposals for high speed service in United States corridors. These descriptions include design, construction, trackage, motive power, control system, speed ranges and operating characteristics. These descriptions were used as a basis for the further study of safety issues.

   The safety issues selected for assessment were based on a review of passenger rail accident history in the United States, and a fault-tree of accident causes and consequences. The results of this review were compared with a list of safety concerns prepared by the FRA (given in Appendix II) to ensure all issues had been included.

2. A selection was made of up to four individual systems for more detailed study. The selection was made on the basis of experience of high speed operation and the level of interest in the installation of the systems in the United States. For these railroad systems (existing and in development), a description was prepared of safety standards, rules, regulations, industry standards, and foreign government regulations which apply in their present operating environment.

   This work was coordinated with the related efforts of Transportation Research Board Committee A2M05 (Intercity Guided Passenger Transportation) to avoid unnecessary duplication.

3. The information obtained in Step 2 was used to collate the information on how individual safety issues are addressed by each system, and compare these with applicable current Federal Railroad Administration safety standards, outstanding waivers, and U.S. railroad industry standards and practices, such as those of the

Association of American Railroads (AAR) and American Railway Engineering Association (AREA).

4. Each safety issue was then reviewed in turn, and a discussion and assessment was prepared of differences in the way in which each issue is addressed by the different systems, and under FRA regulations and in North American railroad practice generally. This led to a determination of individual issues and areas of safety concerns where research may be needed.

5. A final report summarizing the findings of Steps 1 through 4 above, and making recommendations regarding where safety research is to be most critically needed has been prepared.

I.1.3 Guide to this Report

Because of the mass of detailed data generated by the reviews of individual high speed rail systems and safety issues, this report is divided into two parts. Part I provides an overview of the approach used, and discusses highlights of the reviews of individual systems and safety issues. Part II provides the detailed tabulations and descriptions of the individual systems and issues.

In more detail, Part 1 provides the following material:

- A summary of the worldwide development of high speed rail systems.
- A description of the identification of key safety issues.
- A discussion of key safety issues, leading to conclusions and recommendations.

Part II provides two sets of detailed descriptions and reviews. The first describes the individual high speed rail systems, with emphasis on those with the most operational experience, and/or most likely to be installed in the U.S. These descriptions reflect the state of development of the systems in early 1990. The second is a detailed review of each individual safety issue, divided into four groups: rolling stock (locomotives and passenger cars), track and infrastructure, operations and human factors, and signalling, communication and electrification systems.

Finally, other ancillary material, such as lists of information sources, is provided in the appendices.

I.2 IDENTIFICATION OF SAFETY ISSUES

I.2.1 Introduction

The overall issue examined in this report is "what are the major safety concerns associated with the installation of high-speed rail systems in the United States, and what research is needed to resolve these concerns." Under this overall issue, there are numerous individual safety issues relating to different aspects of the construction, operation and maintenance of high-speed rail systems. The primary approach used in this study is to examine the approach taken by existing high speed rail systems to each issue and to review this for compatibility with existing U.S. regulations and practices, and with the likely U.S. operating environment. The first step in carrying out this program is to identify the individual safety issues and organize them into a logical structure. The logical structure is useful both as an aid to making sure that all issues and accident types have been identified and addressed, and to assemble related issues and the corresponding regulations, standards and practices into suitable groups.

The available approaches to identifying safety issues are:

- Develop a list, such as that provided by the FRA, as a minimum set of issues to be covered by this study, (Appendix II), developed by rail safety experts. Such lists can be very helpful, but may be imprecise. There is also the possibility that such lists will include subjects which, while interesting, to railroad professionals, are not strictly safety matters. For example, a lot of the standards followed in passenger car construction are designed to provide a high level of comfort and amenity rather than simply ensure safety.

- Develop a fault tree for all events that could be hazardous to passengers, employees and the public. This includes both events producing an accident, and the performance of systems and procedures designed to reduce the severity of the consequences of an accident. This approach also lays the groundwork for determining effective ways of improving the safety of a given operation. The fault tree is our preferred way of identifying and organizing high speed rail safety issues. The other methods support this approach by providing information to develop the tree and check its completeness, and filling out the detail for each accident cause, or way of mitigating severity.

- Review the history of actual railroad accidents and casualties to identify potential causes and related safety issues. This approach can be helpful, particularly in assigning a level of importance to a safety issue. An issue which is associated with a type of accident which only occurs infrequently or which has minor consequences will be less important than frequently occurring or catastrophic accidents.

The approach taken in this study is to develop a fault tree, supported by the Appendix II list and other similar lists, and an analysis of past accidents. Then a finalized list of issues is developed from the fault tree and used for subsequent analysis.

I.2.2 High-Speed Rail Accident Fault Tree

A high speed rail safety fault tree is shown in Figure I.1. The fault tree shows how different system safety performance parameters contribute to the total of casualties and damage occurring as a result of passenger rail operations.

The "top event" in the fault tree is the overall frequency of casualties arising out of railroad operations. Frequencies can be expressed in casualties per million passenger miles, or other similar measures. This study is not quantitative, but since the primary focus is the danger to people (passengers, employees, the general public), the fault tree is expressed in terms of the frequency of exposure of people to the risk of becoming a casualty.

There are three main groups of events that combine to produce total casualties. These are represented by three main "legs" of the fault tree. The "crescent moon" symbol indicates that any one of the three types of event can produce a casualty — they are not in any way dependent on each other. Figure I.2 illustrates these and other fault-tree conventions. The three groups of events are:

- Casualties due to train derailments and collisions, including those at grade crossings, and with any object obstructing the track.
- Casualties due to collisions between trains and a highway user (including a pedestrian) at a grade crossing, other than those causing a train derailment.
- Casualties due to all other types of events. This category includes all casualties to individuals other than those associated with derailments, collisions and grade crossing collisions, including the important category of on-board train fires.

The fault tree is largely self-explanatory, but a few points of clarification will be useful.

- For all three groups of accident cause, the probability that individuals placed at risk will become casualties and the severity of those casualties is a function of the adequacy of emergency systems and procedures. These include fire protection systems, emergency lighting, emergency escape from vehicles, and arrangements for rapid response by emergency services.

Figure I.1 Fault Tree for Casualties Arising Out of High Speed Rail Operations

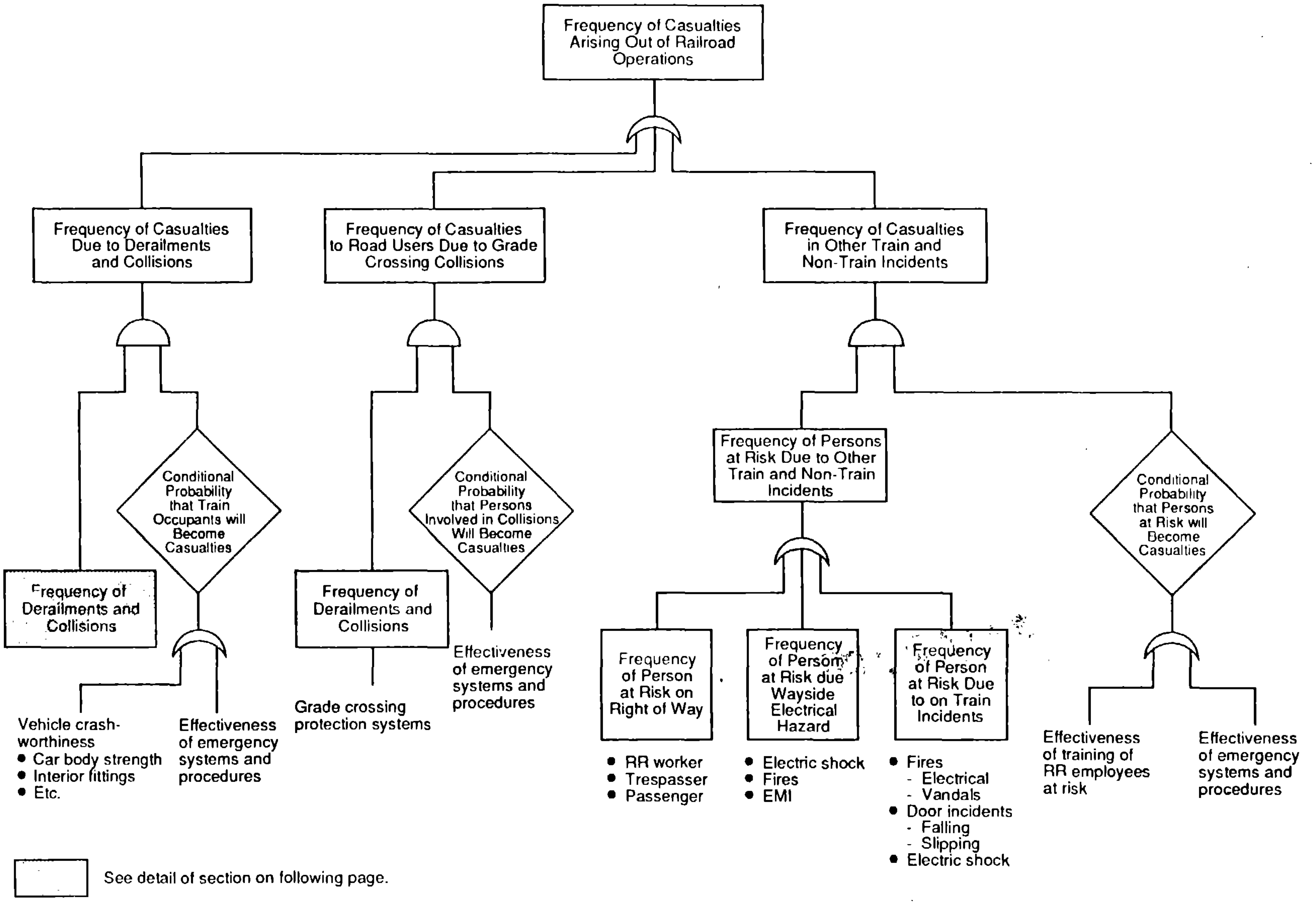


Figure I.1 Fault Tree for Casualties Arising Out of High Speed Rail Operations (continued)

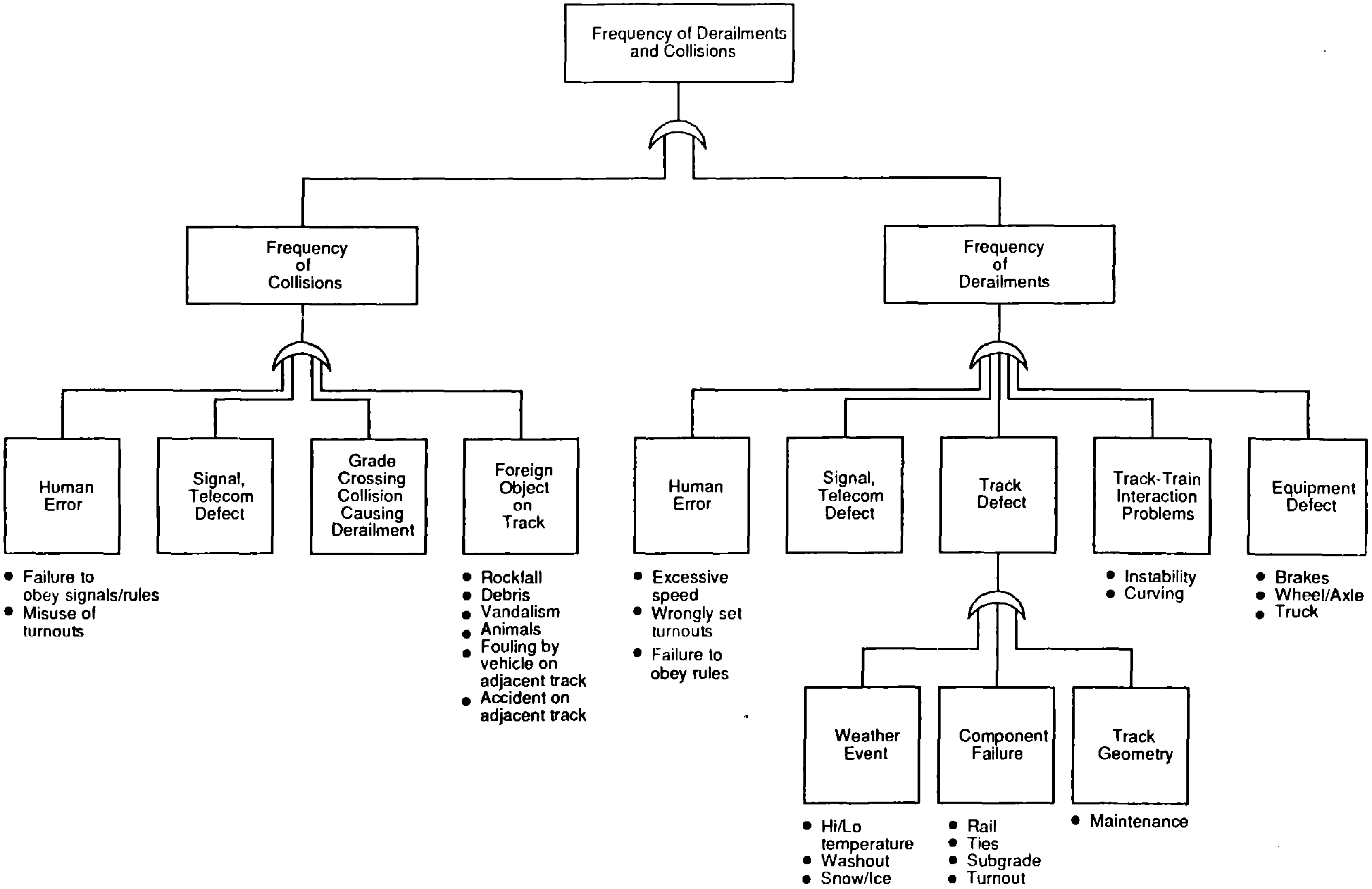
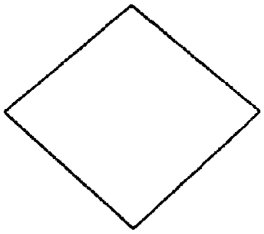


Figure I.2
Fault Tree Conventions



A conditional probability: Expressing the concept if Event A occurs, then the probability of Consequence B following is X.

A frequency of an event—number of occurrences over a given time period.

"And" calculation step, combining a frequency of Event A and a conditional probability for Event B to get the frequency of Event B.

"Or" calculation step, indicating that the input frequencies are additive: either Event A or Event B leads to a hazardous situation.

- In the case of collisions and derailments only, the probability that occupants of a train involved in such an event will become a casualty is a function of speed and vehicle crashworthiness — body strength, coupler strength, interior design details, proper restraint of baggage, etc., in addition to the adequacy of emergency systems and procedures.

- In accordance with the scope of the analysis set out in Chapter I.1, the fault tree is almost exclusively concerned with casualties that arise out of the operation of on-track equipment. The only significant exception to this is the exposure of on-track workers or the public to electrical hazards from high voltage catenary and power supplies. These are included because the catenary has to be energized for train operations to proceed, and in much of the United States only high speed rail systems will be electrified. However, risks such as in stations and terminals (including in boarding trains), or in maintenance workshops that are not directly associated with on-track equipment in normal operations have been excluded.

I.2.3 Past U.S. Rail Passenger Experience

Introduction

The causes of casualties to people and property damage in present rail passenger services in the U.S. can be a useful indication of possible causes of accidents and casualties in high speed rail service. Accordingly, we reviewed passenger service accident and incident data to determine the most significant causes. The sources of these data were the reports of railroad accidents which railroads are required to report to the FRA, and FRA's annual bulletins analyzing railroad and grade crossing accidents and incidents. Specifically, we analyzed a database of railroad accidents for the years 1985-87 for accident data, and used the published 1987 FRA Accident/Incident Bulletins for "injury-only" incidents and grade crossing accidents. In this discussion, we are using the FRA terminology:

- An accident is any event involving on-track railroad equipment causing damage to railroad track and equipment exceeding a defined dollar threshold. An accident need not cause a personal injury or a fatality.

- An incident is any event causing personal injury or fatality, but not property damage exceeding the defined dollar threshold.

- A grade crossing accident or incident is any event involving impact between a train and any vehicle or pedestrian at a grade crossing.

Train Accidents

Data for the years 1985-7 were analyzed in detail, using a tape of FRA accident reports as the source. Both commuter and Amtrak intercity services were included. The very small number of accidents involving excursions trains, and tourist or museum railroads were not included. (Thus, one significant accident to an excursion train was not included — the derailment of a Norfolk & Western Railway steam-hauled train which resulted in 214 injuries.)

Table I.1 gives a breakdown of the average annual number of accidents and casualties by cause and type of operation. Fractional numbers are used because, with the total count at 102 per year, the numbers in some categories are small. It is noteworthy that the number of accidents that cause significant casualties (a fatality, or six or more injuries) are a very small proportion of the total. There were only 20 such accidents out of the total of 305 in the three-year period.

Yard accidents appear to be similar to those in other types of rail operations — minor collisions and derailments. There is no reason to suppose that high speed rail operations will be more hazardous in this respect, since yard operations are conducted at low speed. Indeed, with new purpose-built yards and maintenance facilities and the likely use of fixed consist trains, they are likely to be much better. Virtually all yard accident casualties were railroad employees.

There were 19 commuter and 21 Amtrak equipment-caused accidents in main-line service in the three years, causing a total of 14 injuries and no fatalities. Of these, 18 involved malfunctions of the interaction between a pantograph and the catenary of electrically powered electric locomotives or multiple unit cars, leading to equipment or catenary damage. These produced very minor consequences and no casualties, but emphasize the need for continuing good practice regarding the grounding of rolling stock and power circuit-breakers in electrified systems. The next most common accident type was fire. There were a total 11 fires, but none of these caused a casualty. Again, the potential for a serious incident is obvious, and these have happened at other times, emphasizing the need for continued precautions against fire-related risks. The remaining 11 accidents were mainly caused by truck, wheel and brake defects. One of these produced 13 out of the 14 injuries. Significantly, this was not a defect on a passenger train at all. A truck defect on a freight train on an adjacent track caused it to derail into the path of an approaching passenger train. Thus, the more immediate cause of these injuries was an obstruction in the right-of-way, rather than an equipment defect.

There were 9 commuter and 18 Amtrak track- and signal-caused accidents, of which five were serious. Of the serious accidents, two were caused by washouts, and one by a broken joint bar, all on Amtrak. The other two were apparent signal defects, both on commuter lines. Fortunately, both these involved trains moving at relatively

TABLE I.1

PASSENGER TRAIN ACCIDENT CAUSES AND CASUALTIES

3 Years 1985-87

	Number	Injuries	Deaths
1. Commuter Rail			
A. Yard Operations			
Equipment	2	0	0
Track	6	0	0
Operating Error	23	32	0
Miscellaneous	9	2	0
Total	40	34	0
Per Year	13.3	11.3	
B. Main Line Operations			
Equipment	19	0	0
Track	9	49	1
Operating Error	18	226	1
Grade Crossing*	42	69	0
Miscellaneous	48	9	2
Total	136	387	4
Per Year	45.3	129	1.3
2. Amtrak Intercity			
A. Yard Operations			
Equipment	3	0	0
Track	7	3	0
Operating Error	3	1	0
Other	1	0	0
Total	14	4	0
Per Year	3.7	1.3	0
B. Main Line Operations			
Equipment	21	14	0
Track	18	131	0
Operating Error	8	241	17
Grade Crossing*	43	46	0
Miscellaneous	25	0	0
Total	115	432	17
Per Year	38.3	144	5.7
3. All Passenger			
Total	305	849	21
Per Year	102	283	7
Number serious accidents (6 or more injuries, or a fatality)			
Total	20	733	21
Per Year	7	244	7

* Casualties to road users not included in this table. See Table I.2 for estimates of road-user casualties

slow speeds, otherwise casualties could have been higher. The causes of the remaining less-serious accidents include poor track geometry, defective turnouts and broken rails or joint bars. The total number of casualties in track-caused accidents, at 180 injuries and one fatality was much higher than those caused by equipment defects, and second only to human-error accidents.

Operator error was the most significant cause of accidents, although they are relatively few in number — 8 on Amtrak and 18 on commuter lines in the three-year period. No less than nine of these were "serious" (involving a fatality or 6 or more injuries). This data set includes the disastrous collision at Chase, Maryland which caused 16 of the 20 fatalities. Operator error also caused over half of all injuries — 467 out of 849 in the three year period. The accidents were due to the obvious causes — collisions or excessive speed derailments due to engineers failing to obey signals or instructions, engineer/dispatcher misunderstandings or incorrectly set turnouts.

Grade crossing collisions were the most common cause of reportable passenger train accidents (a total of 85, 34% of all main-line accidents). With one exception, these accidents caused only minor damage to the train and few casualties to train occupants. However, the casualty figures in Table I.1 only include railroad passengers and employees, and not occupants of the road vehicles involved in the collisions. The high number of casualties to road vehicle occupants in grade crossing collisions made such collisions the leading cause of fatalities associated with passenger train operation.

The principal causes of the 73 miscellaneous accidents over the three-year period were catenary defects leading to tearing down of the wire in electrified territory, foreign objects on the track, and various accidents caused by the actions of vandals. The two fatalities in this group appear to be persons occupying highway vehicles or "off-track" track maintenance equipment involved in collisions away from grade crossings. Overall, the consequences were not usually severe, but foreign objects on or fouling the track have the obvious potential to cause a serious accident.

Since three years is a relatively short period, and the passenger railroad accident record is a function of a relatively small number of serious events, we compared the results obtained for 1985-7, with a similar analysis performed by the FRA, using data from the period 1978-1982 (5 years). The result is given in the table below:

Casualties in Train Accidents

	Fatalities		Injuries	
	5 Years 1978-82 (FRA)	3 Years 1985-87 (ADL)	5 Years 1978-82 (FRA)	3 Years 1985-87 (ADL)
Equipment	0	0	49	14
Track	1	1	87	183
Operating Error	4	18	606	500
Grade Crossing	0	0	41	115
Other	5	2	1006	11
Total	10	21	1789	849
Average Per Year	2	7	357	283

Observations on this comparison are:

- The ADL data-set excludes accidents to tourist or excursion trains, as we wished to concentrate on regularly scheduled operations. There was one serious accident to such a train (a Norfolk & Western steam-hauled excursion) producing 214 injuries. When this is included, the average annual number of injuries is virtually the same in the two periods. The N&W accident was track-caused.

- The distribution of casualties is somewhat different in the two periods. Operating errors were important in both periods, but "other" accident causes predominated in 1978-82, whereas track-caused accidents were significant in 1985-87. However, since these numbers reflect the outcome of one or two serious accidents in a year, there will obviously be large period-to-period variations.

- The FRA data is for passengers only, but the ADL data includes a small number of casualties to railroad employees on duty. Casualties to road users at grade crossings and bystanders or trespassers are not included and are discussed separately below.

- Neither set of numbers includes casualties to individuals other than in reportable train accidents causing damage above the preset dollar threshold. These individual, "non-train-accident" casualties are discussed below.

The principal lesson derived from this comparison is that "other" accident causes (such as vandalism, foreign objects on the track, etc.) can be highly significant, even though this did not occur in the 1985-87 period.

Other Incidents Causing Casualties

Apart from casualties in train accidents, there are two other situations which lead to casualties directly attributable to rail passenger operations. These are:

1. Casualties to individuals not associated with a train accident, except at grade crossings.

2. Casualties to road users, including pedestrians, at grade crossings.

Together, these two types of events are responsible for much higher numbers of casualties, and especially fatalities, than the train accidents that receive a much higher level of public attention. To obtain estimates, ADL has used two sources:

- Figures from the FRA rail passenger safety report for the years 1978-82.

- FRA accident/incident and grade crossing bulletins for the years 1985-87.

Since we did not have employee and trespasser casualty data segregated by freight and passenger, estimates of casualties associated with passenger operations have been made by assuming casualties in these categories are a function of train-miles. Passenger train-miles are about 15% of the U.S. total. In calculating casualties, we have assumed 10% of the total (rather than 15%) were due to passenger operations. The basis for this assumption is that locations with intensive passenger service are more likely to be protected from trespassers than the typical freight operation, and there are fewer switching operations to cause employee casualties.

Estimates of grade crossing casualties due to collisions between passenger trains and highway users are available directly from the grade-crossing bulletins.

The results of this analysis is given in Table I.2. The comparisons between the ADL and FRA analyses are reasonable for passengers and employees, but the ADL estimates are much higher for grade crossings and "other persons." The ADL grade crossing figures are taken directly from the FRA bulletins, and are presumed to be correct. We believe that the FRA data is for reportable accidents only, and grade crossing and "other person" casualties not associated with such accidents were not included.

TABLE I.2

PASSENGER TRAIN-RELATED CASUALTIES OTHER THAN IN TRAIN ACCIDENTS

	Average Number of Casualties per Year	
	FRA (1978-82)	ADL (1985-87)
Passenger Casualties Other than in Train Accidents		
Fatalities	7	2
Injuries	728	511
Railroad Employee Train-Operations Casualties, Other than in Train Accidents*		
Fatalities	3	4
Injuries	176	385
Casualties to Persons Other Than Passengers or Employees (Mostly Trespassers)		
Fatalities	0**	55
Injuries	2**	117
Casualties in Grade Crossing Accidents		
Fatalities	15**	44
Injuries	7**	96
Totals		
Fatalities	25	105
Injuries	913	1109

* A large number of employee injuries not involving moving on-track equipment are not included in this total.

** Believed to be casualties associated with reportable train accidents only.

The conclusions from this short analysis are:

- There is high potential for fatalities and injuries to trespassers and road users at grade crossings. The number of fatalities, in particular, is far higher than in train accidents. Clearly, this result shows the benefits of minimizing the use of grade crossings, and of adequate fencing and other precautions to prevent trespass. The likely presence of high voltage catenary in a high speed rail system adds a further hazard to the usual one of being hit by a train, making these precautions even more desirable.

- The number of passenger injuries and employee movement-related injuries are substantially higher than those resulting from train accidents. Passenger injuries seem to be primarily associated with doors, steps, etc., while boarding or alighting from trains, or attempting to board or alight from moving trains. Although this kind of accident is largely unrelated to speed of train operation, it is clearly an important factor to be considered in high speed train system safety.

Summary

In summary, this review indicates that the issues that most importantly need to be considered in HSR system safety are:

- The specification and reliability of signal and train control systems, automatic train protection systems, engineer vigilance devices and similar equipment. All these systems help reduce the risk of operator error.

- Integrity of track structure, particularly with regard to sudden catastrophic events, such as washouts or broken rails.

- Enhanced grade crossing protection systems, where high speed trains operate over existing track, regardless of speed.

- Adequacy of fencing and other means to prevent unauthorized persons trespassing on the track, or coming into contact with high voltage catenary.

- Adequacy of equipment design, inspection and maintenance standards to ensure good crashworthiness performance, and continued low incidence of equipment-caused accidents.

Other areas for consideration include:

- Fire precautions. Minor fires are relatively common and have occasionally escalated into serious accidents.

- Protection against or detection of foreign objects on the track, and other intrusions into the right of way.

I.2.4 Summary of Safety Issues and Sub-Issues

The last step in the process of issue definition is to use the information developed in the previous paragraphs and the list in Appendix II to finalize a list of issues and sub-issues for detailed review. A condensed list of these is given in Table I.3, highlighting the principal issues of interest. A full and detailed list is given in Part II, Chapter II.2 at the beginning of the detailed discussion of each issue. The issues are broken down into four groups:

- Rolling stock
- Track and infrastructure
- Signal and electrification systems
- Human factors and operating practices

Each of the ten primary issues in these four groups is broken down in Chapter II.2 into a series of sub-issues. Each sub-issue is typically the subject of a set of regulations, standards and practices used in the passenger rail industry and of potential significance in a high speed rail system.

Finally, to "close the loop" with the analysis of past accidents and the fault tree, the accident or incident types associated with each issue are also identified in the tables in Chapter II.2. This is also done in a less detailed way in Table I.3 in this chapter.

TABLE I.3

SUMMARY OF HSR SAFETY ISSUES

For a fully detailed list, see Tables II.2.1-II.2.12

Group	Issues	Principal Sub-Issues	Types of Accidents Casualty Affected
Rolling stock	Structural crashworthiness	• Buff strength • Collision posts • Truck-body connection • Engineer's cab strength	• Casualties among occupants of trains involved in accidents
	Construction of trucks and brakes	• Brake system design (fail-safe integrity) • Stopping distances • Wheel axle/bearing integrity • Parking brake performance	• Derailments or collisions due to inadequate truck and brake performance
	Track-train interaction	• Flange climb, rail rollover,track panel shift • Overturning of car • Curvature, cant, cant deficiency • Tilt system integrity • Wheel load variation	• Derailments due to excessive track-train forces and force-ratios • Casualties due to exceptionally poor ride • Collisions due to tilt system failure (violating clearance restrictions)

TABLE I.3

SUMMARY OF HSR SAFETY ISSUES (Continued)

For a fully detailed list, see Tables II.2.1-II.2.12

Group	Issues	Principal Sub-Issues	Types of Accidents Casualty Affected
Rolling stock	Maintenance and inspection	• Inspection requirement • Monitoring systems • Maintenance employee training and qualifications	• Derailments due to degraded or defective components
	Non-structural safety and crashworthiness	• Fire precautions • Doors and windows • Internal fittings attachments (e.g., seats) • Emergency equipment • Baggage restraint • Avoidance of hard surfaces, sharp corners	• Fire risk • Secondary injuries to train occupants during accidents • Getting on and off trains
Track and infrastructure	Track structure integrity	• Track strength • Track quality (includes plain and "special" track)	• Derailments due to track failures of all types

TABLE I.3

SUMMARY OF HSR SAFETY ISSUES (Continued)

For a fully detailed list, see Tables II.2.1-II.2.12

Group	Issues	Principal Sub-Issues	Types of Accidents Casualty Affected
Track and infrastructure	Track maintenance and inspection requirements	• Rail integrity • Track geometry • Ballast and subgrade condition	• Derailments due to degraded track structure or components
	Security of right-of-way	• Grade crossing safety • Encroachment, obstacles on track (prevention, detection) • Earthquakes/weather events • Trespasser prevention	• Grade crossing accidents • Hit person on track • Collision with foreign object on right-of-way • Track damage due to weather, etc.
Signals and electrification systems	Design and construction of signal and train control systems	• Speed thresholds for different system types • Vehicle detection • Operator interface	• Accident due to to signal failure (hardware or software flaws, faulty design and installation, etc.) • Human factors accidents preventable by high capability signal systems

TABLE I.3

SUMMARY OF HSR SAFETY ISSUES (Continued)

For a fully detailed list, see Tables II.2.1-II.2.12

Group	Issues	Principal Sub-Issues	Types of Accidents Casualty Affected
Signals and electrification systems	Maintenance and inspection of signal systems	• Inspection procedures • Training employees and qualifications	• Collisions or derailments caused by signal malfunction
	Design construction and maintenance of wayside electrification equipment	• Electrical clearances • Maintenance procedures • Grounding • Circuit breakers • EMI	• Electric shock casualties • Electrical fires
Human factors and railroad operations	Operating practices	• Dispatching • Brake tests • Train crew practices • Emergency response • Communications procedures	• Accidents or collisions due to human error • Casualties attributable to inadequate emergency response
	Employee-qualifications and training	Training and qualifications of • Engineers • Other train crew • Signal & dispataching staff	• Accidents or collisions due to human error

I.3 WORLDWIDE DEVELOPMENT OF HIGH SPEED RAIL SYSTEMS

I.3.1 Introduction

Full details of all significant high speed rail systems is given in Part II, Chapter I. Most attention is given to those systems with extensive experience of high speed operations, or which are most actively involved in potential U.S. applications.

This chapter provides a brief summary of the current practice in high speed rail systems, in particular identifying the common consensus on the design and operation of the key elements of a high speed rail system.

This discussion is broken down as follows:

- Systems designed to operate on existing, upgraded track at a speed of 125 mph, and possibly slightly higher. The Amtrak Northeast Corridor falls into this group, as do several European systems.

- Systems designed to operate at speeds substantially in excess of 125 mph on new right-of-way. The same trains can usually also operate on existing right-of-way at conventional speed. The French TGV and Japanese Shinkansen fall into this group.

- Carbody tilt systems and high cant deficiency operation. After a gap of about a decade, during which the tricky technical problems of tilt systems were addressed, tilt is now enjoying a revival. Examples are the Swedish X2 train and the Italian Pendolino, both of which are or will shortly be in regular service.

- Discussion of automatic train control and protection issues. Cab signalling and a form of automatic train protection is universally used on new lines operated at over 125 mph, and is being applied more widely to existing lines (for example, in Sweden) to reduce the risk of human-error accidents.

I.3.2 Systems Operating at 125 mph on Existing Tracks

These systems include the Amtrak Metroliner Northeast Corridor system, the British High-Speed Train (HST) and several broadly conventional locomotive-hauled services in France, Germany and Italy.

Based on current practice, 125 mph operation can be regarded as an extension of conventional passenger railroad technology. Very little change is made from 100 mph technology. Customary features of infrastructure and equipment are:

Infrastructure

- Continuously welded rail on concrete ties with elastic fasteners.
- Grade crossings are accepted by some systems, usually where cost of grade crossing elimination is prohibitive.
- Electric traction is used, except for the British HST.
- Conventional signals are supplemented by some form of cab signalling. This can be very primitive, such as the British Automatic Warning Systems (AWS). The cab signalling system usually reflects existing practice at lower speeds on the same system. The exception is the application of the complex "LZB" system to upgraded 200 km/h lines on German Federal Railways (DB). This is described in detail in Chapter II.1.
- Automatic Train Protection is regarded as "desirable" rather than being a mandatory requirement.
- Freight and different types of passenger service share tracks with high speed trains in every case, since these are existing routes with substantial traffic of other types.

Rolling Stock

Like the infrastructure, 200 km/h rolling stock is technically very similar to lower speed equipment. Few significant changes are made. Customary features include:

- Two disc brakes per axle, plus an auxiliary tread brake. As well as providing additional braking power, the tread brake serves to clean the wheel tread and improve adhesion. However, recent advances in disc brake and wheel slide protection system design seem to be reducing the need for the tread brake.
- Use of horizontal yaw dampers between truck frames and car body on both locomotives and passenger cars. Use of this device enables dynamic stability at 200 km/h (125 mph) to be achieved with otherwise conventional truck.
- Locomotive or power cars usually feature truck-supported traction motors with flexible motor-to-wheelset drive systems able to accommodate wheelset to truck movement. This arrangement has two purposes — to reduce unsprung mass and therefore dynamic loads on the track, and to help achieve dynamic stability. Use of traction motors partly supported on the axle (as is the case with the North American freight locomotive) will normally exceed the wheel-rail maximum force standards used by European railways at speeds over 80-90 mph.

Operations

Minimal changes are made to operational practices. The same set of operating rules are used, and as far as we are aware, no special additional training is given to train crew beyond that which would be normally given for a new piece of equipment.

I.3.3 High Speed Systems Operating at Speeds Substantially Over 125 mph

There is a very big change in the engineering of high speed systems once speeds are substantially in excess of 125 mph. Merely "stretching" lower speed technology is no longer considered adequate. The principal changes are as outlined below, reflecting practice on such systems in France, Japan, Italy and Germany.

Track and Infrastructure

- Conventional concrete tie ballasted track appears to be adequate, at least up to 300 km/h (187 mph). There is a French preference for the dual block concrete tie over the monoblock tie, but this does not seem to be critical. Use of slab track appears to be an economic decision. Thus, it is used in tunnels, where access for maintenance is difficult, and extensively on the Japanese Shinkansen where traffic levels are very high and elevated structures are used extensively, but not elsewhere.

- Where tunnels are required, these have a large cross-section area to minimize air pressure shocks. Attention is given to tunnel entrance shape for the same reason.

- Use of overhead catenary electric power supply is universal.

- Because few existing routes are sufficiently straight and flat enough for these high speeds, all operations to date at over 125 mph are on new purpose-built right-of-way.

- On the two systems with the most high speed experience (the TGV and the Shinkansen), the new right-of-way is only used by the high speed trains. On two systems that are approaching completion, the German Neubaustrecken (new-built lines) and the Italian Direttissima, mixed traffic operation is planned. How this will be managed in practice remains to be seen.

Train Control

- Automatic train control with continuous speed supervision and cab signals is universally used, and is considered essential for speeds in excess of 125 mph by all operators.
- No lineside signals are used on the TGV or Shinkansen where the line is exclusively used by the high speed trains. The German and Italian systems have conventional lineside signals to permit the operation of conventional trains not equipped with the ATC system, and also provide a back-up to the ATC system.
- The technical means used varies in sophistication from the relatively simple coded track circuits of the Shinkansen to the vital computer control at the heart of the German LZB system. These differences seem to affect the cost and flexibility of the system rather than the level of safety attainable.

Rolling Stock

The central concerns of all high-speed rolling stock designers are track forces, dynamic stability and brake system performance. Powered axles present the most demand design criteria, since these have inevitably a higher axleload and unsprung mass.

- Strict vertical and lateral track force and force ratio limits are observed. These have usually been derived from those produced by conventional rolling stock at conventional speeds. Low track forces and stability are attained by minimizing the effective mass of both the truck frame and the wheelset and careful choice of vertical and plan-view suspension parameters. Traction motors are effectively supported on the body, and a variety of ingenious gearbox and mechanical drive arrangements have been developed to achieve this. The exception to this is the Shinkansen, where truck mounted motors appear to be acceptable. However, since all or most axles are powered on Shinkansen trains, the mass of an individual motor is low. Also, the Shinkansen operates at lower speeds than are operated or planned elsewhere.
- Maximum acceptable axleload is between 37,600 lb and 44,000 lb, and maximum effective wheelset mass around 4000 lb. The lower figure for axleload (equal to 17 metric tons) seems likely to become a European standard at French insistence.
- Dynamic braking is used on driven axles, and is considered part of the emergency braking system. Motor excitation via independent batteries (or the equivalent) for each axle is used to ensure adequate integrity. This means that a power failure cannot affect dynamic brake performance.

- The primary means of friction brake is the axle or wheel mounted disc brake. Three or four discs per axle are used to ensure sufficient energy absorption capacity. Supplemental tread brakes are also sometimes used, primarily to keep the wheel tread clean and insure adequate wheel-rail adhesion.

- Eddy current track brakes are sometimes used. These are somewhat questionable, as analysis on SNCF and British Rail has shown that their routine use will heat up the rail unacceptably. However, other rail systems plan their use, primarily to aid emergency braking.

- There are few additional crashworthiness precautions over conventional equipment of the same rail system. The TGV power car incorporates an energy absorbing structure ahead of the engineer cab, and high impact resistant windshields are generally used as a precaution against flying objects. The International Union of Railways (UIC) buff strength requirement (followed universally in Europe) is 440,000 lb. compared with the U.S. standard of 800,000 lb. for trains over 600,000 lb. empty weight. The philosophy appears to be to rely on the train control system and other precautions to prevent accidents.

- All trains must be fully sealed and air conditioned to prevent unacceptable air pressure shocks when passing at speed, especially in tunnels.

Operations and Maintenance

- Inspection frequencies, both for infrastructure and equipment, are higher than on existing routes over which conventional-speed services are operated.

- Track geometry tolerances are tighter.

- Sophisticated monitoring of ride and on-board train systems are becoming standard. This is not just a high speed development — such systems are being applied to all types of rail vehicle, including the latest generation of U.S. freight locomotives.

- Although thorough training is given to railroad employees involved in high speed train operations and maintenance, this does not appear to be substantially different in kind from procedures used on the remainder of a given railway system. Most rail systems had established career structures, grade systems, and seniority rules before the advent of high speed services, and these were embodied in agreements with powerful unions. These appear not to have been changed for high speed services.

I.3.4 Carbody Tilt Systems and High Cant Deficiency Operations

Tilting the carbody is an attractive way of increasing train speeds through curves while maintaining passenger comfort within acceptable limits. Thus journey times can be reduced on existing routes where the traffic density is too low for infrastructure improvements to be economically justifiable. There was considerable interest in tilt in the late 1960s in most European countries and on the existing narrow gauge lines in Japan for these reasons. Projects included the Advanced Passenger Train in the UK, the original Pendelino (ETR 401) in Italy, and the LRC in Canada. Unfortunately, achieving satisfactory tilt system performance and reliability proved much more difficult than had been anticipated. As a result, interest in tilt waned through the late 1970s and early 1980. Recently, tilt has enjoyed a revival, with the entry into service of the Italian ETR 450 trainsets, the development of the Swedish X2, the improved Canadian LRC, all active servo-controlled tilt systems, and the success of the Talgo Pendular passive tilt system. This is a result of persistent development work aided by improvements in sensors, microprocessors and control technology. However, apart from the Talgo pendular, there is no extensive history of the operation of these systems in revenue service. Before the recent improvements, the LRC operated in Canada with the tilt system inactive.

Safety and comfort tests on several rail systems indicate that on good track (CWR on concrete ties with good geometrical quality, e.g., FRA Class 6) maximum permissible cant deficiency with carbody tilt is in the range of 8-10 inches. The governing safety criteria used in Europe is the Prudhomme formula for lateral track shift. This is further explained in the section on track-train dynamics in Chapter II.2. In the 1980/81 tests on the Northeast Corridor, the governing criterion was overturning under a postulated sidewind.

Without tilt, non-U.S. rail systems limit cant deficiency to between 4 and 6 inches with conventional passenger cars, as shown in the following table:

Britain	4.3 inches
Germany	5.1 inches
Japan	4.8 inches
Switzerland	5.1 inches (normal
	5.9 inches (special exception)
USA	3.0 inches (FRA regulation)
	4.0 inches (by exception)

France is an exception allowing 7.5 inches, but this is understood to be rarely used.

Apart from having tilt capability, the mechanical configuration of the tilt trains in operation or development in the late 1980s (the LRC, Talgo, Swedish X2 and ETR 450 Pendelino) are all very different. Details are given in Part II, Chapter 1.

I.3.5 Automatic Train Control

Apart from specifically high speed developments, there is a trend toward the application of improved forms of Automatic Train Control (ATC) on all lines of some rail systems. This trend has developed because of:

- Concern over human-error railroad accidents, sometimes resulting from a specific accident or series of accidents.

- Availability of new data communications and vital microprocessor equipment makes ATC possible without prohibitively high costs.

- A desire to improve the reliability and precision of rail operations.

Individual developments within this trend include:

- The Advanced Train Control System project initiated by the Association of American Railroads and the equivalent Canadian organization, the Railway Association of Canada. The approach taken in this project is to define the functions of each system component and develop standardized interfaces. Several levels of performance have been defined within ATCS corresponding to the degree of automatic control provided. The Burlington Northern Railroad is developing the Advanced Railroad Electronic System (ARES), a proprietary ATCS system with similar capabilities to the AAR/RAC proposals, but not conforming to the interface and functional standards.

- Installation of an automatic train control and cab signalling system called Ericab 700 on a growing number of lines in Sweden. This system is manufactured by Ericsson Signal Systems. In this system, a train receives a message at each signal giving maximum line speed over the next block, and the permitted speed at the next signal. If the train fails to observe either the maximum line speed, or braking curve able to reduce speed appropriately by the next signal, the brakes are automatically applied.

- In France, after a series of accidents in 1985, and another in 1988, the SNCF is working on no less than three separate train control systems.

    - An ATC system based on the Swedish model, which is due to be installed on 11000 km of principal lines by 1994.

    - A much more sophisticated system called SACEM (Systeme d'Aide a la Conduit et a la Maintenance), initially to be installed on busy Paris suburban lines. This is a continuous ATC system with capabilities similar to the German LZB system (see Section II.1.6). It also has the potential to be upgraded to an Automatic Train Operation (ATO) system, and incorporates "train-health" monitoring systems, both trackside and on-board.

  - The "Astree" program (Automaisation du Suivi en Temps Reel) — a more ambitious scheme to develop a systemwide real time train location and control system similar to the higher levels defined in the U.S./Canada Advanced Train Control System project.

- In the U.K., British Rail is planning the extensive installation of automatic train protection systems following a disastrous collision at Clapham in South London in 1989. Specifications for the system are under development. Application of this system will also facilitate speeds of 225 km/h (140 mph) on the London-Edinburgh line after completion of electrification.

I.4 SUMMARY OF KEY SAFETY ISSUES AND RECOMMENDATIONS FOR FURTHER RESEARCH

I.4.1 Introduction

Chapter I.2 ended with a tabulation of key high-speed rail safety issues. These are amplified in the detailed discussion of safety issues given in Chapter II.2. Each safety issue or group of issues is discussed in Chapter II.2, and a conclusion reached about the need for future research. Those conclusions are summarized in this chapter.

Action may be needed on a specific safety issue if:

- There are significant differences between U.S. standards and practices and the standards and practices used on foreign high-speed rail systems proposed for application in the U.S.; or
- There are no applicable U.S. standards and practices.

And, if the answer to one of the following questions is "yes,"

- Are there significant differences between the U.S. operating environment and the domestic environment of the foreign train?
- Is this issue associated with a significant passenger rail accident cause?
- Is there reason to believe that accident risks or consequences associated with these issues become more severe as speed increases?

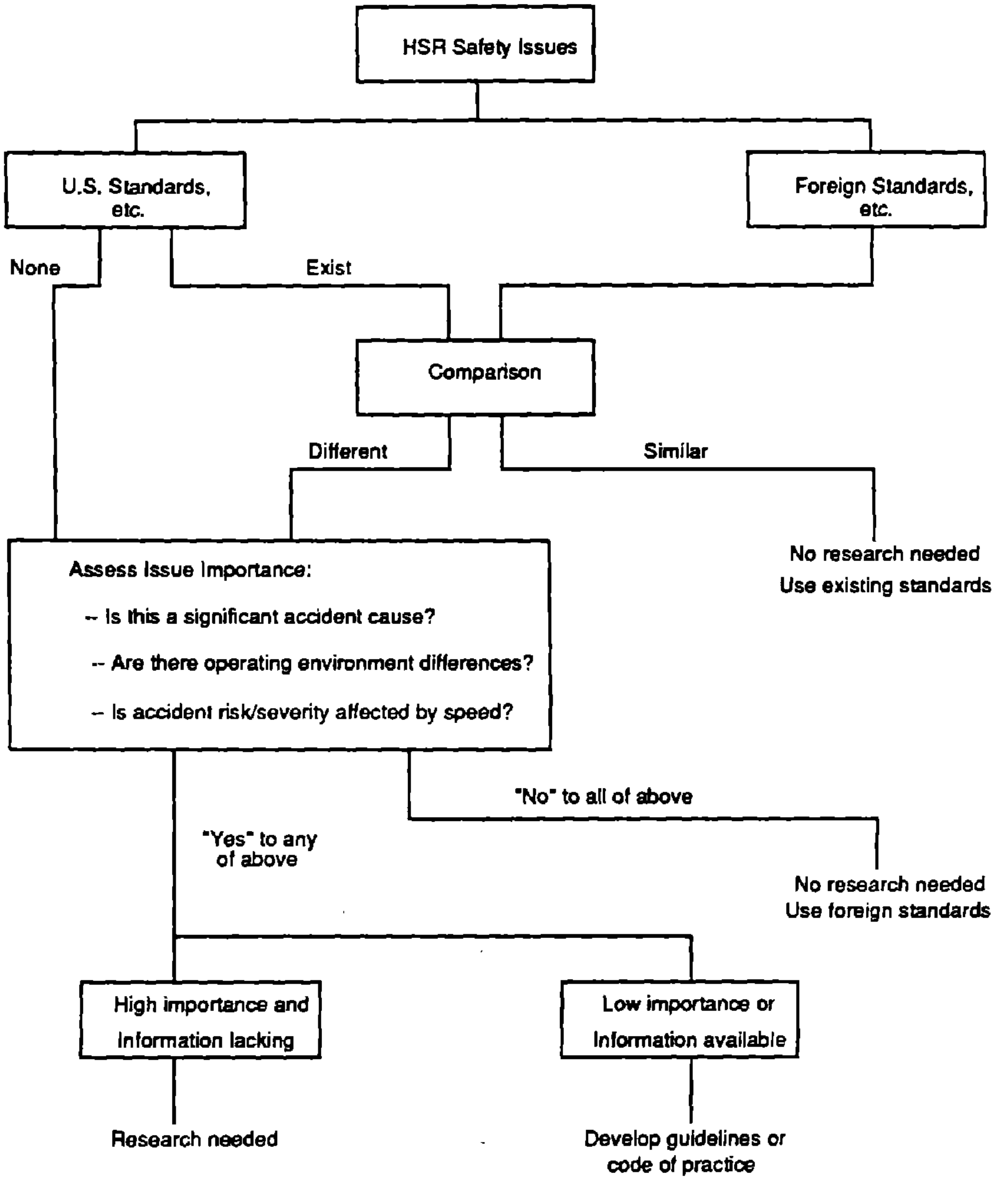
The nature of the action is a function of the apparent importance of the issue and the availability of information from which to determine appropriate HSR practice in the U.S. If the issue appears to be of high importance, and information on which to base future U.S. standards and practices is lacking, then research is justified. If the issue appears to be of lower importance, or there is plenty of pertinent information available, then development of guidelines or a code of practice may be an appropriate response.

Figure I.3 illustrates the logic of this decision process in diagrammatic form.

Based on this logic, research needs have been classified into the following three categories:

Figure I.3

Logic Used to Develop Research Needs



- Priority 1

  - A critical safety issue where substantial research is required, the results from which need to be known at an early stage in the development of a new high-speed rail system.

    A good example of a Priority 1 issue is the question of carbody buff strength. Buff strength requirements have to be specified before equipment can be designed and built, and the actual values chosen will alter equipment weight, cost and performance. Another is the maximum tolerable lateral accelerations to be sustained by standing/walking passengers.

- Priority 2:

  - A critical safety issue where substantive research is required, results from which need to be known before operations of a new high-speed rail system begin, but which do not substantially affect system design, performance or cost. Most operating and inspection issues would fall into this category.

- Code-of-practice development

  - A safety issue where there is a need to set out the principles of good practice, and secure agreement to these among interested parties, but which do not require substantial research.

    Code-of-practice development will typically involve reviewing practices on U.S. and foreign high-speed lines in the same way as in this report, but in much more detail, and adapting these existing practices to the specific needs of high-speed rail in the U.S.

1.4.2 Summary of Recommendation - Rolling Stock

Priority 1

- Carbody structural strength requirements. U.S. and foreign carbody strength requirements are very different. The question remains unresolved as to whether foreign, (specifically UIC), carbody strength standards are acceptable for operations in the United States, and if so, under what circumstances. Details of a proposed program of research to resolve this issue are given in Section II.2.2.1. Briefly, these involve establishing the relationships between train speed, train weight, carbody strength and structural damage in collisions, and using this information to compare the performance of cars built to UIC and AAR structural standards in different accident situations. These should include grade crossing collisions during non-high-speed operation. Also, there is a need to examine the safety of cab car or multiple unit operation at high speed. Both involve operation with relatively lightweight cars occupied by passengers at the head end of a train. Since the first car of a train is vulnerable to extensive damage in a collision, either with another train or an obstruction, such trains are clearly less safe than consists with a locomotive or power car at the head end. Therefore, we recommend that the difference in accident and casualty risks with cab cars be examined to see if operational restrictions on such cars are warranted.

- Engineer's cab structural strength and other requirements. The issue is very similar to the carbody strength issue, and should be studied in the same way. Both cab-cars and locomotives should be studied. There is also a group of other cab safety issues which can be dealt with at the "code-of-practice" level, including layout of controls and gauges, emergency egress, fault diagnostic systems, etc.

- Novel Brake Systems. Foreign high-speed rail systems use dynamic and eddy-current brakes as part of their "vital" emergency brake systems. This is not done in current U.S. practice. Therefore, there is a need to review such systems to understand fully how adequate safety is obtained, and to develop standards or guidelines to ensure adequate safety is achieved in systems put into service in the United States.

Priority 2 Issues

None.

Code-of-Practice Requirements.

There are issues that do not raise critical safety concerns, but there is a need to ensure good practice to ensure safety. In many cases, it may be appropriate to adopt foreign practice, but this should be a conscious decision after due consideration of the operating environment and other pertinent factors.

- Truck design standards
  - Design loads for structural design of truck frame
  - Materials, tolerances for wheels and axles (e.g., balance, roundness, etc.)
  - Bearing requirements
  - Safety back-ups for component failures

- Friction brakes
    - Disc brake discs and pads
    - Braking distances
    - Use of "scrubber" tread brakes
    - Wheel slide protection systems
- Track-train interaction
    - Renew and update lateral force, L/V, vertical impact, axleload and similar criteria
    - Procedures for acceptance tests for new equipment
- Rolling stock inspection
    - Inspection schedules and acceptability criteria (important in maintenance facility design)
- Non-structural carbody details
    - Body equipment attachment strength
    - Baggage restraint, overhead racks and at end of car
    - Avoidance of hard/sharp surfaces
    - Doors and steps, especially automatic locking of doors, and provisions for emergency egress
    - Safety appliances (steps, handholds, etc.)
- Fire safety
    - Review and update UMTA/FRA guidelines on flammability and smoke emission, if necessary
    - Requirements for the fire resistance of floors and bulkheads
    - Fire-fighting equipment, especially on high-speed vehicles with fossil-fueled prime movers

- Glazing regulations
  - Possible need to increase windshield impact speeds in regulations for high-speed trains
  - Adequacy of installation to withstand loads resulting from air pressure shocks when trains pass at speed

I.4.3 Summary of Recommendations—Track and Infrastructure

Priority 1

- Right-of-way security. Right-of-way security is the most important track and infrastructure issue. This involves two distinct sub-issues:

  - Making the right-of-way inaccessible to trespassers. This is important because trespassers hit by trains are the largest group of fatalities associated with rail passenger operations.

  - Making the right-of-way secure against damage or intrusion from accidents on parallel railroads or highways, or by weather events, or providing adequate warning systems for such events.

  The second of these, especially, requires research to establish the degree of risk of damage or intrusion in different situations, and to develop specifications for protective measures such as barriers, snow and ice clearance systems, and warning systems.

- Grade crossings. Although it is standard practice to have no grade crossings on new high-speed lines, many new high-speed services may operate for part of their journey on existing lines which have existing grade crossings. Grade crossing accidents are a major cause of fatalities in rail passenger operations. Therefore, the question will arise of what combination of train speeds, grade crossing protection systems and train types will be permissible. An examination of the grade crossing accident data is required to calculate estimates of grade crossing accident risks, leading to development of grade crossing safety guidelines for high-speed passenger operation.

Priority 2

None.

Codes-of-Practice Requirements

- Track construction. Generally the specification of high-speed track will be similar to that used on the Northeast Corridor and no special research effort is warranted. Some limited research leading to a code-of-practice is needed for novel track components, not currently used extensively in the U.S., such as:

  - Moving-point frogs and other components of very high speed turnouts
  - Slab track, especially rail/slab fastening systems

  - Track inspection and quality standards. Present FRA regulations go up to Class 6 track for 110 mph. Tighter dimensional standards, and more frequent and thorough inspection will be needed at higher speeds. However, such standards and inspection intervals can be defined, using available information on practices on existing foreign high-speed lines and adapting these to the U.S. environment.

I.4.4 Summary of Recommendations—Signalling and Electrification Systems

Priority 1

- Requirements for signalling and train control systems. Present FRA regulations define signalling systems for speeds up to 110 mph. With some enhancements, Amtrak operates up to 125 mph with these systems. Foreign high-speed systems designed to operate at speeds in excess of 125 mph are all equipped with continuous automatic train control systems with speed supervision,and sophisticated cab signalling systems. They also may incorporate novel features such as the use of radio for transmitting "vital" data between track and train, and use of vital microprocessors for interlocking and equivalent functions.

  Therefore, there is a need to research in more detail the capabilities needed for a signal system for speeds exceeding 125 mph, and to specify performance standards or guidelines for the overall system and system components.

Priority 2

- Signal system testing and inspection. The signal systems and system components used in high speed rail train control systems will have new and different requirements for testing and inspection, both on installation, and periodically to ensure continued satisfactory operation. Research is needed to establish those requirements. which will be different from existing procedures. Examples of these differences include the use of radio to transmit "vital" signal data to the train, and total reliance on cab signal systems.

Code-of-Practice

- Electric power supply system. Present codes-of-practice need to be examined to see if there is a need for any additions or modifications to meet the requirements for high-speed operation.

I.4.5 Human Factors and Operating Practices

Priority 2

- Operating staff qualifications and training. The situation of a new high speed rail operation will be very different from the foreign high-speed rail operation, all of which have been developed by an existing railroad with extensive experience of passenger service. The U.S. operation is likely to be a new start-up. Therefore, there is a need to establish appropriate qualifications and training requirements for train operations staff on such a railway. This should be done by looking at both foreign and U.S. railroad practice, and practice in other industries where safety is critical, and using this information to develop suitable requirements.

Unclassified

- Operating rules and practices. More information has to be obtained before we can develop requirements for research or code of practice development regarding operating rules and practices.

Finally, the author would like to point out that an institutional process for establishing high-speed rail standards and codes-of-practice is lacking in the United States. The only operator with any experience of high-speed rail has been Amtrak. Amtrak has developed a number of practices internally for the specific situation of the Northeast Corridor, but these have not generally been published, nor are they necessarily suitable for other situations. The AAR, which traditionally has developed railroad industry standards and codes-of-practice for equipment and signal systems, has primarily a freight railroad membership and now has limited involvement in passenger rail issues.

The AREA, which develops standards and codes-of-practice for the fixed plant of the railroad (other than signal systems) has a broader membership than the AAR, and has recently established a high-speed rail committee.

This is a start, but much remains to be done. As well as the specific research recommendations, it is a strong recommendation of this report that the FRA and the high-speed rail industry work out some process by which safety-related codes of practice, as opposed to Federal Government regulations or guidelines, can be developed.

The effort to develop a code of practice would be similar, but more detailed than that of this report. For each issue, practice on foreign high-speed systems would be reviewed, compared with and adapted to U.S. needs, and a set of recommendations developed. Such action is desirable for many of the safety issues identified in this report.

PART II

DETAILED INFORMATION AND ANALYSIS

II.1 DESCRIPTION OF HIGH SPEED RAIL SYSTEMS

II.1.1 Introduction

The following paragraphs provide some detailed information and data about each of the high speed rail systems which are identified in Appendix I. The information is provided for each system in two parts: rolling stock and fixed plant (track infrastructure, signalling and train control), plus a background discussion describing how the system was developed and the role plays on its domestic rail network. The detailed information includes the following material:

- A tabulation of basic information about consists, power, speeds, weights, axleloads, signal system, braking system, track structure, use of tilt, etc.
- A discussion of the service experience, present status, and future plans for the system on its domestic railway.
- The present nature of the interest in the system for application in the United States.
- A discussion of any design features of the rolling stock or fixed plant that appears to be of particular interest in the context of U.S. applications or the safety issues analyzed in this report.
- Photographs or diagrams illustrating key features of the systems.

The paragraphs describing individual systems vary in level of detail: most detail is provided in those describing systems with an extensive experience of operations at 125 mph and above, and/or in which there is a high level of interest in the U.S. All the high speed rail systems described operate or are designed to operate at speeds of 125 mph or greater.

Some further general points about these systems described are:

- All the European systems are designed to meet or exceed the requirements of the relevant UIC codes. The exception in a few details are the British trains, which are not designed for "interchange" operation on neighboring systems within Europe.
- The principal barriers preventing European trains being used on neighboring systems are:

  - Incompatibility with cab signalling systems. At present, each railway has adopted a unique cab signalling system for high speed lines. If trains are to operate over more than one system, they must be fitted with multiple cab signalling systems.

  - Differences in policy regarding acceptable axleloads, track impact forces and other key parameters.

- Even though some of the high speed systems or system components have not been considered for proposed U.S. applications, this may change in the future. The most important factor is the rapid consolidation of the railroad equipment supply industry in Europe. Swedish ASEA merged with Swiss/German Brown Boveri to form ASEA Brown Boveri, who subsequently acquired a substantial interest in the privatized manufacturing arm of British Rail BREL. Alsthom (French) has merged their railroad activities with Britain's General Electric Company, and subsequently acquired both Metro-Cammell, a British passenger car builder, and a Spanish rolling stock builder. All this and similar future activity is likely to lead to a sharing of high-speed rail technology.

The primary sources for the information presented has been the trade and technical literature. A full list of the sources identified is provided in the bibliography, broken down by country. In using this literature, we have given most credence to material authored by a representative of the railroad system, after the equipment had been put into service. Sources who are equipment suppliers, or technical journalists or articles written when a high speed rail system was still under development have been regarded as less reliable. Where there is any reason to doubt the accuracy of data or information, this is indicated on the text or tables.

The author also has had access to some private communications and other unpublished material. This has been used where there was no alternative source.

Finally, some useful material has been found in U.S. government reports and similar publications. In the late 1970s the FRA carried out the Improved Passenger Equipment Evaluation Program (IPEEP) which, among other activities, involved assembling data on international high speed rail systems. There was also a similar effort on signal and train control systems. Although much of the information is now somewhat out of date, some high speed train systems were in service at that time and have not changed since. These include the British HST, and the earlier Japanese Shinkansen. These sources also include meeting minutes and other material generated by the activities of Transportation Research Board Committee A2M05.

One source was not available for this report. This was the questionnaire sent to Japanese and French high speed rail authorities requesting information on human factors issues such as train operating employee selection, experience and training, and inspection and maintenance practices. The results of these are still awaited, and the intent is to include them in a future report.

The high speed rail systems are described in the following paragraphs in alphabetical order by country.

In the descriptions both the original metric quantities and the U.S. equivalents are given for dimensions, etc. The exception is weight. which is always given in U.S. tons of 2000 lb only, to avoid any confusion with metric tonnes or British long tons.

II.1.2 Canada — The Light Rapid Comfortable (LRC) Train

a) Background

The LRC originated in 1968 as a cooperative venture between Alcan Canada (an aluminum producer), Dofasco (a railcar and locomotive truck manufacturer), and Montreal Locomotive Works, with the support of the Canadian Government. A prototype locomotive and one active tilting passenger car were designed and built over the period 1968 to 1974. This prototype was tested in 1974 at the Pueblo Transportation Test Center and in Canada, achieving a top speed of 210 km/h (130 mph). It was also extensively demonstrated throughout the USA and Canada.

Following the tests and demonstrations with the prototype, two locomotives and ten cars were built and leased to Amtrak for a period of two years. This equipment participated in an extensive series of high cant deficiency safety and comfort tests in 1980 between New Haven and Boston on the Northeast Corridor, and were later put into regular service on this line. When the two-year lease expired, the trains were returned to Canada.

Finally, a total of 30 locomotives and approximately 100 cars were supplied to VIA-Rail Canada for service in the Windsor, Ontario to Quebec City corridor. These are similar to the Amtrak equipment, but with a number of detailed differences in the passenger accommodations. During this period, ownership of the LRC design became the property of Bombardier, Inc.

Reliability problems were experienced with the original carbody active tilt systems on the passenger cars. These were first deactivated by VIA and then modified by Bombardier, Inc. Cars with the improved tilt system began being put into service in 1987, and were demonstrated in the Boston-New York part of the Northeast Corridor in the spring of 1988 as part of the Coalition of Northeast Governors (CONEG) high speed equipment demonstration program.

Maximum speeds in passenger service in Canada are 95 mph, the maximum allowable over grade crossings under Canadian regulations. There may also be concerns over high impact loads exerted on the track by the locomotive at higher speeds, due to the use of axle-hung traction motors.

b) General Description

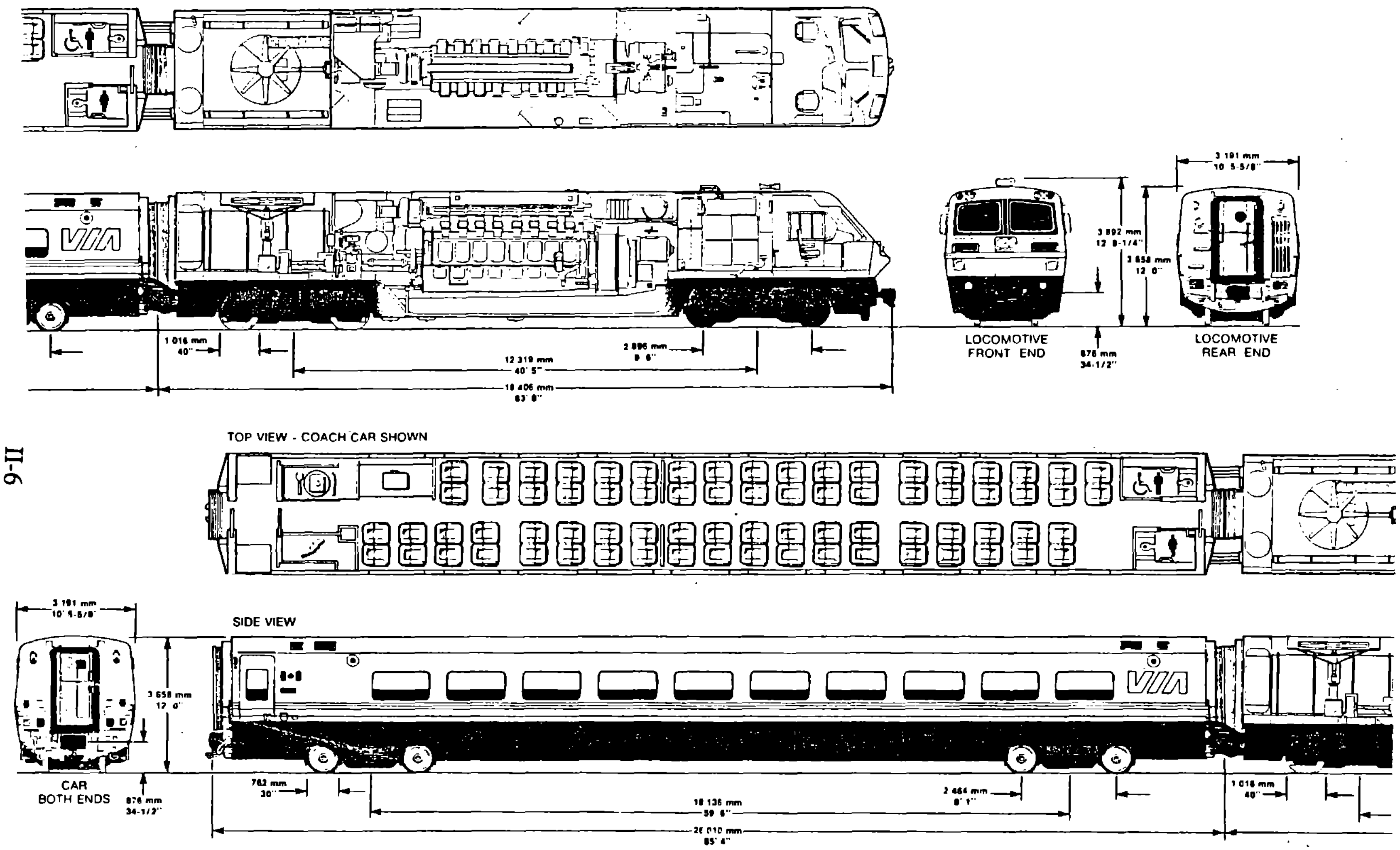
Key data regarding the LRC in the form presently operated by VIA-Rail Canada is given in Table II.1.1. A drawing of the locomotive and car is given in Figure II.1.1.

TABLE II.1.1

HSR CHARACTERISTICS - LRC (CANADA)

Service Speed:	Design speed 125 mph; current operations 95 mph
Max Test Speed:	130 mph
Consists:	Loco + 8-10 passenger cars + loco. Currently operated with 1 loco + 3-5 passenger cars 84 seats/car, less in food service cars
Weight and Length:	Locomotive 127 tons, 64 ft. Passenger car 53 tons, 85 ft. Typical 2 + 8 consist: 678 tons, 1 + 4 consist: 339 tons Maximum axleload (locomotive) 63500 lb.
Carbody Materials:	Cars - welded aluminum Locomotive - steel structure with aluminum sheeting
Power:	Diesel: Each locomotive. ALCO 16 cylinder 251 engine 2780 KW total, 500 kw for hotel power, 2015 KW for traction (after subtracting auxiliary loads)
Brakes:	Standard electro-pneumatic brake system Passenger car: 2 discs/axle + tread Locomotive: tread + dynamic
Right-of-Way:	Existing, unmodified Canadian track
Route:	Quebec City-Montreal-Toronto-Windsor
Operator:	VIA-Rail, Canada 1982-present Initial public service (with Amtrak) 1980
Status:	Locomotives and cars in service
Other:	• Designed to operate over existing North American track • Servo-controlled hydraulically powered active tilt system fitted • Improved active tilt system now being installed in VIA-Rail Canada trains • Speed limited by Canadian grade crossing regulations and concerns about locomotive dynamic vertical wheel loads
Builder:	Bombardier, Inc., Montreal

Figure II.1.1 The LRC Train



Source: Bombardier, Inc. literature

The LRC is an "equipment" system only. It is designed to operate on existing North American track, and there is no specific associated track or train control system. As it uses diesel power, there is no need for an electric power supply system and catenary.

The locomotive is equipped with a 16-cylinder diesel motor of 3725 HP (2780 KW) gross output driving an alternator feeding four conventional axle-hung DC traction motors. Trucks have a "flexicoil" secondary suspension and rubber chevron primary suspension. The high axleload and the high unsprung mass arising from the use of axle-hung motors will lead to high track loads, as compared with other high speed trains described in this document.

The passenger car is noteworthy for the servo-controlled hydraulically activated carbody tilt system. Maximum cant deficiency with the active tilt is 9 inches. This is one of the very few active tilt systems with any significant service experience. Like all other such systems, there have been significant maintenance and reliability problems. An improved system is now being fitted to the cars in service in Canada. The other noteworthy design feature is the aluminum alloy body structure, designed to full North American (FRA and AAR) strength requirements.

c) Present interest in the United States.

The LRC passenger car is an alternative for achieving higher speeds in the Boston-New York segment of the Northeast Corridor. Its tilt capability will be particularly valuable over this very curving route. CONEG and state governments along this route are interested in the acquisition of high performance equipment capable of providing improved service. Maximum speeds are not expected to exceed the current U.S. maximum of 110 mph, at least initially.

Bombardier sold the Montreal Locomotive Works to General Electric in 1989, and appears to have little further interest in the LRC locomotive. The LRC cars and the truck and tilt systems are available.

d) Special features of interest.

- As a design originating in North America, the LRC has been built to relevant AAR, FRA and Canadian regulations. Thus, there is no conflict between these regulations and the LRC design.
- Although designed and tested for 125 mph operation, this train has never operated in regular service at this speed.

- It is the only train to feature enclosed aircraft-style overhead bins, instead of an open rack for baggage in the passenger car. This feature is <u>required</u> under draft Canadian passenger car design safety regulations.
- The same regulations require that carbody tilt systems return the car to upright in the event of a failure and display an appropriate speed reduction instruction to the engineer.

II.1.3 The French Train a Grand Vitesse (TGV)

a) Background

French National Railways' (SNCF) interest in high speed dates back to the early 1950s. A series of test runs were made in 1954 and 1955 culminating in a world record speed of 331 km/h (205 mph) in March 1955. Not revealed until 1981, after the TGV had secured another record, was that these tests were nearly a disaster. Violent truck hunting of the locomotive had produced substantial track shift, as illustrated in the photograph Figure II.1.2. There were also severe problems in maintaining adequate contact between the pantograph and the catenary. These tests greatly stimulated French R&D efforts into these phenomena and laid the foundation for later success. In particular, a series of trials conducted by M Andre Prudhomme into track panel shift led to the Prudhomme formula for maximum lateral force by one wheelset on the track. This formula states that:

Maximum acceptable force (kN) = 0.85 (10 + P/3)

Where P is the axleload in kilonewtons (kN)

This formula is widely used in Europe for maximum acceptable lateral force on the track by an individual axle.

The next steps took place in the mid-1960s. First, opening of the new Tokaido line — the first Shinkansen in Japan — stimulated interest in France in a similar new line between Paris and Lyon. Second, SNCF introduced regular service at 200 km/h (125 mph) in 1969 with conventional electric locomotive-hauled trains over various portions of the line between Paris and Toulouse. Before this, in 1967, tests started with an experimental gas-turbine powered trainset. This trainset was tested at speeds up to 252 km/h (156 mph), and led directly to the construction of gas-turbine powered trainsets for public service. The first of these, termed the ETG, combined gas turbine and diesel power and entered service in 1970. A later version, the RTG was introduced in 1973. Trainsets were supplied to Amtrak as well as SNCF. The current situation and potential future developments of the RTG is discussed in Section II.1.4 below.

The final event in 1967 was the ordering of the first experimental gas turbine-powered TGV, the TGV001. The "T" in this train's title originally stood for "Turbo." Construction of TGV 001, a five-car set, was completed in 1973. This trainset included many of the features eventually incorporated into the electrically-powered TGV's, such as electric transmission, and the articulated layout. Speeds up to 318 km/h (197 mph) were attained. The interest in turbine traction at this time was partly due to a concern about the feasibility of electric power collection at high speed. However, further research overcame this problem, and the petroleum price

Figure II.1.2 Track Condition After the French 205 MPH Record Runs in 1955

Source: Murray Hughes, Rail 300, The World High Speed Train Race, David and Charles, Inc., 1988 rises in 1973/4 made electric traction preferable to gas turbines. The same price rises also led the French Government to approve construction of the new electrified Paris South-East (PSE) high speed line from Paris to Lyon.

Trains were ordered and construction commenced in 1976 with a target date of 1981 for completion. Design operating speed was 300 km/h, and initial operations at 260 km/h (161 mph) were planned. The high speed infrastructure was designated the Ligne a Grand Vitesse (LGV) (high speed line). There are a total of 410 km (254 miles) of new line.

Construction delays and some fiscal constraints meant that only part of the new line was opened in 1981 as planned. The remainder was opened in 1983, and speed raised from 260 to 270 km/h (167 mph).

The TGV and LGV were an outstanding success, both technically and commercially, and led directly to plans for the development of further routes and route extensions. These are shown on the map, Figure II.1.3, and are:

- The TGV Atlantique from Paris to Tours and Le Mans. The line to Le Mans opened to traffic in October 1989, and will be followed by the line to Tours in mid-1990. Maximum service speed will be 300 km/h (187 mph) and there will be a total of 280 km (174 miles) of new line.

- The TGV Nord to the Belgian frontier and the Channel Tunnel via Lille, due to open for service in May 1993, coincidentally with the Tunnel. Maximum service speeds of 320 km/h (198 mph) are contemplated. There will be a total of 340 km (210 miles) of new line.

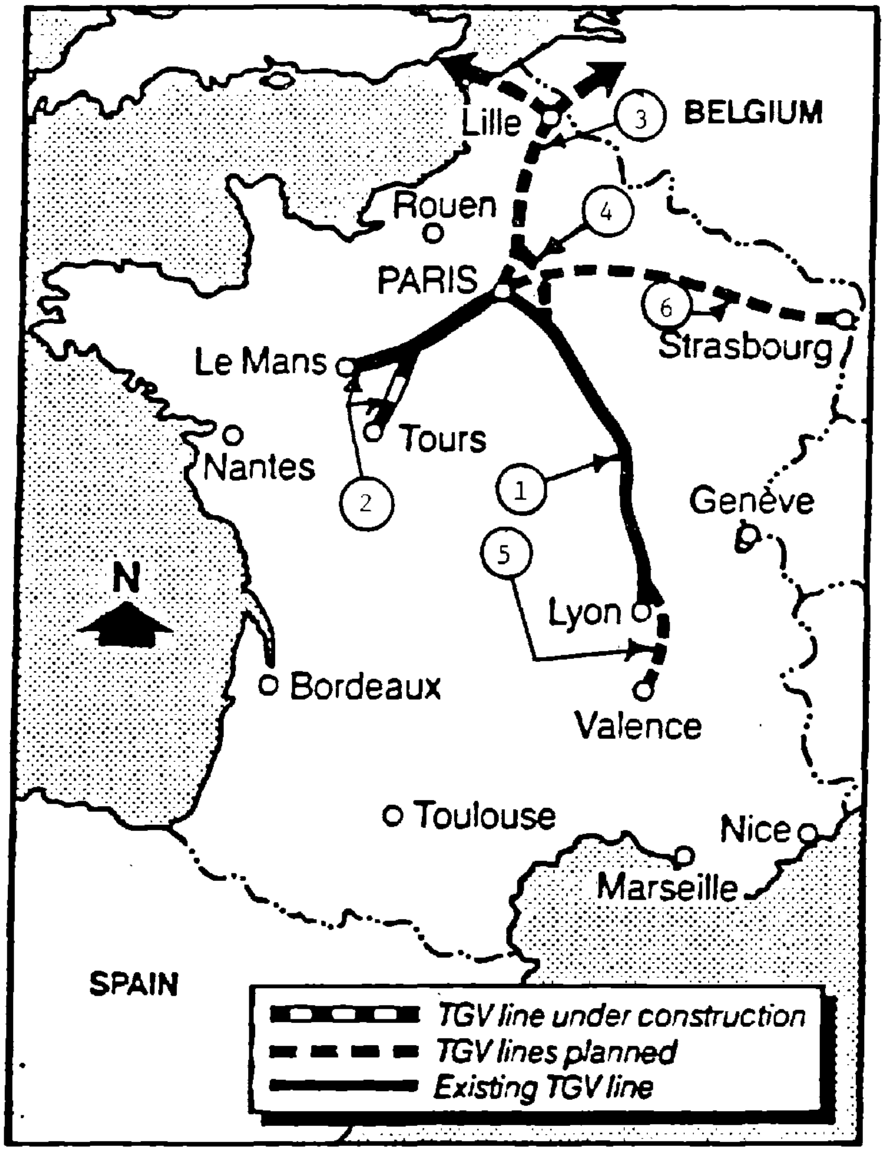
- A bypass to the east of Paris connecting TGV Nord, Charles de Gaulle International Airport, and the Euro Disneyland to the TGV Paris South East and Atlantique lines. There will be a total of 101 km (63 miles) of 270 km/h (167 mph) route, due for completion in 1994.

- A southern extension of the TGV PSE bypassing Lyon to Valence. Length will be 122 km (76 miles). This line is in early planning stage.

b) General Description

The following general description applies to both the TGV/LGV Paris South East and Atlantique systems. Where there are differences, this is stated in both the text and in the accompanying tables.

Figure II.1.3 French High Speed Lines
As of December 1989



1 Paris-South East - In service
2 Atlantique. Construction nearly complete, partial service Fall 1989
3. Nord. Construction starting shortly. In service 1993
4. Interconnexion (Paris bypass). In advanced planning, in service 1994
5. Lyon bypass: early planning
6. TGV Est: early planning

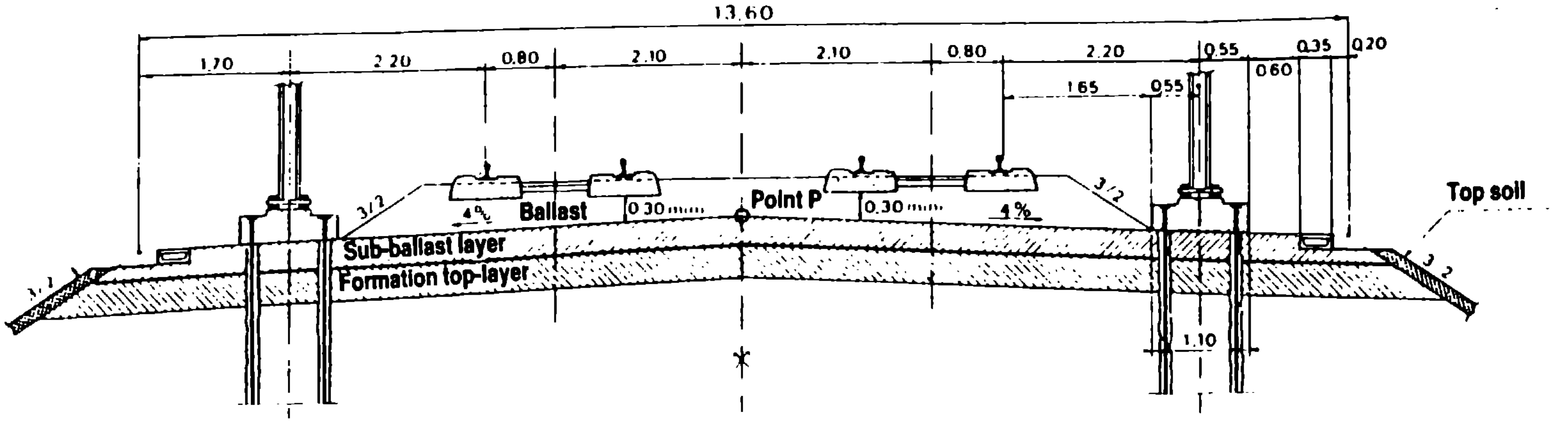
TABLE II.1.2

HSR CHARACTERISTICS - LGV INFRASTRUCTURE (FRANCE)
(Paris South East and Atlantique)

Routes:	Paris-Lyons (254 mi). In service Paris-Le Mans and Tours (174 mi). Operations commenced October 1989
Design Max Speed:	300 km/h (187 mph)
Track:	UIC 60 rail (121 lb/yd) Duo-block concrete ties/elastic fastener/conventional ballast
Maximum Axleload:	18.72 tons (17 metric tons)
Curves:	Min curvature 4000 m (2.5 mi) max cant 180 mm (7.1 in.), cant deficiency 90 mm normal (3.3 in.), max 130 mm (5.1 in)
Lateral Track Spacing:	4.2 m (13.78 ft) PSE (minimum) 4.4 m (14.44 ft) Atlantique (minimum)
Maximum Grade:	3.5% PSE 2.5% Atlantique
Power Supply:	25 kV 50 HZ overhead catenary (NB. TGV trains also accept 1500 V DC for operation on conventional SNCF lines, and some trainsets accept 15 kV 16 2/3 HZ for operation into Switzerland.)
Signals:	Cab signals only, no lineside signals, 2 km (1.44 mi) blocks Automatic speed supervision and braking if overspeed
Other:	• Exclusive use by TGV's • No tunnels on PSE, several on Atlantique

Figure II.1.4 Roadbed and Track Cross-Section for TGV Atlantique

(Dimensions in Meters and Millimeters)



Source: French Railway Review, September 1983

Infrastructure

Details of the LGV (Ligne a Grand Vitesse) are provided in Table II.1.2 for the Paris South East and Atlantique lines. Figure II.1.4 shows the track structure of the Atlantique line highlighting the dual-block concrete ties. The PSE structure is very similar. Elastic rail fasteners are used with a 9mm rubber pad under the rail. A typical high speed moveable frog turnout is illustrated in Figure II.1.5. Speeds can be as high as 300 km/h on the straight-through direction and 220 km/h in the diverging direction. Timber ties are used in turnouts.

Figure II.1.6 illustrates the cab signalling system. There are no lineside signals, only marker boards to indicate the start of each 2 km block. Permitted speed is continuously displayed in the cab. If this is exceeded by 10-15 km/h, as indicated in the diagram, then braking is automatically initiated. The engineer also has a voice radio contact with the TGV control center. The LGV lines are used exclusively by TGV trains and with one exception there has been no need to adapt the signalling, or any other feature of the infrastructure to the needs of conventional trains. This restriction made possible the very steep grades (3-5%) and the resulting reduction in infrastructure costs. The exception is the portion of the Atlantique line that bypasses the city of Tours, where conventional lineside signals have been added for use by conventional trains. The Atlantique signal and communication systems are compatible with both the original PSE TGV's and the new Atlantique trains.

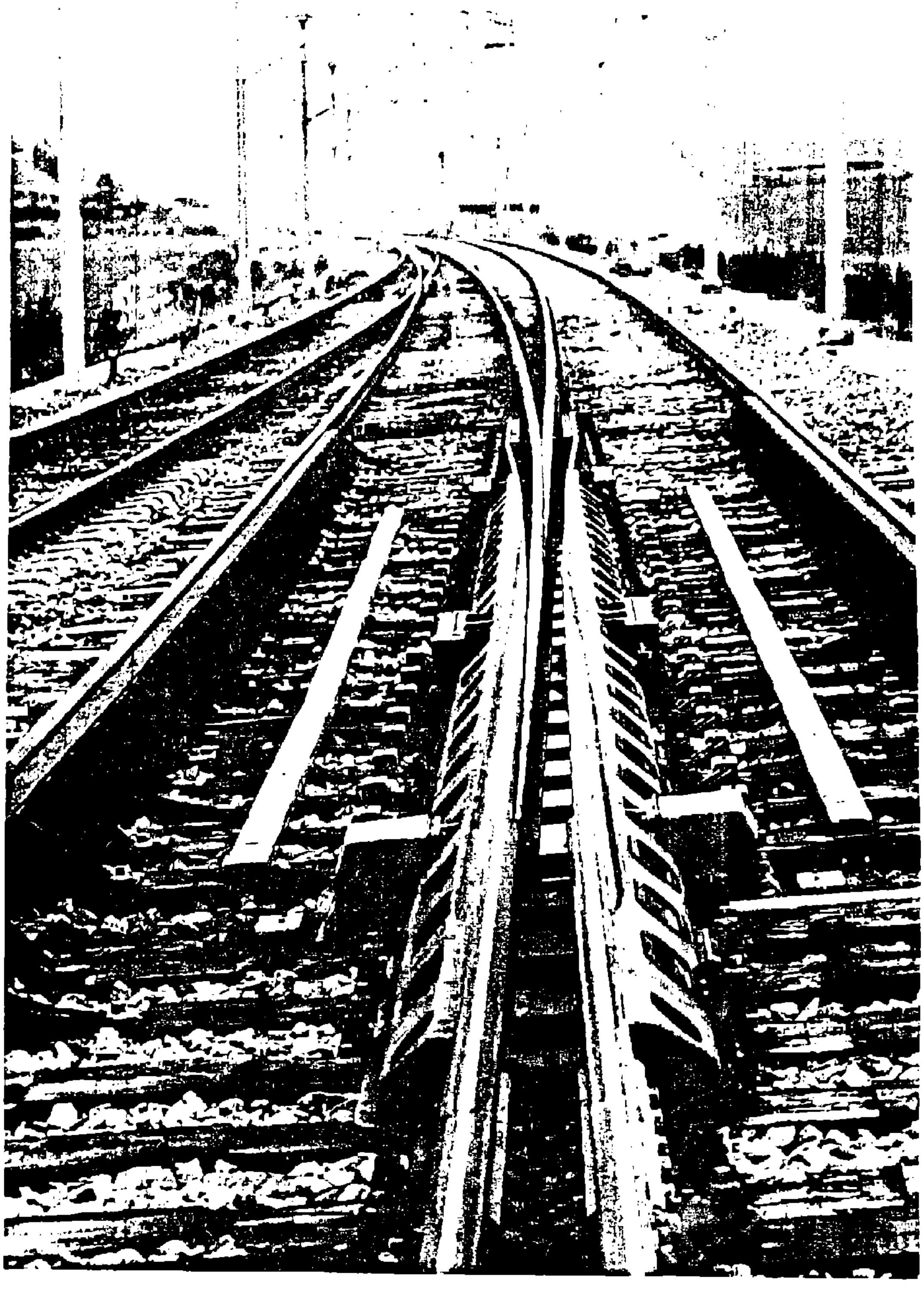
Rolling Stock

The TGV trains consist of a four-axle power car at each end of an articulated trainset. There are 8 cars in the PSE trainsets and 10 in the Atlantique trainsets. Details of the trains are given in Table II.1.3. Figure II.1.7 illustrates the articulation arrangements of both types of TGV.

The principal difference is the use of air springs in the Atlantique version to improve comfort. As well as reducing the total weight of the train, the articulation increases the truck to carbody weight ratios, thus making dynamic stability at high speeds easier to attain. The axleload of the articulation truck is 35.400 lb. Both types of train use axle-mounted disc brakes, with 4 discs per axle on the PSE and 3 on the Atlantique. Brake performance is similar.

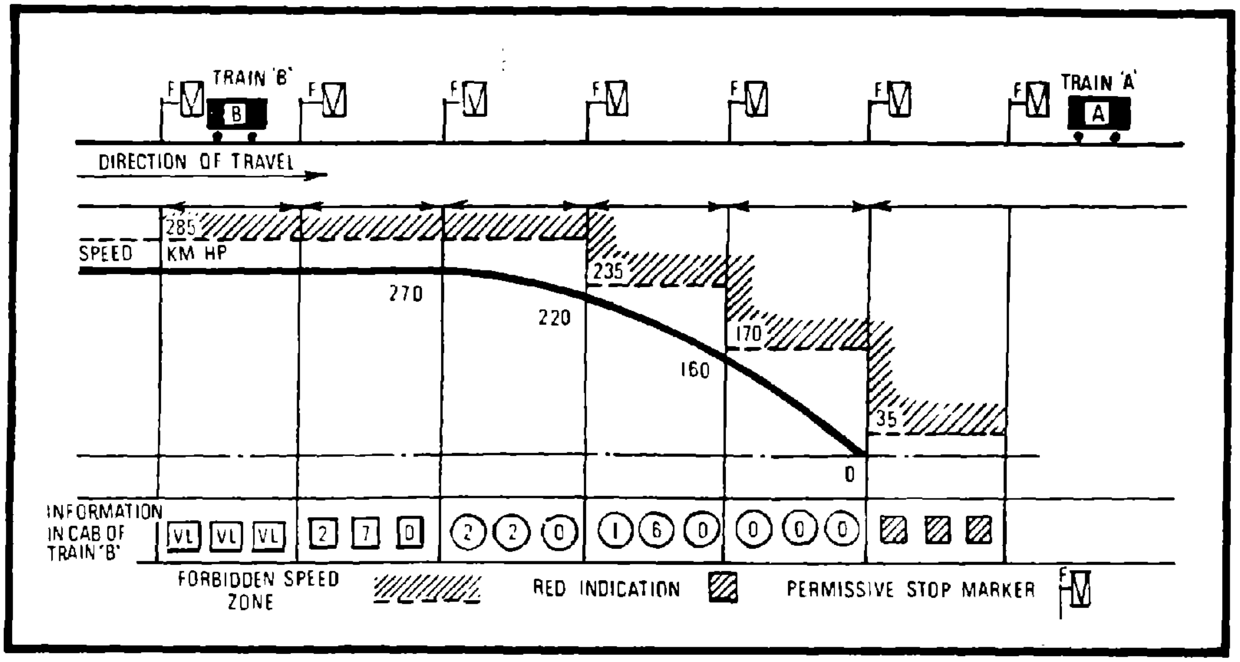
The Atlantique power car is illustrated in Figure II.1.8. Noteworthy features include a crushable energy absorbing structure in the nose cone forward of the engineer's cab, and traction motors supported in the power car body to reduce unsprung mass. Both these features were also present in the TGV-PSE power cars. Use of synchronous AC motors on the Atlantique trains has allowed the use of a trailer rather than a powered truck under the end of the passenger car adjacent to the power

Figure II.1.5 Moveable Frog Turnout on LGV-PSE



Source: Brian Perrin, Modern Railways Special-TGV, Ian Allen Ltd (UK) 1988

Figure II.1.6 Signal System and Braking Performance of the TGV-PSE



The line is divided into uniform 2 km blocks. Normal service braking distance from 270 km/h is 3 blocks or 6 km. Normal minimum headway is 4 minutes, equivalent to nine 2 km blocks at 270 km/h.

Source: Brian Perrin, Modern Railways Special - TGV, Ian Allen (UK) 1988

TABLE II.1.3
HSR CHARACTERISTICS - TGV ROLLING STOCK (FRANCE)

Service Speed:	167 mph (Paris South East); 186 mph (TGV Atlantique)
Max Test Speed:	383 km/h (237 mph)(TGV-PSE) 1981, 482.4 km/h (299.8 mph) (TGV Atlantique) Dec. 1989. This is the current world record (December 1989).[1]
Consists:	Fixed consist trainsets PSE PC + 8 articulated TC + PC, 275 seats 12 axles powered, DC traction motors Atlantique PC + 10 articulated TC + PC, about 330 seats 8 axles powered AC synchronous traction motors Note: trains frequently consist of two trainsets
Weight and Length:	PSE trainset 421 tons; power car 73 tons Atlantique trainset 453 tons approx., power car 74.6 tons Maximum axleload 37400 lb
Carbody Materials:	Power and passenger cars: low alloy high tensile steel
Power:	PSE 6300 KW (8445 HP) per trainset Atlantique 8800 KW (11796 HP) per trainset
Power Supply:	25 kV, 50 Hz AC overhead catenary on new lines 1500 V DC on existing lines
Brakes:	Powered axles - tread + rheostatic or regenerative trailer axles - tread + 4 discs (PSE), 3 discs (Atlantique)
Right-of-Way:	Existing, and new LGV's
Routes:	Paris-Lyon and destinations beyond Paris - west and southwest France
Operator:	French National Railways (SNCF)
Status:	PSE - service started 1981; about 100 trainsets in service Atlantique: service started October 1989
Other:	No tilt
Builder:	Alsthom (principal supplier)

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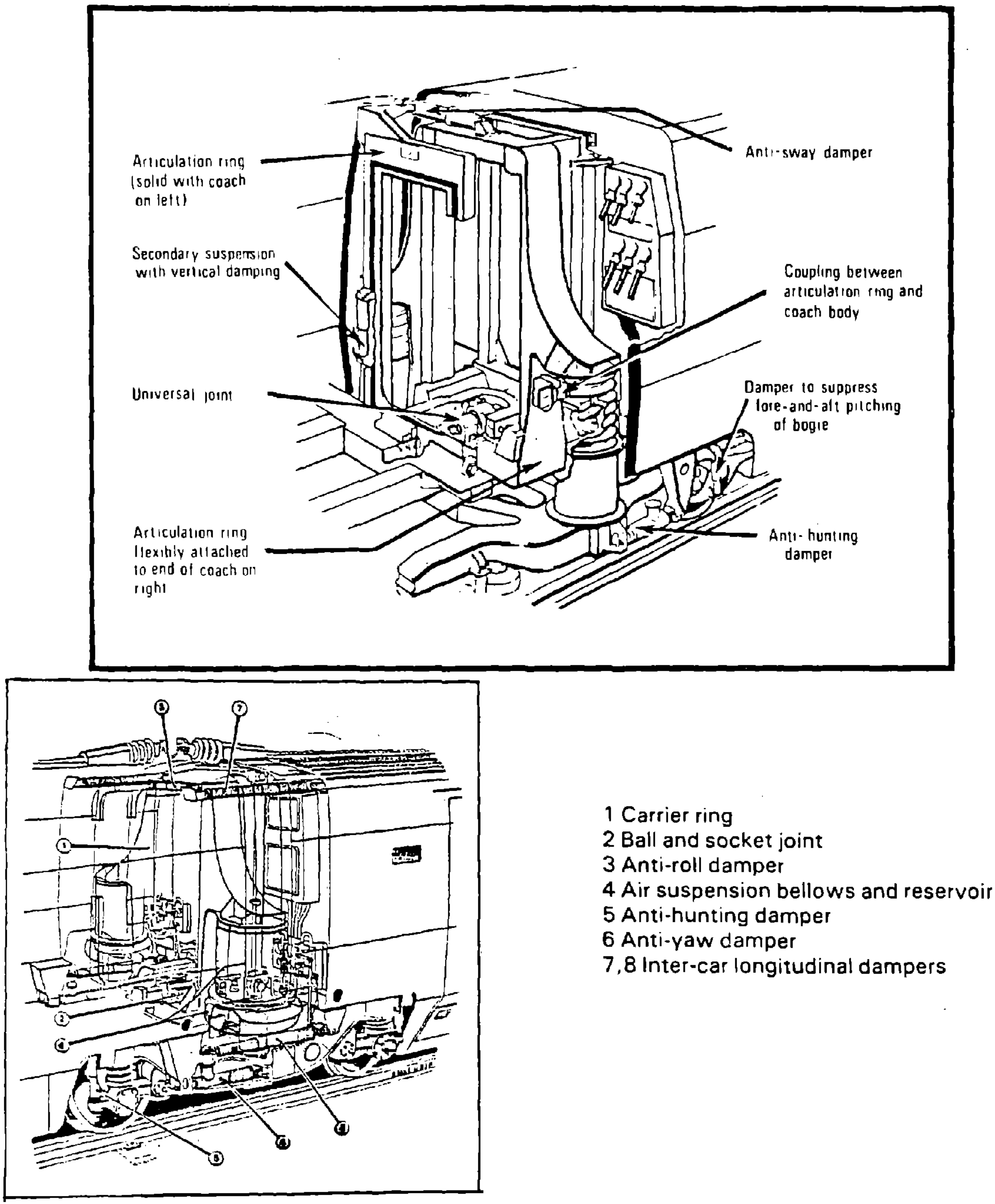
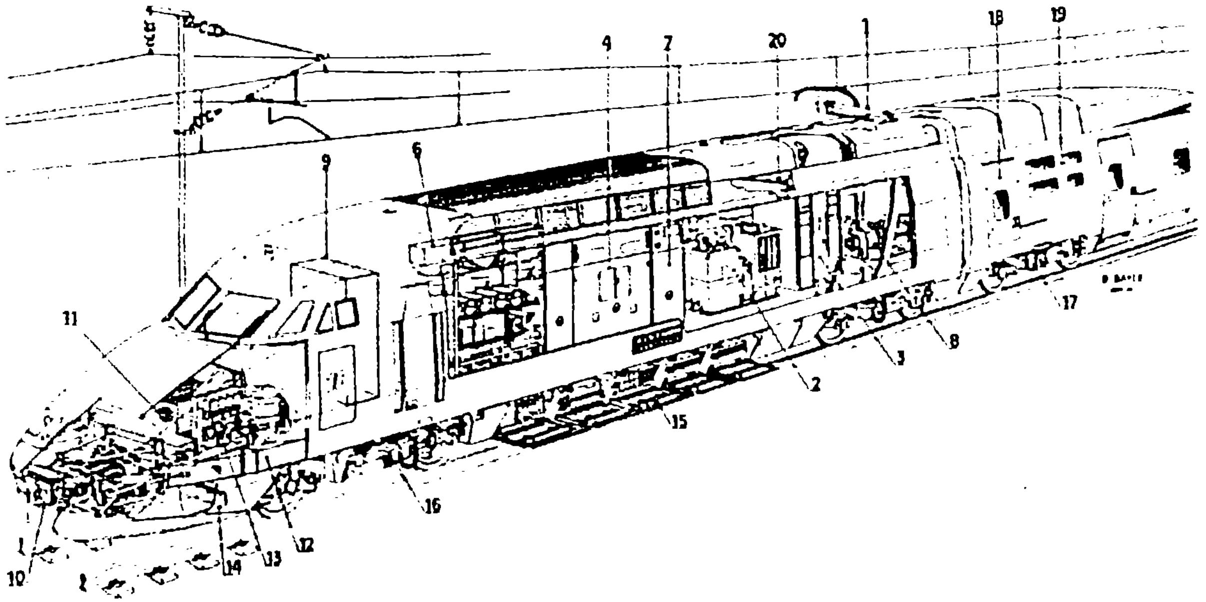
[1] As this report was going to press in May 1990, the TGV speed record was further increased to 515.3 km/h (320.2 mph). This is understood to complete SNCF's program of high-speed tests with TGV-Atlantique equipment.

Figure II.1.7 Articulation Trucks of TGV-PSE (top) and TGV Atlantique



Sources: Railway Gazette, December 1988, and Perrin, Modern Railways Special - TGV

Figure II.1.8 TGV-Atlantique Power Car Arrangement



1 Type GPU pantograph
2 Main transformer
3 Circuit breaker, line filter
4 Traction motor control module
5 Freon cooling for semiconductors
6 Braking resistances
7 Auxiliary power supplies
8 Main compressor
9 Computer and safety equipment
10 Autocoupler
11 Crumple zone
12 High strength structure
13 Braking controls
14 Track circuit code recievers
15 Equipment cases
16 Y230 powered bogie
17 Y237 trailer bogie
18 Baggage compartment
19 Passenger seating
20 Light alloy roof panels

Source: Railway Gazette, December 1986

car. DC motors were used on the PSE trainsets, and the end trucks of the articulated passenger car consist were powered.

Both types of train can operate over both new lines, and on existing tracks at up to 200 km/h (125 mph). They are able to accept both the 25 kV 50 Hz AC power supply on the new lines and the 1500 V DC on most existing SNCF electrified routes. A few PSE trains are also equipped to receive the 15 kV 16 2/3 Hz system on Swiss Federal Railways for international services.

c) Present Interest in the United States

The TGV is the equipment proposed by parties interested in obtaining a franchise for high-speed rail services in Texas between Houston, Dallas and Austin, and between Los Angeles and Las Vegas. The Bombardier Company of Montreal, Canada has North American rights to the TGV rolling-stock technology, and is expected to participate in future high speed rail developments.

d) Special Features of Interest

- To limit track loads, keeps axleloads below 18.7 tons (17 metric tons), and uses body mounted traction motors to minimize unsprung mass.
- Substantial energy-absorbing crushable structure forward of engineer's cab for crash protection.
- Built to UIC (European) standards in all respects.
- Use of continuous speed supervision (automatic train control) and cab signals on new lines. Lineside signals are not used.
- Turnouts have been built for 220 km/h (136 mph) on diverging track, using moveable frogs.
- Holds world speed record for steel wheel on rail of 515 km/h (320 mph). This exceeds the record of 410 km/h attained in the U.S. with the Linear Induction Motor test vehicle at Pueblo in 1975.

II.1.4 France - ANF Turbo Train

a) Background

The origin of the ANF Turbo train was described in the preceding section, II.1.3. The development of high performance turbo trains in France ceased in 1974 with the petroleum price increases. However, 52 trains of the RTG type were built in the mid-1970s and are currently operating on non-electrified routes of the SNCF. Seven RTG's were exported to the U.S. for use by Amtrak. These trains were built to UIC (European) standards, and were operated in the U.S. with the minimum of essential modifications to couplers, etc., and under FRA waiver for non-complying features. Note that total train weight is below 600,000 lbs, thus, compliance with the 800,000 lb. buff strength rule is not required. Later, an American version, the RTL, built to North American structural and other standards was developed by ANF and their U.S. licensee at the time, the Rohr Corporation. Three of the seven RTG's and all six RTL's continue in service between New York and Albany, and have recently been re-engined with improved turbines for increased power and fuel economy.

b) General Description

Table II.1.4 gives general data for the RTG/RTL trainsets in the configuration currently used by Amtrak and the SNCF. The trainsets consist of two power cars at the ends separated by three unpowered passenger cars. About one-third of the power car length is occupied by the engineer's cab, the turbine, hydraulic transmission and other equipment. The remainder of the power car contains passenger accommodations.

The turbine in each power car drives through a body-mounted Voith hydraulic torque-converter, and a mechanical carden-shaft transmission to final drive gear-boxes on both axles of the leading truck. Thus, one train has four powered axles. This arrangement provides relatively low unsprung and truck masses, leading to low track forces and facilitating the attainment of dynamic stability at high speed. The original Turmo III turbines have recently been replaced by the more powerful and fuel efficient Turmo XII. Each Turmo XII turbine provides 1200 KW for traction before transmission losses. An auxiliary turbine for hotel power is also provided. The RTL trains and the three re-engined RTG's operated by Amtrak are equipped with a low power DC electric motor driving through the same transmission as the turbine, and a third-rail pick-up shoe. Maximum speed under electric power is 45 mph, and is used for the final approach to New York terminals through Manhattan.

TABLE II.1.4

HSR CHARACTERISTICS - ANF TURBO (FRANCE)

Service Speed:	120 mph currently, potentially higher. 110 mph in current U.S. operations
Max Test Speed:	260 km/h (161 mph)
Consists:	Fixed consist trainsets: typically power car + 3 passenger cars + power. Approximately 280 seats. Various other arrangements possible (e.g., higher power, longer trains)
Weight and Length:	280 tons (5-car consist). Maximum axleload 38000 lb.
Carbody Materials:	Low alloy high tensile steel
Power:	Gas turbine, 2 x 1200 KW Turmo XI per train, + auxiliary power turbines. 2400 KW (3217 HP) in 5-car consist Third rail 750 V DC electric (Amtrak RTL and re-engined RTG's only)
Brakes:	Powered axles: tread brake; unpowered axles 2 discs and eddy current track brakes
Right-of-Way:	Existing track in U.S.and France
Routes:	In U.S., New York-Albany-Buffalo Various non-electrified routes in northern France
Operators:	SNCF and Amtrak
Status:	52 (14 ETG and 39 RTG) trainsets in operation in France since 1970/5. 13 trainsets (2 versions, the RTG and the RTL) in service in USA since 1973-6). Trains also supplied to Iran and Egypt
Other:	• Proposals exist for new configurations providing higher power/speed capabilities • No tilt but low weight/axleload may permit higher cant deficiencies • The RTL (U.S. built) version of the turbo train is designed to full FRA/AAR structural standards

c) Present Interest in the United States

The existing Amtrak turbos in re-powered form were participants in the Coalition of Northeast Governors' high speed demonstration tests between New York and Boston in 1988. Use of turbine power appears to be an attractive way of attaining higher speed on non-electrified routes. The possibility exists of a turbine "locomotive" consisting of two traction turbines installed in one carbody giving four powered axles, which could be used with existing or new passenger cars.

d) Special Features of Interest

- Relatively low axleload and unsprung mass.
- A version designed to U.S. structural and other standards (the RTL) is in service with Amtrak.
- Third rail electric traction capability.

II.1.5 Germany, the ICE and the Neubaustrecken

a) Background

The main north-south rail lines in West Germany are relatively slow, with many curves and grades, although they are maintained in excellent condition and carry heavy traffic. This is partly because of the hilly terrain and partly because they were regarded as secondary lines when they were first built. Primary lines then radiated from Berlin.

In 1970, German Federal Railways (DB) developed a plan for new rail lines (called Neubaustrecken) to meet the future capacity and performance needs of the system. From this plan, three high priority routes were selected for initial work:

- Hannover to Wurzburg
- Mannheim to Stuttgart
- Cologne to Frankfurt

These lines are shown on Figure II.1.9.

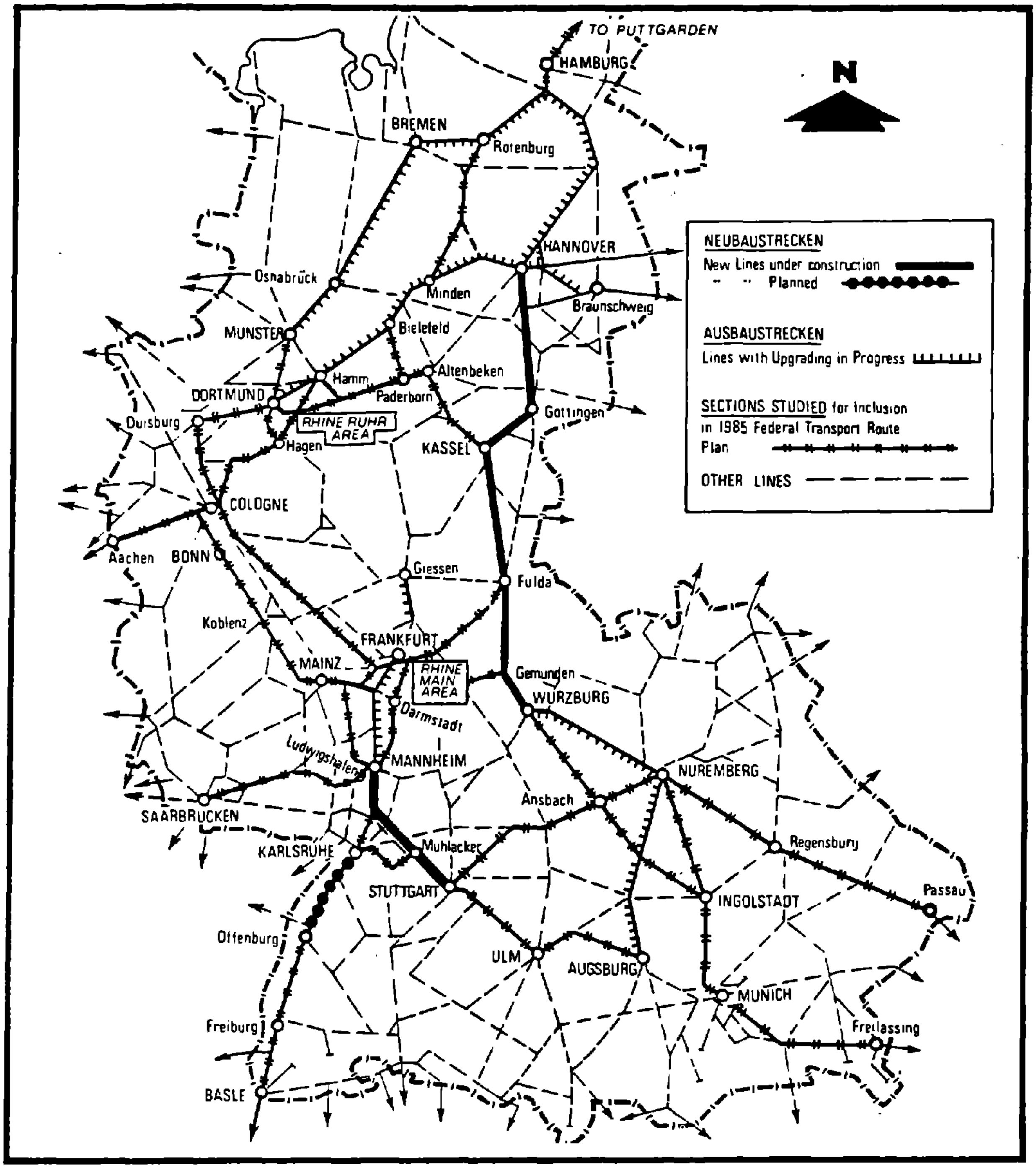
Formidable engineering, environmental and political difficulties quickly put the third of these on hold, but work proceeded on the other two, both of which are now nearly complete. Construction has been very slow because of Germany's complex planning procedures, and numerous environmental objections to the new lines.

The Neubaustrecken (NBS) are built for mixed freight and passenger traffic and for maximum passenger train speeds of 250 km/h (155 mph). At least on the two lines under construction, there was insufficient traffic to make the lines economically viable with passenger services only.

As well as the NBS, there is also a program of rebuilding of existing lines to higher speed standards. Such rebuilt lines are termed Ausbaustrechen (ABS), and are also shown on Figure II.1.9. Maximum speed on portions of the ABS is 200 km/h (125 mph). Much of this work is now complete.

Until 1981, only limited efforts were made in Germany to develop a high-speed train. Three four-car prototype electric multiple unit trains, the ET403 class, had been built in 1973. All axles were driven by truck mounted traction motors, and up to 4° of tilt was available, using the air springs as tilt actuators. They have a top speed of 200 km/h. The ET403 trains ran in regular DB passenger service until 1979, and since 1981 have been operated between Frankfurt and Dusseldorf airports as the "Lufthansa Airport Express." However, DB failed to either build more trains or further develop this concept for higher speeds.

Figure II.1.9 German Federal Railways (DB) "Newbuilt Lines" (Neubaustreken) and "Rebuilt Lines" (Ausbaustrecken) as Detailed in the 1985 Federal Transport Plan



Source: Modern Railways (UK), July 1986

Meanwhile, the Brown Boveri electrical engineering company had been developing three-phase asynchronous traction systems for locomotives, initially for Swiss Railways. This technology was incorporated into DB's 125 mph Class 120 locomotive (briefly described in Section II.1.6 below), development of which started in 1977 and was completed in 1984. The availability of this development, plus the prospects of a French high speed train monopoly in Europe, and of DB having the high speed NBS with no trains to run on them, led to the Intercity Experimental (ICE) program started in 1981. A prototype train consisting of two four-axle end power cars and three intermediate four-axle passenger cars, designed for 350 km/h (217 mph), was completed in 1985. Numerous tests have been carried out with this train, including attainment of a top speed of 408 km/h (253 mph) in 1988. Production trainsets consisting of two power cars and up to 12 intermediate passenger cars were ordered in 1988. Public service on the NBS and elsewhere with these trains is expected to start in 1991.

The most recent developments have been preliminary plans for a TGV-style passenger-only line between Cologne and Frankfurt, and a line westward from Cologne towards Brussels to connect with the TGV-Nord and the Channel Tunnel.

b) General Description

Infrastructure

The basic data for the NBS infrastructure is given in Table II.1.5. The track structure is highly conventional, utilizing UIC 60 kg/m rail (121 lb/yard) on concrete ties and ballast. Slab track is used in a few locations in tunnels. Curvature and gradients are kept low, reflecting the proposed mixed freight and passenger traffic use. Electric power supply is 15 kV, 16 2/3 Hz AC from an overhead catenary. This is the standard system used on the whole DB network, and is virtually identical to the Swiss and Austrian systems.

Terrain and environmental consideration have forced the use of many elevated structures and tunnels. Typical structures are shown in Figure II.1.10. The tunnels have a generous cross-section to minimize the air pressure shocks caused by trains passing at speeds.

Signalling

German Federal Railways have developed a continuous automatic train control and track-train communication system called LZB (for Linienzugbeeinflussung). This system is being applied to both the new lines and upgraded existing lines.

A schematic of the LZB is shown in Figure II.1.11. The heart of the system is the LZB center, essentially a "vital" train control computer that determines authorized

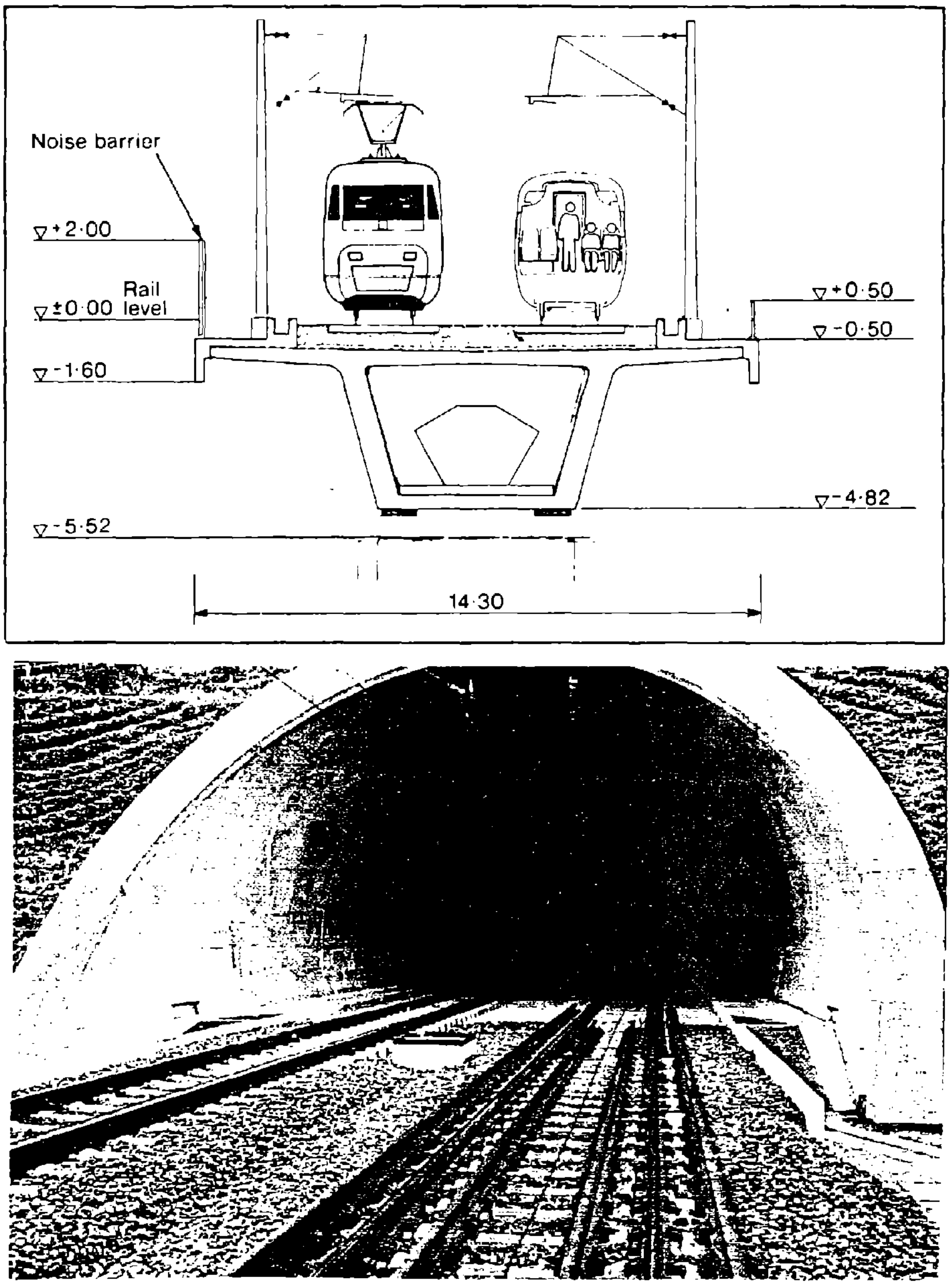
TABLE II.1.5

HSR CHARACTERISTICS - NBS INFRASTRUCTURE (W. GERMANY)

Routes:	Hannover-Wurzburg 203 mi complete Mannheim-Stuttgard 65 mi complete
Design Max Speed:	155 mph
Track:	UIC 60 rail (121 lb/yd); monoblock concrete tie/elastic fastener/conventional ballast. Some slab track in tunnels
Curves:	Minimum radius 7000 m (4.35 mi) normal, 5100 m (3.17 mi) exceptional Maximum cant 150 mm (5.9 in), cant deficiency 60 mm (2.4 in) Lateral track spacing 4.70 m (15.4 ft)
Power Supply:	15 kV 16 2/3 HZ overhead catenary
Signals:	Cab signals, continuous track-train communication and speed supervision; plus conventional lineside block signals
Other:	• Mixed traffic planned (high speed, conventional passenger and freight trains) • Many tunnels and elevated structures • Max gradient 1.25% • Unusual 15.4 ft track centerline spacing (13.8 ft normal) • New lines currently in operation at 200 km/h (125 mph) using conventional locomotive-hauled trains

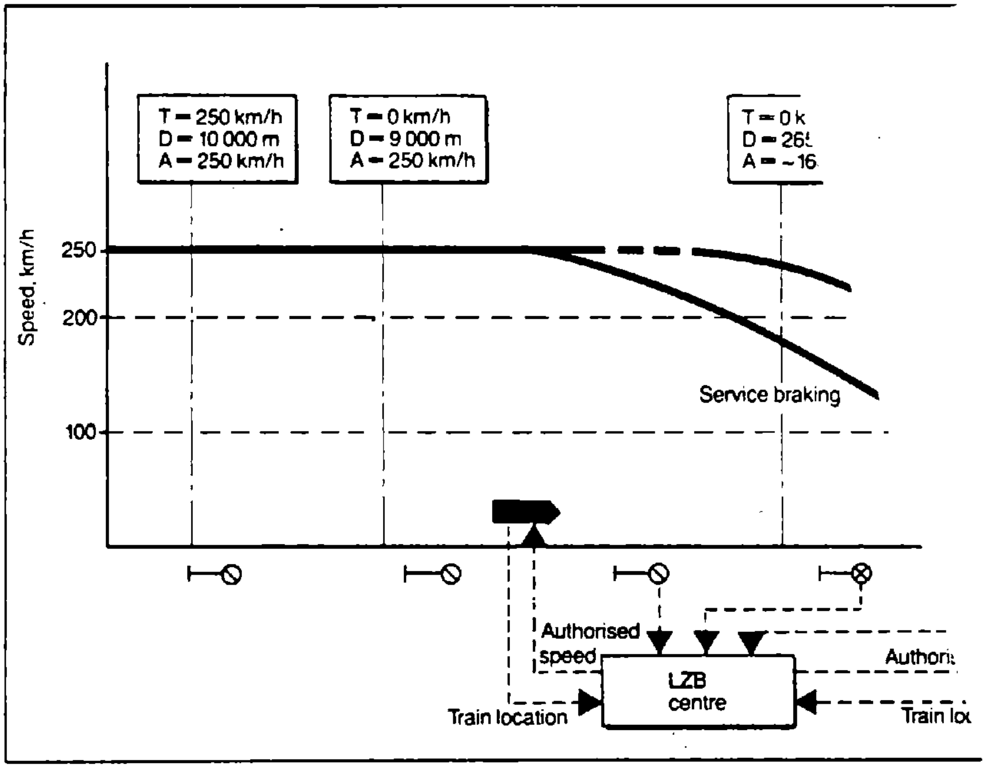
Figure II.1.10 German Neubaustrecken

Typical cross-section on elevated structure and tunnel entrance showing transition from ballasted to slab track



Source: Railway Gazette International, March 1987

Figure II.1.11 Schematic of German Federal Railways LZB Automatic Train Control System



Source: Railway Gazette International, July 1986 speeds and distances to stop and transmits this to the train. Permanent and temporary speed restrictions are included. The LZB also controls lineside signals. These are installed on the NBS for freight and other trains not equipped with LZB receivers. However, one lineside signal block contains several LZB blocks, used to provide greater track capacity and more precise speed control. Non LZB-equipped trains are limited to conventional speeds, and their presence will lead to reduced track capacity.

The normal method of track-train communication is via an inductive loop laid on the track, an extension of mass transit system practice. However, such an installation is costly and vulnerable to damage, especially by track maintenance activities, and DB is experimenting with high frequency radio links as an alternative.

Rolling Stock

Data on the ICE rolling stock is provided in Table II.1.6 and the power car design is illustrated in Figure II.1.12. The passenger cars are basically conventional European design. The trucks are an adaptation of the MD (for Minden Deutz) 52 truck presently in service under existing 200 km/h (125 mph) cars. Three discs per axle are provided to obtain adequate braking effort, and eddy current rail brakes may also be fitted to production trains.

The key features of the power car are primarily aimed at minimizing truck and unsprung mass, in order to keep track forces within acceptable limits. As shown in Figure II.1.12, the final drive gearbox and the three brake discs are supported on the truck frame, with a quill shaft drive to the axle. The motor is partially supported on the truck frame and partially on the power car body.

c) Present Interest in the United States

The builders of the ICE have been very active in promoting the train in the United States, and are a leading technology contender for the "Texas Triangle" (Dallas-Austin-Houston) high speed rail project.

d) Special Features of Interest

- Variable consist train depending on the number of passenger cars installed between the power cars.

- Use of 3-phase AC asynchronous traction technology.

- New lines designed for mixed traffic — high speed and conventional passenger trains and freight trains.

TABLE II.1.6

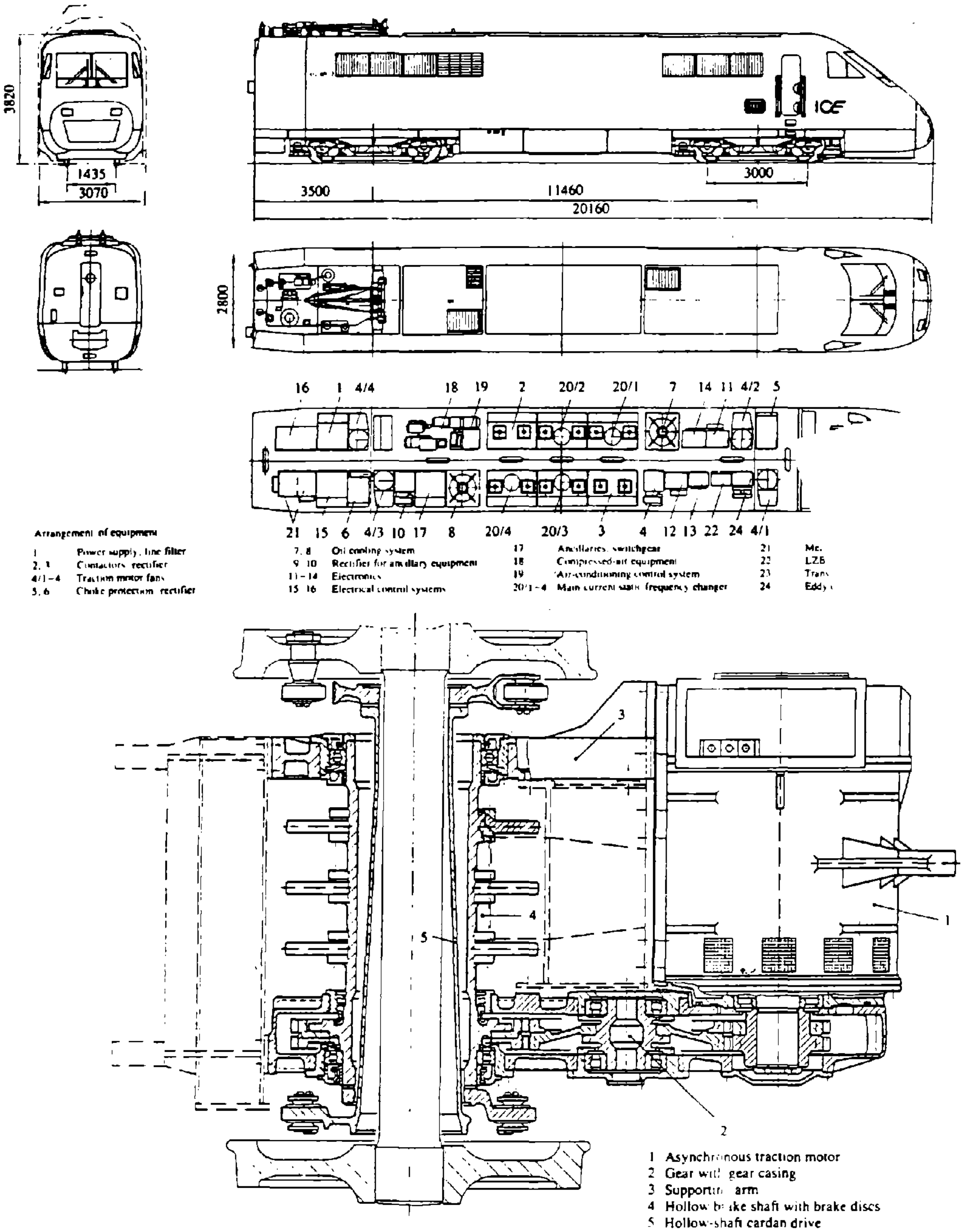
HSR CHARACTERISTICS - ICE (W. GERMANY)

Note: The ICE (experimental) is the train currently undergoing tests in Germany. The ICE (Express) is the service train currently under construction.

Service Speed:	155 mph proposed, potentially higher
Max Test Speed:	252 mph (406 km/h) 1988
Consists:	ICE (experimental) power car + 3 passenger cars + power car ICE (Express) power car + 12 passenger cars + power car
Weight and Length:	Power car: 86 tons. Passenger car: 50 tons Lengths: power car 68 ft, coach: 80 ft (experimental), 87 ft. (Express) Maximum axleload (power car) 43000 lb.
Carbody Materials:	Power car: steel; passenger car: aluminum
Power:	Experimental: each loco 3640 kW (4879 HP), train 7280 kW (9759 HP). Express each loco 4800 kW (6434 HP), train 9600 kW (12868 HP)
Power Supply:	15 kV 16 2/3 Hz AC overhead catenary
Brakes:	3 discs/axle on power car, 3 discs/axle on pass. car, eddy current brakes under consideration
Right-of-Way:	Both new lines and existing DB routes
Routes:	Various
Operator:	German Federal Railways (DB)
Status:	Experimental train in test and demonstration service. Service trains ordered/in manufacture. Revenue service starts 1991.
Other:	• Unusual arrangement of traction motor, partially supported on the body and partly on the truck frame • 3-phase AC asynchronous motors • Because of frequent tunnels, special attention has had to be given to sealing passenger cars against external air pressure shocks produced when trains pass in tunnel
Builders:	Thyssen Henschel, Asea Brown Boveri, Siemens, AEG and others

Figure II.1.12 The ICE Power Car

General layout and final drive system



Source: Railway Engineer (UK) Issue 2, 1988

- Many tunnels and bridges on new lines. This has led to a focus on passenger car air sealing to minimize air pressure shocks on car occupants.
- Extensive use of the very comprehensive LZB continuous automatic train control system on both new and upgraded existing lines.

II.1.6 Germany - The Class 120 Locomotive

a) Background

As mentioned in Section II.1.5, the Class 120 was a development of the 3-phase AC traction motor technology developed by the Brown Boveri Company in Switzerland. Five prototypes were delivered to DB in 1979/80. After extensive trials and modifications to improve reliability, Class 120 locomotives were ordered in quantity in 1985.

b) General Description

Apart from the 3-phase AC traction motors, the 120 is a straightforward 4-axle high power electric locomotive, easily capable of 200 km/h (125 mph), its normal maximum service speed. Details are given in Table II.1.7. The relatively light weight of the AC motor reduces truck mass. Motors are mounted on the truck to minimize unsprung mass.

c) Interest in the United States

None in this specific locomotive. However, the 3-phase AC drive is becoming more and more attractive for both electric and diesel-electric locomotives, especially as new solid-state power control devices become available. Technology from the Class 120 is incorporated into the ICE, and will likely be incorporated into other equipment in the future. Note that the Asea-designed AEM7 locomotives used in the northeast corridor have thrystor-controlled DC traction motors. Three-phase AC drives are being applied to diesel-electric locomotives in the U.S. on a trial basis, and to commuter and subway multiple-unit cars.

TABLE II.1.7

HSR CHARACTERISTICS - CLASS 120 (W. GERMANY)

Service Speed:	200 km/h (125 mph)
Max Test Speed:	254 km/h (154 mph)
Consist:	Single loco for passenger and freight service
Weight and Length:	93 tons (18.34 m) 60 ft
Carbody Materials:	Steel
Power:	5600 kW (7507 HP)
Power Supply:	15 kV 16 2/3 Hz AC overhead catenary
Brakes:	Tread and regenerative
Right-of-Way:	Existing DB track
Routes:	Various
Operator:	German Federal Railways (DB)
Status:	In service since 1986
Other:	3-phase AC traction motors used with solid state invertors for traction control
Builders:	Brown Boveri and others

II.1.7 Great Britain - The HST

a) Background

The British Rail High Speed (diesel) Train (HST) was conceived in 1969 as a stop-gap "conventional" alternative to the more ambitious Advanced Passenger Train (APT). The concept was to build a lightweight diesel-electric trainset consisting of several passenger cars sandwiched between a pair of moderate power diesel electric locomotives. Only the locomotives had to be designed from scratch. The "Mark III" coach (passenger car) incorporated into the train was already in development. The Mark III designation for the car derives from it being the third "generation" of passenger car designs since the formation of British Rail in 1948. Conventional technology was to be used throughout, with the minimum development of trucks and brake systems necessary to be able to operate at 125 mph (200 km/h) and stop from this speed on lines having signal spacing for 100 mph operation with conventional trains. Fortunately, British Rail signal spacings derive from a braking distance curve (called the W-curve) developed in the 1930s with steam traction and cast iron tread brakes, giving generous braking distances at higher speeds. A prototype train was designed and built in the period August 1970-June 1972, and subsequently underwent extensive trials, reaching a top speed of 230 km/h (143 mph). Based on the lessons from these trials, a production version of the train was designed, which entered passenger service in 1976 on the London to Bristol line. No changes were made to the existing signalling or Automatic Warning System (AWS), but considerable trackwork was performed to prepare this route for 125 mph operation. As well as normal relaying with CWR and concrete ties, this included extensive subgrade improvements to ensure continuing good geometry. The AWS is a relatively primitive form of cab signalling. Whenever a signal is passed that is set at other than "all clear," the engineer receives an audible and visual warning and, unless this is cancelled, the brakes are automatically applied. The "all clear" sound signal (a bell) is received at all-clear signals.

Commercially, the HST has been a great success. A total of 98 trainsets were built between 1975 and 1982. They provide service on all major non-electrified routes on BR, carrying about half of all intercity passenger miles. Principal routes are London to the southwest, and London-Yorkshire-Edinburgh. London-Edinburgh is now being electrified and the HST's on that route will be displaced to less demanding services.

Technically, the experience has been mixed, with considerable reliability problems with the high-speed lightweight diesel engine and associated cooling systems. However, there have been no significant accidents or safety problems associated with the HST's or their operation at 125 mph.

Dating from the early 1970's, the HST is now an old design. Its development and operation, however, have provided BR with extensive experience of 125 mph operation on existing tracks.

b) General Description

Key data regarding the HST is provided in Table II.1.8, and Figures II.1.13 and II.1.14 for the locomotive and passenger car.

The HST consists of two 2250 HP power cars at each end of the train and seven or eight passenger cars. Each power car has a 2250 HP diesel engine. Auxiliary and head-end power needs absorb approximately 400 HP, leaving 1850 HP for traction.

Both the locomotive and passenger cars are of conventional steel construction.

c) Present Interest in the United States

None.

d) Special Features of Interest

- The HST is built in accordance with most of the UIC code requirements applying at the time of construction. However, there was no strict need for this since the HST has only operated in the UK.

- Considerable effort was expended to minimize vertical track impact forces. These are termed by BR "P1" and "P2" forces for the high and low frequency components of wheel force response to a vertical rail irregularity. This led to the use of a relatively low axleload for the power car (19.5 tons) and traction motors mounted on the truck frame.

- No new track was built, although most 125 mph track was rebuilt or improved. Virtually all high speed track on BR consists of 113 lb/yard CWR on concrete ties at 30 inch spacing.

- Considerable attention was devoted to engineer protection from flying objects, including high impact windshield and a fiberglass-foam sandwich construction of the nose-cone. The "design case" was a cast iron brake shoe impact at maximum speed. Such shoes occasionally became detached from freight trains running on adjacent tracks.

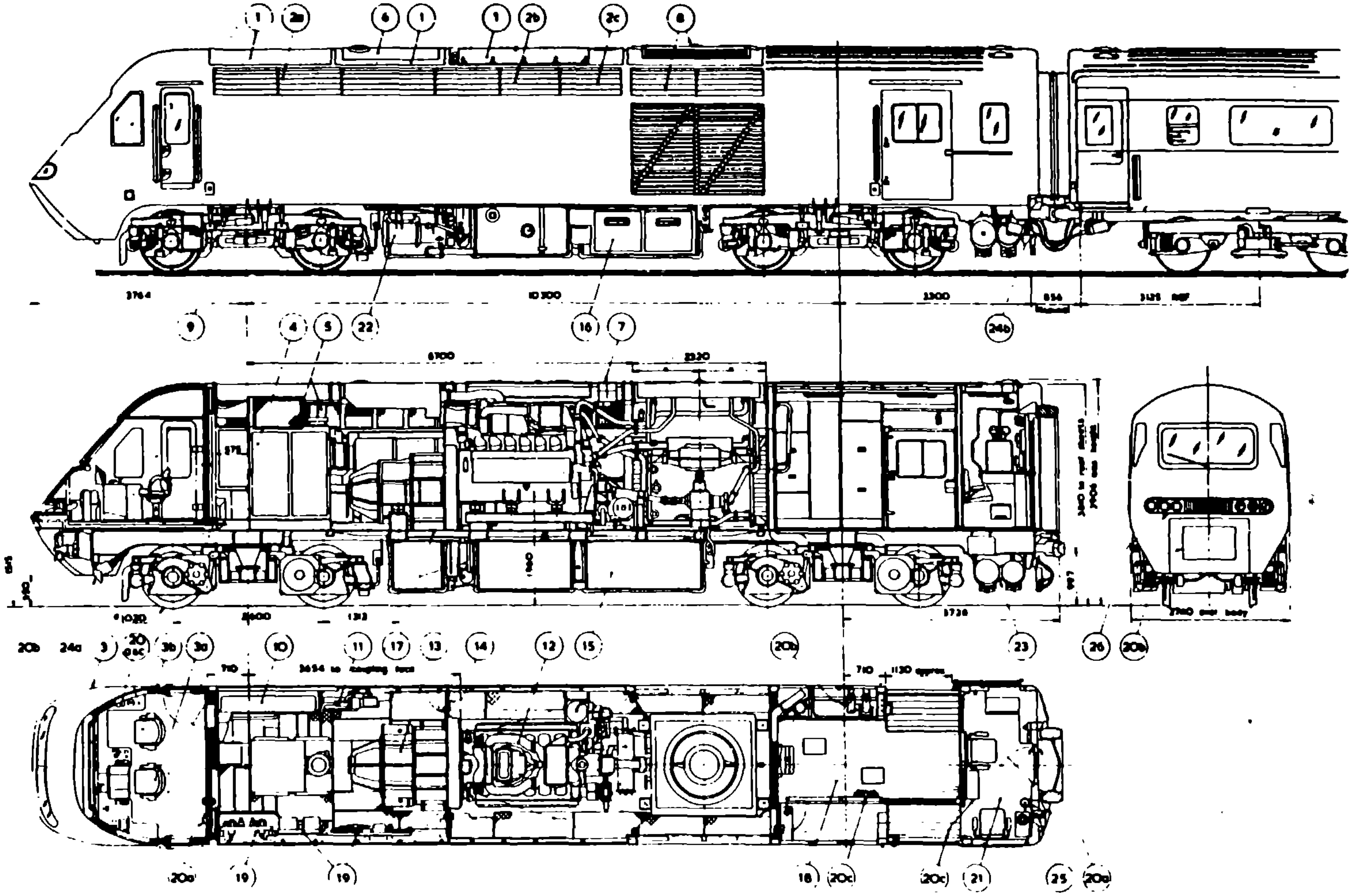
- Track preparations included the elimination, as far as possible, of all grade crossings where trains operate at 125 mph. However, there appears to be no mandatory rule or policy concerning this, and one or two crossings may remain in 125 mph territory. HST's operate over grade crossings at 100 mph or less at many locations.

TABLE II.1.8

HSR CHARACTERISTICS - HST (BRITAIN)

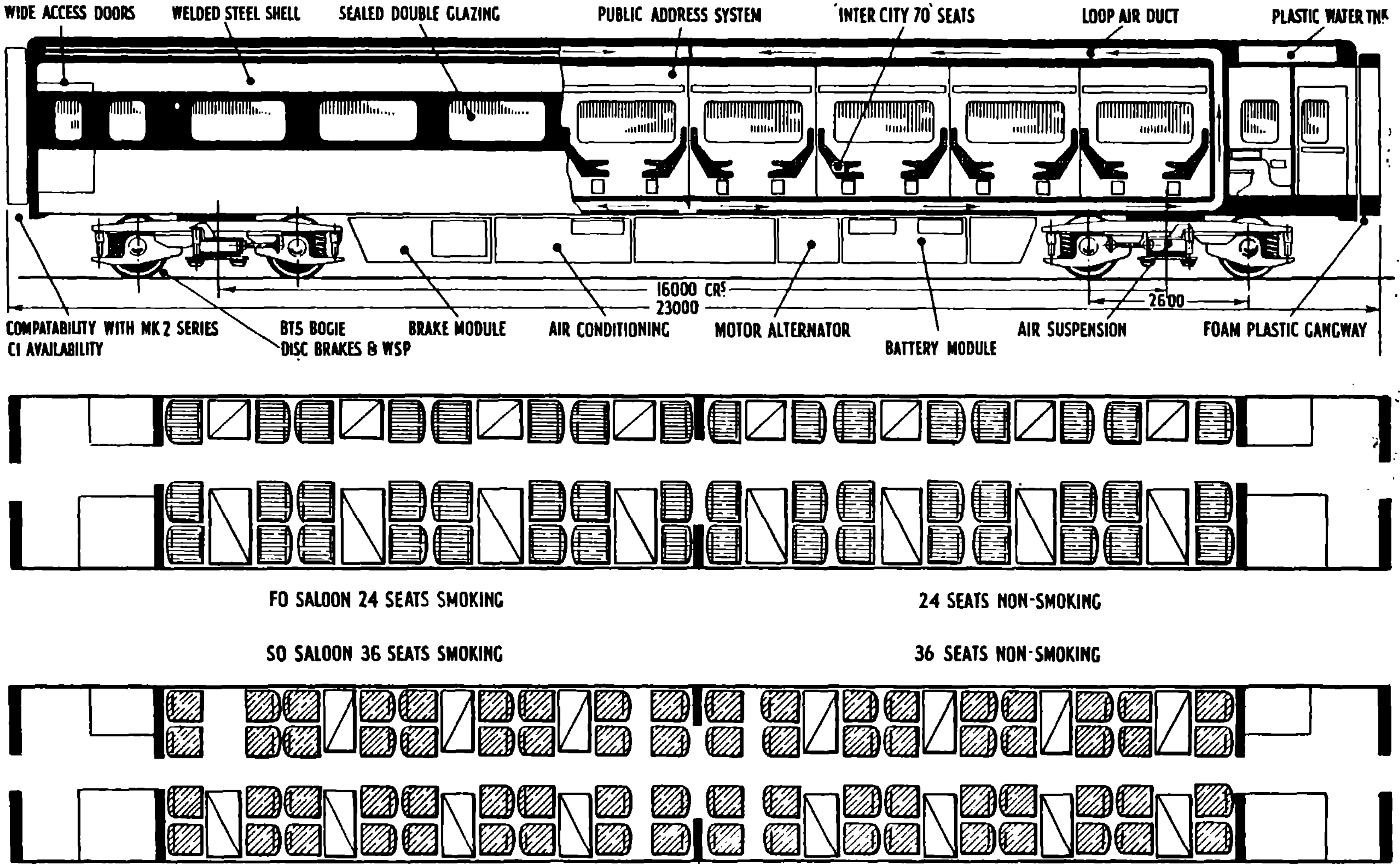
Service Speed:	125 mph
Max Test Speed:	143 mph
Consist:	Fixed consist trainsets Loco + 7 or 8 passenger cars + loco, about 420 seats
Weight and Length:	Locomotive 78.4 tons, 58 ft. Passenger car 38 tons, 75 ft. 8 car train + 2 locos; 392 tons Max axleload 39,200 lb
Carbody Materials:	Cars and locomotives - conventional steel
Power:	Paxman Valenta 12 cyl. diesel engine, each 2250 HP Diesel-electric transmission, power at rail 3540 HP approx. from two locomotives, after subtracting auxiliaries and hotel power
Brakes:	Standard electro-pneumatic brake system Passenger car 2wheel-mounted discs/axle Locomotive 2 wheel-mounted discs/axle + "scrubber" tread brake
Right-of-Way:	Existing unmodified BR right-of-way (concrete ties+ 113 lb/yd CWR)
Routes:	London-Edinburgh, London-Southwest and others
Operator:	British Rail
Status:	• Services commenced in 1976 • 97 trains currently in service, providing about 50% of UK intercity service • Construction finished 1982
Other:	No tilt
Builder:	British Rail, Brush Electrical Machines, General Electric Co.

Figure II.1.13 BR High Speed Train Locomotive (Power Car)



1. Translucent Roof Panels
2. Filtered Air Intakes for.–
   - a Electric m/cs & clean air compartment
   - b Engine combustion
   - c Engine Room ventilation
3. Driving Cab with.
   - a Driving position
   - b Assistant's Seat
4. Electric Control Cubicle
5. Resistance Unit & Short Circuiter
6. Silencer
7. Engine Room Fan
8. Cooling Unit
9. Flexicoil Suspension
10. Rectifier Unit
11. Battery Charging Unit
12. Paxman 'Valenta' Engine, 12 RP 200L
13. Alternators
14. Clean Air Compartment Partition
15. Fuel Tank, 5 680 litre max^{m}
16. Battery Box
17. Spillage Tray & Collecting Tank
18. Luggage Van 1 tonne Nominal
19. Brake & other Pneumatic Equipment
20. Emergency & Safety Equipment:–
    - a Fire Extinguishers
    - b Towing & Propelling
    - c First Aid & Safety
21. Guard's Compartment
22. Air Compressor
23. Main Reservoirs
24. Train Electric Supplies 415V. 3 phase:–
    - a Shore supply
    - b Between cars
25. Parking Brake
26. Horns & Lights

Figure II.1.14 BR High Speed Train Passenger Car



II.1.8 British Rail Intercity 225 (Class 91/Mark IV Coach)

a) Background

The unsuccessful Advanced Passenger Train project, when it was finally abandoned in 1984, left British Rail without any successor to the aging diesel HST's, and no high performance train for electrified routes. Furthermore, planned electrification of the London-Yorkshire-Edinburgh line by 1990 created a need for a high speed electric power train to replace the HST's on that route.

To fill this need, BR developed the Intercity 225 project, consisting of a high power electric locomotive (the Class 91), and a new generation passenger car (the Mark IV). Some engineering features from the APT were retained, most notably the use of body-mounted traction motors on the locomotive to minimize track forces. The articulated layout of the APT was abandoned, but the option was retained to incorporate tilt by using a carbody cross-section that tapered toward the roof.

Specifications for the passenger car and locomotive were prepared in early 1985 and orders placed later that year. The first locomotive was delivered from the builders, GEC, in March 1988 and has been undergoing trials. The first passenger cars, including cab-cars entered service in late 1989.

b) General Description

The IC225 train comprises a Class 91 locomotive, typically 8 or 9 passenger cars, and a cab/baggage car. There will be no passenger accommodation in the cab-car. The train is designed for a maximum speed of 225 km/h (140 mph), although initial operation will be at 200 km/h (125 mph). Enhancements to the present signalling systems will be required for the higher speeds.

The key dimensions and other features of IC225 are given in Table II.1.9. An illustration of the locomotive truck and traction motor arrangements are given in Figure II.1.15. and of the overall consist in Figure II.1.16.

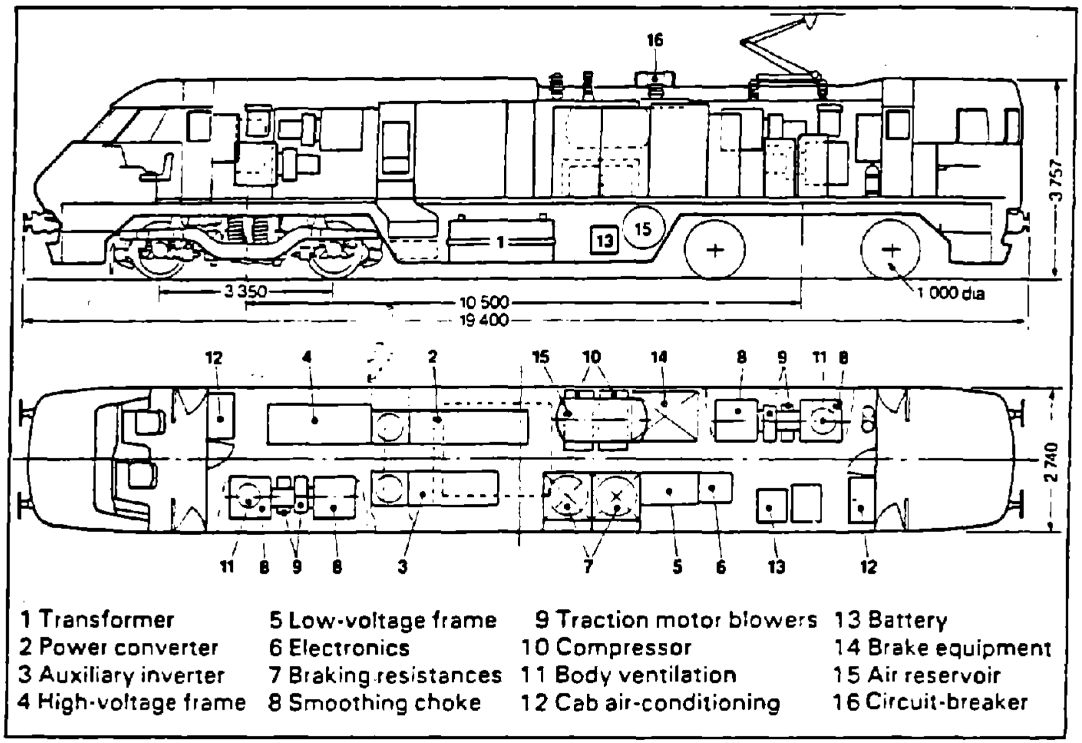
The Class 91 is designed to function as an independent locomotive, as well as part of an IC225 consist. It will power sleeping car and intermodal freight trains at night, as well as IC225 consists during the day. The locomotives have also been designed to meet all BR vertical and lateral track force criteria at up to 9 in. of cant deficiency and 225 km/h (140 mph).

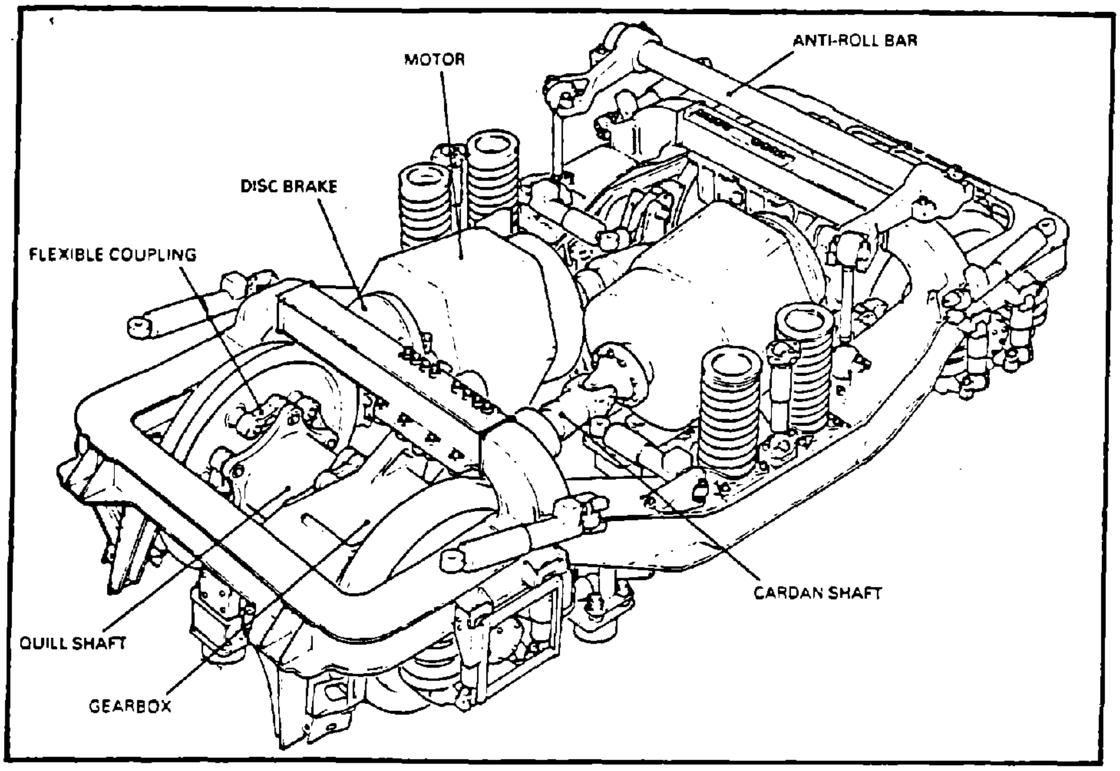
TABLE II.1.9

HSR CHARACTERISTICS - IC225 (CL 91/MK4) (BRITAIN)
(Preliminary)

Service Speed:	125 mph initially; 140 mph potential
Max Test Speed:	N/A, over 160 mph
Consist:	Loco: 8 passenger cars + cab car; about 400-480 seats
Weight and Length:	Loco: weight est. 88 tons, length 61 ft. Passenger car: weight 45 tons, length 77 ft. Cab car: weight 53 tons, length 77 ft. Maximum axleload 44,800 lb.
Carbody Materials:	Locomotive and cars - low alloy high tensile steel
Power:	Bo Bo electric locomotive, 4700 Kw at rail (6300 HP)
Power Supply:	25 kV 50 Hz overhead catenary
Brakes:	Passenger car: 3 discs/axle Locomotive: 1 disc on motor armature shaft + dynamic
Right-of-Way:	Existing British Rail lines with no modification. Enhanced signal capabiliaties necessary for speeds exceeding 125 mph
Routes:	Initially London-Leeds-Edinburgh
Operator:	British Rail
Status:	Locomotives and cars entered service between London-Leeds in late 1989, London-Scotland services start in late 1990
Other:	• High speed cab-car operation • No tilt at present. Car body shape will accommodate 6° of tilt. • Unusual traction motor arrangement. Motors are hung below but supported on the locomotive body. • Locomotives separable and will be used on sleeping car or intermodal trains as well as IC225 services
Builders:	Locomotive: General Electric Co., UK Cars: Metro Cammell

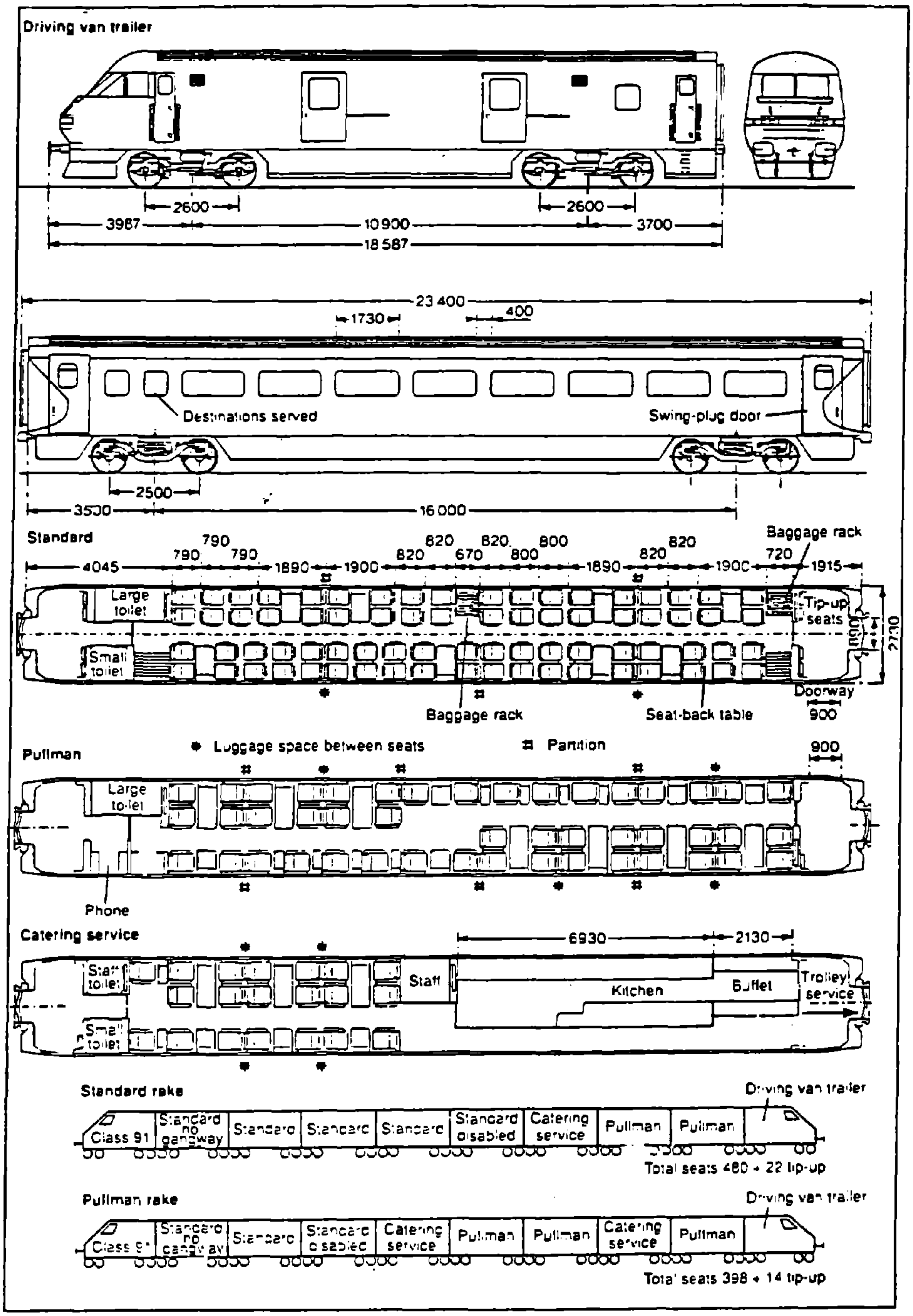
Figure II.1.15 British Rail Class 91 Locomotive Overall Arrangement and Detail of Truck





Sources: Railway Gazette, April 1986, Modern Railways, April 1988

Figure II.1.16 British Rail Mark IV Coach and IC225 Consist



Source: Railway Gazette, May 1988

c) Present Interest in the United States

None. However, GEC (the locomotive builder) has recently merged their railroad equipment interests with Alsthom of France (the TGV builder) and has purchased Metro Cammell, the builder of the Mark IV passenger car. Given Alsthom's interest in the North American market, technical features from IC225 might be applied in future U.S. corridors.

d) Special Features of Interest

There are two features of interest: the high speed cab-car operation and the low track force requirement.

- Cab-cars. BR experienced a disastrous accident in 1984 at Polmont near Glasgow, Scotland, when push-pull train running with cab-car leading hit a cow and derailed at about 90 mph. This car weighed about 38 tons, and had no "cow catcher." As a result of the investigations after this accident, the following requirements were specified for high speed operation with cab-cars, including multiple-unit consists:

  — Minimum axleload 13.84 tons (26880 lb.)

  — Shield or "cow-catcher" capable of sustaining a 67 ton impact.

  — As an additional precaution for the IC225, the cab-car will be a baggage car with no passenger accommodation.

- Low track forces. BR uses the well known "Prudhomme" formula for lateral panel-shift forces on the track and limits on the high and low frequency "P1" and "P2" vertical impact forces.[1] To ensure these limits are not violated, BR specified maximum unsprung mass of 1.88 tons for the powered axle, and body mounted traction motors for the IC225 locomotive. These limits were derived from extensive experimental work with the APT power cars at speeds and cant deficiencies up to the maxima planned for IC225.

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[1] A thorough description of P1 and P2 forces is provided in the paper "Effect of Track and Vehicle Parameters on Wheel/Rail Vertical Forces," H. H. Jenkins, J.E. Stephenson, G. A. Clayton, G. W. Moreland and D. Lyon, Railway Engineering Journal, U.K., January 1974.

II.1.9 Italy - The Pendelino (ETR 450)

a) Background

Like other European railways, Italian State Railways (FS) became interested in tilt body trains in the late 1960s as a way of speeding up services over existing routes without excessive infrastructure investments. As a result, the car builder, Fiat Ferroviaria Savigliano, built first a "test-bed" experimental tilt car, followed in 1975 by a prototype four-car train, the ETR 401. This train was used intermittently in passenger service between 1977 and 1979, and was described and reviewed in the FRA's IPEEP program. The ETR 401 had an active carbody tilt system giving up to 10° of tilt. A similar prototype train was built for Spanish National Railways.

A period of relative inactivity followed until 1985, when FS ordered a total of 130 Pendelino cars, making up ten 11-car trainsets plus four 5 car sets. These were designated ETR 450, and are essentially an updated "production" version of the ETR 401. There has been no change in the concept, but the tilt system and power controls have been modified. The first trains entered passenger service in 1988 between Milan and Rome, operating at 250 km/h over portions of the new "Direttissima" line between Rome and Florence. The Direttissima is described in Section II.1.10, along with the ETR 500 high speed train.

The ETR 450 has been demonstrated in Germany, Switzerland and Austria. There appears to be substantial interest in Germany for use over the heavily curved secondary main lines in that country. A diesel power version using under-floor engines is also planned.

b) General Description

Table II.1.10 gives the technical detail of the ETR 450. Figures II.1.17 and II.1.18 illustrate the overall layout of the car and the truck and body tilt systems.

The ETR 450 is a straightforward multiple-unit train made up of electrically powered married pairs of cars, and unpowered trailer cars. Each married pair has the 4 inner axles powered by a longitudinally mounted electric motor mounted on the underside of the carbody and driving through a longitudinal cardan shaft to an axle-mounted final drive gearbox. Thus, half the axles are powered. One car of the married pair may have an engineer's cab. A pantograph for power collection can be provided, but there is also provision to draw traction power from an adjacent pair to minimize the number of pantographs in contact with the catenary.

TABLE II.1.10

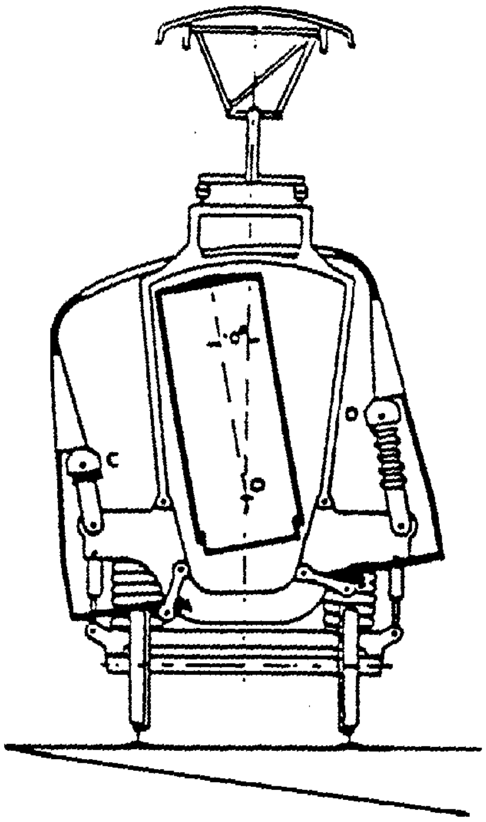
HSR CHARACTERISTICS - ETR 450 PENDELINO (ITALY)

Service Speed:	250 km/h (155 mph) on the new Direttissima line 200 km/h (125 mph) on existing tracks
Max Test Speed:	N/A
Consists:	Variable size MU consists, formed from married pairs; each pair has all 4 inner axles powered by body mounted motors. 1 unpowered food service car is normally added. Likely consist 5 pairs + food car = 11 cars
Weight and Length:	Each pair 103 tons, 168 ft long; 11 car train; 563 tons, approx 430 seats Maximum axleload 27557 lb
Carbody Materials:	Aluminum
Power:	1250 KW/married pair (1676 HP). 5000 kW 6250 KW (8376 HP) for an 11 car train
Power Supply:	3000 V DC overhead catenary
Brakes:	2 discs/axle + tread brake; eddy current track brake shown on some illustrations, but actual status is unknown
Right-of-Way:	Existing FS lines and new Direttissima high speed line
Routes:	Milan - Rome
Operator:	Italian State Railways
Builder:	Fiat Ferroviaria Savigliano
Status:	Passenger service started May 1988; 2 round trips daily Rome-Milan; total of 130 cars delivered or on order
Other:	• Active body tilt system, providing up to 11 in. cant deficiency • Body mounted traction motors to minimize unsprung weight • Diesel powered version planned using under-floor engines

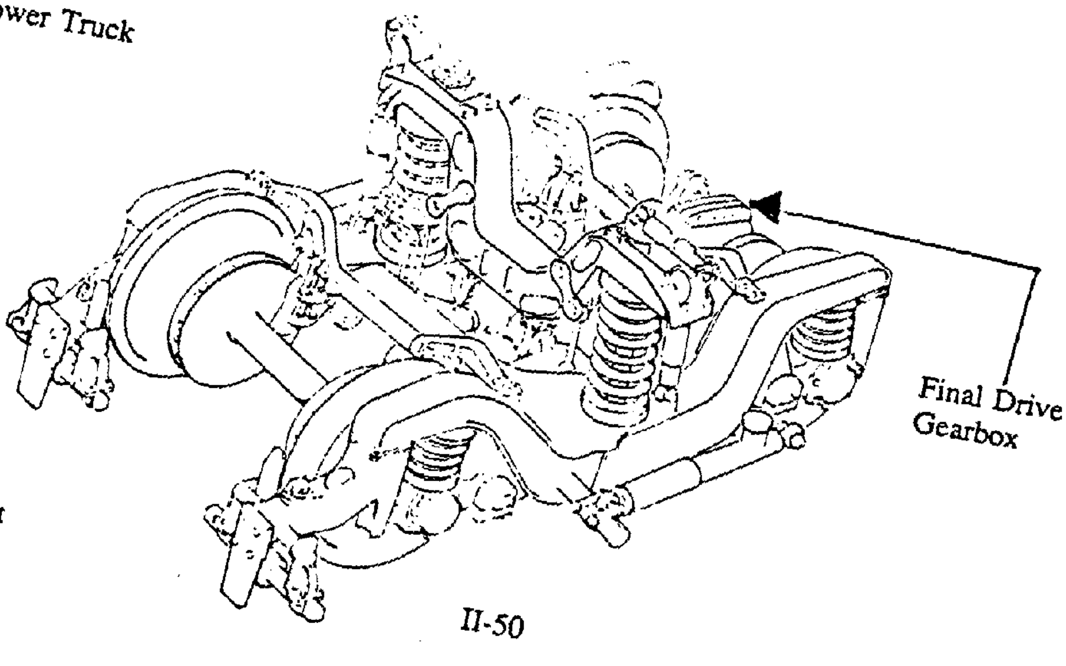
Figure II.1.18 Italian ETR 450

Layout of Truck and Body Tilt System

A. Tilt System



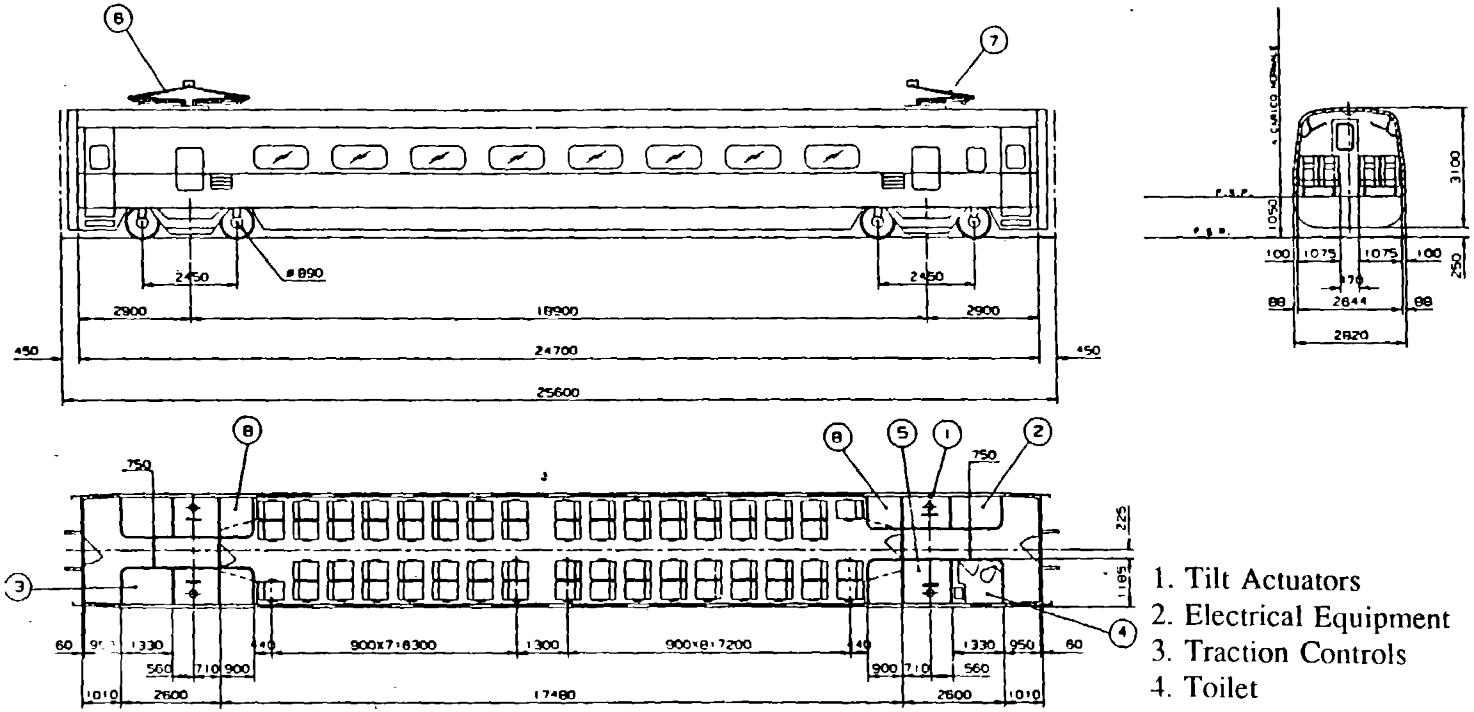
B. Power Truck



Source: Fiat

Figure II.1.17 Italian ETR 450 (Pendolino)

Layout of Typical 2nd Class Car



1. Tilt Actuators
2. Electrical Equipment
3. Traction Controls
4. Toilet
5. HVAC System
6. Pantograph for 3kV DC
7. Pantograph for 15kV 16 2/3 Hz AC
8. Available Space

Source: Fiat

Unpowered trailer cars can be included in the consist. At present, only one such car, the food service car, is included in a 9 or 11 car consist. This consist layout is highly flexible, permitting many variants of train size and power to weight ratio to meet differing service needs. A diesel powered version with the diesel engine directly replacing the under-floor electric motor is planned for service in Germany. The hydraulically-powered active body tilt system is fitted to all vehicles, and illustrated in Figure II.1.18. Maximum tilt angle originally designed was 10-11°. However, we now understand that actual body tilt is limited to 8° (corresponding to 8 inches of cant deficiency), but operation at 10-11 inches of cant deficiency is proposed.

c) Interest in the United States

Fiat have expressed interest in the Coalition of Northeast Governors (CONEG) initiative regarding higher speeds on the Boston-New York portion of the Northeast Corridor.

d) Special Features of Interest

- Very low axleloads and unsprung mass through use of multiple unit concept, with distributed power and body-mounted traction motors.
- Active car-body tilt system in regular passenger services.
- Aluminum carbody construction.
- 250 km/h (155 mph) operation on the new "Direttissima" line, second only to the 270 km/h TGV.

II.1.10 Italy - The ETR 500 High Speed Trains and New Infrastructure

a) Background

The first high speed line in Italy, the Rome-Florence "Direttissima", was conceived in the late 1960s to replace the geographically-difficult existing line. Construction started in about 1970 and portions were opened to service in 1976. Since then, however, progress has been erratic, delayed by construction problems and on/off availability of funding. The line is still not complete, although significant lengths are now open for traffic. This line was built for 250 km/h.

In July 1980 Italian State Railways (FS) announced the "Alta Velocita" (AV) concept. This consists of two new lines — Turin-Venice and Milan-Florence-Rome-Naples — incorporating the Direttissima, and a new high speed train, the ETR 500. The ETR 500 trainset is a concept similar to the German ICE having two end power cars and several non-articulated passenger cars in between. Construction of a prototype power car and one passenger car were completed in April 1988.

b) General Description

Infrastructure

Details of the Direttissima infrastructure are provided in Table II.1.11. The Direttissima is basically a conventional railway using UIC 60 kg/m (121 lb/yd) rail, monoblock concrete ties and conventional ballast. Mixed freight and passenger traffic is operated. This keeps maximum gradients to 0.85%, and requires conventional block signalling alongside a continuous cab signalling and automatic train control system for use by the high speed trains. The high speed line is fully grade separated from highways and other rail lines.

Train

Preliminary details of the ETR 500 are given in Table II.1.12. The planned consist is 2 power cars plus 10 unpowered passenger cars having a total power for traction in each power car of 4000 KW (5361 HP) and 400 KW (536 HP) for auxiliaries and hotel power. Maximum design speed is 300 km/h (187 mph).

c) Present Interest in the United States

None

d) Special Features of Interest

None

TABLE II.1.11

HSR CHARACTERISTICS - DIRETTISSIMA INFRASTRUCTURE

Routes:	Rome - Florence (122 km). In service, additional track under construction, out of total distance of 236 km.
Design Max Speed:	155 mph, higher speeds may be possible
Track:	UIC 60 rail (121 lb/yd;) monoblock concrete tie/elastic fastener, conventional ballast
Maximum Axleload:	44000 lb.
Curves:	Min curvature 3000 m (1.86 mi) Max cant 6.3 in, cant deficiency 5.1 in
Maximum Grade:	0.85%
Lateral Track Spacing:	4.0 m (13.1 ft)
Power Supply:	3 kV DC overhead catenary
Signals:	Conventional block signals plus cab signalling with continuous track-train communication
Other:	• Mixed traffic planned (high speed conventional passenger and freight trains) • Many tunnels/structures, mountainous terrain

TABLE II.1.12

HSR CHARACTERISTICS - ETR 500 (ITALY)

Service Speed:	300 km/h (187 mph) proposed
Max Test Speed:	N/A
Consist:	(Typical) power car + 10 passenger cars + power. About 500 seats
Weight and Length:	(Estimate) Loco: 88 tons, 68 ft. Pass. Car: 44 tons, 86 ft. Maximum axleload 44000 lb.
Carbody Materials:	Passenger cars - aluminum Power cars - aluminum/steel
Power:	4000 kW (5361 HP) per locomotive 8000 kW (10722 HP) per train
Power Supply:	3000 V DC overhead catenary
Brakes:	Loco: tread and rheostatic Car: 3 discs/axle
Right-of-Way:	Existing and new Direttissima and Alta Velocita network
Routes:	N/A
Operator:	Italian State Railways
Status:	Design/construction of prototype in progress. One locomotive and passenger car completed in April 1988
Other:	• No tilt • Body mounted traction motors to minimize unsprung mass and track-train forces
Builders:	Consortium of Italian firms including Fiat, Breda and Ansaldo Trasporti

II.1.11 Japan - The Shinkansen

a) Background

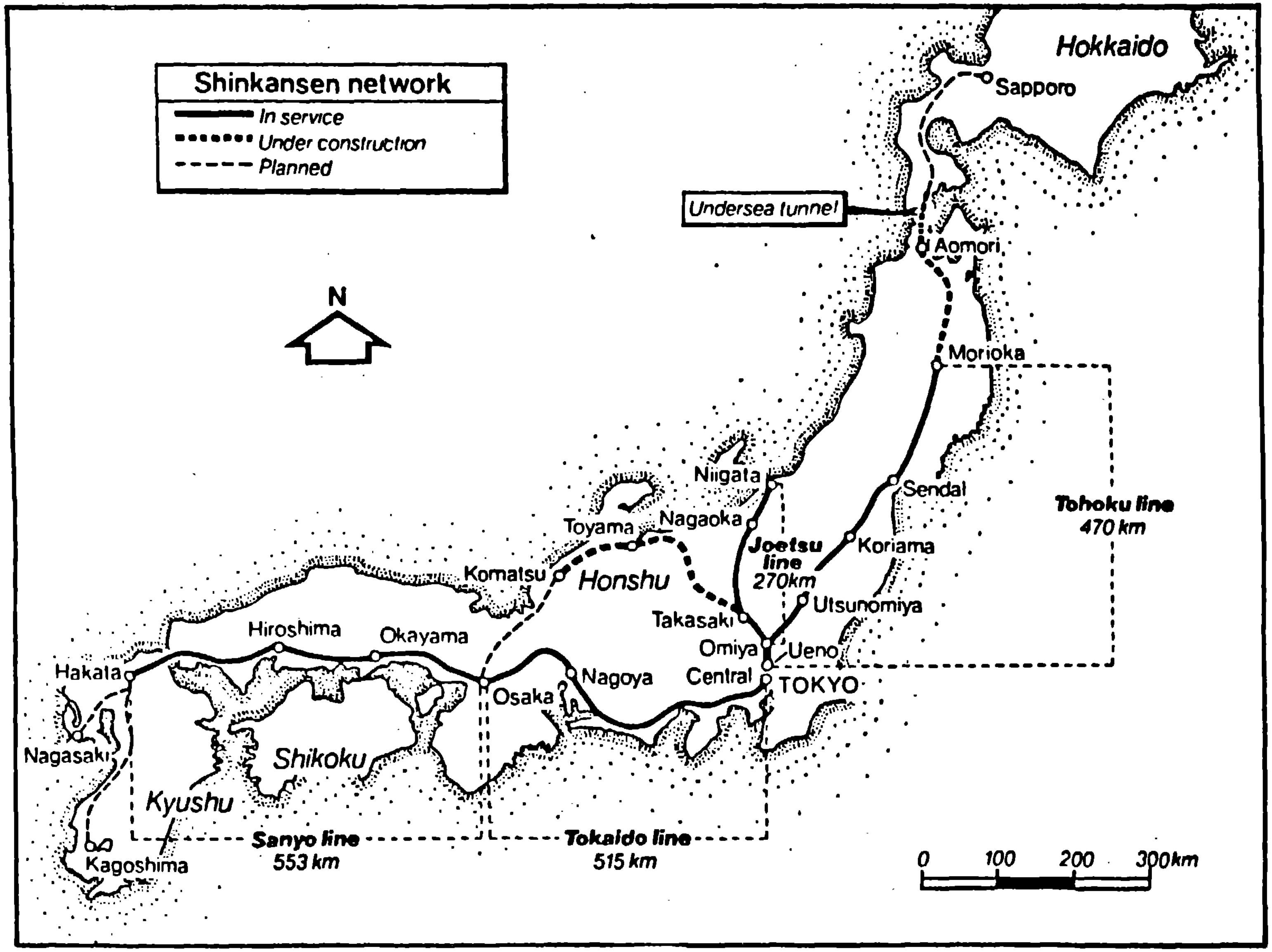
The existing rail line between Tokyo and Osaka (the old Tokaido line) had been considered overloaded as far back as the 1930s. Constructed with narrow gauge (3 ft, 6 in. or 1067mm), and with numerous curves and grade crossings, it had a limited capacity and could only permit speeds of 100 km/h (67 mph). By the 1950s, with the post-war boom gathering pace, something had to be done to add capacity. In response, Japanese National Railways took the bold step of proposing a standard gauge line 515 km (319 miles) long, completely grade separated and segregated from the existing JNR network, but with good interchange facilities at principal stations. The new Tokaido Line project was authorized by the Japanese Government in 1958, and financing was secured from the World Bank. Initially, top speed was to be 260 km/h (161 mph), but this was scaled back to 210 km/h (130 mph) to reduce technical risk. Even this speed was a major advance — the highest regular service speed at the time in Europe was 160 km/h (100 mph) and this by only a few selected trains — 140 km/h or 90 mph was a more common maximum.

JNR embarked on an integrated R&D program to develop rolling stock, train control and track systems for the NTL. The first trains were tested on portions of the new right-of-way in 1962, and the full line was opened to service in 1964. Service speeds were restricted initially, because of track settlement problems, but these were resolved over the first year, and full speeds were attained throughout by October 1985. Like the TGV 17 years later, the NTL was an outstanding technical and commercial success. The achievement was even more impressive given the very short 6-year time span taken to create the whole system.

This success stimulated interest in further lines. The Sanyo line, an eastern extension to the Tokaido line, was commenced in 1967 and completed to Okagama in 1972 and to Hakata in 1975, a total distance of 563 km (348 miles). Finally, construction of the Joetsu and Tohoku lines was authorized in 1971. The map, Figure II.1.19, shows the full Shinkansen network.

Much of the first two Shinkansen lines was built in tunnel or on elevated structures, made necessary by the mountainous terrain and the very dense population. The elevated structures were the source of the principal problem encountered by JNR, the noise and vibration disturbance to the environment of residents near the lines. This is not surprising, since steel structures were used in many locations, and traffic density grew to exceed 200 16-car trains a day (this is equivalent to 30 MGT/year on each track — as much as a U.S. heavy haul freight railroad). Stringent noise and vibration standards were imposed on JNR for both new and existing lines, and there was much local opposition to further new lines. To make matters worse, the petroleum price shock of 1973/74 produced an economic recession and restricted availability of

Figure II.1.19 Map of the Shinkansen Network



Source: Railway Gazette International, September 1986 government funds for line construction. All this, together with civil engineering difficulties, slowed construction of the Tohoku and Joetsu lines. They were finally opened in 1982, having cost substantially more than planned. Partly because of this high cost, and partly because they serve less densely populated regions, the Tohoku and Joetsu lines have been less successful economically than the Tokaido and Sanyo Shinkansen.

After 1982, all plans for major Shinkansen extensions were put on hold pending resolution of Japanese National Railway's (JNR) financial ills. The result of this effort was a total restructuring of JNR. On 1 April, 1987, JNR ceased to exist, being replaced by the Japan Rail (JR) Group, consisting of several regional passenger systems, a freight railway, and a Shinkansen holding company. This last company owns and arranges for the construction of Shinkansen lines, which are then leased to the regional companies to operate.

The technical problems of travelling at speeds greater than 210 km/h were solved in the years following the opening of the new Tokaido line. However, because of the noise and vibration problems, rapidly increasing traffic density and the financial problems, higher speeds were not implemented until 1985 and 1986. Maximum speeds on the Tokaido and Sanyo lines were raised to 220 km/h for the new Series 100 trainsets, and to 240 km/h (149 mph) on portions of the Tohoku and Joetsu lines.

Most recently, the reorganized JR Group has been reconsidering plans for further Shinkansen lines. These include some new infrastructure, dual-gauging of some existing narrow gauge lines to allow low speed extension of direct Shinkansen service at low cost and initiation of the development of a 300 km/h trainset which can meet safety and environmental criteria on the existing Shinkansen lines.

b) General Description

Infrastructure

Each facet of the Shinkansen has evolved as new lines were built. Table II.1.13 gives the basic details about each line.

The first Shinkansen, the new Tokaido line, was built with 100% conventional ballasted track with concrete ties and elastic fasteners. Slab track was extensively used in later construction, which involved more routes in tunnel and on elevated structure. Figure II.1.20 illustrates the slab track and also the sound barrier walls on either side of the track. Apart from easing track construction on elevated structures, slab track was used to reduce maintenance costs under the very heavy Shinkansen traffic (up to 35 MGT annually on each track). 53 kg/m rail was used initially on the Tokaido line, but this has been upgraded to 60 kg/m (121 lb/yard), which is also used on the other lines.

TABLE II.1.13

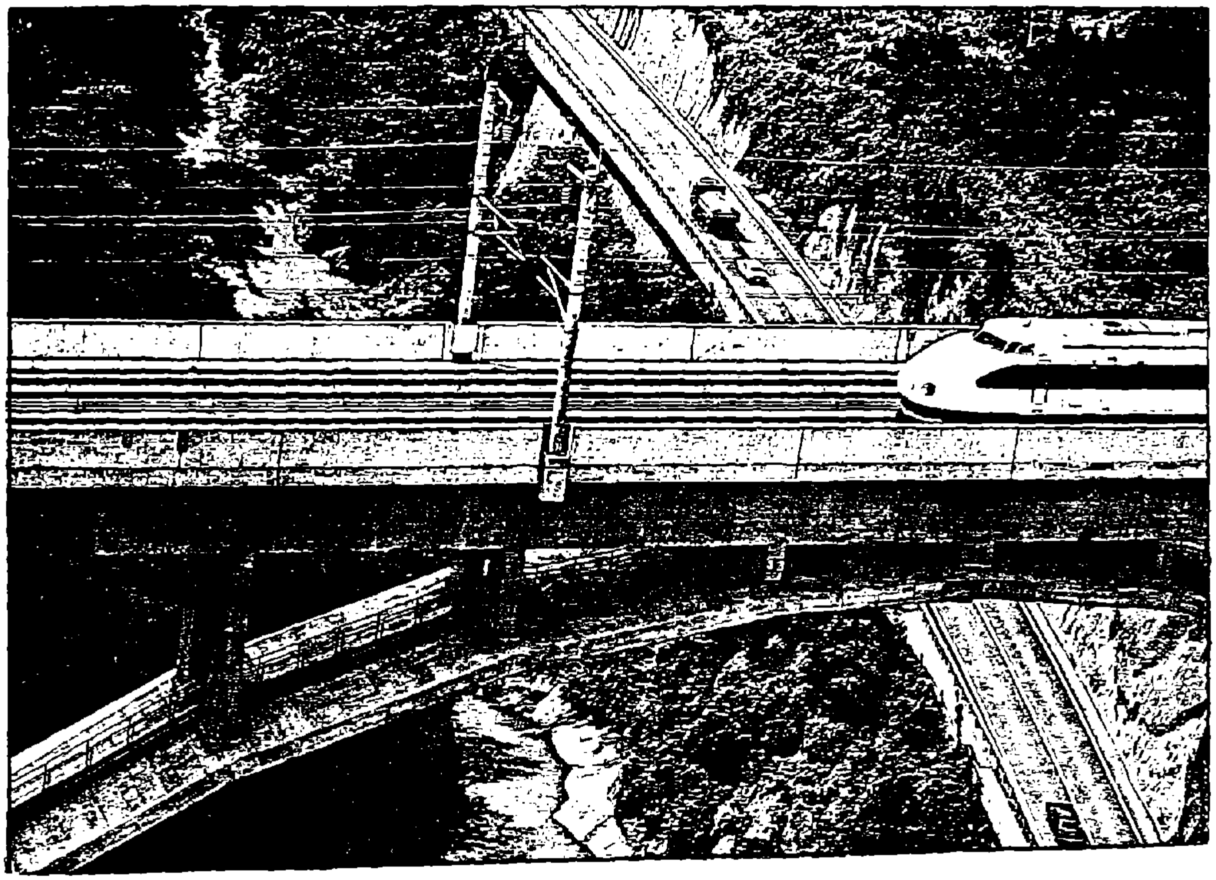
HSR CHARACTERISTICS - SHINKANSEN INFRASTRUCTURE (JAPAN)

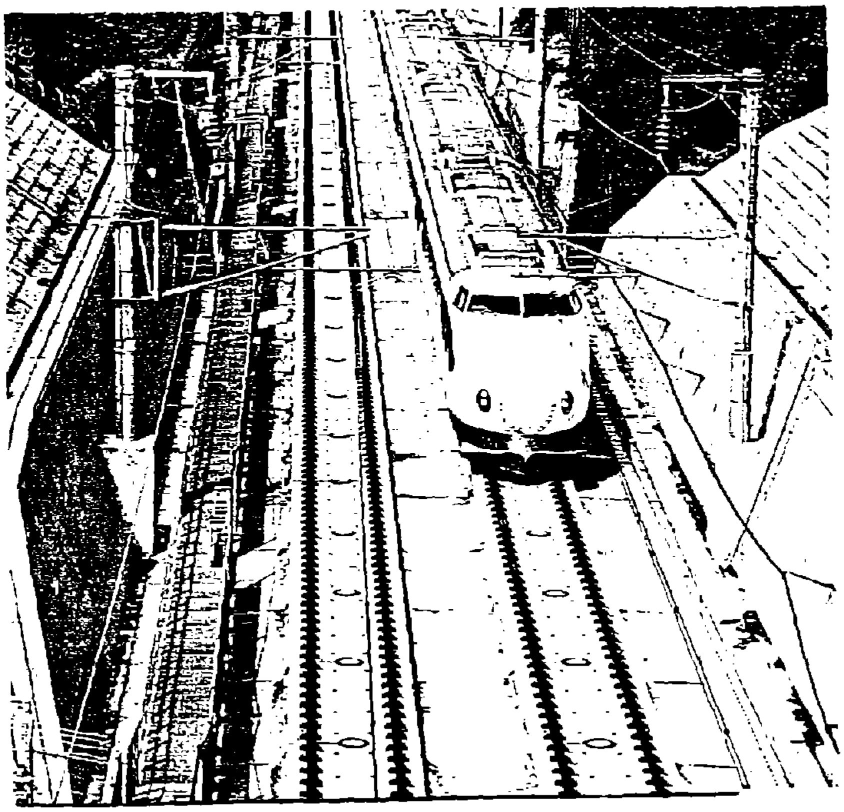
Unless otherwise stated, criteria apply to all four Shinkansen

Routes:	Tokaido:	Tokyo-Osaka	515 km (312 mi) 1964
	Sanyo:	Osaka-Hakata	554 km (343 mi) 1972-75
	Tohoku:	Tokyo-Moriuka	465 km (308 mi) 1982
	Joetsu:	Omiya-Niigata	270 km (167 mi) 1982

Design Max Speed:	260 km/h (161 mph)
Current Speed Operated:	Tokaido and Sanyo: 220 km/h (136 mph) Tohoku and Joetsu: 240 km/h (149 mph)
Track:	Tokaido 53 kg/m (107 lb/yd) rail initially, 60 kg/m (121 lb/yd) now; monoblock concrete ties/elastic fastener/conventional ballast. Continuous concrete slab track with elastic fastener on elevated sections and in tunnels. Percentage slab track: Sanyo 52%, Tohoku 91%, Joetsu 89%.
Maximum Axleload:	Tokaido, Sanyo 35280 lb Tohoku, Joetsu 36382 lb
Curves:	Min curve: Tokaido 2500 m (1.55 mi), others 4000 m (2.5 mi)
Max Cant:	Tokaido 180 mm (7.9 in) Sanyo 110 mm (4.3 in) Others 155 mm (6.1 in)
Maximum Grade:	All 1.5%, except very small amount of 2% on Tokaido
Power Supply:	25 kV, 50 and 60 Hz, AC overhead catenary
Signals:	Cab signals/automatic train control, no lineside signals
Other:	• Numerous tunnels and elevated sections • Exclusive use by Shinkansen trains

Figure II.1.20 Views on the Tohoku and Joetsu Shinkansen Showing Slab Track and Sound Barriers





Source: JR Group

Train Control

A continuous ATC system with automatic override in case of overspeed is used on all Shinkansen lines. Cab signalling only is used; there are no lineside signals. All operations on each line are controlled from a control center in Tokyo. Figure II.1.21 shows a typical control panel, and Figure II.1.22 shows the detail of a portion of the panel. Note the high wind and earthquake detectors. Also supporting the train control is the COMTRAC traffic control system. This replaces manual route setting and aids the dispatcher in responding to train delays, but does not perform "vital" functions.

Rolling Stock

There have been three main series of passenger cars on the Shinkansen:

- Series O, the original design for the Tokaido and Sanyo lines
- Series 200, built for the Joheku and Joetsu lines
- Series 100 introduced in 1985 as replacements for the Series O
- A Series 300 is at the early development stage and is intended to have 300 km/h (187 mph) capability.

Details of the O, 100 and 200 trains are provided in Table II.1.14 and a sketch of a typical car is shown in Figure II.1.23. The design philosophy of the Shinkansen car resembles that of a MU subway or commuter train. All axles are powered with low power electric motors, and all electric power equipment is situated below the car floor or above the roof. Thus all the floor space is available for passenger accommodation. The all-motored arrangement permits the use of rheostatic braking on all axles, minimizing the duty of the friction disc brakes.

Traction motors are mounted on the truck frame with a flexible quill drive to the wheels to minimize unsprung mass.

c) Present Interest in the United States

None in Shinkansen technology. Japanese interests are involved in U.S. high speed rail projects as financiers or construction contractors.

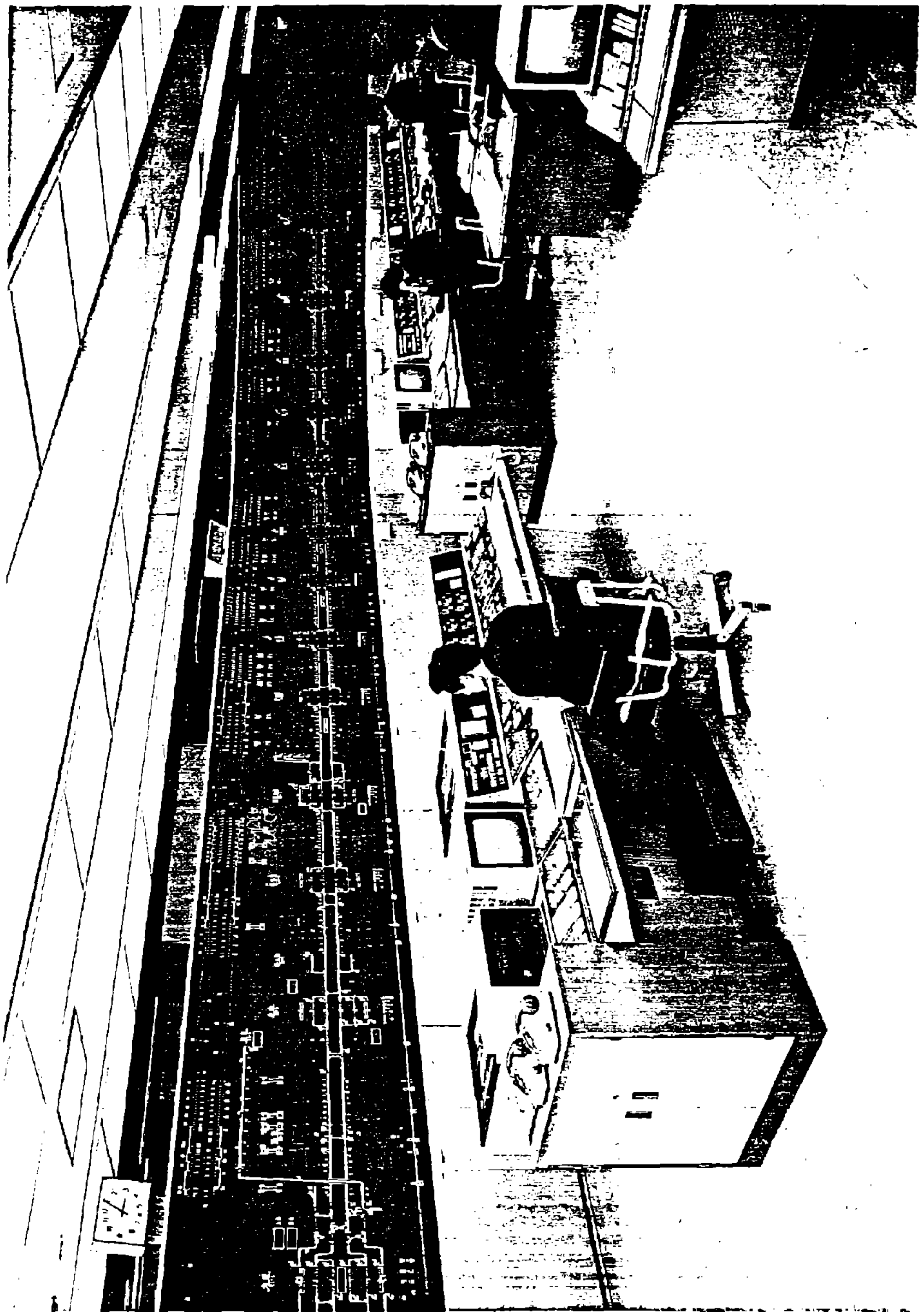


Figure II.1.21 General View of Shinkansen Control Center

Figure II.1.22 Detail of Shinkansen Control Panel

Note high wind and earthquake warning indicators

Indication Panel

TEMPORARY SPEED LIMIT INDICATOR

When train speed is temporarily restricted, an orange lamp lights up for a 70km/h limit, a white lamp in the middle row for 110km/h and a white lamp in the outer row for 160km/h

WIND VELOCITY WARNING INDICATOR:

Lamps show wind velocities exceeding 20m/sec in white, 25m/sec in orange, and 30m/sec in red.

ALTERNATIVE AUTOMATIC ROUTE SETTING INDICATOR

A white lamp shows that routes through this station are being set automatically but not under COMTRAC control

MANUAL ROUTE-SETTING INDICATOR:

Orange lamps show that routes at this station are being set manually by dispatchers at the Center

STATION ROUTE-SETTING INDICATOR

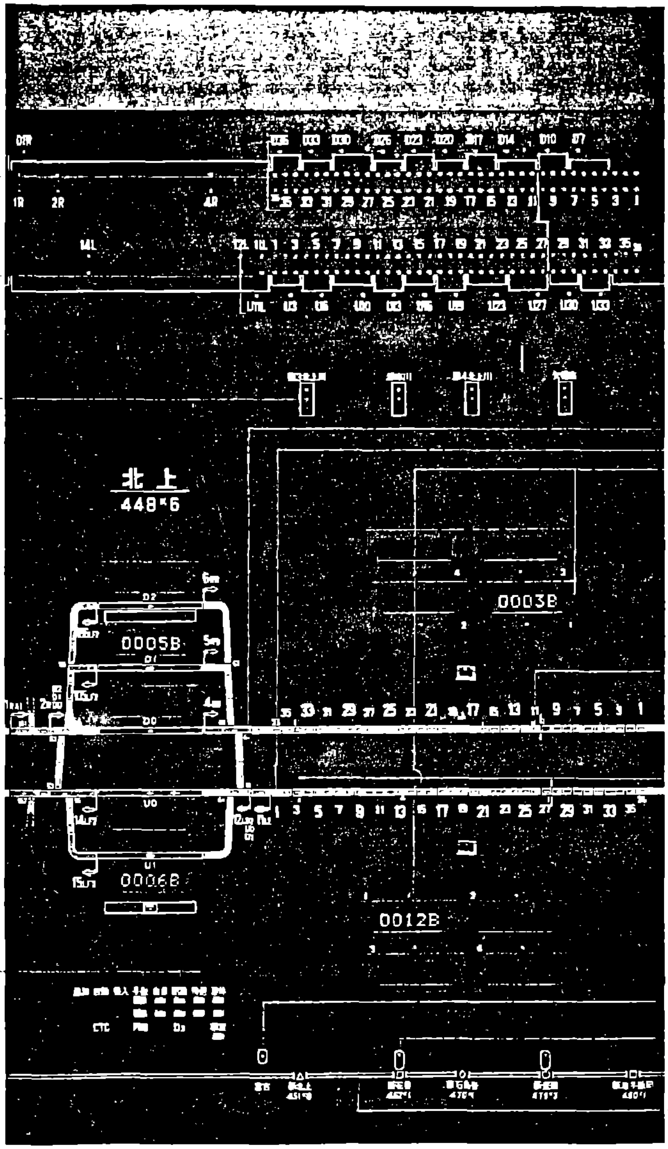
White lamps show that routes are being set at the station, independently of the Center

WAITING TRAIN INDICATOR:

This white lamp shows that a train is waiting at this station for another train to pass under COMTRAC control

TRAIN TRACING INDICATOR:

A red lamp lights up when COMTRAC fails to trace a train.



Tohoku Shinkansen Control Panel (Kitakami area)

ROUTE OPENING INDICATOR:

Green arrow lights when a route is opened for a train to arrive at, depart from or pass through the station

TRAIN POSITION INDICATOR:

Each of the ATC block sections has a white indicator lamp lit when there is a train in that section

TRAIN NUMBER INDICATOR:

The train numbers of trains in the station and between stations are shown here

GROUND COIL INDICATOR:

This white triangle shows the location of a ground coil to check train numbers

POWER FAILURE INDICATOR:

When power supply to the overhead contact wire is cut upon detection of an accident or an earthquake triangular red lamps light up and show the section

COASTAL EARTHQUAKE DETECTION INDICATOR:

A white lamp lights when sensors installed on the Pacific coast detect an earthquake 40 gals or over in intensity

EARTHQUAKE WARNING INDICATOR:

When earthquake sensors at substations along the line detect an earthquake of 40 gals or more, an orange lamp lights up. A red lamp lights for over 80 gals

FEEDER SECTIONING INDICATORS:

The mark indicates a feeder substation, the a feeder sectioning post, the an auxiliary feeder sectioning post and the an AT post

TABLE II.1.14

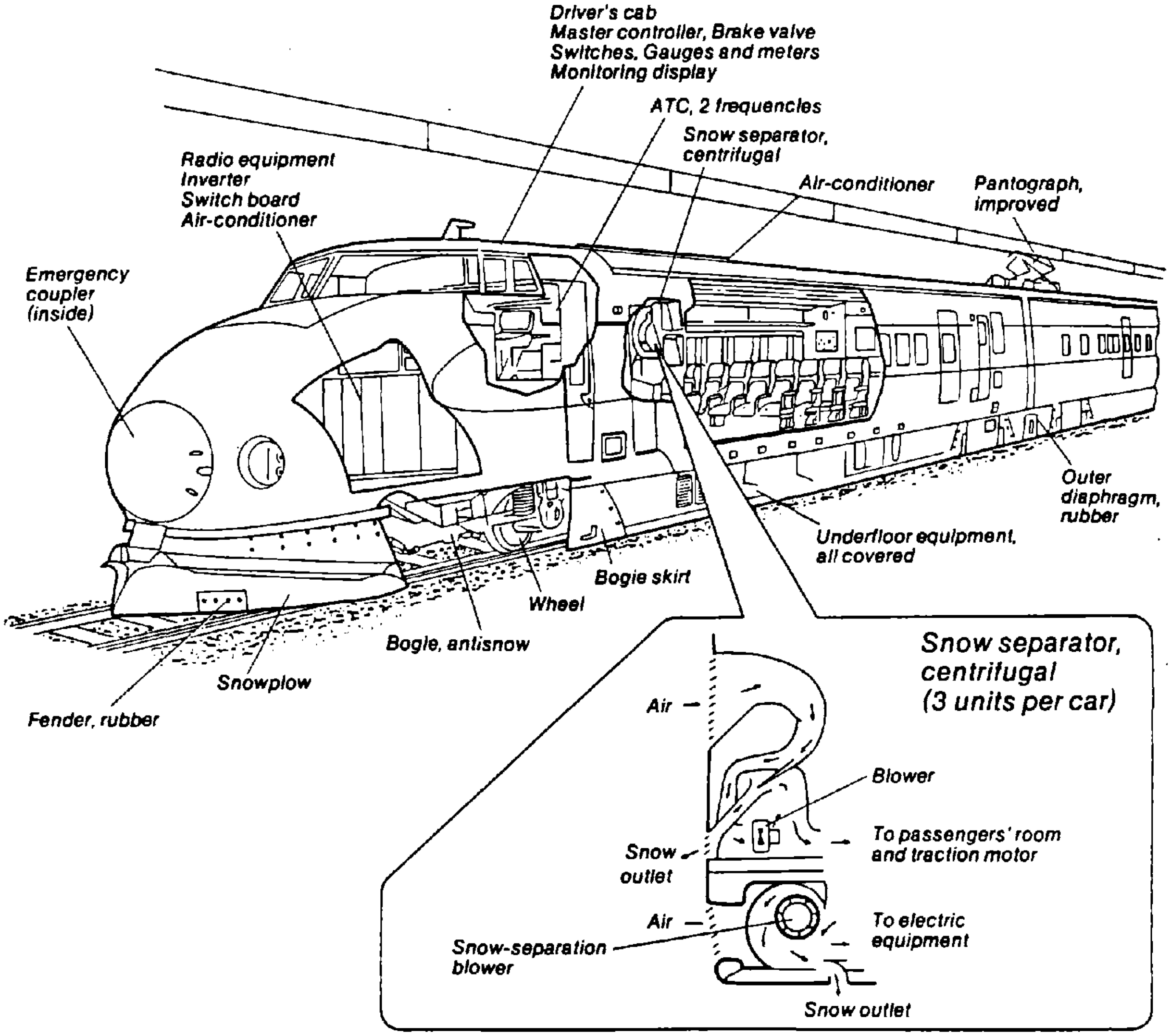
HSR CHARACTERISTICS - SHINKANSEN ROLLING STOCK (JAPAN)

Service Speed:	210 km/h (130 mph) (Tokaido and Sanyo) Type "O" 220 km/h (136 mph) (Tokaido and Sanyo) Type 100 240 km/h (149 mph) (Tohoku and Joetsu) Type 200
Max Test Speed:	320 km/h (198 mph) (December 1979); (Type 961, predecessor of Types 100 and 200 production trains)
Consists:	Fixed MU consists, all axles powered 140 trains Type O: 16 cars, approx 1300 seats Type 100 16 cars (12 powered), approx. 1300 seats, in production 36 trains Type 200: 12 cars, 885 seats
Weight and Length:	Type O each car: 64 tons, 82 ft, train: 1024 tons Type 100 each car: 68 tons, 82 ft, train: 927 tons Type 200 each car: 68 tons, 82 ft, train: 820 tons Maximum axleload 33516 lb
Carbody Materials:	Steel
Power:	Type O: 11840 KW (15871 HP) Types 100 and 200: 11040 KW (14799 HP)
Power Supply:	25 kV 50 and 60 Hz AC overhead catenary
Brakes:	Wheel-mounted disc brakes, dynamic rheostatic brake (all train types)
Right-of-Way:	New right-of-way reserved for exclusive use of Shinkansen trains
Routes:	See text
Operator:	Regional operating companies in the JR Group
Status:	Type O in service since 1964; Type 200 in service since 1982. Type 100 in service since 1986
Other:	• No tilt • Doubledeck used in two cars in the Type 100 consist to increase capacity
Builders:	Various

Figure II.1.23 Type 200 Shinkansen Railcar For Tohoku and Joetsu Shinkansen

Snow protection is an important feature of this railcar type

Tohoku and Joetsu Shinkansen Electric Railcar, Type-200



d) Special Features of Interest

- Automatic train control and route-setting systems able to handle very high traffic densities.
- Noise and vibration suppression measures.
- Snow, earthquake and high wind protection measures.
- Longest experience of high speed operation.
- Operation with very high traffic levels.

II.1.12 Spain - TALGO

a) Background

The TALGO train had its origin in Spanish and American developments in the 1940s. The principals of a lightweight aluminum articulated consist on single-axle trucks with a low center of gravity established then have been retained to the present day.

The present generation of the TALGO, the TALGO Pendular, was developed in the late 1970s and first put into service in Spain in 1980. Since 1980, several hundred Talgo pendular cars have been built for service within Spain, and into France using adjustable gauge wheelsets. A set of six of these cars participated in the CONEG demonstrations of tilt technology between Boston and New York in May 1988.

The TALGO is a passenger car only. There is no associated locomotive or power car, track system or train control system. However, Spanish National Railways operates a small fleet of Krauss-Maffei (German) design 4000 hp diesel hydraulic locomotives, which are exclusively used on Talgo services.

b) General Description

Details of the Talgo train are given in Table II.1.15, and illustrated in Figure II.1.24. In addition to the original design features, the Talgo Pendular embodies the following:

- Suspension near the roof of the car (well above the center of gravity) to produce passive tilt on curves. This tilt is allowed to operate when speed is above 70 km/h (43 mph) and curvature is below 1500 m (5000 ft).

- Design speed of 200 km/h (125 mph).

- Use of long welded aluminum extrusions to construct the body.

- Various incremental improvements in brakes and comfort features.

- Use of air springs instead of coil springs.

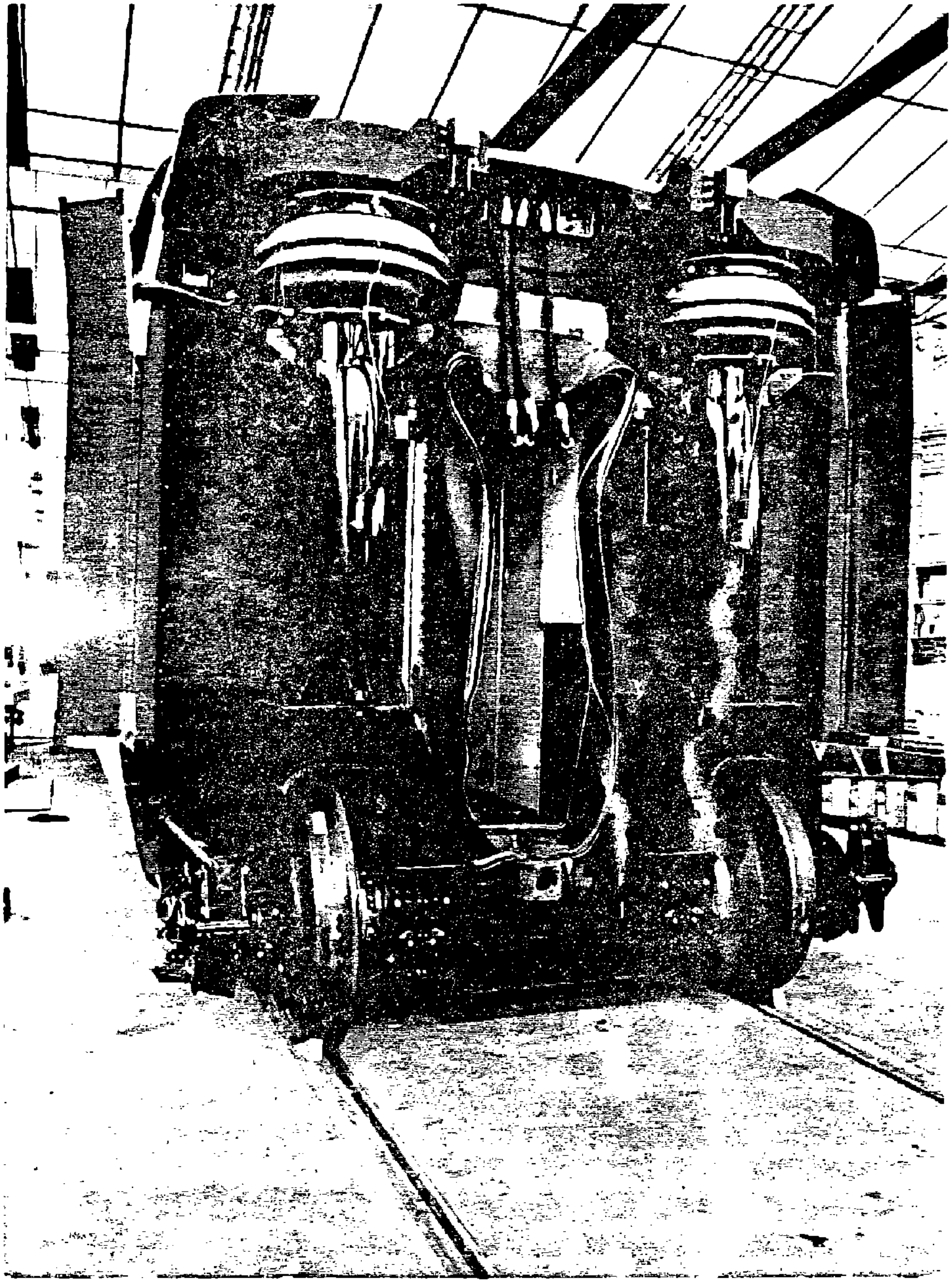
- Provision of a hotel-power generator in an end car. Spanish National Railways has not standardized on a head end power systems, and this is needed to ensure that Talgo trainsets can be hauled by any Spanish or French locomotive.

TABLE II.1.15

HSR CHARACTERISTICS - TALGO/SPAIN

Service Speed:	Design - 125 mph; current operations 100 mph
Max Test Speed:	143 mph. Higher speeds were achieved in trials in Germany in 1989.
Consist:	Unpowered articulated trainsets with single-axle trucks: end service car (with generator set) + 10 intermediate cars + end car with passenger accommodation is typical; approx 375 seats, 180 tons
Weight and Length:	Intermediate car: 14.5 tons (typical), 43 ft. long End car 18.2 - 21 tons, 40 ft. long
Carbody Materials:	Long aluminum extrusions
Power:	Not applicable
Brakes:	Hydraulic actuation, pneumatic control of wheel-mounted disc brakes
Right-of-Way:	Existing track in Spain and France
Routes:	Main routes from Madrid to principal Spanish cities, plus Madrid-Paris and Madrid-Geneva
Operator:	Spanish National Railways (RENFE)
Status:	About 450 individual cars in service on Spanish National Railways and on international services to France. Various configurations of coach, sleeping and food service cars have been built.
Other:	• Passive tilt up to 5 degrees • Variable gauge wheelsets used on international services between Spain and France • Special low-profile diesel-hydraulic locos used to haul Talgos on non-electrified routes in Spain. Conventional electric locomotives are used in electrified territory in France and Spain.
Builder:	Patentes Talgo SA

Figure II.1.24 View of the TALGO Pendular Suspension and Single Axle Truck



Source: Patentes Talgo S.A.

The maximum tilt of the Talgo Pendular is approximately 5° (corresponding to 5 inches of cant deficiency on standard gauge track). Maximum cant deficiency is in the range of 8-9 inches, the actual figure depending on the safety criteria and clearances used on the specific route.

c) Interest in the United States

The TALGO Company in association with Spanish National Railways (RENFE) shipped a six-car TALGO train to the U.S. in 1988 to participate in the trials of tilt technology organized by the Coalition of Northeast Governors (CONEG). During these tests, the TALGO negotiated curves at up to approximately 8 inches of cant deficiency within safety and comfort criteria laid down by the FRA Office of Safety and Amtrak. Maximum speed during these tests was 110 mph.

TALGO/RENFE remain interested in potential application in the U.S., especially the Boston-NY segment of the Northeast Corridor and other routes where numerous curves mean that significant benefits can be realized from the use of tilt technology.

d) Special Features of Interest

The TALGO has many totally unique features:

- Articulated consist employing single axle trucks at the articulation point. The single axles are mechanically steered to a radial position.
- Independently rotating wheels with no solid axle.
- Passive tilt achieved by pneumatically interconnecting air springs placed on top of tall columns mounted on the wheelsets. This tilt is allowed to function when speeds exceed 70 km/h and on curve radius less than 1500 m.
- Hydraulically actuated service brakes.
- Very low floor height and center of gravity. Floor is 650 mm (approximately 26 inches) above rail level compared with typically 45-50 inches on conventional U.S. passenger cars.

II.1.13 Sweden — The X2

a) Background

The X2 originated in 1970 with a program of theoretical research into tilt trains and radial trucks. Following this, an existing electric multiple-unit train was fitted with a series of experimental trucks and tilt systems (the X15). Trials with this train were carried out between 1975 and 1982. These trials included extensive tests of passenger reaction to tilting, leading to the conclusion the partial tilt, not fully compensating for cant deficiency is preferable to full compensation. The final specification called for 80% compensation of cant deficiency (as measured on the truck frame) up to a maximum of 6.5°. Maximum operating cant deficiency is approximately 9 inches and tilt rate 4°/sec.

The present configuration of the train evolved during a period of four years following completion of the test program. At first, Swedish State Railways (SJ) specified an electric MU train with a maximum axleload of 15 tonnes (33.075 lb). No supplier could meet this requirement and provide adequate power for the planned operational speeds. Further iterations led to the present configuration of a non-tilting power car operating a 5-car set of tilting passenger cars "push-pull" fashion with a cab car.

b) General Description

The X2 is a 200 km/h (125 mph) train with active carbody tilt, designed to operate on the existing tracks of Swedish State Railways (SJ). The designer and builders are Asea Brown Boveri and the Swedish car builder Kalmer Verkstad. Details of the train are provided in Table II.1.16. The layout of the train and a schematic of the carbody tilt arrangements are shown in Figure II.1.25. A 6-vehicle consist is used with four passenger cars situated between a 4-axle power car and a cab-car. The power car produces 3260 KW (4370) HP at rail from four independently controlled 3-phase AC traction motors.

The overall objective of the X2 is to achieve the highest performance possible on existing tracks of SJ. Traffic densities are low and extensive investment in new or upgraded right-of-way cannot be justified. This requirement dictated most of the significant design features of the train.

- The carbody tilt, to obtain higher speed on the frequent curves.
- Low track forces. Much Swedish rail is of low weight (50 kg/m or about 100 lb/yd) making this especially important. The principal design requirements are:
  - Maximum L/V at individual wheel — 0.6 desirable; 0.8 max acceptable

TABLE II.1.16

HSR CHARACTERISTICS - X2 (SWEDEN)

Service Speed: 200 km/h (125 mph)

Max Test Speed: N/A. Predecessor experimental train (the X15) reached 238 km/h (147 mph).

Consist: Power car + 4 passenger cars + cab car, 298 seats (planned)

Weight and Length: Power cars: weight 77 tons, length 57 ft.
Passenger cars: weight 55 tons, length 80 ft.
Complete train 352 tons
Maximum axleload (power car) 172 kN (38660 lb)

Carbody Materials: Power and passenger cars: stainless steel

Power: Bo Bo power car 3260 Kw at rail (4370 HP), 3-phase asynchronous AC motors

Power Supply: 15 kV, 16 2/3 Hz AC catenary

Brakes: Power car: regenerative + disc + tread
Passenger car: axle-mounted disc

Right-of-Way: Existing, unmodified Swedish State Railways routes

Routes: (Planned) Stockholm to Goteborg
Stockholm to Malmo

Operator: Swedish State Railways (SJ)
Currently in trials (end 1989)

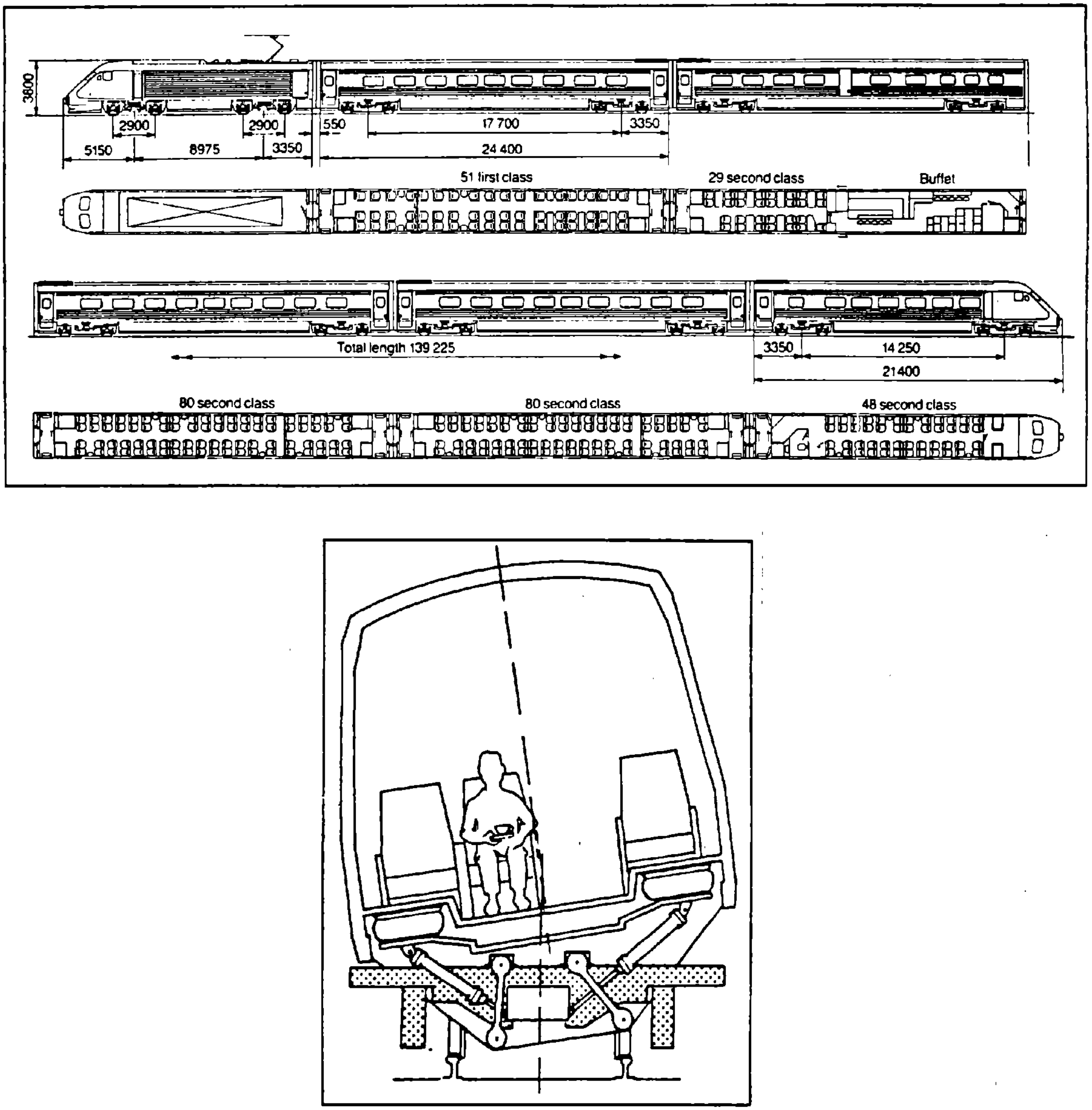
Status: Orders placed for 20 trains to be delivered in 1989

Other:

- Active tilt system provides 6.5° tilt
- Steering trucks are used

Builder: Asea Brown Boveri and Kalmar Verkstad

Figure II.1.25 The ASEA/Swedish State Railways X2 Tilt Train and Schematic of Tilt System



Source: Railway Gazette International, January 1987

— Lateral track panel shift force from an individual axle must not exceed 0.85 (10 + Q/3). the units are kN (= 255 lb), and Q is axleload. This is the well known Prudhomme track panel shift formula widely used by European railways.

— Originally maximum axleload was limited to 150 kN (33750 lb). This, however, proved impractical for a power car and had to be relaxed to 172 kN. Traction motors are mounted on the truck frame and a degree of radial steering is obtained by using soft primary longitudinal suspensions on all trucks to meet lateral force requirements.

In addition to the high speed train, SJ is installing an ATC system on all principal lines (not just the ones where the X2 train will be operated) as a primary safety measure.

c) Present interest in the United States

ASEA Brown Boveri is a partner in the consortium which has been awarded the franchise to operate the Miami-Orlando-Tampa corridor in Florida. However, the proposed train for this service will utilize ABB's electric traction technology with non-tilting rather than tilting cars. The Florida trains will also be built to all applicable U.S. standards, and the consists will have a power car at both ends instead of the X2's push-pull configuration.

The tilting cars are also a potential candidate for improved service between Boston and New York as advocated by CONEG. In view of their construction schedule, they could not be demonstrated with the other equipment during 1988.

d) Special features of interest

- The only train to propose utilization of unpowered cab-cars with passenger accommodations at 125 mph. British Rail's London-Edinburgh operations use a baggage/cab car. Maximum cab-car speeds elsewhere are 90-100 mph.
- Use of partial tilt to compensate for cant deficiency. This approach appears to have significant advantages:
    - — Comfort appears not to be compromised and may be improved because of lower rotational velocity and acceleration in spirals.
    - — Tilt system power requirements and movement amplitudes are reduced. This may reduce transient loads on track.
    - – Clearance problems slightly reduced.
- Use of steering trucks to minimize wheel and rail wear on heavily curved Swedish routes.

II.1.14 Switzerland - Bahn 2000

a) Background

Swiss Federal Railways (SBB) have traditionally focused on service frequency and high reliability rather than high speed. This was because of the mountainous terrain over much of the country, and the relatively short distances between the major cities north of the Alps (Zurich, Bern, Geneva, Basle). Maximum speeds are currently 120 km/h and 140 km/h (74 and 87 mph). 160 km/h (100 mph) is permitted on a trial basis at one location only.

Following this philosophy, SBB introduced a comprehensive regular interval service in 1982 called the Taktfahrplan (Rhythm Timetable). Hourly trains were provided between each city point, with convenient connections between services at designated "nodal" stations. Convenient connections to similar services in Germany and TGV services to Paris were also developed. The success of this development led directly to "Bahn 2000." This further develops the "Taktfahrplan" principal by speeding up services between the nodal stations so that all journeys take a little under one hour. This greatly facilitates design of the timetable to provide the maximum number of connection possibilities at the nodal station, as well as providing useful journey time reduction. Service frequency on principal main lines is to be further increased to every 30 minutes.

"Bahn 2000" plans were first introduced to the public in 1985. A national referendum approved funding for the project at the end of 1987, kicking off equipment procurement and infrastructure improvement activities. Bahn 2000 requires the following developments:

- Push-pull trainsets able to operate at 200 km/h (125 mph) in regular services. Maximum design speed will be 230 km/h (143 mph).
- Construction of approximately 120 km (74 miles) of new 200 km/h alignment and local upgrading on other lines.
- Implementation of new signalling and ATC systems.

The whole project is planned to be complete by the year 2000.

Initial orders for locomotives and cars were placed in 1988 for delivery in 1991.

b) General Description

This general description applies to the proposed rolling stock and signal system only. There are no details yet available of the new lines. Also many of the details are provisional: both the locomotive and passenger car are currently in design and manufacture.

Bahn 2000 trains are planned to consist of a 6100 Kw (8177 HP) locomotive coupled to 8 cars, one of which will be a cab-car. Passive tilt is said to be under consideration. Provisional data about these trains is given in Table II.1.17, but is subject to change as the project develops.

The enhanced signalling system has two aspects:

- The lineside display at each signal will be modified to indicate the maximum speed in km/h at which a train may pass the next signal. For example, 16 displayed means that the next signal may be passed at 160 km/h. This will not include speed limits applicable to a specific train type.

- An "intermittent" cab signalling and ATC system. The lineside conventional signal aspects and speed indication is displayed in the cab. If a speed reduction is required, an on-board control system compares actual train speed with the computed braking speed/distances curve needed to achieve the required speed reduction and overrides the engineer if actual speed exceeds this. An otherwise similar ATC system with continuous communication will also be tested. This will be required for speeds exceeding 160 km/h (100 mph).

c) Interest in the United States

None at present. However, one of the principal engineering firms contributing to the project is Asea Brown Boveri, which has interests in U.S. high speed rail projects. Thus, some aspects of this technology might find applications in the U.S.

d) Special features of interest

- Mention of passive tilt as a possible feature of the passenger cars in one of our sources.

- 200 km/h (125 mph) use proposed of cab-cars occupied by passengers (as with the Swedish proposals).

TABLE II.1.17

HSR CHARACTERISTICS - BAHN 2000 (SWITZERLAND)
(Preliminary)

Service Speed:	200 km/h (125 mph). Max design speed 230 km/h (143 mph)
Max Test Speed:	N/A - not yet built.
Consist:	Locomotive + 7 passenger cars + cab-car
Weight and Length:	Locomotive 88 tons, approx. 54. ft. Passenger car 46 tons, 86 ft. Max axleload 44080 lb.
Carbody Materials:	Passenger car - alumimum likely Locomotive - not known
Power:	6100 kW maximum (8177 HP) 5000 kW one-hour (6702 HP) 3-phase asynchronous traction motors
Power Supply:	Overhead catenary 15 kV AC, 16 2/3 Hz
Brakes:	Locomotive: regenerative + friction Cars: no information
Right-of-Way:	Existing Swiss mainlines + new 125 mph lines
Routes:	Between all principal cities (Zurich, Bern, Basle, Geneva, etc.)
Operator:	Swiss Federal Railways (SBB)
Status:	Ordered, in design and manufacture, delivery of first vehicles 1991
Other:	• Push-pull operation at 125 mph with cab-cars • Possible use of passive tilt
Builders:	Asea Brown Boveri, Siemens, Swiss Loco and Machine, Schindler (cars) and possibly others

II.2 ANALYSIS OF INDIVIDUAL SAFETY ISSUES

II.2.1 Introduction

The process for developing a list of individual safety issues for study was described in Chapter I.2. This process resulted in the detailed lists provided in Tables II.2.1 through II.2.12. Each table is concerned with a major safety issue. For each issue the table provides a list of sub-issues which are typically the subject of a set of regulations, standards and practices, the kind of information needed from these sources, and the types of accident which will be affected by the issue.

The remainder of this section of the report is devoted to a discussion and analysis of each individual issue or group of related issues. Each discussion includes the following material:

a) FRA regulations applicable to the issue, if any.

b) Other U.S. rules, standards and practices, such as those of the Association of American Railroads, American Railway Engineering Association and other standards-setting organizations.

c) Foreign standards and practices

- International codes, such as those of UIC and ISO
- National standards, such as DIN, British Standard, etc.
- Standards and practices applied to the high speed train systems of primary interest
    - — TGV - France
    - — Shinkansen - Japan
    - — ICE - W. Germany

Practices and standards used on other systems will also be mentioned where these seem to be relevant.

d) Commentary. The commentary will be concerned with answers to the following questions:

- What are the key differences between U.S. and foreign approaches to each safety issue (comparability)?
- What are the key differences between the U.S. and foreign operating environment that might bear on each safety issue?

TABLE II.2.1

HSR SAFETY ISSUES — 1 — PRIMARY STRUCTURAL CRASHWORTHINESS

Issue	Sub-Issues	Information Needed Regarding Regulations, Standards and Practices	Relationship to Fault Tree (Types of Accidents/ Incidents or Situations Affected)
<u>Car and Locomotive Structural Integrity and Crashworthiness:</u> Ability of car and locomotive structures to withstand normal service and emergency (collision, derailment) loadings, and to provide adequate protection for occupants	• Buff strength • Collisions posts • Couplers • Anti-climb features • Truck body connection • Structural integrity of engineer's cab	• Buff strength criteria • Collision post strength • Coupler strength and energy absorption • Truck-body connection strength • Engineer's cab protective structure – locomotives – cab-cars • Specific rules for cab-car operation with cab leading • New equipment qualification tests (e.g., squeeze test)	• Reduces risk that occupants of vehicles involved in a high-energy collision or derailment will become casualties

TABLE II.2.2

HSR SAFETY ISSUES — 2A — CONSTRUCTION OF TRUCKS AND BRAKES

Issue	Sub-Issues	Information Needed Regarding Regulations, Standards and Practices	Relationship to Fault Tree (Types of Accidents/ Incidents or Situations Affected)
<u>Truck and Braking System Integrity</u> Ensuring that trucks, especially wheel sets, can withstand the normal operating environment, and that the brake system operates in a proper fail-safe fashion	• Wheel/axle/bearing integrity • Truck structure integrity • Wheel load variation • Ensuring acceptable stopping distance under all operating conditions, relative to signal standards • Avoidance of damage to wheels, brake discs, etc. • Potential failure modes • Adequacy of parking brake • Adequacy of non-conventional brake systems, e.g., hydraulic activation, eddy-current brake)	• Wheel/axle/bearings – dimensions – materials – manufacturing and assembly requirements • Truck structural design criteria • General description of braking system • Brake performance – normal service – emergency – failure modes (e.g., reverting from electric to pneumatic control) – spin/slide protection system • Parking brake design and performance • New design test and qualification procedures	• Reduces risk of derailment caused by equipment defects, such as brake, truck or wheelset failures

TABLE II.2.3

HSR SAFETY ISSUES — 2B — TRACK TRAIN INTERACTION

Issue	Sub-Issues	Information Needed Regarding Regulations, Standards and Practices	Relationship to Fault Tree (Types of Accidents/ Incidents or Situations Affected)
Track Train Interaction Avoiding unsafe wheel-rail forces or force ratios which could damage track or cause derailment or overturning	• Flange-climbing derailments • Track panel shift • Rail rollover • Overturning of car • Safety acceptability of high cant deficiency curving, with or without tilt • Standing and walking passenger safety • Active/passive tilt system integrity	• Acceptability criteria used for – Lateral force at individual wheel, wheelset or truck – L/V force ratios – Max. wheel unloading on warped track – Max. acceleration in passenger space, including those applicable to standing & walking passengers • Maximum cant & cant deficiency permitted as a function of speed & curvature • Precautions against truck hunting • New design qualification test procedures • Tilt system safety features	• Reduces risk of derailments – Overturning – Flange-climbing • Track failures due to excessive wheel-rail forces • Tilt system malfunctions

<u>TABLE II.2.4</u>

HSR SAFETY ISSUES — 2C — ROLLING STOCK MAINTENANCE AND INSPECTION

Issue	Sub-Issues	Information Needed Regarding Regulations, Standards and Practices	Relationship to Fault Tree (Types of Accidents/ Incidents or Situations Affected)
Maintenance and inspection procedures needed to keep vehicles in safe operating condition	• Wheels/axles/bearings	• Frequency/nature of inspection – Acceptability criteria – Wheel wear limits – Use of line-side detectors	• Reduces risk of derailments or collisions due to brake or truck malfunctions arising out of defective components or systems
	• Dynamic stability	• Monitoring devices used – Acceptability criteria	
	• Brakes	• Frequency/nature of inspection – Acceptability criteria	
	• Tilt systems (if fitted)	• Frequency/nature of inspection – Acceptability criteria	
	• Maintenance staff training, qualification procedures	• Staff training and qualification procedures • Quality control in maintenance work	

TABLE II.2.5

HSR SAFETY ISSUES — 3 — NON-STRUCTURAL VEHICLE SAFETY AND CRASHWORTHINESS

Issue	Sub-Issues	Information Needed Regarding Regulations, Standards and Practices	Relationship to Fault Tree (Types of Accidents/ Incidents or Situations Affected)
Non-structural rolling stock safety and crashworthiness Adequacy of non-structural rail vehicle features to protect passenger and train crew from hazards	• Fire precautions • Doors • Vehicle interior crashworthiness • Baggage restraint • Glazing and windows • Emergency access and escape • Air pressure changes (e.g., on tunnel entry) • FRA safety appliances • FRA flammability and smoke-emission standards	• Fire precautions – Warning devices – Firefighting equipment – Flammability standards • Doors – Step heights, etc. – Locking • Glazing standards • Interior crashworthiness – Seat/structure fastening strength – Protection of hard surfaces – Baggage restraint • Air pressure change limits • Emergency access and escape provision • Emergency lighting • Emergency response plans	• Reduces risk of casualties to occupants of colliding or derailed trains • Reduces risk of casualties to passengers boarding or alighting from trains • Reduces risk of casualties to railroad employees working around moving vehicles (coupling switching, etc.) • Reduces casualties due to on-board fires

TABLE II.2.6

HSR SAFETY ISSUES — 4 — TRACK STRUCTURE INTEGRITY

Issue	Sub-Issues	Information Needed Regarding Regulations, Standards and Practices	Relationship to Fault Tree (Types of Accidents/ Incidents or Situations Affected)
Track structure integrity Construction standards for track structure to insure safety under normal operating conditions	• Track strength – Roadbed stability – Panel shift – Rail roll-over safety under normal service loads • Track quality – Geometry – Rail and weld metallurgical quality Includes: – Curves and tangent – "Plain" and "special" trackwork	• Dimensions, materials, specifications, components – Ballast section – Ties – Rail – Welds – Rail-tie fasteners – Special trackwork – Spirals and curves • Critical design criteria - minimum acceptable strengths and material properties	• Reduces risk of accidents due to failure of track structures or components

<u>TABLE II.2.7</u>

HSR SAFETY ISSUES — 5 — TRACK INSPECTION AND MAINTENANCE

Issue	Sub-Issues	Information Needed Regarding Regulations, Standards and Practices	Relationship to Fault Tree (Types of Accidents/ Incidents or Situations Affected)
<u>Track inspection and maintenance</u> Maintenance and inspection needed to insure continuing safety in service	• Track strength – Panel shift – Buckling – Rail rollover • Track quality – Geometry – Rail flaw – Fastening security (not vibrate loose/out) • Strength of subgrade, fills, etc.	• Acceptable standards at different speeds for – Ballast – Ties and fasteners – Track geometry (alignment, warp, crosslevel, profile, gauge) – Rail flaw • Inspection methods and frequencies for geometry & rail flaw • Monitoring of fills, subgrade, etc. against failure • Maintenance practices & equipment • Post maintenance inspection and practices (especially speed restrictions after machine surfacing), weld inspection • Staff qualifications, training and experience	• Reduces risk of accidents due to the degradation of track structures or components

TABLE II.2.8

HSR SAFETY ISSUES — 6 — SECURITY OF RIGHT-OF-WAY

Issue	Sub-Issues	Information Needed Regarding Regulations, Standards and Practices	Relationship to Fault Tree (Types of Accidents/ Incidents or Situations Affected)
Security of right-of-way Physical protection of the right-of-way against hazards from the "external environment" including physical intrusion, vandalism and weather events	• Vandalism and trespassing • Grade crossing safety • Weather hazards – High winds – Snow – Temperature extremes • Shared right-of-way with conventional rail operations • Earthquakes • Protection against obstacles on track	• Grade crossing practice – Max. speed permitted – Protection system used at different speed levels • Fencing right-of-way • Shared right-of-way – Max. speeds in mixed traffic operation – Special precautions taken – Precautions against encroachment from adjacent tracks • Warning systems for intrusion, or foreign objects on track • Weather hazards and earthquakes – Warning devices used – Critical values & actions to be taken	• Reduces risks of – collisions with foreign objects on track or intruding on right-of-way – Grade crossing collisions, whether these cause a train derailment or not – Weather related track/ right-of-way accidents – Hitting person in right-of-way

TABLE II.2.9

HSR SAFETY ISSUES — 7 — SIGNALS AND TRAIN CONTROL

Issue	Sub-Issues	Information Needed Regarding Regulations, Standards and Practices	Relationship to Fault Tree (Types of Accidents/ Incidents or Situations Affected)
Signals and Train Control			
A. Design and manufacture of signal and train control systems	• Use of cab signalling and automatic train control systems • Interlocking of signals and track circuit • Fail-safe verification • Maximum speeds for use of lineside signals • Manual override potential	• General description of train control system control features (vital and supervisory) • Headways • Train-track control center communication systems • Policy regarding speed thresholds at which cab signalling/ATC is required • Requirements for vehicle location detection (e.g., shunting resistance) • Inspection methods and frequencies	• Reduces risk of collisions or derailments due to signal malfunction or faulty design or installation • To the extent that automatic train control or operating features are present, the signal system reduces the risk of human error-caused collisions and derailments
B. Maintenance and inspection of signals and train control	• Inspection procedures • Staff qualifications and training • Quality control	• Staff training and qualification requirement • Quality control methods	

TABLE II.2.10

HSR SAFETY ISSUES — 8 — WAYSIDE ELECTRIC TRACTION POWER SUPPLY

Issue	Sub-Issues	Information Needed Regarding Regulations, Standards and Practices	Relationship to Fault Tree (Types of Accidents/ Incidents or Situations Affected)
Electric Power Supply			
A. Design and construction to ensure safe operation	• Electrical clearance between catenary and structures	Specification details for each issue	• Reduces risk of:
	• Grounding		– Electric shock casualty to either employees or to the public
	• EMI protection		
	• Circuit-breaker performance		– Significant EMI hazards
	• Insulation		– Fires due to wayside power supply failure
	• Electric shock injuries	• Testing and inspection practices	
B. Maintenance and inspection to insure continuing safety	• Deterioration of insulation, etc.	• Training or staff working on or near high voltage lines	

TABLE II.2.11

HSR SAFETY ISSUES — 9 — OPERATING PRACTICES

Issue	Sub-Issues	Information Needed Regarding Regulations, Standards and Practices	Relationship to Fault Tree (Types of Accidents/ Incidents or Situations Affected)
Operating Practices Operational practices, required to assure safe operation	• Dispatching procedures • Brake test procedures • Train crew requirements • Prevention of unsafe actions by passengers • Emergency response procedures • Avoidance of alcohol and drug abuse • Special precaution for operations in tunnels • Use of engineer vigilance devices on locomotives and cab cars	• Applicable rules and practices for each issue – Normal operating rules – Permitted hours of service – Mandatory rest periods during and between shifts – Number of train crew – Procedures to avoid alcohol/drug abuse	• Reduces risk of collisions or derailments due to errors of train crew or signal and dispatching employees • Reduces risk of occupants of trains involved in derailments and collisions becoming casualties, through use of good emergency response procedures

TABLE II.2.12

HSR SAFETY ISSUES — 10 — EMPLOYEE QUALIFICATIONS AND TRAINING

Issue	Sub-Issues	Information Needed Regarding Regulations, Standards and Practices	Relationship to Fault Tree (Types of Accidents/ Incidents or Situations Affected)
Employee Qualifications and Training Qualifications and training requirements for operating employees (train crew, signal operator and dispatcher) to minimize the risk of "human factors" caused accidents	• Engineers and train crew – Qualifications – Experience – Training – Route knowledge – Certification	Details of the qualifications and training requirements for each group of employees, including any aptitude tests used and repeat training to maintain skills	• Reduces risk of collisions or derailments due to operating employee errors
	• Signal operators and dispatchers – Qualifications – Experience – Training	Also details of training to avoid personal casualties (hit by train, electric shock)	• Reduces risk of employee casualties

- Is there any significant past history of accidents relating to each safety issue?

- Do the consequences of an accident related to this issue become more severe as speed increases?

- Any other comments.

e) Conclusions and recommendations. Comments on whether further research appears to be warranted, and suggestions as to its content.

II.2.2 Rolling Stock

II.2.2.1 Rolling Stock Structural Strength

a) FRA Regulations

CFR Title 49 Part 229.141. Structural strength regulations, applicable (on strict interpretation) to Multiple Unit (MU) locomotives only. The key provisions are given in the following table and illustrated in Figure II.2.1.

Weight	Train Empty Weight Exceeding 600,000 lb	Train Empty Below 600,000 lb
Buff strength in line with coupler	800,000 lb.	400,000 lb.
Collision posts		
Number	2	2
Shear strength	300,000 lb.	200,000 lb.
Truck to body shear strength	250,000 lb.	250,000 lb.
Anti-climbing arrangement vertical strength	100,000 lb.	75,000 lb.
Vertical coupler strength	100,000 lb.	75,000 lb.

These loads must be sustained without deformation of the car structure, except for collisions post and truck to body shear loads, which must be sustained without total failure.

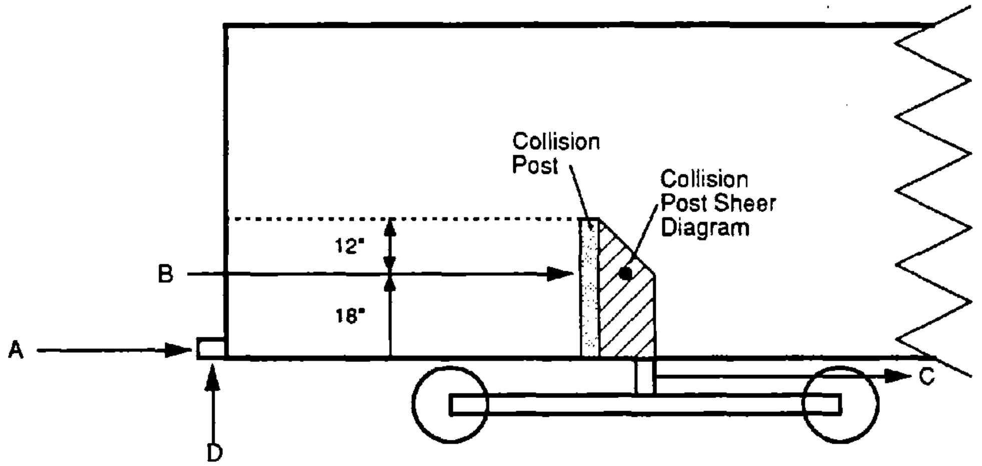
b) Other U.S. Standards and Practices

The Association of American Railroads (AAR) standards apply to all passenger cars operated in trains exceeding 600,000 lb. light weight. They are identical to the FRA standards for MU locomotives described in paragraph a) above.

- The AAR does not now formally issue passenger car standards. However, the standards originally developed by the AAR have been adopted by Amtrak and all other providers of rail passenger service in the U.S. and Canada.

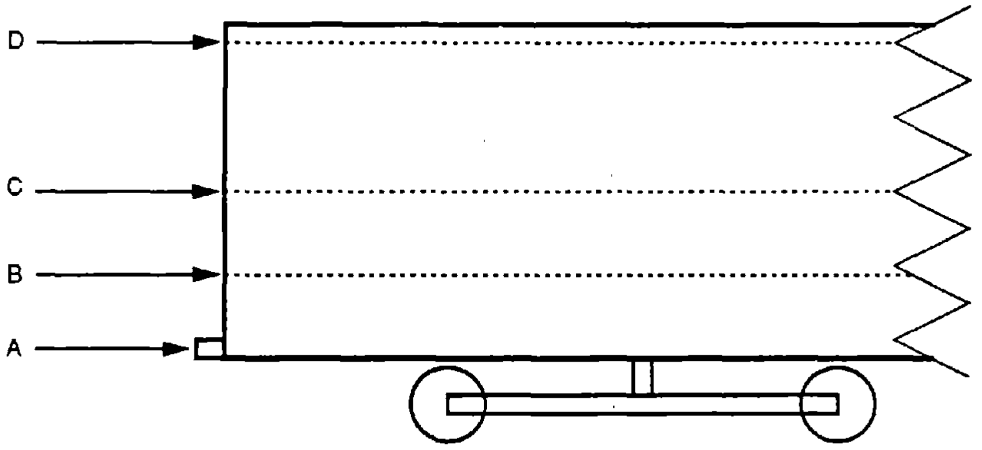
Figure II.2.1
Comparison of North American and European Car Body Strength Requirements

North America (AAR/FRA), for trains exceeding 600,000 lb empty weight



A	Buff	800,000 lb.
B	Collision Post (each of two)	300,000 lb.
C	Truck/Body	250,000 lb.
D	Coupler, etc.	100,000 lb.

Europe (UIC Code 566)



A	Buff	448,000 lb.
B	14" Above A	90,000 lb.
C	Center Rail Level	67,000 lb.
D	Cant Rail Level	67,000 lb.

In addition there is a diagonal load of 112,000 lb. at buffer level.

- Car specifications issued by operators of commuter and intercity rail service operators customarily require compliance with these standards.

- A structural test is normally required by the car purchaser for any new design to confirm that the car meets the buff strength requirement. Design calculations must be submitted as evidence of meeting other strength requirements.

c) Foreign Standards and Practices

The primary standard is UIC Code 566 (OR) used by all European railroads. The minimum forces are illustrated in Figure II.2.1, and are as follows:

2000 kN (449,000 lb)	Longitudinally at buffer level
500 kN (112,000 lb)	Diagonally at buffer level
400 kN (90,000 lb)	350 mm (in) above buffer level
300 kN (67,000 lb)	At "center-rail" level (just below windows)
300 kN (67,000 lb)	At "cant-rail" level (side to roof joint)
1500 kN (337,000 lb)	Tensile force at coupler

In addition, the code requires that car end walls strengthened by anti-collision pillars must be joined to the headstock (buffer beam) center rails and cant rails in such a way as to absorb collision energy and retain a high resistance to "override" shear forces. Specific strength or energy absorption requirements are not set for these.

Since buffers and screw-tensioned chain couplers which cannot sustain vertical loads are commonly used in Europe, the UIC code does not specify any minimum vertical (anti-override) load at the coupler. However, U.S.-style or transit type couplers are used on many equipment types, and these and the articulation design on the TGV are capable of sustaining substantial vertical loads between vehicles.

European truck-to-body shear strength force is a function of car and truck mass. 50,000 lb. would be typical (UIC Code 515).

d) Commentary

- Comparability
  - — UIC structural strengths are much lower than FRA/AAR strengths and the requirement for minimum vertical coupler or anti-climber force is absent.
- U.S. operating environment
  - — Depends critically on the degree of segregation of the high speed rail service from conventional U.S. passenger and freight railroad operations.

  - If not fully segregated, HSR trains will be sharing tracks with conventional U.S. trains built to FRA/AAR standards over at least part of a route.

  - If any grade crossings are present on the route, there is a significant risk of collision with a highway vehicle.

  - Significant risk of intrusion onto the right-of-way, or presence of foreign objects on the tracks, leading to a collision.

- Accident history

  - Frequent grade crossing accidents
  - Frequent right-of-way encroachments

- Effects of higher speed

  - Higher speed means that greater energy will have to be absorbed in structural deformation in the event of a collision, compared with conventional speed operations. Since the energy is a function of the square of speed, this means that the amount of structural deformation in an accident will be much higher than at conventional speeds.

e) Discussion, Conclusions and Recommendations

The substantial differences between U.S. structural standards and those followed in the design of most foreign high-speed train passenger cars lead to the question:

> "Under what circumstances, if any, can cars built to the foreign, and specifically UIC structural standards be operated in the United States?"

This is a critical issue,and strong opinions are held in the HSR industry on both sides.

- Those arguing for acceptance of lower strength standards say that they are appropriate given the lower train weights, the degree of segregation from conventional rail operations, and the lower risk of accidents occurring in the first place because of the use of sophisticated ATC and cab signalling systems.

- Those arguing for compliance with FRA/AAR regulations and standards say that any relaxation of these will result in an unacceptable reduction in passenger protection in a collision or derailment, leading to more casualties.

Information from which to judge the merit of these arguments is presently lacking. Furthermore, early resolution of this issue is of substantial importance to the HSR industry.The choice of structural strength standards has a direct impact on train weight and thus high-speed train performance and cost and project viability.

Therefore, we strongly recommend that research be conducted into how speeds, weight and carbody strength affect structural damage and deceleration experienced during a derailment or collision. Such an analysis should include both an analysis of actual accident conditions and consequences, both domestically and overseas, and analysis of how energy is dissipated in an accident. This analysis would lead to determination of the relationships between train weight, speed, strength and structural damage in accidents. This can then be used to evaluate HSR accident scenarios at different speeds.

- Collisions with conventional U.S. trains
- Collisions with similar high speed trains
- Single train derailments
- Grade crossing collisions with trucks and autos.

II.2.2.2 Engineers Cab Crashworthiness and Safety

a) FRA Regulations

There are no overall structural strength regulations for locomotives as opposed to MU cars, but there are several other safety related requirements in CFR Title 49 Part 229. These are:

- Para. 229.119 requires adequate door and seat fastenings, non-slip floors, good general tidiness and adequate heating and ventilation.
- Para. 229.121 requires maximum eight-hour time weighted sound level shall not exceed 90 Dba.
- Para. 229.123 requires that all lead locomotives be equipped with an adequate pilot, end plate or snowplow.
- Para. 229.127 requires illumination of in-cab instruments and provision of a reading light.

b) Other U.S. Standards and Practices

- The AAR requires all cab interior fittings and surfaces to be provided with rounded corners and be otherwise designed to minimize the risks of injury should a person be thrown against them.
- There are detailed AAR strength requirements for locomotive engineer seats.
- Otherwise, most AAR locomotive cab standards are formulated for compatibility and interchange ability between components from different manufacturers.
- There is growing interest in the so-called "comfort" cab in the U.S. freight railroad industry. This cab design provides an ergonomically designed control console, plus improved temperature control, noise and vibration insulation. These and other features are intended to provide a much improved working environment for the engineers, leading to a reduced risk of engineer-error caused accidents.
- An extensive government/industry research program has studied cab crashworthiness. The results of this work are now being implemented in cab design, including the comfort cab.

c) Foreign Standards and Practices

- UIC Code 617-5 OR lays out detailed requirements for engineer's cabs. The principal provisions are:

  - Overall structural strength — locomotives must meet the same standards as passenger cars (see II.2.2.1), plus a structural design that protects the space occupied by the engineer, with deformations and energy absorption taking place in front of, and behind, this space. Although there are no quantitative requirements for this, this requirement has been considered in high speed train designs, most notably the TGV.

  - Sharp edges, etc., must be avoided to minimize injuries should the cab occupants be thrown against cab internal fittings and surfaces.

- All heavy locomotive components inside the body must be secured to the body structure so that they can sustain longitudinal accelerations of 3g.

  - Proper protection must be provided against accidental contact with high voltage electrical equipment, hot surfaces, etc.

  - An unimpeded emergency passage must be provided to the opposite end for the vehicle.

- Console type controls and consideration of human-factors in the design of controls and instruments is standard practice.

There is no overseas consensus on requirements for unpowered cab cars. Accident experience in the UK has led to a requirement for such cars to have a minimum 13.3 ton axleload and a pilot capable of sustaining a 66 ton impact. Cab car operation at 200 km/h (125 mph) is envisaged in the UK, Sweden and Switzerland, but UK policy is that cab cars operated at this speed will be baggage cars without passenger accommodations.

d) Commentary

- Comparability

  - Overall structural strength of a foreign locomotive body is typically much lower than in U.S. The strength differences are similar to those for passenger cars, except that on a locomotive there is no coupler/anti-climber or truck-to-body shear strength requirement. However, passenger locomotives are fitted with anti-climbing (tightlock) couplers in the U.S.

  - There is no foreign requirement for a pilot or snowplow, except on cab cars in the UK.

  - The principal conflict between foreign and U.S. practice is in the overall structural strength. Otherwise, the UIC code and cab design practice as used in high speed trains pay greater attention to safety and provide a better work environment for the engineer than is customary in the U.S. Provisions such as providing emergency egress, and designing the locomotives or cab structures so that the crush strength of the space occupied by the train crew is higher than the surrounding structure have no equivalents in U.S. regulations, standards or practices.

- U.S. operating environment

  — The comments given in II.2.2.1 for passenger car body structures apply.

- Past History of Accidents

  — The comments given in II.2.2.1 apply.

- Effects of higher speed

  — The comments given in II.2.2.1 apply. In addition, high speeds may mean less margin for human error. Every cab feature that improves the working environment and thus reduces the risk of such errors is a potentially valuable contribution to safety.

e) Discussion, Conclusions and Recommendations

This discussion addresses two distinct types of rolling stock—pure locomotives containing only traction equipment, and the cab cars of push-pull or multiple-unit trains.

Locomotives

Although formal standards or regulations for the buff strength of locomotives are lacking in the U.S., the actual strength of a typical U.S. locomotive is much higher than that of a European locomotive. On the other hand, European practice emphasizes the achievement of a good working environment in the cab, plus additional safety features. These differences raise two questions:

- Under what circumstances, if any, can locomotives built to European standards be operated in the United States?
- What changes are needed, if any, to U.S. locomotive cab design practice to provide additional protection to train crew, or a more appropriate working environment, at speeds exceeding 125 mph?

We recommend that the first of these questions be addressed by research carried out in parallel with that into passenger car strength and using the same approach.

Issues relating to the second question have been extensively studied both in the U.S. (for example, under the auspices of the Locomotive Control Cab Committee) and elsewhere. There has not been time to examine this material within the scope of this study. Therefore, we recommend a preliminary short-term study of the available information on these issues. Further action is dependent on the outcome of such a study. If it appears that present U.S. cab design practice is not adequate for high speed, and it is not appropriate for any reason to accept foreign practice, then further research may be needed.

Cab Cars

Cab cars are used in some foreign push-pull and multiple unit high-speed train consists. As well as the questions raised in the discussion of locomotives and locomotive cabs above (which should be researched in the same way), possible use of cab cars raises the additional question:

- Under what circumstances, if any, can cab car operation be permitted at speeds of 125 mph and higher?

We recommend that research be carried out into whether cab cars, especially when operated in the "push" mode are any more vulnerable to accidents of any kind than locomotive-hauled trains, and how this vulnerability depends on cab-car structural strength, car weight and other factors. Furthermore, we recommend that the research include an analysis of the benefit, if any, of not permitting passenger accommodation in the cab car (as is the rule in the UK for speeds exceeding 100 mph).

II.2.2.3 Truck Design and Construction

a) FRA Regulations

- No regulation strictly applying to unpowered passenger cars.
- Detailed maximum wear and other dimensional requirements relating to locomotive trucks. These are essentially maintenance rather than construction requirements.

b) Other U.S. Standards and Practices

- Association of American Railroads Manual of Standards and Recommended Practices for Wheels and Axles (Section G) and rolling bearings (Section H) are selectively applied to passenger cars. Passenger car axle specifications are given in Section A. Section A also includes some specifications for materials such as steel castings. As explained before, the AAR does not now formally maintain passenger car standards, but standards originally developed by the AAR are widely used.

c) Foreign Standards and Practices

UIC Code 515 lays down many detailed requirements for trucks, including wheel and axle. Some significant provisions are:

- Maximum axleload - 17.6 tons.
- Internal bearings are not permitted because these are incompatible with existing hot box detectors.
- Electrical grounding, as per UIC Code 552 is required.
- If pneumatic suspension (air springs) are used, car must operate safety with springs deflated at maximum speed.
- A program of fatigue tests of the truck frame is required for new designs.
- A series of track tests are specified for new design trucks. These are mainly concerned with track-train dynamics and will be discussed under that heading.

d) Commentary

- Compatibility
  - — Wheels/axles/bearings. These have not been examined in detail. We believe there are minor differences in material and dimensional standards, but these

do not have a material effect on the strength or performance of the components.

  - There is no formal U.S. equivalent to the UIC truck frame test requirements, although similar tests have been commissioned in the past by U.S. passenger rail service operators.

- U.S. operating environment
  - Likely to be similar on newly-built lines.
  - U.S. existing track is often rougher than elsewhere, thus the truck load environment may be more severe in the U.S. than elsewhere.

- Accident history
  - Accidents due to truck failure do occur, most importantly associated with wheelset or bearing failure. Faulty design or material selection is sometimes the cause.

- Effects of high speed
  - Dynamic loads on all components will increase at high speed.

- Other points
  - Numerous powered and unpowered truck designs are being used for high speed rail operations. The configuration of such trucks vary considerably, making specification of standards difficult.

e) Discussion, Conclusions and Recommendations

The structural integrity of truck frames, bearings, wheelsets, and other truck components is critical to safety. The truck operates in a demanding environment with high dynamic loading. Considerable effort has been expended to develop and ensure the integrity of these components by the developers of foreign high-speed rolling stock. It is likely that in most respects these trucks will operate satisfactorily in the U.S., but there is a concern over the effects of the possibly more demanding U.S. operating environment.

Given this, a limited examination of procedures used to ensure the integrity of a truck is recommended to see if operating environment changes call into question any of the practices and standards used in foreign designs. This could include appropriate track and laboratory tests, the selection of appropriate materials and dimensions for wheels, axles and bearings as a function of axleload and speed.

II.2.2.4 Brake Installation and Performance

a) FRA Regulations

Brake requirements are specified in Part 232 of the CFR Title 49.

Most of this Part is concerned with testing, inspection, and maintenance of brake systems, not construction, and is also written primarily for freight train operation.

Key requirements are:

- 85% of all cars in a train must be braked.
- Brakes must be capable of operating in emergency mode at all times, even during a service brake application.

b) Other U.S. Standards and Practices

The Association of American Railroads lays down some brake standards, but many of these are out-of-date, and do not reflect current high-speed passenger car practice.

Amtrak and other passenger operators customarily require use of the 26CS-1 electro-pneumatic brake control system, as supplied by the major U.S. brake systems manufacturers. A wheel slide protection system is also required.

Current Amtrak intercity passenger cars have two disc brakes per axle, plus a wheel tread friction brake to meet the most demanding Northeast Corridor braking requirements.

A hand brake, operated from inside the vehicle, and a "conductor's valve" for initiating emergency braking must be fitted in each vehicle.

c) Foreign Standards and Practices

A series of UIC codes (540-546) specify construction and performance requirements for air brakes. These codes are formulated primarily to ensure compatibility between vehicles of different owners.

An emergency braking rate of 0.85 m/sec (1.9 mph/sec) is required of vehicles approved for operation at 200 km/h. Disc brakes (2 per axle) are also required. In contrast, Amtrak requires 2.5 mph/sec in Northeast Corridor service.

Brake design and performance for speeds above 200 km/h (125 mph) is currently the responsibility of the individual operator. There are no established standards and practices.

Some systems use dynamic braking by power cars and eddy current track brakes to improve emergency braking performance.

d) Commentary

- Comparability
  - The principals of the electro-pneumatic brake system with wheel slide protection are similar in the U.S. and overseas, but there are a number of detail differences, for example, in operating pressures.
  - Reliance on dynamic or eddy current brakes to provide part of the emergency braking effort is not current U.S. practice, but is accepted in Europe and Japan. Adequate integrity is achieved by providing each truck or wheelset with an independent power supply, for example, from batteries. These are arranged so that a systemic failure (such as that of the power supply from the catenary) cannot affect the operation of the brakes.
  - One train design, the Spanish Talgo, uses hydraulically actuated friction brakes. Hydraulic actuation has not normally been acceptable to existing U.S. passenger train operators, although there is no specific prohibition in published rules and standards.
- U.S. operating environment
  - There are no significant ways in which the U.S. operating environment affects the risk of brake failures. One possible issue is that U.S. track, other than on new high speed lines, is likely to be of lower quality than equivalent track in Europe. This means that the shock and vibration environment of truck and axle-mounted equipment will be more severe in the U.S. than elsewhere, and that mechanical arrangements developed elsewhere may need modification.
- Accident history
  - Accidents attributed to inadequate design and manufacture of brake systems are rare. Accidents due to human error related to braking, especially failing to ensure all brakes on a train are operating, are more common. Automatic safeguards against this are desirable. The automatic condition monitoring systems being introduced on the most recent train design (e.g, TGV Atlantique) can achieve this.
- Effects of higher speed
  - Braking duty obviously gets more severe at high speed. Total energy to be dissipated increases with the square of speed, and instantaneous power

dissipation with the cube of speed. Actual braking rates must be compatible with the stopping distances required by the signal system design.

e) Discussion, Conclusions and Recommendations

In order to achieve adequate braking at high speeds, the foreign high speed trains employ unconventional brake systems, such as "vital" dynamic braking and eddy current brakes. A thorough understanding of these systems, especially of how adequate reliability levels are achieved, is desirable for evaluating future U.S. high speed rail proposals.

Apart from this, U.S. and foreign practice concerning conventional electro-pneumatic friction brakes (usually axle-mounted discs) appear to be similar and there should not be any significant difficulties in compliance with existing U.S. practice.

II.2.2.5 Track-Train Interaction, Including High Cant Deficiency Operation

a) FRA Regulations

The track safety standards, 49 CFR Part 213, specify a maximum cant deficiency of 3 inches.

There are no other FRA regulations regarding track-train forces, lateral/vertical force ratios, and related matters.

b) Other U.S. Standards and Practices

There are no other established standards for track-train interaction. However, the subject has been extensively research both in the U.S. and overseas, leading to some generally accepted practices. It should be emphasized that these are recommendations and conclusions from research work, rather than formal standards or guidelines.

The most significant series of investigations were those performed prior to a series of high cant deficiency tests on the Northeast Corridor in 1980-81.[2] In summary, these were:

- Car Overturning:
  - Compliance with the intercept of the force vector in relation to the track centerline given by both of the following formulae:

Steady State Vector Intercept $\leq 18 - (.0153V^2Sh_{cp}/W)$ inches

and

Peak Vector Intercept $\leq 24 - (.0153V^2Sh_{cp}/W)$ inches

Where:

V = the lateral wind speed in mph

S = the lateral surface area of the vehicle in ft^2

h_{cp} = the height of the center of wind pressure in ft

W = one-half of the unloaded weight of the vehicle in pounds

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[2] Patrick L. Boyd, Robert E. Scofield and Joseph P. Zaiko, High Cant Deficiency Testing of the LRC, AEM7 Locomotive and the Amcoach, Report DOT-FR-81-06, January 1982.

- Wheel climb:
  - Peak individual wheel lateral:vertical force ratio (L/V) not to exceed

    $0.056T^{-0.927}$ for $T < 50$ ms
    and 0.9 for $T > 50$ ms

  where T is the duration of the lateral force.

- Rail rollover:
  - Peak truck lateral to vertical force ratio (L/V) equal to or less than

    $0.5 + 2300/Pw$ where $T > 50$ ms
    or $0.113\ (0.5 + 2300\ Pw)\ T^{-0.728}$ where $T < 50$ ms

    Pw is the wheel load in pounds

- Track panel shift:
  - Maximum lateral force

$$= 1 - \frac{A\Delta\Theta}{22320}\ (1 + .458D) \quad .7p + 6600 - (1.28 \times 10^{-3} SV^2)$$

  Where

  A = rail section area, in^2

  $\Delta\Theta$ = max temperature change after rail installation, °F

  D = track curvature, degrees

  P = vertical axleload, lbs.

  S = lateral surface area of vehicle, ft^2

  V = lateral wind speed, mph

- Vertical impact:
  - There are no generally accepted vertical impact standards in the U.S. Maximum axleload acceptable by the AAR Interchange Rules is 66,000 lb.

Application of the above criteria in a series of high cant deficiency tests generally resulted in maximum permitted cant deficiencies of 8-10 inches, depending on the vehicle tested.

c) Foreign Standards and Practices

The most prominent foreign standard for track-train forces is the Prudhomme formula for lateral panel shift. This is:

> Maximum lateral force at a single wheelset in kN = 0.85 (10 + P/3), where P is the axleload in kN.

This formula, or a minor adaptation of it, is used by all European railways and is specified in UIC Code 515. L/V derailment criteria vary from system to system, but are generally lower than the 0.9 customarily accepted in the U.S. However, meaningful L/V measurements are very difficult to make and any standards or data should be used with caution, recognizing that they may be influenced by the method used to measure or estimate L/V.

Since all high-speed operation takes place on track with concrete ties and elastic fasteners, there is little concern in Europe or Japan with rail rollover, and safety criteria have not been developed. Track panel shift is regarded as the most likely form of track failure.

A variety of vertical impact force criteria are used. Application of these criteria generally result in maximum axleload limits for high-speed trains of 18-22 tons, and unsprung (wheelset) masses of around 2 tons.

Maximum cant deficiencies for non-tilting trains are typically in the range of 4 to 6 inches, the limit being set by comfort rather than safety.

d) Commentary

- Comparability
  - Track-train interaction and related safety limits for forces and force ratios have been extensively studied in Europe, Japan and North America. The limits used in the NEC high cant deficiency tests were derived from a review of all this material, and therefore reflect international practice at the time (1980). Since then, European practice has become better established as a result of continuing tests and research, especially in France and Germany. The FRA 3-inch cant deficiency limit is lower than customary elsewhere, and may be overly restrictive where track quality is good.

- Operating environment
  - There will be few differences in the operating environment when high-speed trains are operated on new high-speed lines, which are likely to be built to the same standards as the foreign high-speed lines. Track strength and geometry is potentially different where high-speed trains are used on existing U.S. track, and different track-train force or force-ratio safety criteria might be appropriate. This could be a particular concern if high cant deficiency operation is planned on such track.
- Accident history
  - Track-train dynamics problems are currently a relatively minor cause of passenger train accidents. However, this has not been true in the past. For example, there were a series of accidents in the mid-to-late 1970s with Amtrak's SDP40F locomotive, attributable to excessive lateral wheel-rail forces. A similar series of accidents in the future is possible, if equipment with track-train interaction problems is allowed to enter service.
- Accident consequences
  - Track-train dynamics problems typically lead to derailments, which will be more severe at high speeds.

e) Discussion, Conclusions and Recommendations

The passenger railroad industry is aware that a series of accidents such as those that befell the SDP40F in only avoided by continuing application of adequate track-train force and force ratio standards. As a result, all operators of high-speed train equipment have evolved and apply such standards, and have also developed monitoring and inspection programs to ensure compliance during regular service. In many cases, these foreign standards are more restrictive than those of U.S. origin.

To date in the U.S., such standards and acceptability criteria have only been studied and applied in research and test programs, and do not form part of any FRA regulation or industry standard, with the single exception of maximum axleload. In spite of this, there is a large body of information from this research and test work, as well as similar information for international research, to enable suitable standards to be developed without further fundamental research.

Therefore, we recommend that a limited research project be carried out to develop a draft set of track-train force and force-ratio guidelines, using the 1980/81 FRA/Amtrak research as a starting point, and updating this with international experience and practice that has developed and become available over the past several years. This should include qualification test procedures as well as the standards or guidelines themselves. Such standards may be different for different track types and quality (FRA class, and concrete vs. wood ties). It is likely that this effort will confirm the suitability of either the guidelines used in the FRA/Amtrak 1980-81 test program, or selected foreign standards and practices.

Requirements for tilt trains high cant deficiency curving should form part of such a study, and should include any forces developed as a consequence of tilt systems failure, as well as operation with the tilt system functioning normally.

II.2.2.6 Rolling Stock Inspection and Maintenance Standards

a) FRA Regulations

FRA regulations for inspection and maintenance apply to locomotives only and are contained in 49 CFR Part 229. There are no such standards for passenger cars, although the regulations include standards for freight cars.

In summary, the locomotive safety regulations include the following:

- Locomotives must receive a daily and more detailed 3-monthly, annual and bi-annual inspection by a qualified person for compliance with the regulations. Inspection reports must be prepared using a particular FRA form and retained for review by FRA inspectors.

- Detailed requirements are laid down for the condition of suspension systems, wheels and axles, brakes, and electrical equipment.

b) Other U.S. Standards and Practices

There are few generally accepted national standards, other than the Federal regulations for locomotive inspection and maintenance standards. The Association of American Railroads Manual of Standards and Recommended Practices, Section A, Part III, provides some standards for brakes and couplers, applicable to all vehicle types. Otherwise, standards are developed by individual operating organizations such as Amtrak.

c) Foreign Standards and Practices

Some inspection and condition standards are laid down in the UIC codes for brake systems, wheels, axles and bearings. Inspection of locomotives are the responsibility of individual systems, since locomotives do not normally cross frontiers onto different systems, and are therefore not addressed in UIC codes.

Most high-speed train operators have specified a detailed inspection and maintenance schedule. That for the TGV is as follows:

- Every second day, visual inspection and testing of operational systems.

- Every nine days, interior inspection, mostly "passenger comfort" items (lighting, HVAC, etc.).

- Every 18 days, inspection of running gear (trucks and brakes).

- Every 5 weeks, mechanical inspection, level 1.

- Every 10 weeks, mechanical inspection, level 2.
- Every 20 weeks, general inspection, level 1.
- Every 40 weeks, general inspection, level 2.
- Every 18 months, part disassembly and general inspection.

Also, there are a number of on-board monitoring systems to detect malfunctions and advise the engineer to take appropriate action. An example is the monitoring of truck frame lateral acceleration to detect hunting instability. When this is detected, speed may be reduced, and the truck is inspected for defective components which might have caused the condition, such as a defective yaw damper or a wheel tread profile outside the normally acceptable limits. This process has been further developed on the TGV Atlantique, to include an Artificial Intelligence (AI) system to diagnose defects using sensor outputs, and advise appropriate operational and maintenance actions.

Inspection practice on the Shinkansen is as follows:

- Daily: visual inspection, and checks of wear and functioning on such items as brakes, pantograph contact strips, doors, etc.
- Monthly workshop inspection of electrical equipment, trucks, bearings, axles, etc., in a purpose-built facility.
- Annual: (300,000 km) thorough inspection of trucks involving removal of truck from train and partial disassembly.
- Every three years (900,000 km) full overhaul inspection.

In addition, carbody ride quality is monitored regularly to detect truck problems, especially hunting, which will require truck maintenance. Vibration spectrum analysis is used to analyze data from the monitoring systems, and thus diagnose problems.

d) Commentary

- Comparability
    - — The structure of graded daily, weekly, monthly, etc., inspections is broadly similar on all systems. However, acceptability standards (which we were not able to study within the scope of this study) may be very different from current U.S. practice. This would include such factors as wheel condition, bearing condition, and brake wear or deterioration. U.S. rail systems have

traditionally been more tolerant of "wear and degradation" defects (such as wheel flats) than elsewhere.

- Operating environment.

  — There is likely to be little different between the U.S. and foreign operating environment on a new high speed line as it affects rates of wear or deterioration. Therefore, similar inspection intervals to those used on the foreign systems are likely to be appropriate. Inspection intervals in such service, however, should be more frequent than in traditional normal speed rail operations, since the tolerances for wear, etc., in high speed operation are smaller.

- Accident history

  — Accidents attributable to the failure of deteriorated rolling stock components are a significant accident cause.

- Accident consequences

  — Accident consequences will be more severe as a result of the higher speeds.

e) Discussion, Conclusions and Recommendations

In general, we consider that it will be appropriate to adopt foreign inspection and maintenance practice for any high-speed rail system as used on its domestic system. This usually involves more frequent and thorough inspections and stricter standards than are used in the U.S. for conventional-speed equipment.

The appropriateness of inspection and maintenance procedures are to some extent a function of service plans and operating environment of each individual operation. Inspection and maintenance procedures should be regularly audited by competent external authorities to ensure adequacy.

II.2.2.7 Rolling Stock Non-Structural Safety Requirements

Note: This heading includes car features such as external hand rails and steps as covered in the FRA safety appliance regulations, doors, and the crashworthiness of car interior appointments. Glazing standards and fire safety are reviewed separately.

a) FRA Regulations

These include the safety appliance standards, and various other non-structural standards as summarized below.

- 49 CFR Part 231 - Railroad Safety Appliance Standards. These require (Part 231.14):
  - One handbrake per car, situated so that it can be operated with the car in motion.
  - Various steps and handholds at the end of the car and associated with doors.
- 49 CFR Part 221 - Requires rear-end lights.

There are no regulations regarding door operation, or the strength or nature of car interior fittings.

b) Other U.S. Standards and Practices

The AAR Manual of Standards and Recommended Practice, Section A Part III, specifies the following:

- Sliding doors only shall be used. In spite of this, outwardly opening exterior doors are acceptable to most operators. Inwardly opening doors are definitely not acceptable, because they can prevent escape in an emergency.
- Wrecking tool cabinet must be provided, with an axe and sledgehammer.
- A conductor's brake valve, which can be used to initiate braking in an emergency should be provided in each car.

In addition, Amtrak requires that the attachments of car interior fittings to the structure, including seating, partitions, baggage racks, etc., are designed to withstand the following accelerations:

6g longitudinal
3g vertical
3g lateral

c) Foreign Standards and Practices

The following UIC codes cover various aspects of non-structural car safety:

- Code 566 OR requires the following:
  - — Car component mountings must withstand the following accelerations:

Longitudinal	50 m/sec (5g)
Lateral	10 m/sec (1g)
Vertical	30 m/sec (3g)

A "proof" safety factor (against deformation) of 1.5 should be used in design, increased to 2.0 for components accessible to passengers as a precaution against damage by vandals.

  - — Overhead baggage racks must withstand 1000 N per meter (137 lb/ft) plus 850 N (191 lb) at any point on the front edge.

- Code 560 OR lays down many requirements concerning doors, handrails, steps, etc. Some of the most significant are:
  - — Exterior doors are automatically closed and locked at speeds exceeding 5 km/h.
  - — Doors must have a pressure-sensitive edge and be programmed to open for a short period (10 secs) when obstructed, to prevent accidental entrapment.
  - — Automatic doors must have an emergency means of being opened manually from both inside and outside the car.
  - — The entrance must be adaptable to platform heights of between 300 and 900 mm (12 and 36 inches).
  - — External steps and handrails are required for switching activities (equivalent to the FRA safety appliance standards).

Use of automatically operated sliding-plug doors is becoming universal on European rail systems.

Draft Canadian passenger rail-car regulations require aircraft-style closed overhead baggage bins, and that heavy baggage be segregated from seating areas and stored in racks provided with longitudinal and lateral restraints meeting the following acceleration requirements:

Longitudinal 5g
Lateral and vertical 3g

Canadian door requirements are similar to those of the UIC.

d) Commentary

- Comparability
  - — U.S. regulations and standards are generally less detailed than those in Canada or Europe. However, where there is a standard, these are generally similar. Standards regarding automatic door operation and baggage restraint are lacking in the U.S., although there is little difference in actual practice.
- Operating environment
  - — There is little difference in the operating environment of high-speed trains in foreign systems and the likely environment on a future U.S. system.
- Accident history
  - — The design of non-structural car features has had a significant impact on the number and severity of casualties in train accidents. Many casualties are caused by secondary impact between car occupants and hard surfaces, flying baggage, and detached components, rather than by gross crushing of the car. Lack of adequate arrangements for emergency exits or emergency access for rescue crews has also been a factor. There are also numerous, but mostly minor injuries resulting from slipping and falling while boarding or alighting from rail vehicles.
- Accident consequences
  - — If high-speed train accidents result in greater train decelerations, then the risks for casualties due to secondary impacts will be higher.

e) Discussion, Conclusions and Recommendations

These miscellaneous car design requirements are important. They affect the number and severity of casualties in a train accident, and also help prevent slipping and falling casualties to railroad employees, and to passengers when getting on and off vehicles.

The standards and practices followed on different systems are fairly similar, but there are some differences in emphasis. No system pays close attention to the avoidance of sharp or hard services, or to other ways in which secondary impact injuries can be reduced.

Therefore, a more detailed review of these issues is desirable, focusing on picking the best from international practice, plus consideration of the costs and benefits of additional measures.

II.2.2.8 Fire Safety

a) FRA Regulations

There are no FRA regulations relating to fire safety. However, another US DOT agency, the Urban Mass Transportation Administration, developed a set of flammability and smoke emission guidelines after the 1979 fire on the Bay Area Rapid Transit system. These have been updated from time to time and have now also been adopted by the fRA for application to commuter and intercity railcars. The current version is given in Appendix III.

b) Other U.S. Standards and Practices

- The UMTA guidelines have been adopted by FRA for rail passenger cars of all types in the U.S., including intercity cars operated by Amtrak.
- AAR specifications are used for wiring and other electrical installation in locomotives and power cars (Manual of Standards and Recommended Practices, Section F).
- There is no specific requirement or practice regarding fire-fighting equipment (extinguishers, fire-suppression systems, etc.).
- Although not specifically intended for fire situations, the AAR passenger car standards lay down requirements for emergency egress through windows (2 each side on a normal-length car) and doors (must be capable of being opened from inside and swing out). Emergency lighting, independent of the train's normal power supply, is also required.

c) Foreign Standards and Practices

- The UIC Codes 564-2 OR (for passenger carrying vehicles) and 642 OR (for motive power units and cab cars) provide the fire safety standards used on European equipment. The subjects covered by these codes are:

642 OR — Floors and certain bulkheads must be fire barriers.

— Portable extinguishers must be provided.

— "Engine Rooms" of fossil-fuel powered units must have automatic power shut-down and fire extinguishing systems.

— Provisions of 564-2 OR apply where relevant.

564-2 OR

- — Each car must be equipped with a 6 kg extinguisher (2 in dining and sleeping car).
- — Suitable conduiting in electric cables is required.
- — Car non-metallic materials must meet specified flammability and smoke emission standards.
- — Staff must be trained in fire emergency procedures.

- In the UK, a very comprehensive set of standards have been developed as British Standard 6853:1987 "Fire Precautions in the Design and Construction of Railway Passenger Rolling Stock." This standard includes:
  - — Smoke and flammability tests and standards.
  - — Requirements for fire-barrier performance of bulkheads and floors.
  - — Emergency egress requirements, especially through doors that are normally locked. In this case, emergency manual means of opening must be provided.
  - — Smoke alarms must be provided in sleeping car compartments, toilets and food preparation areas.
  - — More stringent standards are applicable to sleeping cars, and cars in trains which operate for significant distances in tunnels or on elevated structures.

d) Commentary

- Comparability
  - — Flammability and smoke emission standards appear to be broadly similar, although a more detailed examination would be needed to confirm this.
  - — U.S. guidelines do not refer to the need for fire resistant barriers — floors and bulkheads.
  - — Emergency egress requirements are similar, as are those for emergency lighting.
- Operating environment
  - — Incidents of vandalism are more common in the U.S. than elsewhere, and vandalism is a significant source of fire. This problem is likely to be more serious on urban transportation systems than on intercity systems, however.

  - — A positive factor is that it is more common in the U.S. than elsewhere to severely restrict or ban smoking on public transportation vehicles.

- Past accidents

  - — There is a significant past history of on-train fires caused by a vehicle malfunction, vandalism, carelessness or collision, both in the U.S. and elsewhere. Some have been very severe with many casualties.

- Effect of speed

  - — There is no significant way in which speed will affect the incidence or severity of a fire. However, other potential features of a high speed rail system, such as extensive trackage in tunnel or on elevated structure could severely constrain emergency escape and rescue activities.

e) Discussion, Conclusions and Recommendations

Fire safety is an important issue, but not one that is a specific concern of high speed rail operations as opposed to those at conventional speed.

In the broader context of all passenger rail operations, it may of value to reexamine the UMTA guidelines and fire safety practices, both in other transportation modes (e.g., air), and rail service elsewhere in the world, to see what cost-beneficial improvements or additions to present practice might be worthwhile. In doing this, it would be appropriate to examine fire safety on locomotives or power cars with diesel or turbine engines. Issues such as protection and strength of fuel tanks in a collision and use of automatic fire extinguishing apparatus could appropriately form the subject of a study.

II.2.2.9 Car and Locomotive Glazing Standards

a) FRA Regulations

FRA Regulation CFR Title 49, Part 223. Locomotives and cars must be fitted with certified glazing to the following standards:

Type I - Forward facing locations (e.g., driving cabs). Sustain impacts from 24 lb. object with dimensions 8" x 8" x 16" at 44 ft/sec and a 0.22 caliber rifle bullet at 960 ft/sec without penetration. Part 229.119 also requires that the windows provide an undistorted view of the right-of-way from the normal driving position, but does not impose quantitative requirements.

Type II - for side facing windows sustain impacts from a 24 lb object with dimensions 8" x 8" x 16" at 12 ft/sec and a 0.22 caliber rifle bullet at 960 ft/sec.

b) Other U.S. Standards and Practices

Emergency exits: four emergency exits of minimum size, 18" x 24", are required in each 85 ft. long car (AAR Ref).

Maximum window size: normal maximum window size is 1100 sq. inches. This requirement was developed to minimize the risk of passengers being ejected from a car in an accident, particularly after it has overturned.

c) Foreign Standards and Practices

A series of UIC codes refer to window requirements.

- Locomotive or driving compartment, forward facing windows:
  - Code 617-4 requires that these windows in general terms shall (1) be resistant to penetration by solid objects, (2) should be "zoned" so that even if part of the window is damaged, another part will provide sufficient visibility to continue running, and (3) if broken, fragments shall not have sharp edges. There are no specific impact strength requirements.
  - Code 617-7 specifies a minimum field of view from forward facing windows when seated in the driving position.
  - New requirements (1987) added in code 651 (ordered).

- Locomotives or driving compartments, side facing windows and other glass.
  - — Code 617-4 requires that (1) toughened or laminated safety glass be used, i.e., that which if broken will not have sharp edges. (2) Similar standards must be met by any other glass in the cab - internal doors, lockers, gauges, etc. (3) At least one window on each side must be large enough to serve as an emergency escape window. The glass must be breakable to permit emergency escape.
  - — There are no specific impact strength requirements.
- Passenger car side windows.
  - — Code 564-1 requires that (1) all windows shall be of toughened or laminated safety glass. This applies to both panes of double glazing. (2) at least two windows per car (one on each side) shall be emergency escape windows. This can be achieved by having the window removable from its frame, or providing an "emergency hammer" for breaking the glass. The "hammer" approach is the most common. There are no specific impact strength requirements.
- Individual railways use their own specifications to meet or exceed these requirements, especially impact standards for forward facing engineers cab windows.

d) Commentary

- Comparability
  - — The U.S. glazing material requirements are both more specific and more stringent than those used by European railways. There are good reasons for this in the greater likelihood of "foreign objects" on the track, vandalism and use of firearms in the U.S.
  - — The emergency escape requirements from passenger coaches are similar.
  - — There is no European equivalent of the U.S. "maximum size" requirement.
  - — There is no U.S. equivalent of the UIC requirement for emergency escape windows from locomotives and driving cabs.
- Operating environment
  - — Greater likelihood of vandalism, carelessness and use of firearms in the U.S.

- Accident history

  — Earlier incidents led to the introduction of the FRA safety glazing requirements. Railroads and commuter agencies report high incidence of glazing damage due to impacts.

- Effects of high speed

  — Higher impact speeds when foreign objects strike train, especially forward facing windows.

  — Higher air pressure shocks when trains pass at high speed, especially in tunnels.

e) Discussion, Conclusions and Recommendations

The present FRA safety glazing requirements were developed for good reasons, but for generally lower speed operations. Some improvements to reflect the needs of higher speed might be worth study.

— Increasing the impact requirements for forward-facing windows, because of greater impact forces at higher speed.

— Consider a requirement for emergency exit from locomotives or driving cabs.

— Examine whether maximum window size, or some other requirement such as a requirement to sustain minimum force or pressure might be the best way to cover the need to minimize the risk of ejection from windows in an accident.

— Consider ability to withstand air pressure shocks due to high speed trains passing at speed.

II.2.3 Track and Infrastructure

II.2.3.1 Track Construction

a) FRA Regulations

In general, the FRA Track Safety Standards (CFR 49 Part 213) are primarily maintenance standards specifying minimum track condition standards. However, two paragraphs are effectively track design standards. These are:

Para 213.57	Maximum cant (superelevation) 6 inches
Para 213.59	Run-off of cant in each 31 feet must not exceed that specified for the track class

b) Other U.S. Standards and Practices

Apart from FRA regulations, railroad track design standards are developed by the American Railway Engineering Association (AREA) and published in the Manual for Railway Engineering. Chapters of the manual relevant to high speed rail track are:

1. Roadway and ballast
2. Rail
10. Concrete ties

Each of these gives detailed material and performance requirements for track components. There are no slab track standards. This kind of track is used in North America only on mass transit systems and a very few selected locations in tunnels.

The AREA manual also has extensive information on the construction of bridges and other structures, and many other facets of railroad civil engineering.

A new High Speed Rail Committee (Committee 17) has recently been formed by AREA.

A satisfactory U.S. practice for concrete tie/CWR track for 125 mph carrying both freight and high speed passenger traffic has been developed for the Northeast Corridor. Much of this development has been documented in the technical press and FRA reports.

c) Foreign Standards and Practices

Universal practice on high speed lines is to use 60 kg/m (121 lb/yd) continuously welded rail, concrete ties, elastic fastenings and rock ballast. Slab track is extensively used in Japan, and selectively elsewhere.

A series of UIC codes lay down track requirements. These are:

Code	Abbreviated Title
700	Classification of lines and wagon load limits
703	Layout characteristics for lines used by fast passenger train (in preparation, not available)
711	Geometry of turnouts for speeds exceeding 100 km/h (62 mph)
714	Classification of lines for the purpose of track maintenance (in preparation, not available)
720	Laying and maintenance of track made up of continuous welded rails

Our review of this issue was somewhat hampered by unavailability of codes 703 and 714 of which revised versions appear to be in preparation. However, current practice on high speed lines is illustrated in Section II.1 in the discussions of French, German and Japanese track structure.

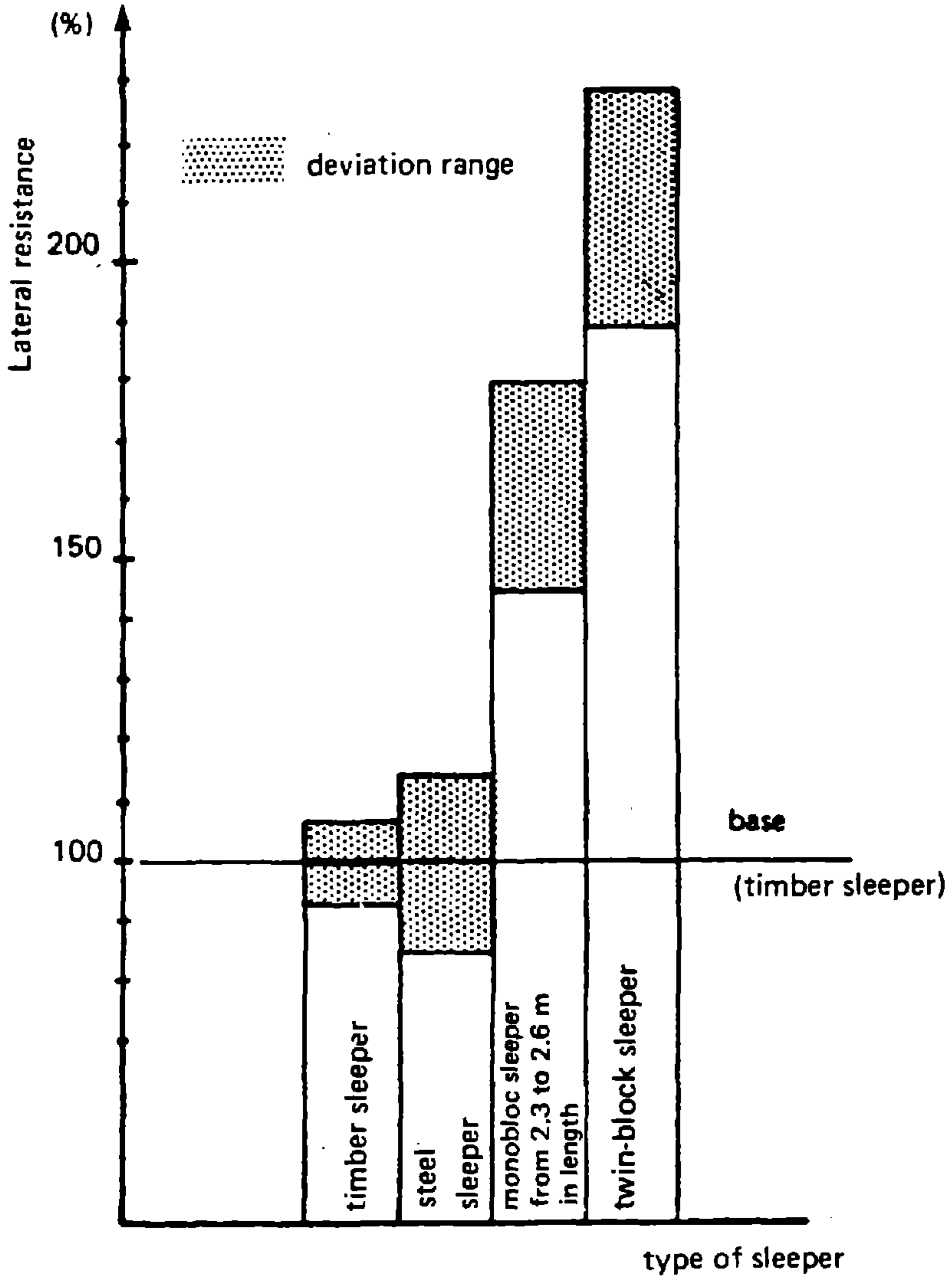
One interesting piece of data, taken from Code 720, illustrates the lateral resistance to deformation of track laid with different tie types. This is shown in Figure II.2.2. Normal tie spacing is 650 mm (25.6 in).

Further series of UIC codes, Numbers 860-866A, lay down material specification for rails, wood ties and other track material. Concrete ties and ballast seem to be the responsibility of individual rail systems. These codes have not been reviewed.

d) Commentary

- Comparability
  - — U.S. concrete tie track is similar to and has, in fact, evolved from European designs of tie and fastener systems. On the most significant installations, heavier rail and tie dimensions are used to withstand the loading from U.S. freight traffic. There is limited U.S. experience of very high speed moveable frog turnouts.
- Environment
  - — If track is used exclusively by high speed trains, there is no difference between the U.S. and foreign operating environment for track. If

Figure II.2.2 Comparative Resistance to Lateral Track Panel Shift as a Function of Tie (Sleeper) Type



Source: UIC Code 720 R "Laying and Maintenance of Continuous Welded Rails" conventional U.S. equipment also uses the track, then the situation is similar to that existing at present in the Northeast Corridor.

  - — Temperature extremes in the U.S. are typically greater than Europe or Canada. Therefore, there may be a greater risk of track buckling incidents under high speed train loads, especially if these involve high cant deficiency operation.

- Past accidents

  - — Track caused accidents are mainly related to deficiencies in maintenance and inspection rather than original construction. Track buckling problems are a possible exception, but these are not particularly associated with high-speed operation.

- Accident consequences

  - — Due to higher speed, the consequences of a track-caused accident will be more severe.

e) Discussion, Conclusions and Recommendations

- Concrete tie ballasted track design in the U.S. is generally similar to Europe or Japan. Since heavier rail sections and tie designs are used in the U.S. (NEC), U.S. track is typically stronger. Therefore, there would seem to be no problems with high speed track strength warranting research (such as tie and fastener design).

- There is little use of high speed turnouts in the U.S. Loadings, strength and geometrical standards should be studied, especially for moveable-point frogs. Amtrak is understood to be currently testing a moveable-point frog in the Northeast Corridor.

- The combination of CWR, high cant deficiency curving, and U.S. temperature extremes may result in a higher risk of track buckling. This deserves investigation.

- There is little background in slab track issues. If use of slab track was proposed by an intending operator, an examination of track loadings and strength would be appropriate, especially rail-slab fastener systems, and how lateral load is shared between adjacent fasteners. It is likely that foreign standards would prove suitable, however, unless there is something unusual about the operating environment.

II.2.3.2 Track and Roadway Inspection and Quality Standards

a) FRA Regulations

The FRA track safety standards CFR 49 Part 213 lay down minimum track quality standards as a function of maximum speed, and inspection frequencies as a function of speed and/or traffic density. The highest FRA track class is Class 6, considered acceptable for passenger train speeds of up to 110 mph. The principal quality and inspection requirements for a typical Class 6 track are:

- Track quality
  - Geometry — as defined in Table II.2.13.
  - Good drainage and absence of excessive vegetation.
  - Minimum 14 good cross ties (out of a normal 20) per 39 ft. (wood tie track only). There are no requirements specifically aimed at the concrete ties and direct fixation fasteners universally used on high speed lines.
  - No rail defect exceeding the specified sizes.
  - Frogs, switches and other special trackwork without defects as specified.
- Inspections
  - Visual or equivalent automatic inspection at least twice weekly.
  - Switches and crossings at least monthly.
  - Annual automatic rail defect inspection, except can be 3 years after installation defect-free new rail.

b) Other U.S. Standards and Practices

There are no formal U.S. track inspection and quality standards and practices other than those embodied in the FRA regulations. Individual railroads have developed in-house practices on standards that are equal to or more stringent than FRA requirements.

Most railroads now operate a track geometry car, at typically 6 to 12 month intervals.

A relatively new AREA Committee, Committee 2, is devoted to automatic track inspection techniques. Committee 32 is concerned with the management of track quality data among other matters. Both are in the process of developing new

TABLE II.2.13

INTERNATIONAL TRACK GEOMETRY STANDARDS

(All quantities in inches)

Note that measurement bases and definitions differ

Quantity	U.S. (FRA Class 6)	SNCF Paris South East 167 mph	British Rail 225 mph (Max Acceptable)	JR Shinkansen 130 mph
Gauge	56"-57.25		N/A	56.34"-56.74"
Alignment	Max deviation ± 0.5" over 62 ft chord		0.09" max. standard deviation over 200 m segment (peak deviation approx. 0.27")	0.24" deviation on 34 ft. chord
Surface	± 0.5" max. deviation on 62 ft chord		0.13" max. standard deviation in 200 m segment (peak deviation approx. 0.39")	0.39" deviation on 34 ft. chord
Crosslevel	0.5" in 31 ft max runoff in spirals. Elsewhere max. variation of 0.625" between any points less than 62 ft apart	See following Table II.2.14	Not Available	0.25" max. twist in 8 ft 0.28" max. crosslevel deviation

recommended procedures, but actual track quality standards are still likely to be the responsibility of individual railroads.

Amtrak operates a track geometry car monthly on the 125 mph sections of the Northeast Corridor. Amtrak also maintains "higher than Class 6" geometry standards, although this may be done primarily for passenger comfort rather than for safety. In addition to the geometry car monitoring, Amtrak monitors ride quality in service trains to identify locations with unsatisfactory track quality.

c) Foreign Standards and Practices

Track geometry quality standards used on various high speed lines are given in Tables II.2.13 and II.2.14 alongside the FRA Class 6 geometry requirements. Note that some of the quantities are not strictly comparable, because of differing measurement chord lengths.

Other quality and inspection criteria are:

- SNCF High Speed Line
  - Acceleration recording on-board train weekly, maximum acceptable transverse acceleration 0.15g.
  - Track geometry car every three months
  - Rail defect detector car. In years 1 and 7, after the rail is laid new, then every two years.
- Shinkansen
  - Track inspection car survey every 10 days.
  - Acceleration recording on-board train every 2-3 days.
  - More sophisticated track inspection car with more capabilities (e.g., corrugation measurement, rail flaw) every 3 months.

d) Commentary

- Comparability
  - Track geometry standards and inspection intervals are generally similar in the U.S. (Amtrak Northeast Corridor) and on high speed lines elsewhere. As would be expected, geometry standards, especially gauge, are tighter than FRA Class 6, but this is true of Amtrak practice in the Northeast Corridor

TABLE II.2.14

TGV TRACK GEOMETRY: ALLOWABLE LIMITS OF DEFECTS FOR SPEEDS ABOVE 137 MPH (220 KM/H)

	Measuring Baseline	Recurrent Defect Limits		Isolated Defect Limits	
		Peak to Peak	Unilateral	Peak to Peak	Unilateral
Longitudinal Level	31 ft (10m)	3/16" (5mm)	± 3/32" (2.5mm)	3/8" (10mm)	± 3/16" (5mm)
	100 ft (31m)	5/16" (8mm)	5/16" (8mm)	3/8" (10mm)	± 3/8" (10mm)
Alinement (Alignment)	31 ft (10m)	1/4" (7mm)	± 1/3" (3.5mm)	1/2" (12mm)	± 1/4" (6mm)
	100 ft (31m)	5/16" (8mm)	5/16" (8mm)	1/2" (12mm)	± 1/2" (12mm)
Cross Level	31 ft (10m)	5/32" (4mm)	± 3/32" (2.5mm)		
Twist (Warp)	10 ft (3m)		± 3/16" (4.5mm/3m)		
Gauge		3/32" (2mm)		3/16" (4mm)	

These defects are generally measured from graphs printed out by the track geometry recording car (Mauzin car). Whether recurrent defects or isolated defects, the allowable limits are measured either by the peak-to-peak value, or the "unilateral" (peak-to-the-average) value.

Source: "Safety Factors Related to High-Speed Rail Passenger Systems," Transportation Research Circular No. 351, Transportation Research Board, July 1989.

also. It is highly unlikely that track with concrete ties and elastic fasteners would have gauge variations anywhere near that permitted by FRA Class 6.

- Operating environment
  - — On lines dedicated to high speed passenger trains, there will be no significant differences between the operating environments in the U.S. and elsewhere. If the lines are also used by conventional U.S. railroad traffic, then the higher axleloads may result in more rapid track degradation, and thus a need for more frequent inspections.
- Accident history
  - — Track defects such as broken rails or subgrade washouts have the potential to cause catastrophic accidents and are a significant accident cause, both in the U.S. and elsewhere.
- Accident consequences
  - — The accidents, usually derailments, will have more severe consequences due to the higher speed operations.

e) Discussion, Conclusions and Recommendations

U.S. and foreign practice regarding track quality standards and inspection intervals are generally similar, and this present practice appears to offer adequate safeguards. The principal exception would be if any local track segment was vulnerable to a weather related hazard, such as a flood, washout, rockfall or similar event. In such a case, additional inspections and hazard detection systems would be warranted. This is further discussed in the section on right-of-way security.

Our initial view is that track quality and track inspection procedures as currently practiced on high speed lines, in both the U.S. and elsewhere, provide adequate safety. However, this practice, both regarding track quality standards and inspection procedures and intervals needs to be codified for potential new operators. Therefore, development of guidelines or codes-of-practice is recommended, based on appropriate U.S. and foreign practice. One accident cause where the U.S. operating environment is more severe than Europe or Japan is track buckling. Temperature extremes are greater and thus greater care has to be taken to avoid occurrences, which would be catastrophic at high speed. A review of previous research on these issues, leading to guidelines on track maintenance practices to avoid track buckling is recommended. This is particularly important if high cant deficiency operation with tilt trains is planned.

II.2.3.3 Right-of-Way Security (Excluding Grade Crossings)

This heading covers such issues as fencing, guarding against right-of-way intrusion and problems arising out of sharing the right-of-way with other types of rail service. The specific issue of grade crossings is dealt with separately.

a) FRA Regulations

There are no FRA regulations.

b) Other U.S. Standards and Practices

The AREA manual provides specifications for fences, but there are no standards or guidelines for where fences should be used, other than in the special case of snow fences. U.S. practice is not to fence railroad right-of-way, except locally where special protection is considered warranted.

Rock slide detector fences (fragile wire) are used where there is a risk of a rock fall encroaching onto the right-of-way. These are linked to the signal system and turn signals to danger when activated.

High wind detectors are used in a few locations, for example, on the Union Pacific Railroad in Wyoming, where high winds have caused incidents with double-stack container trains or multilevel automobile carriers.

Some mass transit systems (for example, Atlanta and Washington Metros) have become concerned about encroachment onto their right-of-way caused by accidents on parallel freight railroads, and have been developing protective measures, such as intrusion sensors and barriers.

c) Foreign Standards and Practices

The French, Japanese and German new high speed lines are fully fenced throughout. In the UK, railroads have had to be fully fenced by law from the earliest time. The original reason was to prevent livestock straying onto the railroad right-of-way. Elsewhere in Europe, rail lines have been selectively fenced as considered necessary, but there has not been a requirement for universal fencing.

We believe that the SNCF has installed intrusion detection systems where major highways run parallel to high-speed lines and also at highway overbridges, but no details are available.

Hazard detection systems, especially for earthquakes, heavy snowfall and high winds, are used extensively on the Japanese Shinkansen, and are linked into the train control system. An alarm triggers speed reductions or cessation of operations as appropriate.

As far as we are aware, none of the countries that operate high speed services on existing track shared with other types of rail traffic (UK, France, Germany) have taken any special precautions to reduce the risk of an accident to a freight or slower speed passenger train impacting a high-speed train.

Regarding safety of railroad personnel working on the track, UIC codes 730-3 and 965R set standards for automatic systems for warning such personnel of approaching trains, and general guidance regarding safe procedures.

d) Commentary

- Comparability
  - Universal fencing of right-of-way is practiced in the UK and on all high speed lines, but not elsewhere.
  - Intrusion and hazard warning devices are used on some systems, especially on the Shinkansen and possibly on the French high-speed lines.
  - No special precautions are taken where high-speed trains share tracks or a right-of-way with other forms of rail traffic, either in the U.S. or elsewhere.
- Operating environment
  - In the U.S., members of the public frequently go onto railroad rights-of-way. This behavior is much less common in Europe. The reason appears to be the relatively low speed, high noise level and low frequency of much U.S. railroad traffic, leading to a public perception that this behavior is not dangerous. In Europe, rail traffic more often consists of frequent, swift and silent electric-powered trains, leading to a greater awareness of the dangers.
  - There is also a greater risk of vandalism to railroad installations in the U.S., although this is a problem elsewhere also, especially in the UK.
  - Weather and earthquake hazards are dependent on location, both in the U.S. and elsewhere.
  - Accidents to U.S. freight trains appear to be frequent enough to pose a significant risk where high-speed trains share tracks or a common corridor with a busy freight line. Recent accidents on freight railroad tracks adjacent to Washington Metro have highlighted this problem.
- Accident history
  - Casualties to trespassers, due to being hit by trains, is a serious cause of casualties on U.S. passenger railroad systems, comparable to casualties in

grade crossing accidents. Being hit by moving equipment, mostly in switching and track maintenance activities, is the most serious cause of casualties to railroad employees and other non-trespassers (for example, employees of railroad contractors).

- Accident consequences
  - — Any accident resulting from a high-speed train hitting an object intruding on the right-of-way will be more serious at high speed. This is also true of any accident that occurs as a result of an earthquake, high winds, flooding, snowfall, and other similar events.
  - — There is also a significantly higher risk of any person on the right-of-way being hit by a train. This is true regardless of whether the person is a trespasser or a railroad employee or contractor with a legitimate reason to be on the right-of-way. Apart from the speed, the likely use of electric traction will make the trains quieter, and they will also be more frequent than normal in the U.S.

e) Discussion, Conclusions and Recommendations

Avoiding right-of-way intrusion, and avoiding conflicts between people and trains are both very significant potential causes of accidents or casualties. Therefore, there is a need to properly evaluate these risks, review international practice in more detail and to develop a set of guidelines for use on high-speed lines.

It is also clear, without any more study, that secure fences throughout will be essential on new high-speed lines, to prevent trespass and vandalism.

The particular issue of the sharing of tracks or transportation corridors with rail freight operations deserves a special study to evaluate what kinds of combinations are acceptable (rail traffic density, train speed and type, etc.), and what measures need to be taken to prevent encroachments or collisions from this cause. A recent study by Arthur D. Little on behalf of a transit authority determined that the risk of encroachment is significant, and the most effective protective measure was a reliable encroachment detection system.

II.2.3.4 Grade Crossings

a) FRA Regulations

- There are no specific FRA regulations governing grade crossings.
- The signal system regulation 49 CFR Part 236 governs signal installations. However, there are no requirements concerning grade crossing protection systems, including any requirements for specific protection systems to be installed in specific circumstances.
- There is a general obligation laid on the FRA and the Federal Highway Administration to work on initiatives to reduce grade crossing accidents and incidents.

b) Other U.S. Standards and Practices

Grade crossings are permitted in the U.S. at rail speeds up to the maximum of 110 mph. In practice, the only 110 mph operations over grade crossings are on the limited stretches on the New York-Albany line with the Turbo trains. All grade crossings on the Northeast Corridor where speed may exceed 100 mph have been eliminated. Most Amtrak trains operate at a maximum speed of 90 mph, where permitted by the signal system. Speeds of 79-90 mph across grade crossings are common. The 1987 Rail Highway Crossing Accident/Incident and Inventory Bulletin gives the following (Table 61):

Speed Range (mph)	81-90	91-100	100-110	110+
Number of Crossings	593	9	5	1

Only 220 of the 593 crossings between 81 and 90 mph are protected by active warning devices (lights, gates, bells).

AAR signal system standards and the Federal Highway Administration (FHWA) Manual on Uniform Traffic Control Devices lay down standards for grade crossing warning systems, but do not specify criteria on where specific types of systems should be installed. An FRA publication, "The Rail-Highway Crossing Resource Allocation Procedure Users Guide, Third Edition (DOT/FRA/05-87/10) provides guidelines on how to calculate the safety benefits of upgrading grade crossing warning systems.

c) Foreign Standards and Practices

- Canada has restricted maximum speed across grade crossings to 95 mph.
- There are no grade crossings on the new high speed lines in Japan, France, Italy or Germany.

- European practice is to permit operation at up to 200km/h (125 mph) over grade crossings on existing lines.

- European practice is governed by two UIC codes:

  - 761 Technical Directives for the Automatic Operation of or Warning to Level Crossings

  - 762 Safety Measures to be Taken at Level Crossings Situated on High Speed Lines

- At least half-barriers, flashing lights and bells are recommended warning devices. The crossing systems should have provisions to sense train speed and provide an approximately consistent warning time to road traffic. It should also be arranged to prevent the very short duration barrier opening that occurs when a second train approaches the crossing from the opposite direction to the first train.

- In the UK, there has been a deliberate program to eliminate crossings on lines operated at 100 mph or more. Very few such crossings now remain.

d) Commentary

- Comparability

  - European practice is to operate at up to 125 mph over grade crossings on existing lines. De facto U.S. and Canadian practice is to restrict speed across crossings to 90/95 mph with few exceptions.

- Operating environment

  - European highway uses appear to be more likely to respect crossing warning systems than U.S. highway users. Also, Europeans are much more familiar with high speed passenger rail operations. Most grade crossings with high speed rail traffic have had frequent and fast passenger rail traffic for many years, albeit at a somewhat lower speed.

- Accident history

  - Grade crossing accidents are one of the two most serious causes of casualties associated with U.S. passenger rail operations (persons hit on the right-of-way is the other). Train accidents due to grade crossing collisions are less significant, but still occur, especially if the highway vehicle is a heavy truck.

- Accident consequence
    - The higher the speed, and the lighter the train, the more likely the grade crossing collision will lead to derailment or serious damage to the train.

e) Discussion, Conclusions and Recommendations

Grade crossing collisions are one of the two major causes of casualties in U.S. rail passenger operations. Grade crossing collisions are also a significant cause of train derailments. Operation at higher speed, and with the lighter weight vehicles typical of high speed trains may increase the risk of derailment or significant damage to the train, and of the collision happening in the first place.

Therefore, a thorough examination of the risks and consequences of grade crossing accidents involving high speed trains is recommended. While we recognize that new high speed lines will be grade separated, use of existing lines for portions of a route is also likely, and the questions of the need for grade separation, maximum speeds over grade crossings and appropriate types of grade crossing protection and other precautions are likely to arise.

II.2.4 Signalling and Electrification Systems

II.2.4.1 Signal and Train Control System Design

a) FRA Regulations

49 CFR Part 236.0 requires that trains operated at speeds of 80 mph or higher must be equipped with an automatic cab signal, automatic train stop or automatic train control system complying with the detailed requirements as defined elsewhere in Part 236. In summary, these systems shall operate in connection with an automatic block signalling system, and either display the same or a more restrictive signal aspect in the cab, and/or initiate braking if a restrictive signal aspect is passed and the engineer fails to initiate braking. Braking must be initiated early enough for the train to stop before an occupied block or conflicting turnout setting. Automatic train stop or control systems may include a device by means of which automatic brake application can be forestalled.

Every train operating in automatic train control or cab signal territory shall be equipped with a system meeting these requirements. Part 236 also includes a large number of detailed requirements regarding track circuit operation, automatic block systems, and individual signalling devices.

49 CFR Part 220 contains instructions for radio communications, and procedures for issuing train orders by radio. Also, all radio communications and radio equipment must comply with Federal Communications Commissions (FCC) requirements.

b) Other U.S. Standards and Practices

There are a very detailed set of signal system standards and practices published by the Communications and Signal Division of the Association of American Railroads. These have not been reviewed in detail.

c) Foreign Standards and Practices

UIC Code 734 R lays down recommendations for signalling systems for high speed lines. These reflect the characteristics of the signalling and train control system used on the French and German high speed lines as described in Chapter II.1.

Some particular points are of relevance:

- Traditional lineside signals are acceptable up to 140/160 km/h (87-100 mph).

- Between 160 and 200 km/h (100 and 125 mph), traditional signals should be enhanced by cab signals and/or automatic train control, and an additional signal aspect or other form of advance warning of a restrictive signal aspect must be added to accommodate the longer braking distances at higher speed.

- Above 200 km/h (125 mph), full cab signalling, and continuous automatic train control with speed supervision must be provided. The speed supervision should include all temporary and permanent civil speed restrictions, as well as responding to any fault detection systems. Lineside signals cannot form part of the system, except as a lower speed backup. Trains must also be provided with voice communication to dispatcher. On mixed traffic high-speed lines, slower traffic does not have to be equipped with the high speed ATC system.

In addition to Code 734, the series of UIC codes 730-739 governs signal system installations, and contain many detailed requirements.

Regarding general practice in European countries, there is a significant trend, most notably in Sweden and France, to install an ATC and a speed supervision system on all principal lines in an effort to reduce human-error accidents.

d) Commentary

- Comparability

  — There is no U.S. regulation, standard or practice for signalling and train control which requires signalling systems having a performance equivalent to that required by UIC Code 734 for speeds in excess of 125 mph, or as used on the Japanese, French or German high speed lines.

  — The signal and train control system characteristics required in Europe for speeds between 100 and 125 mph is broadly similar to the FRA requirement for speeds of 80 mph and over. The principal difference is that in the U.S., all trains operating on a line equipped with cab signals and/or ATC have to meet the minimum requirements. In Europe, only high speed trains have to meet the minimum requirements.

  — There are many detailed differences between U.S. and European "conventional" signalling practice. Some such differences are detailed in the paper by Richard P. Armstrong, "North American Versus European Signalling Philosophies," presented by AAR C&S Division Annual Meeting, 1984. Table II.2.15 is a summary of the differences, taken from this paper. In general, European equipment is more complex but less rugged than North American equipment.

  — Foreign radio communications equipment and procedures may need to be modified to comply with FCC requirements.

- Operating environment

  — In general, signalling equipment in the U.S. has to ensure more severe weather extremes, and may be more subject to vandalism.

TABLE II.2.15

COMPARISON OF SIGNALLING PRACTICE IN U.S. AND EUROPE

ITEM: Recommended practices, including specifications and requisites for design of signalling equipment and systems are set forth by:

NORTH AMERICAN PRACTICE	EUROPEAN PRACTICE
AAR	UIC in Europe and BRB in Great Britain.

ITEM: The Federal regulating Agency which issues the rules, standards, and instructions for repair of signalling systems and appliances is:

NORTH AMERICAN PRACTICE	EUROPEAN PRACTICE
FRA in U. S., similar federal organizations exist in Canada and Mexico.	Federal Regulating bodies similar to FRA exist in the individual European states and Great Britain.

ITEM: System Power:

NORTH AMERICAN PRACTICE	EUROPEAN PRACTICE
Low voltage 10-12V dc logic power supply from batteries	Higher voltage 20-60V dc logic power supply
Battery backup	Motor generator sets/large battery cell groups to accommodate the higher voltage power requirement.

ITEM: Vital relays:

NORTH AMERICAN PRACTICE	EUROPEAN PRACTICE
High efficiency (relative large magnetic structure)	Generally miniaturized, with smaller magnetic structure requiring more power
3000V breakdown	2000V breakdown
Higher dead weight torque by spec.	Lower or unspecified dead weight torque
Minimum of 1/8 inch clearance between case and moving parts by spec.	Lower permitted clearance
Wider temperature range	Smaller temperature range
Non-weldable front contact material by spec.	Both weldable and non-weldable contact material acceptable by UIC. Non-weldable contact material required by BRB.
Relay design generally presents a transfer (F/B) contact arrangement.	Relay design presents an independent contact arrangement.
Intrinsic immunity to AC	Generally not intrinsically AC immune. Exception is BRB special AC immune line of relays.

ITEM: Track Circuits:

NORTH AMERICAN PRACTICE	EUROPEAN PRACTICE
Minimum of 0.06 ohm sensitivity required by FRA.	0.25 - 0.50 ohm shunting sensitivity.
Double rail ac and dc with broken rail detection requirement by FRA.	Both double rail and single rail. Broken rail detection not required. Consequently, intermittent train detection systems such as check-in/check-out and count-in/count-out permitted.
Generally non-resonated impedance bonds used in electrified territory	Resonated (capacitor tuning) used in electrified territory due to higher shunting sensitivity requirement. Resonated impedance bonds considered less reliable.
Long coded dc track circuits with intrinsic immunity to stray dc up to 11,000 feet and elimination of line wires through vital rate decoding.	Coded dc track circuits with vital wayside rate decoding has not been observed.

ITEM: Switch Machines General:

NORTH AMERICAN PRACTICE	EUROPEAN PRACTICE
Rigid front assembly with one throw and detection rod.	Separate throw and detector rods for each switch point.
1/4" fine point adjustment	1/8" fine point adjustment

Source: Richard P. Armstrong and Jeremy C. Hill, "North American Vs. European Signalling Philosophies." Paper to the AAR C&S Division, 1984 Annual Meeting

TABLE II.2.15 (Continued)

COMPARISON OF SIGNALLING PRACTICE IN U.S. AND EUROPE

ITEM: Switch Machines Power:

NORTH AMERICAN PRACTICE	EUROPEAN PRACTICE
Overload protection by current sensitive relay	Overload protection by fuse, circuit breakers, and/or timer.
Low voltage dc switch machines generally applied to CTC territory	High voltage ac/dc switch machines
Non-trailable	Trailable and non-trailable
Manual lever operation	Crank handle

ITEM: Hand Operated Switches:

NORTH AMERICAN PRACTICE	EUROPEAN PRACTICE
Electromechanical lock for movements over 20mph	Electromechanical locks, sometimes similar to Saxby-Farmer interlocking machine and status lamps

ITEM: Signals:

NORTH AMERICAN PRACTICE	EUROPEAN PRACTICE
Multi-aspect configuration also displays route info	Signals require supplementary route indicator signals to temper train speeds at diverging points.
Dwarf signals employed for slow speed movements within interlocking limits	Dwarf signals reserved for shunting (drilling) movements.
Shunting signal aspects incorporated in main signal	Dedicated shunting signal
2 pin, high voltage main filament with or without low wattage backup filament	3 pin, 2 filament 20W lamp with changeover relay
Filament failure reporting by train crew	Automatic filament failure reporting on all signals to central office/local panel.
Light out protection to prevent false upgrade only	Lightout protection on all signals
Approach lighting used	Approach lighting not used
No control on brilliance (day/night)	Day/night signal lamp brilliance control
Lamp supply 10-12V ac/dc	Lamp supply 110/220V in conjunction with step-down transformer

ITEM: Signal Overlaps:

NORTH AMERICAN PRACTICE	EUROPEAN PRACTICE
Signal overlaps not used except mechanical trip stop transit systems which employ full block overlap	Overlap of approximately 200 meters is common

ITEM: Signal System:

NORTH AMERICAN PRACTICE	EUROPEAN PRACTICE
Permits all manner of parallel movements in station areas	Parallel movements in station areas restricted, based on signal overlap provisions
	More hardware intensive relative to provisions:
	Signal overlaps
	Side point protection
	Dedicated shunting signals
	Sophisticated lightout protection

ITEM: Highway Crossings:

NORTH AMERICAN PRACTICE	EUROPEAN PRACTICE
Automatically operated	Many include on-site or remote surveillance
Back lights used	Lamps may be (Hot) filament checked without provision of back lights.
Motion sensing equipment used to reduce road traffic delays	Motion sensing equipment not as extensively used
Intermittent devices/systems not used for warning systems	Intermittent devices/systems commonly used for warning systems
Gates 12V dc operation	Gates 24V dc or higher operation

TABLE II.2.15 (Continued)

COMPARISON OF SIGNALLING PRACTICE IN U.S. AND EUROPE

ITEM	NORTH AMERICAN PRACTICE	EUROPEAN PRACTICE
Train Describer:	More recent development thru use of computer office logic	Common throughout Europe for many years.
Office Control Panels:	Provide only controls and indications necessary for control of territory	Tendency to provide additional test/alarms controls/indications generally considered in North America as "maintenance" aids
Automatic Train Control:	Continuous train detection with emphasis on continuous ATC for both main line and transit	Wide diversification of both intermittent and continuous train detection and ATC
Vital Microprocessor:	Systems based on single processor vitality, as well as systems based on redundant hardware and voting schemes. US&S advocates the single processor vitality concept which presents a more reliable and cost effective system	Systems based on redundant hardware and voting schemes

Both the North American and European signaling philosophies have demonstrated excellent safety records over the years.

AAR equipment specifications for signaling equipment are generally more stringent than that of its European counterparts.

The North American philosophy which generally does not embrace signal overlaps, side protection at turnouts, sophisticated signal lightout protection schemes, etc., for CTC operation provides a less equipment intensive and more flexible operating system. A large share of the credit has to go to the employment of efficient and dependable pneumatic train brake equipment, and the pride and high standards of the "Brotherhood" in qualifying locomotive engineers with their excellent operating record within the operating guideline of the "Standard Code". We compliment the Association of American Railroads including their Signal, Operating, and Maintenance of Way Departments. We also complement the members of the industry and the FRA for jointly developing the traditional set of specifications and regulations that serve as the basis for the successful industry that it is today, and which will continue to serve as the basis for future developments.

- Accident history

  - Accidents caused by a malfunction of a signalling system itself are extremely rare, both in the U.S. and elsewhere. When these do occur, they are often caused by faulty installation or maintenance work. Much more significant are human-error accidents that could have been prevented by a signal system with more comprehensive capabilities.

- Accident consequences

  - Because of the higher speed, accident consequences, signal-malfunction-caused collisions or derailments (damage and casualties) will be more severe. More speculatively, high speed may increase the risk of accidents caused by failure to obey signals and operating rules. However, there is no direct evidence for this.

e) Discussion, Conclusions and Recommendations

Definition of signal and train control system capabilities is one of the most important safety issues for high speed rail. At present, North American signal systems and practices have not been adapted to the needs of high speed rail operations at speeds in excess of 125 mph. For example, there are no standards or practices applicable to systems that place total reliance on cab signal systems, and lineside signals are not used. Furthermore, because of the somewhat different and more arduous operating environment and the potential need for compatibility with existing U.S. regulations and standards, the direct transfer of foreign practice may not be entirely satisfactory.

Therefore, there is a need for research into high speed rail signal requirements. Such research should include:

- A more detailed description and comparison of signalling practice in the U.S. and on foreign high-speed passenger lines.

- Definition of high-speed rail signal system and component performance requirements for the North American environment.

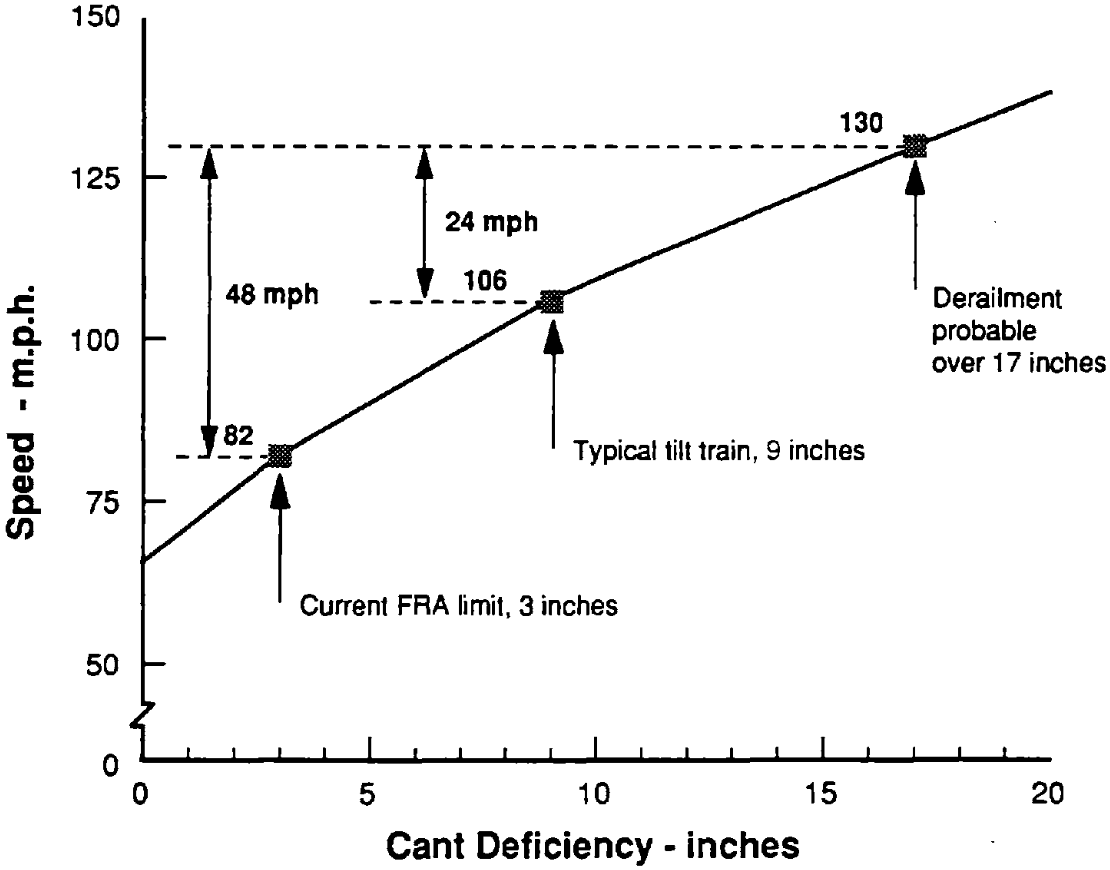
- With the introduction of radio links, microprocessors and other novel equipment into "vital" train control and signalling functions, there is a need to define performance and reliability requirements for these as well as traditional equipment.

- Although not strictly a high speed issue, there is also a need to evaluate the benefits from application of ATC systems to conventional speed rail passenger operation, especially where these involve operation of new designs of high speed trains over existing track at either existing or increased speeds.

- In the special case of tilt train operations at high cant deficiency in curves, there may be a need for a speed supervision system to guard against accidental overspeed. The margin between normal operating speed and an unsafe speed is much narrower with high cant deficiency operation, as illustrated in Figure II.2.3.

Figure II.2.3 Illustration of the Reduced Margin Between Operating Speed and Unsafe Speed When Curving at High Cant Deficiency

Example: 2 degree curve with 6 inches cant



II.2.4.2 Signal System Inspection and Maintenance

a) FRA Regulations

CFR 49 Part 236 specifies a minimum level of inspections and tests to be performed on signal systems and components of all types. Most of these tests are on wayside equipment and involve tests of proper functioning that have to be carried out every 3, 6, 12 or 24 months, depending on the type of equipment.

Cab signal and ATC equipment on a locomotive or in a driving cab has to be inspected and tested daily both "in the shop" when a locomotive is expected to be used in service within 24 hours, and by the engineer on departure or entering ATC territory.

b) Other U.S. Standards and Practices

Numerous inspections and tests are contained in the AAR's manuals of recommended practices. These have not been reviewed in detail.

c) Foreign Standards and Practices

UIC Code 731 R makes some general comments about inspection of signalling systems, but does not lay down any recommendations regarding the frequency of inspections and tests for specific types of equipment. Otherwise, inspection and test practice appears to be the responsibility of individual systems, or as recommended by the signal systems supplier.

Information available on specific inspection and test intervals is rather sketchy, but we have determined the following for the SNCF high speed lines:

- A test car called "Helene" makes a monthly trip over all lines to monitor the condition of track-train communications and train detection systems.
- A total of six signal and train control inspectors are allocated to an 80 km (50 mile) territory. They perform minor maintenance and routine testing. Portable instruments are used for on-site testing and the control center is equipped with test equipment to simulate specific operational conditions. Communications are provided between the control center and the field inspectors.
- Most testing/inspection is carried out at night, when service trains are not operating.

d) Commentary

- Comparability

  — Insufficient information is available for a detailed comparison between U.S. and foreign practice regarding signal and train control systems inspections and tests. However, high speed train signal systems are significantly different from traditional electro-mechanical systems, involving microprocessors, a variety of novel track-train communication systems and on-board installations. These will require very different testing and inspection procedures.

- Operating environment

  — There would not appear to be significant differences in the operating environment for signal and train control systems and components between the U.S. and elsewhere. The only areas might be wider temperature extremes, and potentially greater risk of vandalism.

- Accidents

  — Accidents due to signal system "false all-clear" defects are rare. However, when these occur, they are most often caused by faulty installation or maintenance. Human-error accidents which are preventable by higher-capability ATC systems are significant at conventional speeds.

- Accident consequences

  — Since signal defect-caused accidents typically involve collisions, the consequences of an accident are more severe at high speed.

e) Discussion, Conclusions and Recommendations

Because high speed train control and signalling systems are quite unlike traditional systems, they will have new and different test inspection and maintenance needs.

To ensure safety, it is highly important to have a series of well designed test and inspection procedures:

- To qualify new systems and system component design.

- Acceptance testing of new systems and components at the time of purchase.

- Post-installation testing to ensure proper functioning within the overall system.

- Routine testing at appropriate time intervals.

These requirements apply to both wayside and train-borne equipment. We therefore recommend that a more detailed study of signal test and inspection requirements be carried out. In particular, it will be important to get more detailed information about U.S. and foreign practice, identify the differences, and develop a set of guidelines appropriate to high speed operation in the U.S. environment, and to the kinds of system component being used. A particular concern is the embodiment of novel "vital" microprocessor technology and communication systems into high-speed rail systems.

II.2.4.3 Electric Power Supply

a) FRA Regulations

None.

b) Other U.S. Standards and Practices

- The National Electrical Safety Code for high voltage systems and equipment.
- The AREA manual, Section 33, contains a set of standards and guidelines for overhead catenary electric power supply systems, and the avoidance of interference between the power supply and signalling and communications systems.
- Individual rail systems have also established their own standards for electrification systems, and for procedures for the safe execution of maintenance work and railroad operations activities on and near high voltage catenaries.
- Careful attention to the grounding of all vehicles and fixed plant is essential.

c) Foreign Standards and Practices

European railroads use four systems of overhead catenary electrification:

1500 V DC (France, existing lines)
3000 V DC (Italy)
15 kV 16 2/3 Hz AC (Germany, Switzerland, Austria)
25 kV 50 Hz AC (UK, new lines in France)

In all countries, sets of standards and procedures regarding electrical clearances, protection of high voltage catenaries and other equipment from accidental contact with persons have been established. We have not been able to review this within the scope of this task.

In addition, the following UIC codes are concerned with electrical safety:

- Code 533. Grounding the metal parts of vehicles. Specifies minimum resistance to rail and use of grounding cables and brushes to ensure a low resistance path from the car body to the rail.
- Code 610. Lays down a series of procedures for the testing of electrically powered rolling stock before entry into service.

- Codes 737-3 and 4. Concern with electrical interference between electric traction systems and signalling systems. Preventative measures both on the power system and on signalling systems are specified.

d) Commentary

- On the limited information reviewed, U.S. and foreign practice regarding electrification systems is broadly similar. However, further study will be needed to confirm this.
- Operating environment
  - — Railroad installations in the U.S. are more subject to interference by vandals, and accidentally by trespassers. Such interference can clearly have fatal consequences if high voltage systems are involved. Other possible differences could arise, particularly due to weather environment — high winds, ice storms, etc., which could either cause physical damage or interfere electrically.
- Accident history
  - — There are very few train accidents arising from electrical power supply system malfunctions. Some fires may have such malfunctions as the original cause, but further investigation would be needed to confirm this. Electric shock casualties to employees, and members of the public as a result of trespassing on or other interference with high voltage catenary are potentially important safety issues.
- Accident consequence
  - — There is no reason why the risk of accidents or casualties of accidents associated with the electric power supply system should be different for high-speed systems than for conventional systems. Most casualties are due to electric shock, and are not related to train movements.

e) Discussion, Conclusions and Recommendations

This issue is sufficiently important to warrant more detailed study than has been possible in this review. Therefore, we recommend a more comprehensive effort to gather codes of practice and other material relating to electrical safety, and from these to compare U.S. and foreign practice, leading to development of electrical safety guidelines, where these appear to be not adequately covered in existing codes. These can include:

- — Construction of catenary and power supply systems.

- Protection from accidental contact or deliberate interference (for example, from overline bridges).

- Safety of staff working on the track or on vehicles on electrified track.

II.2.5 Human Factors and Operations

II.2.5.1 Operating Staff Qualifications and Training

a) FRA Regulations

There is a general requirement in 49 CFR Part 217 for railroads to instruct their employees in operating practices, and to conduct periodic tests to monitor and ensure compliance with the operating rules. A description of the nature of these tests and testing schedule must be filed with the FRA.

The exact interpretation of this requirement is the responsibility of each railroad.

b) Other U.S. Standards and Practices

As used by individual railroads.

c) Foreign Standards and Practices

Information on this subject is relatively sketchy in the sources we have been able to use in this study. However, some information has been located, providing the following brief descriptions of practice on the SNCF/TGV and Japanese Shinkansen.

- TGV

  Train crews are recruited from senior employees already qualified for conventional speed intercity trains. Training of a TGV engineer takes 12 days, involving familiarization with TGV controls, instruction in special operating rules applying to the high speed line, and familiarization with the specific features of the line over which they will be operating. The training concludes with theoretical and practical tests. A relatively large number of engineers are trained to drive the TGV, and each will typically drive both TGV's and conventional trains. There is no separate force of TGV engineers.

  The SNCF is also making a broader effort to improve training techniques for all engineers through expanded use of simulators, computer-aided teaching systems, etc.

- Shinkansen

  JR operates an extensive system of schools for craft and management jobs. One of these is a "conversion course" to train narrow-gauge engineers to be Shinkansen motormen. This takes 4 months. Training of personnel without previous experience as an engineer takes 11 months. Courses in other crafts (track maintenance, signal maintenance, etc.) run typically from 1 to 3 months depending on the individual's prior experience.

JR also uses various aptitude and psychological tests to judge the suitability of individuals for operating jobs. Correlation between test scores and accidents has been established, and JR continues to develop and refine these tests.

- British Rail

  BR has also been developing training procedures and aptitude tests.

  — Junior engineers receive a total of about 5 weeks classroom instruction and 10 weeks supervised driving experience before qualifying to go "solo." They will typically then spend several years in less demanding duties before accumulating enough experience and seniority to drive high-speed trains.

  — Personality and aptitude tests form part of the selection procedure for aspiring engineers.

d) Commentary

- Comparability

  — We have little information on U.S. training methods, so comparability cannot be assessed at present. The only high speed passenger service in the U.S. is the New York-Washington Metroliner, so there is little relevant service with which to compare.

- Operating environment

  — Most of the proposed U.S. high speed rail projects envisage introducing services where there has been little previous passenger services of any kind. This is very different from, say, the SNCF, which has a long tradition of operating fast intercity services. The future U.S. operator (with the exception of Amtrak in the Northeast Corridor) will have to train operating staff from scratch.

- Accident history

  — Operator error is a significant cause of accidents to passenger trains in the U.S.

- Accident consequences

  — Because of the higher speeds, there will be more casualties in high speed train accidents.

e) Discussion, Conclusions and Recommendations

Adequate training of operating personnel will be essential for safe operation of a high speed rail service. Foreign practice regarding this training varies considerably. In France, the TGV seems to be regarded as simply another piece of equipment, and training is very brief. However, the SNCF has had long experience of high speed rail operations, and all entry TGV engineers are already senior engineers with long experience.

In Japan, training of 4 to 11 months is provided, depending on the individual's previous experience.

A future U.S. operation will very likely have to train engineers and other operating personnel from the ground up. There is no clear procedure for doing this. Therefore, research into training methods for safety-critical personnel, both in U.S. and foreign railroads, and in industries with comparable safety concerns is highly recommended.

II.2.5.2 Operating Rules and Practices

a) FRA Regulations

Under 49 CFR Part 217, railroads must file a copy of their current operating rules, timetables and other instructions with the FRA. They must also file their programs of tests and inspections, and of employee instructions, keep records of the results, and submit these in an annual report to the FRA. In particular, they must report occasions when employees have been found in violation of "Rule G" prohibiting working under the influence of alcohol or drugs.

49 CFR Part 218 lays down the requirements for protecting rolling stock on which maintenance personnel are working by a blue signal or flag or other means. Another section of the same part provides regulations for the protection of stationary equipment by torpedoes, fusees or flags.

b) Other U.S. Standards and Practices

Most U.S. railroads, at a minimum, have a code of operating rules which includes all the rules contained in the "Standard Code of Operating Rules" published by the AAR.

All railroads also have a set of location-specific operating rules embodied in their timetables and other operating instructions. These typically concern speed limits, where particular types of equipment can operate and similar matters.

One aspect of operating practice is passenger control. Except where high platforms are used (such as in commuter territory and the Northeast Corridor), it is customary for railroad on-board staff (conductors and trainmen) to operate doors and supervise passenger entry and exit.

c) Foreign Standards and Practices

No information on foreign operations is available. A questionnaire has been prepared and sent to Japan Rail and French National Railways, and a response is awaited. If replies are received, these will be incorporated into a future report.

d) Commentary

- Comparability
  - There are significant differences between high-speed rail operations at speeds over 125 mph and traditional U.S. passenger rail operations. Also, the signal and train control systems will be different. Therefore, it will be essential to develop and use appropriate operating rules and practices, which will differ in many respects from present U.S. practice.

- Operating environment
  - — Future U.S. high-speed rail services may be started from the ground up, rather than being a further development on a system with significant past experience of operating high-speed rail service, albeit at a lower speed.
- Accident history
  - — Operator error is the most significant cause of train accidents. Therefore, establishing appropriate operating rules and practices will be very important, even if a sophisticated ATC system is used to supervise engineer actions.
- Accident consequences
  - — Because of the high speeds, accident consequences (casualties and damage) will be more severe in train accidents.

e) Discussion, Conclusions and Recommendations

It has not been possible to conduct an in-depth study of operating rules and practices within the scope of this study. However, it is clear that these are very important in ensuring a safe and accident-free operation. Therefore, a comprehensive study and comparison of high-speed rail operating rules and practices is recommended, leading to guidelines for such rules and practices on a typical future U.S. high-speed rail service. These may need to be compatible with some aspects of existing U.S. practice, and also address the needs of high cant deficiency tilt train operation.

II.3 BIBLIOGRAPHY

II.3.1 Introduction

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A. United States regulations, rules and standards potentially applicable to high-speed rail systems.

B. Technical reports of U.S. origin, primarily prepared by or for U.S. Federal Government agencies, containing material relevant to high-speed rail safety.

C. General literature on international high-speed rail systems, not specific to one foreign railroad system or high-speed rail technology.

D. International standards relevant to high-speed rail systems, primarily the International Union of Railways Codes

Information on individual foreign railway systems and high-speed train technologies, organized by country. The countries included are, in alphabetical order:

E. Canada
F. France
G. Germany
H. Great Britain
J. Italy
K. Japan
L. Spain
M. Sweden
N. Switzerland

Within each group, the literature is presented in chronological order of publication starting with the most recent.

II.3.2 United States Regulations, Rules and Standards

Dates are not stated. The current issue of each document is referenced, unless otherwise stated. Note that the Association of American Railroads (AAR) does not now maintain passenger car Standards and Interchange Rules. However, Rules and Standards originally developed by the AAR are still widely used by U.S. passenger car operators, and have been included in this listing.

A1 Code of Federal Regulations Title 49, current edition

This contains the Federal regulations applicable to rail transportation "on the general railroad system of the United States." Regulations of specific interest in connection with high speed rail are as follows:

Part 210	Railroad Noise Emission Compliance Regulations
Part 213	Track Safety Standards
Part 218	Railroad Operating Practices
Part 223	Safety Glazing Standards - locomotives, passenger cars and cabooses
Part 229	Railroad Locomotive Safety Standards
Part 230	Locomotive Inspection
Part 231	Railroad Safety Appliance Standards
Part 232	Railroad Power Brakes and Drawbars
Part 236	Rules, standards, and instruction governing the installation, inspection, maintenance and repair of signal and train control systems, devices and appliances

A2 Association of American Railroads Manual of Standards and Recommended Practices

The AAR manual is now exclusively concerned with freight car and locomotive standards. However, passenger car standards formerly maintained by the AAR are still widely used in the passenger rail industry, as are standards for individual components such as wheels and brakes. The following sections are of specific interest.

Section A, Part III - Passenger Car Standards (not in current use)

Section B - Couplers and Freight Car Draft Component
Provides details of Type H tightlock couplers for passenger cars

Section F - Locomotive and Electrical Equipment

Section G - Wheels and Axles

Section H - Journal Bearings and Lubrication

A3 Association of American Railroads - The Standard Code of Operating Rules

A4 Association of American Railroads - Communications and Signal Division Manuals of Recommended Practices

These documents provide detailed information regarding the design installation and maintenance of signal and communication systems. They have not been reviewed for the project.

A5 American Railway Engineering Association Manual for Railway Engineering

This is a detailed manual providing standards and practices for all fixed installations of the railroad, including electrification systems, but excluding telecommunications and signalling systems. Specific Chapters of the manual of interest in connection with high speed rail systems are:

Chapter 1	Roadway and Ballast
Chapter 4	Rail
Chapter 5	Track
Chapter 8	Concrete Structures and Foundations
Chapter 9	Highway - Railway grade crossings
Chapter 10	Concrete Ties
Chapter 13	Environmental Engineering
Chapter 15	Steel Structures
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- Volume 3 - ET 403 (Germany)
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- Volume 5 - Series 961 (Japan)
- Volume 6 - TGV-PSE (France)
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Tel (33-1) 42 73 01 20, Fax (33-1) 42 73 01 40.

Ref.	Code Number	Title
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D2	515	Coaches - Running gear (with amendments)
D3	520	Wagons, coaches and vans - draw gear (with amendments)
D4	528	Buffer gear for coaches
D5	533	Protection by the earthing (grounding) of metal parts of vehicles (with amendments)
D6	540	Brakes - Air brakes for freight and passenger trains
D7	541-05	Brakes - Regulations concerning the construction of the various brake components: wheel slip prevention equipment (WSP)
D8	541-5	Brakes - Electropneumatic brakes for passenger and freight trains
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D27	730-3	Automatic warning of track maintenance gangs
D28	731	Inspection of signalling installations
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APPENDIX I

HIGH SPEED RAIL SYSTEMS EXISTING AND UNDER DEVELOPMENT

APPENDIX I

HIGH SPEED RAIL SYSTEMS EXISTING AND UNDER DEVELOPMENT

Canada	-	LRC. 150 km/h now, 200 km/h design performance, active body tilt, existing right-of-way
France	-	TGV. 270-300 km/h, electric power on new right-of-way
	-	ANF Turbo. 200 km/h gas-turbine power, existing right-of-way
W. Germany	-	ICE. 250 km/h electric power, new right-of-way
	-	Class 120 locomotive. 200 km/h electric power, existing right-of-way
Great Britain	-	HST. 200 km/h, diesel power, existing right-of-way
	-	IC 225. 225 km/h electric power, existing right-of-way
Italy	-	Pendelino (ETR 450). 200 km/h plus, electric power, active body tilt, existing right-of-way. Diesel version planned
	-	ETR 500. 250 km/h, electric power, new right-of-way
Japan	-	Shinkansen: (various models). 210-260 km/h, electric power, new right-of-way
Spain	-	Talgo. 160 km/h now, 200 km/h future, unpowered cars only, passive body tilt, existing right-of-way
Sweden	-	200 km/h, electric power, active body tilt, existing right-of-way
Switzerland	-	200 km/h, electric power, existing/new right-of-way
USA	-	AEM7/Amfleet. 200 km/h (125 mph), electric power, existing right-of-way

Note: Countries are given in alphabetical order

APPENDIX II

MINIMUM SET OF CATEGORIES LISTED BY FRA TO BE ADDRESSED IN THE SAFETY ASSESSMENT

APPENDIX II

Minimum Set of Categories Listed by FRA to be Addressed In the Safety Assessment

1. Track construction, roadbed stability
2. Track dimensions, track geometry, track surface
3. Switches, turnouts, crossings, guard rail requirements
4. Horizontal and vertical curving, turn radii, superelevation of curves
5. Vehicle and truck hunting and stability
6. Allowable cant deficiency, vehicle overturning potential
7. Rail rollover, track panel shifting, wheel climb,rail restraint
8. Track location, layout, and proximity to hazards
9. Bridges, stations, platforms and plant structures
10. Weather and seasonal hazards
11. Noise, fumes, electrical or other system generated hazards or environmental issues
12. System security, vandalism, fencing
13. Rail/highway grade crossings
14. Signal and train control systems and applications, including vehicle detection sensitivity
15. Train dispatch, train operations procedures, routing and train priority
16. Vehicle load variations, wheel and axle loading
17. Track-train interaction, in-train forces, train action, coupling
18. Brake systems, stopping distances, parking or train holding systems
19. Inspection frequencies and limits
20. Public hazard awareness, public protection
21. Personnel training, testing, and safety procedures

22. Hazard detection, warning and alert devices
23. Operating rules and procedures, reporting methods
24. Safety appliances
25. High speed vehicle construction, tilt systems, ride comfort limits
26. Fire safety, door operations, glazing, and construction materials
27. Requirements for testing or otherwise qualifying vehicle or equipment designs for use on the system

APPENDIX III

FEDERAL RAILROAD ADMINISTRATION AND URBAN MASS TRANSPORTATION ADMINISTRATION GUIDELINES FOR FLAMMABILITY AND SMOKE EMISSION SPECIFICATIONS

Urban Mass Transportation Administration

Recommended Fire Safety Practices for Rail Transit Materials Selection

AGENCY: Urban Mass Transportation Administration, DOT

ACTION: Notice.

SUMMARY: The Urban Mass Transportation Administration is issuing recommendations for testing flammability and smoke emission characteristics of materials used in the construction of rapid rail transit and light rail transit vehicles. These recommendations are based on the Transportation Systems Center's "Proposed Guidelines for Flammability and Smoke Emission Specifications," which the transit industry, in general, uses on a voluntary basis.

EFFECTIVE DATE: August 14, 1984.

FOR FURTHER INFORMATION CONTACT: James A. O'Connor, U.S. Department of Transportation, Urban Mass Transportation Administration Director, Safety and Security Staff, (202) 426-2896.

SUPPLEMENTARY INFORMATION:

Background

On November 26, 1982, the Urban Mass Transportation Administration (UMTA) published a Notice and Request for Public Comment on "Recommended Fire Safety Practices for Rail Transit Materials Selection," Vol. 47 FR 53559. That Notice proposed recommendations for testing the flammability and smoke emission characteristics of materials used in the construction of rapid rail transit (RRT) and light rail transit (LRT) vehicles. Like the "Proposed Guidelines for Flammability and Smoke Emission Specifications" on which they are based, these Recommended practices are not regulatory in nature. Rather, these Recommended Practices are intended to be used to assess the fire risk of materials used in RRT and LRT vehicles. They do not duplicate actual fire conditions. However, their use will result in the selection of more fire resistant materials, which will minimize the fire threat in RRT and LRT vehicles and thereby reduce the injuries and property damage resulting from transit vehicle fires. Moreover, issuance of the Notice at this time is consistent with the Department of Transportation's position on promoting safety in transportation.

In response to comments, UMTA has made one major substantive change to the Recommended Practices, as well as various editorial and minor substance revisions. The major change was to delete all references to National Fire Protection Association (NFPA) standards. This change is discussed more fully below.

Approximately 25 organizations responded to the November 26, 1982 Notice. The majority of these, including all but one of the commenting transit agencies, generally supported the Recommended Practices. For the most part, these comments suggested only minor changes, such as correcting various typographical errors, and clarifying the list of referenced standards and the notes to Table 1. Most of these comments have been incorporated in this Notice. After careful review, UMTA has chosen not to adopt some comments. UMTA's goal in issuing the Recommended Practices is to suggest a means for providing the highest practical level of safety. It is UMTA's opinion that the comments not adopted would not further this goal.

The major substantive comments that were not adopted concerned: using small scale tests, most notably the American Society for Testing Materials (ASTM) E-162 test method; modifying certain aspects of the performance criteria; substituting tests; addressing toxicity; and expanding the scope of the Recommended Practices.

In regard to using small scale tests, several commenters questioned whether such tests, which test component materials separately, can adequately simulate the synergistic effects of burning the various vehicle assemblies, as may occur in an actual fire. UMTA has determined that small scale tests are the best method to test for the most practical level of safety feasible. Small scale tests are especially useful as a screening device to select materials. As such, they have the advantage of allowing a transit authority to choose its own preferred combination of materials in making up specifications for RRT and LRT vehicles. The fact that there is sufficient correlation between the results of full scale tests and those in the Recommended Practices to support use of those small scale tests has been borne out by full scale tests conducted by the Bay Area Rapid Transit District. Furthermore, there are disadvantages to the use of full scale tests. There are 18 different categories of materials application that require individual testing in a vehicle. A full scale fire test that would determine the merits of combinations of materials would require a series of such tests that would be prohibitive in cost and impossible to perform in a manner that would satisfy all parties. In addition, they would eliminate the small manufacturer who would be unable to compete in such testing. Moreover, one noted expert has stated that full scale tests do not provide basic information on individual components or allow extrapolation to conditions other than those reached in that test.

Also in connection with small scale tests, several commenters referred to the fact that the NFPA states that several of its standards are intended only for use as research and development tools, not for regulatory purposes. Although the Recommended Practices are not regulatory, UMTA recognizes that they will be used for more than research and development. Accordingly, NFPA standards have been deleted from the Recommended Practices. ASTM tests E-662 and E-648 have been substituted for these tests.

Another commenter suggested that a "disclaimer" for the use of the flame spread rating required under a Federal Trade Commission consent order be included in the Recommended Practices. When read in its entirety, however, the disclaimer would not affect the use of the flame spread test as suggested in the Recommended Practices. Given that fact, as well as the fact that the context differs from that of the FTC Consent order, repeating the disclaimer is considered unnecessary.

Several commenters suggested modifying the performance criteria of the tests. Most of these comments suggested relaxing various performance criteria. The most common argument for doing so was that materials are not available that will meet the performance criteria. However, a review of the UMTA materials data bank revealed that in all cases there are sufficient materials to meet the criteria of the Recommended Practices. Moreover, a recent UMTA study, "Assessment of the Benefits and Costs associated with the Adoption of the Recommended Fire Safety Practices for Rail Transit Materials Selection," Transportation Systems Center, Report UMTA-MA-06-0098-81-3, December, 1982, found that the cost of implementing the Recommended Practices would be minimal for new vehicle construction. In addition, several transit agencies recently have used the Recommended Practices successfully in purchasing rail transit vehicles. Again, UMTA believes that relaxing any of the criteria as suggested by the commenters would result in an unacceptable decrease in safety.

Another comment concerning relaxing performance criteria was that the same criteria should not be used for both LRT and RRT vehicles. It is UMTA's position that there is not sufficient difference between the environments on LRT and RRT vehicles to warrant separate tests for their materials. An additional comment was that the restrictions on flammability are such that the restrictions on smoke emissions and, for carpets, critical radiant flux, are unnecessary. UMTA disagrees. There is not necessarily a relationship between flammability and smoke emission, so that the flammabilty test alone does not adequately test for those two characteristics. For example, some situations may result in very little flame spread, but a great deal of smoke. The low flammability will not indicate the smoke emission characteristics of such material.

Several commenters suggested making certain performance criteria more restrictive, for example by requiring additional vehicle materials categories to meet specific optical density requirements for smoke emission. For the most part, these greater restrictions would eliminate otherwise useful materials without a corresponding increase in safety. In the case of electrical cable used for rail transit purposes, there is not at this time enough information available to develop Recommended Practices.

In regard to substituting tests, several commenters objected to the use of the ASTM E-162 test method. UMTA did not adopt these comments because the ASTM E-162 is widely accepted both in the United States and abroad as a means of determining the flame spread of materials that may be used in RRT and LRT vehicles. For example, it is used to test materials for commercial aircraft. On the other hand, although the ASTM E-84, the suggested substitute test, is widely used in the construction industry, it is not necessarily suitable for testing materials for use in LRT and RRT vehicles. For instance, many materials that melt and sag cannot adequately be measured using the ASTM E-84. In addition, the ASTM E-84 is a larger scale test that the ASTM E-162 and therefore more costly. A related issue is whether the Recommended Practices will exist in addition to NFPA Standard 130, or be adopted by the NFPA to replace NFPA Standard 130. One commenter expressed concern over the possible existence of two industry standards. There in fact will be two test protocols if the NFPA does not fully adopt the Recommended Practices, in which case users will choose the best method. UMTA believes that the Recommended Practices reflect the state of the art.

Commenters also requested that UMTA address the issue of toxicity of the products of combustion of these materials in the Recommended Practices. UMTA recognizes the need to address this issue, but because of its complexity, is not able to do so in the Recommended Practices. Instead, in an effort to respond to transit industry needs UMTA has initiated a program to develop guidelines for assessing the combustion toxicity of materials. Recognizing the scope and extreme complexity of this issue. UMTA has requested the National Research Council's (NRC) Transportation Research Board and Materials Advisory Board of the Commission on Engineering and Technical Systems to assist in addressing this issue. In response to this request, the NRC has established a Committee on Toxicity Hazards of Materials Used in Rail Transit Vehicles. This committee, consisting of representatives of industry and academia, will review the present state of knowledge of combustion toxicity, identify specific toxicity hazards related to the use of polymeric materials in transit vehicles, and recommend a plan of action for developing guidelines for testing materials. A workshop will be convened to review the preliminary findings of the study group, with interested parties representing government, mass transit agencies, user groups, and industry in attendance.

Commenters also raised questions about the scope of the Recommended Practices, and their relation to the July, 1979, "Proposed Guidelines for Flammability and Smoke Emissions Specifications." The Recommended Practices supersede those 1979 proposed guidelines. The Recommended Practices are intended for use in selecting rail transit vehicle materials. UMTA does not have jurisdiction over such modes as trucks and mobile homes. Accordingly, it would be inappropriate for UMTA to recommend fire safety tests for selecting materials for those vehicles. Because buses operate in a different environment than RRT and LRT vehicles, UMTA believes it would be inappropriate to use RRT and LRT safety tests for buses. However, UMTA intends to develop similar fire safety materials guidelines for transit bus vehicles in the future.

In addition to suggesting changes to the Recommended Practices, commenters raised several questions that require clarification. One commenter expressed concern that the cost of retrofitting RRT and LRT vehicles would be prohibitively expensive. The Recommended Practices are guidelines, not requirements or regulations. UMTA believes that maintenance of safety on transit systems is a local responsibility and that the application of the guidelines by individual transit systems is a local decision reflecting operating conditions and vehicles in each system. It is not UMTA's intention to direct when and how the guidelines are used, but rather to make them available for use as safety technical assistance to operating and planned rail tansit systems.

Another commenter raised a series of technical questions. The first was whether the materials presented in Table 1 are the only components that require testing. They are. The tests usually prescribe the appropriate specimen geometry for testing the material specimens. If not, the tests should be to the most appropriate geometry.The second was whether Fed-Std. 191A and AATCC-86 are indicative of what will happen to fabrics over their predicted lives. These tests are merely meant to determine whether flame retardant is removed by cleaning the fabrics. The third question was why the Dmax value recommendation for NFPA 258 was deleted. This value was deleted because UMTA determined that measuring smoke obscuration by time was preferable to measuring total maximum smoke obscuration. Therefore, the Dmax value was deemed unnecessary. The final question was when there is more than one material that can be used for a function, to which does the test apply. The answer is that the test applies to all materials that can be used for a particular function.

Recommended Fire Safety Practices for Rail Transit Materials Selection

Scope

The Recommended Fire Safety Practices for Rail Transit Materials Selection are directed at improving the vehicle interior materials selection practices for the procurement of new vehicles and the retrofit of existing RRT and LRT vehicles. Adoption of these recommended fire safety practices will help to minimize the fire threat in rail transit vehicles and, thereby, reduce the injuries and damage resulting from vehicle fires.

Recommended Fire Safety Practices for Rail Transit Materials Selection Application

This document provides recommended fire safety practices for testing the flammability and smoke emission characteristics of materials used in the construction of RRT and LRT vehicles.

Referenced Fire Standards

The source of test procedures listed in Table 1 are as follows:

(1) Leaching Resistance of Cloth, FED-STD-191A-Textile Test Method 5830.

Available from: General Services Administration Specifications Division, Building 197 Washington Navy Yard, Washington, DC 20407.

(2) Federal Aviation Administration Vertical Burn Test,

TABLE 1. RECOMMENDATIONS FOR TESTING THE FLAMMABILITY AND SMOKE EMISSION CHARACTERISTICS OF RAIL TRANSIT VEHICLE MATERIALS

Category	Function of Material	Test Procedure	Performance Criteria
Seating	Cushion[1,2;5;9*]	ASTM D-3675	$I_s \leq 25$
		ASTM E-662	$D_s(1.5) \leq 100$, $D_s(4.0) \leq 200$
	Frame[1;5;8]	ASTM E-162	$I_s \leq 35$
		ASTM E-662	$D_s(1.5) \leq 100$; $D_s(4.0) \leq 200$
	Shroud[1;5]	ASTM E-162	$I_s \leq 35$
		ASTM E-622	$D_s(1.5) \leq 100$; $D_s(4.0) \leq 200$
	Upholstery[1;2;3;5]	FAR 25.853 (Vertical)	Flame Time $\leq$ 10 sec; burn length < 6 inch
		ASTM E-662	$D_s(4.0) \leq 250$ coated $D_s(4.0) \leq 100$ uncoated
Panels	Wall[1;5]	ASTM E-162	$I_s \leq 35$
		ASTM E-662	$D_s(1.5) \leq 100$; $D_s(4.0) \leq 200$
	Ceiling[1,5]	ASTM E-162	$I_s \leq 35$
		ASTM E-662	$D_s(1.5) \leq 100$; $D_s(4.0) \leq 200$
	Partition[1;5]	ASTM E-162	$I_s \leq 35$
		ASTM E-662	$D_s(1.5) \leq 100$; $D_s(4.0) \leq 200$
	Windscreen[1,5]	ASTM E-162	$I_s \leq 35$
		ASTM E-662	$D_s(1.5) \leq 100$; $D_s(4.0) \leq 200$
	HVAC Ducting[1;5]	ASTM E-162	$I_s \leq 35$
		ASTM E-662	$D_s(4.0) \leq 100$
	Window[4,5]	ASTM E-162	$I_s \leq 100$
		ASTM E-662	$D_s(1.5) \leq 100$; $D_s(4.0) \leq 200$
	Light Diffuser[5]	ASTM E-162	$I_s \leq 100$
		ASTM E-662	$D_s(1.5) \leq 100$; $D_s(4.0) \leq 200$
Flooring	Structural[6]	ASTM E-119	Pass
	Covering[7]	ASTM E-648	C.R.F ≥ 0.5 w/cm^2
Insulation	Thermal[1,2;5]	ASTM E-162	$I_s \leq 25$
		ASTM E-662	$D_s(4.0) \leq 100$
	Acoustic[1;2;5]	ASTM E-162	$I_s \leq 25$
		ASTM E-662	$D_s(4.0) \leq 100$
Miscellaneous	Elastomers[1]	ASTM C-542	Pass
	Exterior Shell[1;5]	ASTM E-162	$I_s \leq 35$
		ASTM E-662	$D_s(1.5) \leq 100$; $D_s(4.0) \leq 200$
	Component Box covers[1;5]	ASTM E-162	$I_s \leq 35$
		ASTM E-662	$D_s(1.5) \leq 100$; $D_s(4.0) \leq 200$

*Refers to Notes on Table 1.

Available from:
Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402.

(3) American Society for Testing Materials (ASTM)

(a) Specification for Gaskets, ASTM C-542;

(b) Surface Flammability for Flexible Cellular Materials Using a Radiant Heat Energy Source, ASTM D-3675;

(c) Fire Tests of Building Construction and Materials, ASTM E-119;

(d) Surface Flammability of Materials Using a Radiant Heat Energy Source, ASTM E-162;

(e) Bonded and Laminated Apparel Fabrics, ASTM D-2724;

(f) Critical radiant flux of floor covering systems using a radiant heat energy source, ASTM E-648;

(g) Specific optical density of smoke generated by solid materials, ASTM E-662.

Available from: American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103.

In all instances, the most recent issue of the document or the revision in effect at the time of request should be employed in the evaluation of the material specified herein.

Definition of Terms

1. Critical radiant flux (CRF) as defined in ASTM E-648 is the level of incident radiant heat energy on the floor covering system at the most distant flame-out point. It is reported as W/cm^2.

2. Flame spread index (I_s) as defined in ASTM E-162 is a factor derived from the rate of progress of the flame front (F_s) and the rate of heat liberation by the material under test (Q), such that $I_s = F_s \times Q$.

3. Specific optical density (D_s) is the optical density measured over unit path length within a chamber of unit volume produced from a specimen of unit surface area, that is irradiated by a heat flux of 2.5 watts/cm^2 for a specified period of time.

4. Surface flammability denotes the rate at which flames will travel along surfaces.

5. Flaming running denotes continuous flaming material leaving the site of material burning or material installation.

7. Light rail transit (LRT) vehicle means a streetcar-type transit vehicle operated on city streets, semi-private rights-of-way, or exclusive private rights-of-way.

8. Rapid rail transit (RRT) vehicle means a subway-type transit vehicle operated on exclusive-private rights-of-way with high-level platform stations.

Recommended Test Procedures and Performance Criteria

(a) The materials used in RRT and LRT vehicles should be tested according to the procedures and performance criteria set forth in Table 1.

(b) Transit agencies should require certification that combustible materials to be used in the construction of vehicles have been tested by a recognized testing laboratory, and that the results are within the recommended limits.

(c) Although, at present, there are no Recommended Fire Safety Practices for electrical insulation materials, information pertinent to the selection and specificationof electrical insulation for use in the rail transit environment is contained in the following UMTA reports:

1. Electrical Insulation Fire Characteristics, Volume I, Flammability Tests, December, 1978. UMTA-MA-06-0025-79-1, PB294 840/4GA

2. Electrical Insulation Fire Characteristics, Volume II, Toxicity, December, 1978, UMTA-MA-06-0025-79-2, PB294 841/2GA

3. Combustibility of Electrical Wire and Cable for Rail Transit Systems, Volume I, Flammability, May 1983, UMTA-MA-06-0025-83-7, PB83-233742

4. Combustibility of Electrical Wire and Cable for Rail Transit Systems, Volume II, Toxicity, May 1983, UMTA-MA-06-0025-83-7, PB83 233759

Available from: The National Technical Information Service, Springfield, VA 22161

Notes

1. Materials tested for surface flammability should not exhibit any flaming running, or flaming dripping.

2. The surface flammability and smoke emission characteristics of a material should be demonstrated to be permanent by washing if appropriate, according to FED-STD-191A Textile Test Method 5830.

3. The surface flammability and smoke emission characteristics of a material should be demonstrated to be permanent by dry-cleaning, if appropriate, according to ASTM D-2724. Materials that cannot be washed or dry cleaned should be so labeled and should meet the applicable performance criteria after being cleaned as recommended by the manufacturer.

4. For double window glazing, only the interior glazing should meet the material requirements specified herein; the exterior need not meet those requirements.

5. ASTM E-662 maximum test limits for smoke emission (specific optical density) should be measured in either the flaming or non-flaming mode, depending on which mode generates the most smoke.

6. Structural flooring assemblies should meet the performance criteria during a nominal test period determined by the transit agency. The nominal test period should be twice the maximum expected period of time, under normal circumstances, for a vehicle to come to a complete, safe stop from maximum speed, plus the time necessary to evacuate all passengers from a vehicle to a safe area. The nominal test period should not be less than 15 minutes. Only one specimen need be tested. A proportional reduction may be made in dimensions of the specimen provided that it represents a true test of its ability to perform as a barrier against undercar fires. Penetrations (ducts, etc.) should be designed against acting as conduits for fire and smoke.

7. Carpeting should be tested in accordance with ASTM E-648 with its padding, if the padding is used in actual installation.

8. Arm rests, if foamed plastic, are tested as cushions.

9. Testing is performed without upholstery.

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Ralph L. Stanley,

Administrator.

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