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Safety of High Speed Magnetic Levitation Transportation Systems

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Washington, DC 20590

Preliminary Safety Review of the Transrapid Maglev System

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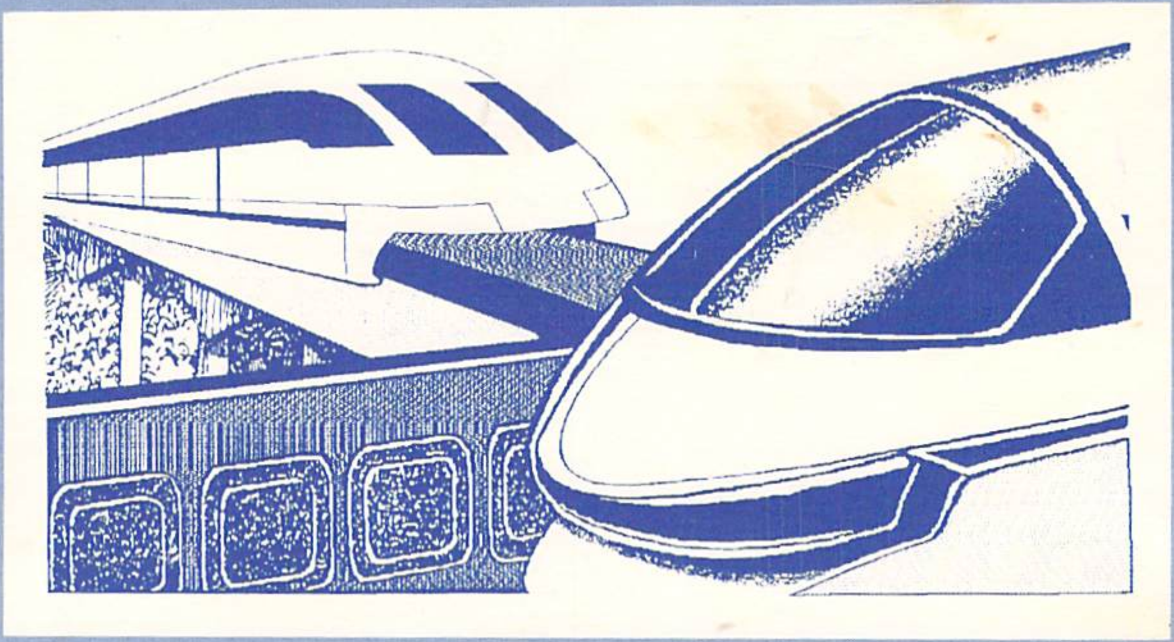

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16. Abstract

The safety of various magnetically levitated trains under development for possible implementation in the United States is of direct concern to the Federal Railroad Administration. This report, one in a series of planned reports on maglev safety, addresses safety issues related to a specific maglev technology, Transrapid.

The Transrapid maglev system has been under development by the German Government over the last 10 to 15 years and has evolved into the current system with the TR-07 vehicle. A technically based safety review has been under way over the last year by the U.S. Department of Transportation. This interim report presents the initial results of this review to identify and assess potential maglev safety issues.

Section 1 provides a history of the project and explains the need for Federal involvement. Section 2 describes the safety evaluation approach applied to the review of the Transrapid system. Section 3 describes the current Transrapid technology in some detail. Section 4 lists the potential maglev safety issues identified to date. Section 5 reviews the risk assessment of the identified safety issues. Section 6 proposes resolution options for the identified hazards, including a list of areas where modified or new Federal regulations need to be developed. Section 7 presents the conclusions of this review and provides recommendations on potential rule-making actions.

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PREFACE

The use of magnetically levitated (maglev) vehicles for high speed ground transportation in the United States may become a reality within the next five years. As a result of this development, there is a need to assess the safety of this new guided ground transportation technology. This is the responsibility of the Federal Railroad Administration (FRA), United States Department of Transportation, which is charged with assuring the safety of maglev systems in the United States under the Rail Safety Improvement Act of 1988.

With this in mind, the FRA has embarked on a multiyear research program to establish the appropriate safety measures that should be applied to this new maglev technology. During this research program it is intended that potential maglev system developers and operators alike and state and local governments will be provided with an awareness of the potential for the establishment of safety requirements so as to minimize adverse economic impact later in any maglev project development. **Any "findings" reported as a result of this research program should not be construed as having the force of law or regulation, but rather merely of an advisory nature.**

This report is the first in a series of reports that will address maglev transportation safety and the Federal role in assuring it. Future reports will cover, in addition to the Transrapid electromagnetic technology, such areas as the review of foreign maglev safety standards, operations and maintenance guidelines, and safety verification test requirements related thereto. Both electromagnetic and electrodynamic maglev technologies will be covered by this multiyear program.

This report presents a preliminary safety assessment and its methodology as applied to a review of the Transrapid TR-07 maglev technology and notes areas of concern relative to maintaining acceptable levels of system safety. The various technology areas represented in the maglev system and their related standards, regulations and guidelines are listed. Both foreign and domestic information sources are utilized. Subject areas that may require regulatory modification or development for this new technology are also covered.

This report was sponsored by the Federal Railroad Administration's Office of Research and Development. The authors wish to thank Arne J. Bang, of that office, for his direction and guidance during the preparation of this document, and Thomas Schultz and Donald Gray, also of the Office of Research and Development, for their valuable inputs and reviews.

Prepared by the Safety and Security Systems Division of the Office of Research and Analysis and the Office of Technology Applications of the U.S. Department of Transportation, Research and Special Programs Administration/Transportation Systems Center, the Report's primary authors are William T. Hathaway and Robert M. Dorer. The authors wish to acknowledge the important contributions of the following maglev task-force members: Dr. Aviva Brecher for contributions to the overall safety analysis and for preparation of the fault trees and regulation matrix; Stephanie H. Markos for contributions to the overall report and development of the hazard checklist, fault trees, and regulation matrix; and Herbert Weinstock, Raymond A. Wlodyka, Michael R. Coltman, and Andrew Sluz for their contributions to the system description, fault trees, and report conclusions and recommendations. The authors also would like to thank the following individuals for their assistance in preparing specific sections of this report: John J. Stickler for the preparation of the system description; Harvey S. Lee for the description of the vehicle design and operation; and Carol A. Rickley for assistance in preparing the hazard scenarios and fault trees. Finally, the authors would like to express their appreciation to Dawn M. LaFrance for her assistance in the preparation of this report.

The current level of understanding of the Transrapid system would not have been possible without the excellent cooperation of the Federal Ministry for Research and Technology, TÜV Rheinland, the Transrapid Consortium, and the Versuchs-und Planungsesellschaft fur Magnetbahnsysteme mbH (the test and planning organization for maglev train systems), all of the Federal Republic of Germany, in providing a wide variety of detailed technical information and the opportunity to observe developmental testing of the system.

During the course of this review, information and analyses have been contributed by Professor David N. Wormley, Head of the Mechanical Engineering Department, and Dr. Emanuel Bobrov, National Magnet Laboratory, both of the Massachusetts

Institute of Technology and Dr. Ashok B. Boghani, Dr. Alan J. Bing and Thomas J. Rasmussen of Arthur D. Little, Incorporated.

METRIC / ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

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

AREA (APPROXIMATE)

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

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz) = 28 grams (gr)
1 pound (lb) = .45 kilogram (kg)
1 short ton = 2,000 pounds (lb) = 0.9 tonne (t)

VOLUME (APPROXIMATE)

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

TEMPERATURE (EXACT)

$[(x - 32)(5/9)]$ °F = y °C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

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

AREA (APPROXIMATE)

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

MASS - WEIGHT (APPROXIMATE)

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

VOLUME (APPROXIMATE)

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

TEMPERATURE (EXACT)

$[(9/5)y + 32]$ °C = x °F

QUICK INCH-CENTIMETER LENGTH CONVERSION

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

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

QUICK FAHRENHEIT-CELCIUS TEMPERATURE CONVERSION

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

For more exact and/or other conversion factors, see NBS Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50. SD Catalog No. C13 10 286.

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1. INTRODUCTION

This interim report presents the results of a preliminary safety review of the Transrapid maglev system for the Office of Research and Development of the Federal Railroad Administration. The review was directed at identifying, in a peer review manner, safety issues presumed to exist at the time of this review and the hazards which potentially lead to them. The interim report reviews relevant Federal regulations and industry practices in the U.S. and compares them to the proposed foreign standards that are to be met by the Transrapid technology for its application in the Federal Republic of Germany and prior to export. The proposed foreign and existing domestic U.S. standards are compared for their similarities, differences, appropriateness, applicability, and missing provisions with respect to the maglev transportation system technologies involved. Included are recommendations, based on research "findings," for new regulatory efforts, modifications to existing regulations and the adoption of standards from other industries that may be used to address the safety issues identified up to this point. The "findings" should not be construed as having the force of law or regulation.

1.1 THE FEDERAL RAILROAD ADMINISTRATION ROLE IN REGULATING MAGNETIC LEVITATION SAFETY

The Railroad Safety Act of 1970 includes the following declaration of purpose: "promote safety in all areas of railroad operations ...". In the Act, the Secretary of the U.S. Department of Transportation (USDOT) is charged to "prescribe, as necessary, appropriate rules, regulations, orders and standards for all areas of railroad safety ...".

The Rail Safety Improvement Act of 1988 made clear the jurisdiction of the Federal Railroad Administration (FRA) by defining the term railroad to include: "all forms of non-highway ground transportation that run on rails or electromagnetic guideways, including (1) commuter or other short-haul rail passenger service in a metropolitan or suburban area" and "(2) high-speed ground transportation systems that connect metropolitan areas without regard to whether they use new technologies not associated with traditional railroads."

1.1.1 FRA Regulations

The FRA promulgates the necessary regulations to achieve its charter. These regulations are published in the Code of Federal Regulations (CFR) and currently are comprised of CFR, Part 49: parts 173, 174, 179, and 200 through 268.

The regulations in the CFR that relate to safety issues tend to be technology specific and adopted from years of railroad operating experience. Nevertheless, some of these regulations can either be specifically applied or their intent adopted to other types of guided ground transport technologies, such as maglev.

In addition to the regulations in the CFR, the FRA also relies on industry standards and practices such as the Association of American Railroads' (AAR) Manual of Standards and Recommended Practices and Field Manual of A.A.R. Interchange Rules, and the American Railway Engineering Association's (AREA) Manual for Railway Engineering. These industry standards tend to be of a detailed specification nature relating to conventional railways and are not performance based. Thus to apply them to other technologies, such as maglev, may, in most cases, prove difficult.

1.1.2 Other U.S. Federal Agencies and U.S.Industry Standards

In addition to FRA standards, other potentially relevant standards for transportation systems with similar attributes exist, both in other Federal regulations and in industry standards. For example, the Federal Aviation Administration (FAA) has windshield strength standards for airplanes that, although different from the FRA's standards for locomotive windshields, may have some relevance to maglev. Some of the Urban Mass Transportation Administration's (UMTA) emergency preparedness procedures recommended for rail transit systems may also be relevant. Various Department of Defense (DOD) specifications such as MIL STD 882B, System Safety Program Requirements, also contain valuable information that may be applicable.

Industry standards (as well as FAA standards) in areas such as software verification and control for "fly-by-wire" planes may be applicable to the automated control systems required by maglev vehicles.

1.2 PROJECT BACKGROUND

Transrapid maglev technology is currently under consideration for application in several different corridors in the United States as well as Germany. A proposal to use the technology in a demonstration project in Florida is the most advanced of the various projects.

1.2.1 The Florida Magnetic Levitation Demonstration Project

In 1984, the Florida legislature established the Florida High Speed Rail Transportation Commission (FHSRTC). The FHSRTC was charged to "implement the innovative mechanisms required to effect the joint (public-and-private) venture approach to planning, locating, permitting, managing, financing, constructing, operating, and maintaining an interregional high-speed rail line for the state, including providing incentives for revenue generation, operation and management by the private sector." In 1988, the Florida legislature passed the Magnetic Levitation Demonstration Act and assigned responsibility for this effort to the FHSRTC as well.

As a result of this act, proposals to provide a maglev demonstration project in Florida were solicited. The only bidder to respond to the request for proposals for a magnetic levitation demonstration project was Maglev Transit, Inc. (MTI) of Orlando, Florida. MTI is a team of companies which includes the Forum for Urban Development and Transrapid International (itself, a consortium of Thyssen Henschel, Kraus Maffei and Messerschmitt-Bolkow-Blohm).

MTI's proposal is to link the Orlando International Airport to a point west southwest of the airport on International Drive (a length of approximately 13.5 miles) with a maglev system utilizing the Transrapid maglev technology. The guideway proposed will be elevated for the majority of the route.

1.2.2 The Florida Certification Process

The FHSRTC is charged with reviewing the project proposals responding to the requirements of the Magnetic Levitation Demonstration Act for compliance with the requirements of the act. The FHSRTC has held public hearings to gather input as to the concerns about the project from a wide variety of impacted people and businesses and special interest groups. After the modification of the route in March of 1990, the commission has forwarded their conditional recommendation for approval for certification, to an independent hearing officer. Additional public hearings will be held and the recommendation of the hearing officer forwarded to the Governor and Cabinet which will make the decision as whether or not to issue the certification.

If the certification is issued, MTI will be expected to provide additional information to the FHSRTC. **Items such as emergency response plans, operator training plans, operations and maintenance policies and the like will be required. This information is fundamental to a complete safety assessment of the system, thus any assessment, such as this, can only be preliminary in nature until all aspects have been covered.**

1.2.3 Safety Programs Required by the FHSRTC

The FHSRTC has recommended that a variety of specific conditions of certification be imposed on MTI. Some of these recommended requirements are of interest in the area of design and operational safety of the maglev system. These recommendations include requests for additional information on items such as failure-mode analysis and information on the testing of TR-06 and TR-07. Also, prior to final operational approval, items such as operational, maintenance, and emergency evacuation plans will be required of MTI.

1.3 OTHER POTENTIAL INSTALLATIONS OF TRANSRAPID TECHNOLOGY

In addition to the Florida demonstration project, Transrapid maglev technology may be applied in several other corridors such as the Los Angeles (Anaheim) to Las Vegas route and the Pittsburgh to Harrisburg route.

The potential for use on longer intercity routes adds some safety issues to be addressed that are not directly relevant to the Florida demonstration project. These include items such as the implications of double track or single track guideways with long passing siding operation; the high speed passing of maglev trains both in the open and in tunnels; the entering of tunnels by vehicles at high speed; and the traversing of maglev switches at high speed.

Another major difference in any of these other systems will be the need for the control system to be capable of safely handling more than one moving train on the guideway at one time. Issues such as how multiple trains are safely brought to a halt and evacuated if necessary, during an emergency systemwide shutdown must be considered for such applications of the technology.

These generic Transrapid safety issues are addressed in this report and will be addressed in a subsequent interim report on the review of the draft German maglev safety standards.

1.4 TRANSRAPID GERMAN SAFETY CERTIFICATION

Independent of the proposed U.S. applications, the Transrapid maglev system is undergoing safety certification in the Federal Republic of Germany (FRG) for both in country use and for export. TÜV Rheinland, a safety certification group in the FRG, is responsible for certifying the safety of the unique technology aspects (excluding operation and maintenance) of the Transrapid maglev. Much of this certification is being conducted at the Transrapid Test Facility (TVE) in the Emsland region of the FRG.

The Transrapid Test Facility is operated by an independent test organization, IABG, for the Versuchs- und Planungsgesellschaft fur Magnetbahnsysteme, (the Test and Planning Organization for Maglev Train Systems) MVP, a group founded in 1984 by the German national airline, Lufthansa, the German Federal Railway, (DB) and IABG at the instigation of the German government and with support from the Federal Ministry for Research and Technology. IABG was established jointly in 1961 by the Federal Ministry of Defense and the German Aerospace Industry.

It is understood that technology-specific matters relating to operational and maintenance procedures are to be the responsibility of the proposed operating authority and based upon recommendations provided by the Transrapid system developers. The status of these materials as they relate to safety are unknown at the time of this report.

Currently the TR-07, the vehicle planned for revenue service, is undergoing the final stages of certification testing at the Transrapid Test Facility in Emsland, Germany. It is expected that all systems, except for the automatic control system, related to the TR-07 maglev system, including the vehicle, guideway, switches, and control systems will be safety certified by German authorities by June of 1991. Testing, approval and licensing will be determined by the Ministry of Economics and Transportation of Lower Saxony based on the final report of TÜV on certification of the TR-07 system.

1.5 REPORT STRUCTURE

Section 2 of this report describes the safety evaluation approach applied to the review of the Transrapid system. Section 3 describes the current Transrapid technology in some detail. Section 4 lists the potential maglev safety issues identified to date. Section 5 reviews the risk assessment of the identified safety issues. Section 6 proposes resolution options for the identified hazards, including a listing of areas where modified or new Federal regulations need to be developed. Section 7 presents the conclusions of this review and provides recommendations on potential rule-making options.

Appendices are included that list the safety issues and the various regulations, standards and guidelines that are relevant to specific technology areas.

2. SAFETY EVALUATION APPROACH

The safety goal of a transportation system should be to provide patrons and employees with the highest level of safety practical. Achieving this goal requires that safety be a primary consideration throughout the system life cycle. Safety hazards must be identified and resolved during the acquisition (concept definition, design, construction, and inspection/testing/certification) and operations (operation, training, maintenance, modification, and disposal) phases of the system life cycle. Various analysis methodologies may be employed to examine portions of the system and evaluate the level of safety provided in the phases of the life cycle. The safety analysis methodology employed in this evaluation is the System Safety Concept. This section describes its application to Transrapid.

2.1 THE SYSTEM SAFETY CONCEPT

System safety is the application of special technical and managerial skills to the systematic, forward-looking identification and control of hazards throughout the life cycle of a project, program, or activity (Roland and Moriarty,1983). This approach calls for safety analyses and hazard-control activities throughout the life cycle of a system, beginning with the preliminary design phase and continuing through the operation phase. Figure 2-1 illustrates the types of system safety activities which should be conducted through the design and operations phases to ensure that safety is an integral part of the system.

The advantage of applying the system safety approach is that it provides the opportunity to identify hazards early in the life cycle and then recommend and request any design and operational modifications necessary to ensure safety. Doing this prior to system development, construction, and operation will serve to enhance safety and minimize cost. As applied to the maglev system, the focus at this early, pre-production stage, is on the prevention of accidents by eliminating and/or controlling safety hazards in a systematic manner. This preventive approach, through the most effective use of resources, will serve to reduce the risks from system hazards to the lowest practical level.

It should be noted at the outset that a system safety analysis is not the same as failure analysis. This distinction is important, because a hazard involves the risk of

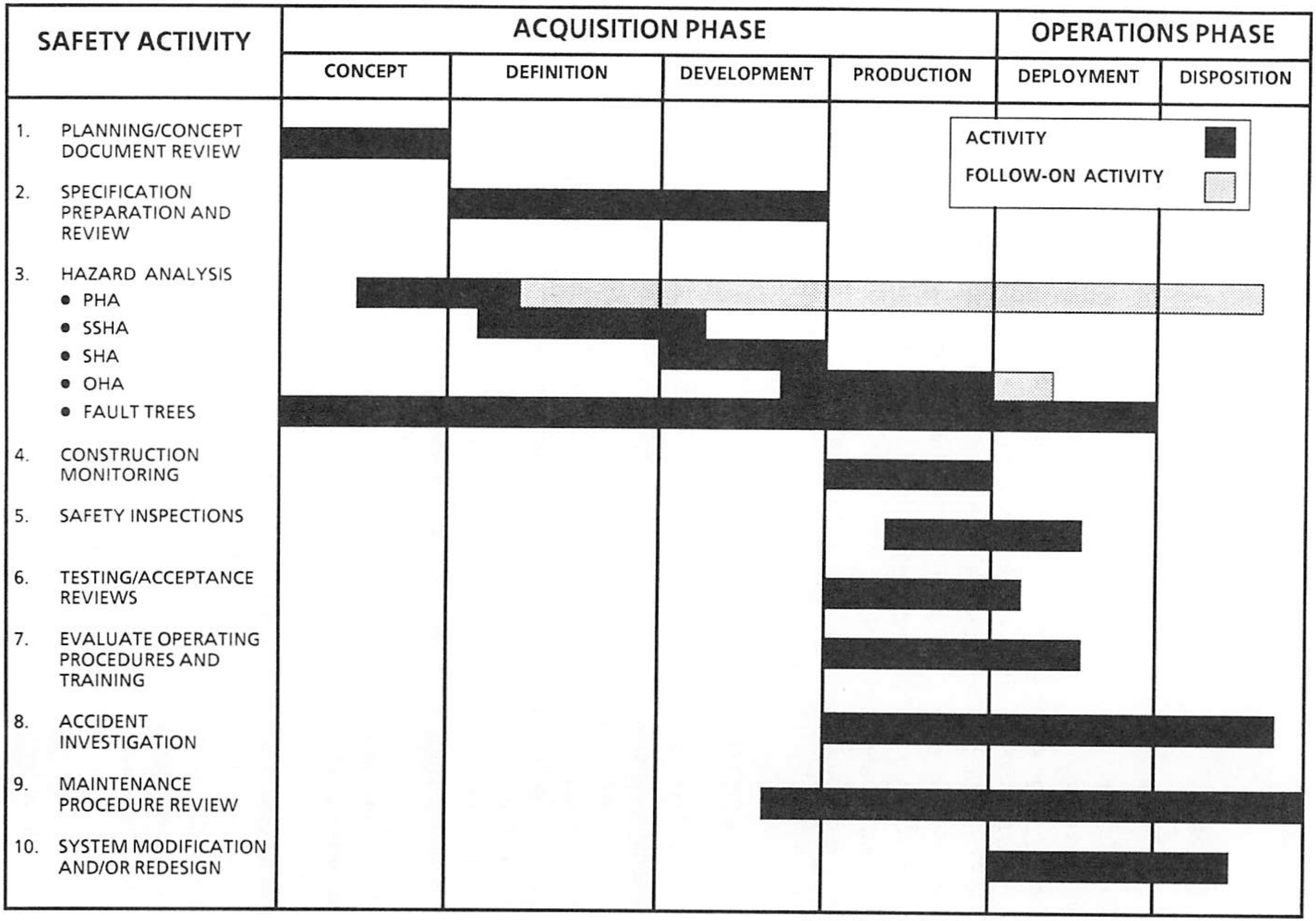


FIGURE 2-1. SYSTEM SAFETY LIFE CYCLE ACTIVITIES

loss or harm, while a failure does not always result in loss or harm, unless it is a "critical" single-point failure on the "Safety-Critical Items List" (SCIL). The System Safety approach employs the Hazard Resolution Process, depicted in Figure 2-2, from the Acquisition phase through the Operations phase of the particular system. This hazard resolution process should be followed in order to ensure that passengers, the operating personnel, and the public are provided with the highest degree of safety practical.

2.1.1 System Definition

The first step in the hazard resolution process is to define the physical and functional characteristics of the system to be analyzed. These characteristics are presented in terms of the major elements which make up the maglev system:

- Equipment and facilities,
- Procedures,
- People, and
- Environment.

A knowledge and understanding of how the individual system elements interface with each other is essential to the hazard identification effort. Section 3 of this report briefly describes the reference maglev system, organized in terms of the design of subsystems, the people, and operational procedures.

2.1.2 Hazard Identification

The second step in the hazard resolution process involves the identification of hazards and the determination of their causes. When identifying the safety hazards present in a system, a major concern is that only a portion of the total number of system hazards have been identified. The type and quality of the hazard analysis will influence the total number of hazards identified. There are four basic methods of hazard identification that may be employed to identify hazards. These methods are:

- Analysis of operating experience or data from previous accidents (test data, case studies).

DEFINE THE SYSTEM

- DEFINE THE PHYSICAL AND FUNCTIONAL CHARACTERISTICS AND UNDERSTAND AND EVALUATE THE PEOPLE, PROCEDURES, FACILITIES AND EQUIPMENT, AND THE ENVIRONMENT

IDENTIFY HAZARDS

- IDENTIFY HAZARDS AND UNDESIRED EVENTS
- DETERMINE THE CAUSES OF HAZARDS

ASSESS HAZARDS

- DETERMINE SEVERITY
- DETERMINE PROBABILITY
- DECIDE TO ACCEPT RISK OR ELIMINATE/CONTROL

RESOLVE HAZARDS

- ASSUME RISK OR
- IMPLEMENT CORRECTIVE ACTION
    - ELIMINATE
    - CONTROL

FOLLOW-UP

- MONITOR FOR EFFECTIVENESS
- MONITOR FOR UNEXPECTED HAZARDS

FIGURE 2-2. HAZARD RESOLUTION PROCESS

- Scenario development and judgment of knowledgeable individuals (expert opinion, or the Delphi Approach).

- Use of generic hazard checklists (Appendix B).

- Formal hazard analysis.

Section 4 describes how these methods were employed in the hazard resolution process and presents the key hazards identified for a representative maglev system.

2.1.3 Hazard Assessment

The third step in the hazard resolution process is to assess the identified hazards in terms of the severity of the expected consequence (C) and the probability (P) of occurrence.

To accomplish this, the qualitative hazard and safety risk ranking procedure is used as outlined by the Defense Department in Military Standard: System Safety Program Requirements (Mil-Std. 882B). Mil-Std. 882B, Figures 2-3 and 2-4 show the ranking criteria. Figure 2-3 contains four severity categories and provides a general description of the characteristics which define the event. Figure 2-4 lists the qualitative ranking of probability categories and describes the characteristics of each level.

The Hazard Risk Index (HRI), presented in Figure 2-5 is a value derived by considering both the severity and the probability of a given hazardous event. The HRI presents the hazard analysis results in a format useful to the decision maker in determining whether hazards should be eliminated, controlled, or accepted (i.e., 1 = Unacceptable). This provides a logical basis for management decision making, considering both the severity and probability of any individual hazard in a weighted fashion.

Sometimes the hazard can be completely eliminated through a design change, or via changes in and restriction on operating procedures. The probability, and therefore the risk, can normally be greatly reduced by incorporation of safety devices, warning devices, prevention procedures, and personnel training, or a combination thereof.

The potential severity of a hazard also can be reduced by mitigation and control measures (e.g., fire extinguishers and sprinklers to control a fire once it occurs).

Section 5 further explains how the maglev system hazards identified in Section 4, were evaluated in terms of their severity and probability.

CATEGORY	SEVERITY	CHARACTERISTICS
I	CATASTROPHIC	DEATH OR SYSTEM LOSS
II	CRITICAL	SEVERE INJURY, SEVERE OCCUPATIONAL ILLNESS, OR MAJOR SYSTEM DAMAGE
III	MARGINAL	MINOR INJURY, MINOR OCCUPATIONAL ILLNESS, OR MINOR SYSTEM DAMAGE
IV	NEGLIGIBLE	LESS THAN MINOR INJURY, OCCUPATIONAL ILLNESS, OR SYSTEM DAMAGE

SOURCE: MIL-STD-882B

FIGURE 2-3. HAZARD SEVERITY CATEGORIES

DESCRIPTION*	LEVEL	SPECIFIC INDIVIDUAL ITEM	FLEET OR INVENTORY**
FREQUENT	A	LIKELY TO OCCUR FREQUENTLY	CONTINUOUSLY EXPERIENCED
PROBABLE	B	WILL OCCUR SEVERAL TIMES IN LIFE OF AN ITEM	WILL OCCUR FREQUENTLY
OCCASIONAL	C	LIKELY TO OCCUR SOMETIME IN LIFE OF AN ITEM	WILL OCCUR SEVERAL TIMES
REMOTE	D	UNLIKELY, BUT POSSIBLE TO OCCUR IN LIFE OF AN ITEM	UNLIKELY, BUT CAN REASONABLY BE EXPECTED TO OCCUR
IMPROBABLE	E	SO UNLIKELY, IT CAN BE ASSUMED OCCURRENCE MAY NOT BE EXPERIENCED	UNLIKELY TO OCCUR, BUT POSSIBLE

* DEFINITIONS OF DESCRIPTIVE WORDS MAY HAVE TO BE MODIFIED BASED ON QUANTITY INVOLVED.
** THE SIZE OF THE FLEET OR INVENTORY SHOULD BE DEFINED.

SOURCE: MIL-STD 882B

FIGURE 2-4. HAZARD PROBABILITY CATEGORIES

FREQUENCY OF OCCURRENCE	HAZARD CATEGORIES			
	I CATASTROPHIC	II CRITICAL	III MARGINAL	IV NEGLIGIBLE
(A) FREQUENT	I A	II A	III A	IVA
(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

HAZARD RISK INDEX

I A, I B, I C, I 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

SOURCE: MIL-STD 882B

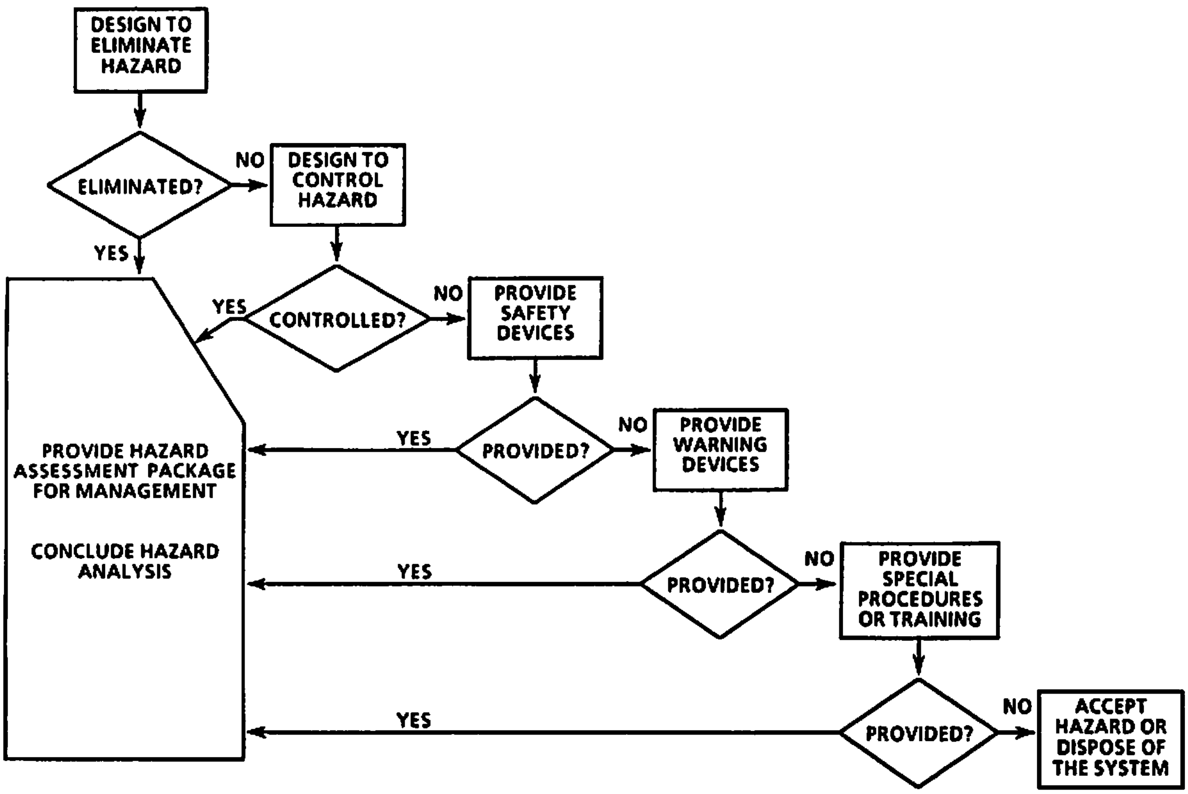
FIGURE 2-5. HAZARD ASSESSMENT MATRIX

2.1.4 Hazard Resolution

After the hazard assessment procedure is completed, hazards can be resolved by deciding to either assume the level of risk associated with the hazard, or to eliminate or control it. Various means can be employed to reduce the risk level to a threshold acceptable to management. Figure 2-6 presents a process for hazard reduction precedence that can be used to determine the extent and nature of preventive actions that can be taken to reduce risk to an acceptable level. Resolution strategies or countermeasures in order of preference include the following:

Design to Eliminate Hazards

This strategy generally applies to acquisition of new equipment or expansion of existing systems; it also can be applied to any change in equipment or individual subsystems. In some cases, hazards are inherent and cannot be eliminated completely through design.



Source: Roland and Moriarty System Safety Engineering and Management. 1983

FIGURE 2-6. HAZARD REDUCTION PRECEDENCE

Design for Minimum Hazards

A major safety goal during the system design process is to include safety features that are fail-safe or have capabilities to handle contingencies through redundancies of critical elements. Complex features that could increase the likelihood of hazard occurrence should be avoided. Damage control, containment, and isolation of potential hazards, along with gradual system performance degradation, should be specified through system safety inputs. The safety inputs should be implemented in addition to other traditional design considerations.

Safety Devices

Known hazards which cannot be eliminated or minimized through design may be controlled through the use of appropriate safety devices. This could result in the hazards being reduced to an acceptable risk level. Safety devices may be a part of the system, subsystem, or equipment.

Warning Devices

When it is not possible to preclude the existence or occurrence of an identified hazard, visual or audible warning devices may be employed for the timely detection of conditions that precede the actual hazard occurrence. Warning signals and their application should be designed to minimize the likelihood of false alarms that could lead to creation of secondary hazardous conditions.

Procedures and Training

When it is not possible to eliminate or control a hazard using one of the aforementioned methods, safe procedures or emergency procedures should be developed and formally implemented. These procedures should be standardized and used in all test, operational, and maintenance activities. Personnel should receive training to carry out these procedures.

Hazard Acceptance/ System Replacement/ Disposal

When it is not possible to reduce a hazard by any means, a decision must be made to either accept the hazard or replace/dispose of the unsafe system.

For this report, risk reduction countermeasures were developed to address the maglev undesired events, as identified in the hazard scenarios and hazard checklists, and formal analyses (Section 4). Section 6 assesses hazard control or countermeasure effectiveness; and discusses options for maglev safety hazard resolution and the type of FRA regulatory safety requirements are recommended.

2.1.5 Follow-up

The last step in the hazard resolution process (Fig. 2-2) is follow-up. It is necessary to monitor the effectiveness of recommended hazard prevention and control measures, and to ensure that new hazards are not introduced as a result. In addition, whenever changes are made to any of the system elements (equipment, procedures, people, and/or environment), a hazard analysis should be conducted to identify and resolve any inadvertently introduced new hazards.

2.2 APPLICATION OF SYSTEM SAFETY TO PROPOSED MAGLEV SYSTEMS

Implementing the system safety concept is, in essence, implementing a hazard management program. The implementation of a hazard management program throughout the life cycle of a transportation system will result in a system in which the hazards have been eliminated or minimized. For a transportation system in Germany, the approach to providing safe transit is that each such system must be licensed and certified to operate. This is accomplished by an independent organization that examines and certifies the system. The certification process has been applied by TÜV Rheinland to the Emsland test facility and is called "Investigation into Safety Features in a Project Accompanying Way" (ISPAW) or Program Accompanying Safety Certification (PASC). This approach is similar to the System Safety approach in that it is initiated in the program acquisition phase and continues into the operational phase of the system. System operation is the responsibility of the system operator. This approach may be employed for the proposed maglev system in Florida with ISPAW. The developer is provided with performance-oriented safety goals that are to be achieved. TÜV Rheinland will certify the accomplishment of these goals. At present, TÜV is developing a maglev safety standard. Maglev systems are currently being operated in non-revenue service in Germany, but no maglev-specific standards exists as yet. The standard presently in development will require certification in the following 12 topic areas:

- System Properties, Especially Safe Levitation.
- Power Plant, Suspension.
- On-Board Energy Systems.
- On-Board Management System.
- Load Assumptions.
- Strength and Stability Safety Certification.
- Construction Manufacturing and Quality Assurance.
- Switch.
- Operations Management Technique.
- Lightning Protection, EMI/EMC, ESD.
- Fire Protection.
- Rescue Concept.

These areas are directed only at the maglev technology-specific safety operations that have been selected by TÜV Rheinland based on its experience. The Transrapid system presently undergoing tests is being employed as the vehicle for the development of a maglev standard.

Recognizing that no maglev-specific standard existed during the design and construction phase of the Transrapid system, the system developer must work to design and manufacture a system in which there will be a minimum of hazards. Producing a system with minimum hazards requires that the developer identify and address potential safety hazards to ensure they do not result in unsafe conditions. From a designer and manufacturer's perspective, this can be accomplished by a series of hazard analyses which are intended to identify and resolve the potential hazards that may result in the unsafe conditions.

Notwithstanding the above, for the proposed maglev system, the developer should be required to conduct a series of safety analyses to provide some assurance that the potential system hazards have been identified and resolved.

Recognizing the present lack of a comprehensive standard for maglev systems, the system safety approach will nonetheless provide a clear and concise understanding of the safety hazards present in maglev operations. This approach also allows for the recognition and resolution of how unacceptable hazards may be addressed.

3. SYSTEM DESCRIPTION

As described by Heinrich and Kretzschmar (1989) and Maglev Transit, Inc. (1989) the Transrapid TR-07 maglev system is an electromagnetically suspended transportation system designed for cruising speeds of 400 to 500 km/h (250 to 312 mph). It operates with an air gap of 8 mm (0.315 in.) and uses magnetic attractive forces for both suspension and guidance. The magnetic suspension system follows the guideway and employs a secondary air-suspension system to improve ride quality. The system uses a linear synchronous motor (LSM) constructed as an integral part of the long-stator guideway to provide the vehicle propulsion.

The TR-07 train is comprised of multiple-articulated sections, each section having a length of 25.5 meters, a weight of 45 metric tons, and a payload capability of 16 metric tons (98 passengers per section). Trains can be configured for bidirectional operation (with an operator's control station at each end) and expanded in length by adding additional sections (without the operator's console) between the end sections.

The TR-07 proposed for commercialization in the United States is similar to the earlier TR-06, but includes improvements emanating from the high-speed tests of the TR-06 at the Transrapid Test Facility. Examples of design changes are better vehicle streamlining, lower vehicle mass, a reconfiguration of the primary and secondary suspension and improved electronics/control systems and related hardware. While the technical changes did not represent major departures in engineering design, they were sufficient to preclude automatic certification of the TR-06 subsystems for use in the TR-07. Few changes have been made in the civil aspects of the Transrapid guideway since introduced, and most guideway certifications for the TR-06 continue to be valid for the TR-07. However, certain functional elements of the guideway such as the stator pack fastening system have been changed and must be recertified. In addition, a new "double span" 50-meter steel section is being certified at the test facility.

The Transrapid vehicle uses a suspension system that wraps around the guideway in a manner that effectively captures the guideway. An important vehicle design feature is the uniform distribution of suspension and guidance magnets over the length of the vehicle. This produces an even loading of the guideway with potentially less stress in the guideway girder.

Transrapid's guideways are typically elevated and use welded steel or concrete girders of nominally 25 to 50 meters span length. Column support substructures are either A-shaped or slim-line ("H") concrete pillars. In special sections of the guideway, at-grade guideways are used with 12 meters approximate span length. Final fitting of the beams onto the guideway supports is performed on-site using computer-aided measurements.

Computer-based technologies are used in the design, construction, and installation of the Transrapid guideway. The guideway route and guideway fabrication and alignment are optimized for lowest cost and best vehicle ride quality. The use of computer-integrated manufacturing techniques plays a major role in achieving high precision guideway installation.

The central control facility maintains automated control of the train operations during normal conditions and most emergencies. Longitudinal (propulsion) control of the vehicle is maintained by varying the excitation voltage and frequency of the guideway linear synchronous motor. The detection of vehicle position and the transmission of data/voice information is accomplished by on-board vehicle electronics and devices; other functions, such as route control, vehicle control, station supervision and control, and communications are maintained through decentralized wayside equipments but coordinated by the central control facility.

Failure-tolerant operation is an important requirement for acceptance of the high speed maglev system. To achieve fault-tolerant operation at these speeds, automatic control is essential. System components must have high mean-time-between-failure (MTBF). Critical circuits must be made sufficiently redundant to ensure high system reliability.

3.1 SYSTEM OPERATIONS

The Operational Control System (OCS) is designed to ensure the safety, control, and effective supervision of maglev operations. The functions performed by the OCS include six major categories: protection, control, supervision, data transmission, passenger information, and peripheral systems. All these functions are required for operations although vehicle protection and the related control and data transmission functions are the most critical ones for ensuring system operational safety.

The OCS functions are both spatially and functionally distributed throughout the system, as illustrated in Figure 3-1. The magnetic guidance, levitation, and on-board brake are vital core functions which are critical to the rescue strategy and are located on-board the vehicle. Other vital on-board vehicle functions include vehicle location, and vehicle protection and control. The vehicle detection functional element determines the vehicle position, travel direction, speed, acceleration and deceleration; while the vehicle protection and control functional element processes vehicle detection data, status and error messages, and monitors on-board equipment including the braking subsystems. Data transmission is critical for normal system operation, but it is not a vital link and allowances for its failure are made.

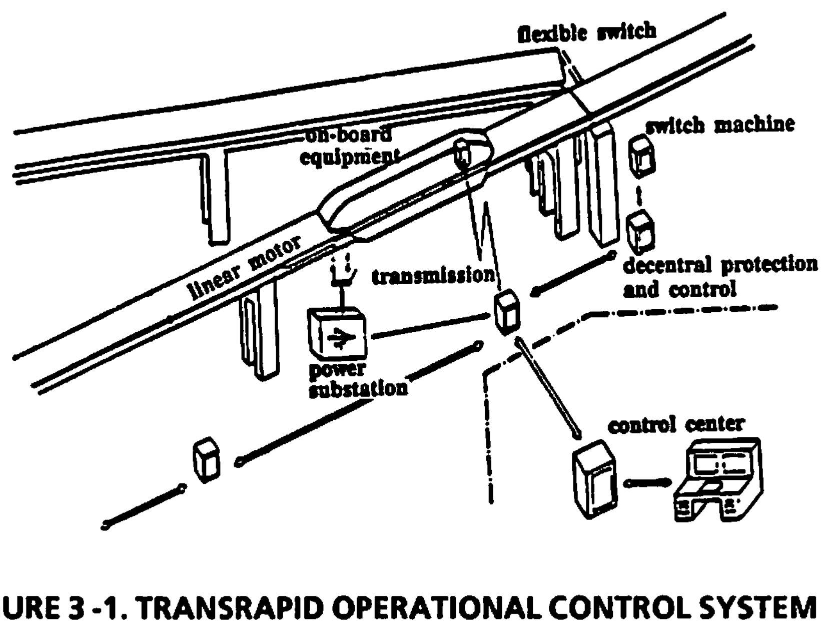


FIGURE 3-1. TRANSRAPID OPERATIONAL CONTROL SYSTEM

Functions peripheral to the core functions are spatially distributed between the trackside equipment and the vehicle. Decentralized and centralized wayside control functions for route control, vehicle control, station supervision and control, and communications are used. The important fail-safe control and protection functions are delegated to wayside (trackside) units, which includes the trackside interfaces to power stations for the propulsion/brake control, and to the vehicle for the safe hovering system. Less critical functions, such as the monitoring and supervision of systems operations for the automatic speed/position control, are assigned to the central control facility.

The speed control required to maintain safe operating distances between vehicles is executed by means of the long-stator, linear propulsion system which is arranged in sections. By separate and alternate power feeding of the left and right sections of propulsion system windings, additional propulsion reliability is achieved.

3.1.1 Safe Hovering

Uncontrolled vehicle contact with the guideway is considered unacceptable. The manufacturer has designed a system to preclude total loss of either the levitation or guidance system. The TÜV Rheinland High-Speed Maglev Trains Safety Requirements state that the vehicle levitation and guidance functions will not be lost for any combination of system failures, and that the vehicle will maintain its own suspension until it is brought to a stop by either the central control or its own internal control system.

Safe hovering (levitation) requires a high level of reliability. The design attempts to achieve this reliability for some subsystems through redundancy and minimum values of mean-time-between-failures (MTBF) of critical components. The manufacturer uses highly independent redundant systems for both levitation and guidance. Each magnet has an individual control system with redundant gap sensors. The gap sensors are offset such that only one of the gap sensors will sense a guideway longitudinal beam gap at any one time. This eliminates errors which might otherwise be introduced by discontinuities (expansion joints) between the individual guideway beams.

The Transrapid safe hovering concept requires that the vehicle comes to a stop only at guideway locations where auxiliary power and evacuation means are provided. The following five requirements are listed by the developer as necessary to ensure "safe stopping areas" are always reachable.

(1) **The vehicle must develop sufficient velocity before leaving a station so that it can reliably coast to the next allowed stop location.** This requirement is met by evaluating the vehicle condition at a checkpoint within the vehicle acceleration zone. If the vehicle has enough velocity (kinetic energy) to reach the next stop point, it is allowed to continue. If not, then it is braked to a stop at a station or at an auxiliary point outside that zone.

(2) **The vehicle must be able to reach that next allowable stop location independent of the wayside power system (i.e., relying solely on an on-board energy supply).** This requirement is met by assuring sufficient energy is available from batteries and linear generators to control levitation, braking, and other loads before the vehicle is dispatched from the station. According to the TÜV Rheinland High-Speed Maglev Trains Safety Requirements, Folio 2, the required energy must be able to be supplied by any two of the four battery systems. Thyssen-Henschel has reported that two battery systems can supply all loads including air conditioning, lights, etc., for 7 1/2 minutes without auxiliary power.

(3) **The vehicle safe hover and safe stopping systems must have the required reliability, with electrical and physical autonomy, to limit the risk of multiple failures to an acceptably low level.** This requirement is met by validating the electrical and mechanical systems through design, analysis, and test to eliminate the probability of systemic failures. Once the design is validated, failure mode and effect analyses are performed to assure that subsystems fail in safe modes and do not jeopardize the vehicle functional safety.

(4) **The vehicle must be able to bring itself to a safe stop at a safe stopping location without any input or guidance from the central control system.** This requirement is met by incorporating position location tracking and control software in the vehicle control system. Should wayside communications fail, the vehicle control system takes control and brakes the vehicle by means of an independent second brake. The wayside control then shuts down propulsion immediately.

(5) **The vehicle control system must have the reliability to assure safe operations independent of the central control system.** This requirement is met by redundancy within the vehicle. Two redundant microprocessor-based systems are used for vehicle control. Each system contains three channels which are continuously

monitored. Loss of one channel in either system is tolerated. A second channel failure in one unit leads to a stop at the next stop location.

3.1.2 Automatic Train Control (ATC) Operations

The Transrapid signal and control system is a fully automated control system designed to ensure train operating safety. It serves the two basic functions of (1) providing a safe and unobstructed travel path, i.e., route integrity, and (2) maintaining vehicle speed within designated operating specifications, i.e., safe speed enforcement.

The signal and control system is a SIMIS (Siemens Corp.) based control system referred to by the German acronym as the BLM. The SIMIS hardware system has been approved by the German Federal Railways (DB), so that TÜV Rheinland does not intend to recertify it. (TÜV Rheinland will, however, certify the control system software through software validation analyses and tests.) Currently the BLTII, a subquantity of the BLM, is undergoing certification tests at the Transrapid Test Facility in Emsland for conformance with the TÜV Rheinland High-Speed Maglev Trains Safety Requirements, Folios 4, 8, and 9 (On-board ATC, Switch, and Operational ATC Technology). On-board ATC is defined as all the functions and installations of the operational and vehicle control systems that are located on the vehicle. Switch includes all security functions concerned with the movement of the bending switch (i.e., synchronism of the switch positioning motors) and the end switch terminal position(s). Operational ATC technology is defined as the functions and installations whose purpose is the safety, control, and supervision of vehicle operations, as well as intercommunication between them.

Speed Control (Safe Speed Enforcement)

The Transrapid control system relies on various microprocessors at the central control, at decentralized (wayside) control locations, and on-board the vehicles. These microprocessors are designed, implemented, and their operation verified with several fail-safe, fail-active, and fail-tolerant methodologies for both the hardware and software. In addition, a variety of sensors are utilized for vehicle location, switch position, and monitoring wind speed and temperature.

The predetermined speed profiles and operating scenarios, available in the central control computer data files, are selected by the central control operator for implementation. Once the desired speed profile or operating scenario is chosen, it is automatically transferred to the decentralized control points for the coordination of vehicle propulsion and braking. The on-board vehicle control computer is continuously provided with adequate information (such as vehicle and safe stopping area locations) via its data link to central control, so as to permit stopping of the vehicle at any time during the trip at the next available safe stopping point independent of further outside information from either the central or wayside control.

Position Control (Route Integrity)

Once the speed profile is chosen, the decentralized (wayside) portion of the control system requests the necessary route to implement the operational plan. Before such authority is granted, the condition of the requested route such as switch position and location of other vehicles relative to the safe granting of such authority is checked by wayside components of the signal and control system. Only when the route is deemed safe to proceed on (predetermined switch position requirements and guideway occupancy conditions, i.e., safe headway between trains, etc., are met) is authority given by the route integrity portion of the control system to the control elements governing the propulsion systems for the cleared portion of the route. When a route is cleared for operation and operation commences, the safe speed enforcement portion of the control system monitors vehicle speed to assure it remains within the specified profile.

The route integrity portion of the control system is responsible for determining if the route requested by the system operator at the central control is safe for the requested operation. Before the switch is deemed "in place", all end position and locking sensors must register the correct position. The switch is kept in place by a mechanical lock.

The switch position sensors must be able to accurately determine switch position within a required +/- 1.5 mm tolerance. Before the switch is deemed "in place," all three sensors (left, right, and center), must register the correct position. For the hydraulic switch each of eight hydraulic switch cylinders must be monitored, the hydraulic locks must be activated, and the position sensor for each sensor must be set within 2.5 percent of the design location for that cylinder.

The vehicle location system is the Incremental Vehicle Location System (INKREFA), a passive loop coding in the guideway that is integrated (scanned) by an active vehicle mounted sensor system. These position tags (position identification markers or points) in the guideway are located at varying distances on the order of 200 meters. This gives the raw position. A stored table delivers an absolute vehicle position according to the tag number. Starting from these raw positions, fine position is achieved by counting the stator pack groves. Redundancy is introduced in the determination of both the raw and fine position of the vehicle by locating two readers on each side of the vehicle and placing tags on both sides of the guideway. Vehicle location, when verified by internal checks, is transmitted to the central control via a data transmission link comprising a 40 GHz radio link between vehicle and wayside receivers and a fiber-optic cable link between the receivers and the central control. The system is designed so that two receivers are in range at any one time, and the vehicle has two autonomous transmitters. At least two of the four position readers must agree. Otherwise, the most recent successful location reading is used to extrapolate the correct position until the next successful reading.

3.1.3 Emergency Brake Operations

Effective vehicle braking is necessary to ensure controlled deceleration in the event of an emergency. The Transrapid TR-07 includes both a primary and secondary braking system. The secondary braking system functions independently of the primary braking system and provides controlled braking should the primary brake fail.

The primary brake is initiated by the central control system, which controls the long stator propulsion motor (drive) to reverse vehicle thrust. Electrical energy generated during vehicle braking is dissipated in load resistors at the substation. An eddy current braking system provides secondary braking using longitudinal vehicle magnets to induce eddy currents in the nonlaminated track guide rails.

Each vehicle has two eddy-current brakes. Each brake consists of a 16-pole longitudinal magnet 2 meters long grouped into four autonomous 4-pole units, each powered by a separate chopper from one of the four independent 440 Vdc on-board power networks. The eddy-current brake force decreases sharply below about 150 km/h so that final emergency braking requires the levitation magnets to be de-energized and the vehicle to come to a stop on landing skids. At the test track in Germany, the vehicle settles on skids at 120 km/h instead of the design speed of 50 km/h. This increase in de-levitation speed was required because of high magnetic forces on the guide rails. For revenue application stronger guidance rail mounting is planned to allow for eddy current brake operation down to 50 km/h.

3.2 FACILITIES DESCRIPTION

3.2.1 Central Control

The central control serves as an operating base for the staff assigned to handle traffic timetables and line information. The center houses high-capacity process computers, with peripheral equipment, with the responsibility for supervisory control over the moving vehicle (route control) and for the display of traffic information in a manner conducive to interactive dialogue among staff.

The operational handling of the traffic network entails the responsibility for automatic control of the operational sequence, i.e., timetable data. However, operating staff can intervene and make modifications to the timetable, thereby changing the operational sequence as required. In case of minor disturbances in the scheduled operations, the systems operation is able to adjust operations by changing or modifying the timetable. Should major problems in scheduling occur, the operator can take measures to correct or bypass faults via the timetable development. Process computers in the central control allow a timely prognosis of the intended measures through simulations which permit predictions to be made of the effect of alternative scheduling or timetables.

3.2.2 Maintenance Facility

The Florida Maglev Demonstration Project will include a single maintenance facility located slightly west of the International Drive terminal (passenger station). The facility will have six berths (guideway tracks) to accommodate four trains plus guideway maintenance and emergency vehicles. The facility will serve both as a maintenance area for vehicle servicing and repair and as a base for educational tours for the public.

The maintenance facility is designed to service a fleet of five trainsets of five cars each, with the option to extend to eight cars per train. The maintenance bays will be long enough to accommodate complete trainsets (five-cars). Two tracks are equipped with dual-level platforms, the upper level for cabin access for interior vehicle cleaning and maintenance, and the lower level for maintenance on the levitation, guidance, and power supply systems. Two tracks have only a single platform for maintenance on the levitation and guidance magnets and other equipment located below the passenger cabin. Two tracks are for the ancillary or special purpose vehicles. An overhead traveling crane is planned for this bay for loading and maintaining any wheel-propelled vehicles.

3.2.3 Passenger Stations

The Florida Maglev Demonstration Project will include two passenger stations, one at the Orlando airport and another at the International Drive terminal end of the maglev line. The siting and design of the terminal at the airport will be governed by the special requirements of the Greater Orlando Aviation Authority (GOAA).

The two passenger stations must satisfy the passenger flow and baggage handling requirements and constraints of the two sites. Since both stations have different passenger flows and functional processes, their approaches to passenger handling will be different. In particular, the maglev airport terminal will function in a manner similar to the existing Orlando airside terminal, with passengers accessing the maglev terminal coming primarily from the landside Orlando airport via an Automated Ground Transport (AGT). Two AGT berths will be available for alternating shuttles between the maglev and landside airport terminals.

The International Drive terminal will function as a combination airport landside and airside terminal with an upper level for the maglev departure and drive-up access ramp. The middle level will be the maglev platform level with the guideway track to extend beyond the passenger terminal on to the maintenance facility (located west of the passenger terminal). The lower level will be the maglev arrival level with baggage claim and drive-up access for passenger and baggage pickup.

3.2.4 Power Substations and Distribution Line

Electrical power for the maglev propulsion system is provided by substations (typically spaced 10 to 30 km apart) which convert 3-phase utility power into variable voltage, variable frequency (VVVF) power as required by the maglev. The substations are dual redundant power systems, with each half of the substation having a transformer rectifier unit feeding a pair of 3-phase inverters.

The Florida Maglev Demonstration Project has three substations: Substations 1 and 2 located at each end of the guideway track, and Substation 3 located at the maintenance area. Substation 3 is operated independently of the Substations 1 and 2.

The substation equipment is sized so that either half of the system can power the vehicle at reduced speed to the next station from any point in the system. The inverter outputs are fed to the guideway feeder lines through transformers connected in series or parallel according to the inverter frequency. Substations 1 and 2 have an output phase current of 700 A, with 6.9 kv per phase for each stator side for a maximum power output of 29 mvA per substation. Substation 3 has a total output of 4 mvA and has no output transformers.

The inverters are controlled to yield maximum thrust by adjusting the voltage frequency and phase so that maximum current loading of the propulsion windings coincides with the maximum magnetic field produced by the field coils. At low speeds (below 100 km/h), the inverters are directly connected to the feeder; the transformer secondaries act as current-equalizing inductors and parallel the inverter outputs, enabling higher currents at lower voltages. At higher speeds (greater than 100 km/h), the transformer primaries are reconnected to the inverters and the secondaries are connected in series. This provides higher voltages at reduced currents as required to sustain vehicle operation at the higher speed range.

The substation variable voltage, variable frequency power output is distributed to the guideway long stator motors through a linear network of feeder cables. Switching stations for connecting the power distribution line to the propulsion winding are positioned along the track at intervals between 300 and 3000 meters.

Low-wear vacuum circuit breakers at the switching stations are used to connect the motor section to the inverter. The long-stator motor sections are arranged in staggered fashion on both sides of the guideway such that each inverter group powers alternate sections along each track side. This ensures that the maglev vehicle is always over an energized track segment if power from either inverter section should be lost. This scheme takes advantage of substation redundancy and guarantees that the vehicle can complete its trip, although at reduced speed.

3.3 VEHICLE

The Transrapid vehicles are operated as a train of multiple coupled cars, or sections, with nose sections at each end. Each section is 25.5 meters long with a capacity of about 100 passengers. Listed in Table 3-1 are the dimensions and weights of the TR-07 vehicle.

Dimension	
Coach Body (single end section)	
Length	25.5 (m)
Width	3.7 (m)
Overall Height	3.95 (m)
Height Above Floor Edge	2.27 (m)
Weight	
Coach Body Carcass (single end section)	5,173 (kg)
Tare Weight (two end sections)	90 (t)
Payload (two end sections)	16 (t) (200 passengers)
Support and Guidance System	19.5 (t)

TABLE 3-1. TRANSRAPID TR-07 VEHICLE DATA

The coach body performs several functions. The enclosure, with equipment for heating and cooling, provides a protective and comfortable housing for passengers. Also, as a load-carrying member, it provides a path for the load to be transmitted to the suspension system. Finally, the external shape of the shell can be streamlined to minimize aerodynamic drag.

The coach body is constructed with prefabricated units with sections having optimized profiles with a smooth outer surface. The body underfloor structure is bolted to the floor frame by T-nuts. The transverse section consists of prefabricated aluminum trusses which are joined on their underside to form a continuous smooth underfloor with glued-in sandwich plates. The roof, rear wall and floor likewise consist of a glued-in sandwich plate.

The top part of the vehicle is a form of sandwich shell made of glass fiber plastic and is bonded to the floor frame and cylindrical, longitudinal wall of the coach body. The undercarriage area which encloses the guideway is encased in fiberglass shrouds which complete the lower outer shell.

The side windows consist of two panes, individually bonded into the coach structure from inside and outside. The front windows are constructed of three chemically hardened float glass panes.

Doors are located at the extremes of the vehicle structure for increased stiffness. They are single-wing, swinging/sliding doors with inflatable seals. To meet passive fire protection standards, the interior furnishings meet the 1988 Air Transport Standards (five-minute fire at 1100°C without the emission of harmful fumes at 120°C on the outside of the interior vehicle cladding to protect the vehicle structure).

3.3.1 Suspension and Guidance

Suspension systems are commonly divided in at least two stages, a primary and a secondary suspension. The Transrapid maglev vehicle's primary suspension directly interfaces with the guideway to support and guide the vehicle using magnetic forces. The secondary suspension system provides additional isolation of the vehicle body from the guideway to provide acceptable ride quality.

In the primary suspension system, the support and guidance functions of the vehicle are performed by electromagnets generating an attractive force on the guideway. The axial flux support magnets on the vehicle are oriented to produce a vertical attractive force at the bottom face of the stator, lifting the vehicle up. A separate set of transverse flux guidance magnets on the vehicle are oriented to produce a lateral attractive force on the guidance rail to guide the vehicle. The field strength on the magnets is actively controlled to maintain an eight-millimeter gap between the magnets and the reaction surfaces on the guideway. Shown in Figure 3-2 is a lengthwise view of the vehicle suspension.

To follow the lateral and vertical irregularities on the guideway, the magnets along the length of the vehicle are connected together to form a chain-type arrangement. Each magnet is 3 meters long, with 30 support magnets and 24 guidance magnets over the two vehicle sections (Figure 3-2). The support and guidance magnets are mounted on the bow of the levitation frame and are arranged to pivot relative to each other to form hinge points. The support magnets slide on lateral guides and are sprung laterally on the levitation frame, while the guidance magnets slide on vertical guides and are sprung vertically. An axonometric view of the levitation frame with its support and guidance magnets is shown in Figure 3-3 while the cross sectional view of the suspension system is shown in Figure 3-4.

The secondary suspension provides an additional level of isolation between the coach body and guideway. There are 32 pneumatic springs that provide vertical suspension between the two coach bodies and the levitation frames. To permit free lateral motion of the coach body from the levitation frame without hindering the function of the vertical pneumatic springs, a series of rods are used to control the lateral suspension. The coach bodies are suspended in a pendulum fashion swinging on 32 guide rods to control both the lateral and vertical motions (Figure 3-4).

To control the roll motion of the coach body, a series of roll stabilizing devices are used in the secondary suspension. There are 12 pairs of roll stabilizers for the two vehicle sections. Each roll stabilizer consists of a pair of hydraulic cylinders that are connected to permit unconstrained vertical movement, but provide a stiff roll natural frequency of 3 Hz. Shown in Figure 3-5 is a cross-sectional view of the vehicle with the roll stabilizer.

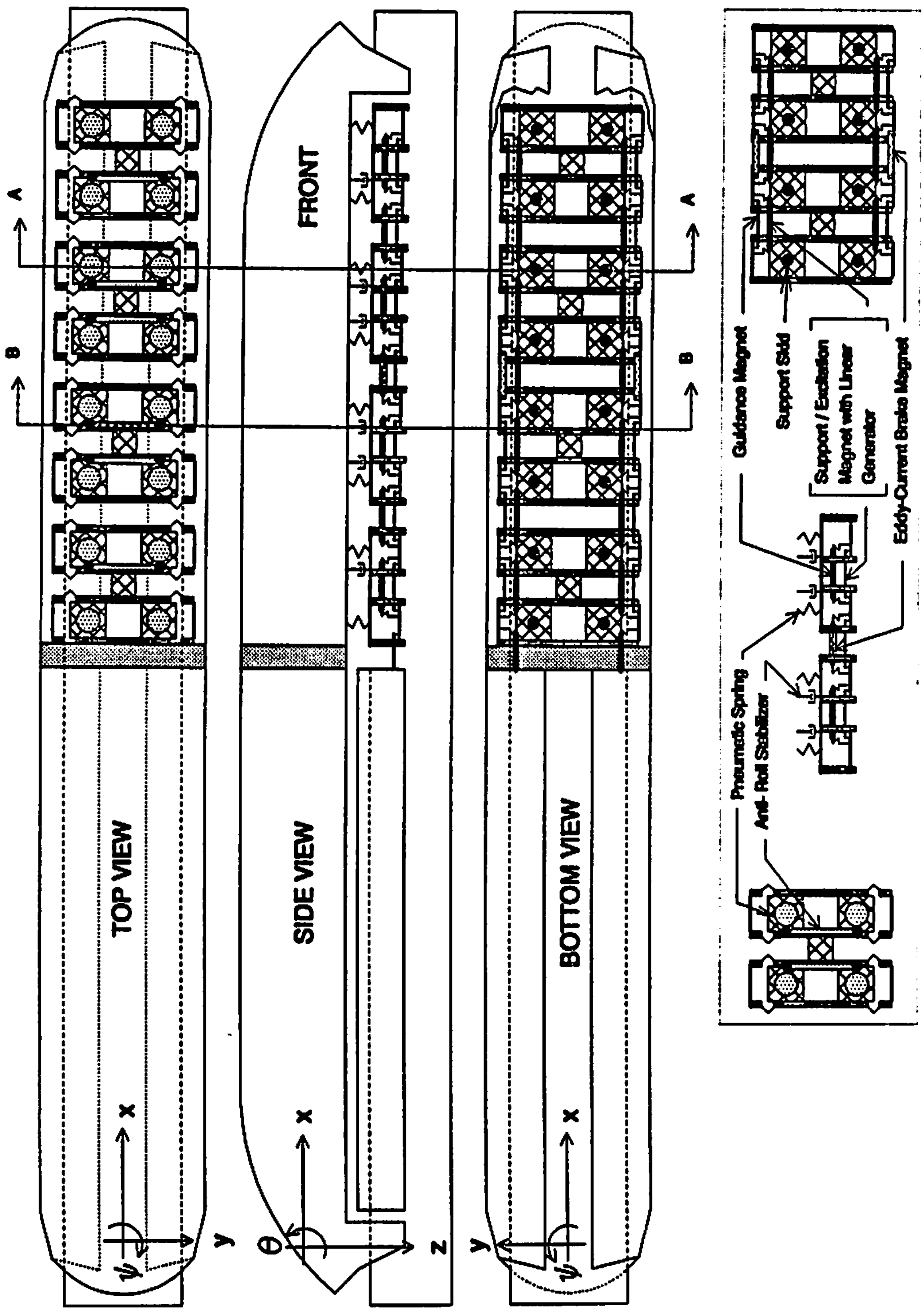


FIGURE 3-2. LENGTHWISE VIEW OF VEHICLE SUSPENSION CONFIGURATION

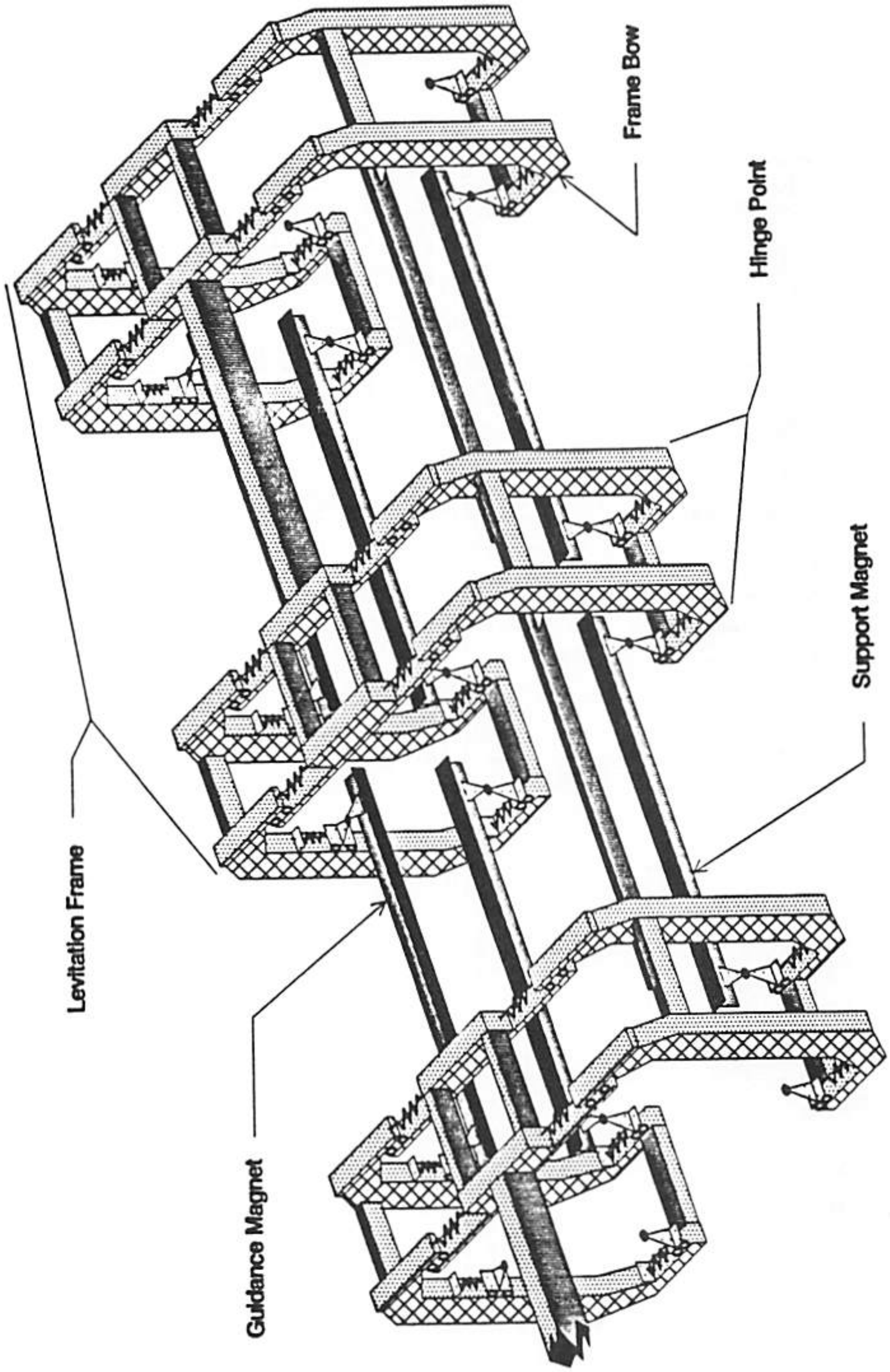


FIGURE 3-3. AXONOMETRIC VIEW OF LEVITATION FRAME WITH SUPPORT AND GUIDANCE MAGNETS

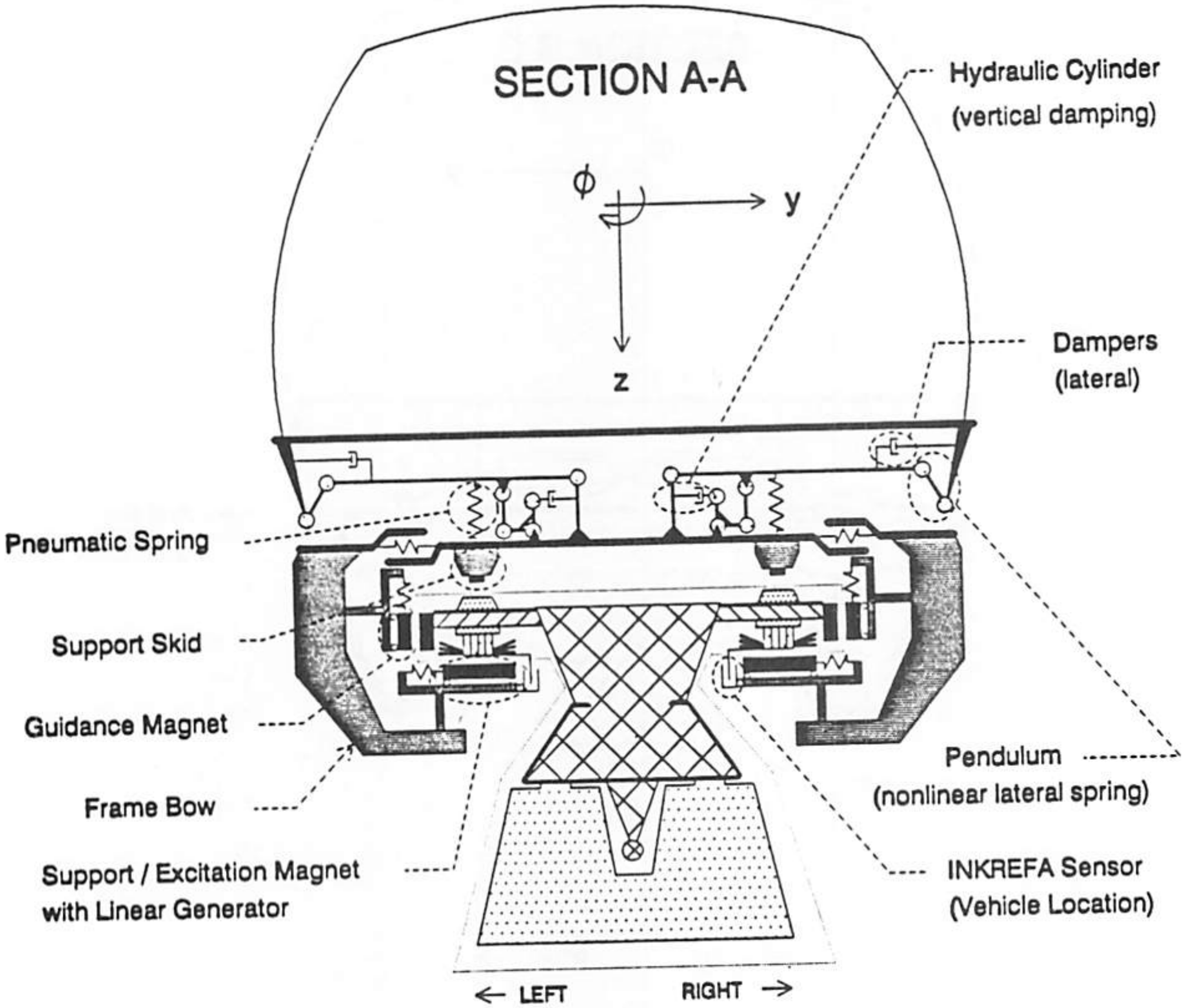


FIGURE 3-4. CROSS SECTIONAL VIEW OF VEHICLE SHOWING PRIMARY AND SECONDARY SUSPENSIONS

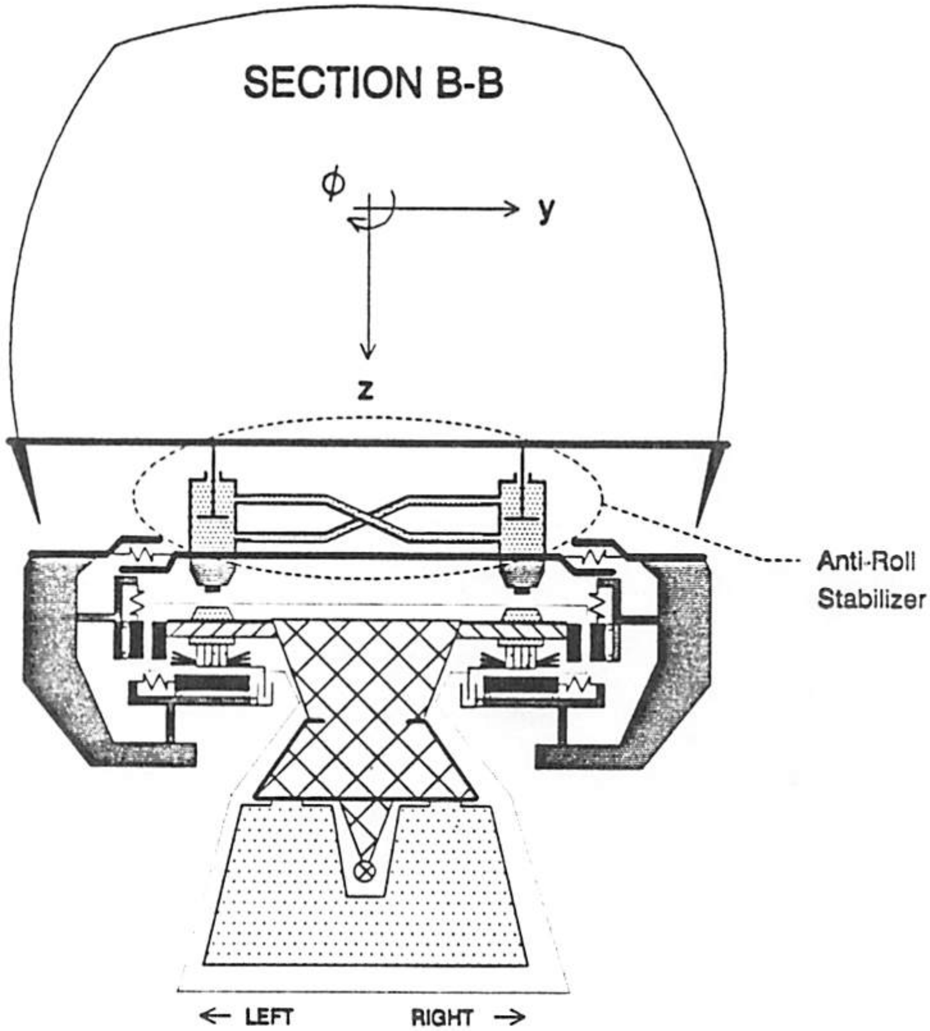


FIGURE 3-5. CROSS SECTIONAL VIEW OF VEHICLE SHOWING ANTI-ROLL STABILIZER IN SECONDARY SUSPENSION

3.3.2 Propulsion and Braking

Propulsion of the Transrapid vehicle is performed electrically by means of a linear synchronous motor. The vehicle, acting as the rotor portion of a synchronous motor, contains the direct-current excited field windings. The magnets on the vehicle that are used to generate the field poles for propulsion in the linear motor are also the same as the support magnets. The excitation (or support) magnets are of the axial flux type with a nominal pole pitch of 0.258 meters which interacts with the traveling magnetic field on the guideway stator to provide thrust to the vehicle.

Once the vehicle is in motion, there are two methods of decelerating the vehicle. The linear motor becomes a brake by reversing its thrust to decelerate the vehicle. When functioning in this mode, the linear motor becomes the operating brake. In the event of failure in the motor, eddy-current or throughbrakes are used to decelerate the vehicle. (See Section 3.1.3 Emergency Brake Operations.) These brakes are axial flux magnets acting on the guidance rail which generates a drag force only while the vehicle is in motion. There are two eddy-current brakes with four autonomous function units in each vehicle section. Once the vehicle has reduced its speed sufficiently and the eddy-current brakes lose efficiency, the vehicle can be lowered on its support skids to bring the vehicle to a stop.

3.3.3 Power Supply and Collection

The Transrapid vehicles do not contain any on-board power plant. There are on-board storage batteries that provide power independent of any external sources. Each vehicle section contains four electrically isolated battery buffered 440-volt circuits. These batteries are recharged by power transmitted from the guideway through linear generators as the vehicle is moving.

The linear generators provide for noncontact power collection to the vehicle by induction with the magnetic flux from the guideway-mounted long-stator motor sections. Integrated with each support magnet are windings in the pole shoes to form two 5-phase symmetrical linear generators. The linear generators are effective only while the vehicle is in motion. At speeds below 100 km/h, power from the linear generators supplements the batteries to provide adequate power for vehicle operation, while above 100 km/h, power from the linear generators is used for providing all vehicle power as well as recharging the storage batteries.

3.3.4 Magnet Controller Redundancy

In the Transrapid TR-07 design, the vehicle is supported and guided by trains of magnets, each three meters long, supported by brackets which link the magnets together in a manner which produces a kinematic hinge between the magnets as shown schematically in Figure 3-6. As described below, the forces acting on the magnets are controlled to maintain (on the average) a constant distance between the hinge points and the levitation (or guidance) surfaces.

The position of each hinge point is controlled by two independent control circuits as illustrated in Figure 3-6. If one of the control units was to fail, the second unit is fully capable of performing the function of controlling the hinge location and supplying the needed levitation or guidance force. Each magnet is divided electrically into two magnetic units and contains two gap sensors and an accelerometer at each end of the magnet. The gap at the hinge point is controlled by controllers 2 and 3. For controller 2, the gap signal is obtained by combining gaps measured by gap sensors A-3 and B-1. This gap signal is compared to the desired gap to provide the gap error signal used in the control loop discussed in Section 3.4.3. The required acceleration signal is provided by accelerometer AA-20. Controller 2 and chopper provide the current to magnetic unit 2A to generate magnetic forces to reduce the gap and position errors. Similarly, controller 3 combines the gaps measured by gap sensors A-4 and B-2 to produce a change in the current in magnet unit 1B. Controllers 2 and 3 and their associated sensor circuits are completely independent.

The physical separation of the two gap sensors permits the gap control to be maintained over thermal expansion joints in the support and guidance rails. A large gap signal occurs at a sensor when it passes over an expansion joint. The controller is designed to ignore this effect by combining the signals from sensors on each side of the hinge. Since the gap sensors are separated from each other, only one sensor at a time encounters the expansion joint. The other sensor gives an accurate measurement of gap. The controller compares the two gaps to create the gap signal

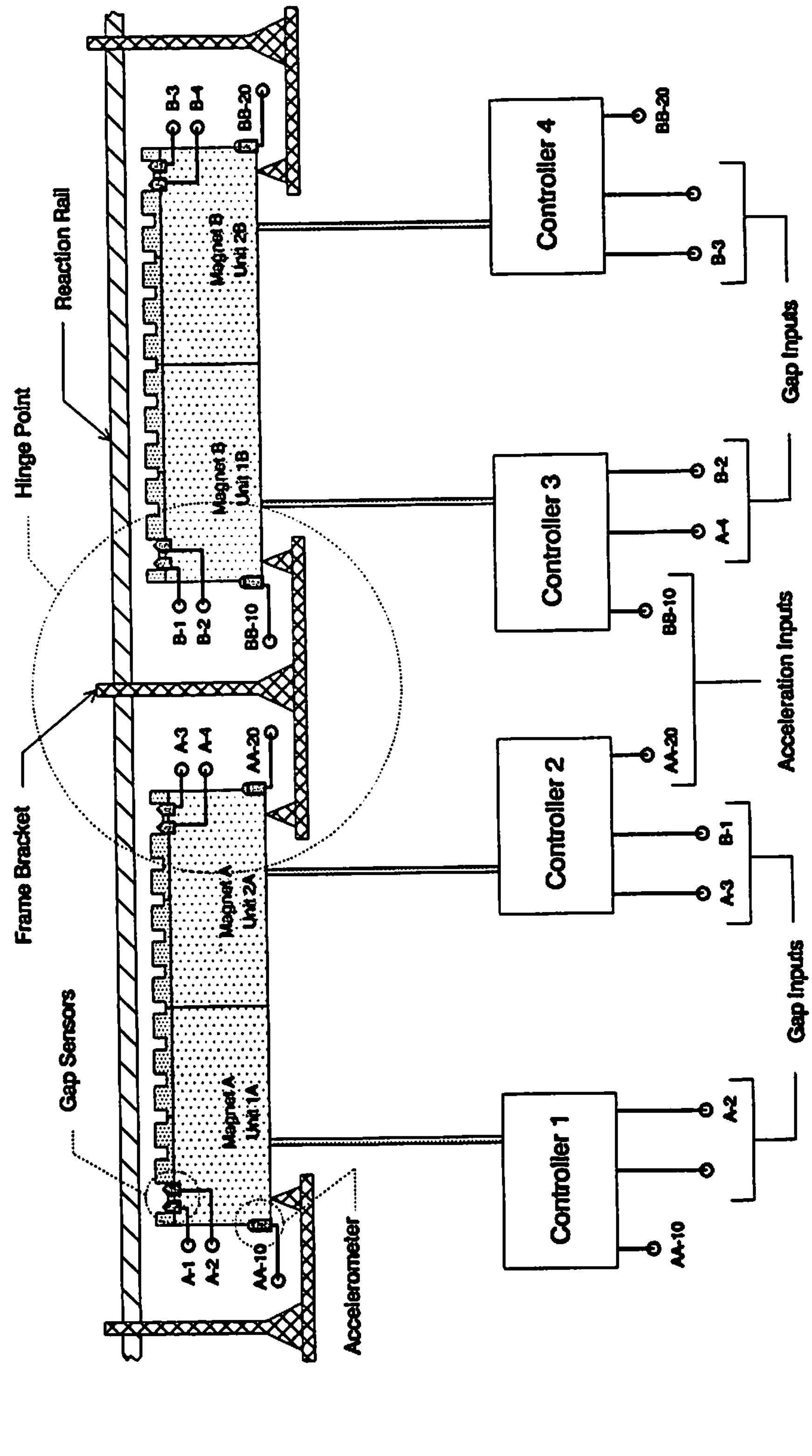


FIGURE 3-6. MAGNET CIRCUITS WITH CONTROLLER REDUNDANCY AT HINGE POINT

and if the difference between the measurements is greater than 1.5 mm, the smaller gap is taken as the input. Otherwise, the gap signal used for control is the average of that obtained from each sensor.

3.4 GUIDEWAY

In a tracked transport, the guideway constitutes the stationary structure whose principal function is to bear the supporting and guiding loads of the vehicle. It can also contain electronically active elements serving as an integral part of the propulsion system and automated to control speed, start, and stop functions of the vehicle. With the vehicle being confined to move linearly with the guideway, provisions are made to allow for branching out and merging together of the various routes by guideway switch mechanisms.

3.4.1 Guideway Construction

The main supporting structure of the Transrapid guideway is a concrete or steel girder with a T-shaped cross section where the vehicle wraps around the top of the guideway. A cross section of the guideway is shown in Figure 3-7 illustrating the wrap-around design of the vehicle.

While the guideway girder provides the load support for the vehicle, functional components are required on the guideway for the vehicle to operate. There are three types of functional components mounted on the guideway girder (Figure 3-8). Underneath each cantilever of the T-shaped guideway are the long stators which, perform the following functions: produce the traveling magnetic field for the linear motor, provide power through induction for the linear generators, and serve as an attractive-reaction rail for the levitation magnets. On both outside edges of the cantilevers are the guidance rails that interact with the guide magnets to provide the lateral attractive force to guide the vehicle and reaction rail for eddy current brake. The third component is the two parallel gliding planes on the top surface of the girder which the support skids of the vehicle contact when the vehicle is lowered onto the guideway.

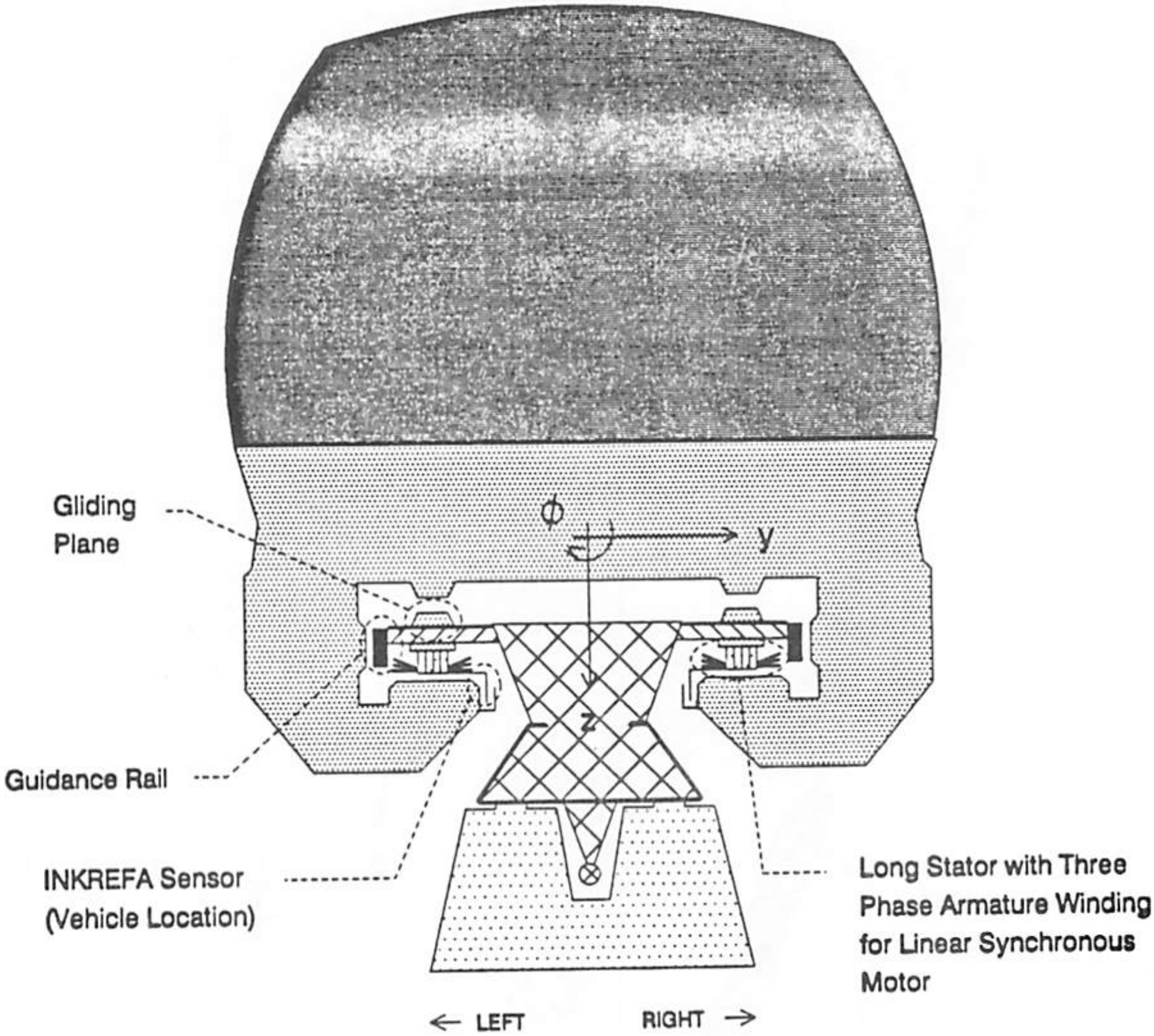


FIGURE 3-7. CROSS SECTIONAL VIEW OF GUIDEWAY

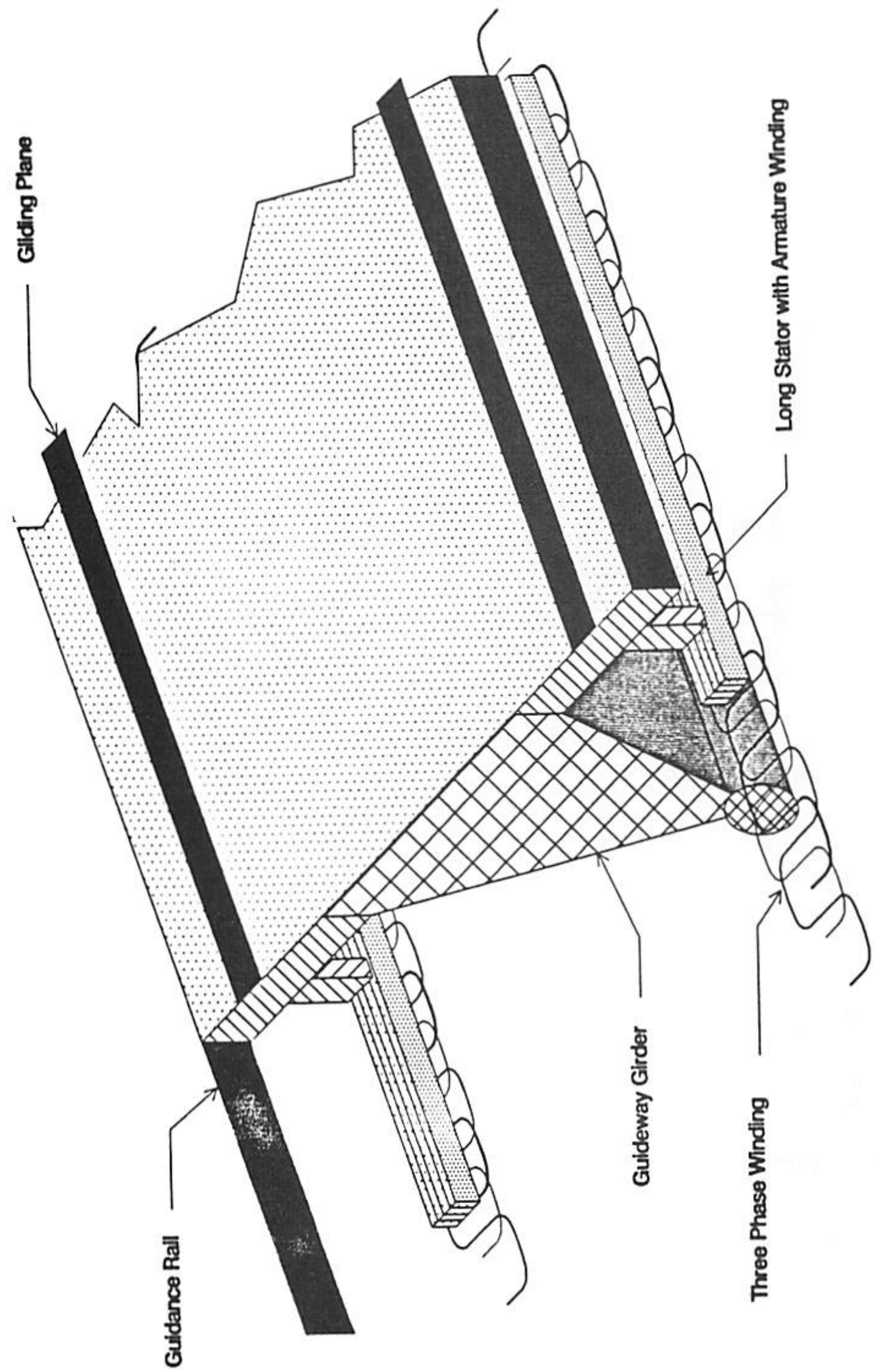


FIGURE 3-8. AXONOMETRIC VIEW OF GUIDEWAY

3.4.2 Guideway Geometry

Tolerances are imposed on the Transrapid guideway geometry deviations to provide acceptable dynamic response of the vehicle and to maintain minimum clearances between the vehicle and guideway. Areas where deviations in the guideway can occur include the spacing where two girders meet, deflections in the girder, and variations in the position of the stator packs and guidance rails.

In the following some typical values of TVE for elasticity, precurvature and tolerances are given, which in detail vary with temperature, single or two span design, material and designed speed.

Each span of the guideway girder is cambered to limit the girder curvature under vertical loads. An upward camber of 3.4 mm above the ideal profile is built into a single 25-meter span, which results in a maximum downward displacement of 6.8 mm under loaded condition, or a deflection of 3.4 mm below the ideal profile (Table 3-2 and Figure 3-9b).

Deflections in the guideway girder can occur in both the lateral and vertical directions. Shown in Table 3-2 and Figure 3-10 are tolerances for guideway deflections which are specified over a single 25-meter span. A larger tolerance is permitted for a single vertical deviation (Figure 3-10b) than for a periodic vertical deviation (Figure 3-10c).

GUIDEWAY	Dimension	Tolerance
Beam Camber vertical upward precurvature for 25 meter span	3.4 (mm)	—
Lateral Beam Deviation lateral tolerance in a 25 (m) span	—	4.1 (mm)
Vertical Beam Deviation vertical tolerance in a 25 (m) span for a single perturbation	—	8.0 (mm)
Vertical Beam Deviation vertical tolerance in a 25 (m) span for a periodic perturbation	—	6.2 (mm)

TABLE 3-2. GUIDEWAY DEFLECTION

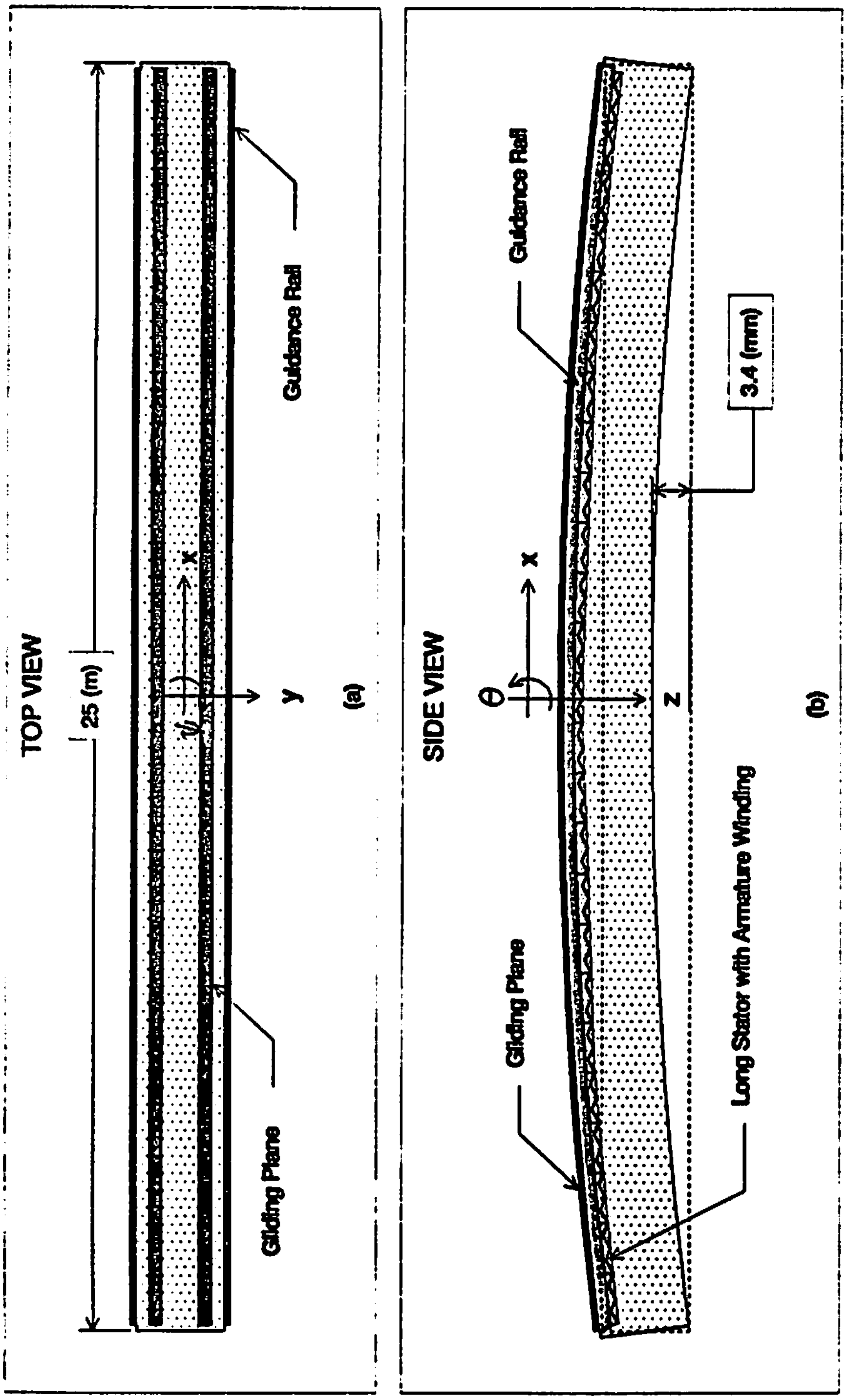


FIGURE 3-9. LENGTHWISE VIEW OF SINGLE SPAN GUIDEWAY GIRDER WITH FUNCTIONAL COMPONENTS: (A) TOP SURFACE OF GUIDEWAY, AND (B) VERTICAL CAMBER

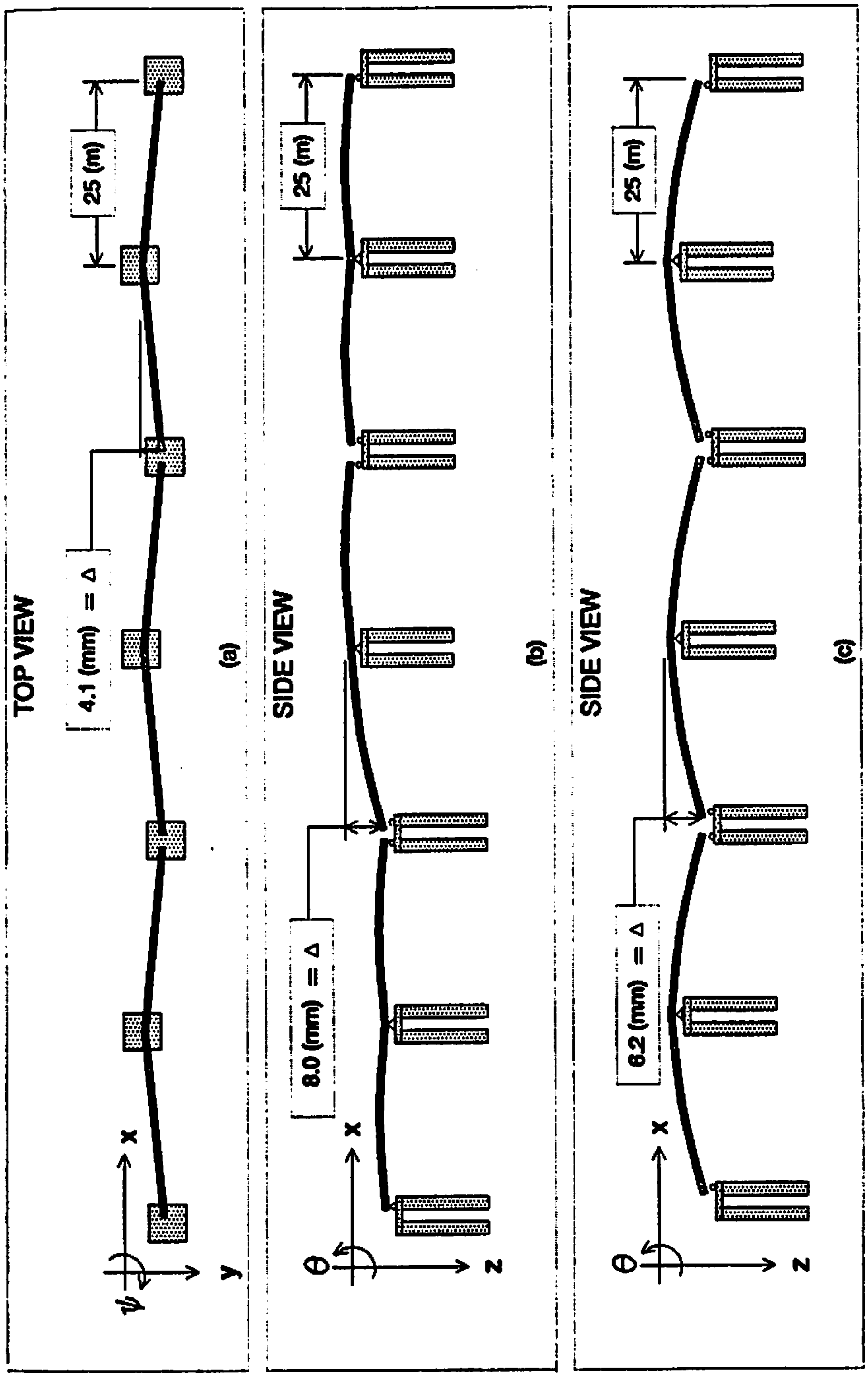


FIGURE 3-10. TOLERANCES FOR GUIDEWAY GIRDER DEVIATION FOR (A) LATERAL DEVIATIONS, (B) SINGLE VERTICAL DEVIATIONS, AND (C) PERIODIC VERTICAL DEVIATIONS

The guideway is composed of individual girders and a smooth transition is necessary as the vehicle rides over the space between consecutive girders. The spacing produces longitudinal gaps, and lateral and vertical steps between the functional components. Shown in Figure 3-11 and Table 3-3 are the dimensions and tolerances between functional components on consecutive girders.

Along the guideway girder, variations in position can exist in the individual functional components. Tolerances for these variations are shown in Figure 3-12 and Table 3-4.

3.4.3 Vehicle/Guideway Interaction

The Transrapid system uses controlled electromagnetic elements to support and guide the vehicle. The force attracting the magnet to the support rail is approximately proportional to the ratio of current (I) to gap (s) squared.

$$F = \frac{C I^2}{s^2}$$

For small gap variations, the electromagnet and the Transrapid control scheme could be represented as a simple spring mass system with a natural frequency of 5 Hz for an effective stiffness of 0.5 kN/mm or 10 Hz for a stiffness of 2 kN/mm.

However, if the control is based only on the deviation of the gap from the nominal gap, the system would have no damping and would have a large response to guideway irregularities at the wavelength which corresponded to the natural frequency of the spring mass system at the operating speed.

In order to provide damping, the Transrapid maglev system uses a filter to create a signal proportional to the rate of change of the gap combined with the signal from an accelerometer.

Guideways have irregularity spectra that typically consist of large amplitudes at long wavelengths and small amplitudes at short wavelengths. Long wavelengths typically

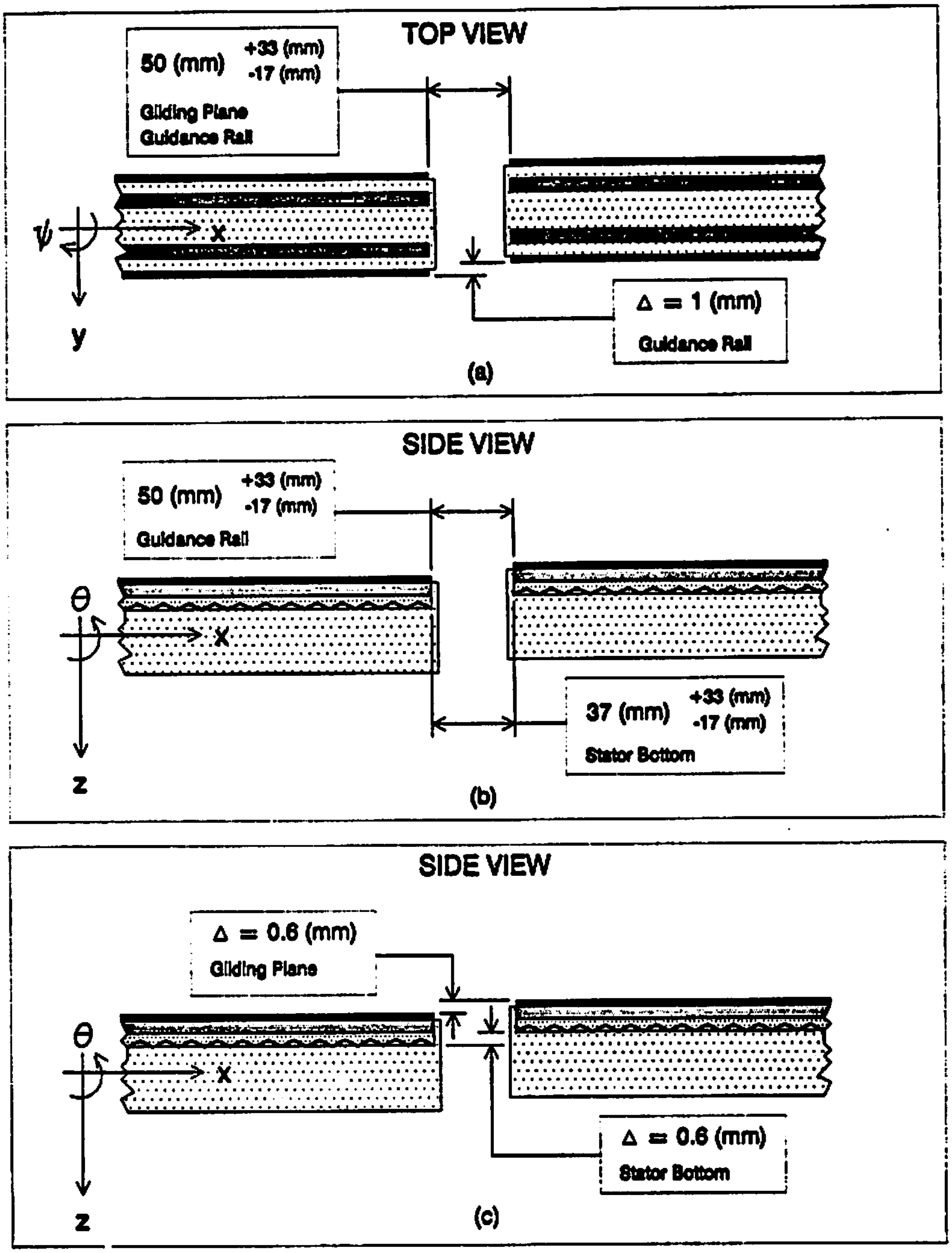


FIGURE 3-11. TOLERANCES BETWEEN FUNCTIONAL COMPONENTS WHERE TWO GUIDEWAY GIRDERS MEET: (A) LONGITUDINAL GAP AND LATERAL STEP, (B) LONGITUDINAL GAP, AND (C) VERTICAL GAP

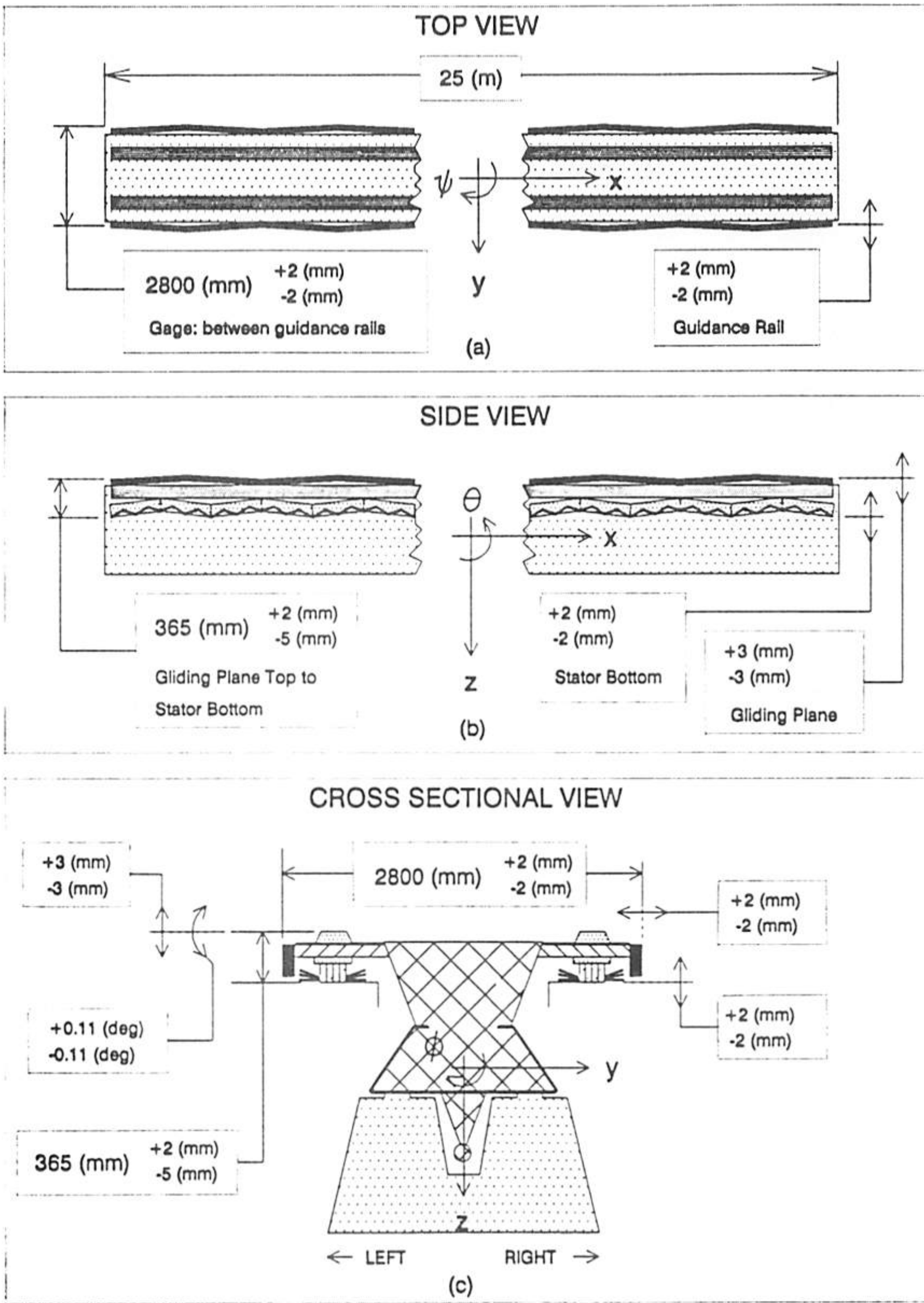


FIGURE 3-12. TOLERANCES IN FUNCTIONAL COMPONENTS ON GUIDEWAY GIRDER: (A) LATERAL TOLERANCE, (B) VERTICAL TOLERANCE, AND (C) LATERAL AND VERTICAL TOLERANCES

GUIDEWAY	Dimension	Tolerance
Gliding Plane longitudinal gap tolerance between gliding plane	50 (mm)	+33(mm) -17(mm)
Gliding Plane vertical step tolerance between gliding planes	—	0.6 (mm)
Guidance Rail longitudinal gap tolerance between guidance rails	50 (mm)	+33 (mm) -17 (mm)
Guidance Rail lateral step tolerance between guidance rails	—	1 (mm)
Stator Pack longitudinal gap tolerance between bottom surfaces of stator packs	37 (mm)	+33 (mm) -17 (mm)
Stator Pack vertical step tolerance between bottom surfaces of stator packs	—	0.6 (mm)

TABLE 3-3. GUIDEWAY TOLERANCE OF FUNCTIONAL COMPONENTS BETWEEN CONSECUTIVE GIRDERS

GUIDEWAY	Dimension	Tolerance
Track Gauge outside distance between guidance rails	2800 (mm)	+/- 2 (mm)
Gliding Plane vertical tolerance	—	+/- 3 (mm)
Gliding Plane cant tolerance	—	+/- 0.11 (deg)
Guidance Rail lateral tolerance	—	+/- 2 (mm)
Stator Pack vertical tolerance for bottom surface of stator pack	—	+/- 2 (mm)
Stator Pack/Gliding Plane vertical distance from top of gliding plane to bottom surface of stator pack	365 (mm)	+2 (mm) -5 (mm)

TABLE 3-4. GUIDEWAY TOLERANCE OF POSITIONAL VARIATIONS IN FUNCTIONAL COMPONENTS

represent route alignment while short wavelengths are typically due to surface roughness and assembly tolerances.

In the design of the Transrapid type of maglev system, there is a trade-off between the guideway tolerances and the power required for levitation. This trade-off, combined with limitations on achievable magnet force to weight ratios and electromagnet inductance define the frequency (irregularity wavelength and speed) response requirements of the gap control system.

For any reasonable gap, it is necessary for the magnet to follow long wavelengths. For short wavelengths, it is desirable to use the gap to accommodate the irregularities, since a higher gap frequency response results in more power consumption and more difficult to achieve electromagnet physical characteristic requirements. However, a lower gap frequency response requires a larger gap or tighter guideway irregularity tolerances. A larger gap is also associated with increased power requirements, while tighter tolerances are normally associated with increased guideway costs. The Transrapid system uses a transition frequency of between 5 and 10 Hz.

A schematic of the control system is shown in Figure 3-13. For frequencies below the transition frequency, the system is dominated by the gap control loop which works to maintain a constant value of the gap to cause the magnet to follow the guideway alignment including irregularities at long wavelengths. At wavelengths corresponding to frequencies above the transition frequency, the "position" control loop containing the accelerometer acts to maintain straight line motion ignoring short wavelength irregularities. The position control loop also acts to prevent gap changes from occurring as a result of sudden transient changes in load on the magnet.

The integration shown in the gap control loop serves to compensate for variations in vehicle weight implied by passenger loads.

Based upon discussions with Transrapid personnel, it is believed that the 5 Hz system is a good representation of the TR-06 control system and that efforts are being made to achieve the 10 Hz characteristic for the TR-07 vehicle.

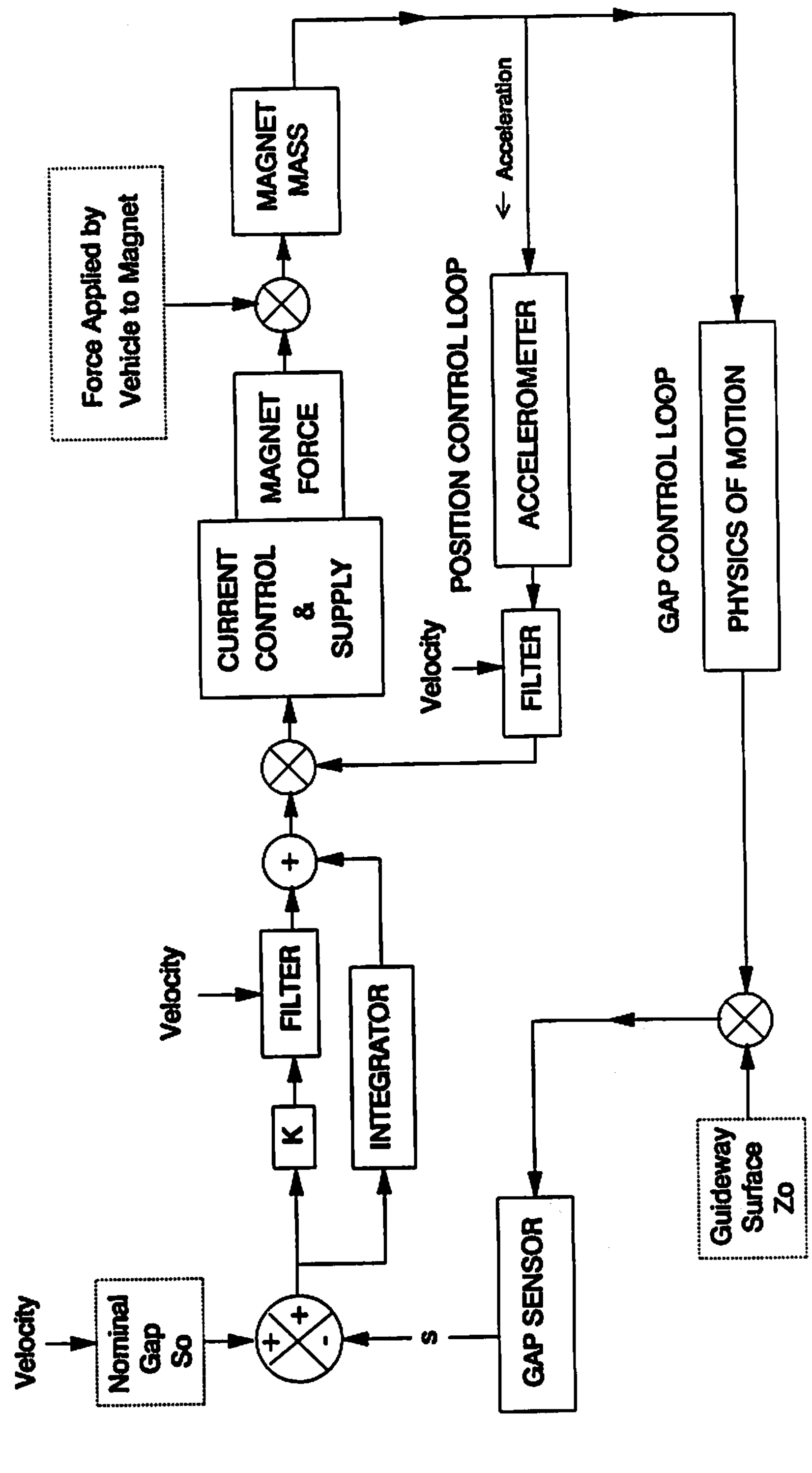


FIGURE 3-13. MAGNET CONTROL LOOP

In Figures 3-14 and 3-15, the irregularity amplitude required to produce an 8mm gap change for the hypothetical electromagnetic levitation control system is shown as a function of frequency or wavelength and vehicle speed. Wavelengths at the 25 meter pillar spacing produce a 5 Hz input to the vehicle at 500 km/h.

3.4.4 Guideway Switch

In a tracked transport, as the path of a guideway diverges to two or more paths, a mechanism is required to switch a moving vehicle smoothly from one path of the guideway to another. The Transrapid guideway accomplishes the switching operation by having a section of the guideway bend to direct a vehicle to one of two paths of the guideway. The bending switch is designed with a box girder cross section that is continuously welded for multiple span. Each span, except at support 0 where it is fixed and at the following supports with small lateral movement where there are glide bearings, is supported on a transverse support frame with two wheels to allow for lateral movement of the guideway. An electromechanical or hydraulic actuator is employed at each movable span to bend the guideway. Figure 3-16 shows the bending switch.

While the girder bends during the switching operation, the functional components that are mounted on the girder do not participate in the bending. Each of the functional components is mounted as short discrete units about one meter long to provide a piecewise linear change in direction. The individual units are mounted with one end fixed while the other end is attached by an axial bearing to allow for small changes in the arc length of the girder without affecting the functional components.

Finally, since the switch is a movable mechanism of the guideway, a properly aligned and locked switch is necessary to ensure safe passage of a vehicle. In the electromechanical drive, there are three locking devices. The switch is locked by actuating rods fixed through a knuckle-joint effect. It is also locked through a braked-in drive motor and a self-locking gear.

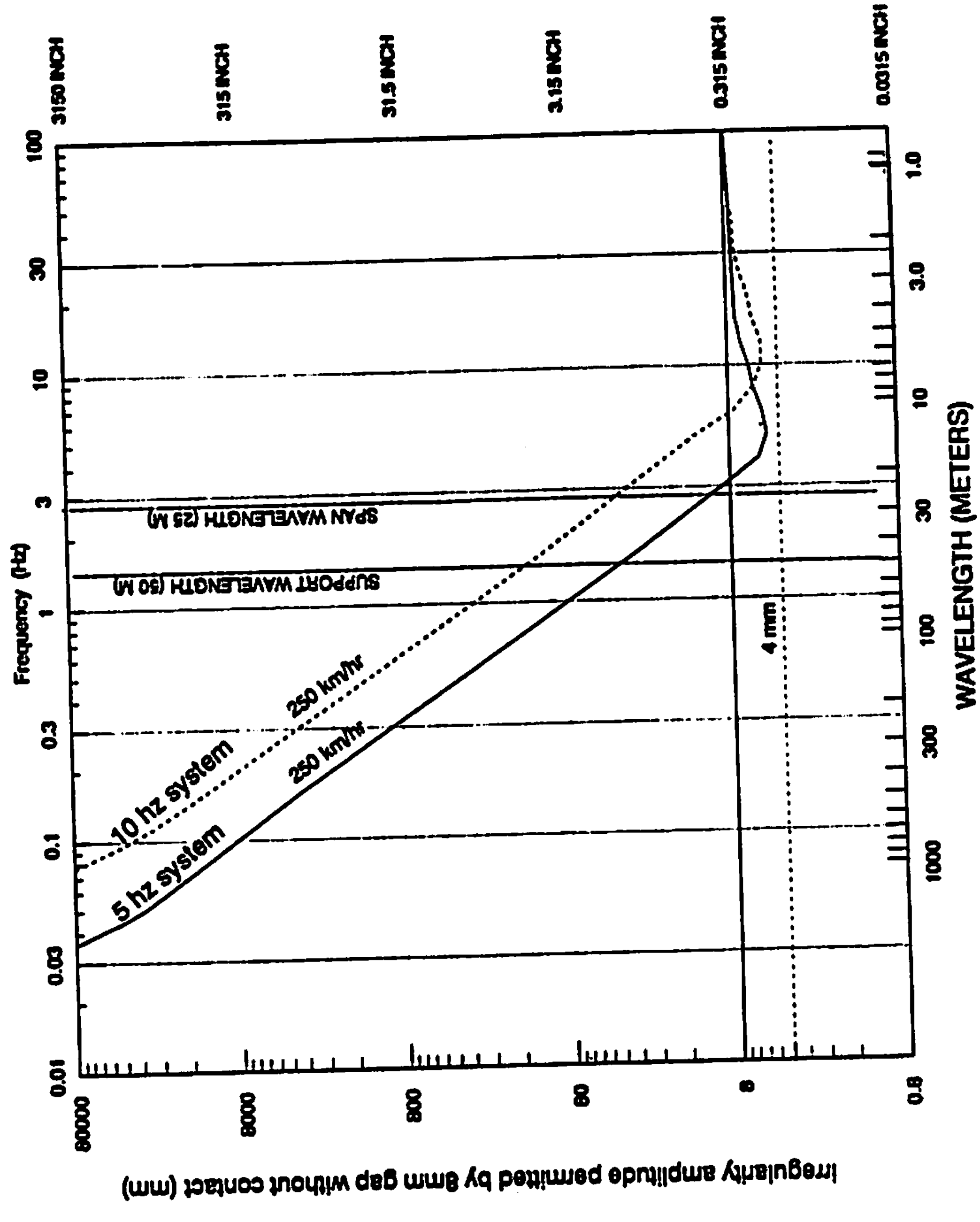


FIGURE 3-14. IRREGULARITY AMPLITUDE TO PRODUCE 8MM GAP CHANGE FOR HYPOTHETICAL MAGNETIC SUSPENSION CONTROL SYSTEMS TRAVELLING AT 250 KM/H

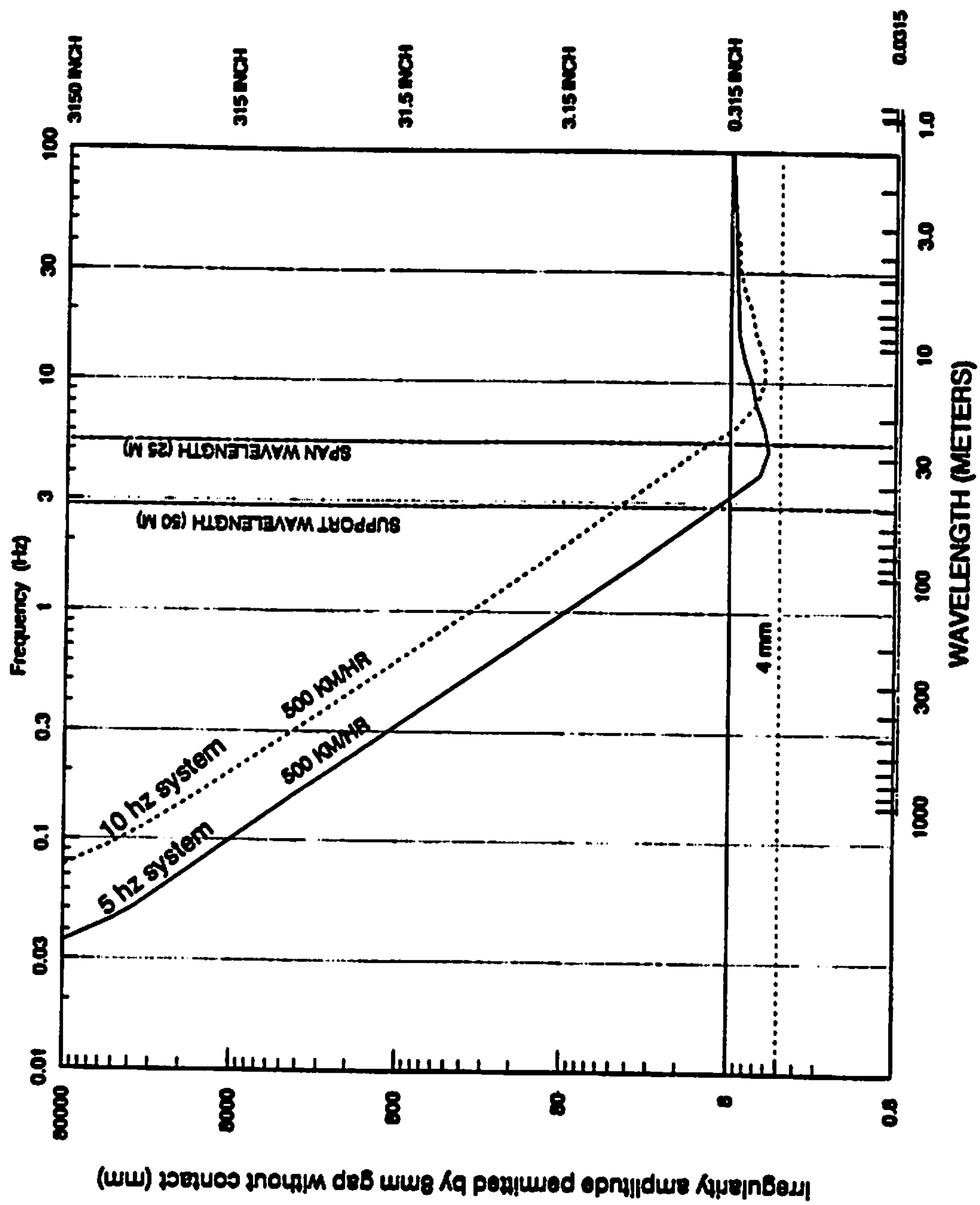


FIGURE 3-15. IRREGULARITY AMPLITUDE TO PRODUCE 8MM GAP CHANGE FOR HYPOTHETICAL MAGNETIC SUSPENSION CONTROL SYSTEMS TRAVELLING AT 500 KM/H

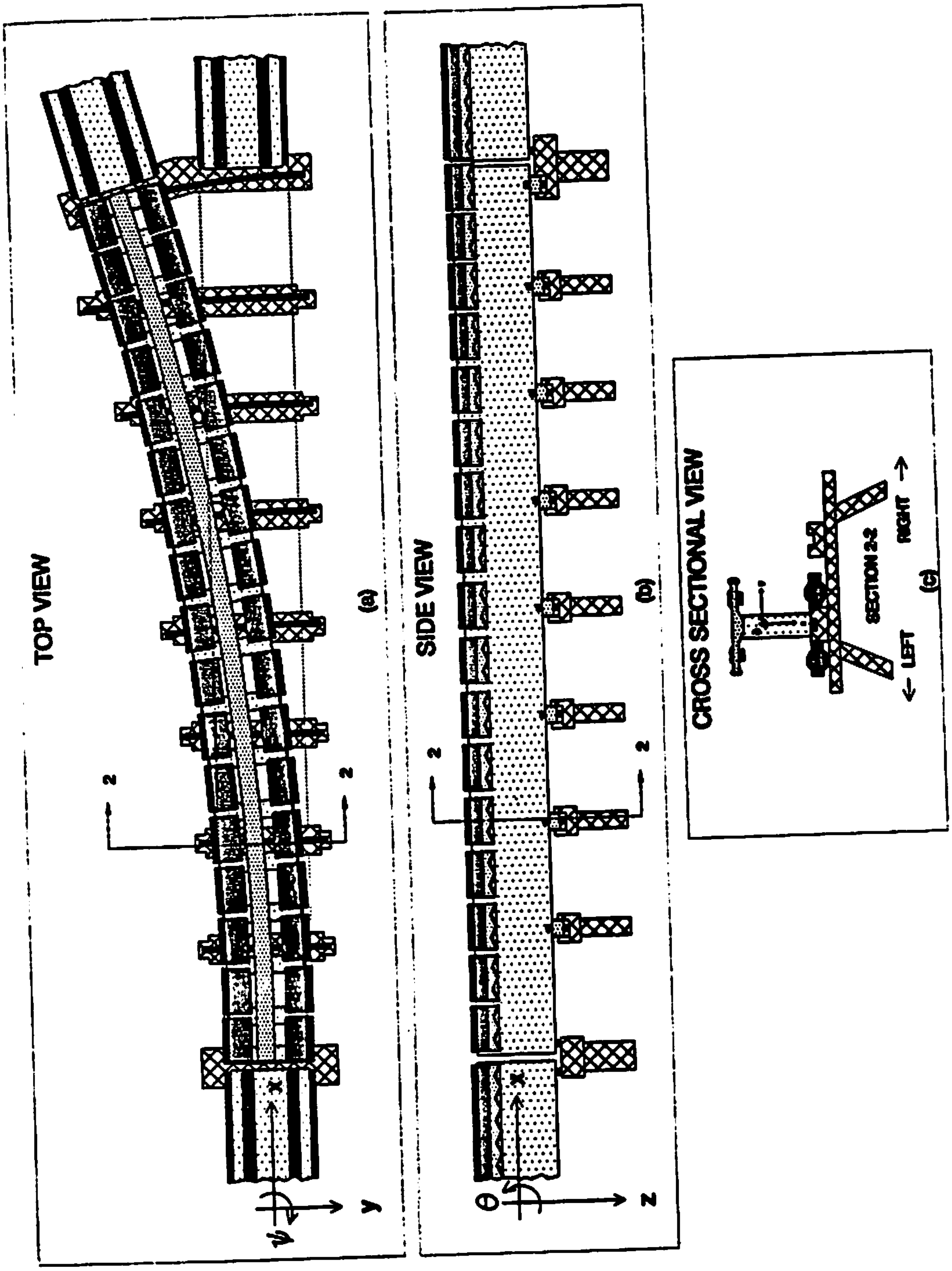


FIGURE 3-16. BENDING SWITCH: (A,B) TWO VIEWS OF SWITCH IN THE BENT POSITION SHOWING THE POSITIONING OF THE FUNCTIONAL COMPONENTS, AND (C) VIEW SHOWING THE SUPPORT WHEELS

3.5 PROCEDURES

3.5.1 Revenue Operation Procedures

Revenue operations are managed primarily by the control center under the supervision of the Operations Supervisor. The procedures for revenue (and non-revenue) operation are contained in the operating manual which describes the various system tasks and functions, types of operations, and methods of handling malfunctions in systems operations. Close coordination of revenue operations with the technical department is required to ensure the use of trains is consistent with maintenance and service scheduling requirements.

The driver of the train is not actively in control of the train. Local control of the train by the train driver occurs only for the routine command for station train departures (after consulting with train attendants). The exception is during emergencies or other abnormal operating conditions when manual control is exercised.

The central control initiates and controls the train operations according to demand or selected time schedules using dual redundant computer systems. Control and monitoring panels facilitate the operations management by providing convenient visual displays of operations and means for implementing control functions.

3.5.2 Maintenance Procedures

An effective maintenance program is important to ensure the maglev system maintains a high level of operating efficiency. This requires the construction of maintenance facilities and the development of a maintenance plan for operating subsystems and system equipments.

Vehicle Maintenance

Maintenance for maglev vehicles falls into the following categories; car cleaning, preventive maintenance, corrective maintenance, and component repair and overhaul.

Preventive maintenance should be planned so that successive preventive maintenance includes previous activities as well as additional tasks determined to be necessary to maintain the high operational integrity of the system. The vehicle preventive maintenance program is based on passenger unit and annual run distance and is controlled by life-cycle data.

Corrective maintenance involves the restoration of a failed or defective unit to an operable or normal state. It can vary from correcting minor defects to failures which result in stopped trains. The schedule for corrective maintenance depends on the type of equipment malfunction with those malfunctions which result in stopped trains receiving the highest priority. The procedures for corrective maintenance and the use of diagnostic and test equipment to isolate a fault in the appropriate subsystem are described in the maintenance manual.

Wayside Maintenance

The goal of wayside maintenance is to maintain the stationary facilities and equipment in a safe and reliable operating condition. Wayside maintenance includes the maintenance of the guideway structure, guideway equipment, telecommunications, energy supply equipment, and guideway switches.

Periodic reviews of maintenance procedures are required to determine if specific changes should be made in the frequency or content of the preventive maintenance program.

The wayside maintenance program includes different types of inspections, services, and tests depending upon the component involved. For example, wayside switches require servicing and refilling of fluids in the hydraulic switch devices.

3.5.3 Emergency Procedures

While the Transrapid system is designed to limit the likelihood of a critical system failure, emergency procedures are required should a system failure occur requiring partial or total system shutdown.

3.6 PERSONNEL

The number of personnel involved in the construction of the Transrapid system cannot be precisely determined though it is estimated a minimum of 1000 persons is required for the demonstration project installation. Once completed, it is estimated the project will employ at least 300 persons in train operations, maintenance, baggage handling, and other areas.

Subsequent to the completion of the Transrapid system and during the commissioning phase, key personnel will be recruited to supervise the future operation and maintenance of the TR-07 maglev. It is understood that training for these personnel is to be provided by experts of Transrapid's technical staff. The following identifies three operations and seven maintenance staff positions and respective duties for which staff recruitment may be required.

3.6.1 Operations Staff Personnel

(1) Operations Manager
Duties: Overall management and direction of operations; responsible for material, manpower and annual budgets and implementing policies and procedures to ensure cost-effective operations.

(2) Operations Supervisor
Duties: Responsible for planning, scheduling, and implementing all aspects of the system operation; supervises system operators; responsible for all aspects of day-to-day operations including responses to passenger inquiries; coordinates engineering and maintenance activities with scheduled operations and coordinates and directs personnel in event of emergencies.

(3) System Operator
Duties: Responsible for daily operation of the control center including monitoring system operations, train movements, electrical distribution system, station operations, and control system operations; responsible for safe operation of the system, authorizing maintenance activities in and around the guideway, including responses to stalled trains and vehicle retrieval operations.

(4) On-board Attendant

Duties: Responsible for all manual-related train operations during normal and emergency conditions; responsible for monitoring and implementing on-board vehicle control functions and alerting Central Control of irregular vehicle operations or on-board equipment malfunctions; responsible for manual control of train during emergencies, and directing and supervising vehicle evacuation under stalled conditions.

(5) Station Clerk

Duties: Responsible for effective operation of passenger station including passenger ticketing and providing scheduling information and assistance to passengers as required; responsible for implementing security measures to ensure train operational safety during station arrivals and departures; responsible for advising Central Control of circumstances which could affect train scheduling.

3.6.2 Maintenance Staff Personnel

(1) Maintenance Manager

Duties: Overall management and direction of maintenance activities; in conjunction with operations manager, is responsible for material, manpower, and annual budgets and implementing policies and procedures to ensure cost-effective operations.

(2) Maintenance Controller

Duties: Schedules, coordinates, and documents maintenance and inspection activities as directed by the maintenance manager; reviews system maintenance requirements and insures materials, parts, supplies and equipment required to support maintenance effort are requisitioned and scheduled.

(3) Maintenance Supervisor

Duties: Overall supervision and guidance of maintenance activities in accordance with policies, procedures and practices established by the maintenance manager; supervises personnel in inspection, cleaning, maintenance, and repair of vehicles/guideway and associated mechanical systems and support equipment.

(4) Lead Mechanical Technician

Duties: Inspects, troubleshoots, removes, installs, repairs mechanical systems and components as directed by Maintenance Supervisor.

(5) Mechanical Technician

Duties: Inspects, troubleshoots, removes, installs, repairs mechanical systems and components under direction of lead mechanical technician.

(6) Lead Electrical/Electronic Technician

Duties: Inspects, troubleshoots, repairs, removes and installs electronic and electrical equipment and test equipment under direction of maintenance supervisor. Supervises electrical/electronic technicians.

(7) Electrical/Electronic Technician

Duties: Inspects, troubleshoots, repairs, removes, and installs electronic and electrical equipment and test equipment under direction of lead electrical/electronic technician.

4. IDENTIFICATION AND EVALUATION OF POTENTIAL MAGLEV SAFETY ISSUES

Having defined the system, the next step in the hazard resolution process is the identification of the potential hazards. When identifying the safety hazards present in a system, a major concern is what portion of the total number of system hazards has been identified. The quality or type of hazard analysis will greatly influence the total number of hazards identified. There are many types of generic and specific safety hazards associated with the operation of any transportation system. Some safety hazards may be anticipated; others may go unnoticed until one of them results in the occurrence of an undesired, injury-producing, or life-threatening event. The principal undesirable event (safety issue) for maglev operation, from the viewpoint of public safety, is a "casualty" (implicitly including passenger and personnel injuries as potential casualties - see Figure 4-10). Property loss and system loss are not considered to be a safety issue in this analysis contrary to some FRA accident criteria which consider these as safety issues.

4.1 HAZARD IDENTIFICATION APPROACH

There are four basic methods of hazard identification that may be employed to identify hazards. These methods are:

- o Data from previous accidents (case studies) or operating experience,
- o Judgment of knowledgeable individuals and scenario development,
- o Generic hazard checklists, and
- o Formal hazard analysis techniques.

With the exception of the hazard checklists, the initial step in identifying the hazards in each of these methods is the identification of the undesired event that may result if the hazard(s) is not eliminated or controlled. For the purposes of this analysis, the identified undesired events are the safety issues that must be resolved to provide the passengers and employees with the highest level of safety practical. Each individual undesired event may be precipitated by any one or more hazards.

4.1.1 Data from Previous Accidents

Examination of previous accident experience can provide an insight into what has happened in the past. High speed maglev vehicles, although having been under development for many years, do not have a large exposure base in passenger service. The limited operating experience of high speed maglev systems has not resulted in the occurrence of any deaths or serious injuries. The German Transrapid TR-06 maglev vehicle and system conducted a public demonstration during June 1988. This demonstration consisted of twenty-five days operation in which 333 trips were made and 16,650 passengers transported. During this demonstration period, the system averaged 14.3 trips per day and a total of 96 hours of operation. Of the 333 trips, only four trips experienced problems and of the four, the vehicle had to be towed back only once. This limited data is insufficient to provide a thorough understanding of the variety of potential hazards that may occur in maglev operations.

Recognizing that the information available on maglev systems is very limited, it is necessary to examine data from other types of transportation vehicles to identify potential undesired events and the contributing safety hazards and gain insight into the kinds of potential emergency situations which could occur. In examining other systems, it is important to understand that the maglev system has several characteristics unique to maglev operations and several characteristics that are common among all transportation systems. For example, the concept of movement without guideway contact is unique to maglev, whereas the fire safety characteristics of the vehicle interior materials is common to all transportation systems.

Finally, it is important to note that identification of hazards solely through review of previous accident data or experience is not a satisfactory approach because identified hazards will be limited only to previous accidents while new and future hazards will not be identified.

4.1.2 Expert Opinion and Hazard Scenarios

The primary safety concern associated with maglev operation is the occurrence of a passenger or employee casualty. To assist in understanding the mechanism by which these events may occur, hazard scenarios have been developed. The first step in the development of the hazard scenarios is the identification of undesired events that may occur and thereby result in the occurrence of such a casualty. Judgment by knowledgeable individuals was used to provide a starting point for the identification of the types of emergency situations or "undesirable events," which can occur.

The following nine undesired events represent situations that may result in a casualty:

- Fire/explosion in vehicle,
- Fire in other critical system element,
- Vehicle collision,
- Vehicle leaves guideway,
- Sudden stop,
- Vehicle does not slow/stop at station,
- Vehicle stranded between stations or, safe evacuation points,
- Inability to reach and rescue maglev vehicle occupants, and
- Passenger injury/illness.

Table 4-1 presents a listing of these undesired events (safety issues) and provides in more detail, by cause and by type of subevents, how such events may occur.

Appendix A presents hazard scenarios developed to assist in understanding the mechanisms by which these undesired events may occur. The accident scenarios selected for illustration in Appendix A are intended to represent potential real-world events and, as such, have been derived primarily from the experiences of existing transportation systems. These scenarios briefly outline potentially hazardous external factors (weather, intruders, obstacles on the guideway), operational emergency situations (fire in the vehicle or the control room), and equipment malfunctions (e.g., magnet failures) which could impact on the safety of the vehicle and the persons on board. Scenarios include the selected undesirable event (e.g., vehicle collision, fire, inability to reach safe evacuation point, etc.) and the possible series of events that may result in the final occurrence of that undesired event.

TABLE 4-1
LIST OF UNDESIRED EVENTS
WITH EXAMPLES OF HOW MAGLEV CASUALTY MAY OCCUR

1. Fire or Explosion in the Vehicle
   - accidental:
     lightning-induced shortout or fire
     on board battery overload
     cable or equipment overheats
     arcing of ungrounded networks
     disposal of smoking materials
   - intentional (arson, sabotage,terrorism)

2. Fire or Explosion in Other Critical System Element
   - accidental:
     powerplant (transformer or converter failure, or sabotage/terrorism)
     power distribution wayside stations
     central computer control facility (dispatcher/ control location)
     stations/terminals/safe areas
     on parallel side road, or at interstate highway underpass, etc., which could spread and reach cables, or train, or stations
   - intentional (arson, sabotage, terrorism)

3. Vehicle Collision
   - by type:
     with other vehicle (maintenance or passenger train)
     with object, individual, or debris on guideway
     with object not on guideway (bird or rock)
     with station platform (clearance failure)
   - by cause:
     operational command failure
     equipment failure (switches)
     signal/control failure
     faulty sensors
     communication error
     human error

4. Vehicle Leaves Guideway
   - by type:
     at open end of failed or unsupervised switch segment
   - by cause:
     failure to sense train position
     failure to command switch closure
     failure to execute commanded switch closure
     failure to signal and/or control train
     failure to supervise open guideway segments/ends
     failure to display correct status
     operator error

5. Sudden Stop
   - Vehicle makes sudden emergency stop, with rapid deceleration occurring in the passenger compartment, due to inadvertent or erroneous command on command, but with malfunction (wrong speed profile, wrong braking rate)
   - Obstruction on guideway
   - Guideway alignment out of specification, due to:
     sag
     bulge
     foundation settling of pillar/post
     collapse of pillar/post
     collapse of guideway span
     faulty gap sensing
     faulty gap control

6. Vehicle Does Not Slow/Stop at Station, due to:
   - loss of safe-hover function (with uncontrolled touch-down)
   - loss of power (with inertia)
   - loss of control
   - central or distributed computer crash or malfunction
   - operator error
   - incorrect data transmission
   - sensors failure (position, speed)

7. Vehicle Stranded Between Stations or Safe Evacuation Points:
   - without adequate power or speed to safe levitate to station
   - over water or swamp
   - over busy interstate highway
   - without adequate means of passenger rescue
   - without adequate means of towing to station

8. Inability to Rescue Maglev Occupants in Case of Breakdown or Accident:
   - unforeseen accident type and conditions
   - difficult terrain
   - inaccessible location
   - inadequate emergency planning or preparedness (insufficient escape ladders or short chutes)
   - inadequate rescue vehicle (capacity, mobility, design, access)

9. Passenger/Employee Injury or Illness
   - by injury cause:
     door locks malfunction
     accident in (dis)embarkation
     improper emergency evacuation or rescue
     intentional (suicide)
   - illness

Each of the types of emergency situations illustrated may be the result of a number of hazardous conditions and causal effects that involve a variety of events or enabling conditions. Although a number of potential hazards and causal effects were identified, this initial effort identified only a limited portion of the potential hazards. Hazard scenarios are often useful in uncovering the weak links in the safety chain. These hazard scenarios were of limited assistance in identifying the potential for future accidents, and the necessary prevention and control measures (e.g. monitoring and failure detection systems, physical separation limits, operating procedures for emergency conditions) as further discussed in Section 6.

4.1.3 Generic Checklists

Generic checklists may be used to identify potential hazards. With this approach, the depth of detail and applicability of the hazard checklists has an impact on the quality and quantity of hazards identified. Appendix B contains a generic checklist which groups hazards within the categories of basic design deficiencies, inherent hazards, malfunctions, maintenance hazards, environmental hazards, human factors, and fire hazards. This checklist will, as the system design evolves, provide additional insight into the safety hazards that may be present in the system.

4.1.4 Formal Analysis

A number of formal analysis methods are available for use in identifying hazards. The following sections describe the two formal analysis methods which are being employed to identify hazards associated with maglev systems. The analysis are in process and will be presented in more detail with their results in the next safety assessment report.

4.2 FAULT TREE ANALYSIS (FTA)

A fault tree is a graphical representation of the relationship between certain specific events and an ultimate undesired event. FTA is a deductive analysis technique which uses the top-down approach (what and/or why did a particular event happen) to determine the possible causes of an undesired event or system failure.

Fault tree analysis was chosen as one of the principal tools for identifying hazards because it is a systematic method of analyzing the complex series of events which may occur during an accident. Each event or sequence of events can also be examined to identify appropriate hazard control and mitigation countermeasures. Fault tree diagrams can and should be used in the following manner:

- As an educational tool to fully examine how an accident might occur and to display all the contributing factors,
- As an aid in developing maglev system design, procurement, and safe operation specifications,
- As an aid in developing emergency response plans and evacuation procedures.
- As an aid in developing maglev preventive maintenance, repair and operational practices,
- As an aid or checklist for safety assurance, and
- As an aid in determining required hazard controls to arrest the propagation of a failure chain through the system (design "interrupt nodes").

4.2.1 Fault Tree Development

A typical fault tree diagram is constructed as follows: A particular undesired event is selected. This "top" undesired event is the event whose occurrence must be prevented, or probability minimized, or whose consequence must be mitigated. Primary undesired events, and their interactions and causes, leading to the undesired top-level event are then examined and broken down into secondary undesired events organized by causal pathways (chains) of subevents. This reverse reasoning process continues until there is either insufficient information to proceed or an event is not considered significant enough for further analysis. Various symbols are used to represent the relationship between certain specific events and the ultimate undesired event (see Figure 4-1.). An example of a simple fault tree for the undesired event "fire " is illustrated in Figure 4-2: Fuel, oxygen, and an ignition source (fabric, air, electric short) are all necessary for the fire event to occur; hence, the presence of the "and" gate; if any one element is missing (e.g. that there is no electric short, then there is no "ignition source "), the fire will not occur. In contrast, the use of an "or" gate would indicate that only one of any of the three causes: fuel or oxygen or heat, would be required for a fire to occur. This is clearly false as all three must be present. An example of an "or" gate is the occurrence of a maglev

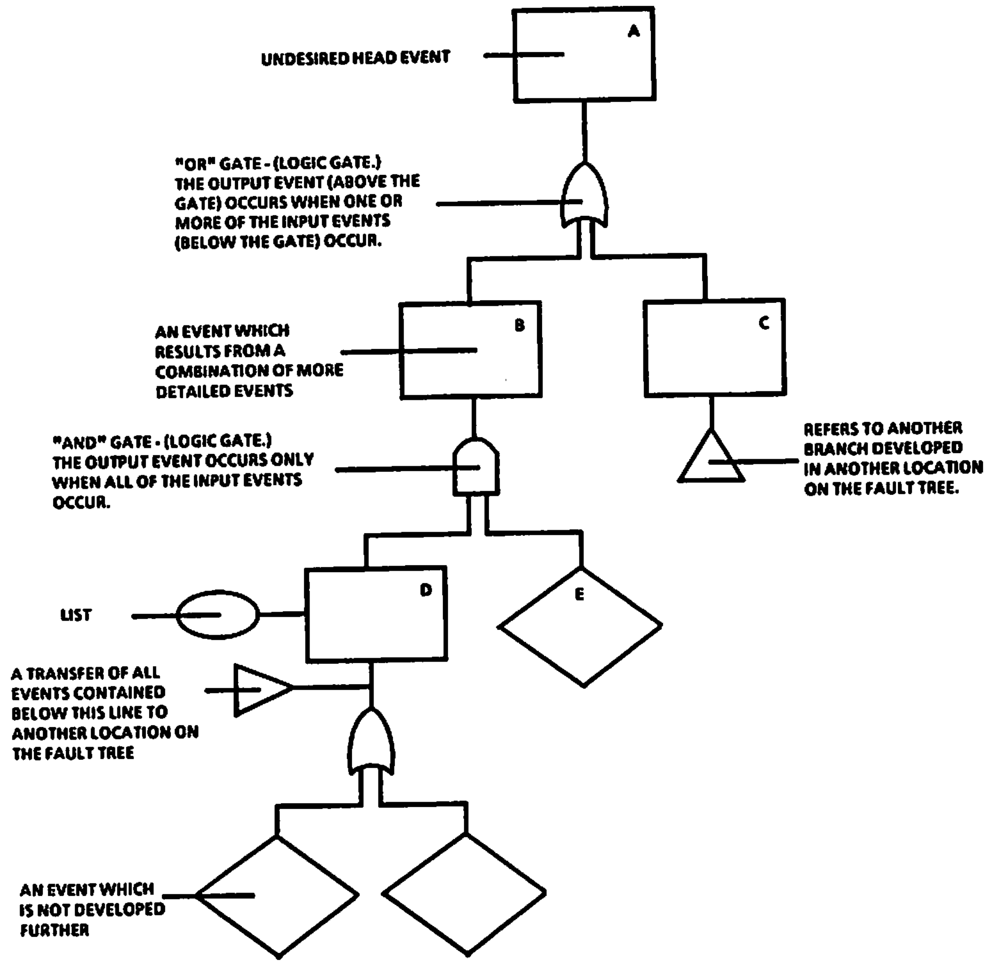


FIGURE 4-1. FAULT TREE SYMBOLS

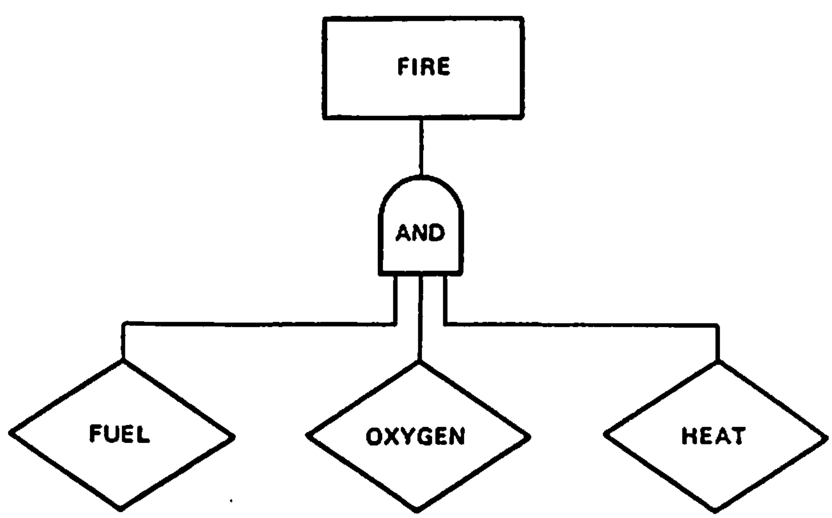


FIGURE 4-2. FIRE FAULT TREE EXAMPLE

system casualty. A maglev casualty may occur in the vehicle, "or" on the guideway, "or" in a station. Reference #3 provides a detailed discussion of fault tree construction.

The qualitative fault trees developed for this report are presented in Appendix C and provide overall pictorial diagrams leading to the top undesired event: "Potential Maglev Casualty Occurs" (see Figure 4-3). This casualty could occur in several distinct locations; in the vehicle, on the guideway, in the station, and may be due to a number of accident categories (for example, collision between vehicles, with station, or with debris on guideway). These logical alternatives were developed into fault tree diagrams to the extent that technical information was available and conceptual, "what if," accident scenarios allowed for this preliminary effort. Each of these second level undesired events has been examined from the point of view of where the hazardous condition occurs, and whether the condition can or will be controlled fully, or appropriately.

The undesired maglev events listed in Table 4-1 and the hazard scenarios presented in Appendix A provide a starting point for the top level undesired events contained in the fault tree. These undesirable events have been developed down to the third subsystem failure or event level in the illustrative fault tree diagrams of Appendix C.

4.2.2 Fault Tree Findings

The undesired events depicted in these fault trees closely parallel those identified in the hazard scenarios (see Appendix A) and employed in the Preliminary Hazard Analysis (PHA) discussed in Section 4.3. While the causes of the undesired events in the fault trees are identified more fully than in the scenarios, not all causes are covered to the extent that they will be when the following PHA is completed. This is because the emphasis of the fault tree diagrams is to identify and present the progression and combination of potentially hazardous failure/fault events which could lead to a maglev casualty. Moreover, the format of the fault tree diagrams illustrates the importance of understanding the technical interrelationships between propagating failure events.

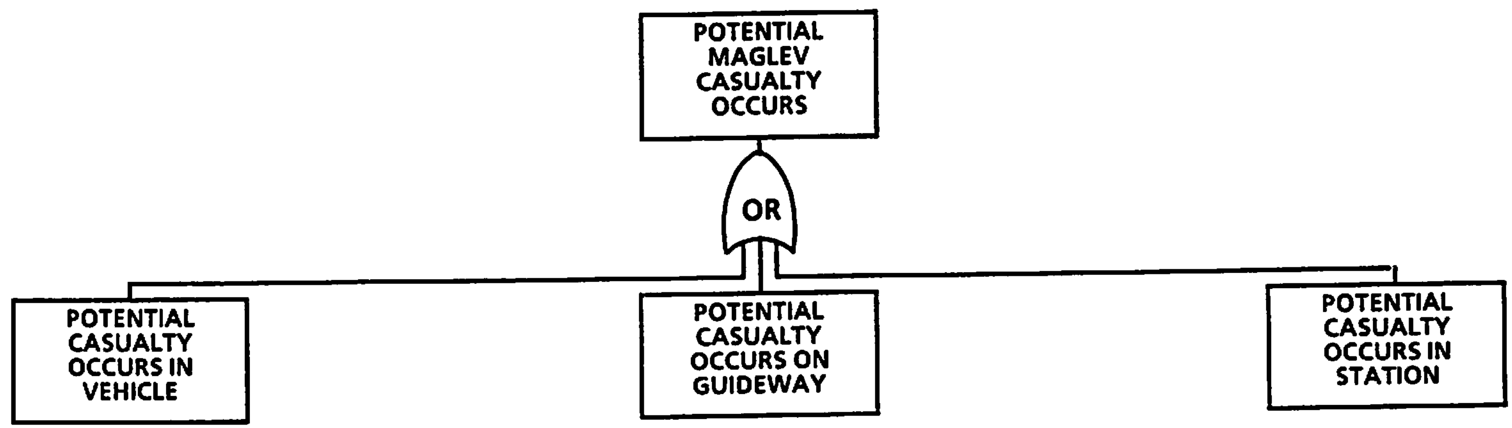


FIGURE 4-3. OVERVIEW: POTENTIAL MAGLEV CASUALTY OCCURS - FAULT TREE

A review of the fault tree diagrams shows that a maglev system casualty could occur either in the maglev vehicle, on the guideway, or in the station. This is an important point because both the severity of the potential hazard and the necessary level of emergency response effort will vary widely depending on the location of the maglev casualty. Certain events and hazards which could result in a casualty will occur while the maglev vehicle is in the station. This is particularly true of passenger slips and falls. Such events are less severe and also occur more frequently. This is in contrast to a fire which occurs in the vehicle at an inaccessible point on the guideway.

While the prevention of as many hazards as practical is desirable from a safety standpoint, certain hazards are either inherent to the operation of the system or cannot be completely eliminated. Thus, a significant element in the fault tree presented is the indication of "and" gates to signify a double point hazard (simultaneous occurrences or conditions), as aggregated at higher levels of the fault tree diagram. That is, an undesired event occurs and it is not controlled or responded to in some active way. For an example, a passenger that is neither restrained nor assisted, can be injured if they fall in the maglev vehicle. A second and very serious example is the occurrence of a fire on the vehicle with the presence of a passenger or crew member in the vehicle.

The fault tree diagrams which depict the actions and facilities pertaining to passenger escape and rescue from various conceivable emergency conditions, illustrate some key points relating to passenger safety. Proper advance planning, provision of predetermined emergency procedures, proper signage and its posting, adequate and frequent personnel and support organization training, and the availability of emergency equipment, all contribute greatly to the success of swift, effective emergency response operations.

Examples of potential undesired events that may escalate if the passengers and crew are not rescued include vehicle fire, vehicle collisions, vehicle stranding, and sudden stops, etc.. These undesired events may involve system malfunctions, unsafe operations, etc. and may result in injury-producing or life-threatening situations.

4.3 PRELIMINARY HAZARD ANALYSIS (PHA)

Preliminary Hazard Analysis (PHA) is a basic hazard analysis technique used to identify, list and logically organize hazards into categories by causative subevents. The PHA format provides an organized, systematic framework to define potential hazards (their nature, types and their causes) and to recommend possible safeguards and control measures. The PHA is an inductive method, that uses the bottom-up approach (what happens if a specific hazard exists) to determine what the effect of a hazardous event or system malfunction will be. A key point concerning this type of analysis is that it provides a more expanded and system specific checklist of potential hazards, and the opportunity to consider a large number of conceivable hazards (some of which, however improbable, could possibly occur). This is important, because historical data and experience do not necessarily reflect all potential safety hazards and their effects. A PHA is usually carried out in the early phases of conceptual system definition, design, and operations planning.

The PHA is being developed using the maglev system definition presented in Section 3 of this report and the organizational approach shown in Figure 4-4. The main functional areas (elements) of the system are: equipment and facilities/structures, environment, procedures, and people. Each functional area (equipment and facilities/structures being considered separately) is represented by a number from 1 (equipment) to 5 (procedures) as shown in Figure 4-4. The functional areas are then broken down further into systems and, if applicable, subsystems. Figures 4-5 through 4-9 show complete organizations for each of the five functional areas. Each system represented under a functional area is uniquely identified by a number composed of the functional area it belongs to and its own arbitrary sequence number. For example, the passenger vehicle is the first system under the equipment functional area. In Figure 4-4 equipment received the identifier "1." The passenger vehicle would then be represented as "1.1." The next system under equipment is the guideway maintenance vehicle which would then be "1.2." Each subsystem is identified by continuing the pattern so that the fifth subsystem of the passenger vehicle (the suspension) is identified as "1.1.5." This method of referring to the functional elements, systems and subsystems will be used throughout the PHA and is the basis for the PHA's "control numbers" which will be discussed shortly.

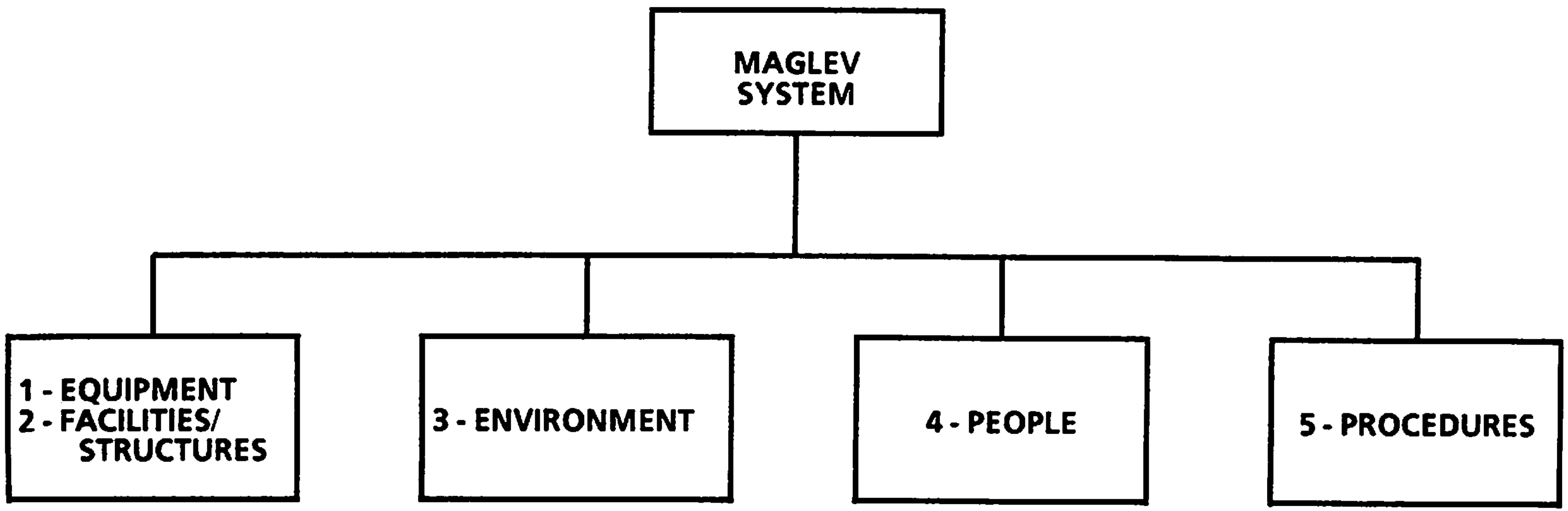


FIGURE 4-4. MAGLEV SYSTEM PHA ORGANIZATION

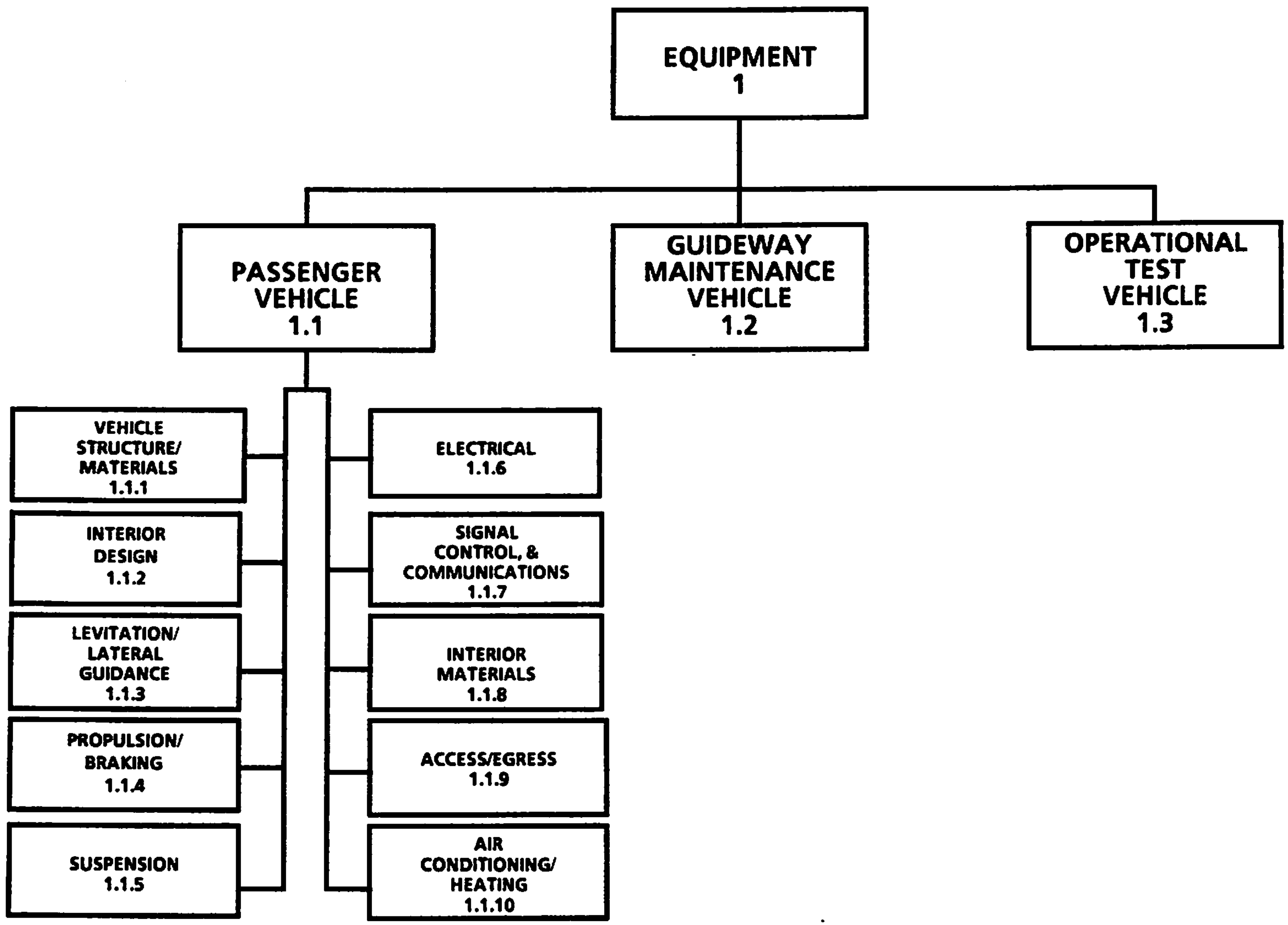


FIGURE 4-5. MAGLEV SYSTEM FUNCTIONAL AREA - EQUIPMENT

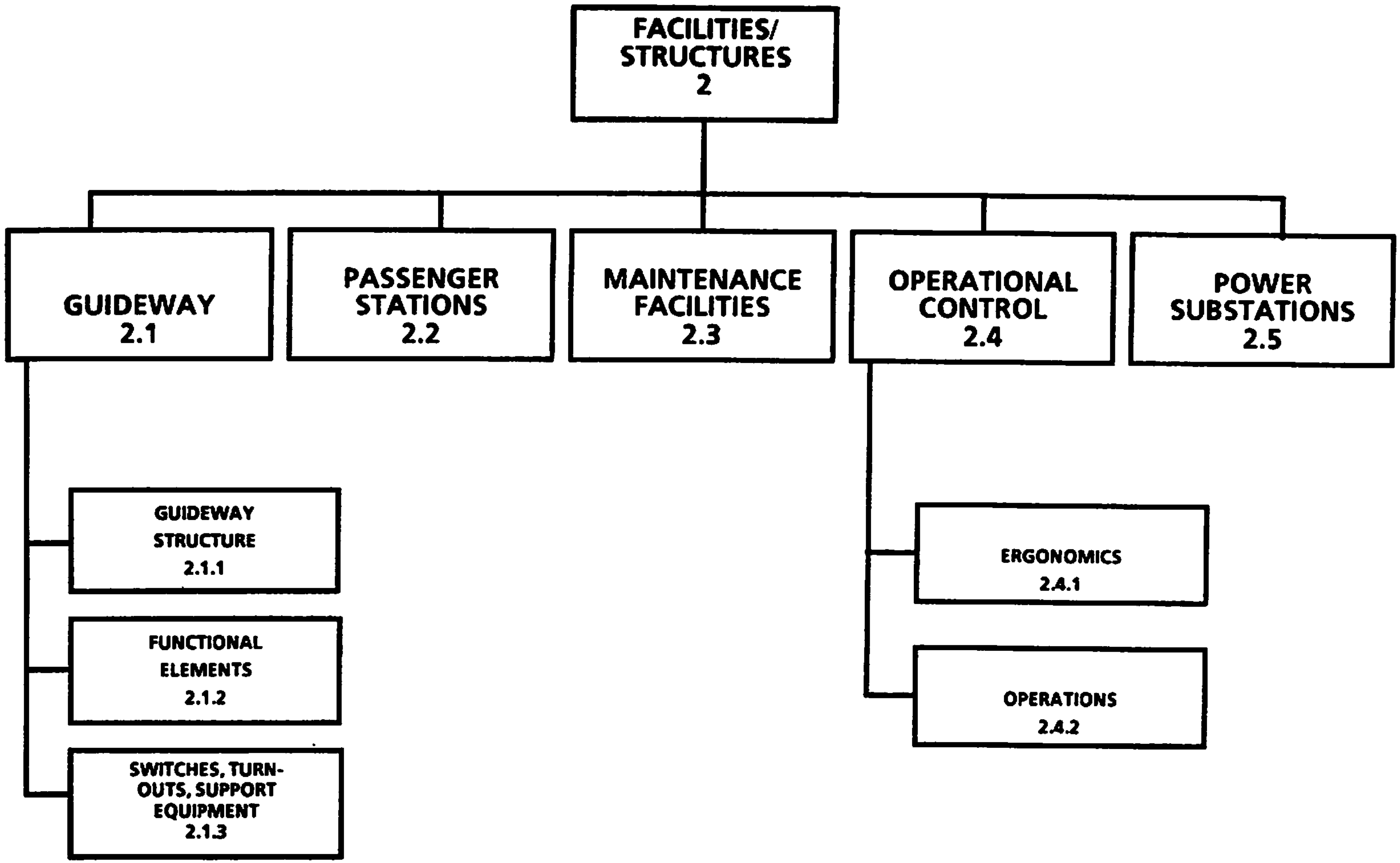
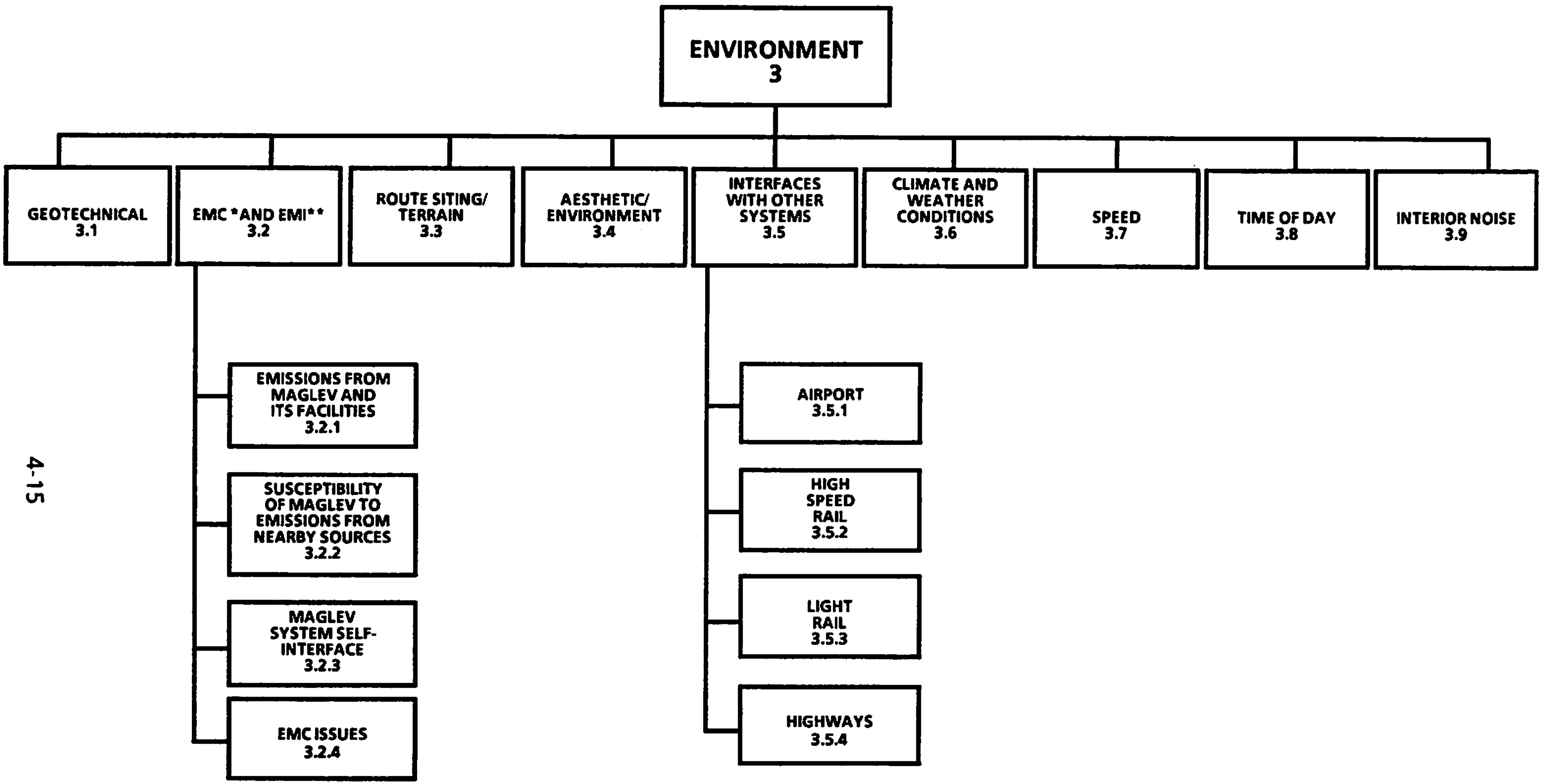


FIGURE 4-6. MAGLEV SYSTEM FUNCTIONAL AREA - FACILITIES/STRUCTURES



Electromagnetic Compatibility
Electromagnetic Interference

FIGURE 4-7. MAGLEV SYSTEM FUNCTIONAL AREA - ENVIRONMENT

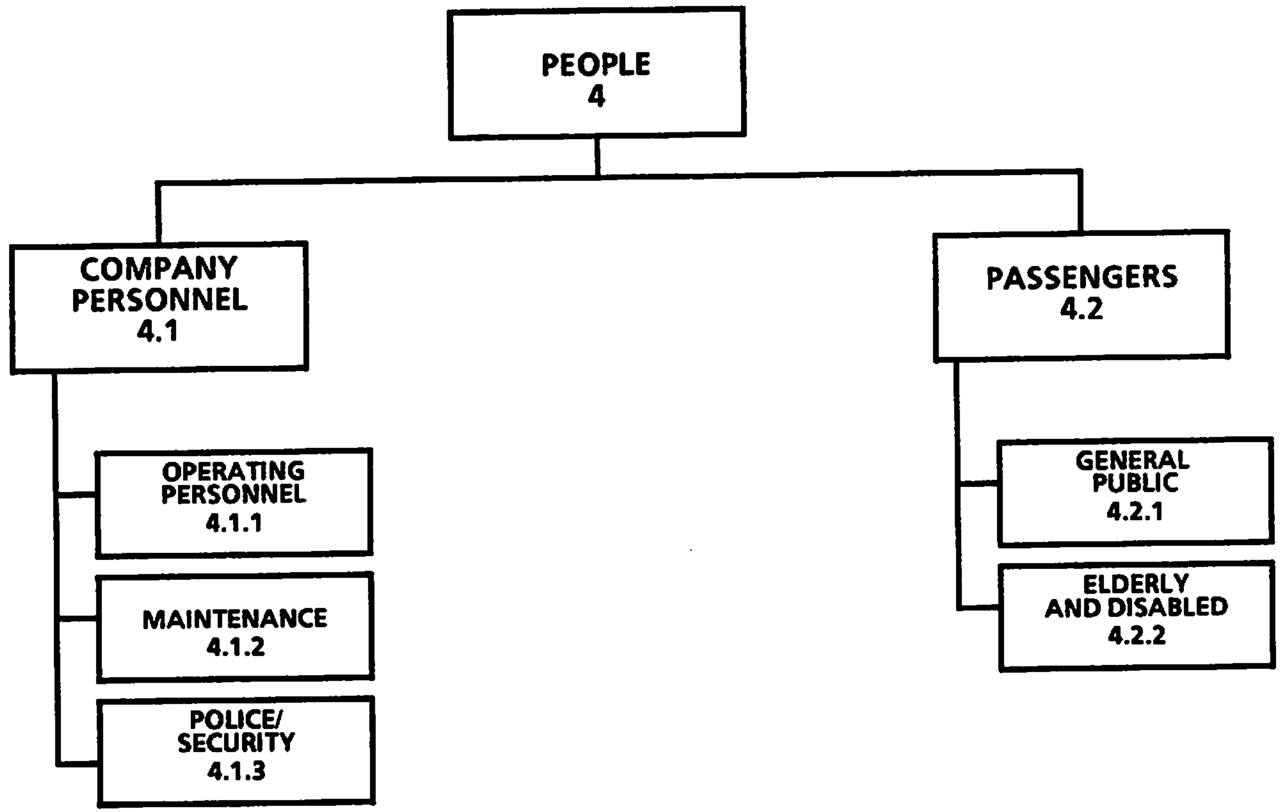


FIGURE 4-8. MAGLEV SYSTEM FUNCTIONAL AREA - PEOPLE

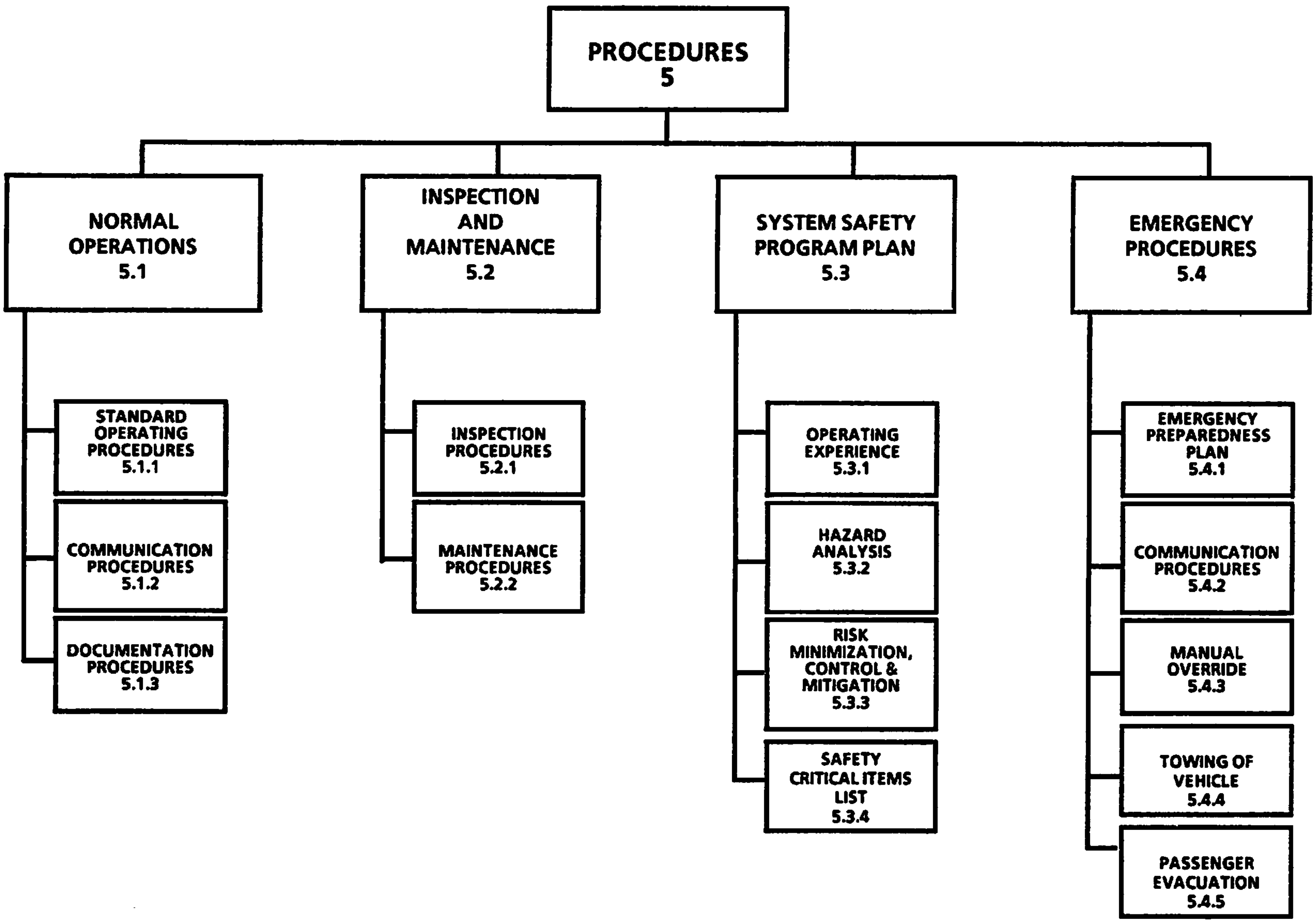


FIGURE 4-9. MAGLEV SYSTEM FUNCTIONAL AREA - PROCEDURES

Hazards will be identified for each of the subsystems within the main functional areas by reviewing the available literature, representative accident scenarios, the generic checklist contained in Appendix B, and discussions with technical experts, designers, operators, other project staff, and consultants. Each hazard identified in a subsystem will receive an identifier built upon the subsystem identifier discussed above. Following the same pattern, the second hazard identified for the suspension subsystem (identified as "1.1.5") will receive the identifier "1.1.5.2." Since it is possible for a single hazard to have various causes, the identifier is then further specified to represent causes as well. The first potential cause of a hazard will receive the identifier "A" and the second one "B", etc. Letters rather than numbers are used here to insure that the focus always remains on the hazard as the logical grouping. This is the basis for the final unique identifier, or control number, which consists of the hazard ("1.1.5.2" - from above) and one specific cause ("A" - for the first cause) in the form "1.1.5.2-A."

Control numbers can be seen in the first column of the PHA worksheet sample in Figure 4-10. They are the organizing principle upon which the PHA is being based. The hazard description and causal factors are listed in the next two columns. (Note that the element, system and subsystem are listed in the upper left hand corner of the worksheet. Once again this allows the focus to remain on the hazards while they remain grouped meaningfully under the subsystems.) The fourth column lists the hazard effects, which are the same as the "undesired events" listed in Table 4-1. The fifth column contains the Risk Assessment Category (RAC) value assigned to each hazard (see Section 2.1.3 Hazard Assessment). The RAC represents the hazard risk in terms of both its severity, and its probability. For example, "IID" indicates the hazard severity is "II" (critical) and its probability is "D" (remote) (see Figures 2-3 through 2-5). Selection of the RAC often involves subjective judgment, open to other opinions, since adequate data to determine the probability are usually unavailable. The recommendations presented in column six describe methods which may be employed to eliminate the cause or, alternatively, minimize and/or control the adverse effects of each hazard. Some recommendations are based on existing standards, regulations, and guidelines, others on common sense and experience of the evaluators. The effect of these recommendations, in terms of changing the RAC, is presented in column seven. (Note: This second RAC often reflects a reduction in hazard probability, but not in its severity.) The eighth column lists the applicable

ELEMENT: EQUIPMENT
SYSTEM: PASSENGER VEHICLE
SUBSYSTEM: VEHICLE STRUCTURE / MATERIALS

PRELIMINARY HAZARD ANALYSIS
PROJECT: MAGNETIC LEVITATION TRAIN
DATE: 06/13/90

CONTROL NUMBER	HAZARD DESCRIPTION	CAUSAL FACTOR	HAZARD EFFECTS	RAC	RECOMMENDATIONS	RAC2	REFERENCES AND NOTES
1.1.1.1-A	VEHICLE NOT CRASHWORTHY	INADEQUATE DESIGN	INJURY / CASUALTY	IID	FOLLOW TUV FOLIO 6 STRUCTURAL REQUIREMENTS	IIE	MODIFY FRA REQUIREMENTS FOR MAGLEV
1.1.1.1-B	VEHICLE NOT CRASHWORTHY	MANUFACTURING FLAW	INJURY / CASUALTY	IID	FOLLOW TUV FOLIO 7 MANUFACTURING REQUIREMENTS	IIE	ADAPT 49 CFR 229 TO MAGLEV VEHICLE
1.1.1.1-C	VEHICLE NOT CRASHWORTHY	DESIGN LIMITS EXCEEDED	INJURY / CASUALTY	IID	INSTALL LOAD SENSORS TO PROVIDE WARNING	IID	STANDARDS NEED TO BE DEVELOPED
1.1.1.1-D	VEHICLE NOT CRASHWORTHY	POOR MAINTENANCE	INJURY / CASUALTY	IIC	FOLLOW 49 CFR 299	IID	MODIFY FRA REQUIREMENTS FOR MAGLEV SYSTEMS
1.1.1.1-E	VEHICLE NOT CRASHWORTHY	CORROSION / FATIGUE	INJURY / CASUALTY				
1.1.1.2-A	UNDERBODY OF VEHICLE / SUSPENSION UNABLE TO RETAIN VEHICLE ON GUIDEWAY IF TOUCHDOWN OCCURS	INADEQUATE DESIGN	INJURY / CASUALTY				
1.1.1.2-B	UNDERBODY OF VEHICLE / SUSPENSION UNABLE TO RETAIN VEHICLE ON GUIDEWAY IF TOUCHDOWN OCCURS	MANUFACTURING FLAW	INJURY / CASUALTY				
1.1.1.3-A	FAILURE OF TOWING POINT ATTACHMENT	IMPROPER DESIGN OR MATERIALS SELECTION	INABILITY TO RESCUE VEHICLE				
1.1.1.3-B	FAILURE OF TOWING POINT ATTACHMENT	IMPROPER FABRICATION OR INSTALLATION	INABILITY TO RESCUE VEHICLE				

SAMPLE FORM

FIGURE 4-10. PHA WORKSHEET SAMPLE

sections of regulations, standards, and guidelines, which were used as reference sources for the recommendations. These references can include applicable sections of the Federal Railroad Administration Code of Federal Regulations (CFR), draft German safety standards for Maglev, and published regulations and guidelines from other Modal Administrations UMTA, FAA etc. or trade associations.

The PHA effort is focusing primarily on the identification and resolution of hazards which could result in the undesired events presented in Table 4-1. The Preliminary Hazard Analysis and the results of the hazard resolution effort will be presented in the next report on the assessment of the draft German maglev safety standards.

5. RISK ASSESSMENT

The results of the hazard identification process have been described in Section 4. This process resulted in the identification of nine undesired events that may result in a maglev passenger or crew casualty. For the assessment conducted in this section, the undesired event which causes a vehicle collision has been expanded to include vehicle-to-vehicle collision and vehicle-to-object collision.

Associated with each of these undesired events are the hazards and contributing factors that precipated them. Each of the undesired events could, if the appropriate countermeasure is not taken, result in a passenger/crew casualty. Furthermore, each undesired event may be brought about or be a result of one or more hazards and causal effects that are present in one or more of the maglev systems or subsystems. Adequately addressing the safety of a maglev system requires that each safety relevant system and subsystem be examined and that the appropriate action be taken to mitigate the occurrence of any undesired event.

The following sections address the assessment of the undesired events. The results of this assessment provide insight into the safety needs of individual maglev systems and subsystems.

5.1 UNDESIRED EVENT SEVERITY AND PROBABILITY CATEGORIES

As a means of establishing an understanding of the risk associated with maglev operations and the countermeasures that may be employed to address those risks, the undesired events have been assessed for severity and probability of occurrence. This effort is subjective, but can provide an indication of which undesired events pose the largest threat to passenger casualties and maglev system loss. As operating experience is accumulated, the assigned hazard assessment values can be adjusted to more realistically reflect the severity and probability of the hazards identified. Understanding the subjective nature of the risk will assist in determining which of the available countermeasures may be employed to address those threats.

To assist in establishing event severity and probability of occurrence categories, the hazard categories presented in MIL STD 882B have been modified to address the specific undesired events associated with maglev systems. Figures 5-1 and 5-2 present these modified severity and probability categories.

5.1.1 Severity of Undesired Event

The severity or magnitude of the consequences of an undesired event will depend on two factors: first, when the event occurs in the operating cycle; second, whether the event is time-dependent and whether it can be controlled is very important and will affect the event severity. For the purpose of the assessment presented here, the operating cycle has been defined as having the following phases:

- At station.
- Vehicle leaving/arriving at station.
- At inaccessible point along guideway.
- At safe, accessible evacuation point on guideway.

Estimates of the severity associated with these undesired events which could involve the maglev system operation and its passengers/crew are contained in Table 5-1. It is recognized that the severity of the individual event may vary considerably. However, for the purpose of this study, the most severe consequence has been postulated. In passenger transfer at the station, the severity or effect of a certain event on a passenger or crew member may be less than when it occurs on an inaccessible portion of the guideway. For example, the passenger/crew may easily evacuate the emergency situation during passenger transfer to and from a station. In contrast, a stalled/stopped maglev vehicle on an inaccessible portion of the guideway may not provide sufficient time or the ability to escape.

When passengers/crew are not able to evacuate under certain emergency conditions, the undesired event will likely result in more severe consequences. In this situation, the severity of the undesired event is deemed to be Category I, Catastrophic. Although the severity or consequences of an event could be large, the probability of the undesired event occurring could be quite small. This is because both the emergency condition must occur and the passengers/crew must be unable

CATEGORY	SEVERITY	CHARACTERISTICS
I	CATASTROPHIC	Death to passenger or employee, loss of maglev system.
II	CRITICAL	Severe injury to passenger or employee; hazard or single point failure may lead to catastrophe if action is not taken to control situation or rescue individual. Critical systems are involved and maglev vehicle is unable to move to evacuation area. Time of response is important in preventing death or system loss.
III	MARGINAL	Minor injury not requiring hospitalization or the hazard present does not by itself threaten the safety of the maglev system or passengers. No critical systems are disabled, but could be if additional failure(s)/malfunction(s)/hazard(s) occur.
IV	NEGLIGIBLE	Less than minor injury. Does not impair any of the critical systems.

FIGURE 5-1. UNDESIRED EVENT SEVERITY CATEGORIES

CATEGORY	LEVEL	SPECIFIC EVENT
A	FREQUENT	Not an unusual event, could occur several times in annual operations.
B	PROBABLE	Event could occur several times in the lifetime of the maglev system.
C	OCCASIONAL	Expected to occur at least once in the lifetime of the maglev system.
D	REMOTE	Event is unlikely to occur during the lifetime of the maglev system.
E	IMPROBABLE	Event is so unlikely that it is not expected to occur in the lifetime of the maglev system.

FIGURE 5-2. UNDESIRED EVENT PROBABILITY CATEGORIES

TABLE 5-1. UNDESIRED EVENT SEVERITY ESTIMATES

EVENT DESCRIPTION	OPERATIONAL PHASES INVOLVING PASSENGERS			
	Passenger Station Transfer	Leaving/Arriving Station	Accessible Areas of Guideways	Inaccessible Areas of Guideway
Fire/Explosion in Vehicle	II	I	I	I
Fire in Other Critical Element	III	III	II	I
Vehicle Collision with Object	II	II	I	I
Vehicle to Vehicle Collision	II	II	I	I
Vehicle Leaves Guideway	II	II	I	I
Sudden Stop	N/A	III	II	I
Does Not Slow/Stop at Station	N/A	II	N/A	N/A
Stranded on Guideway	N/A	II	II	I
Inability to Rescue Occupants	III	II	II	I
Passenger Illness/Injury	III	II	II	I

LEGEND:
- I Catastrophic
- II Critical
- III Marginal
- IV Negligible
- N/A Not applicable

to evacuate or avoid that emergency condition in time to prevent the occurrence of a casualty.

5.1.2 Probability of Occurrence of Undesired Event

To establish, in absolute terms, the probability that an event will occur requires a calculation based on previous experience. This calculation should take into consideration that the event may have occurred or been reported to occur a certain number of times. For passenger-carrying maglev systems, no publicly available database exists from which to calculate the probability of occurrence of an undesired event. Operating experience and data for other mass transit systems exist; however, the availability and level of detail are limited. To provide an indication of the relative probability of occurrence of the undesired events, the Hazard Probability Matrix of MIL STD 882B has been modified as shown in Figure 5-2. The term "several" is intended to connote that an event may occur 10 times in a designated period (i.e. ten times a year for frequent and ten times in a lifetime for probable etc.). Table 5-2 presents an estimate of the probability of occurrence of the undesired events. These estimates are subjective based on the analyses shown in the fault trees in Appendix C. It should be noted that both the hazard and the inability or failure to control the hazard must be present for an undesired event to occur. Thus, for a fire/smoke casualty to occur, a fire/smoke incident must occur and the fire not be contained or controlled.

5.2 RISK ASSESSMENT ESTIMATES

The risk associated with an undesired event is the product of the severity of the event and the probability of occurrence of that event.

For the purpose of this assessment, the worst estimated severity value has been assigned to each evaluated undesired event. As shown in Table 5-1, the severities assigned to the identified undesired events at this time were primarily the critical or catastrophic level. The estimated levels assigned in Table 5-2 indicate that the probability of occurrence of such events would not be common.

The Risk Assessment Matrix shown in Figure 5-3 can assist in the decision-making process to determine whether individual system or subsystem hazards should be

TABLE 5-2. UNDESIRED EVENT PROBABILITY ESTIMATES

EVENT DESCRIPTION	OPERATIONAL PHASES INVOLVING PASSENGERS			
	Passenger Station Transfer	Leaving/Arriving Station	Accessible Areas of Guideway	Inaccessible Areas of Guideway
Fire/Explosion in Vehicle	D	D	D	D
Fire in Other Critical Element	C	C	C	C
Vehicle Collision with Object	C	C	C	C
Vehicle to Vehicle Collision	D	D	D	D
Vehicle Leaves Guideway	E	E	E	E
Sudden Stop	N/A	D	D	D
Does Not Slow/Stop at Station	N/A	D	N/A	N/A
Stranded on Guideway	N/A	D	C	C
Inability to Rescue Occupants	D	D	D	C
Passenger Illness/Injury	C	C	C	C

LEGEND:
- A Frequent
- B Probable
- C Occasional
- D Remote
- E Improbable
- N/A Not applicable

eliminated or controlled to reduce the occurrence of the undesired event or otherwise accepted. Although the probability of the undesired events in most cases is estimated to be low, the potential severity of some of the identified undesired events requires that some type of action may be suggested to minimize the risk.

Employing the Assessment Matrix in Figure 5-3 to evaluate these undesired events suggests that action should be taken to minimize the potential risk associated with the IC (catastrophic/occasional), ID (catastrophic/remote), IIC (critical/occasional), IID (critical/remote), IIE (critical/improbable) and IIIB (marginal/probable) risk values identified in Table 5-3. Section 6 identifies and presents 10 broad areas of countermeasures that may be employed to reduce the potential risk of the undesired events.

FREQUENCY OF OCCURRENCE	UNDESIRED EVENT CATEGORIES			
	I CATASTROPHIC	II CRITICAL	III MARGINAL	IV NEGLIGIBLE
(A) FREQUENT	I A	II A	III A	IVA
(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

HAZARD RISK INDEX

I A, I B, I C, I 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

SOURCE: MIL STD 882B

FIGURE 5-3. UNDESIRED EVENT ASSESSMENT MATRIX

TABLE 5-3. RISK ASSESSMENT ESTIMATES

EVENT DESCRIPTION	OPERATIONAL PHASES INVOLVING PASSENGERS			
	Passenger StationTransfer	Leaving/Arriving Station	Accessible Areas of Guideway	Inaccessible Areas of Guideway
Fire/Explosion in Vehicle	IID	ID	ID	ID
Fire in Other Critical Element	IIIC	IIIC	IIC	IC
Vehicle Collision with Object	IIC	IIC	IC	IC
Vehicle to Vehicle Collision	IID	IID	ID	ID
Vehicle Leaves Guideway	IIE	IIE	IE	IE
Sudden Stop	N/A	IIIC	IIC	IC
Does Not Slow/Stop at Station	N/A	IID	N/A	N/A
Stranded on Guideway	N/A	IID	IIC	IC
Inability to Rescue Occupants	IIID	IID	IID	ID
Passenger Illness/Injury	IIIC	IIC	IIC	IC

LEGEND:

I Catastrophic
II Critical
III Marginal
IV Negligible

A Frequent
B Probable
C Occasional
D Remote
E Improbable
N/A Not applicable

6. RESOLUTION OF MAGLEV SAFETY ISSUES

The hazard scenarios presented in Appendix B provide an insight into what emergency situations may occur during the operation of a maglev system. An assessment of each of the undesired events identified in the scenarios and the fault trees was presented in Section 5. With few exceptions, for each undesired event, the severity was estimated to be "Critical" or "Catastrophic." However, the probability of occurrence is less than "Probable," and, in most instances, is "Remote" or "Improbable." In terms of the acceptance criteria suggested in MIL STD 882B and the Risk Assessment Matrix presented in Figure 5-3, certain actions should be taken to minimize both the consequences or severity of the undesired event and the probability of its occurrence.

Actions to be taken to minimize the potential risk are termed "countermeasures." For the purpose of this study, a countermeasure may be defined as any action or series of actions that may be taken to reduce the risk of a casualty associated with the operation of a maglev system. This section presents a discussion of the types of countermeasures that may be applied to minimize the risk. The risk reduction may be accomplished by the application of these countermeasures to either eliminate or control the identified hazard, thereby eliminating the occurrence of the event or minimizing its effect. Elimination or prevention of the event is preferable, but not always possible. Recognizing this, the hazard reduction precedence presented in Section 2.1.4 (Figure 2-6) has been employed. This precedence requires that the hazard first be eliminated or controlled through system design. If that is not possible, safety devices, warning devices, and/or special procedures and training should be provided. Finally, if none of those countermeasures provide the necessary level of safety, the decision must be made to accept the hazard or dispose of the system. Countermeasures that may be implemented to address identified safety issues or hazards may involve the system design, training, operations, maintenance, testing and inspection, configuration management, emergency preparedness, and recertification/reinspection.

The risk reduction countermeasures described in this report are primarily design oriented and emphasize the prevention of the occurrence of the event (primary countermeasures). Secondary countermeasures that address issues associated with system training, operation, maintenance, testing and inspection, configuration management, emergency preparedness, and recertification/reinspection are also briefly discussed and will be addressed in more detail in a subsequent report. The following sections present a summary of primary and secondary countermeasures that may be implemented.

6.1 DESIGN COUNTERMEASURES

During the conduct of this preliminary safety review, it was found that in many instances countermeasures to address safety issues or hazards may be implemented by following existing regulations, standards, or guidelines. Appendix D provides a summary of existing safety regulations, guidelines, and requirements adopted by U.S. government and industry organizations (i.e. FRA, AAR, etc.) and foreign government and industry organizations (i.e. EBO, MBO, UIC, etc.) that may be potentially applicable to maglev systems. These existing codes and standards were developed for application to railroads (In the U.S.: Title 49 of the Code of Federal Regulations) as well as other transportation systems in the U.S. and Europe. The current FRA regulations, standards, and guidelines address many of the subsystems and equipment hazards from the design standpoint.

Redundant or backup systems may be recommended for critical systems and subsystems. Although backup systems are expensive and often complex, such systems are likely to offer the best way to reduce the probability of certain undesired events. However, in some instances other methods of controlling hazards may be more appropriate. The decision regarding which systems require backup has to be based on the information available at the time the analysis was completed.

Fire safety of materials for the interior spaces of the maglev vehicle was identified as a major concern. The FRA and UMTA have developed guidelines for passenger vehicle interior materials for intercity railcars and transit cars. The criteria in these guidelines could also be applied to the maglev vehicle to improve fire safety.

The following maglev safety issues should be explored further by the FRA and the developers:

- Evacuation capability from, and access to, the maglev vehicle.

- Passage of a fire from outside the occupant compartment into the occupant compartment.
- Provision of alarms to indicate loss of power, air or fluid leakage, or fire/smoke.
- Provision for reaching a safe evacuation area.
- Vehicle crashworthiness and minimizing the potential for collisions on the guideway with objects and other vehicles (See p. 7-1, 4).
- Automatic activation of emergency lighting upon electrical power loss.
- Protection against battery explosion.
- Redundant ability for communications and vehicle location.
- Validation of fail-safe or vital software.

Other aspects of maglev safety associated with training, operations, maintenance, and documentation do not appear to be adequately covered by existing codes, standards, or regulations. Safety issues in these areas are often characterized by a high incidence of human interaction. The following sections describe general countermeasures that may be employed to address the identified safety issues.

6.2 TRAINING COUNTERMEASURES

Training programs should be developed for all safety-related phases of the maglev system operation. Guidelines, which include minimum qualifications for applicants in critical positions, should be established. A training path leading to certification should be clearly defined, as well as measurable goals and objectives for each aspect of the training. The training guidelines prepared for other rail systems could be adapted for maglev system personnel.

The training program should clearly represent a systems approach to training and should include, but not be limited to, the following:

- A training assessment phase to determine training needs (knowledge, skills and abilities) and training objectives.

- A training development phase to select training methods and to develop the training courses.
- A training phase during which training is conducted.
- An evaluation and feedback phase which should continue throughout the maglev system life-cycle. This feedback can assist in determining if the training is appropriate for the tasks being performed, and to assure that any operational or equipment changes are reflected in the curricula.

6.3 OPERATIONAL COUNTERMEASURES

The FRA currently has regulations regarding operating rules and practices for railroads. Railroads must file copies of their operating rules, timetables, programs of tests and inspections, record keeping, and drug and alcohol violations with the FRA. Most of these regulations, if not all, are applicable to the maglev system but must be reviewed for application when the maglev system's operational requirements are further defined. Areas that may require FRA guidelines include:

- Developing and implementing a system safety program.
- Emergency preparedness and response.
- Operating in adverse weather conditions.
- Passenger awareness of emergency operations.

6.4 MAINTENANCE COUNTERMEASURES

Maintenance countermeasures include the development of maintenance procedures and management documentation for all safety-related systems and subsystems. This includes routine maintenance procedures and preventive maintenance procedures and plans. These are assumed to have been developed during the design and development phase by the developer and prior to application will be reviewed by the appropriate operating authority and FRA. Moreover, audits or periodic inspections should be conducted to assure that approved procedures are being implemented and that preventive maintenance is being performed.

The FRA presently has regulations regarding inspection and maintenance of railroad locomotives. The maglev system vehicles and guideway are quite different and may require that existing regulations be modified significantly.

6.5 TESTING AND INSPECTION COUNTERMEASURES

A testing and acceptance program should be implemented to determine if all maglev safety-related systems meet operational requirements. All test procedures and results of the tests should be documented and provided to the appropriate safety assurance authorities. These tests should include the following:

- Subsystem Tests (e.g. electrical systems).
- System Test .
- Operational Tests.
- Operating Authority Acceptance Tests.
- Periodic Emergency System Tests by Operating Authority.

6.6 CONFIGURATION MANAGEMENT COUNTERMEASURES

A configuration management program should be implemented to ensure that design, development, and operational changes to safety-related systems and subsystems for the maglev system are subjected to strict configuration control and reevaluation testing. These documents should, as a minimum, include training materials, test documentation, system maintenance documents, operating procedures, and emergency procedures.

6.7 EMERGENCY PREPAREDNESS COUNTERMEASURES

An emergency preparedness plan should be developed to address all aspects of emergency planning and emergency response. This document should, as a minimum, include emergency operating procedures, procedures for rescue, operating emergency equipment, and operating in inclement weather; and procedures for coordination with other local emergency response organizations.

6.8 RECERTIFICATION OR REINSPECTION COUNTERMEASURES

As previously indicated, all maglev safety-related systems and subsystems should be periodically inspected by the appropriate authority. Criteria should be developed for determining when (other than normal periodic inspections) a maglev system should be inspected. Incidents which could require immediate inspection include, but are not limited to, the following:

- Stop from a high speed at higher than normal braking rate.
- A major change in operating parameters.
- Major system replacements.
- System modifications (engineering changes).
- Unscheduled repairs.
- Accident repair to the guideway or vehicle.
- Severe environmental events (storms, earthquake, etc.).
- Vehicle has been overhauled.
- Transfer of ownership.

6.9 DEGRADED OPERATION COUNTERMEASURES

As with intercity rail, transit, aircraft, ships, or other transportation systems, maglev systems can operate in a degraded mode. Minor malfunctions such as burned-out light bulbs and faulty indicators may not jeopardize the safety of the passengers or crew. However, criteria should be developed to clearly indicate which failures or combinations of failures constitute a minor inconvenience, and which should result in the suspension of system operations, particularly where component redundancy and/or failure tolerant subsystems are involved.

7. SUMMARY AND FINDINGS

After completing a preliminary review of the safety aspects of the Transrapid maglev system, the following summary and findings are provided for consideration.

7.1 SUMMARY

1. Although the maglev transport system consists of the same basic system elements (i.e., facilities and equipment, people, procedures and environment) as any ground guided or rail transport system, there are several characteristics that are unique to it. Examples of the unique maglev characteristics are the elevated guideway with wraparound vehicle design, the safe hovering concept, the programmed automatic train operations during emergencies, and the operating procedures for the removal of disabled trains or vehicles from the guideway. Therefore, the direct application of most railroad regulations will be difficult, although some regulations can be found to be appropriate for maglev as well as railroads.

2. Extensive maglev operational data exists for the TR06 and TR07 vehicles at TVE. However, complete determination of the scope and magnitude of maglev safety incidents or accidents likely to be found in revenue service operations requires, at a minimum, detailed analysis of this data. Analysis of certain safety issues may only be possible with additional data.

3. The forthcoming TÜV Rheinland system operational readiness verification testing, endurance running on the TVE Test Track and the one-year test program of the Florida Maglev Demonstration Project are necessary and must be considered as required in order to produce the necessary information concerning the maglev safety issues raised or that may be raised as the study progresses and which must be resolved prior to revenue service.

4. The resolution of some initial safety issues identified that need to be confirmed prior to consideration of revenue service are fire safety, vehicle crashworthiness, on-board battery supply reliability, suspension system failure at high speeds, safe hovering reliability, emergency preparedness

(emergency evacuation with wraparound vehicle design, programmed, controlled operations during emergencies, enhanced emergency braking/stopping, vehicle evacuation, lightning protection, earthquake impact, etc.), air quality of the passenger cabin during emergency conditions, and fail-safe mechanical guideway switching.

5. The FRA employs elements of Title 49 of the Code of Federal Regulations (CFR) to regulate existing passenger rail systems. Several of these regulations can be applied directly to a maglev system and others can be applied in concept. However, many of the requirements contained in these regulations are not applicable to a maglev system. The FRA will need to modify these regulations and develop new regulations to address the maglev-specific safety issues. A number of TÜV Rheinland and other transportation industry safety standards and guidelines exist that may be applied to the proposed U.S. maglev transportation systems.

6. This preliminary safety analysis has identified ten undesired events, discussed in Section 4, that may result in a casualty or loss of the maglev system. Although the probability of occurrence of each event is low, the projected severity of some requires that action be taken to mitigate their consequences (see Table 5-3). Action may have already been taken by those responsible for Transrapid safety in Germany.

7. This report has been directed at the early identification of safety issues during the development process such that they may be addressed prior to the final design of the system to be deployed for U.S. operations. Some of these safety issues may have already been resolved or may find resolution through the application of the countermeasures discussed in Section 6.

8. In order to more fully evaluate the ability of the Transrapid system to perform safely in the proposed U.S. applications, more detailed information or analysis is required on the following:

    a) The final design-gap frequency-response characteristics for guideway irregularities and external force loadings;

b) Failure detection and compensation algorithms and systems in the event of failure of a magnet hinge control component;

c) Controls to be applied to guideway geometry variations and operational procedures to detect and correct guideway irregularities prior to the occurrence of an unsafe condition;

d) Emergency preparedness plans;

e) Fail Safe and Safe Life philosophies and their applications; and

f) Crashworthiness.

9. The Transrapid philosophy for dealing with potential casualties is to use autonomous, redundant systems in safety critical areas, e. g., control, safe hover, guidance, and braking systems. The system is failure tolerant rather than fail safe, and the probabilities of casualties are remote. The FRA can alleviate these issues by promulgating regulations dealing with some of the safety issues arising from failure tolerant designs. The following are some safety concerns relating to failure tolerance that have been identified at this stage of the safety assessment study:

a) Abuse of Failure Tolerant Design - In a failure-tolerant design dependent on two or more autonomous, redundant systems, it is possible to continue operations even though some part of the redundant systems has failed. There is the danger that the system operator will disregard such failures and continue operations with a system that is no longer failure-tolerant.

Operating procedures can mitigate this concern by forbidding operations beyond the point where failure tolerance is jeopardized; and requiring that such failures be tracked in a nondestructable storage medium (e. g., a black box recorder).

b) Emergency Evacuation - A concern exists in that passengers cannot exit the TR07 vehicle safely in the event of any emergency unless the vehicle is at a preestablished exit location. Analysis of the low probability of the vehicle being stranded must be confirmed. However, this issue could also be alleviated through alternative evacuation techniques. For example, the TR-06 model is provided with evacuation chutes, similar to those on commercial aircraft, for vehicle evacuation. Where the guideway is too high for practical evacuation by chute, there is a walkway installed on the guideway for passenger access to evacuation ladders.

Incorporating this evacuation method into the TR07 maglev system may be one approach to providing emergency egress equivalent to those available on existing aircraft and ground systems; however, unpredictable guideway heights at the time of need limits the use of the evacuation method used in TR-06.

c) Emergency Brake - The Transrapid vehicle does not have a classical emergency brake system which will bring the vehicle to an immediate stop in all situations. Continued operation of certain vital automated systems until a stop is achieved is required by this system.

11. The ability of the relatively light guideway to withstand the applied forces over time needs further analysis. For example, are single, double or triple spans required to provide acceptable dynamic interaction between vehicles and guideway? Definition of the applied forces should be reviewed to ensure an adequate design. Conditions, such as, very high winds, erosion, oxidation, extreme thermal conditions, etc., that may affect the guideway structure at potential U.S. sites must be taken into account.

    Tolerances required for electromagnetic levitation system operation require that the guideway be built to a higher degree of precision than normal construction tolerances require for transportation systems in this country. Even though span girders are manufactured to ensure precision, they will be set on foundations and columns built in the field to specifications more demanding than specifications and procedures used in most U.S. construction projects.

Finally, long-term structural performance of the guideway structure and its long stator (or propulsion) appurtenances should be reviewed. This includes not only how the structure will actually degrade with use in various site environments, but also concerns over how inspection and maintenance will be executed.

7.2 FINDINGS

To provide the traveling public with the highest practical level of transportation safety, all critical safety issues associated with maglev transportation must be identified and resolved. Sections 4 and 5 identify these issues and Section 6 suggests the types of countermeasures that may be employed to resolve them. The first priority is to select and implement those countermeasures that most effectively eliminate the hazard or safety issue. This initial hazard assessment of the Transrapid system provides research findings relative to new rules that should be considered for establishment and existing FRA rules and other transportation industry rules that should be modified or adopted. In the consideration of optional approaches to complete compliance with an existing FRA regulation, the "equivalent systems safety" concept may be explored and, where feasible, considered for adoption.

7.2.1 New Federal Railroad Administration Rule Making Initiatives

Suggested new rule making activities that the Federal Railroad Administration (FRA) should consider undertaking to minimize the potential for occurrence of an accident and the consequences of accidents that may happen are contained in the following initial findings:

1) Being adequately prepared to effectively respond to the occurrence of an accident requires emergency response planning. Without a plan, the effects of the emergency will not be minimized. For this reason, the FRA should require the development of an emergency plan which addresses

systemwide emergency response training and equipment, and facility emergency preparedness.

2) Emergency access and egress to and from the maglev system and the vehicle is a necessity as accidents/incidents will occur over the lifetime of the system. Provisions must be made to allow passengers and employees to exit the vehicle and allow emergency response personnel access to the vehicle at any location where a stopped vehicle emergency can occur. At present, with the exception of the requirement for four window exits, the FRA does not have any guidelines, regulations, or standards addressing this issue.

3) Emergency equipment is briefly addressed in the existing FRA regulations, relative to the need for rear end lights and the need for a handbrake. This regulation is applicable in intent, but additional rule making should be considered to address the need for emergency lighting, emergency communications, ventilation (excessive heat buildup of confined air from sun thermal load), etc.

4) Fire safety is a major concern as the ability of patrons and employees to egress from the vehicle is extremely limited. The existing FRA fire safety guidelines address only the flammability and smoke-emission characteristics of the vehicle interior compartment materials. The materials requirements are only one element of the fire safety concern. fire detection and suppression are two additional issues that need to be addressed. A vehicle fire may develop, propagate and, if not detected and suppressed, result in a major accident. For the proposed TR07 maglev system, with its very limited access and egress, the lack of fire detection and suppression system could result in a minor incident propagating into a major fire and thereby resulting in a catastrophic accident. Fire safety guidelines should also address the need for fire containment and fire walls/barriers.

5) Eliminating the possibility of or detecting the presence of people or objects on the guideway, no matter how remote, is of paramount importance if casualties or collisions on the guideway are to be avoided.

Consideration should be given to requiring an intrusion detection system or a physical barrier to ensure the security of the guideway, especially in areas where the guideway may be easily accessible. This approach will minimize the probability of an undetected individual or object being present on the guideway during vehicle operations. Operational and training procedures will also play a major role in reducing the likelihood of personnel being hit by a train.

6) Verification of the safety of the signal and control system is critical for a fully automated transportation system such as is envisioned in the Transrapid maglev. The FRA should require positive verification that the control system is indeed fail-safe. Regulations should be established to identify the procedure for verifying the safety of control systems, including the listing of all vital circuits and documentation certifying the verification of critical software components. Possible failure modes of the control system should be integrated with the emergency preparedness plans to minimize the potential for injuries and casualties.

7) As required for existing rail operations, the FRA should consider developing requirements for guideway inspection techniques and criteria for determining the need for maintenance.

7.2.2 Modifications to Existing FRA Rules

In a number of instances, the safety issues identified in this maglev system analysis are similar to those issues that pertain to existing U.S. rail systems. Recognizing this, the safety regulations applied to the existing rail systems may then be modified for application to the maglev system. In this connection, the concept of "equivalent systems safety" should be a major consideration. The following recommendations address the safety issues identified thus far and the existing regulations, guidelines, and standards that may be modified to resolve them:

1) The design of the maglev vehicle and the crashworthiness of the vehicle structure should be addressed. The structural (semimonocoque) design of the maglev vehicle is similar to that of aircraft and, therefore, not designed to withstand the buff forces railcars are required to withstand.

An indepth evaluation of the requirements for crew/passenger safety in a crash environment is essential.

2) Existing FRA regulations specify braking requirements for rail cars. In the proposed maglev system design, the vehicle brake performance does not provide for immediate emergency braking capability in all situations (49 CFR 236.24). Modification conditionally allowing such a design, as is compatible with the automatic location detection and control system, should be considered.

3) The window glazing for the lead car windshield in the maglev vehicle must reflect the conditions in which the maglev vehicle operates. While existing FRA regulations are oriented towards impacts with relatively large objects, the higher speed at which the maglev vehicle operates (in excess of 250 mph) leaves its windshield more vulnerable to damage from impact with small objects, such as birds. High speed bird impacts may be a situation more analogous to an aircraft than a train. Federal Aviation Administration aircraft window glazing requirements (FAR 25.631) should be considered for use in modifying existing FRA regulations.

4) The present FRA signal and train control regulations will require modification as noted in item 6 of Section 7.2.1.

5) In addition to existing FRA regulations requiring the submittal of operating rules adding a requirement for the submittal of a manufacturing and construction quality assurance plan and an inspection and maintenance program plan should be considered. Such plans are essential to ensure that improper materials, fabrication, maintenance and operations do not degrade the safety design of the maglev system.

6) Other areas that may require modification are as follows:
   a) Electrical safety and electric power supply.
   b) Operating personnel qualifications and training.
   c) Operating rules and practices.
   d) Noise, interior and exterior.

7.2.3 Adoption/Modification of Other Rules

In addition to existing FRA and other Federal regulations that can be adopted, or modified and adopted, or created, other standards and rules do exist or are being developed that may, in some cases, be applicable to maglev safety.

1) The maglev-specific standards coordinated by TÜV Rheinland, are being reviewed in detail for potential adoption into the existing FRA regulations. The results of this review will be contained in the next of a series of reports on the Safety of High Speed Magnetic Levitation Transportation Systems, titled, Review of German Safety Requirements for the Transrapid System.

2) Passenger car doors are a major cause of injury in mass transit systems. The maglev system doors are completely different from the doors on intercity railcars. As such, the maglev vehicle should have pressure sensitive doors similar to those required in UIC 560.

3) EMC/EMI and lightning protection. Electromagnetic interference (EMI) associated with power conditioning equipments can have a disruptive effect on communication control and on-board data processing equipments. Existing foreign DIN Standards and VDE Regulations on EMI and appropriate methods for EMC measurement must be reviewed to establish their applicability to future maglev systems. The lack of U.S. standards limiting the impact of lightning on maglev safety and operation may require that new standards be developed in this area.

APPENDIX A. MAGLEV HAZARD SCENARIOS

FIRE/EXPLOSION IN VEHICLE

Scenario 1

EVENT: Electrical fire occurs.

CAUSE: Short circuit, faulty wiring, overloaded circuit, etc.

RESULT: Fire, possible loss of power.

Scenario 2

EVENT: Battery explosion occurs.

CAUSE: Buildup of Hydrogen gas and spark.

RESULT: Exploding/burning gas results in fire and burns materials and passengers.

Scenario 3

EVENT: Ignition of seats and/or floors occurs.

CAUSE: Passenger inadvertently ignites seats, floor, etc.

RESULT: Vehicle fire, heat buildup, and/or damage to equipment.

FIRE IN OTHER CRITICAL SYSTEM ELEMENTS

Scenario 1

EVENT: Fire occurs in central control room.

CAUSE: Short circuit, faulty wiring, sabotage/terrorism, etc.

RESULT: All vehicles would be stopped at unknown points with no communications.

Scenario 2

EVENT: Fire occurs at power plant.

CAUSE: Transformer failure, converter failure, sabotage/terrorism, etc.

RESULT: Loss of power to central control room, equipment damage.

VEHICLE COLLISION

Scenario 1

EVENT: Vehicle collides with debris on guideway.

CAUSE: Maintenance equipment, fallen tree, rocks on guideway, malicious damage, etc.

RESULT: Damage to vehicle, passenger injury from impact.

Scenario 2

EVENT: Vehicle collides with individual on guideway.

CAUSE: Unauthorized, undetected individual on guideway.

RESULT: Injury to individual on guideway, damage to vehicle, injury to vehicle passengers from impact.

Scenario 3

EVENT: Vehicle collides with other vehicle.

CAUSE: Vehicle not aware of the presence of other vehicle (due to loss of communication, human error, switch malfunction, etc.).

RESULT: Damage to one or both vehicles, passenger injury from impact.

Scenario 4

EVENT: Vehicle collides with other moving object.

CAUSE: Bird, falling tree, bullet, rock, etc. hits vehicle.

RESULT: If object penetrates shell, possible passenger injury.

VEHICLE LEAVES GUIDEWAY

Scenario 1

EVENT: Vehicle leaves guideway at open switch.

CAUSE: Undetected flexible switch malfunction (due to loss of power, hydraulics system failure, faulty switching signal, etc.).

RESULT: Damage to vehicle, passenger injury from impact.

Scenario 2

EVENT: Vehicle is operated at excessive speed and leaves guideway.

CAUSE: Guideway irregularities too large for speed.

RESULT: Damage to vehicle, passenger injury from impact.

Scenario 3

EVENT: Vehicle leaves guideway at point of span/beam failure.

CAUSE: Span/beam failure ignored or not detected.

RESULT: Damage to vehicle, passenger injury from impact.

SUDDEN STOP

Scenario 1

EVENT: Untimely vehicle braking occurs.

CAUSE: Signaling/communications system failure, loss of vehicle power.

RESULT: Passenger injury, possibly strikes interior of vehicle.

Scenario 2

EVENT: Loss of safe hover occurs.

CAUSE: Magnet gap control loop malfunction, guideway irregularities too large for speed.

RESULT: Vehicle drops on skids, damage to vehicle, passenger injury from impact.

Scenario 3

EVENT: Unsymmetrical touchdown occurs.

CAUSE: Ignored or inadequate warning of crosswinds above safety limits.

RESULT: Vehicle drops on skids, damage to vehicle, passenger injury from impact.

VEHICLE DOES NOT SLOW/STOP AT STATION

Scenario 1

EVENT: Vehicle unable to slow/stop at station.

CAUSE: Loss of control, operator error, excessive speed, braking subsystem failure, etc.

RESULT: Possible damage to vehicle and station platform, as well as to patrons standing on the platform.

Scenario 2

EVENT: Braking not sufficient for accumulation of ice on guideway.

CAUSE: Severe weather conditions.

RESULT: Loss of stopping capabilities, possible damage to vehicle and station platform, as well as to patrons standing on the platform.

VEHICLE STRANDED BETWEEN STATIONS OR SAFE EVACUATION POINTS

Scenario 1

EVENT: Accidental shutdown of main power occurs before on board batteries are charged.

CAUSE: Operator error, defective battery indicator sensor.

RESULT: Vehicle stranded, mass passenger anxiety.

Scenario 2

EVENT: Vehicle stops before accumulated magnetic levitation electrostatic charge has been grounded.

CAUSE: Emergency stop in unplanned stopping area.

RESULT: Possible passenger exposure to Electrostatic Discharge (ESD) hazards.

INABILITY TO RESCUE MAGLEV PASSENGERS IN CASE OF BREAKDOWN, OR ACCIDENT

Scenario 1

EVENT: Vehicle inaccessible to rescue equipment.

CAUSE: Vehicle stranded over water, swamp, busy interstate highway, etc.

RESULT: Mass passenger anxiety.

Scenario 2

EVENT: Vehicle rescue attempt is not made promptly.

CAUSE: Assistance is not available, rescue personnel are unavailable, rescue equipment is not available.

RESULT: Mass passenger anxiety, possible passenger injury or death.

PASSENGER INJURY/ILLNESS

Scenario 1

EVENT: Individual slips or trips entering or exiting the vehicle.

CAUSE: Smooth wet surface, uneven surface, no railing, no assistance, etc.

RESULT: Possible passenger injury.

Scenario 2

EVENT: Passenger becomes ill while inside vehicle.

CAUSE: Motion sickness, heart attack, toxic fumes.

RESULT: Possible passenger death.

Scenario 3

EVENT: Passenger caught in automatic doors.

CAUSE: Door locks malfunction.

RESULT: Passenger injury, possibly crushed.

APPENDIX B. GENERIC HAZARD CHECKLIST *

1. **BASIC DESIGN DEFICIENCIES**

   a. Examples:

      (1) Sharp corners
      (2) Instability
      (3) Excessive weight
      (4) Inadequate clearance
      (5) Lack of accessibility

   b. Causes: Improper or poor design

   c. Control Methods: Improve or change design

2. **INHERENT HAZARDS**

   a. Examples:

      (1) Mechanical (i.e., rotating equipment, vibration)
      (2) Electrical
      (3) Explosives
      (4) Flammable gases or liquids
      (5) Toxic substances
      (6) Acceleration (flying objects)
      (7) Deceleration (falling objects)
      (8) Temperature

   b. Cause: Integral characteristic which cannot be designed out

   c. Control Methods:

      (1) Safety Devices

         (a) Isolation (separation)
         (b) Barriers (guards)
         (c) Interlocks (deactivation)
         (d) Pressure release
         (e) Temperature sensor (fuse)

      (2) Warning Devices (Five Senses)

         (a) Visual (see) - color, shape, signs, light
         (b) Auditory (hear) - bell
         (c) Tactile (touch) - shape, texture
         (d) Olfactory (smell)
         (e) Gustatory (taste)

---

*This checklist was developed by TSC using material adapted from <u>Product Safety Management and Engineering</u> by Willie Hammer, 1980. While the checklist provides a starting point for hazard identification, it does not present a comprehensive, exhaustive listing of all hazards and/or their causes.

(3) Procedures and Training

(a) Use of safe procedures
(b) Training
(c) Backout/recovery procedures
(d) Protective equipment
(e) Emergency procedures

3. **MALFUNCTIONS**

a. Examples:

(1) Structural failures
(2) Mechanical malfunctions
(3) Power failures
(4) Electrical malfunctions

b. Causes:

(1) Faulty design
(2) Manufacturing defects
(3) Improper or lack of maintenance
(4) Exceeding specified limits
(5) Environmental effects

c. Control Methods: Design

(1) Fail safe design
(2) Higher safety margins (i.e., reduce stress, increase load strength, etc.)
(3) Redundant circuitry or equipment
(4) Timed replacement

d. Other Control Methods: Safety devices, Warning Devices, Procedures and Training (See Point 2. c. 1-3)

4. **MAINTENANCE HAZARDS**

a. Examples:

(1) Improper connections
(2) Component failures
(3) Equipment damage
(4) Operational delay

b. Causes:

(1) Lack of maintenance
(2) Improper maintenance
(3) Hazardous maintenance conditions

c. Control Methods:

(1) Design

(a) Simplified design
(b) Fail-safe design
(c) Easy access to equipment
(d) Elimination of need for special tools or equipment

(2) Safety devices

(a) Guards for moving parts
(b) Interlocks

(3) Warning devices

(a) Labels/Signs
(b) Bells
(c) Chimes
(d) Lights

(4) Procedures or Training

(a) Documentation of proper procedures
(b) Improved training courses
(c) Housekeeping

5. ENVIRONMENTAL HAZARDS

a. Examples:

(1) Heat
(2) Cold
(3) Dryness
(4) Wetness
(5) Low friction (slipperiness)
(6) Glare
(7) Darkness
(8) Earthquake
(9) Gas or other toxic fumes

b. Causes:

(1) Inherent
(2) Foreseen or unforeseen natural phenomena/conditions which do or could occur

c. Control Methods :(see also 4.c)

(1) Design

(a) Increased resistance to temperature changes
(b) Increased resistance to dryness or wetness
(c) Fail-safe design

(2) Safety Devices

(a) Sufficient heating or cooling capability
(b) Adequate insulation
(c) Restricted access
(d) Temperature sensor

(3) Warning devices

(a) Visual
(b) Auditory
(c) Smell

(4) Procedures and Training

(a) Use of safe procedures
(b) Protective equipment
(c) Training

6. HUMAN FACTORS

a. Examples: (Also see all other items)

(1) Stress (sensory, mental, motor)
(2) Physical surroundings (environment)

(a) Noise
(b) Illumination
(c) Temperature
(d) Energy sources
(e) Air and humidity
(f) Vibration

(3) Errors

(a) Omission
(b) Commission

(4) Nonrecognition of hazards
(5) Incorrect decisions
(6) Tasks done at wrong time
(7) Tasks not performed or incorrectly performed

b. Causes:

(1) Inadequate attention to human design criteria
(2) Poor location, layout of controls
(3) Equipment complexity
(4) Inherent hazards
(5) Incorrect installation
(6) Failure of warning devices
(7) Inadequacy of procedural safeguards

(a) Failure to follow instructions
(b) Lack of knowledge of procedures

(8) Inadequate training
(9) Lack of or improper maintenance

c. Control Methods:

(1) Design (to address items (1) - (6)
(2) Safety Devices (Redundancy)

(a) Isolation (separation)
(b) Barriers (guards)
(c) Interlocks (deactivation)
(d) Temperature sensor (fuse)

(3) Warning Devices (Five Senses) (Redundancy)

(a) Visual (eye) - color, shape, signs, light
(b) Auditory (hear) - bell
(c) Tactile (touch) - shape, texture
(d) Olfactory (smell)
(e) Gustatory (taste)

(4) Procedures and Training

(a) Clear warning labels (nature of hazard, action to avoid injury, consequences)
(b) Use of complete, proper, safe procedures
(c) Adequate training (also refresher training)
(d) Backout/recovery procedures
(e) Protective equipment
(f) Emergency procedures
(g) Proper maintenance procedures

7. FIRE HAZARDS

a. Examples: Rapid fire spread, smoke/toxic gas buildup

b. Causes:

(1) Electrical (short circuit, overload, etc.)
(2) Vandalism
(3) Flammable Liquids or Gases
(4) Explosion

c. Control Methods:

(1) Design

(a) Materials Selection
(b) Equipment placement

2) Safety Devices

(a) Insulation/barrier material
(b) Extinguishing system

(3) Warning Devices

(a) Smoke detection
(b) Overheat/overtemperature sensors

(4) Procedures and Training (see 2.c.3)

APPENDIX C MAGLEV FAULT TREES
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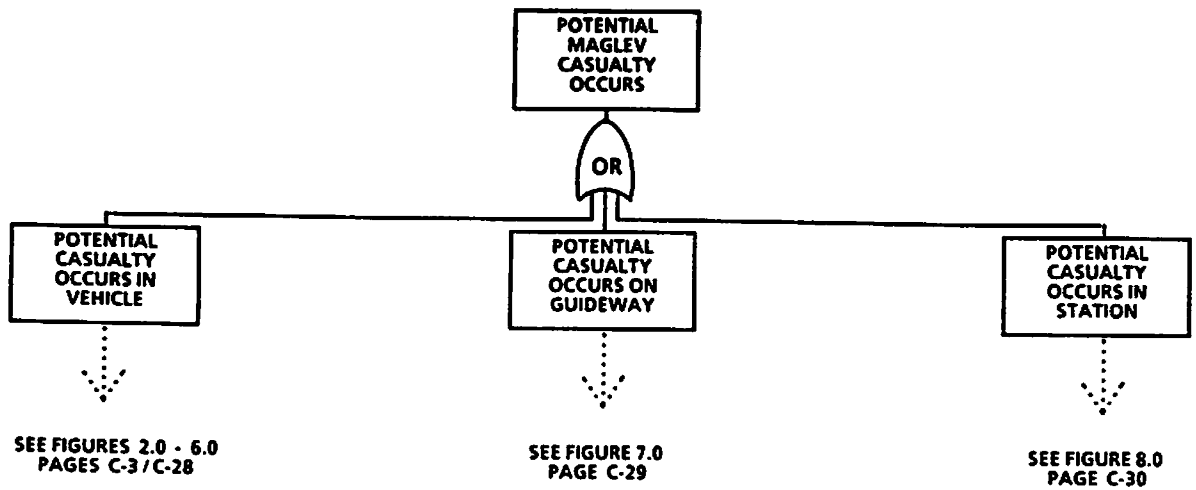

FIGURE 1.0 OVERVIEW: POTENTIAL MAGLEV CASUALTY OCCURS

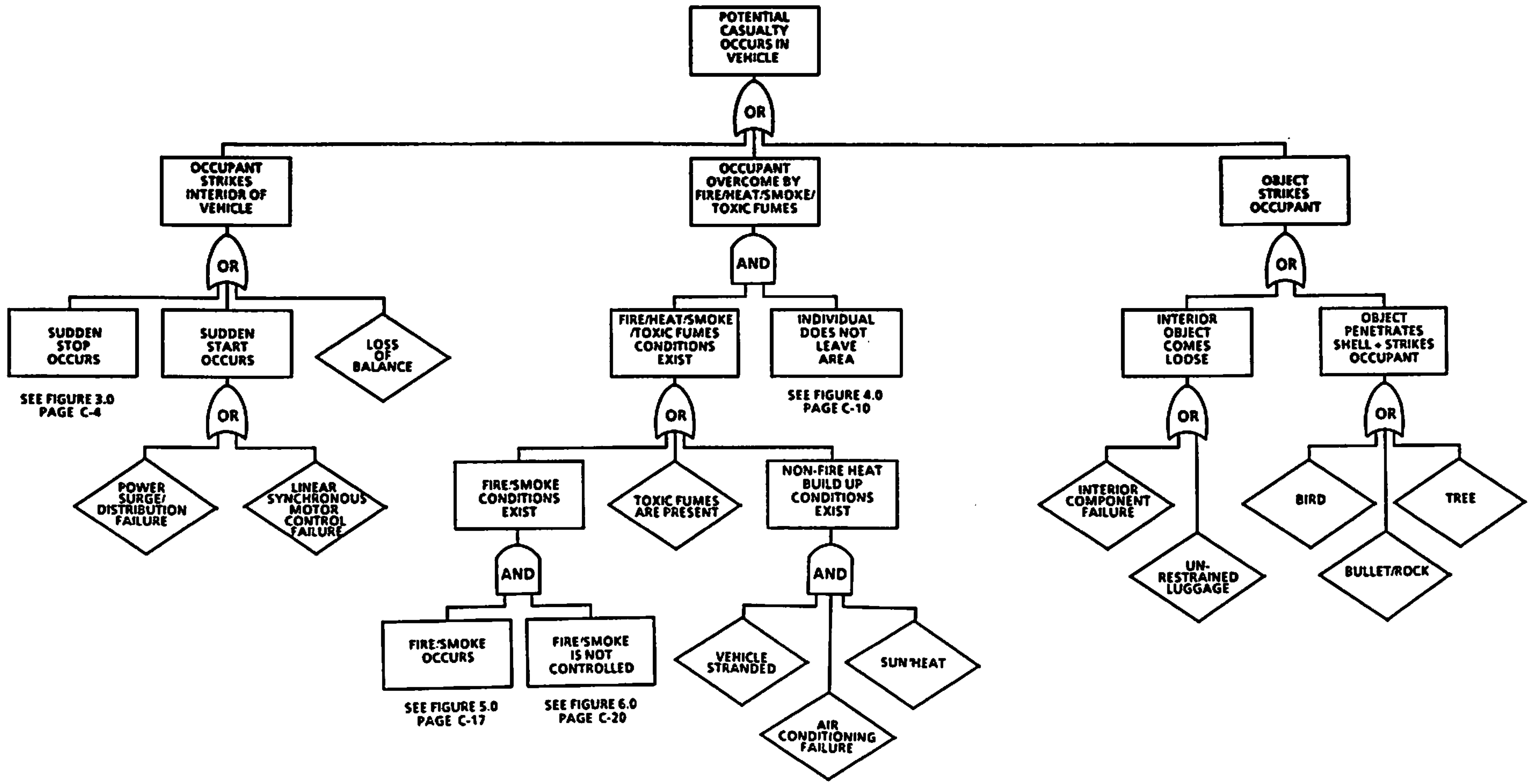

FIGURE 2.0 POTENTIAL CASUALTY OCCURS IN VEHICLE

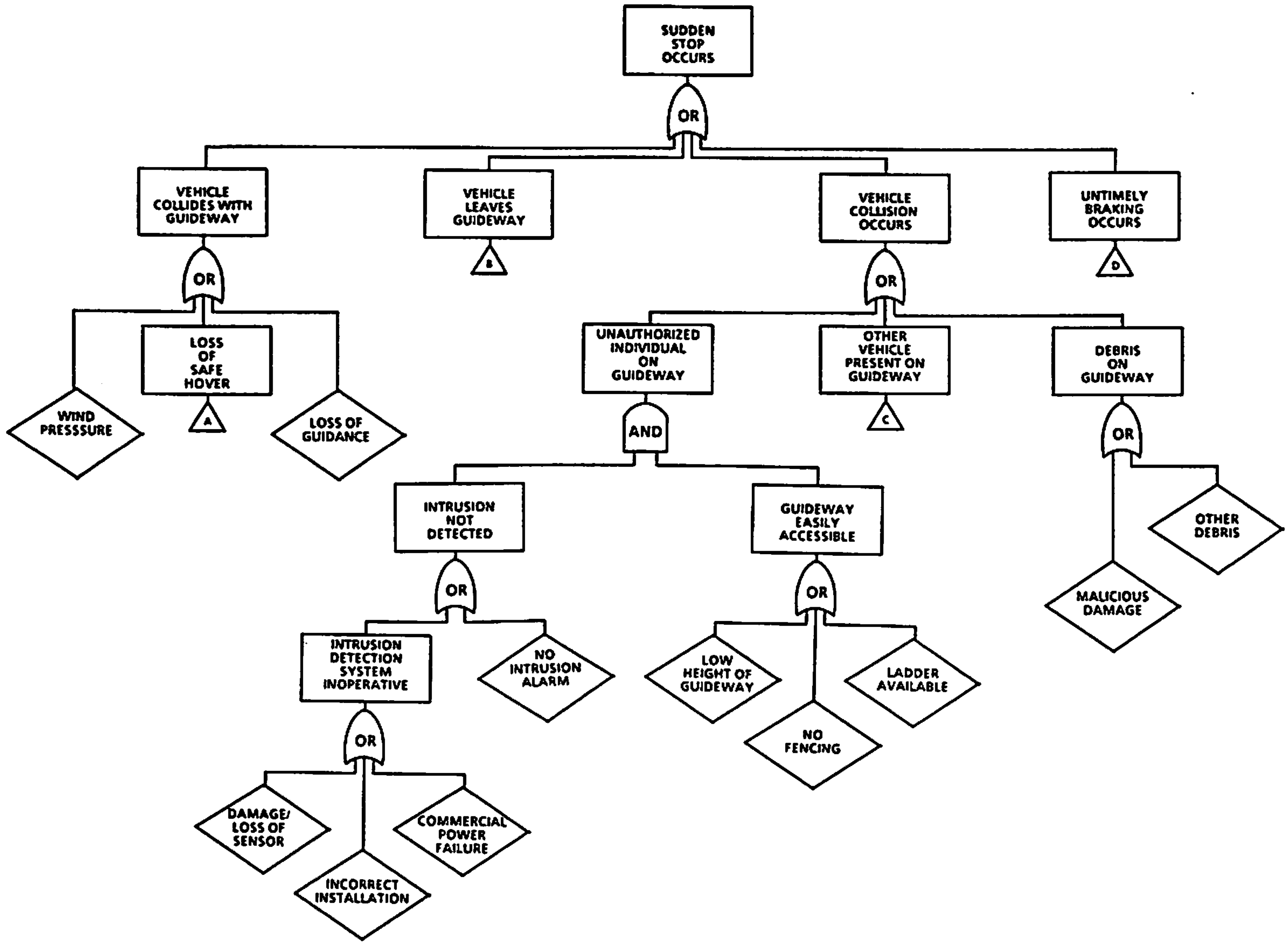

FIGURE 3.0 SUDDEN STOP OCCURS

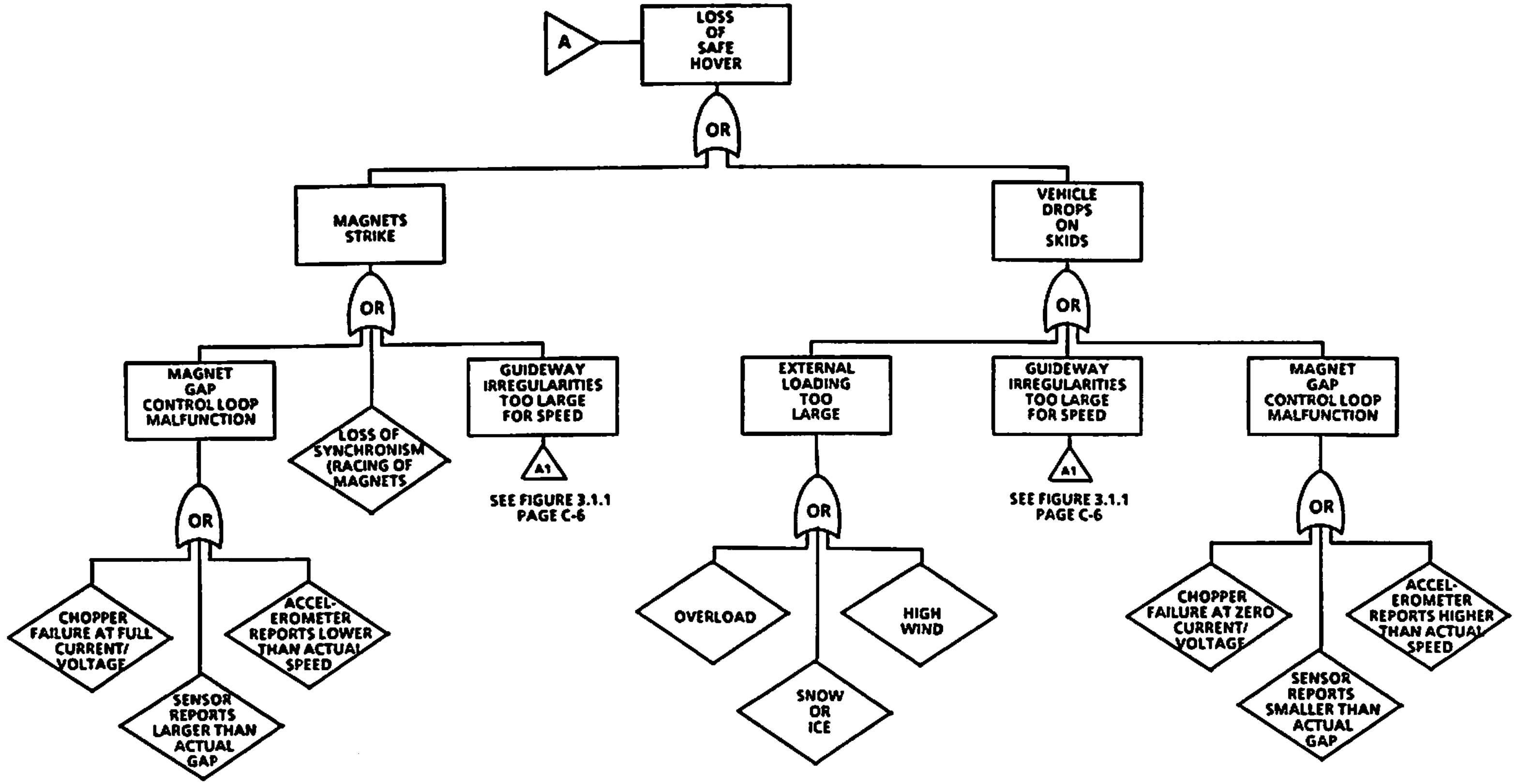

FIGURE 3.1 A: LOSS OF SAFE HOVER

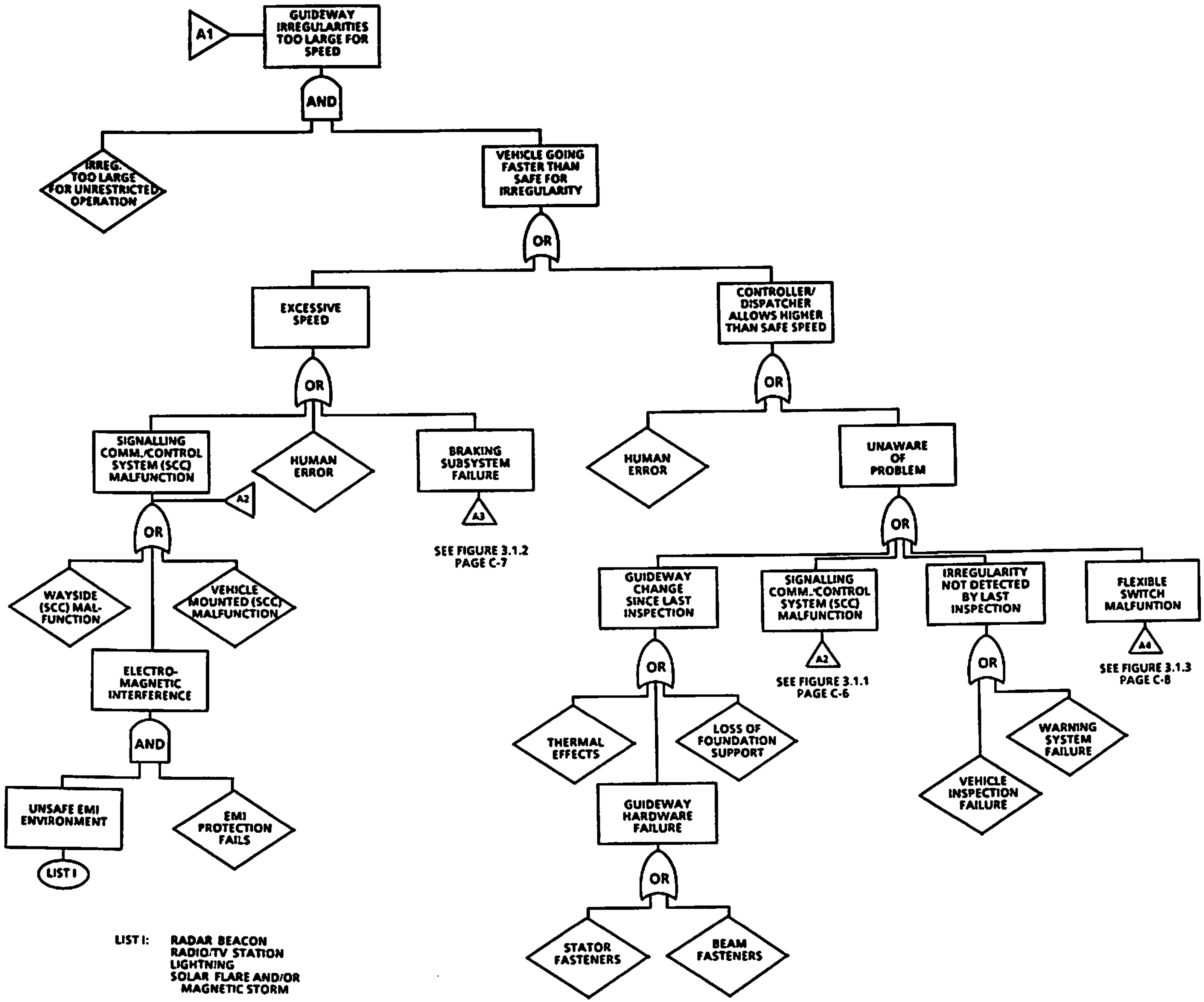

FIGURE 3.1.1 A1: GUIDEWAY IRREGULARITIES TOO LARGE FOR SPEED

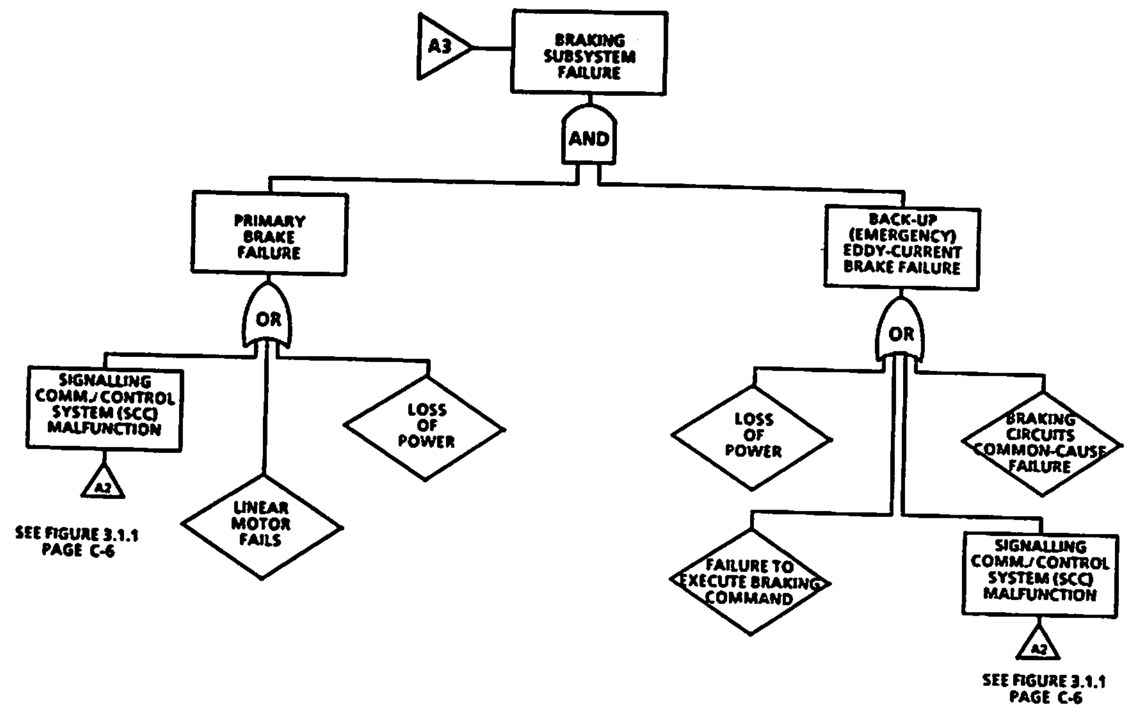

FIGURE 3.1.2 A3: BRAKING SUBSYSTEM FAILURE

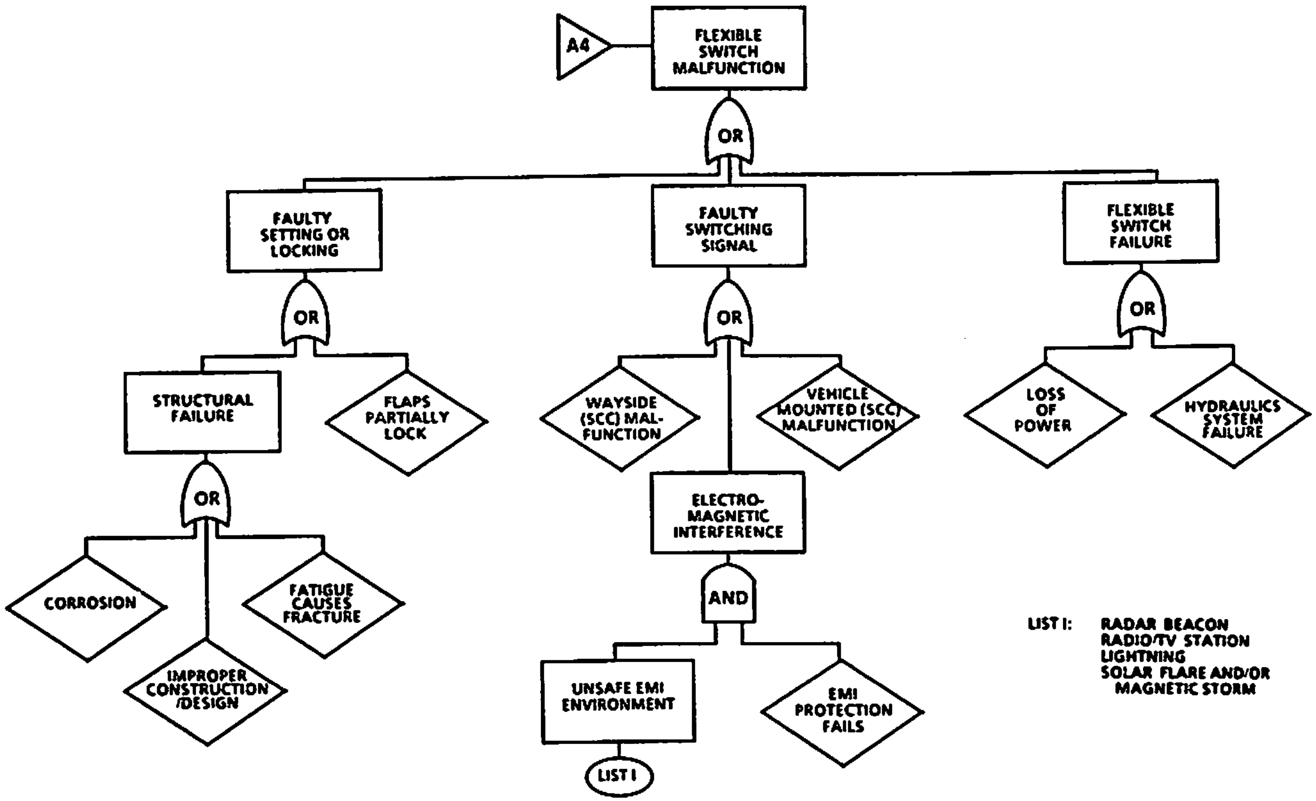

FIGURE 3.1.3 A4: FLEXIBLE SWITCH MALFUNCTION

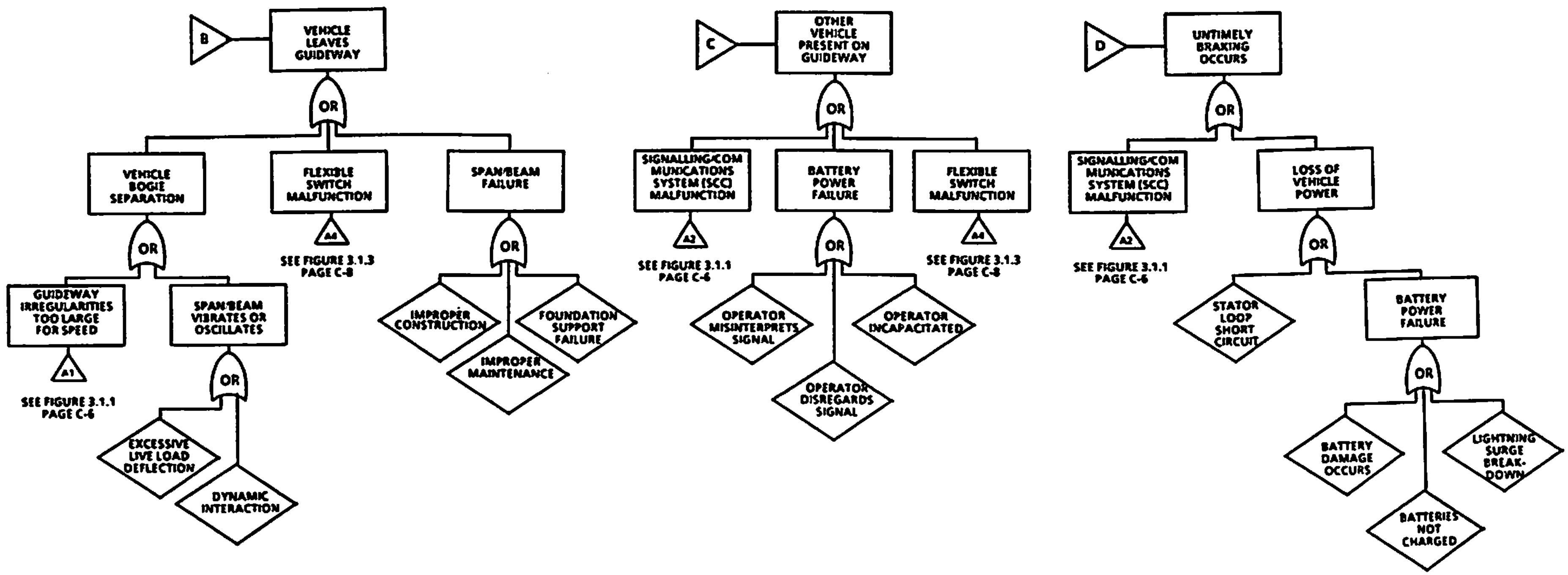

FIGURE 3.2 B: VEHICLE LEAVES GUIDEWAY
C: OTHER VEHICLE PRESENT ON GUIDEWAY
D: UNTIMELY BRAKING OCCURS

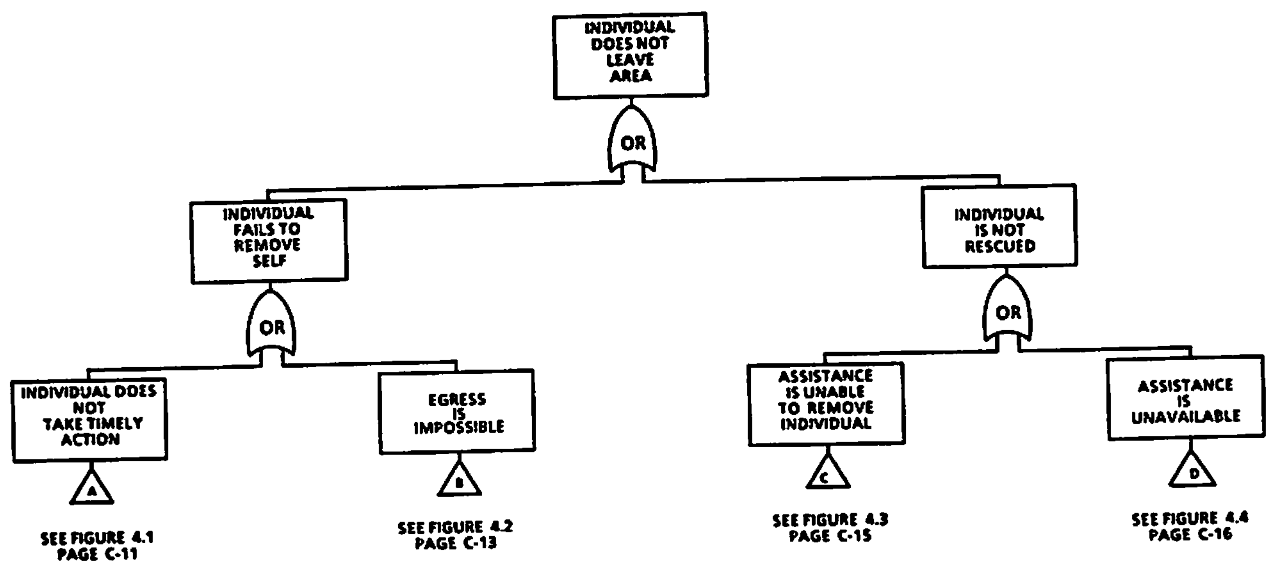

FIGURE 4.0 INDIVIDUAL DOES NOT LEAVE AREA

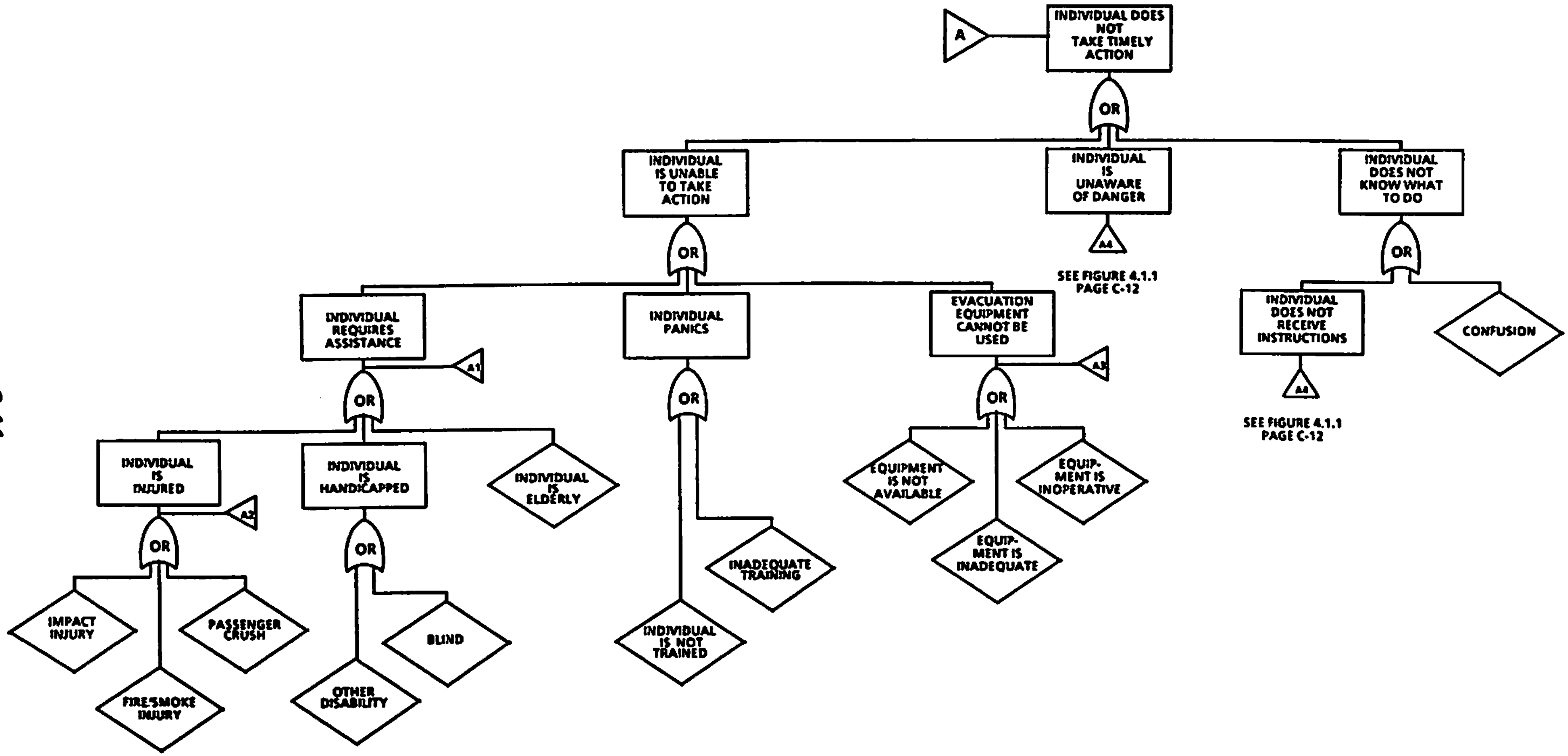

FIGURE 4.1 A: INDIVIDUAL DOES NOT TAKE TIMELY ACTION

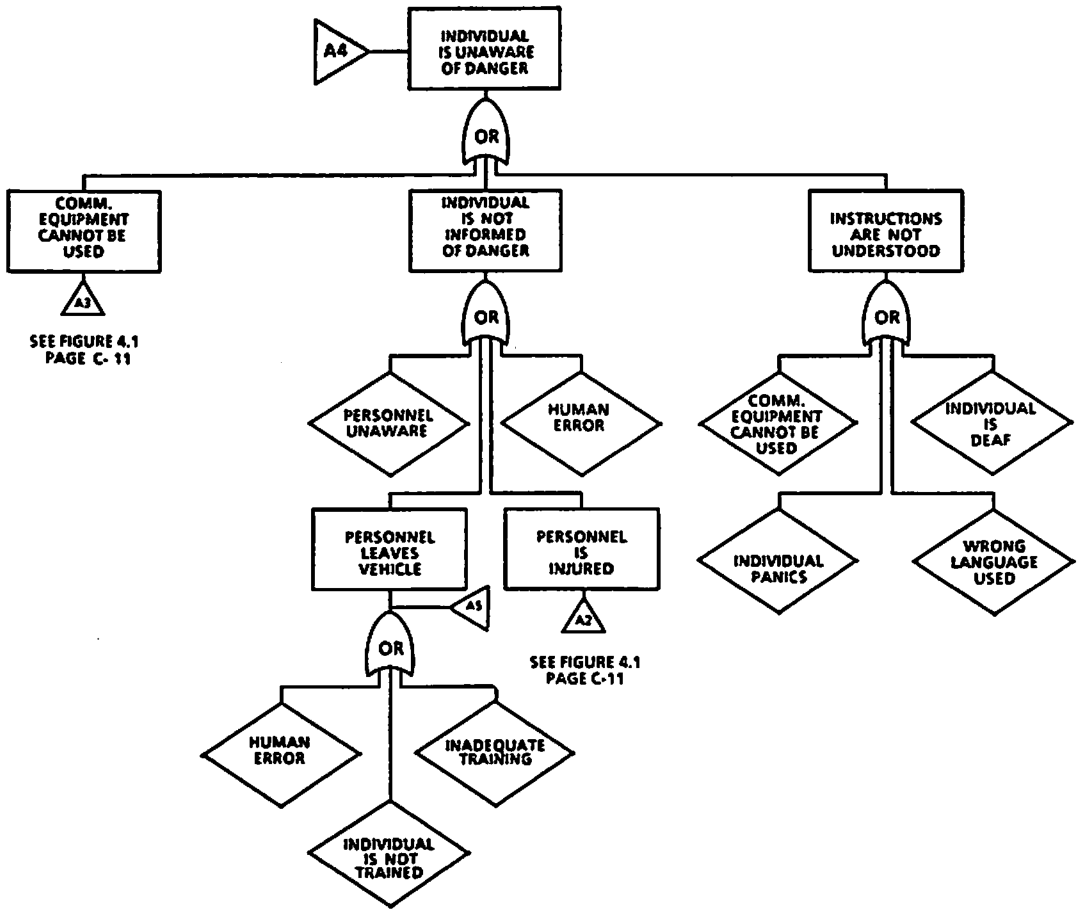

FIGURE 4.1.1 A4: INDIVIDUAL UNAWARE OF DANGER

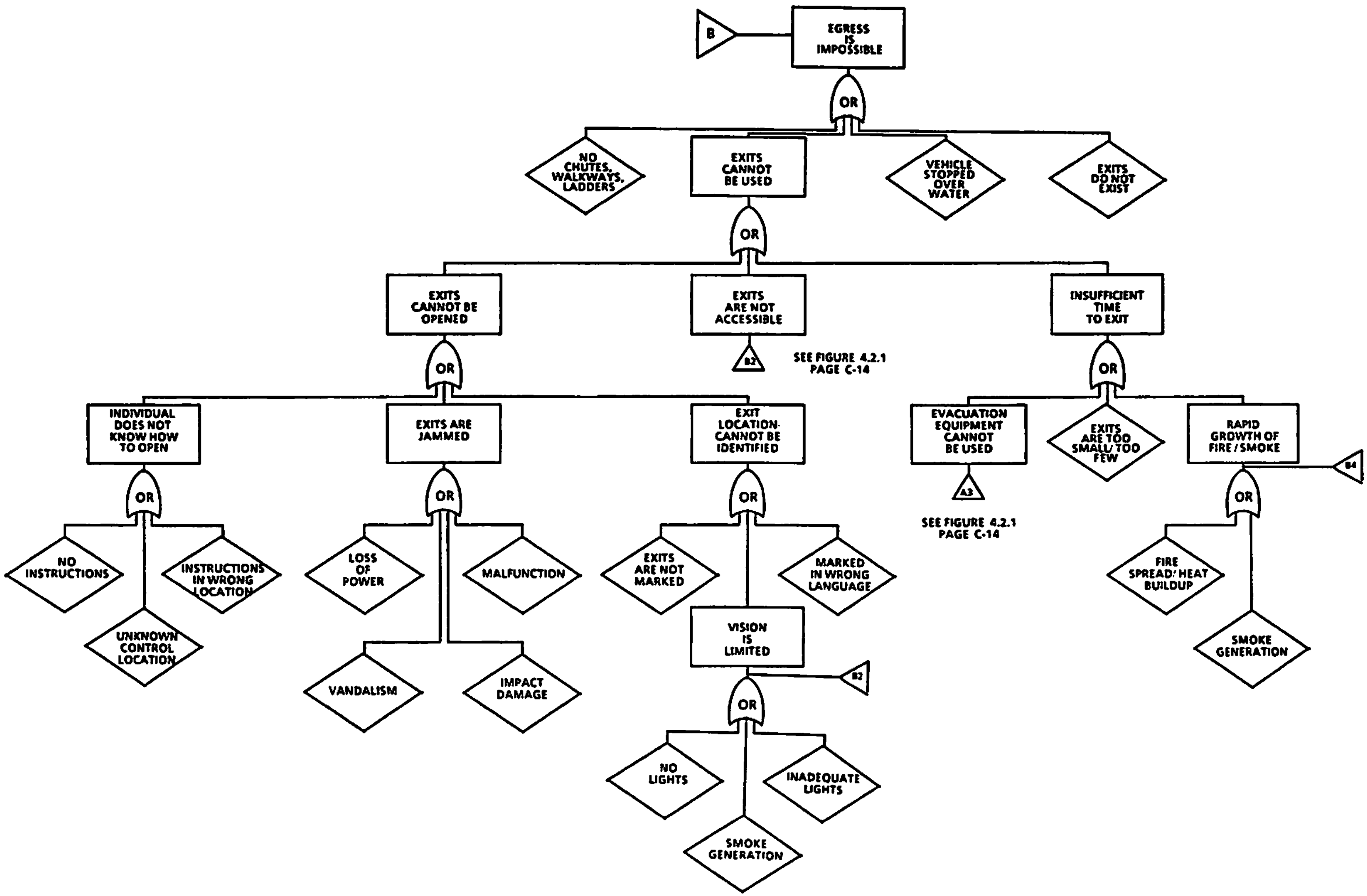

FIGURE 4.2 B: EGRESS IS IMPOSSIBLE

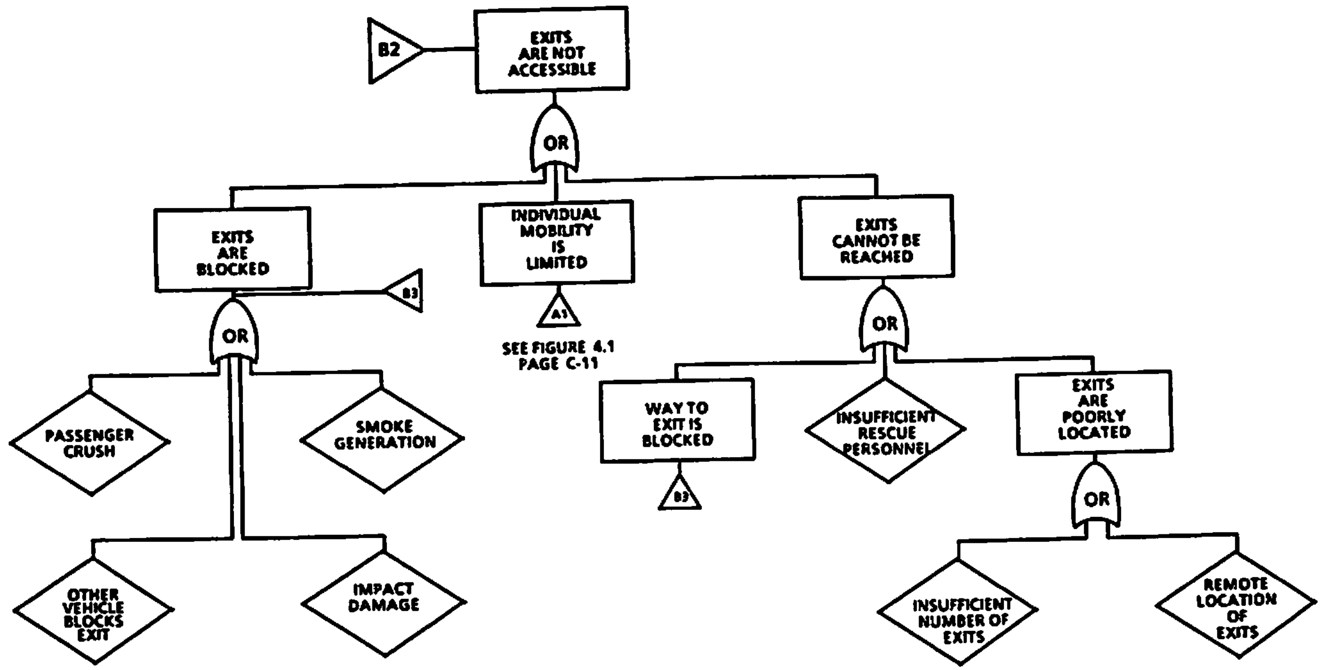

FIGURE 4.2.1 B2: EXITS ARE NOT ACCESSIBLE

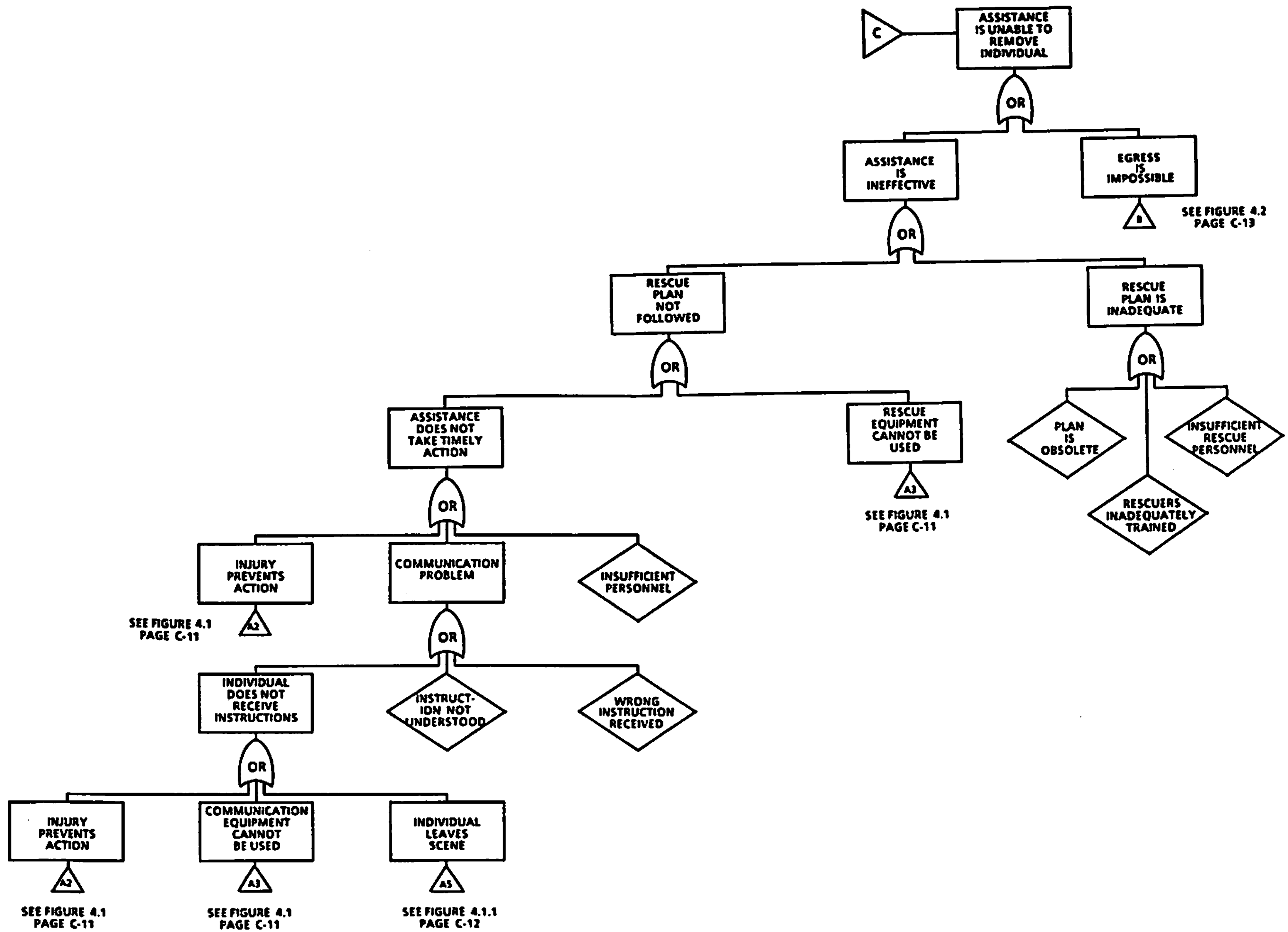

FIGURE 4.3 C: ASSISTANCE UNABLE TO REMOVE INDIVIDUAL

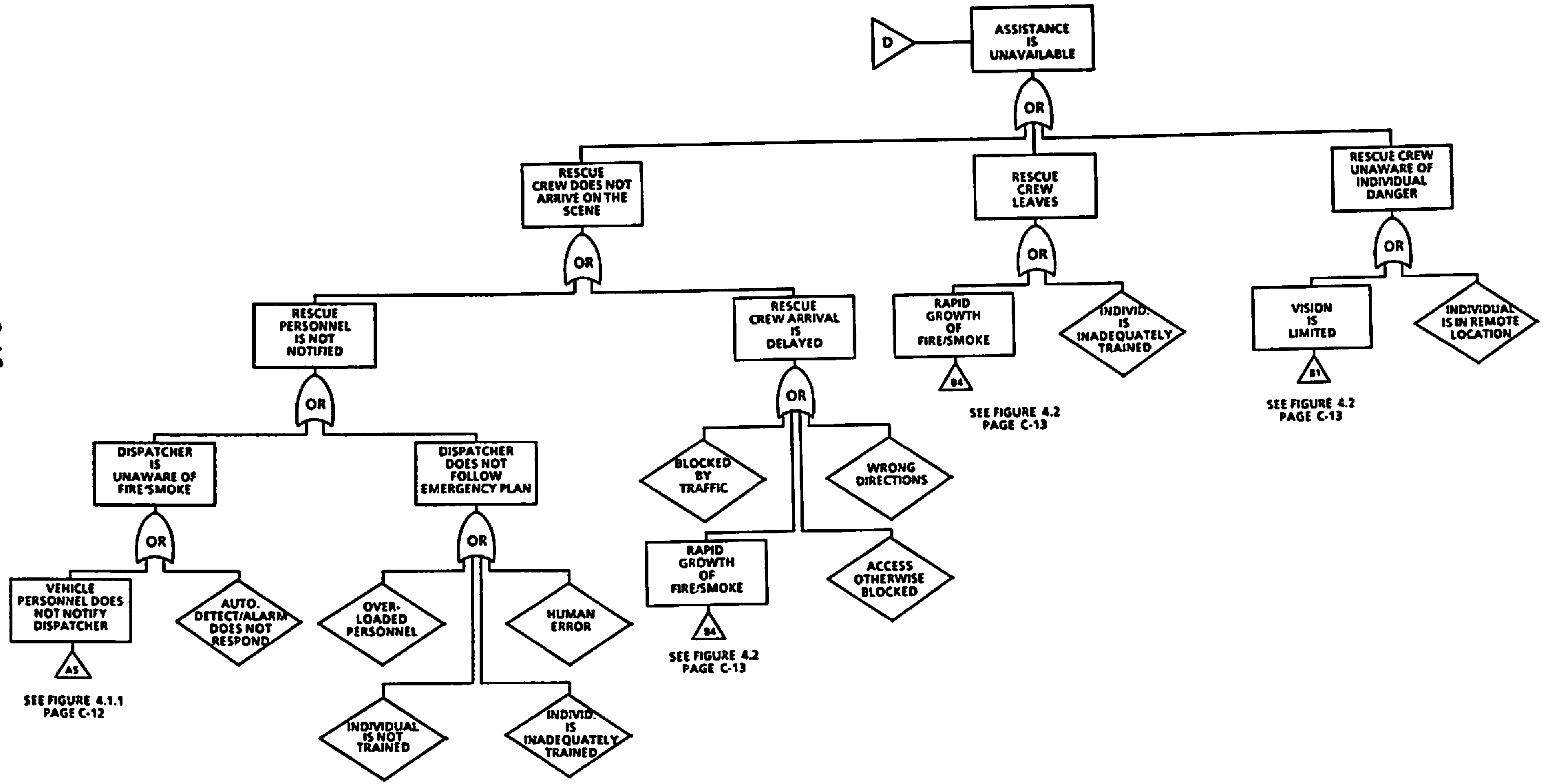

FIGURE 4.4 D: ASSISTANCE IS UNAVAILABLE

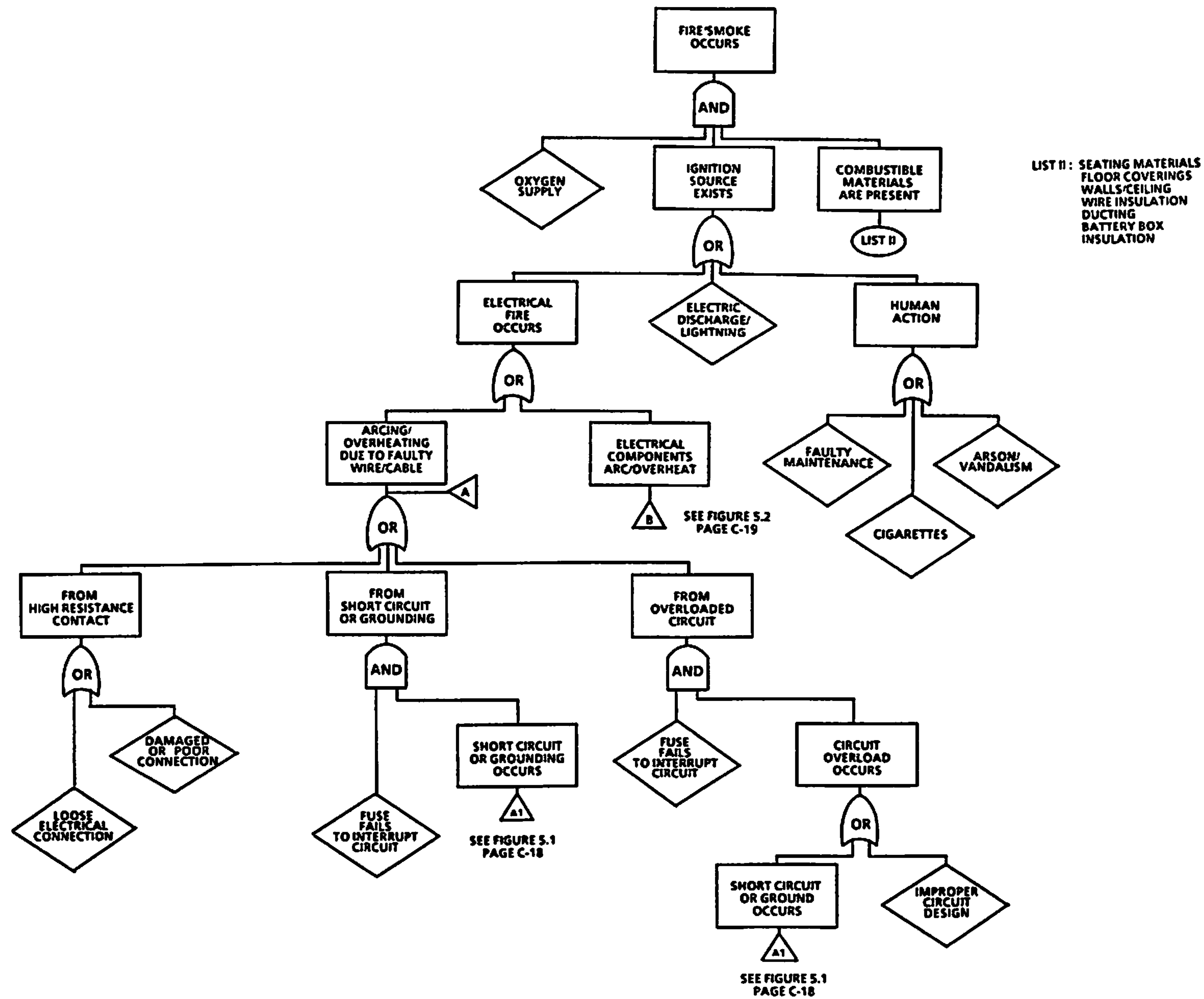

FIGURE 5.0 FIRE/SMOKE OCCURS

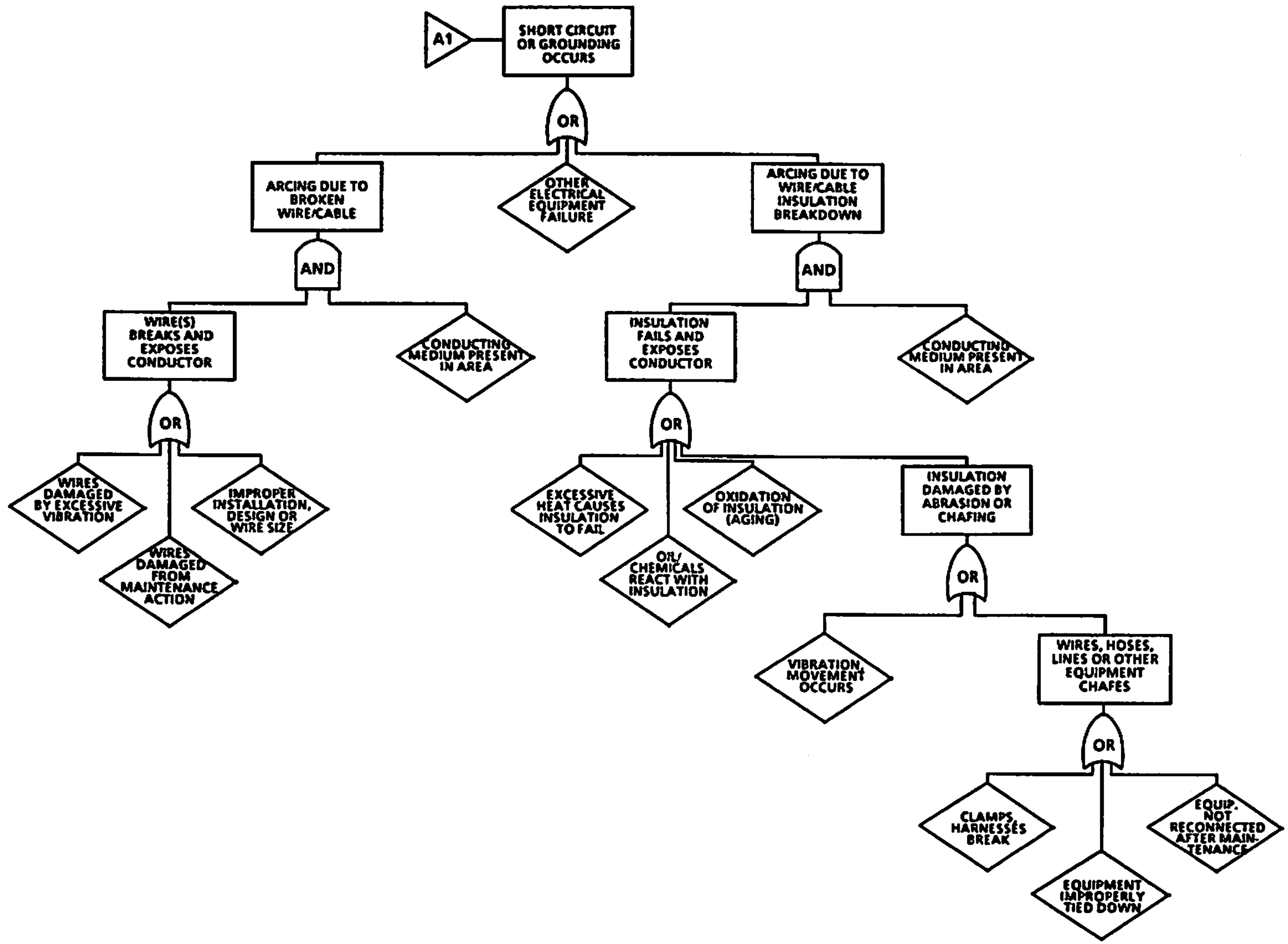

FIGURE 5.1 A1: SHORT CIRCUIT OR GROUNDING OCCURS

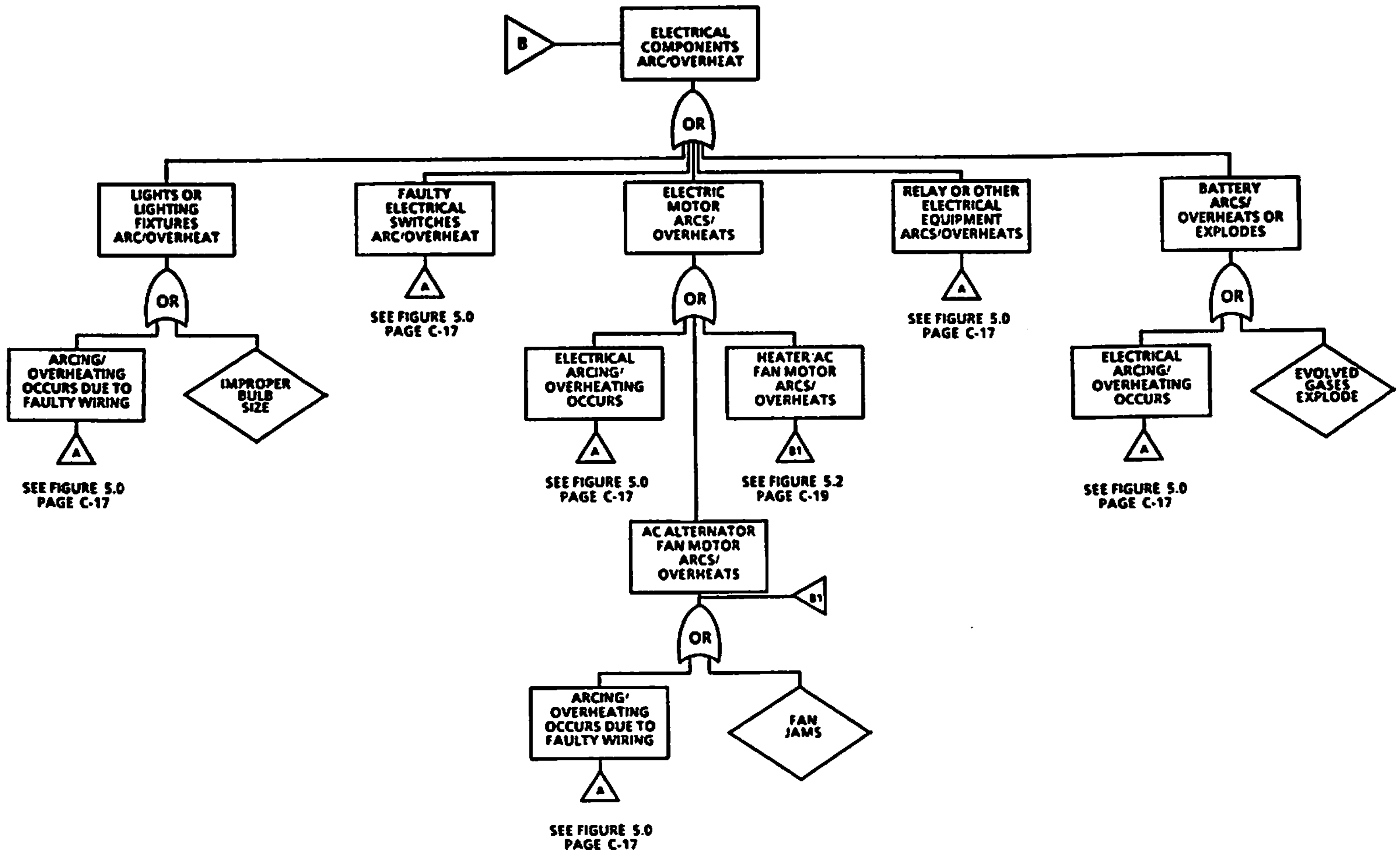

FIGURE 5.2 B: ELECTRICAL COMPONENTS ARC/OVERHEAT

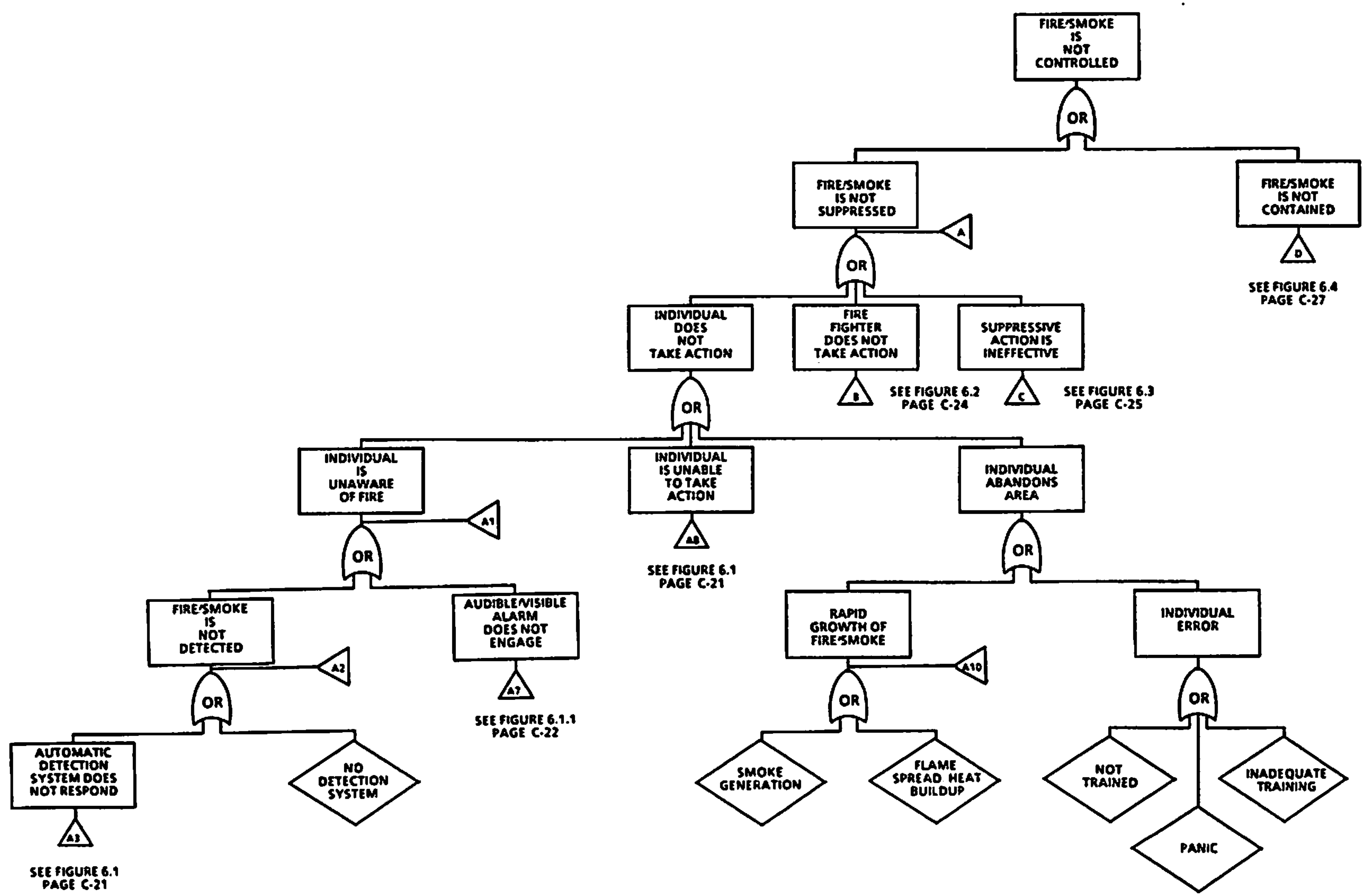

FIGURE 6.0 FIRE/SMOKE IS NOT CONTROLLED

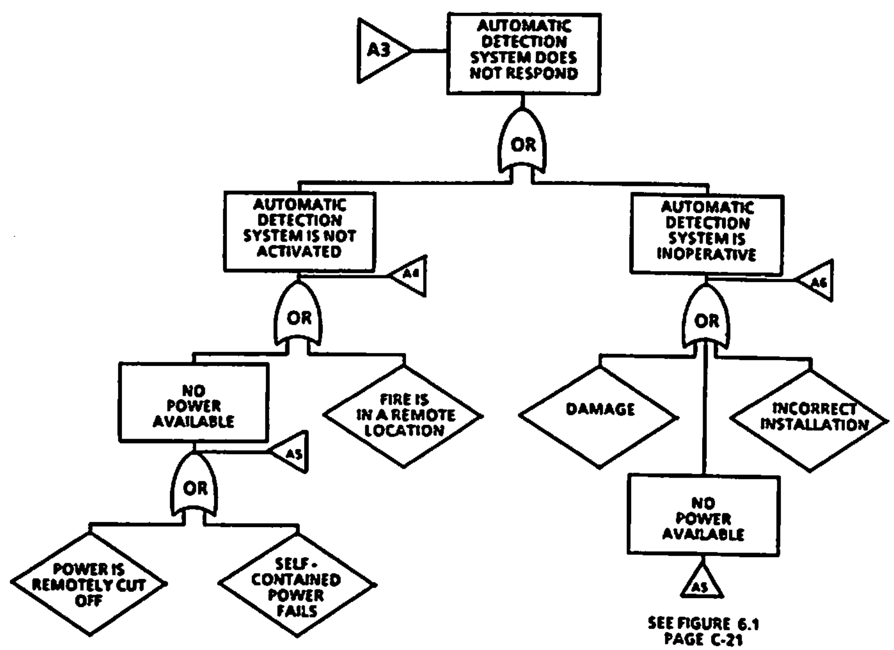

FIGURE 6.1 A3: AUTOMATIC DETECTION SYSTEM DOES NOT RESPOND

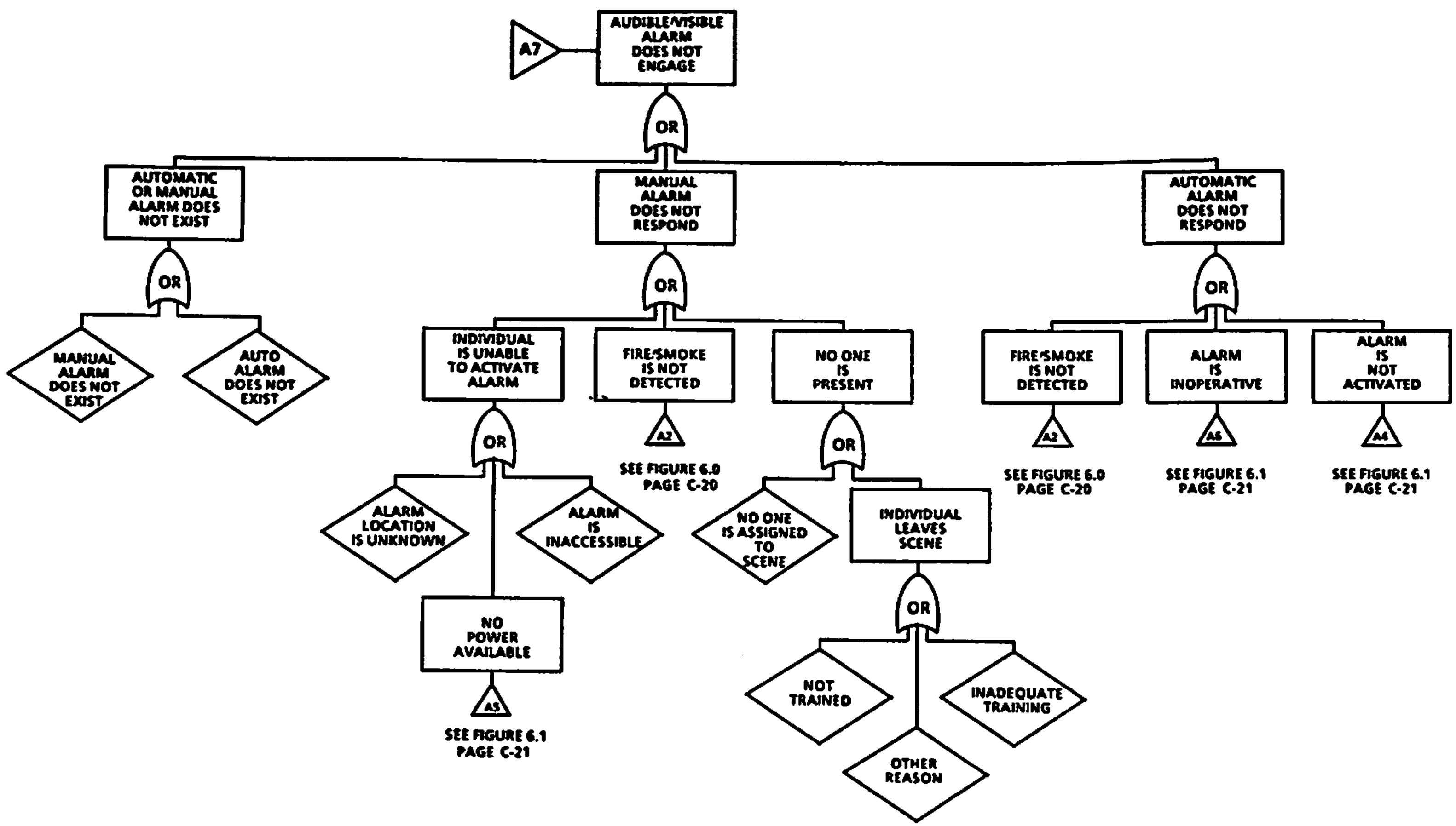

FIGURE 6.1.1 A7: AUDIBLE/VISIBLE ALARM DOES NOT ENGAGE

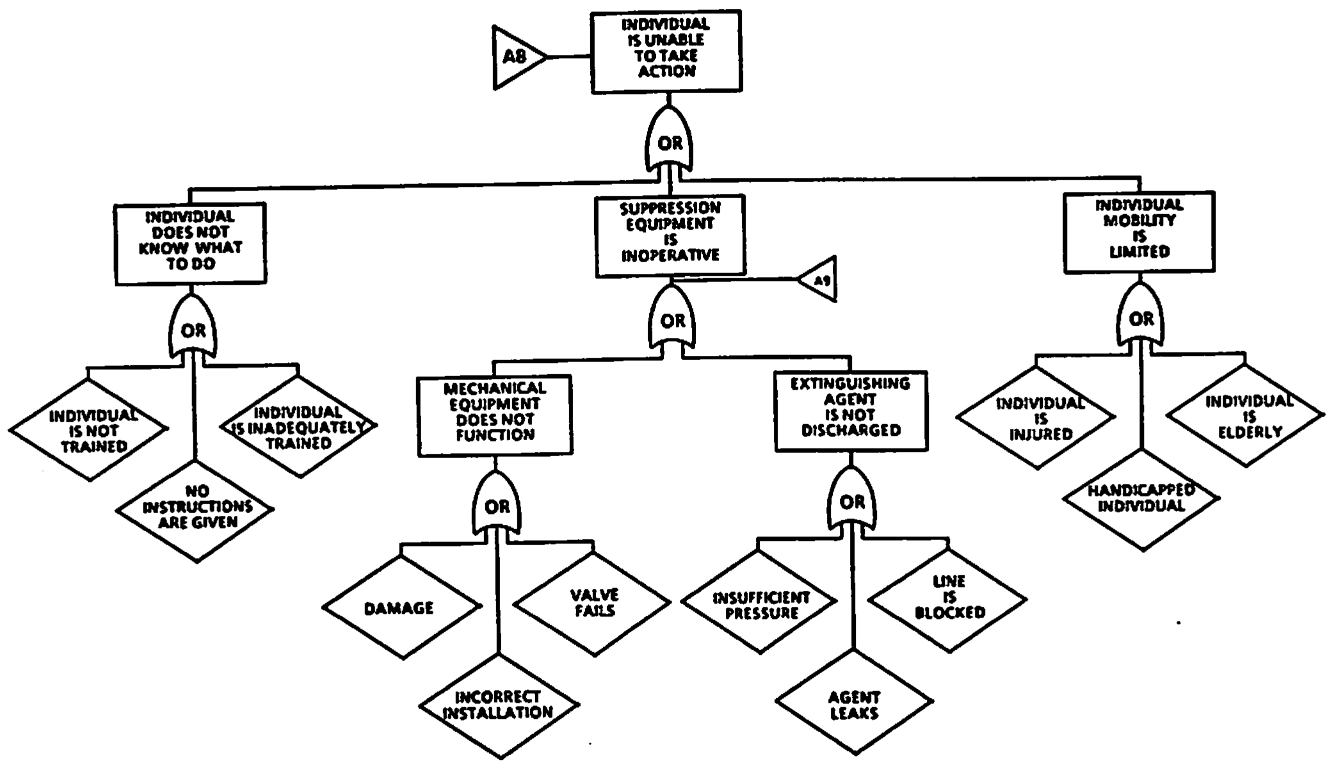

FIGURE 6.1.2 A8: INDIVIDUAL UNABLE TO TAKE ACTION

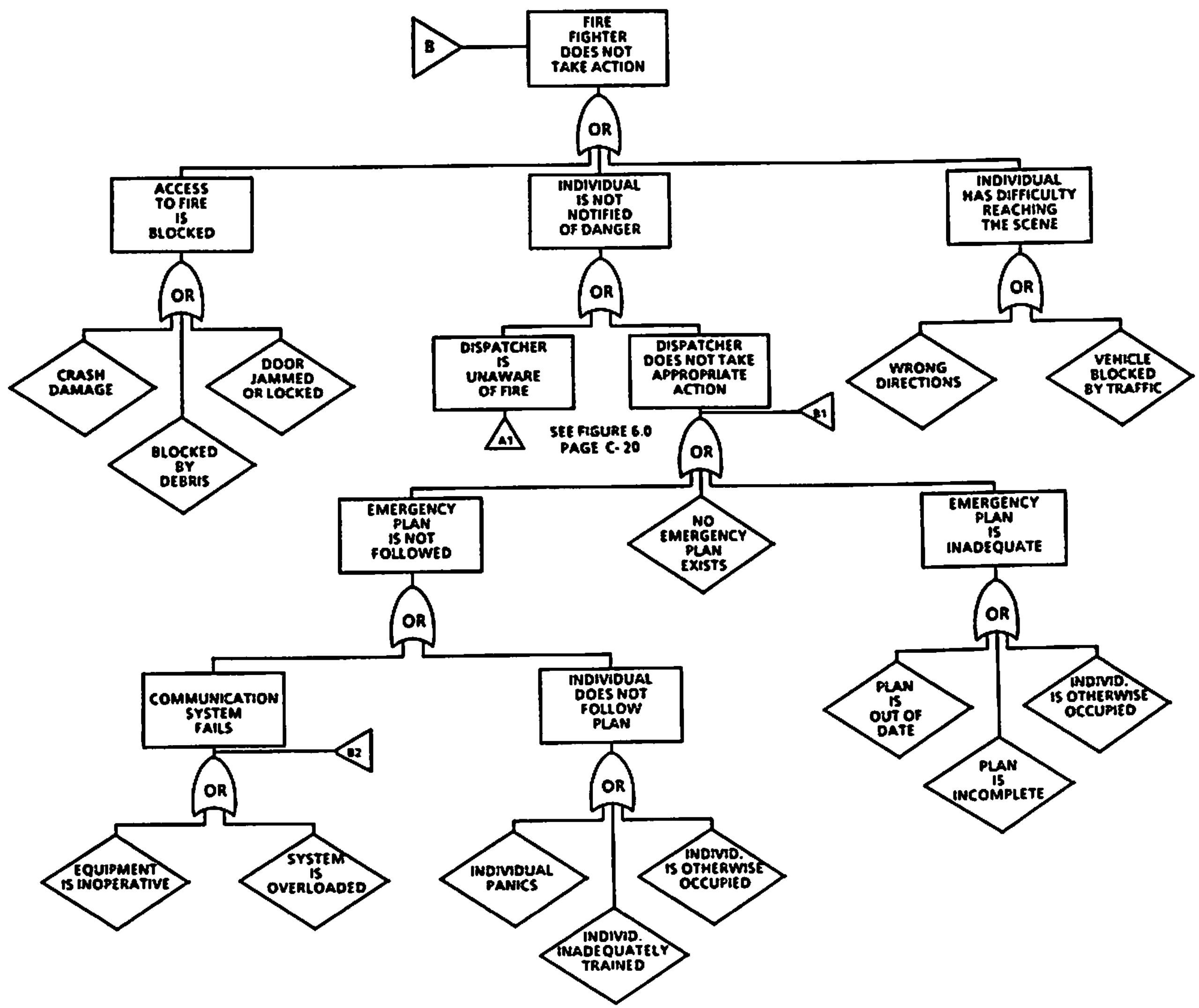

FIGURE 6.2 B: FIRE FIGHTER DOES NOT TAKE ACTION

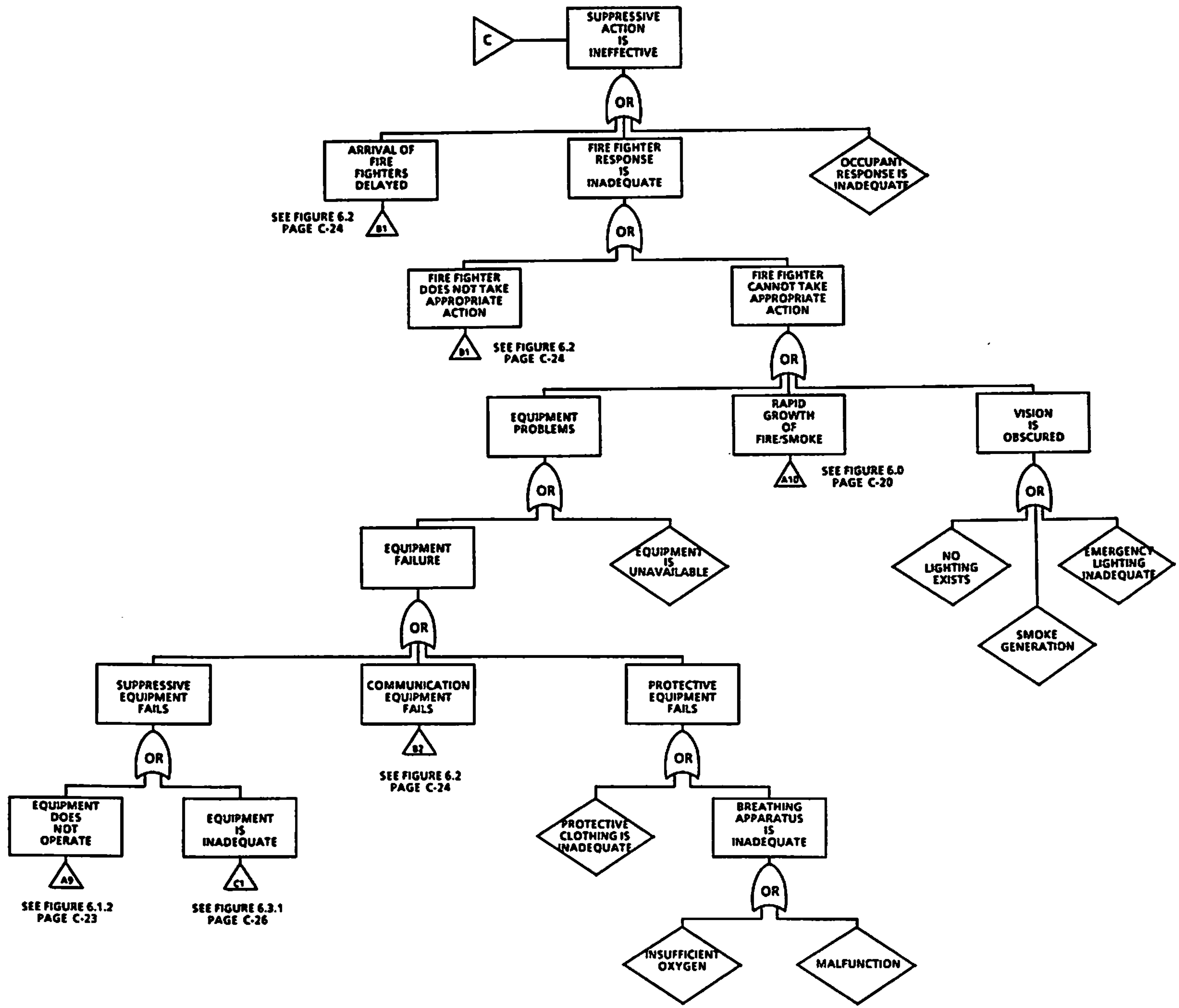

FIGURE 6.3 C: SUPPRESSIVE ACTION IS INEFFECTIVE

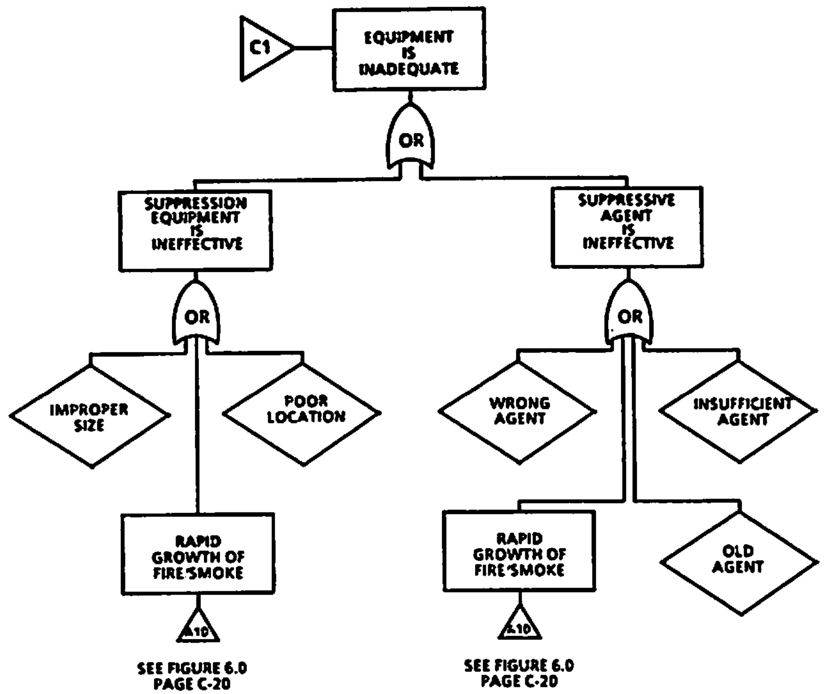

FIGURE 6.3.1 C1: EQUIPMENT IS INADEQUATE

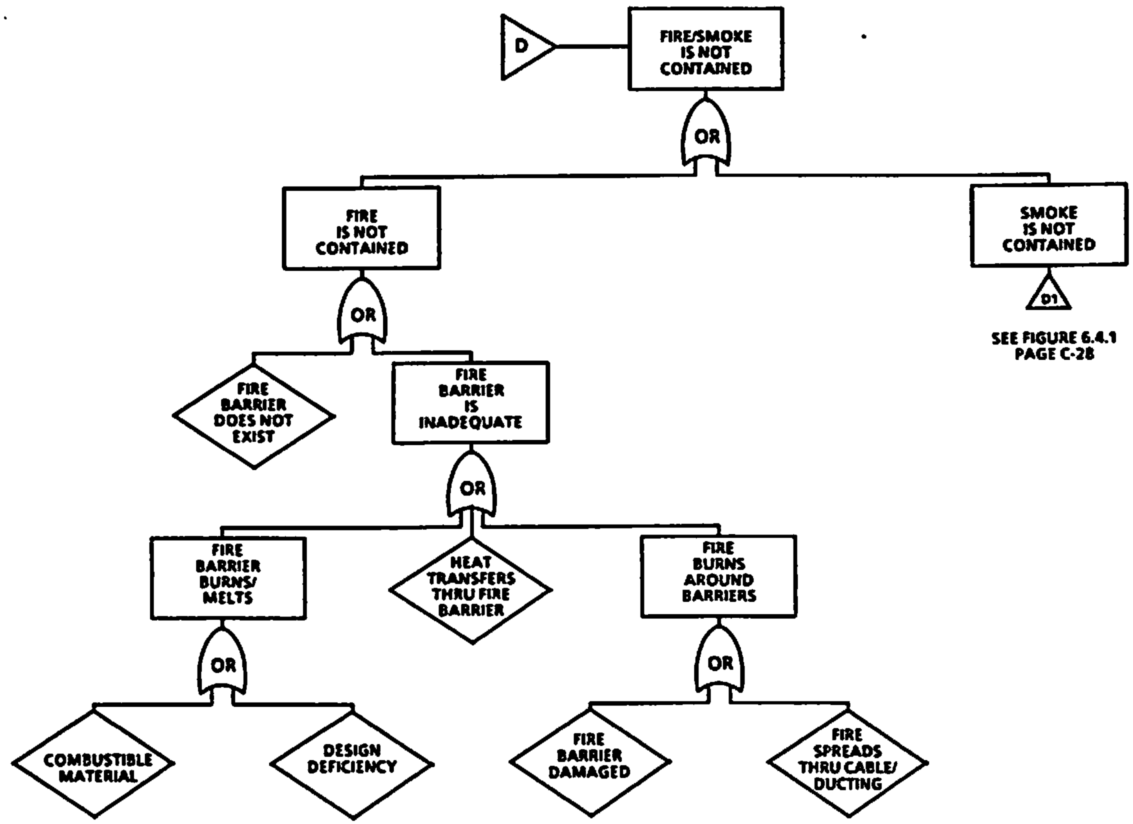

FIGURE 6.4 D: FIRE/SMOKE IS NOT CONTAINED

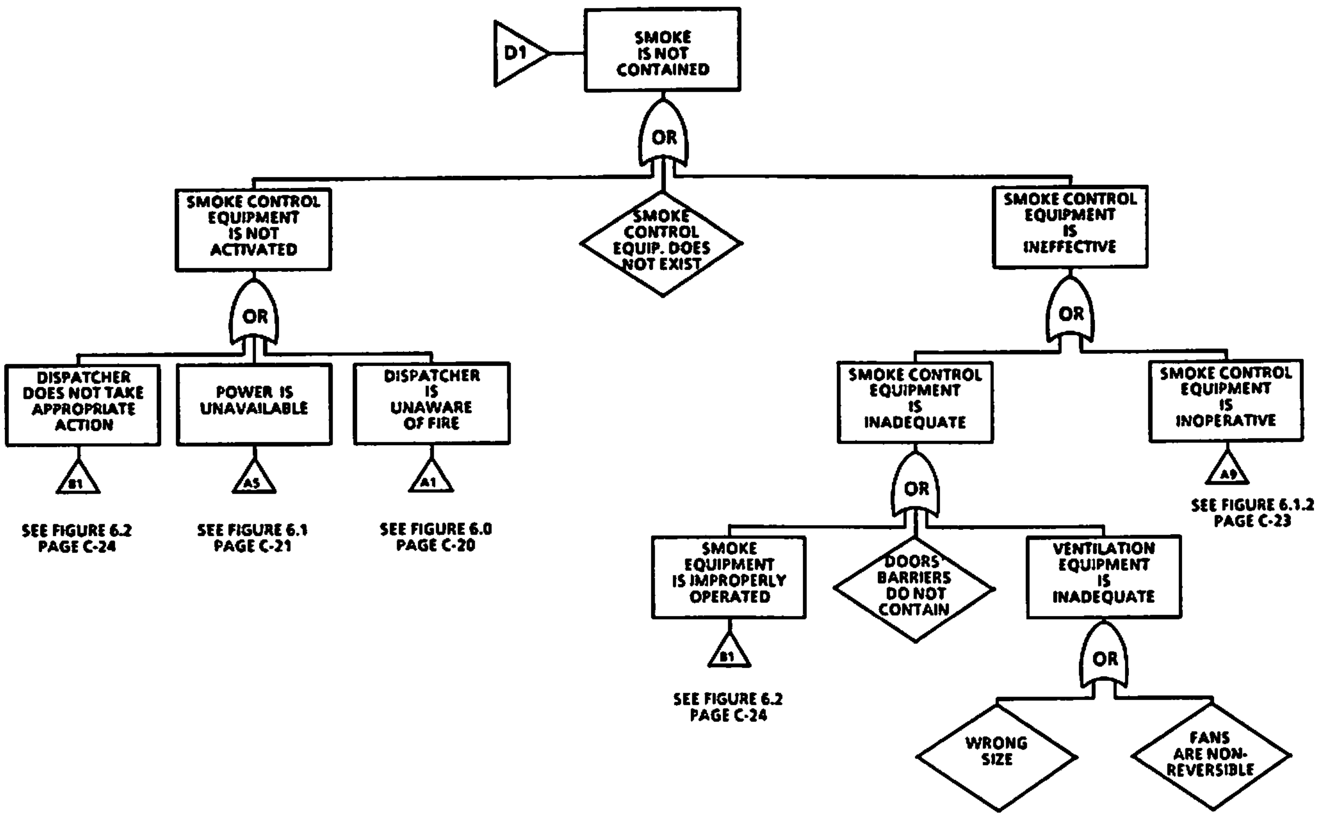

FIGURE 6.4.1 D1: SMOKE IS NOT CONTAINED

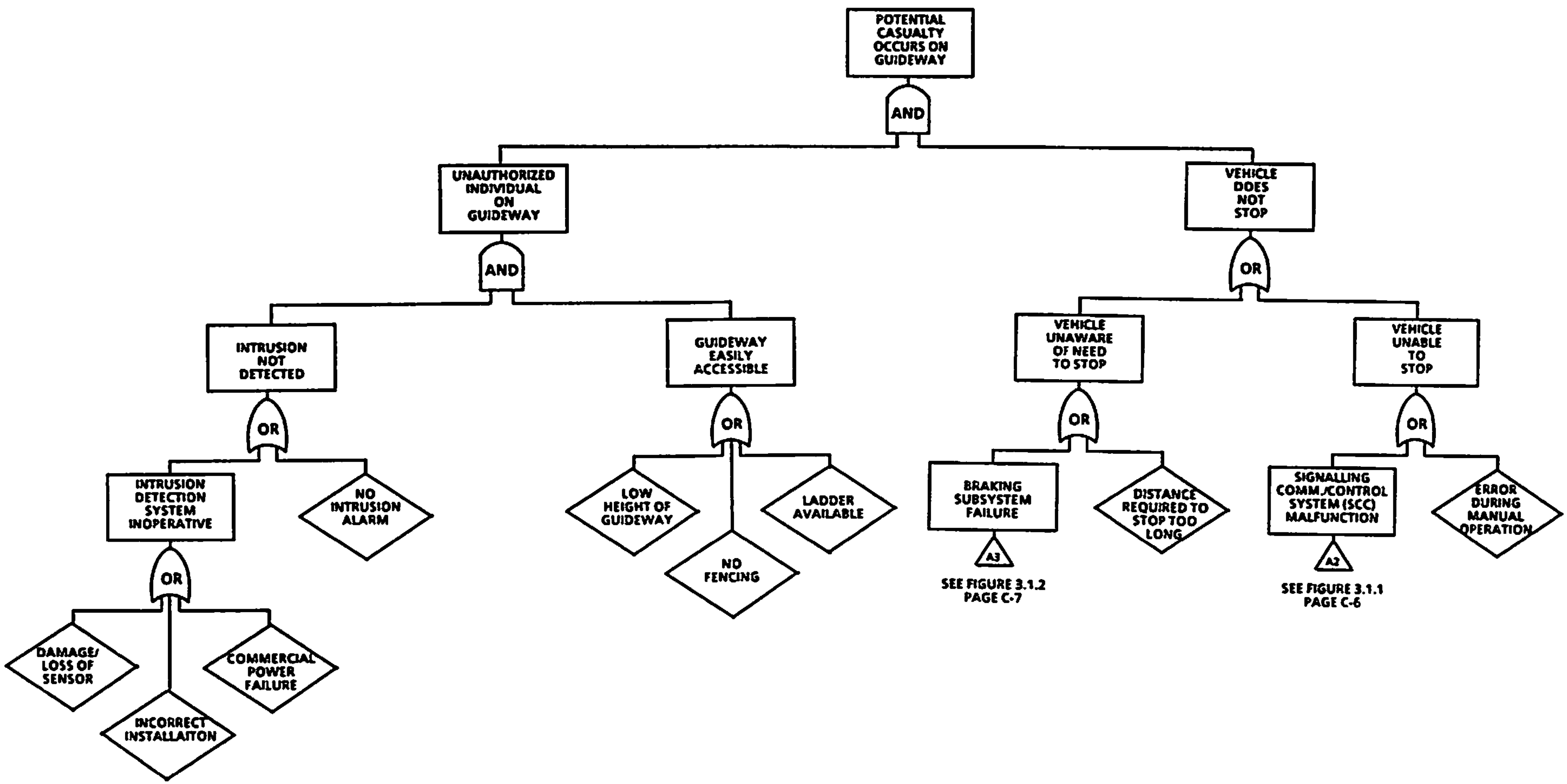

FIGURE 7.0 POTENTIAL CASUALTY OCCURS ON GUIDEWAY

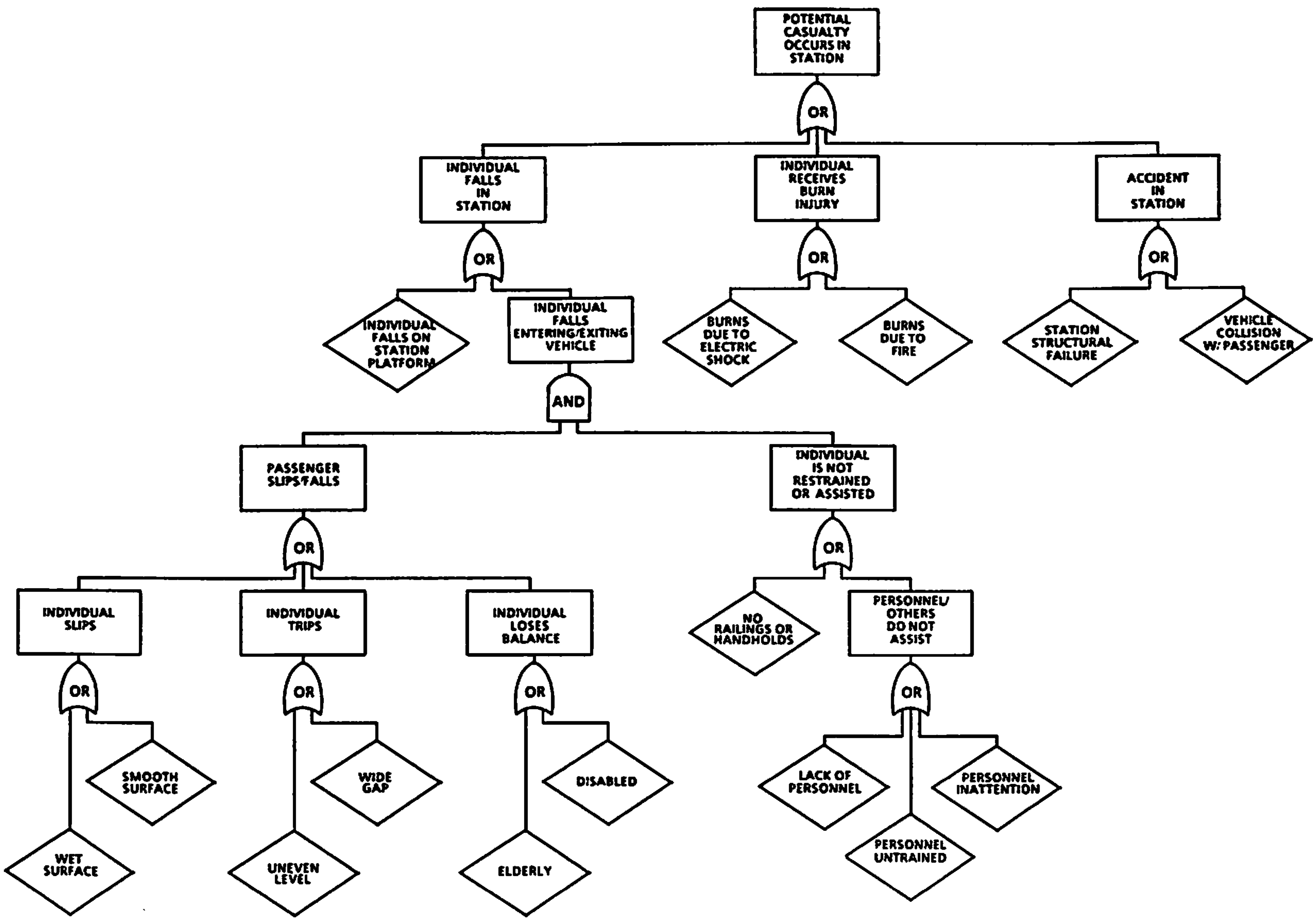

FIGURE 8.0 POTENTIAL CASUALTY OCCURS IN STATION

APPENDIX D. SAFETY REGULATIONS, GUIDELINES, AND REQUIREMENTS POTENTIALLY APPLICABLE TO MAGLEV

The attached tables contain a preliminary regulatory comparison, both U.S. and foreign, for the following list of railroad elements. Much of the data was derived and adapted from a report prepared for FRA by ADL, enhanced by TSC to include German and non-FRA applicable regulations, guidelines, and requirements.

1. **GENERAL SAFETY ENGINEERING**
2. **VEHICLE**
3. **GUIDEWAY (TRACK)**
4. **SIGNALING, CONTROL, COMMUNICATIONS AND ELECTRIFICATION**
5. **PERSONNEL/OPERATIONS**

ABBREVIATIONS

AAR - Association of American Railroads

ADL - Arthur D. Little, Inc.

APTA - American Public Transit Association

AREA - American Railway Engineering Association

DIN - German Standards Institute

EBO - German Railroad Construction and Traffic Regulations, 1982 Edition

FAA - Federal Aviation Administration

- * AC - Advisory Circular
- * FAR - Federal Aviation Regulation

FRA - Federal Railroad Administration

49 CFR - Code of Federal Regulations, Title 49

MBO - Construction and Operating Code for Magnetic Levitation Rail System, January 1988, DRAFT

MIL-STD - Military Standard (U.S.)

NASA - National Aeronautics and Space Administration

NFPA - National Fire Protection Association

SNCF - French National Railways

TGV - Train à Grand Vitesse (French High Speed Train)

TÜV - High-Speed Maglev Trains Safety Requirements, 1991*

VDI - Association of German Engineers

VDE - Association of German Electrical Technicians

UIC - International Union of Railways

UMTA - Urban Mass Transportation Administration

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* Folios available as of March, 1991

TABLE D-1. SAFETY REGULATIONS, GUIDELINES, AND REQUIREMENTS POTENTIALLY APPLICABLE TO MAGLEV

GENERAL SAFETY	FRA/ 49 CFR	AAR/ INDIVIDUAL RAILROADS	OTHER U.S.	GERMAN	UIC/ OTHER FOREIGN	COMPARISON	COMMENTS
SAFETY/SYSTEM SAFETY	211-236: Define topics and regulations related to railroad (RR) safety, in the context of FRA's mission: "The purpose of the national RR safety program is to promote safety in all areas of RR operations in order to reduce deaths, injuries and damage to property resulting from RR accidents" (212.101).	AAR: No requirements. Individual railroads use their own.	MIL-STD 882B, System Safety Program Requirements, July 1987 FAA AC 25.1309-1 A System Design and Analysis. FAA: Part 25.1309 A Equipment, Systems and Installations (6/21/88) APTA: Manual for the Development of System Safety Program Plan. FAA: FAR 91.105	TÜV, Folios 0, 1 refer to DIN, VDE definitions VDI 2244:Design Standards for Products with Proper Safety Features DIN VDE 31000, T 2, 12/87, and VDE 1000, General Guide to Safety Design of Technical Products DIN VDE 0831 or MUe (German Fed. RR. Reg.) 8004: Defines safety level customary in RR engineering. DIN V31004 Defines operational safety so as not to exceed a certain risk limit.	MBO,3/88: Ch.1: "Facilities and vehicles must be safe: "Safety measures (1.7); railway safety systems (2.4); Restrictions for vehicles (safety envelope) (3.3);travel safety (4.3)		

TABLE D-1. SAFETY REGULATIONS, GUIDELINES, AND REQUIREMENTS POTENTIALLY APPLICABLE TO MAGLEV

GENERAL SAFETY	FRA/ 49 CFR	AAR/ INDIVIDUAL RAILROADS	OTHER U.S.	GERMAN	UIC/ OTHER FOREIGN	COMPARISON	COMMENTS
SAFETY/SYSTEM SAFETY (con't)			NFPA 101, Life Safety Code. NFPA 130, Standard for Fixed Guideway Transit Systems. MIL-STD-882B-1('86): System Safety Program Requirements for Space Systems and their Facilities MIL-STD-1574 A (rev'85): System Safety Program for Space and Missile Systems. NASA: NHB 1700.1, NASA Safety Manual				

TABLE D-1. SAFETY REGULATIONS, GUIDELINES, AND REQUIREMENTS POTENTIALLY APPLICABLE TO MAGLEV

GENERAL SAFETY	FRA/ 49 CFR	AAR/ INDIVIDUAL RAILROADS	OTHER U.S.	GERMAN	UIC/ OTHER FOREIGN	COMPARISON	COMMENTS
FAIL-SAFE SYSTEMS and SAFE-LIFE			UMTA, Safety in Urban Mass Transportation: Guidelines Manual. (Battelle) FAA: FAR 91.105 FAA: AC 25.1309-1A System Design and Analysis.	TÜV: Folio 0, Definitions.of fail-safe and safe-life. Folio 1, Acceptance tests are required to prove fail-safe behavior; and FTA and acceptance tests are needed to prove safe-life. DIN25,448(6/8): Failure Effect Analysis reqs. VDI/VDE 3542, 12/88: Ability of technical system to remain in safe state, or switch to another safe state for certain types of break-down; Reliability, redundancy and fail-safe design of safety-critical systems. VDI 2244, 5/88, safe-life def: During the anticipated service life, neither the product as a whole, nor any of its critical subfunctions may fail.	MBO: implicit in Safety measures (1.7); railway safety systems (2.4); travel safety (4.3)		Operating error is most significant cause of accidents.

TABLE D - 1. SAFETY REGULATIONS, GUIDELINES, AND REQUIREMENTS POTENTIALLY APPLICABLE TO MAGLEV

GENERAL SAFETY	FRA/ 49 CFR	AAR/ INDIVIDUAL RAILROADS	OTHER U.S.	GERMAN	UIC/ OTHER FOREIGN	COMPARISON	COMMENTS
RELIABILITY AND REDUNDANCY	No specific reliability requirements are made at system level, or at safety-critical subsystem level, beyond specified subsystem design and operating, maintenance, and inspection requirements.		DoD H-108: Sampling procedure and table for life and reliability testing. MIL-R-22732: Reliability requirements for shipboard electronic equipment. MIL-R-26484 Reliability. reqs for develpment of electronic subsystems for equipment. MIL-R-22667 Gen. specs. for reliability and longevity for electronic equipment. MIL-R-22973 Gen. specs. for reliability. assurance for product acceptance of avionic equipment. MIL-STD-721: Definitions for Reliability Engineering. MIL-STD-785: Requirements for Reliability Program (Systems and Equipment). NASA NPC-250-1: Reliability Program provisions for space Systems Contractors.	TÜV, Folio 1: General reliability and redundancy requirements for safety-critical functions and subsystems (e.g. levitation function, power supply, control system, braking system). DIN 40,041E, 11/88: Definition of redundancy. DIN VDE 0831: Reliability level of information installation to preclude loss of information. VDI/VDE 3542, 12/88:Reliability, redundancy and fail-safe design of safety-critical systems. VDI 2244, 5/88: (see previous page) MBO: Implicit in Secs.3.3-Restrictions for vehicles and 2.4 railway safety systems. VDI 4005: Effect of environment-al conditions on reliability of technical products			

TABLE D-1. SAFETY REGULATIONS, GUIDELINES, AND REQUIREMENTS POTENTIALLY APPLICABLE TO MAGLEV

GENERAL SAFETY	FRA/ 49 CFR	AAR/ INDIVIDUAL RAILROADS	OTHER U.S.	GERMAN	UIC/ OTHER FOREIGN	COMPARISON	COMMENTS
AVAILABILITY				DIN 40,041E, 11/88: Definition: probability of encountering a unit, at any given time within the required service life, in a functionally capable state; Availability and MTBF of safety-critical systems.			
QUALITY ASSURANCE (See also Table D-2, Vehicle Certification)				TUV:Folio 7, Design, Production, and Quality Assurance of Mechanical Structures			

TABLE D-2. SAFETY REGULATIONS, GUIDELINES, AND REQUIREMENTS POTENTIALLY APPLICABLE TO MAGLEV

VEHICLE	FRA/ 49 CFR	AAR/ INDIVIDUAL RAILROADS	OTHER U.S.	GERMAN	UIC/ OTHER FOREIGN	COMPARISON	COMMENTS
STRUCTURAL STRENGTH	229.141: For MU locomotives only. For train empty weights, above and below 600,000 lb. Requirements for buff strength, collision posts (number and shear strength), truck-to-body shear strength, anti-climbing arrangement/ vertical strength, and vertical coupler strength. Loads must be sustained without deformation of structure except collision posts and truck-to-body.	AAR: All passenger cars exceeding 600,000 lb. per FRA MU Requirements. Commuter and intercity rail service operators must meet above requirements. Structural test required to confirm buff strength requirements. Design calculations to be submitted for other strength requirements.	FAR25.301-30: Definition of Loads and Proof of Structure FAR 25.331(d): Gust Conditions; FAR 25.571: Damage tolerance and fatigue evaluation of structure.	EBO, Ch.24, Traction and Buffing Equipment; Buffing and coupling layout spring requirements. TÜV: Folio 5, Load Assumptions for vehicle loads, free body forces, and excluded loads (includes environment) Folio 6, Stability Analyses Folio 7, Vehicle Design, Production and Quality Assurance of Mechanical Structures MBO, Ch.3: includes basic strength reqs. for vehicles DIN 18200: Quality Control of construction materials and structural parts.	566: Minimum forces for longitudinally and diagonally at buffer level, 330 mm above buffer level, at center rail level, at cant-rail level, and tensile level. Car end wall/anti-collision pillars must absorb collision energy and retain high resistance to override shear forces. 515: 50,000 lb. truck to body shear strength forces. Japan: Buff strength is 222,000 lb. TGV: Articulation design is capable of sustaining substantial vertical loads.	European truck-to-body strength force is a function of car and truck (50,000 lbs would be typical). For structural strength, UIC load values for locomotive body are much lower than FRA/AAR. Strength differences are similar for both foreign locomotives and passenger cars, except that there is no coupler/anticlimber or truck-to-body shear strength requirement; however, passenger locomotives will have anticlimbing couplers. Buffers and screw-tensioned chain couplers which cannot sustain vertical loads are commonly used in Europe. UIC: Has no requirement for vertical anti-override coupler or anti-climber force except that passenger locomotives will have anti-climbing couplers; however, U.S. style or transit couplers are used in many instances.	The higher the speed, the greater the structural deformation in an accident. Re FAR 25.341: Unlike this FAR, must assume for maglev loading from a combination of high speed and severe gusts, since maglev operates at low altitude and high speeds. FAR 25.571 Could apply to maglev suspension and guideway components, and to some other car body components.

TABLE D - 2. SAFETY REGULATIONS, GUIDELINES, AND REQUIREMENTS POTENTIALLY APPLICABLE TO MAGLEV

VEHICLE	FRA/ 49 CFR	AAR/ INDIVIDUAL RAILROADS	OTHER U.S.	GERMAN	UIC/ OTHER FOREIGN	COMPARISON	COMMENTS
LOCOMOTIVE (DRIVER) CAB CRASH-WORTHINESS	No overall structural strength requirements. 229.123: Lead locomotive requires adequate pilot, end plate, or snow plow.	AAR: Detailed strength requirements for engineer seats. AMTRAK: None.		EBO, Ch.28, Tractive Unit Equipment: Requires cow-catcher (pilot), speed indicator, etc. No specific reference to structural integrity of cab.	617-5: Locomotives must meet same standards as MU cars plus a structural design that protects space occupied by engineer, with deformations and energy absorption in front of, and behind this space. TGV: Has considered above requirement for high-speed design. UK: Requires a snowplow capable of sustaining 66 ton impact on unpowered cab cars.	Design of cab structure such that crush strength of space occupied by train crew is higher than surrounding structures has no U.S. equivalent. No foreign requirement (except UK) for pilot or snow plow.	Head-end train crew could be especially vulnerable in high-speed crash.

TABLE D - 2. SAFETY REGULATIONS, GUIDELINES, AND REQUIREMENTS POTENTIALLY APPLICABLE TO MAGLEV

VEHICLE	FRA/ 49 CFR	AAR/ INDIVIDUAL RAILROADS	OTHER U.S.	GERMAN	UIC/ OTHER FOREIGN	COMPARISON	COMMENTS
LOCOMOTIVE CAB (DRIVING) WINDOWS (GLAZING) (See also Fire Safety and Emergency Access/Egress)	223: Windows must sustain impact of 24 lb. object, 8" by 8" at 44 ft/sec., and 0.22 caliber rifle bullet at 960 ft./per sec. with no penetration. Distortion-free view of R-O-W. Side-facing windows must sustain impact of 24 lb. object, 8" by 8" at 12 ft/sec., and same rifle bullet requirement as above.	None	FAR: 25.631 Bird Strike Damage (8 lb. Bird at Vc)	EBO, Ch.29: Requires safety glass on all windows, doors and walls MBO, Ch.3: Sec.3.4, safety glass on windows, doors and walls (mirrors)	617-4, 617-7, 651: Forward facing windows require resistance to penetration by sharp objects, provide visibility even if partially damaged, and if broken, have no sharp-edged fragments. Side facing windows and other glass (internal doors, gauges, etc.) require safety glass.	UIC does not have specific impact requirements.	The greater the speed, the greater the effect of striking objects, particularly forward facing windows.
PASSENGER CAR SIDE WINDOWS	Same impact requirements as above.	None		EBO, Ch.29: Railroad Car Equipment: Requires safety glass on all windows, doors and walls MBO, Ch.3: Sec.3.4, safety glass on windows, doors and walls (mirrors)	564-1: All windows must be toughened or laminated or safety glass, including both panes of double glazing.	U.S. glazing materials are both more specific and more stringent than European, because of the greater likelihood of foreign objects on tracks, vandalism, and use of firearms.	

TABLE D-2. SAFETY REGULATIONS, GUIDELINES, AND REQUIREMENTS POTENTIALLY APPLICABLE TO MAGLEV

VEHICLE	FRA/ 49 CFR	AAR/ INDIVIDUAL RAILROADS	OTHER U.S.	GERMAN	UIC/ OTHER FOREIGN	COMPARISON	COMMENTS
NON-STRUCTURE: LOCOMOTIVE (Driver) CAB (Including acceleration/deceleration resistance for components, noise, lighting, etc.)	229.119: Adequate door and seat fastenings, non-slip floors, "tidiness," adequate heating and ventilation. 229.121: 8-hour weighted sound level not to exceed 90 Dba. 229.127: Illumination of in-cab instruments and reading light.	AAR: All cab interior fittings and surfaces must be rounded and otherwise designed to minimize risk of injury. Strength requirements for locomotive engineer seats.		EBO, Ch.28: Tractive Unit Equipment: No specific interior safety issues Requires spark arresters, etc., when liquid fuel is being burned. MBO, Ch.3: Sec.3.4 requires front and back end lights and audible warning system. Specific requirements for materials and construction to meet state of the art in fire protection	617-5: Avoid sharp edges, etc., to minimize injuries from cab internal fittings and surfaces. Secure all heavy locomotive structures so as not to break away in sudden acceleration, to withstand ± 3 g longitudinally. Proper protection against hazards such as high voltage, hot surfaces, etc.	No national or international requirements for unpowered cab cars.	Non-structural car features have had a significant impact on the number and severity of train accidents. If high speed accidents result in greater train deceleration, risk of injuries due to secondary impact could be greater. High speeds may mean less margin for human error; therefore, any feature which improves working environment could result in reducing risk of such areas. Standard Practice: Good human factors design of controls and instruments.

TABLE D - 2. SAFETY REGULATIONS, GUIDELINES, AND REQUIREMENTS POTENTIALLY APPLICABLE TO MAGLEV

VEHICLE	FRA/ 49 CFR	AAR/ INDIVIDUAL RAILROADS	OTHER U.S.	GERMAN	UIC/ OTHER FOREIGN	COMPARISON	COMMENTS
NON-STRUCTURAL: PASSENGER CAR (Including acceleration/ deceleration resistance for components, lighting, etc.)	No regulations for strength or nature of car interior fittings. 221: Rear end lights.	AMTRAK: Interior car fittings including seating, partitions, baggage racks, etc., must withstand: 6g longitudinal, 3g vertical, and 3g lateral accelerations.		EBO, Ch.29, Railroad Car Equipment: Warning signage required, lighting and heating equipment specs, safety appliances for crewmen. MBO: Sec 3.4, front and end of car lighting, audible warning signals Sec 3.11, signage & posting general requirementss for maglev.	566: Car components must withstand 5g longitudinal, 1g lateral, and 3 g vertical acceleration. Safety design factor of 1.5 against deformation. Overhead baggage racks must withstand 137 lb/ft plus 191 lb at any point on front edge. Canada (draft): Aircraft style overhead baggage bins. Heavy baggage to be segregated from seating and stored in racks with restraints meeting 5 g longitudinal, both panes of double glazing.	In general, U.S. regulations and standards are less detailed than Europe or Canada. However, where standards do exist, they are similar. Standards regarding baggage restraint are generally lacking in U.S. although similar in actual practice. No requirments by any national or international code for avoidance of sharp hard surface or other ways to reduce secondary impact injuries in passenger cars.	Non-structural car features have had a significant impact on the number and severity of train accidents. If high speed accidents result in greater train deceleration, risk of injuries due to secondary impact between car occupants and hard surfaces, flying baggage, and detached components could be greater than from gross crushing of the car.

TABLE D-2. SAFETY REGULATIONS, GUIDELINES, AND REQUIREMENTS POTENTIALLY APPLICABLE TO MAGLEV

VEHICLE	FRA/ 49 CFR	AAR/ INDIVIDUAL RAILROADS	OTHER U.S.	GERMAN	UIC/ OTHER FOREIGN	COMPARISON	COMMENTS
PASSENGER CAR DOORS (See also Emergency Access/Egress)	No regulations regarding door operation. 231: Various steps and handholds at the end of car and at doors.	AAR: Sliding doors shall be used. Outwardly opening exterior doors are acceptable to most operators.		EBO, Ch.29, Railroad Car Equipment: Locking requirements for doors, pinch protection on doors, sliding door requirements, safety glass requirements. MBO: Sec 3.4: Requirements for safety glass for doors, emergency exits, and general reqs for door locks and status supervision and control.	560: Doors are automatically closed and locked at speeds exceeding 5 km/h. Doors must have pressure-sensitive edge and be programmed to open for 10 sec. when obstructed. Entrance must be adaptable to platform edges of between 12 and 36 inches. Canada (draft): Door requirements are similar to UIC.	Use of automatically operated sliding plug doors is becoming universal on European rail systems. Standards regarding automatic door operation are lacking in U.S. although there is little difference in actual practice.	

TABLE D-2. SAFETY REGULATIONS, GUIDELINES, AND REQUIREMENTS POTENTIALLY APPLICABLE TO MAGLEV

VEHICLE	FRA/ 49 CFR	AAR/ INDIVIDUAL RAILROADS	OTHER U.S.	GERMAN	UIC/ OTHER FOREIGN	COMPARISON	COMMENTS
FIRE SAFETY MATERIALS AND DEVICES (See also Emergency Features/ Equipment)	FRA Rail Passenger Equipment Guidelines for Selecting Materials to Improve their Fire Characteristics. Federal Register, January 17, 1989 These guidelines cover fire and smoke emission limits for seating, walls and ceilings, glazing, floors, etc.	AAR Manual of Standards and Practices: For wiring and other electrical installations, for locomotives and power cars.	NFPA101, Life Safety Code NFPA 130, Standard for Fixed Guideway Transit Systems. FAR 25.851, Fire Extinguishers. FAR 25.853:App F, part III and IV, Fire testing of material samples for qualification (burn thru and radiation tests) FAR 25.1357, Circuit Protective Devices. FAR 25.1359 (b) thru(d), Electrical System Fire and Smoke Protection. FAR 25.581, Lightning Protection. APTA, Manual for the Development of System Safety Program Plan.	TUV: Folio 11, Fire protection. MBO: Sec.3.4: Fire protection requirements for maglev car materials and construction to comply with state of the art DV 899/35, Sec VI, FRG Memo Testing combustibility of materials. DV899/55, Memo for testing fire behavior of solid materials for RR. DIN 4102: Fire behavior of construction materials and structural parts. Part 1, Maglev is Class A: choice of incombustible materials. Parts 2,4,5: Qualification testing. DIN 5510: (6 parts): Preventive fire protection in rail vehicles. Part 1: Fire protection stages (maglev is grade 4), measures, records.	564-2: Suitable electrical conduit. Flammability and smoke emission standards for non-metallic materials Fire testing.on specimens or models (App A, Method A or B) 642: (For motive power units and cabs) Floors and bulkheads must be fire barriers. Portions of 564-2 OR as relevant. UK: British Standard 6853.1987. Similar to 564-2 OR and 642 plus smoke alarms. More stringent requirements for trains operating in tunnels or on elevated structures.	Flammability and smoke emission standards appear to be broadly similar. British add smoke alarm requirement and requirements for elevated structures.	Vandalism is a significant cause of fires in the U.S. Elevated structure could be an issue during emergency to get away from fire; see also Emergency Access/Egress.

TABLE D - 2. SAFETY REGULATIONS, GUIDELINES, AND REQUIREMENTS POTENTIALLY APPLICABLE TO MAGLEV

VEHICLE	FRA/ 49 CFR	AAR/ INDIVIDUAL RAILROADS	OTHER U.S.	GERMAN	UIC/ OTHER FOREIGN	COMPARISON	COMMENTS
FIRE SAFETY MATERIALS AND DEVICES (Continued)			FAR 125 Subpart E Special airworthiness requirements for cabin interiors, firewalls, etc.	DIN 5510 (con): Part 4:Vehicle design, safety engineering requirementss. Part 5: Fire safety for operating electrical equipment. Part 6: Automatic fire alarms and testing; function of emergency brake and information systems. DIN 18200: General principles of monitoring, testing, and quality control of construction materials and structural parts DIN 50060: Testing of fire behavior of materials and products. DIN VDE 0266: Halogen-free cable insulation for improved performance in a fire.	DS 899/35, Sec.VI: Reqs. for testing of flammable materials used in maglev structures (e.g. smoke development) ATS 1000.001, Air Bus Industry- fire, smoke & toxicity test specs.(sec. 7.3)		

TABLE D-2. SAFETY REGULATIONS, GUIDELINES, AND REQUIREMENTS POTENTIALLY APPLICABLE TO MAGLEV

VEHICLE	FRA/ 49 CFR	AAR/ INDIVIDUAL RAILROADS	OTHER U.S.	GERMAN	UIC/ OTHER FOREIGN	COMPARISON	COMMENTS
EMERGENCY ACCESS/EGRESS		AAR: Manual 4 emergency exits of minimum size 18" by 24" are required for each 85 ft. long passenger car. Maximum size of windows is 1100 sq. inches to minimize the risk of passenger ejection. Doors must be capable of being opened from inside and outside and swing out.	NFPA: 130, Standard for Fixed Guideway Transit Systems. NFPA: 101, Fire and Life Safety Code. FAR 25.803, Emergency Evacuation. Demonstration of emergency evacuation procedure UMTA: Recommended Emergency Preparedness Guidelines for Rail Transit Systems. Recommended Emergency Preparedness Guidelines for Elderly and Disabled Rail Transit Passengers. Recommended Emergency Preparedness Guidelines for Urban, Rural, and Specialized Transit Systems.	TUV: Folio 12, Rescue Plan. MBO, Sec.3.4: emergency exits are provided, and audible warning signals and 2-way emergency communications system are required.	560: Automatic doors must have an emergency means of being opened manually from both inside and outside of car. 564-1: At least 2 windows per car (1 on each side) to be emergency escape windows. 617-5: At least 1 window on each side to be breakable and large enough to serve as an emergency escape. 617-5: Unimpeded emergency passage to be provided to opposite end of engineer's cab. UK 6853: 1987: Emergency means to open doors normally locked.	Emergency escape requirements for passenger cars are similar. No U.S. equivalent to UIC requirement for emergency escape windows from locomotives and driving cabs. No European equivalent of the U.S. maximum size window requirements.	

TABLE D-2. SAFETY REGULATIONS, GUIDELINES, AND REQUIREMENTS POTENTIALLY APPLICABLE TO MAGLEV

VEHICLE	FRA/ 49 CFR	AAR/ INDIVIDUAL RAILROADS	OTHER U.S.	GERMAN	UIC/ OTHER FOREIGN	COMPARISON	COMMENTS
EMERGENCY FEATURES/ EQUIPMENT (See also Fire Protection)	231: 1 handbrake per car situated so that it can be operated with the car in motion. 221: Rear end lights. No specific requirements for fire fighting equipment (extinguishers, suppression systems, etc.)	AAR: Manual Section A, Part III: Emergency lighting, independent of normal power supply. Wrecking tool cabinet to include ax and sledge-hammer. Conductor's brake valve for initiation of emergency stop.	NFPA: 130, Standard for Fixed Guideway Transit Systems NFPA: 101, Fire and Life Safety Code. UMTA: See Recommended Guidelines cited previously.. FAR 25.851, Fire Extinguishers. FAR 25.1359 (b) thru(d), Electrical System Fire and Smoke Protection. FAR 25.581, Lightning Protection. APTA: Manual for the Development of System Safety Program Plan	TUV: Folio 12, Rescue Plan. EBO, Ch.26, Signal Brackets and Configuration of Rear Signal Lights. EBO, Ch.29, Railroad Car Equipment, Sec. 748, Warning Signs. MBO,Sec.3.4- General principles of maglev vehicle design (safety zones, fire protection, rescue, emergency commun-ications, etc.	564-2R: 6 kg fire extinguisher in each car (2 in diners and sleeping cars). 642: (For motive power units and cabs) Portable fire extinguishers must be provided. Engine room (fossil fuel powered units) must have automatic engine power shut down and fire extinguishing system.	Emergency lighting requirements are similar.	

TABLE D-2. SAFETY REGULATIONS, GUIDELINES, AND REQUIREMENTS POTENTIALLY APPLICABLE TO MAGLEV

VEHICLE ISSUES	FRA/ 49 CFR	AAR/ INDIVIDUAL RAILROADS	OTHER U.S.	GERMAN	UIC/ OTHER FOREIGN	COMPARISON	COMMENTS
TRUCK DESIGN AND CONSTRUCTION	229: Detailed maximum wear and other dimensional requirements relating to locomotive trucks; maintenance rather than construction; locomotive cab noise limits. 215: Freight car components (although not for passenger cars, the intent may be relevant).	AAR:Manual Section G for wheels and axles and Section H for rolling bearings are selectively applied to passenger cars. Passenger car axle specs. and materials specs. for i.e., roller casings are in Section A.	FAR 25, Subpart (d), Design and construction, specifically: 25.601 thru 631, For materials properties, specifications and QA.	EBO, Ch.32, Vehicle Acceptance and Inspection: Vehicles must be systematically inspected. Record-keeping required. MBO, Ch.3: Basic requirements for maglev vehicles, including loads and construction materials.	515: Maximum axle load 17.6 tons. Internal bearings are not permitted due to incompatibility to existing hot box detectors. Electrical grounding per UIC 552. If pneumatic suspension (air springs) are used, car must operate safely with springs deflated at maximum speed. Fatigue tests of truck frame is required for new designs.	No formal U.S. equivalent to UIC truck frame test requirements. Unclear of applicability to Maglev except that axle load, electrical grounding and suspension system items are related.	Dynamic loads on all components will increase at high speed.

TABLE D - 2. SAFETY REGULATIONS, GUIDELINES, AND REQUIREMENTS POTENTIALLY APPLICABLE TO MAGLEV

VEHICLE	FRA/ 49 CFR	AAR/ INDIVIDUAL RAILROADS	OTHER U.S.	GERMAN	UIC/ OTHER FOREIGN	COMPARISON	COMMENTS
BRAKE INSTALLATION AND PERFORMANCE	232: Testing, inspection, and maintenance, not construction. 85 % of all cars in train must be braked. Brakes must be capable of operating in emergency mode at all times even during a service brake application. Primarily for freight train operation.	AAR: Out-of-date and do not reflect current high speed practice. AMTRAK Requires braking rate of 2.5 mph/sec. in NE Corridor. 26CS-1 Electro-pneumatic brake control system used. Wheel slide protection. 2 Disk brakes per axle plus wheel tread brake friction brake. Hand brake operated from inside car and conductor's valve to initiate emergency braking must be fitted within each car.		EBO, Ch.23, Brakes: Continuous brake is required; Activation requirements (handles and locations). EBO, Ch.35, Equipping Trains with Brakes: Required braking distances (1000m), brake test requirements. MBO, Sec.3.6: Braking system for maglev must include 2 independent systems; Sec.4.2 : Brake testing.	540-546: Emergency braking rate of 1.9 mph/sec. Additional foreign: Brake design and performance for speeds above 125 mph is currently responsibility of individual operator.	Some foreign systems use dynamic braking by power car and eddy current track brakes to improve emergency braking performance. UIC and US electro-pneumatic brake system w/ wheel slide are similar. Automatic brake condition monitoring systems being introduced on TGV will help safeguard against brake failure.	Although Maglev equipment does not have wheels, the concept of braking requirements is applicable. Although not accepted US practice, each dynamic/eddy current brake truck has independent power supply (i.e. batteries) to insure adequate integrity. Braking duty more severe at high speed. Total energy to be dissipated increases with the square of speed and instantaneous power dissipation with the cube of speed. Actual braking rates must be compatible with the stopping distances required by the signal system design. Accidents will be more severe at high speeds.

TABLE D-2. SAFETY REGULATIONS, GUIDELINES, AND REQUIREMENTS POTENTIALLY APPLICABLE TO MAGLEV

VEHICLE	FRA/ 49 CFR	AAR/ INDIVIDUAL RAILROADS	OTHER U.S.	GERMAN	UIC/ OTHER FOREIGN	COMPARISON	COMMENTS
INSPECTION AND MAINTENANCE	229: For locomotives only. Locomotives must receive a daily and more detailed 3 month, annual, and bi-annual inspection by a qualified person, and reports must be kept. Detailed requirements for condition of suspension systems, wheels, axles, brakes, and electrical equipment.	AAR: Manual Section A, Part III, for brakes and couplers. AMTRAK: Yes, but not specified.	FAR 21.50, Requirements for continuing maintenance to maintain airworthiness. FAR 21.99, Enforcement of Airworthiness Directive.	EBO, Ch.32, Vehicle Acceptance and Inspection: Vehicles must be systematically inspected. Record-keeping required. EBO, Ch.33, Vehicle Equipment Requires Monitoring. EBO, Ch.35, Equipping Trains with Brakes: Sec 7: Brake test prior to operation and when cab or cars are changed, except when only added to. MBO, Ch.4: Inspection and maintenance not explicit, but checkout and safety responsibility before a trip implies them.	UIC: Contains some standards (not specified) for brake systems, wheels, axles, and bearings. TGV: Includes schedule for visual, and testing of operational systems, interior (lighting, HVAC, etc.) running (trucks and brakes), 2 levels of inspection for mechanical and general inspection, and part disassembly and inspection. On board monitoring systems to detect malfunctions. Japan: Daily visual for brakes, pantograph contact strip, doors, etc.; monthly workshop inspection of electrical equipment, trucks, bearings, axles, etc.; annual inspection involving removal and partial disassembly of trucks; and full overall inspection every 3 years. Body ride quality is also monitored regularly.	Actual structure of inspection intervals seems similar both for U.S. and others; however, acceptability standards may be different.	Tolerances for wear, deterioration, etc. will be smaller in high speed operations, requiring more frequent inspection intervals than traditional normal speed rail service.

TABLE D-2. SAFETY REGULATIONS, GUIDELINES, AND REQUIREMENTS POTENTIALLY APPLICABLE TO MAGLEV

VEHICLE	FRA/ 49 CFR	AAR/ INDIVIDUAL RAILROADS	OTHER U.S.	GERMAN	UIC/ OTHER FOREIGN	COMPARISON	COMMENTS
TRAIN-GUIDEWAY (TRACK) INTERACTION	213: Maximum cant deficiency of 3 inches. No other regulations regarding train-track forces, lateral/vertical force ratios, etc. Research (1980-81) has investigated overturning, wheel climb, rail rollover, and track panel shift. What about issue of curve (spiral) design, is there a FRA reg?	No established standards for train-track interaction. Vertical impact maximum axleload acceptable by AAR Interchange rule is 66,000 lbs.	FAR 25.23, Load Distribution Limits. FAR 25.25, Weight Limits. FAR 25.181, Dynamic Stability. FAR 35.251, Vibration and Buffeting FAR 25.255, Out-of-Trim Characteristics. FAR 35.367, Unsymmetrical Loads due to Engine Failure.	EBO, Ch.40, Travel Speed: Max. speed set by make-up of train. MBO: Sec.2.1.6- Guideway dimensioning to withstand all resulting loads (interaction implicit) Sec.4.4, Speed selection and safe speed	None listed.		Train/track dynamics typically lead to derailments which will be more severe at high speed. FAR 25.25 is more applicable to superconducting maglev with large gaps(>1 in), specifically to flutter instability resulting from combination of aerodynamic and magnetic suspension forces. The maglev analog to FAR 25.367 is an asymmetrical suspension failure, and ability of maglev to avoid high speed asymmetrical touchdown.
CERTIFICATION			FAR 21.19, Significant design change requires re-certification. FAR 21.31- Definition of "type design." FAR 21.127, Pre-service Quality Assurance Test on each vehicle. FAR 21.305 (b), Technical Standard Orders (TSO) for 3rd party manufactured parts. FAR 21.601 thru 621, Details of administration of TSO system.	TUV: Rheinland Certification and Test Requirements for maglev service operation.			

TABLE D - 3. SAFETY REGULATIONS, GUIDELINES, AND REQUIREMENTS POTENTIALLY APPLICABLE TO MAGLEV

GUIDEWAY (TRACK)	FRA/ 49 CFR	AAR/ INDIVIDUAL RAILROADS	OTHER U.S.	GERMAN	UIC/ OTHER FOREIGN	COMPARISON	COMMENTS
DESIGN AND CONSTRUCTION NOTE: Maglev guideways do not use ties, rails or ballast. Therefore, this table does not contain detailed reference in most cases to these items, unless potentially applicable.	213.57: Maximum cant (super-elevation) = 6 inches. 213.59: Run off of cant in each 31 feet must exceed that specified for track class. No slab track standards.		AREA: Detailed material and performance requirements for track components. Chapter 1, Roadway and Ballast. Also, extensive info on bridge construction and other structures and many other aspects of railroad civil engineering. Chapter 17, high speed rail is under development. NFPA: 130, Standard for Fixed Guideway Transit Systems	TUV: Folio 5, Load Assumptions. Folio 6, Stability Analyses. Folio 7, Design, production, and quality assurance of mechanical structures. Folio 8, Switch. DS804, Regulation for RR bridges and miscellaneous engineering structures (e.g., environmental stresses, loads on guideway, switches, pillars) D899/59, Special provisions for RR bridges and new RR lines. DV899/35 re: fire behavior, (combustibility, smoke) of RR materials. DV899/55, memo for testing fire behavior of solid materials for RR. DIN 4102, Fire behavior of construction materials and structural parts. EBO, Ch.10, Distance Between Running Lines (min 4 m).	700: Classification of lines and wagon load limits. 703: Layout characteristics of lines used by fast passenger trains. 711: Geometry of turnouts for speeds exceeding 62 mph. 714: Classification of lines for the purpose of track maintenance. Japan: Movable point frogs are commonly used on high speed turnouts.	Slab track is extensively used in Japan, selective use elsewhere. U.S. uses slab track only on mass transit systems and a very few selected locations in tunnels.	Temperature extremes in the U.S. are typically greater than in Europe or Canada. This could potentially lead to switch buckling incidents under high-speed train loads; especially if these involve high cant deficiencies. Track caused accidents are mainly related to deficiencies in maintenance and inspection rather than original construction.

TABLE D-3. SAFETY REGULATIONS, GUIDELINES, AND REQUIREMENTS POTENTIALLY APPLICABLE TO MAGLEV

GUIDEWAY (TRACK)	FRA/ 49 CFR	AAR/ INDIVIDUAL RAILROADS	OTHER U.S.	GERMAN	UIC/ OTHER FOREIGN	COMPARISON	COMMENTS
TRACK (GUIDEWAY) INSPECTION AND QUALITY NOTE: Maglev guideways do not use ties, rails or ballast. Therefore, this table does not contain detailed reference in most cases to these items, unless potentially applicable.	213: Minimum track quality standards as function of speed and inspection standards as a function of speed and/or traffic density. For Class 6 includes geometry, good drainage and absence of excessive vegetation, frogs, and switches. Visual or automatic inspections twice weekly monthly for switches and crossings, and annual automatic rail defect inspection.	AMTRAK: Operates a track geometry car on the 125 mph sections of the NE Corridor.	AREA Committee 2: Automatic track inspection techniques. AREA Committee 32: Management of track data. Committee 17: High Speed Rail	EBO, Ch.17, Railroad Inspection and Supervision: General requirements. to inspect the RR in a systematic manner. MBO, Ch.2: Includes Roadway, and RR Safety Systems requirements for maglev facilities. MUE 8004: Safety level typical of RR engineering	UIC codes include gauge, alignment, surface, and cross level standards for track geometry. SNCF: Weekly acceleration recording on board train, maximum acceptable transverse acceleration 0.15. Track geometry car every 3 months, and rail defect car, year 1 and 7 after new track is laid, and every 2 years following. Japan: Track inspection car survey every 10 days, acceleration recording on-board every 2-3 days, and higher capability track inspection car every 3 months.	Track geometry measurement bases and definitions differ from U.S. Most U.S. railroads operate a track geometry car at typically 6 to 12 month intervals.	Highest FRA track class is Class 6 for passenger trains up to 110 mph. Accidents, particularly derailments will have more severe consequences due to high speed.

TABLE D-3. SAFETY REGULATIONS, GUIDELINES, AND REQUIREMENTS POTENTIALLY APPLICABLE TO MAGLEV

TRACK (GUIDEWAY)	FRA/ 49 CFR	AAR/ INDIVIDUAL RAILROADS	OTHER U.S.	GERMAN	UIC/ OTHER FOREIGN	COMPARISON	COMMENTS
RIGHT-OF-WAY SECURITY	None	Individual railroads: Rock slide detectors (fragile wire) and high wind detectors are used in certain locations.	AREA Manual: Specifications for fences only, but not where they should be except for snow fences. AREA Committee 17 specifics in this area are currently under development	TUV: Folio 9, Operational control system, Folio 4, On-board control system, Folio 8, Switch EBO, Ch.11: RR crossings surveillance requirements. EBO, Ch.17, RR Inspection and Supervision, may also apply. MBO, Sec.4.3: Re: travel safety (roadway must be free and clear, and safe spacing); Sec 2.4 Re: safety systems and railway security.	No requirements for universal fencing. New French and Japanese high speed lines are fully fenced throughout, other lines are fenced as determined necessary. All railroads in U.K. have always been fenced. SNCF: Has installed intrusion detection along R-O-W shared with major highways. Japan: Hazard detection devices for earthquakes, heavy snowfall and high winds are used extensively and are linked to the train control system . An alarm triggers speed reductions or cessation of service. 730-3/965 R: Automatic systems for warning track personnel of approaching trains.	U.S. practice is not to fence R-O-W except where special protection is considered warranted. Some type of intrusion/ warning device is used in all countries.	Earthquake and weather hazards are dependent on location. Any accident involving a high-speed train hitting an object or person will be more severe than at lower speeds. There is a greater risk of vandalism in U.S. than other countries. There is a greater awareness of dangers of frequent, swift, and silent trains.

TABLE D - 4. SAFETY REGULATIONS, GUIDELINES, AND REQUIREMENTS POTENTIALLY APPLICABLE TO MAGLEV

SIGNALING, COMMUNI-CATIONS, AND ELECTRIFICATION	FRA/ 49 CFR	AAR/ INDIVIDUAL RAILROADS	OTHER U.S.	GERMAN	UIC/ OTHER FOREIGN	COMPARISON	COMMENTS
SIGNAL AND TRAIN CONTROL DESIGN	236: Trains operated at 80 mph or above must have automatic cab signal, automatic train stop(ATS) or automatic train control (ATC) system complying with detailed requirements in 236. Shall operate in connection with an automatic block signaling system, displaying same or more restrictive signal in cab and/or initiate braking if a restrictive signal is passed and engineer fails to initiate braking. Braking must be initiated early enough for the train to stop before an occupied block or conflicting turnout setting.	AAR: Very detailed set of signal system standards and practices.	AREA: Committee 17 is developing requirements for high-speed rail	TUV: Folio 4, On-board Control System and Folio 9, Operational Control Equipment: Requirements for maglev signal and control subsystem for safety in design and operations logic. DIN VDE 0831: Electric RR Signaling Systems DIN 57 831/ VDE 0831: Electrical signaling systems safety for railroads. VDI/VDE 3542: Reliability, redundancy and fail-safe design of safety- critical systems. DIN 40 041E: Availability and MTBF of safety-critical systems. DIN 57 160/VDE 160: Electronic equipment to be used in electrical power installations, and their assembly into electrical power installations.	734 : For high speed lines: Traditional lineside signals are acceptable up to 87-100 mph. Between 100 and 125 mph traditional signals should be enhanced by cab signals and/ or automatic train control and an additional signal aspect or other form of advance warning of a restrictive signal aspect must be provided to accommodate the longer braking distances at higher speed. Above 125 mph, full cab signaling and continuous train control must be provided. Speed supervision should include all temporary and permanent civil speed	There is no U.S. regulation, standard or practice for signaling and train control which requires signaling systems having a performance equivalent to that required by UIC 734 for speeds in excess of 125 mph. The train and signal control characteristics required in Europe for speeds between 100 and 125 mph are broadly similar to the FRA requirements for above 80 mph. (Exception: all trains in U.S. operating on a line equipped with cab signals and/or ATC have to meet minimum requirements.) There are many detailed differences between U.S. and European "conventional" signaling practice (See ADL reference to Armstrong paper). In general, European equipment is more complex, but less rugged than U.S.	U.S. signal and train control system have not been adapted to the operation at speeds in excess of 125 mph. Accidents caused by malfunction of a signaling system itself are extremely rare; when they occur they are often caused by faulty installation. Because of higher speed, the consequences of accidents (collisions, derailments) caused by signal malfunctions will be more severe. There is a need to define performance and reliability requirements for radio links, microprocessors, etc., which are incorporated into vital train control and signaling functions.

TABLE D - 4. SAFETY REGULATIONS, GUIDELINES, AND REQUIREMENTS POTENTIALLY APPLICABLE TO MAGLEV

SIGNALING, COMMUNI-CATIONS, AND ELECTRIFICATION	FRA/ 49 CFR	AAR/ INDIVIDUAL RAILROADS	OTHER U.S.	GERMAN	UIC/ OTHER FOREIGN	COMPARISON	COMMENTS
SIGNAL AND TRAIN CONTROL DESIGN (continued)	Automatic train stop or control systems may include a device to forestall automatic brake application(cf. premature or inadvertant). Also includes a large number of requirements regarding track circuit operation, automatic block systems and individual signaling devices			EBO, Ch.14, Signals and Switches: refers to the most restrictive situation as the default position; Required braking distances for signal spacing, track occupancy restrictions at converging points, automatic train stop for speeds >100 km/hr. MUe 8004: Re: functional efficiency and correctness of software for controlling safety-relevant functions. MBO, sec.2.4: Railway safety systems. Sec 4.3, Travel Safety.	Restrictions as well as responding to any fault detection systems. Lineside signals cannot form part of system, except as lower speed backup. Trains must also be provided with voice communication to dispatcher. 730-739: Govern signal system installations and contain many detailed requirements.		

TABLE D-4. SAFETY REGULATIONS, GUIDELINES, AND REQUIREMENTS POTENTIALLY APPLICABLE TO MAGLEV

SIGNALING, COMMUNICATIONS, AND ELECTRIFICATION	FRA/ 49 CFR	AAR/ INDIVIDUAL RAILROADS	OTHER U.S.	GERMAN	UIC/ OTHER FOREIGN	COMPARISON	COMMENTS
SIGNAL SYSTEM INSPECTION AND MAINTENANCE	236: Specifies a minimum level of inspections and tests to be performed on signal systems and components of all types. Most involve tests of way-side equipment to ensure proper functioning.	AAR: Numerous inspections and test are contained in Manuals of Recommended Practices. Tests have to be carried out at 3, 6, 12, or 24 months depending on type of equipment. Cab signal and ATC equipment in a locomotive or driving cab has to be inspected and tested daily both in the shop and by the engineer on departure or on entering ATC territory.		EBO, Ch.17, RR Inspection and Supervision: general inspection requirement	731: General comments about inspection of signaling systems but does not cover frequency of inspections and tests for specific types of equipment. Otherwise, responsibility is that of individual railroad or as recommended by signal systems supplier. SNCF: Test car makes a monthly trip to monitor the condition of track-train communications and train detection systems. 6 signal and train control inspectors are allocated to a 50- mile territory and perform minor maintenance and routine testing. Portable instruments are used for on-site testing and Central Control can simulate certain operating conditions.	Insufficient information is available for a detailed comparison between U.S. and foreign practice.	High speed train signal systems involving microprocessors, a variety of novel track-train communication systems and on-board installation will require very different testing and inspection procedures. Wider temperature extremes and vandalism could be important factors in U.S.

TABLE D-4. SAFETY REGULATIONS, GUIDELINES, AND REQUIREMENTS POTENTIALLY APPLICABLE TO MAGLEV

SIGNALING, COMMUNI-CATIONS, AND ELECTRIFICATION	FRA/ 49 CFR	AAR/ INDIVIDUAL RAILROADS	OTHER U.S.	GERMAN	UIC/ OTHER FOREIGN	COMPARISON	COMMENTS
COMMUNICATIONS	220: Contains radio standards and procedures including protocol for clarity and consistency of communications, instructions for radio voice communications and procedures for issuing train order by radio.		All radio communications and radio equipment must comply with FCC requirements.	EBO, Ch.14, Communica-tion Facilities. MBO, Sec.2.4: Maglev Safety Systems performance specs (may include non-interference with communications Sec. 3.4: gen reqs re 2-way communication system (vehicle with control room). TUV, Folio 4, On-Board ATC: 8. Transmission Installation, a wireless data transmission channel, for secure telegram safe transmission (a fail-safe computer with 3 channels);9. Passenger Emergency Signal transmitted to on-board Safety Computer. VDE 0225, Parts 1,2,5: Interference of grounding fault diagnostics with communications wires.			

TABLE D - 4. SAFETY REGULATIONS, GUIDELINES, AND REQUIREMENTS POTENTIALLY APPLICABLE TO MAGLEV

SIGNALING, COMMUNI-CATIONS, AND ELECTRIFICATION	FRA/ 49 CFR	AAR/ INDIVIDUAL RAILROADS	OTHER U.S.	GERMAN	UIC/ OTHER FOREIGN	COMPARISON	COMMENTS
COMMUNICATIONS (Continued)				**DIN VDE 0228:** Measures for interference protection of telecommunicat-ions system from power installations **VDE 0800:** Provisions for builders and operators of telecom systems, including ADP systems **VDE 0816:** External cables for telecommunicat-ion systems specs **VDE 0845:** Protection of telecom systems against overvoltage **VDE 0871** Radio interference suppression (RIS) of high frequency equipment. **VDE 0888:** light wave communication technology (optical cables)			

TABLE D-4. SAFETY REGULATIONS, GUIDELINES, AND REQUIREMENTS POTENTIALLY APPLICABLE TO MAGLEV

SIGNALING, COMMUNICATIONS, AND ELECTRIFICATION	FRA/ 49 CFR	AAR/ INDIVIDUAL RAILROADS	OTHER U.S.	GERMAN	UIC/ OTHER FOREIGN	COMPARISON	COMMENTS
COMMUNICATIONS (Continued)				DIN VDE 0228: Measures for interference protection of telecommunications system from power installations. VDE 0800: Provisions for builders and operators of telecom systems, including ADP systems. VDE 0816: External cables for telecommunication systems specs. VDE 0845: Protection of telecom systems against overvoltage. VDE 0871 Radio interference suppression (RIS) of high frequency equipment. VDE 0888: light wave communication technology (optical cables).			

TABLE D - 4. SAFETY REGULATIONS, GUIDELINES, AND REQUIREMENTS POTENTIALLY APPLICABLE TO MAGLEV

SIGNALING, COMMUNI-CATIONS, AND ELECTRIFICATION	FRA/ 49 CFR	AAR/ INDIVIDUAL RAILROADS	OTHER U.S.	GERMAN	UIC/ OTHER FOREIGN	COMPARISON	COMMENTS
ELECTRICAL SAFETY AND ELECTRIC POWER SUPPLY	236: While no general safety regulations regarding electrical systems apply, Part 236 contains numerous rules, standards and instruction re installation, inspection, testing, safe operation and maintenance of signal and control systems, and appliances, including electrical cabling insulation, batteries, relays,ground tests, and electronic devices.	AREA Manual, Section 33: Contains standards and guidelines for overhead catenary electric power supply systems, and the avoidance of interference between the power supply and signaling and communication systems. Individual railroads have established their own standards for electrifi-cation systems and procedures for safe execution of maintenance work. For wiring and other electrical installations, for locomotives and power cars.	NFPA: National Electrical Safety Code for high voltage systems and equipment is applicable FAR 25.1357, Circuit Protective Devices. FAR 25.1359 (b) thru(d), Electrical System Fire and Smoke Protection. FAR 25.581, Lightning Protection.	TUV: Folio 2, Propulsion Including Energy Supply: design and operational safety reqs. for propulsion unit, including: overload and short protection,dis-conection, electrical safety of cabling and subsystems. Folio 3, On-board Energy Systems: electrical safety, personnel and passenger protection against dangerous body currents, power transmission, storage, conversion and distribution subsystem safety. Folio 10, Lightning Protection/ EMC/ ESD: protection of system elements and people from electrical discharges damage.	In all countries, standards and procedures regarding electrical clearances, protection from high voltage catenaries and other equipment from accidental contact with persons have been established. 503: Grounding of metal parts of vehicles,specifies minimum resistance to rail and use of grounding cables and brushes to ensure a low resistance path from the car body to rail. 610: Procedures for testing of electrically powered rolling stock before entering service.	Based on limited information available, U.S. and foreign practices regarding electrification are similar.	Attention to grounding of all vehicles is essential. Very few accidents occur because of electrical system malfunction. Most casualties are due to electric shock due to trespassing or other interference. Railroad installations in the U.S are more subject to vandalism. Systems such as the GRS VPI (Vital Processor Interlocking) with SAL (Safety Assurance Logic), although not specifically approved by FRA, are considered to meet 49 CFR requirements related to signal and control safety issues.

TABLE D-4. SAFETY REGULATIONS, GUIDELINES, AND REQUIREMENTS POTENTIALLY APPLICABLE TO MAGLEV

SIGNALING, COMMUNI-CATIONS, AND ELECTRIFICATION	FRA/ 49 CFR	AAR/ INDIVIDUAL RAILROADS	OTHER U.S.	GERMAN	UIC/ OTHER FOREIGN	COMPARISON	COMMENTS
ELECTRICAL SAFETY AND ELECTRIC POWER SUPPLY (continued)				DIN 57 160/VDE 0160: Electronic equip. used in electrical power; installations and their assembly into same. DIN VDE: 0100 Parts 410,430,523,540 Protective measures against dangerous body currents from overload and shorts, for electric power installations at up to 1 kV AC and 1.5 kV DC 0101: Same as 0100, for electric power installations above 1 kV, grounding protection from high-intensity current systems, and ground fault monitoring unit. 0105: Operation of power installations and high intensity current systems. 0106: Parts 1,101, Regs. of safe separation in electrical operating equipment.			

TABLE D-4. SAFETY REGULATIONS, GUIDELINES, AND REQUIREMENTS POTENTIALLY APPLICABLE TO MAGLEV

SIGNALING, COMMUNICATIONS, AND ELECTRIFICATION	FRA/ 49 CFR	AAR/ INDIVIDUAL RAILROADS	OTHER U.S.	GERMAN	UIC/OTHER FOREIGN	COMPARISON	COMMENTS
ELECTRICAL SAFETY AND ELECTRIC POWER SUPPLY (continued)				DIN VDE: 0108: Part 1, danger zones for propulsion unit(long stator windings and feeder circuits) 0109: Insulation in low voltage systems 0110:Provisions for dimensioning of air creep sectors and clearance of electrical operating equipment. 0115: Permissible contact voltage in case of ground fault, for railroads, including power feed via sliding contacts (NA to maglev?). 0122: Testing specs for batteries and energy storage devices. 0141, Grounding system specs, including lightning protection.			

TABLE D-4. SAFETY REGULATIONS, GUIDELINES, AND REQUIREMENTS POTENTIALLY APPLICABLE TO MAGLEV

SIGNALING, COMMUNICATIONS, AND ELECTRIFICATION	FRA/ 49 CFR	AAR/ INDIVIDUAL RAILROADS	OTHER U.S.	GERMAN	UIC/OTHER FOREIGN	COMPARISON	COMMENTS
ELECTRICAL SAFETY AND ELECTRIC POWER SUPPLY (continued)				0160, Protection of/from equipment in high intensity current systems with electronic operating equipment. 0185: Part 1, lightning protection and grounding; Part 2, explosion hazards control. 0250,0278: Provisions for insulated power lines; esp. heavy current, high voltage 280, 282, 287 and 293, Part 4, Current loadability. 0266, halogen free cables, with improved performance in case of fire. 0298,Parts 2,3,4, Use of cables of insulated lines for hi-intensity current systems.			

TABLE D-4. SAFETY REGULATIONS, GUIDELINES, AND REQUIREMENTS POTENTIALLY APPLICABLE TO MAGLEV

SIGNALING, COMMUNI-CATIONS, AND ELECTRIFICATION	FRA/ 49 CFR	AAR/ INDIVIDUAL RAILROADS	OTHER U.S.	GERMAN	UIC/OTHER FOREIGN	COMPARISON	COMMENTS
ELECTRICAL SAFETY AND ELECTRIC POWER SUPPLY (continued)				0472: Guidelines for the perform-ance of test on insulated lines and cables; fire proofing cabling and preservation of function during fire. 0510: Battery capacity and loading, prevention of explosions. 0532: Transformers and choke coils design safety. 0558: Electrical safety for power converters and rectifiers, esp. from high voltage. 0660, Part 103: Re: specs for high voltage contactors and switchgears, to protect from shorts and overvoltage. 0670, Part 6: Protection from high voltage with isolating gaps (esp. for feeder switch stations).			

TABLE D-4. SAFETY REGULATIONS, GUIDELINES, AND REQUIREMENTS POTENTIALLY APPLICABLE TO MAGLEV

SIGNALING, COMMUNI-CATIONS, AND ELECTRIFICATION	FRA/ 49 CFR	AAR/ INDIVIDUAL RAILROADS	OTHER U.S.	GERMAN	UIC/ OTHER FOREIGN	COMPARISON	COMMENTS
ELECTRICAL SAFETY AND ELECTRIC POWER SUPPLY (continued)				0675: Guidelines for overvoltage protection. 40046,Part 38: Environmental testing for electrical technology. 40050: Types of protection. 57600: Short circuit and ground fault-proof lines, test specs.			

TABLE D-4. SAFETY REGULATIONS, GUIDELINES, AND REQUIREMENTS POTENTIALLY APPLICABLE TO MAGLEV

SIGNALING, COMMUNICATIONS, AND ELECTRIFICATION	FRA/ 49 CFR	AAR/ INDIVIDUAL RAILROADS	OTHER U.S.	GERMAN	UIC/ OTHER FOREIGN	COMPARISON	COMMENTS
EMC/ EMI AND LIGHTNING PROTECTION			FCC dockets 20780 and 80284 UMTA: Guidelines-for the Rail Transit EMI/EMC Program, theory and test procedures reports for: Conductive Interference, Inductive interference. Radiated interference. Laboratory and field testing procedures. IEEE (proposed) Standard 985 recommends practice for rail transit EMC of electrical/ electronic subsystems. MIL-STD-461A, Limit for broad-band emissions. FAR 25.581, Lightning Protection.	TUV, Folio 10,Lightning Protection/EMC/ ESD, deals with grounding, screening, EM compatibility of subsystems, radiated magnetic fields, electrostatic charge/ discharge of vehicle DIN 57600, Parts 500, A1:Short circuit, ground contact proof. VG 95 371,Parts 2,3, EMC, general foundations DIN VDE 0100, part 410: Max. permissible ESD levels are 350 mJ, but could be lower for maglev. DIN VDE 0185, part 2: Maglev vehicle should not be part of external lightning protection, nor susceptible to resulting fire or explosion.	564-2: Suitable electrical conduit. 737-3/4: Concerns electrical interference between electric traction systems and signaling systems. Specifies preventive measures both on the power system and signaling.		See also Electrical Safety German regulations. dealing with grounding system specs and monitoring units.

TABLE D-4. SAFETY REGULATIONS, GUIDELINES, AND REQUIREMENTS POTENTIALLY APPLICABLE TO MAGLEV

SIGNALING, COMMUNICATIONS, AND ELECTRIFICATION	FRA/ 49 CFR	AAR/ INDIVIDUAL RAILROADS	OTHER U.S.	GERMAN	UIC/ OTHER FOREIGN	COMPARISON	COMMENTS
EMC/ EMI AND LIGHTNING PROTECTION (continued)				DIN VDE 0225 Parts 1,2: interference limit voltage of electrical propulsion system and, in case of ground fault, with communications wires. VDE 871, Radio interference suppression (RIS) of high frequency equipment. VDE 874, RIS of electrical equipment and installations. VDE 877, guidelines for measuring radio interference.			

TABLE D - 4. SAFETY REGULATIONS, GUIDELINES, AND REQUIREMENTS POTENTIALLY APPLICABLE TO MAGLEV

SIGNALING, COMMUNI-CATIONS, AND ELECTRIFICATION	FRA/ 49 CFR	AAR/ INDIVIDUAL RAILROADS	OTHER U.S.	GERMAN	UIC/ OTHER FOREIGN	COMPARISON	COMMENTS
COMPUTER SAFETY FOR OPERATIONS MONITORING AND CONTROL	None		MIL-STD 882B, System Safety Program Requirements, includes both hardware and software hazard analysis specs: Task Sec 300, Software Hazard Analysis, and Software System Safety. DOD-STD-2167A, and AFR-800-14, Software Development Documents. 2168, Defense Software Quality Assurance , These standards include configuration management, reliability, risk analysis and management. FAA: AC20-115A 8/12/86 for using radio technical commission for aeronautics (Doc. RTCA/DO-178A)	TUV: Handbook,1986, Microcomputers in Safety Techniques TUV: Folios 4, On board control System and 9: Oper-ational Control Equipment(inter ference proof), with high grade software and assured power supply; and fail-safe data transmission computer. DIN VDE 0831 Safety level, errors in data channels. DIN 0845: Effect of environmental conditions on reliability of technical products. VDI/VDE 3542, Reliability, redundancy and fail-safe design of safety- critical systems. DIN 66001, Information processing, symbols and their use	EUROCAE/12A, Re: software reliability. British Health and Safety Executive's guidelines for process control equipment		

TABLE D-4. SAFETY REGULATIONS, GUIDELINES, AND REQUIREMENTS POTENTIALLY APPLICABLE TO MAGLEV

SIGNALING, COMMUNI-CATIONS, AND ELECTRIFICATION	FRA/ 49 CFR	AAR/ INDIVIDUAL RAILROADS	OTHER U.S.	GERMAN	UIC/ OTHER FOREIGN	COMPARISON	COMMENTS
COMPUTER SAFETY FOR OPERATIONS MONITORING AND CONTROL (Continued)			RTCA/DO-178A Software considerations in airborne systems & equip. certification.	DIN 66230, Information processing, program documentation. MUe 8004: Software correctness and efficiency req. for safety relevant computer functions. VDI 3559: Scope of documentation on hardware and software for process computer systems.			

TABLE D-5. SAFETY REGULATIONS, GUIDELINES, AND REQUIREMENTS POTENTIALLY APPLICABLE TO MAGLEV

PERSONNEL/ OPERATIONS	FRA/ 49 CFR	AAR/ INDIVIDUAL RAILROADS	OTHER U.S.	GERMAN	UIC/ OTHER FOREIGN	COMPARISON	COMMENTS
QUALIFICATIONS/ TRAINING	217: Railroads are required to instruct employees in operating practices and conduct periodic tests to monitor and ensure compliance with operating rules.	AAR: No requirements. Individual railroads use their own.	MIL-STD 882B, System Safety Program Requirements July 1987, includes training (Task 208) UMTA: Recommended Emergency Preparedness Guidelines for RailTransit Systems Recommended Emergency Preparedness Guidelines for Elderly and Disabled RailTransit Passengers. Recommended Emergency Preparedness Guidelines for Urban, Rural, and Specialized Transit Systems. These documents include training guidelines relating to Emergency Preparedness.	EBO, Chs.47-53 Age, vision, hearing requirements, etc. EBO, Ch. 54, Training and Testing, general requirements. EBO, Sec 1.6: Maglev operator is responsible for T& Q certification; Sec.4.2: Personnel prerequisites.	SNCF/TGV: 12-day training of train crews already recruited from senior employees already qualified for conventional speed trains. Includes familiarization with TGV controls, special operating rules for the high speed line and familiarization with the specific features of the specific line. SNCF: Trying to improve training methods through expanded use of simulators, computer-aided teaching systems, etc. Japan: Various aptitude and psychological tests are used for operating jobs. Conversion course to train narrow gauge engineers to be Shikansen	There is no separate TGV work force; a relatively large number of engineers are trained to drive both conventional speed and TGVs. ADL did not feel it had sufficient information available for comparison. Only U.S. high-speed passenger service is the New York-Washington Metroliner.	U.S. personnel pool is limited with exception of OTHER U.S., so that training will need to occur from scratch for most personnel. Operating error is chief cause of accidents. FRA is currently working on issue of certification for locomotive operators.

TABLE D - 5. SAFETY REGULATIONS, GUIDELINES, AND REQUIREMENTS POTENTIALLY APPLICABLE TO MAGLEV

PERSONNEL/ OPERATIONS	FRA/ 49 CFR	AAR/ INDIVIDUAL RAILROADS	OTHER U.S.	GERMAN	UIC/ OTHER FOREIGN	COMPARISON	COMMENTS
QUALIFICATIONS/ TRAINING (Continued)					motormen, length is 4 months. Training of personnel without previous experience as an engineer takes 11 months. Courses in other crafts (track and signal maintenance), run typically 1-3 months depending on prior experience. UK: Personality and aptitude tests are part of selection procedure for engineers. Junior engineers receive 5 weeks of classroom and 10 weeks supervised training before going solo. They will then spend several years before accumulating enough experience to drive high-speed trains.		

TABLE D - 5. SAFETY REGULATIONS, GUIDELINES, AND REQUIREMENTS POTENTIALLY APPLICABLE TO MAGLEV

PERSONNEL/ OPERATIONS	FRA/ 49 CFR	AAR/ INDIVIDUAL RAILROADS	OTHER U.S.	GERMAN	UIC/ OTHER FOREIGN	COMPARISON	COMMENTS
OPERATING RULES AND PRACTICES	217: Railroads must file a copy of their current operating rules, timetables and other instructions with FRA. Also to be filed are programs of tests and inspections, and employee instructions, records kept of results and submitted these in an annual report. Specifically, must report employees who have violated Rule G (drugs or alcohol).	AAR: All railroads must have a code of operating rules which, as a minimum, contain all rules contained in the Standard Code of Operating Rules. Location specific operating rules are contained in timetables and other operating instructions of individual railroads. These include speed limits, where particular equipment can operate, etc.	14CFR, FAR 91.105, Basic VFR weather minimum visibility requirements.	TUV: Folio 1, System properties, especially "Safe hovering" Folio 9, Operations Control Equipment DIN V31004 Defines operational safety so as not to exceed a certain risk limit. EBO, Sec.4, Chs. 34-46: Details how trains should be made up and operated (speed, personnel, etc.). MBO, Ch.4: Specs. for maglev rail service (e.g. checkout procedures in 4.1, travel safety in 4.3, and speed profile in 4.4)	No information available.		Operating error is most significant cause of accidents. There are significant differences between high-speed (over 125 mph) and traditional U.S. passenger rail operations. Signal and train control systems will also be different. It is therefore necessary to develop and use appropriate operating rules and practices for high speed operations, even if a sophisticated ATC system is used.

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PERSONNEL/ OPERATIONS	FRA/ 49 CFR	AAR/ INDIVIDUAL RAILROADS	OTHER U.S.	GERMAN	UIC/ OTHER FOREIGN	COMPARISON	COMMENTS
EMERGENCY PLAN/PROCEDURES (See also Table 2, Vehicle: emergency feaures/equipment and emergnecy access/egress.			UMTA: Recommended Emergency Preparedness Guidelines for Rail Transit Systems. Recommended Emergency Preparedness Guidelines for Elderly and Disabled Rail Transit Systems. These documents contain guidelines for developing emergency plans and procedures, and training programs.	TUV: Folio 12, Rescue Plan EBO, Ch.37, Providing Trains with Equipment to render first aid. MBO, Sec.3.4: General requirementss for emergency exits and passenger comfort; also platform design for entry/exit safety, door operation and status. Sec 4.3: Specs for Travel Safety. No specific requirement for emergency plan, procedures, and training.	564-2: Passenger car staff must be trained in fire emergency procedures.		

REFERENCES

1. Code of Federal Regulations, Title 14, "Aeronautics and Space", Office of the Federal Register National Archives and Records Administration, October 1, 1989.

2. Code of Federal Regulations, Title 49, "Transportation", Office of the Federal Register National Archives and Records Administration, October 1, 1989.

3. Construction and Operating Code for Magnetic Levitation Rail System (MBO), Federal Republic of Germany, January 22, 1988, draft.

4. Department of Defense, Military Standard 882B, System Safety Program Requirements. Washington, D.C., 1984.

5. Dr.-Ing. Klaus Heinrich and Dipl.-Ing. Rolf Kretzschmar, executive editors. Transrapid Maglev System,.Hestra-V'erlag, Darmstadt, Federal Republic of Germany, 1989.

6. Hölscher, H. and J. Rader, Microcomputers in Safety Technique, Verlag TÜV Rheinland, Cologne, Federal Republic of Germany, 1984.

7. Maglev Transit, Inc. "Application Submission for: The Magnetic Levitation Demonstration Project.", Volumes 1-4, February 1, 1989.

8. Railroad Construction and Traffic Regulations (EBO), German Federal Railways, Federal Republic of Germany, effective May 28, 1967, 1982 edition.

9. Roland, Harold E. and Brian Moriarty, System Safety Engineering and Management, John Wiley and Sons, New York, 1983.

10. Transrapid Maglev Safety Requirements, TÜV Rheinland, Cologne, Federal Republic of Germany, various editions, 1989 and 1990.

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