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Collision Avoidance and Accident Survivability
Volume 4: Proposed Specifications

Arthur D. Little, Inc.
Acorn Park
Cambridge, MA

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13. ABSTRACT (Maximum 200 words)

This report is the fourth of four volumes concerned with developing safety guidelines and specifications for high-speed guided ground transportation (HSGGT) collision avoidance and accident survivability. The overall approach taken in this study is to first formulate collision scenarios to which an HSGGT system may be exposed. Then existing U.S. and foreign rules, regulations, standards and practices concerned with either preventing the occurrence of a collision, or mitigating the consequences of a collision are reviewed, together with pertinent practices from other forms of transportation, leading to the formulation of guidelines and specifications for collision avoidance and accident survivability.

This volume provides a detailed specification for HSGGT system collision avoidance and accident survivability. The specification is structured in three levels. The first level specifies an overall system safety performance requirement in terms of accident and casualty rates that must not be exceeded. The second level provides separate minimum requirements for collision avoidance and accident survivability in terms of severities of consequences or frequencies of occurrence that must not be exceeded. The third level provides minimum requirements for safety critical subsystems such as vehicle brakes and signal and train control systems. Supporting sections of the report describe the considerations leading to the development of the specification, and methods of performing risk analyses called for in the specification.

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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 (1)
1 pint (pt) = 0.47 liter (1)
1 quart (qt) = 0.96 liter (1)
1 gallon (gal) = 3.8 liters (1)
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)

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

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 yeards (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 milliliters (ml) = 0.03 fluid ounce (fl oz)
1 liter (1) = 2.1 pints (pt)
1 liter (1) = 1.06 quarts (qt)
1 liter (1) = 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)

$[(9/5)\ y + 32]\ ^{o}C = x\ ^{o}F$

QUICK INCH-CENTIMETER LENGTH CONVERSION

INCHES	0			1			2			3			4			5		6			7			8		9		10
CENTIMETERS	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	25.40		

QUICK FAHRENHEIT-CELSIUS TEMPERATURE CONVERSION

^oF	-40°	-22°	-4°	14°	32°	50°	68°	86°	104°	122°	140°	158°	176°	194°	212°
^oC	-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 10286.

PREFACE

In recent years there has been increased interest in high speed guided ground transportation (HSGGT). In May of 1991 the state of Texas awarded a franchise for the construction of a high speed rail system linking Dallas/Ft. Worth, San Antonio, and Houston, and in January of 1992 a detailed franchise agreement was signed for construction of a system using the French Train à Grande Vitesse (TGV). In June of 1989 the Florida High Speed Rail Commission (now part of the Florida Department of Transportation) recommended awarding a franchise for construction of a maglev system linking Orlando airport and a major attractions area on International Drive in Orlando, and in June of 1991 a franchise agreement was signed by the state of Florida for construction of a system using the German Transrapid TR07. In November of 1992 Amtrak began testing the Swedish X2000 tilt-train on the Northeast Corridor and in 1993 Amtrak will test the German Inter-City Express (ICE) train on the Northeast corridor. In 1991 four contracts were awarded for the development of a U.S. designed maglev system, as part of the National Maglev Initiative. The Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991 provides for the further development of a U.S. designed maglev system. In addition to the current active projects, there have been numerous proposals throughout the country for new high speed systems and for increasing the speeds on current rail corridors.

All of the systems proposed for operation at speeds greater than current practice employ technologies that are different from those used in current guided ground transportation systems. These different technologies include advanced signaling and control systems and lightweight car-body structures for all or most HSGGT systems. The differences in technology, along with the increased potential consequences of an accident occurring at high speeds, require assurances that HSGGT systems are safe for use by the traveling public and operating personnel.

This report on collision safety is part of a comprehensive effort by the Federal Railroad Administration (FRA) to develop the technical information necessary for regulating the safety of high speed guided ground transportation. Other areas currently being studied by the FRA as part of its high speed guided ground transportation safety program include:

- Maglev Technology Safety Assessments (both electromagnetic and electrodynamic)
- Development of Emergency Preparedness Guidelines
- Electromagnetic Field Characteristics
- Guideway Safety Issues
- Automation Safety
- Human Factors and Automation

Collision safety comprises the measures taken to avoid collision and also to assure passenger and crew protection in the event of an accident. The results of this study, presented in the four-volume report, provide a basis for evaluating the collision safety provided by a given HSGGT system. These measures must be evaluated concurrently for a coordinated, effective approach. Based on the results of this study, work is currently planned to evaluate the collision safety of a proposed system and to evaluate the effectiveness of modifications on the collision safety of an existing conventional system.

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ABBREVIATIONS AND TERMINOLOGY

Many abbreviations are in common use for railroad and governmental organizations and high-speed guided ground transportation systems and their components. This list provides a convenient reference for those used frequently in the different volumes of this report. The same list is used in all volumes but not all abbreviations appear in every volume. Note that some abbreviations, particularly those used for different train control systems (ATC, ATCS, ATP, etc.), may not have the same meaning for all users. Commonly accepted meanings are given.

AAR	Association of American Railroads
AIS	Abbreviated Injury Scale
ANF	French railroad equipment manufacturer — builder of gas-turbine powered train sets
APTA	American Public Transit Association
AREA	American Railway Engineering Association
ASTREE	Automation du Suivi en Temps (French on-board train control system)
ATB	Articulated Total Body — computer analysis code used to model human body dynamics
ATC	Automatic Train Control — systems which provide for automatic initiation of braking if signal indications are not obeyed or acknowledged by train operator. Usually combined with cab signals
ATCS	Advanced Train Control Systems — a specific project of the AAR to develop train control systems with enhanced capabilities
ATD	Anthropomorphic Test Device (Dummy)
ATO	Automatic Train Operation — a system of automatic control of train movements from start-to-stop. Customarily applied to rail rapid transit operations
ATP	Automatic Train Protection — usually a comprehensive system of automatic supervision of train operator actions. Will initiate braking if speed limits or signal indications are not obeyed. All ATP systems are also ATC systems.
AVE	Alta Velocidad Espagnol — Spanish high speed rail system currently comprising one line between Madrid and Seville
AWS	Automatic Warning System — a simple cab signalling and ATC system used on British Rail
BART	Bay Area Rapid Transit (San Francisco, CA)

ABBREVIATIONS AND TERMINOLOGY (continued)

BN	Burlington Northern (Railroad)
BR	British Rail
CFR	Code of Federal Regulations
CPU	Central Processing Unit (core unit of a microprocessor)
CTC	Centralized Train Control — system of supervision of railroad operations from a central location
DB	Deutche Bundesbahn — German Federal Railways
DIN	Deutches Institut fur Normung — German National Standards Institute
DLR	Docklands Light Railway, London, U.K.
EMD	Electro-Motive Division of General Motors (Locomotive Manufacturers)
EMI	Electro-Magnetic Interference — usually used in connection with the interference with signal control circuits caused by high power electric traction systems
FAA	Federal Aviation Administration (United States)
FAR	Federal Aviation Regulations
FCC	Federal Communications Commission (United States)
FEA	Finite Element Analysis
FHWA	Federal Highway Administration (United States)
FMEA	Failure Modes and Effects Analysis
FMVSS	Federal Motor Vehicle Safety Standards (United States)
FNC	Frazer-Nash Consultancy
FRA	Federal Railroad Administration of the United States Department of Transportation
FTA	Federal Transit Administration (United States)
g	gravitational acceleration, equivalent to 9.81 m/sec^2 or 32.2 ft/sec^2
HA	Hybrid Analysis (for collision analysis)

ABBREVIATIONS AND TERMINOLOGY (continued)

HIC	Head Injury Criterion
HSGGT	High-Speed Guided Ground Transportation
HSR	High-Speed Rail
HST	High-Speed Train — British Rail high-speed diesel-electric trainset
HYGE	High-g (high acceleration) sled testing facility
ICE	Inter-City Express — a high speed train-set developed for German Federal Railways consisting of a locomotive at each end and approximately 10 intermediate passenger cars
IIT	Illinois Institute of Technology
ISO	International Standards Organization
Intermittent	A term used in connection with ATC and ATP systems to describe a system that transmit instructions from track to train at discrete points rather than continuously
J	Joule: metric (SI) unit of energy, equivalent to a force of one Newton (N) moving through a distance of one meter (m)
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
LCX	Leaky co-axial cables — LCX cables laid along a guideway can provide high quality radio transmission between the vehicle and wayside. LCX is more reliable than air-wave radio, and can be used where air waves cannot, for example, in tunnels
LGV	Ligne a Grand Vitesse — French newly-built high-speed lines. See also TGV
LMA	Lumped Mass Analysis
LRC	Light Rapid Comfortable. A high-speed tilt-body diesel-electric train-set developed in Canada
LZB	Linienzugbeeinflussung — Comprehensive system of train control and automatic train protection developed by German Federal Railways

ABBREVIATIONS AND TERMINOLOGY (continued)

Maglev	Magnetic Levitation, usually used to describe with a guided transportation system using magnetic levitation and guidance
MARTA	Metropolitan Atlanta Rapid Transit Authority
MU	Multiple Unit. A train on which all or most passenger cars are individually powered and no separate locomotive is used
N	Newton: metric (SI) unit of force equivalent to the force needed to accelerate a mass of one kilogram (kg) at one meter per second^2
NBS	Neubaustrecken — German Federal Railway newly-built high-speed lines
NCAP	New Car Assessment Program of the National Highway Safety Traffic Administration
NHTSA	National Highway Traffic Safety Administration (United States)
NTSB	National Transportation Safety Board (United States)
PATCO	Port Authority Transit Corporation (Lindenwold Line)
PHA	Preliminary Hazard Analysis
PSE	Paris Sud-Est. The high-speed line from Paris to Lyon on French National Railways
QRA	Quantitative Risk Analysis
RENFE	Rede Nacional de los Ferrocarriles Espanoles - Spanish National Railways
ROW	Right-of-Way: strip of land on which an HSGGT guideway is constructed.
SACEM	System to aid control and maintenance. French ATO/ATP system applied to high density Paris commuter rail lines
SBB	Schweizerische Bundesbahnen - Swiss Federal Railways
SELTRAC	Moving-block signaling system developed by Alcatel, Canada
Shinkansen	Japanese high speed wheel-on-rail systems
SI	International system of metric units based on the meter (m) kilogram (kg) and second as primary units
SJ	Statens Jarnvagar — Swedish State Railways

ABBREVIATIONS AND TERMINOLOGY (continued)

SNCF	Societe Nationale des Chemin de Fer Francais — French National Railways
SSI	Solid State Interlocking in a railroad signalling system
STWR	(Vehicle) Strength to Weight Ratio
TALGO	Spanish articulated lightweight trainset featuring single axle trucks and passive pendular tilt
TGV	Train à Grand Vitesse — French High-Speed Train. Also used to refer to complete French high-speed train system
TR	Transrapid — German electro-magnetic maglev design
UIC	Union Internationale de Chemins de Fer (International Union of Railways)
U.K.	United Kingdom
ULA	Ultimate Load Analysis (for collision analysis)
UMTA	Urban Mass Transportation Administration of the U.S. Department of Transportation. The name of this agency has now changed to the Federal Transit Administration (FTA)
U.S. or US	United States
Vital	A "vital" component in a signal and train control system is a safety-critical component which must be designed to be fail safe and/or have a very low incidence of unsafe failures.
VNTSC	Volpe National Transportation Systems Center
WMATA	Washington Metropolitan Area Transit Authority

Acronyms for individual computer analysis packages are not provided in this list.

1. INTRODUCTION

This Volume 4 of the report on Collision Avoidance and Accident Survivability presents a draft safety specification for HSGGT systems operating in the United States. The specification is based on the research documented in Volumes 1, 2 and 3, and has been designed, as far as possible, to:

- be independent of HSGGT technology
- be performance based, avoiding specific dimensional, material, and strength requirements.
- permit flexibility on the part of the HSGGT system designer with regard to ways of meeting the specification, especially in choosing between collision avoidance and accident survivability approaches to meeting the specified requirements.

The specification has been developed for the types of HSGGT system that are at an advanced stage in development, and which may be implemented in the United States over the next ten to twenty years. It is not structured, in its present form, for more innovative HSGGT systems, for example, those that envisage the operation of large numbers of small vehicles at close headways. However, the specification constitutes a valuable step toward an HSGGT safety specification of general applicability, that ensures public safety but is independent of HSGGT system technology and operating environment.

The specification should be read in conjunction with the other volumes of this report. The collision scenarios against which the safety specification provides protection are described in Volume 1, together with the derivation of safety performance targets and guidelines for collision avoidance and accident survivability. Volumes 2 and 3 provide detailed information on collision avoidance and accident survivability respectively, concluding with guidelines for application of collision avoidance and accident survivability principles to HSGGT systems.

Finally, it is emphasized that this is a draft specification, and is offered in the expectation that the safety specification will continue to evolve as the results of further research into HSGGT safety issues become available. It is also recognized that further research is required, particularly to "test" the specification in realistic situations to see whether all relevant safety threats are addressed, and conversely to ensure that the requirements generally work as intended, and are not overly restrictive. Research is also required into safety assessment techniques, and to accumulate the data required to support the types of quantitative risk analyses called for in the specification. The need for research is particularly acute in the area of safety-critical software and microprocessor systems, and in the validation of analyses of the behavior of HSGGT vehicle structures in collisions.

Chapter 2 of this volume provides a general discussion of the structure and content of the HSGGT safety specification, particularly explaining the derivation of the three-level (system, major subsystem, component) form of the specification. Chapter 3 contains the specification itself, including the performance requirements at each of the three levels, together with applicability and compliance verification procedures for each requirement. Chapter 4 provides a discussion of system safety analysis techniques which can be used for compliance verification.

2. OBJECTIVE, FORM AND CONTENT OF THE SAFETY SPECIFICATION

2.1 OBJECTIVE OF THE SPECIFICATION

An HSGGT collision safety specification must be developed in order to minimize risk to the public and employees in the operation of rail and other high-speed guided ground transport vehicles. Wheel-on-rail and maglev high-speed guided ground transportation systems which may be put into public service in the U.S. must be covered by such a specification, to ensure the safety of the public at large, and users and employees of an HSGGT system.

This specification has to be such that a system designed, built, operated, and maintained in compliance with the specification results in an acceptably low risk of accidents and other adverse effects on the public and employees.

From the perspective of the designer and operator of an HSGGT system, this specification should be structured in a way that facilitates the design, construction, and operation of a system that will be in compliance with the specification. This means that the specification should avoid ambiguity and imprecision, and should be clear regarding the safety requirements and acceptable means of demonstrating compliance.

An HSGGT Collision safety specification, thus, should provide a fair and convenient way of assuring collision safety from both the perspective of the public, and from the perspective of the system operator.

2.2 FORM OF THE SPECIFICATION

The risk that an HSGGT system poses to the public and employees depends on the features of the system, and the aggregate safety performance of many individual subsystems. For example, the risk to the passengers and crew from collision depends on how well the system can avoid the failures and errors that lead to a collision, as well as how good it is in protecting vehicle occupants once the collision occurs. In this case, the performance of the signal/control subsystem and vehicle structure thus determine the performance of the vehicle system. The performance of some subsystems is linked to the performance of the employees, and the performance of many subsystems is dependent on the quality of ongoing inspection and maintenance activities. Furthermore, the degree of safety in the performance of individual subsystems can depend on many factors: materials used, dimensions, degree of redundancy.

A safety specification for a complex system, made up of multiple subsystems and components, can take many forms. At one extreme, only the overall safety goal could be specified, for example, fatalities must not exceed a specified level per 10^9 passenger-kilometers. How this performance is achieved is left entirely to the HSGGT system designer and operator. Such an approach gives the HSGGT designer and operator complete freedom regarding ways of designing and operating the system in order to comply with the specification.

At the other extreme, the characteristics of each safety-critical component, as well as the qualifications and training of each employee, are specified in great detail and the system designer and operator must follow each requirement meticulously. With such a specification, the specifying authority must have determined in advance that components manufactured in accordance with the specification, used in combination with the specified staffing and operating practices, yield an adequate safety performance. Existing conventional railroad safety regulations and industry standards tend towards this form of specification, relying on extensive past experience for assurance that compliance with the regulations will produce the desired safety performance.

There are advantages and disadvantages associated with each extreme approach. If the safety specification is expressed only in terms of the overall performance, the HSGGT system designer can take an extremely nonconventional approach and still meet the specification. For example, a vehicle with a very flimsy structure but with a operations control system that creates extremely low likelihood of collision could theoretically meet such a specification. However, such an extreme approach would likely not be acceptable to the public. Most importantly, if the operations control system does not perform as expected, the resulting collision would be catastrophic, with grave implications for the HSGGT system and the responsible specifying authority. Another disadvantage of this approach is that it is difficult to evaluate compliance with the specifications prior to obtaining service experience. Both the system designer and any responsible regulatory authority would have to perform, and/or review and accept, a system safety assessment which may include many judgmental estimates of component and subsystem performance that are difficult to verify.

The alternative of a highly restrictive specification which dictates the design of each component is also inappropriate. Such a specification leaves no room for flexibility and ingenuity in meeting safety requirements, completely stifles innovation, and potentially imposes high costs on an HSGGT system, which could render it economically infeasible. Also, a separate specification would be required for each HSGGT system and subsystem technology, adding to the volume and complexity of the specification.

There has to be middle way between simply stating a desired global safety goal, and the highly restrictive approach of ensuring safety by a detailed specification. An in-between approach would specify overall performance goals, but also place limits on the performance of individual subsystems and components. This approach ensures that a design based on an extreme interpretation of an overall performance specification is not acceptable, at least, not without very substantial analysis and testing. A good in-between approach will also emphasize the specification of component or subsystem performance rather than the specification of component dimensions, materials, and strengths. Use of performance specifications minimizes the need for technology-specific requirements, and gives the HSGGT system designer a choice among different ways of meeting the specification.

Subsystem and component requirements can also be used to ensure that the HSGGT system is provided with adequate protection against all the collision scenarios described in Volume 1 of this report, including those scenarios that may only affect an individual subsystem or component.

Thus, based on these considerations, an appropriate HSGGT safety specification is that which contains both overall system level and various subsystem and component performance requirements.

System level performance requirements in the specification assure a satisfactory overall performance and allow the HSGGT system designer to adopt the most efficient means of achieving the desired level of safety, taking into account the exposure of a specific HSGGT system to different hazards.

Subsystem and component level performance requirements assure a **minimum** level of safety performance to protect against unforeseen accident threats and HSGGT subsystem or component failures, and also assure protection against all the collision and accident scenarios described in Volume 1 of this report. Subsystem and component level requirements must be applied in combination with the system level performance requirements. They are not, on their own, a complete safety specification.

2.3 CONTENT OF THE SPECIFICATION

A comprehensive safety specification, whether for a complete HSGGT system, a subsystem or a component, should include the following elements:

- *Definitions of terms* used in the specifications. The specification may be used by both U.S. and foreign designers and operators of HSGGT systems, and also individuals or firms that may not be familiar with conventional U.S. railroad terminology or with present Federal Railroad Administration (FRA) regulations. Thus, carefully worded, precise definitions are required to avoid misunderstandings and misinterpretation of the specification.

- *The applicability of the requirement.* Requirements within the specification may apply to specific subsystems or components (for example a brake system), to operations in a specific speed range, or to particular kinds of HSGGT operations. In any of these cases it is essential to specify the applicability of the requirement, so that the user of the specification is clear as to whether compliance is required or not in a particular instance.

- *A specification of the performance required.* The required performance is the key provision of the specification, and should preferably be expressed in numerical terms. To the extent possible, the specification should be expressed in performance terms; design-type requirements specific to a particular HSGGT system or subsystem technology should be avoided. Typical performance specifications might take the form of specifying that the vehicle or train sustain a collision at a specified speed with a specified object without penetration or crushing of occupant space; or the incidence of unsafe control system failures should not exceed a specified number in a specified period. Use of qualitative terms such as "extremely improbable" are an alternative to numerical requirements but are less desirable as they may be open to differing interpretations. Another alternative is to specify that the performance of a particular system, subsystem, or component should be equal to or better than a particular existing system.

  One area of difficulty in specifications is the problem of updating them as new information and experience become available. Changing a formal specification is sometimes a cumbersome process, involving review and agreement by many parties. A possible alternative is to make the primary specification a short and simple statement of the performance goal and performance verification requirements. A detailed amplification of the performance goal and descriptions of verification methods are provided in a supporting document, which is more easily amended. This approach is used by the Federal Aviation Administration (FAA) for commercial airplane airworthiness requirements. Advisory Circulars amplify the FAA requirements by detailing acceptable ways of complying with a requirement, but can be more easily amended than a formal regulation.

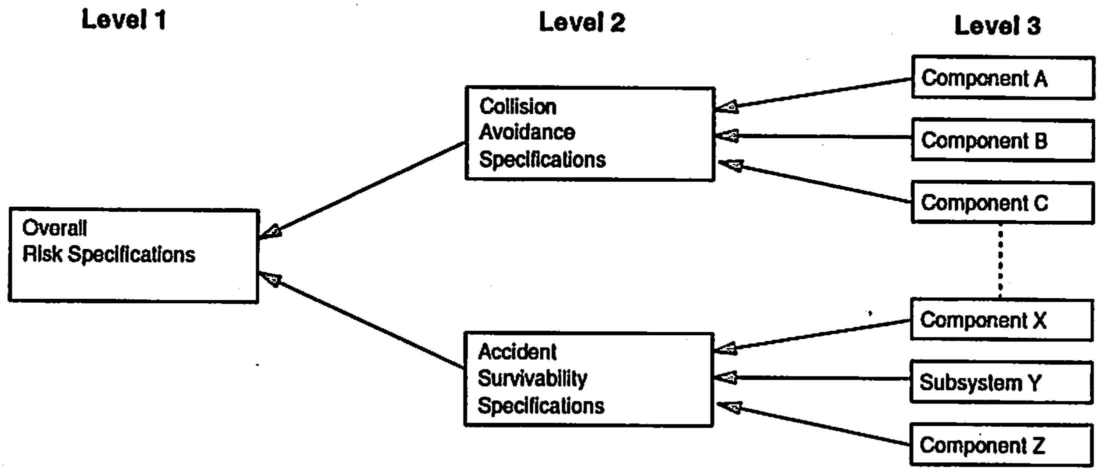
- *Methods to be used to verify compliance with the specification.* It must be possible for the designer and operator of the HSGGT system, and the authority responsible for the specification to be able to determine whether a specific system, subsystem, or component complies with the specification. A specification that lacks a means of compliance verification is of little value. The method of compliance verification will depend on the nature of the individual requirement, and the technical and economic feasibility of different analysis and testing procedures. Applicable methods can include simple visual inspection and measurements, various kinds of analysis (such as structural analysis, vehicle dynamics analysis, or risk analysis), and various kinds of testing. Use of particular analytical techniques, computer codes, or specific testing facilities may be required to ensure consistent application of the specification.

Based on the requirements for both the form and content of the specification, as discussed above and in Section 2.2, a three level format has been devised. The format is illustrated in diagrammatic form in Figure 2-1.

The top level is the required overall system safety, expressed as an accident risk profile — a plot of accident frequency vs. severity. The top level may also include other overall system safety requirements or goals, usually in the form of limits on the frequency of casualties to passengers, employees, or bystanders; or property damage caused by accidents. The overall safety requirement should apply to both a whole HSGGT system and to individual routes. It would likely not be acceptable to have one very hazardous route within a large and otherwise very safe system, even if the overall system met the top-level safety requirements. Verification of compliance is through a risk analysis, covering all safety threats to the system.

The second level disaggregates safety performance into "collision avoidance" and "accident survivability" components, and specifies minimum acceptable performance levels for each. This level of the specification ensures that extreme concepts cannot be used. An example of an extreme system design concept would be a structurally weak vehicle that relies totally on a high performance control system for collision avoidance. The requirement for a minimum collision survivability performance is justified by the possibility of a sequence of unforeseen events leading to a collision, with catastrophic consequences. However, provision can be made for the acceptance of non-complying systems, provided more rigorous analysis, testing, and monitoring of the system is carried out to verify the adequacy of safety performance. Collision avoidance criteria are expressed as a frequency of occurrence for collisions that must not be exceeded for specified operating scenarios. Collision avoidance requirements are applicable to all subsystems that contribute to the avoidance of collisions between vehicles or trains. Collision avoidance performance is verified by an appropriate risk analysis. Accident survivability requirements are expressed as the maximum damage to vehicles or trains, or maximum severity of casualties that

Overall Structure



	Level 1	Level 2	Level 3
Performance Requirements	• Must not exceed specified risk profile casualty rates	• Avoidance: Must not exceed specified collision rates • Survivability: Must not exceed specified consequences (Casualties/damage) in defined collisions	• Required features, subsystems or components • Subsystems, components must not exceed specified failure rate • Must meet specified performance criteria -- acceleration, vibration tolerance -- impact strength -- etc.
Applicability	• Whole system	• All collision avoidance installations for accident scenarios to which system is exposed • All HSGGT vehicles for accident scenarios to which system is exposed	• To specified components or subsytems • To specified HSGGT system/subsystem technologies • In specified accident scenarios to which system is exposed
Compliance Verification	• Risk Analysis	• Risk Analysis • Collision Analysis and/or testing	• Performance Tests • Measurements • Visual Inspection • Risk analysis • Structural analysis • Etc.

Figure 2-1. Three-Level HSGGT Safety Performance Specification

could result in event of defined collisions or other accidents. The survivability requirements are applicable to all vehicles operated, and performance may be verified through an appropriate mix of analysis and testing of structural collision .

The third level of the specification defines minimum performance levels for individual subsystems and components. In part, these requirements are concerned with protecting against collision or accident scenarios that involve only a small number of subsystems or components, and in part with setting minimum acceptable performance for subsystems that affect overall vehicle accident frequency and survivability performance. In the latter case, the minimum performance requirements are needed to ensure that extreme solutions are not adopted without rigorous analysis.

An essential feature of this three-level specification structure is that compliance with lower level requirements does not necessarily ensure compliance with the next higher level. For example, compliance with Level 3 requirements regarding vehicle interior fittings and surfaces does not necessarily ensure that a vehicle will meet the accident survivability requirements of Level 2. The separate collision avoidance and accident survivability requirements of Level 2 do not reflect the exposure a particular system may have to accident threats. Thus, compliance with all Level 2 requirements does not necessarily ensure compliance with Level 1 requirements. This feature provides the flexibility in the specification. The HSGGT designer can choose to improve either collision avoidance features or accident survivability features over the minimum requirements to ensure that the overall system meets the first level requirement. Also, the lowest level specifications do not necessarily cover all HSGGT sub-systems and components that affect safety.

Further flexibility is provided by the use of performance rather than design-oriented requirements in the specification, wherever possible. In particular, performance requirements are not specific to one HSGGT system or subsystem technology, and may allow significant choice in ways of meeting the different individual requirements.

Finally, the Level 2 and 3 requirements can include the general provision that variations are permitted, provided a request for variation is adequately supported by analysis and test data to demonstrate that the Level 1 requirement can be met. In other words, variations are permitted provided that it can be proven that the FRA's guiding principal of "equivalent safety" is being honored.

3. DRAFT HSGGT SAFETY SPECIFICATIONS

3.1 OBJECTIVE AND SCOPE

This specification provides performance requirements that ensure that the risk that a High-Speed Guided Ground Transportation (HSGGT) vehicle will be involved in a collision, and should a collision occur, the incidence and severity of casualties among vehicle occupants do not exceed specified limits. As described in Chapter 2, the specification includes performance requirements at three levels:

Level 1: Overall system performance requirements, given in Section 3.4

Level 2: Separate Collision Avoidance and Accident Survivability performance requirements, given in Section 3.5

Level 3: Component and subsystem performance requirements, given in Section 3.6

The specification at each of the three levels and for each system, subsystem or component, consists of a statement of the requirement, a definition of the applicability of the requirement, and means for verifying compliance. Each requirement is followed by comments on the rationale for the requirement. Administrative procedures for enforcement of the specifications and reporting of failures and accidents are not addressed.

As far as possible, the specification is structured in a way which will allow HSGGT system designers and operators flexibility at every level to select a technical approach to meeting the specification that best suits the individual HSGGT system.

The overall goal of the specification is to ensure that the safety of any HSGGT system put into service in the United States is equivalent to or better than existing public intercity passenger transportation systems, thus meeting the Federal Railroad Administration's "equivalent safety" requirement.

3.2 APPLICABILITY OF THE SPECIFICATION

This specification applies to vehicle movements, outside maintenance or storage facilities, on HSGGT systems operating at speeds up to 500 km/h (300 mph). Both operations on a dedicated guideway and a shared guideway are covered by the specification. The specification is also independent of HSGGT technology, and is applicable to both wheel-on-rail and maglev systems.

The specification is intended to be an alternative to the existing FRA railroad safety requirements for vehicles, track, and signal and train control systems contained in the parts of 49 CFR listed in Table 3-1, <u>for HSGGT operations on a dedicated guideway</u>.

Except where expressly noted, the specification does <u>not</u> replace the existing FRA railroad safety requirements for vehicles, track and signal and train control systems listed in Table 3-1, for the operation of HSGGT vehicles or trains over tracks shared with conventional North American

Table 3-1. FRA Safety Regulations for Railroad Track, Vehicles and Signal and Train Control Systems

Part	Title
213	Track Safety Standards
215	Railroad Freight Car Safety Standards
221	Rear End Marking Device - Passenger, Commuter, and Freight Trains
223	Safety Glazing Standards - Locomotives, Passenger Cars, and Cabooses
229	Railroad Locomotive Safety Standards
231	Railroad Safety Appliance Standards
232	Railroad Power Brakes and Drawbars
236	Rules, Standards, and Instructions Governing the Installation, Inspection, Maintenance, and Repair of Signal and Control Systems, Devices, and Appliances

railroad trains, built and operated in accordance with the FRA regulations and other applicable rules, standards, and practices.

3.3 DEFINITIONS

3.3.1 Introduction and Applicability

The following definitions of HSGGT system features, subsystems, components and concepts apply whenever the defined terms are used in the safety specification for Levels 1, 2, or 3, as provided in Section 3.4, 3.5, and 3.6 respectively.

3.3.2 Definitions

1. System and Guideway

a. A *High Speed Guided Ground Transportation* (HSGGT) system is any system of transportation where vehicles or trains are designed to follow a guideway at or near the ground, at speeds in excess of 177 km/h (110 mph).

b. A *wheel-on-rail HSGGT system* is an HSGGT system which is supported and guided by flanged wheels running on conventional railroad rails.

c. A *Magnetic Levitation (maglev) HSGGT system* is an HSGGT system in which high speed support and guidance is provided by magnetic attraction or repulsion forces between vehicle and guideway.

d. A *Conventional North American Railroad System* is a system on which all vehicles, track, signal systems, and operations comply with applicable Federal Railroad Administration (FRA) regulations, and U.S. railroad industry standards and practices. Intercity passenger trains (e.g., Amtrak), commuter passenger trains and freight trains may operate on such systems.

e. A *Right-of-Way* is the strip of land on which the HSGGT guideway is constructed, or on which support structures for an elevated guideway have their foundations.

f. A *Dedicated Right-of-Way* is a right-of-way occupied by one or more guideways of one type of HSGGT system.

g. A *Shared Right-of-Way* is a right-of-way occupied by two or more transportation modes or technologically-differing systems. Transportation systems sharing a right-of-way can include highway, conventional rail lines of all kinds (freight, passenger, transit), pipelines, overhead electric utility lines, waterways, and different types of HSGGT systems. A "shared right-of-way" exists whenever the modes are near enough to potentially interfere with one another during normal operation or in an emergency situation.

h. The *guideway* is the fixed structure that supports vertical and guidance forces from HSGGT vehicles or trains. A conventional railroad track and a maglev or monorail support beam are guideways.

i. A *dedicated guideway* is a guideway only used by similar vehicles or trains.

j. *Similar vehicles or trains* have the following characteristics:

- They have a common cross-section.
- They are built to the same "accident survivability" requirements, and use the same approach to meeting these requirements.
- They are of the same train type (e.g., multiple unit, locomotive hauled, etc.).

The weight and length of individual vehicles and the number of vehicles and vehicle sections in a train may vary.

k. A *shared guideway* is a guideway used by different types of vehicles or trains at the same time, subject only to normal separation being maintained by the signal and train control system.

2. Vehicles

a. *A vehicle-section* is the smallest individual structural unit of a vehicle or a train, and is connected to other vehicle sections by a coupling that allows relative movement in at least one degree of freedom.

b. *A vehicle* is made up of one or more vehicle-sections and is the smallest element of a train that can be attached or detached in service, or operated independently. Vehicle-sections can normally only be detached from each other in a workshop.

c. *A train* is made up of two or more coupled vehicles.

d. *End vehicles* or *vehicle-sections* are found at the leading or trailing ends of a train. They may be structurally or functionally different from *intermediate vehicles* or *vehicle-sections* that are never found at the ends of a train. Some end-vehicles are equipped with operating controls and function as a cab vehicle (see below).

e. A *cab vehicle* is either the end vehicle of a multiple unit (MU) train, or an unpowered end vehicle having a set of operators controls. Unpowered cab vehicles, also known as driving-trailers, are normally used at one end of trains operated on the push-pull principle, with a locomotive at the other end.

f. A *locomotive or power vehicle* is a vehicle or vehicle-section wholly or primarily containing propulsion equipment. Power vehicle use is normally confined to wheel-on-rail HSGGT systems. Power vehicles usually are provided with an operator's cab and usually, but not always, are situated at the ends of a train. Conceptually, it is possible to situate the locomotive in the middle of a train, with cab vehicles at each end.

g. *Multiple unit* (MU) vehicles or trains are those in which propulsion equipment is installed on most or all vehicle sections in the train. A normal characteristic of MU trains is that end and intermediate vehicles normally have similar structures and mass, and all contain passenger accommodations.

3. **Subsystems and Concepts**

a. *Equivalent safety* is the concept that the overall safety performance of an HSGGT system should be equal to or better than other intercity public transportation systems.

b. A *safety brake system* is the brake system or combination of systems fitted to an HSGGT vehicle. It is expected to stop the vehicle from any speed within specified braking distances and with a very low probability of failure.

c. A *non-safety braking system* is a braking system that may be used in normal operations, but which is not relied upon for stopping the vehicle or train within specified braking distances.

d. An *automatic train control (ATC) system* is a system that initiates automatic braking if signal indications are not obeyed or acknowledged by a vehicle or train operator.

e. An *automatic train protection (ATP) system* is a system that initiates automatic braking if at any time a vehicle or train exceeds the permitted speed, taking into account train control instructions, signal indications, train braking performance, permanent or temporary guideway speed limits, and individual vehicle or train speed limits.

f. *Automatic braking* is braking initiated by an ATC or ATP system, or any other automated subsystem on an HSGGT system designed to initiate braking in the event of a subsystem or component failure.

g. An *acceleration pulse* is the time-history of acceleration experienced by a colliding vehicle or train while the colliding vehicle structure is being distorted during a collision.

3.4 SPECIFICATION FOR OVERALL SYSTEM PERFORMANCE (LEVEL 1)

3.4.1 Applicability

This portion of the specification applies to all vehicle or train operations on an HSGGT system as a whole, except that large systems having a total of over 1000 route-kilometers (620 miles) must be divided into smaller subsystems, and each subsystem must comply individually with the specification. Operations of wheel-on-rail HSGGT vehicles or trains over tracks shared with conventional North American trains **must be** included when evaluating compliance

3.4.2 Overall Risk to Vehicle Occupants

The overall risk of vehicle occupants (passenger and crew) of an HSGGT vehicle or train becoming a casualty in any kind of train accident shall not be greater than the general level of risk experienced in travelling by other public intercity modes of transportation in the United States, such as intercity rail or scheduled commercial airlines. An estimated rate of occupant fatalities in accidents not exceeding 0.2 per 10^9 passenger-km will satisfy this requirement.

3.4.3 Incidence of Accidents

The incidence of accidents of different levels of severity shall not exceed the general level of accident risk in other intercity public transportation systems operating in the United States. Estimated accident rates that do not exceed the suggested HSGGT safety boundary shown in Figure 3-1 will satisfy this requirement. Additionally, every effort shall be made to achieve the safety levels represented by the suggested HSGGT target performance level also shown on Figure 3-1.

3.4.4 Incidence of Accidents to Employees

The rate of fatal accidents to employees of all occupations on an HSGGT system shall not exceed the current level of fatality risk in all employment in the United States. In 1990, this rate was 9 fatalities per 100,000 employee-years. In addition, every effort shall be made to achieve a fatality rate of 4 per 100,000 employee years. Accidents to persons employed by contractors to the HSGGT system working on the property of the system shall be included in this total.

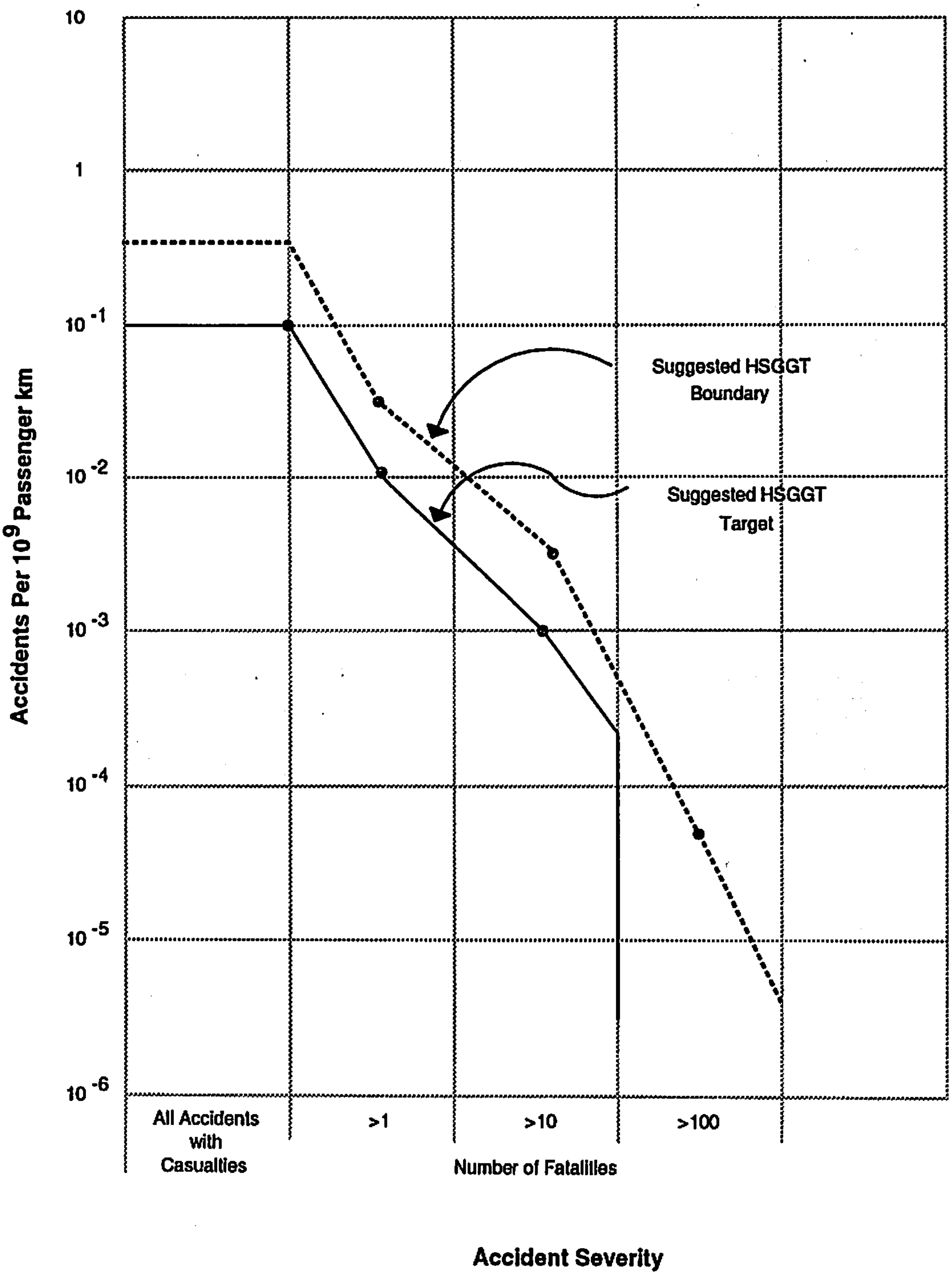
3.4.5 Incidence of Casualties to Bystanders

The incidence of fatal accidents to bystanders outside the HSGGT right-of-way as a result of vehicle or train accidents, or defects in HSGGT fixed structures and systems, shall not exceed 1 per 200 x 10^9 passenger-km (1 per 125 x 10^9 passenger-miles). In addition, the operator of HSGGT services shall make all reasonable efforts to minimize the incidence of casualties to trespassers on the HSGGT right-of-way.

3.4.6 Compliance with Requirements

Compliance with the requirements of paragraphs 3.3.1 and 3.3.2 must be shown by analysis, supported as necessary by test and historical performance data. The analysis must consider:

- All anticipated accident scenarios to which the HSGGT system may be exposed in a particular application.
- All anticipated modes of failure of HSGGT subsystems and components.



Source: Volume 1, Chapter 4

Figure 3-1. Accident Risk Profiles for HSGGT Systems

- The effectiveness of warning and monitoring systems designed to detect failures, loss of redundancy, or other adverse events that might threaten safety.

3.4.7 Comments on Section 3.4

The derivation of quantitative vehicle occupant safety requirements (fatality rates), and the risk profile and safety performance requirements for employees and bystanders is given in Chapter 4 of Volume 1, where the safety performance of different intercity transportation modes is discussed. These quantitative safety requirements are derived from an interpretation of the meaning of "equivalent safety," based on an analysis of recent accident data for passenger railroads and U.S. domestic commercial air services.

Paragraph 3.4.6, which describes analysis requirements, is modelled on the aircraft system-safety requirement contained in 14 CFR Part 25.1309. This requires analysis to demonstrate adequate safety but does not specify the technique to be used. Available techniques the FAA may consider adequate to meet the requirements are discussed in a guideline document, Advisory Circular No. 25.1309-1A "System Design and Analysis." These guidelines may be considered to have a function comparable to the description of risk analysis methods provided in Chapter 4.

Further related discussion is provided under the individual collision avoidance and accident survivability performance requirements in Section 3.5 below.

3.5 SPECIFICATION FOR COLLISION AVOIDANCE AND ACCIDENT SURVIVABILITY PERFORMANCE (LEVEL 2)

3.5.1 Overview

The HSGGT system should achieve, at a minimum, the specified accident survivability and collision avoidance performance with respect to four collision scenarios described in Sections 3.5.3 and 3.5.4. Two scenarios are low-speed collisions, developed to provide a measure of accident survivability performance. Two scenarios are high-speed collisions, developed to provide a measure of collision avoidance performance under high-speed operating conditions. The criteria for train occupant casualties and accident incidence and severity include the provision that HSGGT designers and operators may propose alternative performance criteria for consideration, supported by relevant analysis and test data.

3.5.2 Applicability of Level 2 Requirements

The low- and medium-speed collision requirements apply to the collision performance of all HSGGT vehicles and trains, whether operated on a shared or dedicated guideway.

The high-speed collision avoidance requirements apply to all operations at 129 km/h (80 mph) and above on a segregated guideway, and to operations between 129 km/h (80 mph) and 200 km/h (124 mph) on a shared guideway if HSGGT trains are being operated that do not comply with the structural strength requirements of 49 CFR Part 229 and other conventional North American railroad vehicle strength requirements. HSGGT trains used in such shared operations must also meet the additional collision survivability requirements of Section 3.6.3 of this specification.

3.5.3 Low-Speed Collision Survivability

An HSGGT train-set of the maximum size normally operated shall sustain a 10 km/h (6 mph) impact with a similar stationary train. The consequences shall not exceed the following:

1. There shall be no permanent structural damage to either train, except to energy absorbing structure forward of any passenger or train crew compartment in the colliding end vehicles.

2. The magnitude of the resulting acceleration pulse applied to vehicle occupants shall not exceed levels that would lead to injury of standing or seated passengers. The following acceleration and jerk levels are suggested as thresholds above which a typical standing passenger with a good hand hold would fall over and risk injury.

Maximum longitudinal acceleration	0.2g
Maximum rate of change of acceleration (jerk)	0.3g/sec

(Alternative acceleration and jerk thresholds may be proposed if supported by adequate analysis or test data.)

3. Compliance with this requirement must be demonstrated either by analysis of the performance of energy absorbing structure or equipment incorporated into the leading vehicle of a train, or by a test of this equipment or structure that accurately represents the scenario.

4. Alternative performance criteria may be proposed for consideration, together with test data and analysis to show that an equivalent safety level is maintained.

Comments on Section 3.5.3

This scenario is intended to represent a "rough coupling" operating error. The acceleration and jerk limits suggested correspond roughly to levels at which most standing or walking passengers with a good hand hold will not lose their balance and fall over. The acceleration and jerk levels are adapted from a report by Boyd and Owens "Railroad Passenger Ride Safety" DOT/FRA/ORD 89/06, April 1989, in which safety limits on railroad car "rough riding" conditions are discussed.

That report recommended a limit of 0.15g and a maximum change of acceleration in any one-second period of 0.25g. These levels may be encountered by a tilt body wheel-on-rail train entering a curve on track with poor geometry. The low speed collision is likely to occur much less often than this situation, and thus somewhat higher acceleration and jerk levels, corresponding to a higher probability of standing passengers falling over, can be accepted.

With the specified acceleration and jerk limits, and the initial speed of 10 km/h (6 mph), the length of compression on each colliding vehicle is approximately 1.5m (5 ft). This distance is not an unreasonable length to be provided by energy absorbing drawgear and crushable structure.

The question of validation of collision analysis may be a difficulty. Computer modelling techniques exist for massive plastic structural distortion in an impact, but validation data is very limited. Further discussion is provided in Volume 3, but it may be necessary to accept results for unvalidated models for at least a trial period until more research has been performed and data become available. However, even an imperfect attempt at collision analysis is considered worthwhile.

3.5.4 Medium Speed Collision Survivability

An HSGGT train of the maximum size normally operated shall sustain a 50 km/h (30 mph) collision with a similar stationary train. The consequences shall not exceed the following:

1. There shall be no crushing of any space normally occupied by passenger seating or train crew.

2. The shape and magnitude of the acceleration pulse produced by the collision must be such that no seated passenger or crew member will sustain a significant injury. Injury criteria should include the Head Injury Criteria (HIC) with a maximum impact value of 1000, and any other injury criterion that may be of significance given the internal arrangement of seats and other fittings. This acceleration pulse must be applied in both directions, independent of the direction of travel of the vehicle at the time of impact.

3. All baggage and equipment in the passenger vehicle shall be adequately restrained, such that there is no loss of restraint and no structural damage or major distortion of interior vehicle fittings in the collision. Minor distortion that does not significantly change the functioning of the vehicle's interior in the collision is permitted.

4. Compliance with this requirement shall be demonstrated through an acceptable combination of validated structural analysis, and tests on individual components.

5. An alternative lower-speed collision survivability requirement may be submitted with regard to a specific HSGGT system, provided that the collision speed is not less than 35 km/h (22 mph), and a collision avoidance system with at least the performance required in Paragraph 3.5 is operational at speeds above the specified collision speed.

6. Alternative performance criteria may be proposed for consideration, together with test data and analysis to show that an equivalent safety level is maintained.

Comments on Section 3.5.4

This scenario is based on the premise that all HSGGT systems, even those that normally operate under full automatic control, will have a backup mode of operation under manual control. Manual operation may be used, for example, to rescue stranded trains or vehicles in the event of system failure. It is presumed that the maximum speed of such operations would not exceed 50 km/h. This scenario also provides a minimum level of collision survivability on all HSGGT systems, even those which have full automatic control or automatic train protection at all speeds and at all times. Some level of collision survivability is considered essential on all systems, to protect against the consequences of an unforeseen failure leading to a collision.

This requirement is somewhat experimental, and more analysis is needed to determine whether it is either too strict or too lenient, or whether the collision speed should be adjusted as a function of the low-speed control system, and the nature of back-up operating procedures. However, it is believed that a requirement that specifically requires protection in a moderate 'survivable' collision, but that leaves broad freedom for the system designer regarding how to meet the requirements is appropriate. This requirement is based on the U.S. Motor Vehicle Safety Standard 200-series, that requires automobile models to be tested in a 48 km/h (30 mph) collision with a fixed barrier. A full description of the motor vehicle requirements and test procedures is provided in Volume 3 of this report.

Procedures to demonstrate compliance should include static crush or collision tests of a portion of vehicle structure, and sled tests in which seated instrumented dummies in a mock-up of two rows of seats are subjected to the expected acceleration pulse. The question raised in the comments on Section 3.5.2 above concerning the availability of validated models also applies to this section. A <u>validated</u> model capable of performing an HSGGT collision analysis does not exist, but unvalidated models and techniques can provide useful insight and should be used on an interim basis.

3.5.5 High-Speed Collision Avoidance (129-202 km/h)(80-125 mph)

1. This requirement applies to HSGGT operations at between 129 and 202 km/h (80-125 mph), <u>except</u> for speeds not exceeding 177 km/h (110 mph) on existing railroad track where track, vehicles, and signal systems are constructed and maintained in accordance with existing FRA regulations. Locations where operations at up to 202 km/h (125 mph) are permitted under a waiver to existing FRA regulations are also excluded from this requirement.

2. The signalling and train control system must be such as to ensure that the maximum frequency of collisions between vehicles or trains does not exceed the following:

   a. Multiple unit or push-pull train configurations that have passenger accommodations in the leading vehicle

      5×10^{-3} collisions per billion passenger-km

b. Trains that do not have passenger accommodations in the leading vehicle

2×10^{-2} collisions per billion passenger-km

3. Compliance with this requirement shall be demonstrated by analysis, supported as necessary by test and historic performance data.

Comments on Section 3.5.5

This scenario applies to HSGGT operation at speeds between 129 km/h (80 mph), below which present FRA regulations do not require cab signalling and ATC, and 200 km/h (124 mph). The specification for collision avoidance is based on the premise that collision at this speed, whether with a similar HSGGT train or vehicle or with another type of train or vehicle in shared guideway situations will result in severe damage, and that fatalities among vehicle occupants are likely. The number of casualties which result if end vehicles contain passenger accommodations are likely to be significantly higher than if the end vehicle is a power car, another type of unoccupied vehicle, or a vehicle occupied only by the operating crew. Hence, different standards apply to trains that have passenger accommodation in the end vehicles and trains that do not.

Risk analysis techniques should be used to demonstrate compliance with this requirement.

It should be noted that the requirement in Section 3.5.4, Paragraph 2 is equivalent to one high-speed collision in approximately 33 years on Amtrak's North East Corridor for locomotive-hauled trains. The kinds of signal and train control system, and operating employee training and qualification standards needed to attain this performance will be very similar to those currently applicable in the North East Corridor.

3.5.6 Very High-Speed Collision (over 202 km/h)(125 mph))

Where HSGGT operations take place at over 202 km/h (125 mph), the signalling and train control systems must be such as to ensure that the maximum frequency of collisions does not exceed 0.5 in 10^{12} passenger km.

Compliance with this requirement shall be demonstrated by analysis, supported as necessary by test and historic performance data.

Comments on Section 3.5.6

The requirement for this scenario is based on the premise that a collision at speeds exceeding 200 km/h will be catastrophic. Thus, the performance target is for less than one collision in a trillion passenger km operated at high speed. This requirement is derived from the risk profile in Figure 2-1, for the "100 fatalities in an accident" consequence level. Although it is not possible to estimate the casualties from a very high speed collision with any certainty, it is clear that such an accident will have very severe consequences both in terms of injury and casualties, and in the larger sense in its impact on HSGGT activities in the United States.

It should be pointed out that the Japanese Shinkansen systems have carried a total of approximately 10^{12} pass-km since services began in 1964 without a passenger fatality. TGV high-speed experience is about one order of magnitude less, at 10^{11} pass-km, also without a passenger fatality. The recommended specification corresponds to one very-high-speed collision accident in about 100 years of present French TGV operations, or in 15 years of present Japanese Shinkansen operations.

3.6 SPECIFICATIONS FOR INDIVIDUAL SUBSYSTEMS AND COMPONENTS (LEVEL 3)

3.6.1 Introductory Comments

These requirements serve two purposes. The first purpose is to provide adequate protection against collision scenarios other than collisions between two trains of a similar type, provided for in the "Level 2" requirements described in Section 3.5 above. Additional collision avoidance and/or accident survivability measures may be required to protect against other collision or accident scenarios. The second purpose is to define a minimum performance requirement for each HSGGT subsystem or component that contributes in a significant way to the overall collision avoidance or accident survivability performance of an HSGGT system. It is not the intention that compliance with these minimum requirements will ensure compliance with system-level (Level 1) safety requirements, or the Level 2 collision avoidance or accident survivability requirements. Compliance with Levels 1 and 2 must be evaluated separately.

The requirements are divided into two groups: those addressing collision avoidance, and those addressing accident survivability. The individual headings, with minor amendments, are similar to those used in Volume 1 of this report for the discussion of existing safety practice, and are as follows:

<u>Collision Avoidance</u>

1. Signal and Train Control Systems
2. Intrusion and trespass protection
3. At-Grade rail-highway crossings (wheel-on-rail HSGGT systems only)
4. Vehicle braking systems
5. Miscellaneous vehicle features

<u>Accident Survivability</u>

1. Collision performance of overall vehicle structures
2. Collisions with small objects
3. Impact resistance of outer shell, including windows
4. Vehicle interior fittings and equipment

In general, these requirements apply to all HSGGT systems designed to operate at speeds exceeding 177 km/h (110 mph). Some specific requirements are also provided for operations at speeds of 177 km/h (110 mph) or below, for HSGGT systems that do not comply in all respects with existing FRA railroad safety regulations as listed in Table 3-1. The specifications do not conflict with existing FRA regulations; rather they are requirements addressing vehicle types and operating parameters, especially speed, that are outside the scope of the existing railroad safety regulations.

3.6.2 Collision Avoidance

3.6.2.1 Signal and Train Control Systems

1. Applicability

These requirements apply to all HSGGT systems **except** conventional wheel-on-rail railroad systems built to applicable Federal Railroad Administration (FRA) regulations and North American standards and practices, and operating at speeds at or below 177 km/h (110 mph), or at speeds up to 202 km/h (125 mph) under a waiver from the FRA regulations.

2. Speed Ranges

Minimum signal and control system capabilities are defined by speed range operated at a specific location on an HSGGT system.

0-47 km/h	(0-29 mph)	Low Speed
48-128 km/h	(30-79 mph)	Moderate Speed
129 -200 km/h	(80-124 mph)	High Speed
202 km/h and over	(125 mph and over)	Very High Speed

3. Requirements for Speed Range 0-47 km/h (0-29 mph)

Movements are permitted under manual control with verbal instructions or train-orders from an operations control center or dispatcher.

4. Requirements for Speed Range 48-127 km/h (30-79 mph)

Vehicle or train movements are permitted under manual control, using lineside visual signals. Automatic means of detecting the position of a train or vehicle on the guideway, and an interlocking system which prevents train movements conflicting with each other and switch settings must be used. Automatic block systems on a conventional railroad, conforming to the requirements of 49 CFR Part 236.400-499, are equivalent to these requirements.

5. Requirements for Speed Range 129-200 km/h (80-124 mph)

An automatic cab signal, and automatic train control (ATC) system shall be added to the requirements of paragraph 4 above, for vehicles or trains operated under manual control at speeds at or above 129 km/h (80 mph). The capabilities and features of the ATC system must be as follows:

a. The cab signal indication shall be the same as the wayside signal, where wayside signals are used.

b. An audible warning shall be provided whenever the cab signal indication changes to a more restrictive aspect.

c. If the operator does not acknowledge the audible warning within a specified time interval, an automatic brake application must be made.

d. Lineside signals may be entirely replaced by the cab signal system. Routing signals at junctions may also be replaced if the cab signal system can provide equivalent information in the cab.

e. All vehicles and trains operated on a line segment equipped with a system meeting the requirements of this paragraph must be equipped with cab signals and the equipment to make an automatic brake application.

Requirements a-e above are equivalent to the current requirements applicable to conventional trains operated on the Boston-Washington North East Corridor and selected connecting lines, as specified in the Federal Register, Volume 52, No. 223 (11/19/1987) and Volume 53, No. 97 (10/21/1988).

6. Requirements for Speeds at and Above 202 km/h (125 mph), and for all Speeds for Vehicles and Trains Operated by an Automatic Train Operation (ATO) System

An automatic train protection (ATP) system is required. The ATP system shall continuously compare actual train or vehicle speed with maximum permitted speed, taking into account speed limits for the individual vehicle, temporary or permanent speed limits imposed because of guideway conditions, vehicle or train control instructions, and train braking capability. If actual speed exceeds permitted speed by 15 km/h (10 mph) an automatic brake application must be initiated to reduce speed to a level at or below the permitted speed before manual operation can be resumed. Programmed braking to bring the vehicle or train to rest at a safe stopping point is an acceptable form of automatic braking.

The vehicle operator must not be able to override the automatic brake application in any way that would allow the vehicle or train to be operated at a speed exceeding the maximum permitted speed by more than 15 km/h (10 mph).

The portion of the ATP system that compares actual train or vehicle speed with permitted speed, and initiates automatic braking where required, shall be independent of the portion of an Automatic Train Operation (ATO) system that controls power and braking on the train or vehicle in normal operations.

7. **Safety Performance of Signal and Train Control Systems**

All safety-critical components of signal and train control systems must be of fail-safe, fault-tolerant, or redundant design such that failures leading to an unsafe condition are extremely improbable. Safety critical components include, but are not limited to, the following:

- sensors indicating guideway status, such as switch position, and vehicle or train location
- interlocking systems
- vehicle-guideway communication systems
- lineside and cab signals
- systems which initiate automatic braking

Extremely improbable means that the rate of unsafe failures must not exceed 1×10^{-9} events per vehicle or train operating hour.

Comments on Section 3.6.2.1

Minimum signal and control system capabilities are defined by speed range as indicated in paragraph 2. It is not necessary for a given vehicle to operate under the same signal and train control system for all segments of a journey. Different systems can be used for different portions of a journey, depending on the speeds operated. At lower speeds, the only variation from the requirements of present FRA regulations in 49 CFR Part 236.0. is to require block signalling at speeds of 50 km/h (30 mph) and above, instead of 97 km/h (60 mph) and above. Operating in unsignaled "dark" territory at up to 95 km/h (59 mph) is not considered appropriate for HSGGT vehicles that are not required to meet conventional U.S. railroad vehicle strength requirements.

Cab signals used for speeds of 129 km/h (80 mph) and above must have the ability to initiate an automatic brake application, if the train or vehicle operator fails to acknowledge a warning of a more restricted signal. This ability is not required under existing FRA regulations for speeds between 129-175 km/h (80-110 mph), but is required on the North East Corridor lines and specified connecting lines.

The requirements for speeds at or above 202 km/h (125 mph) are equivalent to those applied to wheel-on-rail high-speed trains in France, Germany and Japan, and to those proposed for high-speed maglev systems such as the German Transrapid system. The requirements apply to both manually and automatically operated systems.

The safety performance requirement in item 7 is intentionally general and not specific to particular kinds of signal and train control equipment. This is so that it can cover both traditional relay-based systems, and innovative systems using fault-tolerant or redundant microprocessors, and the variety of system architectures which could be used on high-speed maglev systems.

It should be emphasized again that these signal system requirements are applicable to all HSGGT systems <u>except</u> wheel-on-rail systems operated at speeds at or below 177 km/h (110 mph) and which are in all respects built and maintained and operated in accordance with present applicable

FRA regulations and railroad industry standards and practices. This limitation means that the proposed requirements do not conflict with current FRA signal system regulations in 49 CFR Part 236.

3.6.2.2 Right of Way Intrusion and Trespass Protection

1. Security Fencing and Signage

a. Fencing or equivalent protection against trespassers, and stray domestic and wild animals, as specified in paragraphs d and e below, is required along all rights of way where HSGGT trains and vehicles are operated at speeds exceeding 177 km/h (110 mph), with the exception of conventional rail lines operated by trains built to applicable North American regulations, standards, and practices, where fencing is required at speeds above 202 km/h (125 mph).

b. Fencing is highly recommended at all speeds of 130 km/h and above.

c. In addition to the right of way, safety-relevant wayside equipment such as power supply substations and signal, train control, and communications equipment must be either fenced, or enclosed in a secure building.

d. Where it is judged that a high risk of trespass exists (such as in parts of urban areas), and around power supply, vehicle control, and communications installations, high-security fencing shall be provided with a minimum height of 2.4m (8 ft.). Guideway configurations providing equivalent protection, such as an elevated guideway at least 2.4m (8 ft.) above ground are acceptable as an alternative to fencing.

e. HSGGT rights-of-way, away from areas where high security fending in accordance with Paragraph d above is required, must be provided with fencing meeting the requirements of AREA Chapter 1, Part 6, Class A or B.

f. All fencing must be provided with signs warning of hazards from HSGGT operations, high voltage electrical installations, and any other relevant hazards, at any location where the public may reasonably be expected to approach the right-of-way.

2. Intrusion from an Adjacent Guideway, Highway, or Other Transportation System

a. Protection against accidental intrusion from adjacent transportation facilities and operations must be provided whenever an HSGGT guideway shares a right-of-way with another mode of transportation, except in the following cases:

-- Only conventional North American wheel-on-rail railroad vehicles or trains built to applicable regulation, standards, and practices are operated at speeds at or below 177 km/h (110 mph), or at speeds up to 202 km/h (125 mph) under a waiver to existing FRA regulations.

-- HSGGT vehicle or train speeds do not exceed 127 km/h (79 mph).

b. The preferred form of intrusion protection is adequate lateral separation, a berm, a ditch, or a physical barrier that will effectively prevent an out-of-control vehicle from an adjacent transportation right of way intruding onto the HSGGT guideway, impacting a structure supporting an HSGGT guideway, or otherwise damaging the guideway and other safety-relevant equipment.

c. If physical protection by a barrier or lateral spacing is not possible, an alternative permissible form of protection is an intrusion detection system linked to the vehicle or train control system, that will stop operations in the event of an intrusion.

d. A risk analysis of the effectiveness of the systems chosen to protect against collisions between an intruding object and an HSGGT vehicle or train must be performed, and must be included in the overall system safety analyses required under Section 3.1.4.

3. **Overbridges**

a. Bridges over the HSGGT guideway that are accessible to people or vehicles, and where HSGGT speeds exceed 177 km/hr (110 mph), must be equipped with the forms of protection specified in Paragraphs b to e below, except where conventional North American wheel-on-rail railroad vehicles or trains built to applicable regulations, standards, and practices are operated at speeds up to 202 km/h (125 mph) under a waiver from existing FRA regulations.

b. 8 ft. high fences are required, as specified in paragraph 1.d above.

c. Highway overbridges must be equipped with normal highway bridge rails, "New Jersey barriers," or equivalent barriers to restrain an out-of-control vehicle.

d. A safety barrier extending 2m (6.6. ft.) laterally from the bridge over the HSGGT guideway is required, capable of arresting a 11 kg (24 lb.) cinder block dropped from the top of the fence.

e. A "fragile wire" or equivalent warning device connected to the train control system is required, to detect when a heavy object falls through the safety barrier.

Comments on Section 3.6.2.2

Fencing is required to reduce the risk of trespassers and animals from gaining access to the HSGGT right of way. Trespassers are at risk of being hit by moving vehicles or trains, and may vandalize HSGGT installations and cause an accident. Fences will also minimize the risk of animals straying onto the guideway. The 8 ft. high security fence requirement, for locations where there is a high risk of trespass, is taken from the American Public Transit Association guidelines for the design of rail rapid-transit systems.

The requirements for shared right-of-way intrusion protection are not fully defined at this point, since information on both intrusion risks and accident consequences in different situations is not known, and in any case is likely to be specific to particular combinations of an HSGGT system and an adjacent transportation mode. Intrusion risks, and other safety threats arising from an HSGGT service sharing a transportation corridor with another mode are the subject of a separate VNTSC study.*

The overbridge protection requirements are adapted from those used on the TGV Atlantique line in France, and are designed for "cinder block dropped by vandals" or "masonry dropping from bridge" scenarios, and the situation where an out-of-control highway vehicle or derailed rail vehicle breaks through the bridge rails and falls onto the guideway. Obviously, a warning system is only partially effective. If the HSGGT train or vehicle is approaching the bridge when such an event occurs, it will be unable to stop in time to avoid a collision. The benefit from a warning system is a function of traffic density on the HSGGT system, and the effectiveness of vehicle containment on the bridge. A risk analysis of the performance of overbridge and other protection requirements is required to demonstrate that adequate performance can be provided.

3.6.2.3 At-Grade Rail-Highway Warning and Protection System

1. Applicability

The requirements of this section apply only under the following conditions:

a. When wheel-on-rail HSGGT vehicles or trains of any type are operated over at-grade rail-highway crossings at speeds above 177 km/h (110 mph)

b. When wheel-on-rail HSGGT vehicles or trains that do not conform to current FRA regulations and applicable conventional U.S. passenger railroad vehicle standards and practices are operated over at-grade rail-highway crossings at speeds at or above 48 km/h (30 mph)

At-grade rail-highway crossings over guideways carrying passenger traffic are not permitted on any type of HSGGT system other than wheel-on-rail systems.

2. HSGGT Operations Between 48 and 127 km/h (30 and 79 mph)

At a minimum, at-grade rail-highway crossings must be equipped with the following warning devices.

a. Gates for the full width of the highway
b. Flashing lights or highway signals
c. Bell

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*Hadden, J., D. Kerr, W. Lewalski and C. Ball, "Shared Right-of-Way Safety Issues," Federal Railroad Administration Report DOT/FRA/ORD-92/13.

3. **HSGGT Operation at Between 129 and 159 km/h (80-99 mph)**

In addition to the requirements specified in Paragraph 2 above, all at-grade rail-highway crossings, at a minimum, must have the following features.

a. Crossing gate controls that prevent short-duration opening of less than thirty seconds when a second train approaches the grade crossing shortly after the passage of an initial train.

b. Signs must be posted to advise highway users that the rail line is used by high speed trains.

4. **HSGGT Operation at Between 160 and 200 km/h (100-125 mph)**

In addition to the requirements specified in Paragraph 3 above, all at-grade rail-highway crossings, at a minimum, must have the following features.

a. Detector systems on the crossing gates and in the roadway, interlocked with the train control system such that permission for the train to proceed can only be given after the crossing gates are fully closed, and there is no obstruction detected on the tracks.

b. The obstruction detection system must be capable of detecting vehicles of the size of a subcompact automobile and larger.

5. **HSGGT Operation at Speeds Exceeding 202 km/h (125 mph)**

At-Grade rail-highway crossings are prohibited. Full grade separation must be provided.

6. **Miscellaneous Requirements, All Speeds Over 50 km/h (30 mph)**

a. Where an overhead catenary is used for power supply to trains, a warning structure indicating maximum safe road vehicle height must be provided on both sides of the crossing, not less than 50 m (164 ft) before the crossing gate.

b. The highway surface profile through the crossing must be smooth, and changes in profile sufficiently gradual as to eliminate the risk of low clearance highway vehicles becoming grounded and stuck on the crossing.

Comments on Section 3.6.2.3

Existing safety regulations do not require the installation of specific grade crossing warning systems as a function of railroad and highway traffic levels, speeds, and other factors, although these factors are used in allocating funds for improvements to these systems. Actual practice is to install higher capability warning devices and gates on crossings with higher rail and road traffic levels, and at locations with a poor accident record.

This suggested requirement is based on the premise that at-grade rail-highway crossings will only be considered on a wheel-on-rail high-speed train system where no reasonable alternative exists, such as where an HSGGT vehicle or train is using existing track for a part of a journey. The train itself may not necessarily be built to conventional U.S. railroad passenger car structural requirements, but a grade crossing collision scenario must be considered during structural design as specified in Paragraph 3.6.3.1.

The grade crossing warning system requirements for speeds between 160 and 200 km/h (100-125 mph) are derived from the approach taken in Sweden for 200 km/h (125 mph) operation across grade crossings with the X2000 train. Inductive loops embedded in the roadway are used to detect the presence of road vehicles.

Low-clearance highway vehicles becoming stuck on at-grade crossings due to an uneven road surface is a common cause of grade crossing collisions with trucks. Special attention to road surface profile is warranted at crossings used by high-speed trains.

It should be emphasized that the requirements in Section 3.6.2.3 are minimum requirements. Research continues on ways of reducing the incidence of collisions between rail and highway vehicles at at-grade crossings, and new ways of providing warning or protection may be developed and shown to be effective. The fruits of such research should be incorporated into HSGGT at-grade rail-highway crossing system requirements wherever an adequate benefit exists.

3.6.2.4 Vehicle Braking Systems

1. Applicability

These requirements apply to the safety braking systems for all HSGGT trains and vehicles designed to operate at speeds exceeding 202 km/h (125 mph). The safety braking system is the system on the train that is relied upon to provide braking with a high degree of certainty, independent of the availability or performance of other braking systems that may be installed on the train.

2. Braking Distance

A maximum stopping distance curve or deceleration rate achievable with the safety brake shall be defined for all types of train operation. The specified stopping distances from all speeds must be equal to or less than the stopping distances used in the design of the signal and train control system, determining the minimum headways between vehicles or trains, and establishing operating criteria for braking systems designed to bring the vehicle to rest at a designated safe stopping point. Tests must be carried out to demonstrate that the defined stopping distances can be achieved with the safety brake with at least one, and not less than 15 percent of braking units in the train inoperative. Note that having 15 percent of brake units inoperative is a test condition only, and does not mean that trains or vehicles may be operated in regular service with inoperative brakes.

3. Safety Brake Control and System Requirements

a. The safety brake must always be available for operation when the train or vehicle is in motion, and must be independent of any external power source.

b. Propulsion systems must be shut off automatically or shifted to braking mode on the initiation of safety braking.

c. Other "non-safety" braking systems fitted to the train or vehicle must either blend with the safety brake to achieve the desired stopping distance or be shut off reliably on initiation of safety braking. Under no circumstances should the state of non-safety brakes, whether operative or not operative, affect safety braking capability.

d. The overall brake control system must be designed such that any equipment failure which would render the vehicle or train unable to stop is extremely improbable. Extremely improbable means that vehicle or train brake failure probability must not exceed once in 10^9 operating hours.

4. Individual Braking Units

a. A train must be equipped with multiple independent braking units. There is no minimum number, but requirement 2 above must be adhered to.

b. The condition of inoperative individual brake units must be such that they can be guaranteed not to suffer damage or interfere in any way with normal vehicle operations and the safety braking function.

c. Brake units must be capable of absorbing or transmitting the maximum braking energy and power during a test stop from maximum speed, with at least one, and not less than 15 percent of brake units inoperative, as defined in Paragraph 2 above, without permanent damage. Analyses and dynamometer brake tests must be performed to confirm that energy absorption or transmission performance is satisfactory.

5. Parking Brakes

All individual vehicles (as defined in Section 3.3) must be provided with a parking brake capable of holding the vehicle at rest on the steepest gradient of the system.

Comments on Section 3.6.2.4

These braking requirements have been developed on the assumption that a traditional railroad vehicle or train control philosophy is followed: that the separation between vehicles or trains operating on the same guideway is the specified stopping distance from maximum speed (as defined in Paragraph 2 above), plus allowances as required for:

operator reaction time

- block length, where a fixed block system of vehicle or train control is used
- safety margin

The proposed braking requirement is not applicable in its present form to HSGGT systems where vehicle separation is less than the stopping distance at the maximum speed operated. Also it is assumed that brake systems consist of a high-integrity control system, and multiple independent braking units even on the smallest vehicle or train operated in public service. In both instances different brake system concepts will require different brake safety requirements.

The proposed specification is independent of the actual means of brake control (e.g., pneumatic or electrical), or the means of producing retardation (e.g., by friction, eddy current, magnetic, or other).

No requirements are specified for brake systems that may be used in routine operations (such as rheostatic or regenerative braking using rotating or linear motors) but are not designated as a "safety brake," except that they must not adversely affect the availability and operation of the safety brake. For example, the Transrapid maglev system uses a linear synchronous motor with a guideway-mounted long stator as the primary braking system. However, the possible failure modes of this brake are such that it cannot function as a safety brake. The safety brake is an eddy-current brake system mounted on the vehicle.

Redundancy, fault tolerant or fail-safe/"safe life" philosophies may be applied to designing the brake control system to ensure that the specified maximum rate of unsafe brake control system failures is not exceeded. The traditional railroad air brake follows the fail-safe principal, in that most failures (such as an air-line leak or hose bursting) causes the brake to be applied. A redundant or fault-tolerant approach is used for the safety brake controller in the Transrapid maglev vehicle, where the brake control computer is a two-out-of-three voting microprocessor system.

3.6.2.5 Miscellaneous Vehicle Requirements

1. Applicability

These miscellaneous requirements apply to all HSGGT vehicles capable of operating under manual control, regardless of speed of operation.

2. Audible Warning Devices

All lead vehicles must be equipped with an audible warning device meeting the requirements of the FRA regulation for conventional locomotives 49 CFR Part 229.129 (providing a minimum sound level of 96 dBA at 100 ft forward of the lead vehicle in its direction of travel). The device must be easily operable by the vehicle operator. Compliance with this requirements must be verified by a test as specified in 49 CFR Part 229.129, Paragraph b.

3. Headlight

All lead vehicles must be equipped with a headlight meeting the requirements of the FRA regulation for conventional locomotives 40 CFR Part 229.125 (Minimum of 200,000 candela, and able to illuminate a person 800 ft ahead on the track of guideway).

4. Rear End Markers

All rear end vehicles of a train or the rear of a single vehicle train must be equipped with an approved rear end marker meeting the requirements specified for conventional passenger railroad equipment as specified in 49 CFR Part 221, including testing and approval procedures.

Comments on Section 3.6.2.5

The primary purpose of requiring this conventional railroad vehicle safety equipment is to facilitate lower speed operations under manual control. Either a maglev and wheel-on-rail high-speed system may operate at low speed under manual control after a system malfunction, and lights and an audible warning device will be required for safe manual operation. A wheel-on-rail HSGGT train may operate over conventional rail lines at conventional speeds, where these devices will be required under current FRA regulations in any case.

3.6.3 Accident Survivability

3.6.3.1 Overall Vehicle Structure

1. Applicability

This requirement applies to all HSGGT vehicles, except operations at speeds of up to and including 177 km/h (110 mph) with conventional North American railroad vehicles, and up to 202 km/h (125 mph) where permitted under a waiver to the current FRA regulations.

2. Supplementary Collision Performance Requirements

In addition to the collision scenarios specified in Section 3.5 above, the collision performance of wheel-on-rail HSGGT vehicles or trains that operate over grade crossings and/or share a track with conventional United States railroad trains must be evaluated for the following impacts. The severity of consequences detailed in Section 3.5.3 for medium-speed collisions must not be exceeded.

a. An At-Grade Rail-Highway Crossing Supplementary Collision Scenario, applicable to all wheel-on-rail trains that operate over at-grade rail-highway crossings.

A train of the maximum size normally operated shall undergo an impact with a dry van tractor-trailer highway vehicle loaded to 80,000 lb. at the mid-point of the van body, at a speed of 159 km/h (99 mph) or the maximum speed at which the train will be operated over at-grade rail-highway crossings, if this speed is lower. Damage and casualty severity must not exceed the criteria specified in Paragraph c below.

b. A Conventional United States Train Supplementary Collision Scenario, applicable to HSGGT vehicles or trains that share tracks with conventional United States trains.

A train of the maximum size normally operated shall undergo a 50 km/h (30 mph) impact with the locomotives of a stationary North American freight train consisting of three four-axle locomotives and 1,000 tons trailing load without exceeding the injury and damage criteria specified in Paragraph c below.

c. The consequences of the collisions specified in a and b above shall not exceed the following (repeated from Section 3.5.3):

i. There shall be no crushing of any space normally occupied by passenger seating or train crew.

ii. The shape and magnitude of the acceleration pulse produced by the collision must be such that no seated passenger or crew member will sustain a significant injury. Injury criteria should include the Head Injury Criteria (HIC) with a maximum value of 1000, and any other injury criterion that may be of significance given the internal arrangement of seats and other fittings. This acceleration pulse must be applied in both directions, independent of the direction of travel of the vehicle at the time of impact.

iii. All baggage and equipment in the passenger vehicle shall be adequately restrained, such that there is no loss of restraint and no structural damage or major distortion of interior vehicle fittings in the collision. Minor distortion that does not significantly change the functioning of the vehicle's interior in the collision is permitted.

iv. Compliance with this requirement shall be demonstrated through an acceptable combination of validated structural analysis, and tests on individual components.

v. Alternative performance criteria may be proposed for consideration together with test data and analysis to show that an equivalent safety level is maintained.

d. Compliance with the requirements of Paragraphs a, b, and c above shall be demonstrated through a combination of validated structural analysis and tests on individual components.

3. Vehicle Crush Behavior

Maximum use of vehicle body crushability to absorb collision energy shall be made by designing the operator's cab and the passenger compartments to be significantly stronger than unoccupied equipment spaces in power vehicles, and vestibule or equivalent spaces at the ends of passenger vehicles and vehicle sections.

4. Intervehicle Connection

Connections between vehicles and vehicle sections shall be designed so that override, and lateral and vertical buckling of a train, does not occur under the compression loads estimated to be present in the collision scenarios.

5. Truck and Suspension Attachments

Truck and suspension attachments must be designed so that trucks and suspension components will remain attached to the vehicle under the longitudinal acceleration loads estimated to be present in the collision scenarios.

Comments on Section 3.6.3.1

Overall vehicle structural performance in collision is addressed in the "Level 2" specifications for low- and medium-speed collisions. This part of the specification adds requirements for accident survivability for wheel-on-rail HSGGT vehicles or trains that operate over track shared with conventional North American passenger and freight trains. Trains other than the HSGGT trains, the track and signalling systems, and the railroad operation are assumed to comply with applicable FRA regulations, and railroad industry standards and practices. This sharing exposes the HSGGT vehicle or train to collisions with conventional trains and collisions with highway vehicles on at-grade rail-highway crossings, which may be more severe than specified in the "Level 2" collision survivability requirements. Thus, these additional requirements have been developed. It should be noted that the collisions specified are not intended to be the worst that could occur (heaviest obstruction, highest speed). Rather, they represent collisions that the HSGGT vehicle or train should be able to undergo without causing serious injury to occupants. The performance specified is similar to that exhibited by conventional North American passenger trains of recent construction in the same scenarios. For example, the energy dissipated by a 500 tonne (550 ton) HSGGT train in the freight train collision specified in Paragraph b would be about 48.3 MJ (33.1×10^6 ft-lbf). As discussed in Chapter 2 of Volume 1, North American trains generally survive such collisions with few serious injuries and no fatalities.

This part of the specification, therefore, provides a way for wheel-on-rail HSGGT vehicles and trains to be qualified to operate over existing tracks in the U.S. without being required to meet conventional North American passenger car structural requirements, and without any loss of occupant protection. The requirements of Paragraph 3.6.3.1 do not apply to HSGGT systems with completely segregated guideways, on which only similar HSGGT vehicles and trains operate, and which do not have any at-grade rail-highway crossings.

One way of meeting these requirements with trains that do not conform to conventional North American rail vehicle structural requirements is to avoid using the end vehicles of a train for passenger accommodations. Experience in actual accidents suggests that end vehicles are severely damaged in accidents, and when occupied they result in large numbers of casualties. In contrast, intermediate vehicles are not damaged except in exceptionally violent collisions, and occupants survive with only minor or moderate injuries.

3.6.3.2 Collisions with Small Objects

1. Applicability

This requirement shall apply to all HSGGT vehicles operating at speeds exceeding 177 km/h (110 mph), except conventional North American railroad vehicles or trains operating at speeds up to 202 km/h (125 mph) where permitted under a waiver to current FRA regulations.

2. Requirements

a. All lead vehicles must be fitted with an end plate, pilot, or snow plow capable of sustaining an impact with a small object on the guideway at maximum operating speed.

b. The pilot shall have the minimum possible clearance to the guideway surface, or the top of the rails in a wheel-on-rail system, taking into account maximum vehicle movements on suspension, maximum wheel wear and similar considerations.

c. Guideways, including trough-type maglev guideways, shall be configured so that snow, debris, and small objects on the guideway can be readily swept clear of the guideway.

d. The mass of the small object shall be assumed to be 25 kg (55 lb).

e. The pilot may suffer local damage and distortion on impact, but this must be such that no portion of the pilot becomes detached, or interferes in any way with continued safe operation of the vehicle.

f. The possibility that very small objects might pass under the pilot and hit under-vehicle equipment such as braking and suspension equipment must be recognized. Components vulnerable to impact must be fitted with shields, deflector plates or equivalent protection to minimize the risk of potentially hazardous damage. Components provided with protection should particularly include cables, air and hydraulic hoses, sensors, and other such easily damaged and potentially safety-critical equipment.

Comments on Section 3.6.3.2

In spite of all precautions, small obstructions and debris may be found on the guideway, as well as accumulations of snow and ice. The primary protection against such debris causing an accident is to provide the vehicle with an impact resistant pilot or end plate. This end plate must be capable of sweeping aside small objects without causing other than local distortion of the end plate. There is also the possibility that objects smaller than the clearance between the pilot and guideway may pass under the vehicle. Under-vehicle installations must be designed so that they cannot be damaged by such small objects.

In general, it is believed not practical at present to use detection systems to protect against small obstructions. Hence, use of detection systems has not been required, and the emphasis in the requirement is on surviving impacts with small objects.

3.6.3.3 Impact Resistance of Vehicle Outer Shell, Including Windows

1. Applicability

These requirements apply to all HSGGT vehicles intended for operation at speeds exceeding 200 km/h (125 mph). They are also highly recommended for guided vehicles operating at speeds below 200 km/h, other than conventional US railroad equipment constructed to existing FRA safety regulations, and applicable standards and practices.

2. Forward Facing Windows

a. All forward facing windows shall be capable of sustaining an impact from a 1 kg (2.2 lb) standard projectile (illustrated in Figure 3-2) at the vehicle's maximum operating speed plus 160 km/h (100 mph). If the guideway is more than 30 m (100 ft) from another guideway, then the impact speed is reduced to maximum operating speed. A forward-facing window is any window installed in the vehicle with an angle less than 80° relative to a transverse plane through the vehicle facing the direction of travel.

b. Compliance with this specification must be demonstrated in a test. The test may be conducted with the window at right angles to the direction of travel, or at the angle as installed in the vehicle. In the latter case test certification can only be given for the specific angle tested or a greater angle. The test specimen shall be of the maximum size used, and mounted in the frame in the same way as in the vehicle.

c. Test procedure shall be identical to that described in the FRA regulation 49 CFR Part 223, Appendix A, except with regard to the requirement for the test specimen to be mounted in the window frame, and the alternative of testing the glazing at the angle installed in the vehicle, as specified in Paragraph b above. The criteria for acceptance are that the projectile must not penetrate the inside surface of the glazing material, and no glazing fragments from the impact may penetrate a 0.006 inch aluminum witness plate positioned 150 mm (6 in) behind the inside surface of the glazing.

All glazing installed in the vehicle shall be marked with the maximum permitted speed, test angle, a reference number for the test certificate, and the identity of the manufacturer and brand.

3. Forward Facing Surfaces Other Than Windows

All forward facing surfaces having an angle of 80° or less to a transverse plane through the vehicle shall be subjected to an impact test with a 1 kg (2.2 lb) projectile as illustrated in Figure

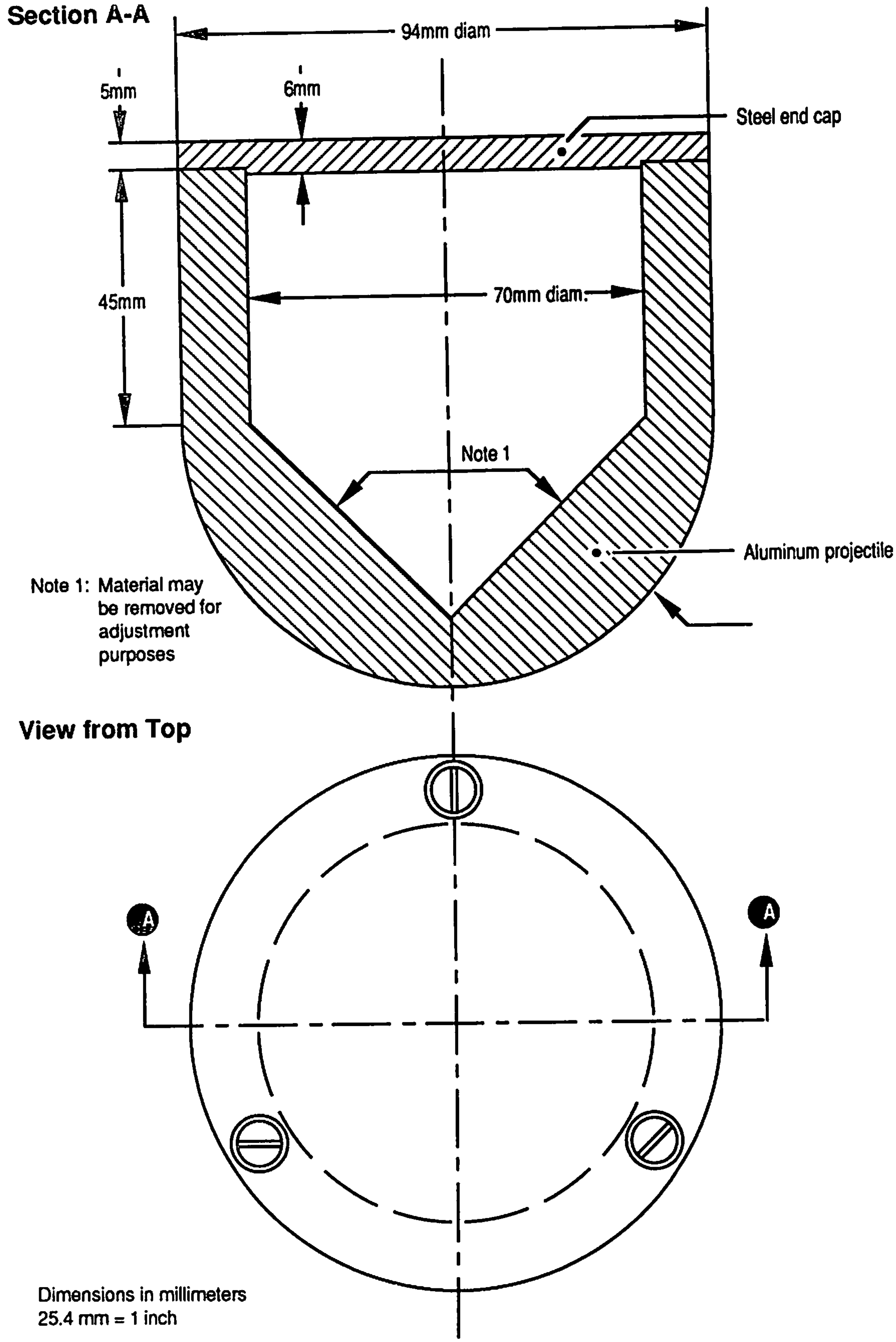


Figure 3-2. UIC Standard Projectile for Testing Forward Facing Windows

3-2 at the maximum vehicle operating speed plus 160 km/h (100 mph). The surfaces must be tested with the material at right angles to the direction of travel.

Criteria for acceptance are that the projectile must not penetrate into any space occupied by passengers or vehicle crew, or into any space occupied by safety-critical equipment. Safety-critical equipment shall include equipment performing any of the following functions: vehicle braking, train control, vehicle-guideway communications, active suspension systems (including maglev magnets), onboard power supplies, or cables carrying power or control signals associated with any of these functions.

4. **Side Windows**

All side windows must be fitted with glazing certified as being in compliance with FRA Type II requirements, as specified in 49 CFR Part 223.

5. **Bullet Impact Requirements**

a. All windows (both side and forward-facing) shall be certified as being in compliance with the bullet impact requirement in 49 CFR Part 223, including test methodology and criteria for acceptability.

b. All exposed surfaces (sides, roof, ends) shall sustain a bullet impact as defined in 49 CFR Part 223, without penetration into a space occupied by passengers or crew, or safety-critical equipment as defined in paragraph 3 above.

Comments on Section 3.6.3.3

The projectile and impact speeds for impact on forward facing windows and other surfaces is taken from the UIC windshield impact test requirement in UIC Code 651. The reason for adding 160 km/h (100 mph) to the speed of the struck vehicle is to represent the situation where a projectile becomes detached from or is kicked up by a vehicle traveling in the opposite direction on an adjacent guideway. While objects are unlikely to become detached from an HSGGT vehicle or train at high speed, it is still possible for small objects lying on the guideway to be thrown up following impact with a vehicle travelling in the opposite direction. The requirement to add 160 km/h (100 mph) is waived when there is no second guideway within 30m (100 ft). If an HSGGT system operates at varying speeds and with or without another guideway within 30m (100 ft) over different portions of a route, then the worst case impact speed requirement shall apply.

A possible alternative to the UIC projectile test is the FAA bird-strike test, using a 1.8 kg (4 lb) bird. Impact energies are similar to those of the UIC test, but since the bird is softer than the UIC projectile, the FAA test may be slightly less demanding. Also impact with a hard object is more likely with a guided ground vehicle than an aircraft.

A further alternative to the standard FAA bird impact test or the UIC projectile test is a test similar to the FAA test, but with a heavier bird. In some parts of the country, such as parts of

Florida, there is an abundance of heavy birds, leading to a significant risk of an impact. It is understood that a 3.2 kg (7 lb) bird strike requirement is under consideration as a requirement for maglev operations on the proposed Orlando Transrapid single guideway system, and could be an alternative to the UIC projectile test specified in Paragraph 2 above.

Since some HSGGT vehicles may be manufactured with thin skin material relative to existing railroad equipment, the small object impact test requirements have been extended to the vehicle body shell.

The FRA bullet impact test has been adopted for all windows and the exterior skin or the vehicle. If the FRA requirement is made more demanding (for example by increasing the specified bullet weight or velocity), then this requirement should be changed also.

3.6.3.4 Vehicle Interior Fittings and Components

1. Applicability

These requirements apply to all HSGGT vehicles and trains operating at speeds exceeding 177 km/h (110 mph) except conventional North American railroad vehicles or trains operated at speeds up to 202 km/h (125 mph) where permitted under a waiver from current FRA regulations.

2. Attachment Strength of Interior Fittings and Equipment

All interior fittings and equipment must be able to sustain longitudinal accelerations of 5.0g and lateral and vertical accelerations of 3.0g without failure or significant distortion. Each seat must be assumed to be occupied by a 84 kg (185 lb) person. All baggage and equipment storage compartments must sustain the specified acceleration without failure or significant distortion when containing the maximum permitted weight of contents. Maximum permitted weight must be indicated on each compartment.

3. Baggage Storage

All baggage must be stored in one of the following approved locations:

a. In enclosed overhead bins. If open overhead racks are provided, they must only be used for soft objects such as clothing.

b. Under the seat in front of the seat occupied by the owner of the baggage, where a seat faces the back of another seat.

c. In end-of-car baggage compartments designed to restrain baggage against the accelerations specified in paragraph 2 above.

4. Surface Treatments

All surfaces directly in front of seated passengers, including seat backs, and partitions must be padded to minimize the risk of injury during sudden deceleration. In addition, any sharp edges, or projecting objects which might injure a person moving about a passenger compartment must be padded.

All surfaces, sharp corners and protruding objects in the operator's cab and crew compartment shall be rounded and padded wherever possible, with particular emphasis on corners, surfaces and objects directly in front of the operator.

Comments on Section 3.6.3.4

The exact acceleration environment inside a rail vehicle during a collision is unknown, since there have been no instrumented tests. Empirical experience with existing conventional rail vehicles has led to seat and equipment attachment strength requirements of 5g longitudinal and 3g laterally and vertically, which appear to be adequate in most collisions. Arguments can be developed to suggest the weight to crush strength ratios of the various types of HSGGT vehicles and trains could differ from conventional North American railroad equipment, leading to a different acceleration environment in the vehicle. However, there is no clear indication of how to adapt existing interior strength requirements for HSGGT vehicles. Until more information is available, the recommended requirements follow those for existing conventional railroad vehicles. It should be noted however, that there is good agreement between independently evolved United States and European (UIC) strength requirements, both of which derive from actual experience of vehicles in accidents.

The interior requirements for the padding of hard surfaces and sharp corners are adapted from the FAA requirements for aircraft interiors. The specified requirements are considered a minimum level which should be provided in all HSGGT vehicles, even when under automatic operation or supervision at all times. Even if the risk of a collision is very low, there is still the possibility of a sudden stop caused by a guideway or vehicle defect.

4. SYSTEM SAFETY ANALYSIS METHODOLOGIES

4.1 INTRODUCTION

The safety specification detailed in Chapter 3 requires that an HSGGT system developer must demonstrate that a specific system, installed in a particular route, will achieve the desired safety performance. The system developer also has to demonstrate that the failure rate of certain safety-critical subsystems, such as vehicle brakes and the vehicle movement control systems, do not exceed specified levels.

A number of methodologies are available for analyzing the safety performance of an HSGGT system as a whole, and the safety performance of the individual safety-critical subsystems and components. The results of these analyses can be used to satisfy the system safety analysis requirements in the specification. The purpose of this chapter is to provide brief descriptions of relevant analysis techniques.

System safety analyses of HSGGT systems, subsystems, or components involves identifying and assessing the frequency of occurrence and severity of all undesired events that might occur as a result of operating the system. An undesired event is one which leads to either casualties to persons (i.e., injuries and fatalities), or less seriously, to property damage or a disruption of operations. The overall system safety performance is the aggregate of all the frequencies and severities of individual undesired events. If this performance is outside the specified limits, it is necessary to modify the system to reduce the frequency and/or severity of undesired events. Limits of acceptability are applied in the specifications to the system as a whole, to particular kinds of undesired events, to particular classes of person (e.g., passengers and system employees), and separately to the frequency of occurrence and severity of particular kinds of events.

Analysis techniques which can be used singly or in combination to meet the analysis requirements of the specification are Fault Tree Analysis, absolute and comparative Quantitative Risk Analysis (QRA), and Preliminary Hazard Analysis. The techniques and their advantages and disadvantages are described in the following paragraphs.

4.2 FAULT TREE ANALYSIS

Fault Tree Analysis is a procedure for identifying and structuring human errors and component and subsystem failures that are the root causes of accidents, and defining the relationship of such errors and failures with the accident survivability performance of the HSGGT system, and the overall safety performance of the system.

To illustrate the technique, a fault tree has been prepared for an HSGGT system, and is shown in Figure 4-1. Figure 4-2 defines fault tree symbol conventions. The fault tree shows how the incidence of undesired events corresponding to the collision scenarios defined in Chapter 2 of Volume 1 of this report are combined to obtain an understanding of overall HSGGT system safety performance.

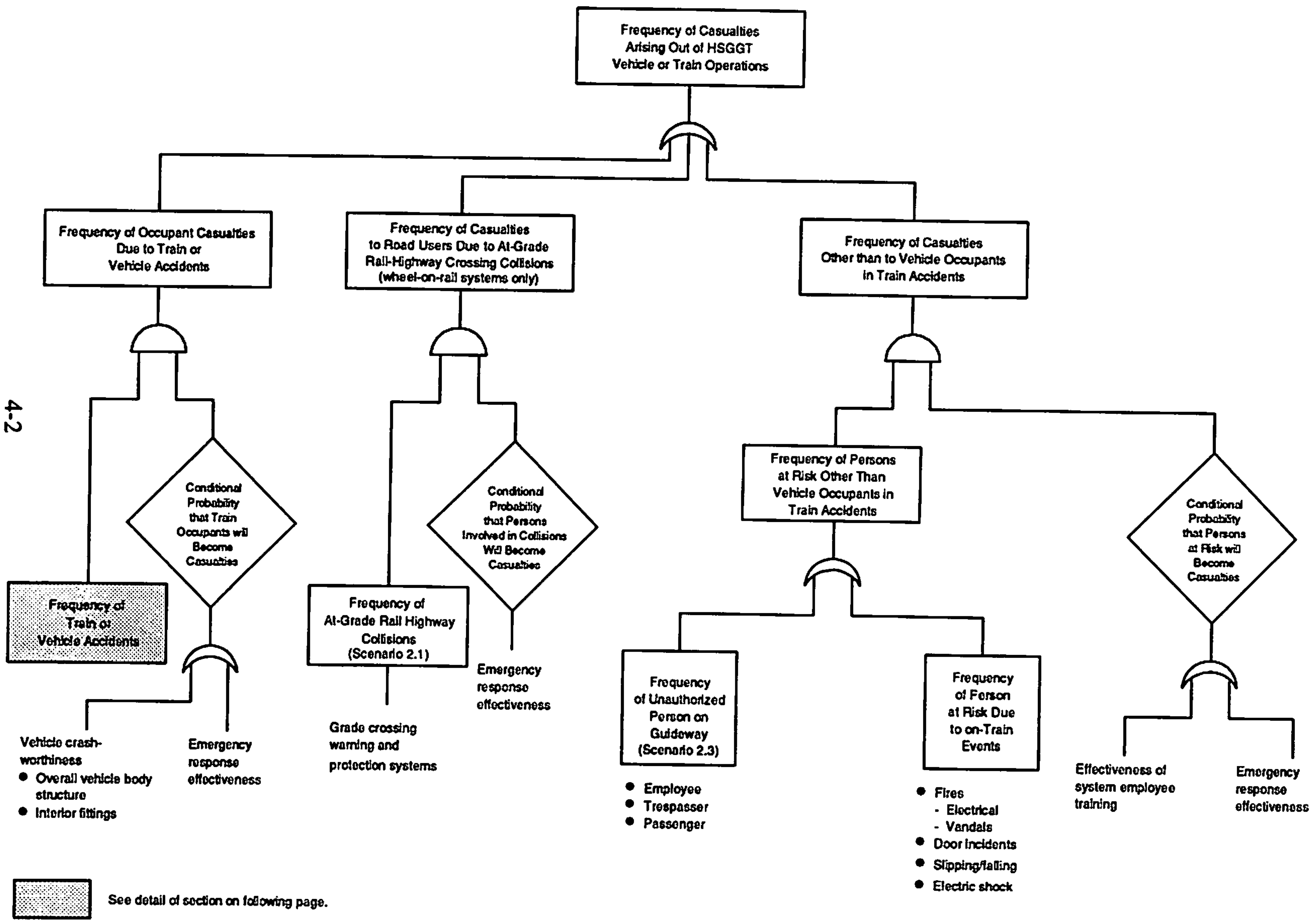


Figure 4-1. Fault Tree for Casualties Arising Out of HSGGT Vehicle or Train Operations

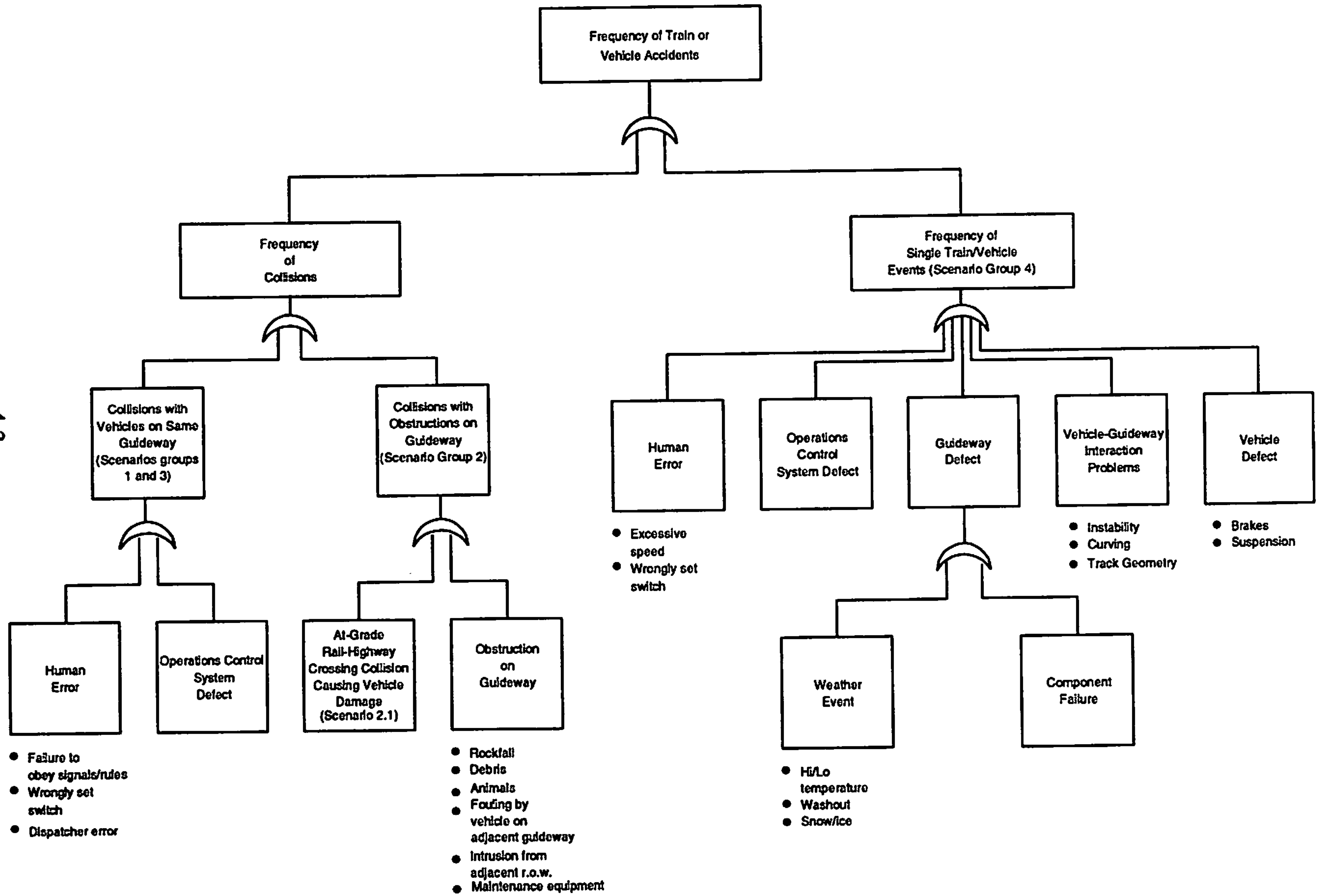
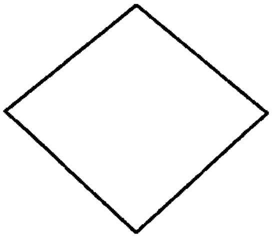


Figure 4-1. Fault Tree for Casualties Arising Out of HSGGT Vehicle or Train Operations (continued)



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.

Figure 4-2. Fault Tree Conventions

The fault tree of Figure 4-1 covers all casualties to people that could arise from HSGGT vehicle operations. Casualties that could occur to people away from a moving vehicle, for example, in a terminal building or during vehicle or guideway maintenance, are not covered. The fault tree shows how individual "undesired events" contribute to the overall "top event," in this case the total casualties arising out of HSGGT vehicle or train operations. Similar fault trees can be developed where the top event is aggregate property damage, or disruptions to operations. More detailed fault trees can also be developed to study failures of individual subsystems or components.

Starting from the top event, the fault tree has three main branches, organized by the location of the person who becomes a casualty, and the type of undesired event.

1. Casualties to vehicle occupants in vehicle or train accidents.

2. Casualties to highway vehicle occupants in at-grade rail-highway crossing collisions.

3. Casualties to individuals on the guideway, or to vehicle occupants other than in train or vehicle accidents.

In each case, the frequency of casualties is a function of the frequency of occurrence of people being placed at risk (for example, by a person being in a vehicle involved in a collision, or being on the guideway without appropriate authorization) and the conditional probability that a person at risk will become a casualty. The frequency with which people are placed at risk is primarily a function of the measures adopted to <u>avoid</u> collisions, accidents and other undesired events in the HSGGT system. The conditional probability that a person at risk will become a casualty is primarily a function of HSGGT system features designed to ensure <u>survivability</u> should an undesired event occur.

Lower levels of the fault tree identify individual types of collisions, accidents, or other undesired events (such as trespass on the guideway) that could place a person at risk of becoming a casualty, and some representative causes of undesired events. Collision and accident scenarios and scenario groups from Volume 1 are identified on the fault tree, thus showing how the frequency of occurrence of the different collision or accident scenarios and corresponding collision/accident survivability measures contribute to the overall system safety performance of the HSGGT system.

The fault tree can be expanded to further disaggregate the scenario groups into individual scenarios, each with characteristic frequencies of occurrence and conditional probabilities of persons at risk becoming casualties.

An HSGGT system-safety analysis involves estimating the frequency of occurrence of each collision and accident scenario, and quantifying the effectiveness of survivability features of the system to yield conditional probabilities, and using the fault tree logic to estimate the overall frequency of casualties and other relevant safety performance measures.

The following two sections describe risk analysis techniques that use fault tree analysis as a starting point.

4.3 ABSOLUTE QUANTITATIVE RISK ANALYSIS

Absolute Quantitative Risk Analysis (absolute QRA) is the name given to the process of assigning quantitative values to all the event frequencies and conditional probabilities shown in the fault tree, and calculating an estimate of casualty rates. The key feature of absolute QRA is that risks are expressed in direct terms such as likely fatalities or injuries per billion passenger-km, or the frequency of accidents at each severity level. Absolute QRA has been widely used in the chemical and nuclear industries to calculate risks, and to select strategies to reduce risks to acceptable levels. One of the most comprehensive manuals for QRA is published by the Institute of Chemical Engineers.**

Estimates of the frequency of undesired events (errors and component/subsystem failures) can be developed from analysis of past experience, or by engineering analyses of the component system in question. Past experience is useful for a system for which extensive operating experience is available, such as a conventional railroad. The second method, engineering analysis, needs to be used where such experience is lacking. The performance of components and subsystems that make up the overall system (e.g., braking or a signalling system) is quantified in terms of likely failure rates. At the most detailed level the analysis may involve detailed structural or dynamic analyses of a subsystem or component, or a subsidiary failure analysis, using failure rates of the individual elements of the component. The latter approach is often used for electronic systems.

The conditional probabilities relating to the survivability performance of HSGGT vehicles in accidents can be derived from past experience, and from analyses and tests. Data from past experience is used in an analysis in Chapter 2 of Volume 1 to relate the severity of damage and casualties in conventional train collisions and accidents to speed and energy dissipation. The use of computer models and test procedures to evaluate the performance of HSGGT vehicle structure and interiors in collisions is discussed extensively in Volume 3.

Absolute QRA techniques, combined with fault tree analysis, can be used to address risk analysis requirements at each of the three levels of the proposed specification.

At the lowest level, Level 3, of the specification requirements for individual components and subsystem have much the same form as existing railroad safety regulations. The individual requirements specify what components and subsystems are required, the acceptable failure rates, the acceptable consequences of failure, the acceptable physical characteristics, and similar requirements. The tests and analyses to be used to evaluate compliance are also specified absolutely. QRA techniques can be used to estimate the failure rates of specific subsystems, such as vehicle brake systems and vehicle movement control systems.

***Guidelines for Chemical Process Quantitative Risk Analysis*, Center for Chemical Process Safety, American Institute of Chemical Engineers, New York, 1989.

At Level 2, limits on the frequency of occurrence of collisions and the related severity of consequences are specified. These numbers can be estimated from component and subsystem performance characteristics, using the absolute QRA and the fault tree analysis. The severity of consequences, in terms of fatalities, is derived from various analyses, tests and the experience of past accidents.

At Level 1, overall risk limits are specified in terms of maximum individual risk (for example, per 10^9 passenger-km), and in the form of a risk profile that provides a boundary for various combinations of accident frequency and severity of consequences, as shown in Figure 3-1. The development of the risk profile requires classifying accidents in the QRA and fault tree into categories according to likely severity of consequences. Then the frequencies of collisions in each category can be summed to arrive at the required combinations of frequencies and consequences for developing a risk profile.

The advantages of Absolute QRA used to support the proposed 3-level specification are:

- QRA is the most suitable and complete form of analysis available for determining HSGGT system safety performance relative to the Level 1 and Level 2 in the requirements specification.

- QRA is the most effective way of balancing collision avoidance and accident survivability features of an HSGGT system, to meet the specified overall system-safety performance.

- Even if numerical results are not very accurate, the process of carrying out the analysis provides excellent insight into how individual HSGGT subsystem and component performance contributes to overall system safety performance.

The disadvantages of using absolute QRA for HSGGT safety assessment are:

- Determination of the likely collision frequency and consequences of collisions from component and subsystem level performance requires considerable effort by the HSGGT system designer and by the specification authority to verify compliance.

- The data required to perform the QRA calculations may be incomplete or of suspect quality.

- Public sensitivity to expressing risk in explicit terms such as limits on maximum fatalities per year may render absolute QRA inappropriate in some circumstances.

- Absolute QRA cannot be very accurate because of the considerable uncertainties in quantifying individual failure rates and consequences. Thus some skill is required to interpret the inherently uncertain results of the analysis performed by the developer of a new system, and to judge whether they indicate compliance with the specification. For a complex system, the accuracy of QRA is of the order of plus or minus half an order of magnitude. However, the degree of uncertainty can be reduced if there is significant operating experience with the same or a similar system, with which to calibrate QRA results.

In conclusion, performance of an absolute QRA for an HSGGT system is clearly a substantial challenge and the result is unlikely to be very accurate. However, the process of attempting to structure a QRA using a fault tree and to estimate failure rates will be of great value in understanding the risks to which an HSGGT system is exposed. Also, QRA can be used by the designer of an HSGGT system in top-down fashion to determine performance requirements for individual safety-critical subsystems.

4.4 COMPARATIVE QUANTITATIVE RISK ANALYSIS

Comparative QRA is a variation on Absolute QRA, which can be used where the detailed data to support an absolute QRA is not available, and also where public sensitivity to expressing accident risk in explicit terms makes absolute QRA impractical. In comparative QRA risks, accident frequencies and accident consequence severities are expressed in terms of comparative indices, derived from a comparison with a known reference system, or an arbitrary reference standard. The overall Risk Index is a function of a Frequency Index and a Consequence Index, thus:

Risk Index = Frequency Index x Consequence Index

In this expression, the Frequency Index represents (but is not) the likely annual frequency of the undesired event, while the Consequence Index represents the likely consequence of an undesired event. Comparative QRA can be used to evaluate the performance of an HSGGT system relative to the three level specification structure shown in Figure 3-1, replacing numerical performance requirements by equivalent comparative performance requirements.

As with the Absolute QRA approach, risk can be expressed in terms of a risk profile in addition to a Risk Index number. To develop a risk profile, the accidents are divided into categories according to severity level, in the same way as with Absolute QRA. Then, sets of Frequency and Consequence Indices are calculated, from which a risk profile can be prepared. This approach preserves the flexibility of the absolute QRA approach, in that the developer of an HSGGT system can balance collision frequency and severity of consequences, as long as the limits on both these indices individually and the limit on the overall Risk Index are met.

Risk indices can be calculated using the following procedure.

Step 1: Assign a weight to each component/subsystem that affects the frequency or consequence of a collision or an accident.

This weighting is based on the relative importance of the component in determining likelihood of the collision or its consequences. Thus, the in-cab signalling or braking system would get a higher weighting than a headlight or windshield wipers. They all help prevent collisions, but the contribution of the first two will be more significant than the latter two.

Step 2: Score the likely performance of the component or subsystem in terms of its ability to perform as required.

This score is based on the presence of the component/subsystem, the level of redundancy, past history of failure, and similar factors.

Step 3: Calculate the weighted scores for frequency and consequence severity.

In this step, the scores are multiplied by the appropriate weighting, and then added to determine weighted scores for frequency and for consequence level. These weighted scores can themselves be used as the Frequency and Consequence Indices. Alternatively, some normalizing may be required to obtain a consistent result for all system types likely to be evaluated under the system.

The advantages of using Comparative QRA for assessing HSGGT safety are as follows:

- It is relatively simple to use, both for the developer and for the regulator.
- It preserves the flexibility of Absolute QRA approach to balance collision avoidance and accident survivability.
- It does not pose the public sensitivity issue that Absolute QRA poses: the risk is expressed in terms of an index and not in terms of fatalities or casualties.
- The inherent coarseness of the procedure means that the data requirements are less onerous than for the Absolute QRA.

The disadvantages of using the Comparative QRA system safety performance approach are:

- The acceptability of an estimated Risk Index cannot be judged unless the procedure is calibrated by reference to an existing system that is considered to be adequately safe. However, since the principle of equivalent safety is being used to set targets, this is not a difficulty. The calibration is carried out by analyzing an existing system of known satisfactory safety performance.
- While it requires less data on component or subsystem performance than absolute QRA, it does require some effort to obtain data and quantify component and subsystem performance.
- Assigning scores and weightings requires judgment. This could lead to disagreements between the specification authority and the HSGGT system designer.
- The inherent approximations in the approach, referred to earlier as an advantage, could also make this approach unable to distinguish the differences between two very similar systems.

4.5 PRELIMINARY HAZARD ANALYSIS (PHA)

PHA is an entirely qualitative process of identifying and ranking hazards to which a guided transportation system may be exposed. The procedures are fully described in a U.S. Military Specification MIL-STD 882 B, *System Safety Program requirements.*

PHA is a four-step process as follows:

Step 1: *Identify Hazards*, using checklists, previous accident history, expert opinion, and similar methods.

Step 2: *Assess Hazard Severity*, by developing qualitative estimates as to both the frequency with which a specific hazardous event could occur (approximately to an order of magnitude), and the severity of consequences (death, major injury, minor injuries, minor property damage, or operation delay). The assessment again depends partly on experience and partly on expert judgment. Combinations of high frequency and severe consequences are ruled unacceptable, and mitigating actions are required. The Acceptability Matrix is shown in Figure 4-3.

Step 3: *Resolve Hazards* by taking corrective action with regard to unacceptable hazards, to reduce either the frequency of occurrence, or the severity of consequences.

Step 4: *Monitor Performance* during system testing, and after the system is put into service. A record of the incidence of potentially hazardous events and their consequences should be maintained. If either differs significantly from the estimates incorporated in the PHA, or if unanticipated hazardous events occur, then the PHA is reworked, and fresh corrective actions are taken as necessary.

The advantages of PHA are as follows.

- PHA can be performed at any stage in HSGGT development. Since data requirements are very modest, it is particularly appropriate for reviewing system safety performance at an early stage in a system development.

- There are no specific data requirements. PHA can be performed using professional judgment alone, if no other sources of information are available. Therefore, it is not constrained by data needs.

- The ability to balance accident frequency against the severity of consequences is built into the process.

- Overall, the benefits of PHA are its simplicity and the lack of specific data requirement that might restrict its useability.

The primary disadvantage of PHA is that it is a process that lacks specific hard requirements. Therefore, it is a question of judgment whether it has been carried out adequately in any specific instance-that hazards and corrective actions have been properly assessed with regard to

Frequency of Occurrence	Hazard Categories			
	I Catastrophic	II Critical	III Marginal	IV Negligible
(A) Frequent	I A	II A	III A	IV A
(B) Probable	I B	II B	III B	IV B
(C) Occasional	I C	II C	III C	IV C
(D) Remote	I D	II D	III D	IV D
(E) Improbable	I E	II E	III E	IV E

<u>Hazard Risk Index</u>

I A, I B, I C, II A, II B, III A	1	Unacceptable
I D, II C, II D, III B, III C	2	Unacceptable (management decision required)
I E, II E, III D, III E, IV A, IV B	3	Acceptable with review by management
IV C, IV D, IV E	4	Acceptable without review

Figure 4-3. Hazard Categories Used in a Preliminary Hazard Analysis

frequency of occurrence and consequences. Much of the apparent advantage of PHA over the other approaches may be lost if extensive analysis or testing is required to classify hazards.

Overall, PHA is a valuable safety assessment technique for use at an early stage in the development of an HSGGT system, but it cannot on its own meet the needs of assuring that an HSGGT system meets the specification detailed in Chapter 3.

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