FRA45-92-0006
Contract DTFR53-91-C-00071

April 1992

Maglev Program Test Plan

Final Interim Test Requirements Analysis Report

U.S. Department of Transportation

Federal Railroad Administration

MARTIN MARIETTA
Air Traffic Systems

FRA45-92-0006
Contract DTFR53-91-C-00071

Maglev Program
Test Plan

April 1992

Final Interim Test Requirements Analysis Report

MARTIN MARIETTA
AIR TRAFFIC SYSTEMS

475 School Street, SW
Washington, DC 20024

FOREWORD

Martin Marietta Corporation, Air Traffic Systems submits this Interim Report to the Federal Railroad Administration (FRA) as required under Contract No. DTFR53-91-C-00071, Maglev Program Test Plan.

TABLE OF CONTENTS

APPENDICES

1.0 EXECUTIVE SUMMARY

The purpose of this study is to identify test requirements for a national maglev development program. This interim report is submitted in accordance with the Maglev Test Plan Contract DTFR53-91-C-00071 and includes the following:

- Conclusion of a literature search in which 160 citations were reviewed for relevancy,
- Interview results from 31 industry experts,
- Identification of 94 distinct program development risks,
- Characterization of risk by subsystem, severity, type, mitigation method, and
- Recommendation for scheduling risk mitigation activities into 5 development phases consistent with the Intermodal Surface Transportation Efficiency Act of 1991.

A Test Requirements Analysis Team, comprised of contractor personnel, successfully executed a process to identify, document, and analyze the following maglev system aspects:

- Architecture,
- Operational concepts,
- Leading maglev system developers,
- Test planning and facilities exercised in prior related activities, and
- Development risk.

Analysis within this report substantiates a notion that dynamics, reliability, maintainability, and availability risks dominate the maglev program not only in total number of risks but in risk severity as well. Aging and electromagnetic field risks are also numerous and severe. Control, cryogenics and emergency, although few in total number of risks, are high severity and warrant close attention in the development program. These 7 risk types constitute 41 of the 94 total risks (24 of which are high severity). Collectively, they suggest the need for a carefully crafted and intensive mitigation plan, executed early in the program, in which analysis and high-fidelity testing is performed at a scale commensurate with the risk. An additional 52 risks are characterized into 13 types that are generally less severe.

With the conclusion of the literature search and risk characterization phase of the study, activity has turned to test planning and facilities utilization strategies, the results of which will be presented in a final report.

2.0 INTRODUCTION

2.1 BACKGROUND

Maglev systems represent a promising evolution in high speed ground transportation, offering the possibility of speeds in excess of 134 m/s (300 mph) along with the potential for low operating and maintenance costs and minimal environmental impact. Maglev transportation may be a competitive alternative to short-haul inter-urban air and highway travel. The Departments of Transportation and Energy, the Army Corps of Engineers and other government agencies have combined to sponsor the National Maglev Initiative. The goal of this effort is to investigate the feasibility and viability of maglev systems for the United States. Emergence of sophisticated maglev designs and technologies is anticipated as a result of the initiative. Parallel to the technology assessment phase, the sponsoring agencies have recognized a need for initial planning of a supporting integrated test program. Initial test planning is being conducted under BAA 90-1, area 203, "Maglev Program Test Plan". This report documents the approach used to plan the coordinated research test program and the determination of maglev development test requirements and facilities.

One objective of the test planning research is to identify and mitigate technical risks by establishing well defined test requirements during the conceptual phase of the development process. Definition of test requirements leads to the achievement of another research objective—the identification of test strategies. Various test philosophies must be assessed as part of the research to determine their applicability to the maglev system. Included are evaluations of trade-offs involving test fidelity and the effectiveness of sub-scale versus full-scale testing. The final objective of this research program is to identify test planning and facility requirements. Emphasis is placed on maximizing the use of domestic resources while incorporating the experiences of non-domestic developers in defining test and facility requirements.

Information gathered has been used to construct a point-of-departure maglev system architecture. The system architecture provides for a convenient means of classifying the various components, subsystems and system operational concepts encountered in surveying maglev development. The framework of the architecture facilitates systematic consideration of development risk and testing needs through the various levels of the system hierarchy. This is especially important, since, at various levels of the system architecture, competing hardware alternatives have been identified.

For example, the levitation subsystem depends on a choice between electromagnetic (attractive) concepts or electrodynamic (repulsive or shear) concepts. The system architecture was used as a cross-check to verify that all system components were addressed in the risk identification process.

Achievement of the research objectives has been accomplished by surveying experiences from previous maglev development programs both foreign and domestic and interviews of knowledgeable individuals involved in maglev research or testing. The development of test and facility requirements in this effort is based on close coordination with other maglev contractors and an open exchange of the testing needs identified during the technology assessment phase. The effort is seen as an application of a sound systems and concurrent engineering approach. Such an approach is critical to assuring the successful development and implementation of the integrated test plan.

Products resulting from this research program include international lessons learned in planning and conducting maglev system tests, discussions of notional maglev architecture for classification of subsystems and components and a compilation of optimum test strategies with a point-of-departure test plan and test facilities requirements. The test plan, to be included in the final report, will delineate test classifications and timing including engineering evaluation tests, concept demonstration tests, and sub-scale and full-scale prototype hardware evaluation tests.

2.2 SCOPE

The Maglev Program Test Plan effort has three objectives:

- To limit technical risk associated with development of a maglev system
- To formulate an initial framework for planning and implementing a maglev system test program which meets the needs of any operational concept which may evolve out of early development effort
- To identify long-lead test support needs

To meet these program objectives three major tasks have been identified. These tasks consist of conducting test requirements analysis, performing the preliminary identification and planning of required system tests and facilities, and documenting all program results in a final report.

The test requirements definition is complete and documented in this interim report. The test requirements analysis included a literature search and review of pertinent references, a survey of knowledgeable individuals involved in maglev development and a rationalization of the information gathered to define a comprehensive maglev system architecture. Figure 2.2-1 illustrates the basic scheduling for the program. The approach to be taken in carrying out the remaining principal task of identifying point-of-departure test plans and facilities is presented in Section 3.5.

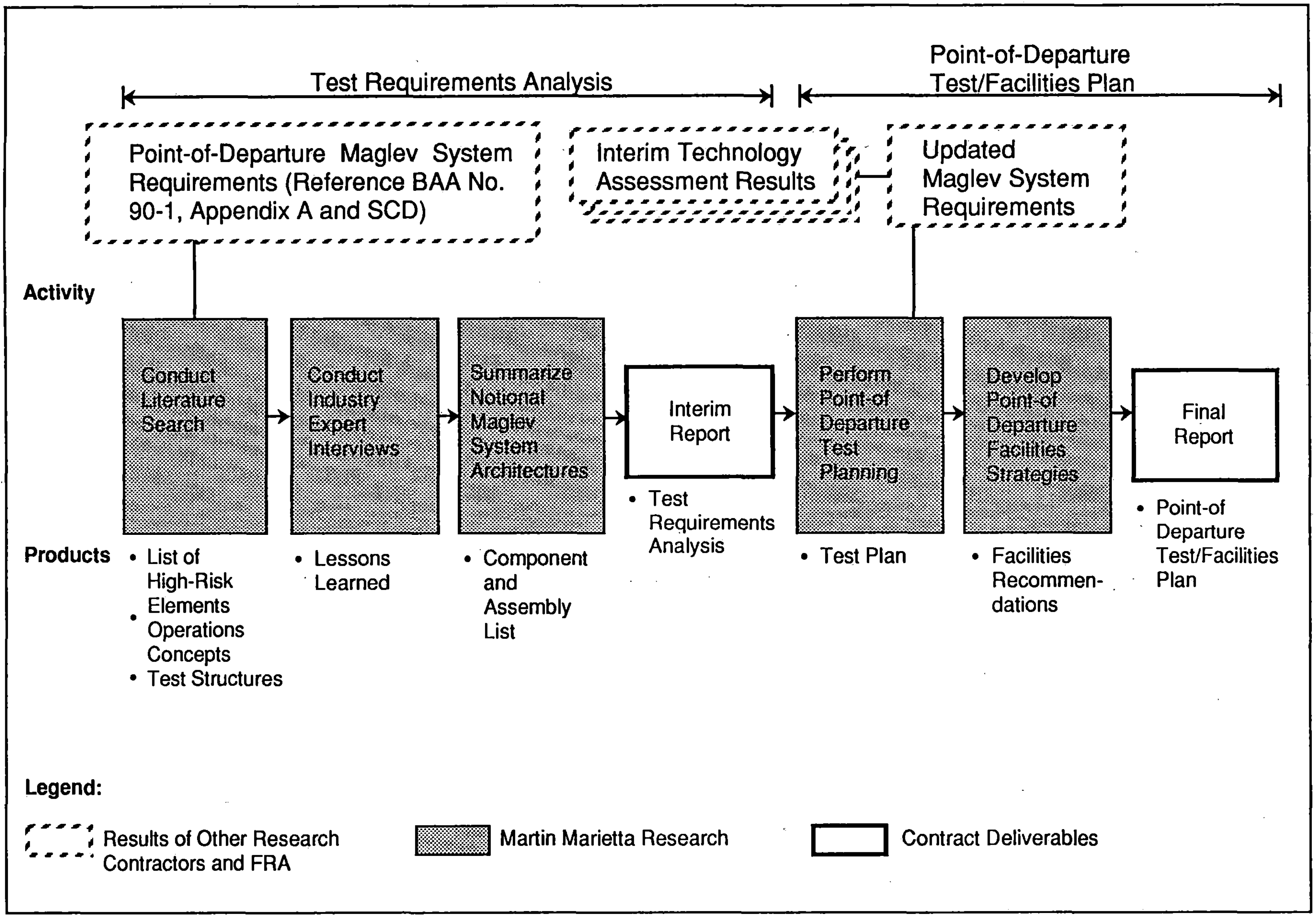

Figure 2.2-1 Maglev Program Test Plan

3.0 TASKS PERFORMED AND FINDINGS

3.1 LITERATURE SEARCH

3.1.1 Task Objectives

The initial subtask of the test requirements analysis effort consisted of a review of pertinent literature. The objectives of the literature search were to:

- Gather applicable source material,
- Assimilate the gathered material in order to systematically address maglev development issues,
- Compile and assess maglev system and subsystem technical risks and mitigation approaches, and
- Identify knowledgeable sources for further contact.

The literature search served to provide a spectrum of technical data which has been used to understand maglev system requirements and the operational characteristics of competing system and subsystem concepts. That body of data provides a basis for the formulation of the maglev system architecture presented in Section 3.3. The literature reviewed served as source material for compilation of development risks and potential analyses and testing approaches for limiting risk. The literature review was also one of the means used in generating the list of individuals who were contacted to provide additional up-to-date information as part of the test requirements analysis.

3.1.2 Compilation of Sources

The literature review began by surveying citations from a number of technical databases. Those databases used were:

- The Department of Transportation Library,
- The Transportation Research Board Library,
- The National Technical Information Service Database, and
- The Library of Congress.

These surveys led to the acquisition of approximately 160 pertinent citations. These citations were further screened for applicability with regard to system architecture, technical development risk and preliminary planning of development tests and test facilities. The screening focused on recent material, but some early material which provided historical development perspective was included.

That screening narrowed the focus to approximately 50 citations. Additions to the original list of citations reviewed in depth have been made through cross-referencing, subsequent contacts and the September 1991 Maglev Technology Assessment Symposium reports.

3.1.3 Classification of References

The citations reviewed in depth were sorted by principal subject areas. These principal subject areas were:

- Systems Integration,
- System Architecture,
- Vehicle Subsystem (excluding electromagnetic subsystems),
- Guideway Subsystem,
- Electromagnetic Subsystems (levitation, guidance, propulsion, power management),
- Control and Communications Subsystems, and
- System and Subsystem Testing.

The principal subject areas were matched against the expertise of the individual members of the test requirements analysis team. Many citations pertained to more than one principal subject area and were thus assigned to multiple reviewers.

3.1.4 Results

References reviewed in depth included those from the initial literature search and those compiled through subsequent research. They have been summarized and sorted by principal subject matter. An index to the reference list along with the collection of abstracts is contained in Appendix A.

The literature search resulted in the identification of references in each principal subject area. The effort pointed out the extent to which European and Japanese maglev development has outpaced U.S. efforts. The information gathered can best be used as a "lessons learned" database to avoid development pitfalls encountered by earlier programs. Careful attention to the lessons learned can lead to greater effectiveness and higher probability of success in the National Maglev Initiative. These will chiefly be utilized in the next phase of this study. Analysis of findings from the literature review effort are further reflected in this report as follows: system operational concepts and architecture—Section 3.3, risk identification—Section 3.4, test planning and facilities—Section 3.5.

3.2 INTERVIEWS OF KNOWLEDGEABLE SOURCES

3.2.1 Task Objectives

The interview task was conducted to complement the information gathered in the literature search. The objectives were to:

- Compile information on maglev operational concepts
- Elucidate system-subsystem relationships and relationships between subsystems in support of system architecture definition
- Identify maglev system and subsystem technical development risks
- Assess development testing strategies
- Survey existing test facilities and capabilities applicable to maglev development

Advantages of gathering information through interviews were noted. Information gathered by interview was current. Interviews often prompted spontaneous responses and follow-up questions not possible from literature review.

3.2.2 Identification of Contacts

The individuals on the contact list were selected so that each basic classification area (see Section 3.1.3) was addressed. Most contacts were chosen on the basis of recent involvement with a specific development issue. However, several contacts were included who have broad knowledge of maglev development dating back to efforts in the '70s. Generally, at least two contacts were identified for each basic topic to obtain independent perspectives. Authors of recent pertinent literature were among the first contacts identified. Contacts include many co-participants in the BAA 90-1 Technology Assessments. Other contacts have been made through the contractor's own initiatives in maglev research and development. Table 3.2-1 identifies the final list of contacts.

3.2.3 Results

Thirty-one individuals were interviewed. Ten of those were face-to-face meetings. Some personal visits were conducted as a matter of opportunity in conjunction with the Technology Assessment Symposium (September 1991) in Cambridge, Massachusetts. Other contacts were selected for personal interviews on a prioritized basis, balancing the value of the contacts against budgetary limits. The remaining contacts were made by telephone. A standard interview form was prepared which helped to guide and focus the dialog during personal visits and telephone interviews. The standard interview form is included as Appendix B. The standard interview form was useful for most of the contacts whose maglev involvement was related to the development of specific subsystems. For those other individuals who were contacted in consideration of the breadth of their maglev knowledge, interviews were conducted in a free exchange format. Table 3.2-2 lists development risks identified by the interviewees. Additional decomposition of the findings from the interviews related to system operational concepts and architecture, risk identification and test planning issues is reflected in Sections 3.3, 3.4 and 3.5 respectively.

The original list of risks culled from the interviews includes many duplications. As part of the risk assessment process a Test Requirements Analysis Team was formed to review the list of

Table 3.2-1 Contact List

Name of Contact	Organization	Subject	Date of Contact	Type of Contact	Contact By
Ayers, Robert	ARINC	Author of Report on Data Comm. for Advanced Train Control Systems	12/16/91	TI	DK
Barrows, Dr. Timothy	Draper Lab	Aerodynamic Forces	12/5/91	TI	AG,LK
Boon, Chris	Canadian Institute of Guided Ground Transport	Maglev Technology Assessment	2/6/92	PV	AG
Bower, John	Babcock & Wilcox	Guideway Sensor Systems	12/20/91	TI	DK
Carlton, Steve	Martin Marietta	Guideway and Route Integrity	1/29/92	PV	DK
Coffey, Dr. Howard	Argonne National Lab	Maglev Development Facility	2/5/92	PV	AG
Cope, Dr. David	Foster-Miller	Power Transfer to High-Speed Vehicles	11/27/91	TI	AG,LK
Daniels, Laurence	Parsons Brinckerhoff	Influence of Guideway Flexibility on Vehicle/Guideway Dynamic Forces	1/27/92	TI	LK
Dietrich, Fred	Electric Research & Management	Sample Msmt. & Analysis of Magnetic Fields from Existing Transport Syst.	1/22/92	TI	LK
Falkowski, Kris	Intermagnetics General	Superconducting LIM	12/19/91	TI	LK
GangaRao, Dr. Hota	West Virginia University	State-of-the-Art Assessment of Guideway System	12/4/91	TI	AG,LK
Guere, Jim	ABAM	Guideway Construction Issues	12/11/91	TI	CS
Hanson, Dr. Carl	Harris Miller Miller & Hanson	Noise from High-Speed Maglev	9/25/91	PV	AG,LK
Key, Scott	Babcock & Wilcox	Guideway Struct. Design in Relation to Power/Propulsion/Braking	12/4/91	TI	AG,LK
Klassen, Bruce	Booz-Allen	Certification for Cal-Nev Corridor	1/2/92	TI	CS
Kolm, Henry	Magneplane International	Guideway	1/23/92	PV	CS
Lala, Dr. J.H.	Draper Lab	Verif. Methods for Fault Tolerant, Fail-Safe Computers for Control Systems	9/25/91	PV	LK
Leatherwood, Dr.	Langley Research Center	Ride Comfort Simulation	8/23/91	PV	CS
Luedeke, Jonathan	Battelle	Evaluation of Concepts for Safe Speed Enforcement	12/12/91	TI	DK
Nerem, Arne	General Atomics	Advanced Power Conditioning	12/2/91	TI	AG
Parker, Dr. James H.	J.H. Parker & Assoc., Inc.	Maglev Technology in North America	9/26/91	PV	AG
Samavedem, Dr. G.	Foster-Miller	Advanced Low-Cost High Performance Guideway Concepts	12/5/91	TI	AG,LK
Sara, Carl	Martin Marietta	Maglev Technology Integration and Development	1/29/92	PV	AG,DD,LK
Stauffer, Jack	Assoc. of American Railroads, Transportation Test Center	System Test Facilities	2/21/92	PV	LK,AG
Taylor, Tom	Parsons Brinckerhoff	Maglev-Rail Intermodal Equipment and Suspension	1/30/92	TI	LK
Thornton, Dr. Richard	MIT	Low-Cost LSM Propulsion Systems	12/19/91	TI	LK
Vermilyea, Mark	General Electric Company	Cryogen-Free, Actively Shielded Superconducting Magnets	11/23/91	TI	AG
Weinberg, Dr. Marc	Draper Lab	Comparison of EMS vs. EDS Levitation Systems	12/23/91	TI	LK
Wike, Paul	Westinghouse	Vehicle Testing	1/29/92	TI	AG,LK
Wooden, Bruce	Specialized Systems, Inc.	Tests, Risks, Superconductivity	1/23/92	TI	AG,LK
Wormley, Dr. David	MIT	Vehicle Suspension/Guideway Interaction	9/27/91	PV	AG,DD,CS,LK

Notes: Type of Contact: PV-Personal Visit, TI-Telephone Interview

Contact By: DD - Dean deBenedet, DK - Dave Kampsnider, CS - Carl Sara

AG - Arnold Gilchrist, LK - Linda Karanian

Table 3.2-2 Summary of Risks Identified through Expert Interviews Sorted by Contact Name

Contact	Risk/Area of Concern
Ayers, R.	Adequate Software Test Control Software Compatibility High Speed Intolerance to Control Failures
Barrows, T.	Pressure Effects of Passing Vehicles Pressure Effects of Tunnel Entrances Cross-Wind Aerodynamics Cross-Wind Induced Ride Quality
Boon, C.	Controlling Content of Concrete Components with Magnetic Properties Guideway Dynamic Performance Guideway Suitability for All Domestic Geotechnical and Weather Conditions Active Tilt Systems Biological Effects of Electromagnetic Fields Failure Modes of Power Distribution Systems Lateral Guidance for EDS Systems Overpressure Effects in Tunnels Passenger Perception of Speed Switching and Service Braking in a Trough Shaped Guideway Superconducting Magnet Quench Management Vehicle Fire
Bower, J.	Guideway Integrity Sensor Function in High Magnetic Field Environment
Carlton, S.	Guideway Alignment Obstruction Detection False Alarm Obstruction Detection Sensor Effectiveness under Operating Conditions Ride Quality Vehicle Collision with Foreign Stationary Objects Vehicle Collision with Vehicle
Coffey, H.	Active/Passive Tilt Demands on Lateral Guidance Availability of GTO Thyristors Biological Effects of Electromagnetic Fields Control of Lateral Dynamics Dynamic Linkage between Vertical and Longitudinal Motion (Surging) Noise Turnouts Vehicle Collision with Foreign Stationary Objects Eddy Current Losses in Magnets Interaction of Magnets Quenching and Shedding Current Superconducting Magnet Quench Management
Cope, D.	Adequate Inductive Power Transfer for Hotel Functions
Daniels, L.	Guideway Positional Adjustability Suitability of Concrete for Use as Guideway Material (Tolerance Failures) Tolerance Build-Up in Guideway Construction Passenger Egress from Vehicle under Emergency Stop Conditions High-Speed Vehicle Impact with Small Object Vehicle Dynamic Effects of Cross-Wind and Headwind
Dietrich, F.	Biological Effects of Electromagnetic Fields
Falkowski, K.	Superconducting Linear Induction Motor Issues—Performance, Quenching from Mechanical Vibration Friction, Heat Dissipation
Gangarao, H.	Non-Magnetic Structural Components in Guideway (EDS Systems) Vehicle/Guideway Dynamics and Interaction

Table 3.2-2 Summary of Risks Identified through Expert Interviews Sorted by Contact Name (Continued)

Contact	Risk/Area of Concern
Guarre, J.	Adaptation to Existing Rights-of-Way Non-Magnetic Structural Components in Guideway (EDS Systems) Biological Effects of Electromagnetic Fields Environmental Acceptability High Speed Turnouts Noise
Hanson, C.	Noise, Startle Effects
Key, S.	Dynamics of Simple vs Continuous Guideway Support Non-Magnetic Structural Components in Guideway (EDS Systems) Seismic Induced Guideway Integrity Wind Effects on Spans
Klassen, B.	Tolerances in Switches Adequate Inductive Power Transfer for Hotel Functions Biological Effects of Electromagnetic Fields Crashworthiness and Survivability Ride Quality System Controls Vehicle-Guideway Interface Tolerances
Kolm, H.	Aluminum Production Capacity Aluminum Combustibility Operation under Severe Weather Conditions Vehicle Dynamic Stability
Lala, J.	Control System Comprehensiveness, Failure, and Recovery Control System Test Thoroughness and Fidelity Control System Verification and Validation
Leatherwood, J.	Interior Noise Passenger Acceptance of Lateral Accelerations/Jerk Passenger Acceptance of Longitudinal Roll Ride Quality
Luedeke, J.	Degree of Incorporating Man-In-The-Loop for Vehicle Control Environmental Effects on Guideway - Mounted Sensors
Nerem, A.	Power Conditioning Component Degraded Performance or Failure
Parker, J.	High Speed Power Collection Inadequate Provision of Dedicated Development Testing Facilities
Samavedam, G.	Fatigue Failure of Guideway Mounted Aluminum Sheet Guideway Manufacture, Assembly, and Field Erection Ice and Snow Accumulation in Trough Shaped Guideway Reliability of Continuous Welds in Guideway Mounted Aluminum Sheet Thermal Loads and Deflection of Guideway Mounted Aluminum Sheet
Sara, C.	Electrostatic Corrosion of LSM Components Guideway Availability Ratcheting of LSM Components Causing Accelerated Attachment Fatigue Central Control with Man-In-The-Loop Efficient Regenerative Braking Electrodynamic Control of Vehicle Attitude in Underdamped Condition Mismatching Structural and Crossing Frequencies at All Operational Speeds Operating Non-Tilt Systems at other Than Design Velocity Operational Use of Landing Gear Robust, Long-Life Vehicle/Guideway Interface Standard

Table 3.2-2 Summary of Risks Identified through Expert Interviews Sorted by Contact Name (Concluded)

Contact	Risk/Area of Concern
Sara, C.	Software Reliability Vehicle Precession into Turns Cryostat Reliability
Stauffer, J.	Inadequate Provisions for Dedicated Development Testing Facilities Inadequacy of Scale Model Testing of Electromagnetic Systems Full-scale Testing in All Weather Extremes
Taylor, T.	Biological Effects of Electromagnetic Fields Electromagnetic Compatibility of On-Board and Encountered Systems Maintenance of Levitation Gap Lightweight and Environmentally Benign Air Conditioning Thermal Effects of Not Maintaining Constant Leviation Clearance Vehicle Tolerance of Pre-Lift-Off Dynamics
Thornton, R.	Guideway Availability and Modularity Non-Magnetic Structural Components in Guideway (EDS Systems) Propulsion and Suspension Coil Attachment to Guideway Geological Effects of Electromagnetic Fields Technical Community Agreement on Excessive Decelerations (0.5g) Vehicle Failure and Fault Tolerance Weight of Cryogenically Cooled Superconducting Magnets
Vermilyea, M.	Cryostat Reliability Superconducting Magnet Manufacturing Flaws Superconducting Magnet Mechanical Integrity Superconducting Magnet Quench Superconducting Magnet Reliability and Maintainability
Weinberg, M.	Damping of Lateral Vibrations Fidelity of Flux Simulations Levitation Uniformity Leading to Ride Quality Risk Mass Required to Mitigate Biological Effects of Electromagnetic Fields Null Flux Performance Uncertainties Time Dependent Field Decay
Wike, P.	Guideway Degradation Due to Environment Guideway Degradation Due to Fatigue Guideway Tolerances Ride Quality
Wooden, B.	Adequate Preventive and Predictive Maintenance Guideway/Vehicle Interaction Obstruction Detection Active Cancellation of Magnetic Fields Active Suspension Systems Vehicle Health Management
Wormley, D.	Vehicle/Guideway Dynamics Passenger Ride Quality Guideway Misalignment Tolerances

risks, eliminate duplicates, group related risks and classify the risks by severity. The team consisted of individuals with experience in one or more maglev disciplines which together constitued a comprehensive set of skills matched to the variety of identified risks. Table 3.2-3 identifies the make-up of the team conducting the risk assessment.

Table 3.2-3 Test Requirements Analysis Team

Team Member	Discipline
Steve Carlton	Maglev Systems Analysis
Dean deBenedet	Transportation Systems Testing
Arthur Feldman	Reinforced Concrete Structures, Geotechnical Considerations
Arnold Gilchrist	Vehicle/Guideway Dynamics, Vehicle Subsystems
David Kampsnider	Communications and Controls
Linda Karanian	Environmental Systems Testing
Calvin Markwood	Electromagnetic Systems Testing
Carl Sara	Maglev Systems Integration
John Wollan	Electromagnetic Systems Design

The team found that the 140 risk items of Table 3.2-2 reduced to 94 after eliminating duplicates. The 94 risks were found to group into 20 basic risk types. These basic risk types are identified in Table 3.2-4 and are discussed below.

Table 3.2-4 Identified Maglev Risk Types

Risk Type	Risk Type (continued)
Acoustics	Human Factors
Aerodynamics	Materials
Aging	Operations
Construction	Power
Control	Programmatics
Cryogenics	Reliability, Maintainability, Availability
Dynamics	Sensors
Electrodynamics	Software
Electromagnetic Fields	Structures
Emergencies	Weather and Geotechnical

Acoustics—This risk type includes two aspects. The first aspect deals with risks associated with external noise propagated by maglev vehicles to adjacent rights-of-way. The intensity of acoustic fields associated with passing maglev vehicles will dictate guideway routing hence land acquisition costs, operating constraints and the public acceptance of maglev systems. Uncertainty exists as to how persons near maglev routes will cope with the "startle effect" created by the sudden onset of aero and/or acoustic disturbances. Operators of motor vehicles in shared rights-of-way may be particularly sensitive to such a phenomenon. Test data from Transrapid is being compiled and analyzed as part of BAA Task 191. Additional aeroacoustic testing was foreseen to differentiate between acoustic effects associated with the passage of the maglev vehicle form itself versus noise generated aeroelastically by the vehicle skin and aerodynamically by protuberances. Results from such tests could be used to quantify total noise beside maglev routes and point towards vehicle design measures to mitigate external noise.

The second acoustics aspect involves interior noise on maglev vehicles. Noise is known to significantly degrade passenger perception of ride comfort and thus bears scrutiny with regard to maglev competitiveness. Interior noise is likely amenable to conventional aircraft treatment however, so this has been accounted for in the assignment of risk severity.

Aerodynamics—The concern is sudden aero-induced pressure gradients associated with two specific maglev operational aspects. The first is pressure changes associated with tunnel entry and exit, and the second is pressure change associated with passage of high speed vehicles on adjacent guideway. These pressure changes drive requirements for vehicle sealing and pressurization to mitigate discomfort to passengers. These aero effects could also drive glazing requirements.

In addition to those specific aerodynamic concerns, maglev vehicles encounter other self induced aerodynamic forces as well as interactions with cross-winds and headwinds. These effects represent disturbances to overall control of maglev vehicle dynamics and have therefore been addressed in the Dynamics risk category.

Aging—A number of risks have been identified related to the long-term viability of a maglev system. Included in this category are technical risks such as long-term differential settlements creating guideway misalignments beyond what the maglev guidance and/or suspension systems can accommodate and fatigue of guideway structure and electromagnetic system components. The aging category also includes a non-technical risk element related to the robustness of the vehicle-guideway interface. A significant risk which must be avoided is to commit to a vehicle-guideway configuration which cannot accommodate the next 50 years worth of evolution in maglev technology.

Construction—A set of risks were identified related to the ability to construct guideway and switch elements for maglev. Risk elements involve meeting construction tolerances which will result in safe, comfortable ride quality and developing cost effective construction methods without which maglev may not be economically viable. Innovative approaches to guideway manufacture, assembly and field erection may be necessary and with the innovation, testing will likely be needed to mitigate the associated risk.

Control—The focus of the maglev system control is to prevent collisions, both collisions between vehicles and collisions between vehicles and significant foreign objects. Preventing vehicle to vehicle collisions is a fundamental function of the hierarchal maglev control system. The catastrophic consequences for failure of that system dictate thorough testing throughout the development of the entire system. Collisions with other significant foreign objects could also be catastrophic and unfortunately the definition of the hazard is difficult to define. BAA -146 is an assessment of this type of risk with development of possible countermeasures. Testing of the ability to detect and respond appropriately to foreign objects fouling the guideway will certainly be needed.

Cryogenics—One risk element was identified related to superconducting EDS type systems which did not fit with other reliability and electrodynamic functional risk categories. The risk develops from the possibility of parasitic thermal losses being generated in the superconducting magnets from limit cycling of the levitation clearance. Small losses may be a drain on levitation system efficiency. Larger losses could result in magnet quenches.

Dynamics—A large number of risks found through the literature and interviews were related to vehicle dynamics. Many of these risks are driven by the requirement to provide passenger ride comfort. Both the vibrational and quasi-steady aspects of ride comfort are involved. Other risks though are related to performance of, and interaction between, the various subsystems which control vehicle dynamics such as levitation, guidance, propulsion and switches. Vehicle vibration is influenced not only by random disturbances from guideway irregularities and aerodynamic turbulence but also periodic influences from the elastic behavior of elevated spans.

Quasi-steady vehicle dynamics include vertical and horizontal curve negotiation including the transitions into the curves. The quasi-steady aspect of vehicle dynamics is dictated by route alignment and speed profiles. Some maglev system architectures propose passive or even active tilt systems to attain acceptable ride comfort while negotiating more severe horizontal curves. The benefit is a likely reduction in guideway right-of-way acquisition cost. The development of a viable 134 m/s passive or active tilt system is however a technical risk.

Coordination between analytical and experimental research will be critical to successful maglev development. Vehicle and guideway dynamics must be thoroughly analyzed and understood in the preliminary maglev development stages. The importance of such analysis must be clearly recognized. Many of the vehicle dynamics risks identified arise from subsystem interactions, and the ability to experimentally confirm such interactive behavior can only occur in the late stages of maglev development when system level test facilities are in hand.

Electromagnetic Fields—Risks were identified associated with the ability to analyze and control electromagnetic fields. These risks include possible harmful biological effects of EM fields or the difficulty of convincing a wary public that maglev EM field exposure is indeed harmless. Undesirable effects of EM fields on equipment located within or adjacent to maglev rights-of-way are also a risk. The control of EM fields drive requirements for shielding onboard the vehicles. Extensive passive shielding would pose risks of exceeding weight allocations and complicating vehicle integration. Active shielding schemes have also been proposed which pose development risk.

Electrodynamics—Interviewees identified a number of risk items related to electrodynamic subsystem performance. The risks addressed the ability to thoroughly analyze certain performance aspects such as forces from large scale null flux loop interactions and steady state variations in performance arising from given guideway and aerodynamic disturbances. The ability to control the steady state variation in electrodynamic performance affects efficiency loss through electromagnetic drag and burdens the quench prevention subsystems.

Emergency—The focus of maglev safety is reliable control of the vehicles both from the standpoint of their capture by the guideway and their movements relative to other vehicles or detectable hazards. By comparison to other transportation modes, it is likely that even beyond all precautions taken in the vehicle control systems to prevent catastrophes, requirements will be levied relating to crashworthiness and survivability.

Human Factors—A number of human factors issues were identified which affect maglev viability. One of these is passenger ride comfort. Specific aspects of ride comfort are also addressed with respect to vehicle dynamics risks. Human acceptance of maglev transportation also encompasses such aspects as visual perceptions from within a vehicle operating at ground level at 134 m/s. Another human factors issue is the conflict between passenger freedom and the possible need for aggressive emergency braking rates. Capacity and hazard detection limitations may dictate requirements for aggressive emergency decelerations. Such decelerations would virtually require full time passenger restraint which may detract from maglev competitiveness. Conversely if passengers are permitted the freedom to move about the vehicles, deceleration limits will have to be set accordingly with implications for headway and hazard detection.

Human factors considerations also enter into the selection of vehicle-guideway configuration and vehicle provisions for handling emergency egress situations.

Materials—Several risk elements identified in the assessment phase dealt with desirable but uncommon material characteristics. Some examples include light weight cryosystem components, non-ferrous concrete reinforcement strands, fire suppressing vehicle interiors etc. Development efforts could be necessary to mitigate one or more of these risks.

Operations—One concern identified in the interview process had to do with defining and implementing the appropriate level of coordination between manual and automated vehicle control operations. Under certain circumstances it could be desirable to intervene manually in the vehicle and system operation hierarchies. Once human intervention is permitted however, a much broader array of failure scenarios must be addressed. Also procedures for transitioning from automated to semi-automated and vice versa must be thoroughly evaluated.

Power—Two issues fell in the category of power management. The first is the ability to transfer sufficient power from the wayside to the vehicle. The most promising method is by inductive (non-contacting) means. The needed power transfer capacity at target maglev speeds is likely to require additional development. A second issue is the management of power developed from regenerative braking. Regenerative braking offers the potential to reduce total power demand of maglev systems by returning power to the supply grid when decelerating vehicles. Experience with electrified rail systems indicates that many institutional factors limit regenerative braking possibilities.

Programmatic—Several risk elements relate to program viability. These include the environmental and land use acceptance of maglev, adaptability of maglev to existing rights-of-way. Some proposed maglev concepts feature intensive use of aluminum perhaps beyond current production capacity. Public acceptance of the safety of a new mode of transportation is also one of these issues.

Reliability, Maintainability and Availability (RMA)—This group of risks was second only to maglev vehicle dynamics in terms of the number and severity of risk elements. Reliability, maintainability and availability each constitute a fundamental measure of system effectiveness. Early development work is needed to determine requirements for each measure. RMA allocations can then be made by the various subsystems. As development progresses subsystem and then system reliability testing is called for to evaluate performance against allocated requirements.

Sensors—Effort in the Route Integrity BAA Technology Assessment has identified a number of technical challenges in developing reliable, accurate detection systems needed to sense hazards on or about the guideway. Challenges include differentiating between true and false returns, operating in the high EM field environment and operating in harsh weather conditions.

Software—Maglev operation is expected to involve very sophisticated automated systems. In addition to the moment to moment operation of vehicles, system scheduling, system health statusing, integration of sensor information all involve large degree of automation in information processing. With the extent of automation, a significant software development effort is entailed. A common pitfall encountered in development of sophisticated automated systems is to underestimate the software development effort. Such risks were identified by a number of interviewees. Areas of concern were establishing well defined software requirements and functionalities to avoid incompatibility between software modules and providing for adequate and rigorous software testing to establish the software effectiveness.

Structures—A number of risks were listed which had in common a concern about structural robustness. The particular structures of concern were various attachments or structural components of the guideway as well as structural members of the magnet assemblies.

Weather and Geotechnical—A conceptual goal for maglev is that it be the least affected intercity transportation mode in times of extreme weather. Several risks were identified relating to all-weather operation, response to seismic events, weather related guideway degradation etc.

3.3 DEFINITION OF MAGLEV ARCHITECTURE

Concurrent with this technology study, the Federal Railroad Administration, the Department of Energy, and the Army Corps of Engineers among others, are sponsoring multiple studies directed toward the first order definition of maglev system concepts. Completion of these studies, estimated for late in calendar year 1992, are expected to provide a comprehensive definition of maglev concepts adaptable to revenue service in the continental United States. Additionally, studies have been sponsored to evaluate the social and economic benefits/impacts of the introduction of maglev systems into the American infrastructure by the year 2000. Collectively these studies will allow the government to formulate a consistent system operational concept that will in turn provide the technical basis for a comprehensive system specification to which industry can respond consistent with the aims of the National Maglev Initiative and the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991. Accordingly, this study is limited to formulating a preliminary system architecture based on literature published to date, suggestions obtained from the interview of industry experts, and inputs from principle investigators responsible for conducting concurrent technology studies. Information contained in this interim report will be updated in the event that more detailed results are available from the System Concept Definition Studies prior to the publication of the final report scheduled for June 1992.

3.3.1 Task Objectives

The definition of a conceptual top-level architecture for a complete maglev system is essential to the establishment of a preliminary development test program scenario and required test facilities. At this stage of maglev development there are two major viable alternatives for maglev systems. These systems are the electromagnetic (attractive) system being developed by the German Transrapid Consortium and the electrodynamic (repulsive) system being developed by Japanese Railways. The electromagnetic and electrodynamic systems differ with respect to the fundamental generation of levitation and guidance forces. The differences consequently give rise to significant variations in the composition of component, subassembly and subsystem hardware. The objective of this task then is to develop a generalized system architecture that allows for the accommodation of the two diverse solutions, and potentially other novel solutions which may yet be identified. The system architecture allows for a conceptual framework about which a generalized test program can be structured to assist in minimizing system development risk.

3.3.2 Results

Development of the Notional Maglev System Architecture included in this section is based on the following information sources:

- Definitions and system element descriptions provided in Appendix A of BAA-90-1,
- The product structure identified in the Maglev System Concept Definition Request For Proposal No. DTFR53-91-R-00021,
- Maglev Technology Assessment, Task 5, published by the Canadian Institute of Guided Ground Transport in March 1986 and the associated update published in May 1990,
- The structure implemented in the development of the Transrapid Maglev System,
- Results obtained from interviews of industry experts that were conducted as part of this study, and

- Martin Marietta experience in systems development for the Department of Defense and the National Astronautics and Space Administration.

Following the review and consideration of cited sources of system architecture information it was concluded that use of the Canadian Institute of Guided Ground Transport (CIGGT) approach as a point-of-departure would be appropriate. This decision was made on the basis that, (1) this body of work was the most comprehensive found in the literature search, and (2) the framework developed by the CIGGT studies allows for incorporation of both electrodynamic and electromagnetic levitation and guidance force generation hardware element definition. Figure 3.3-1 illustrates the four major subsystems identified by the CIGGT Maglev Technology Assessment Study. It should be noted that the architecture identified by CIGGT is focused exclusively on the vehicle/guideway and associated power and control elements and does not address the elements of terminals.

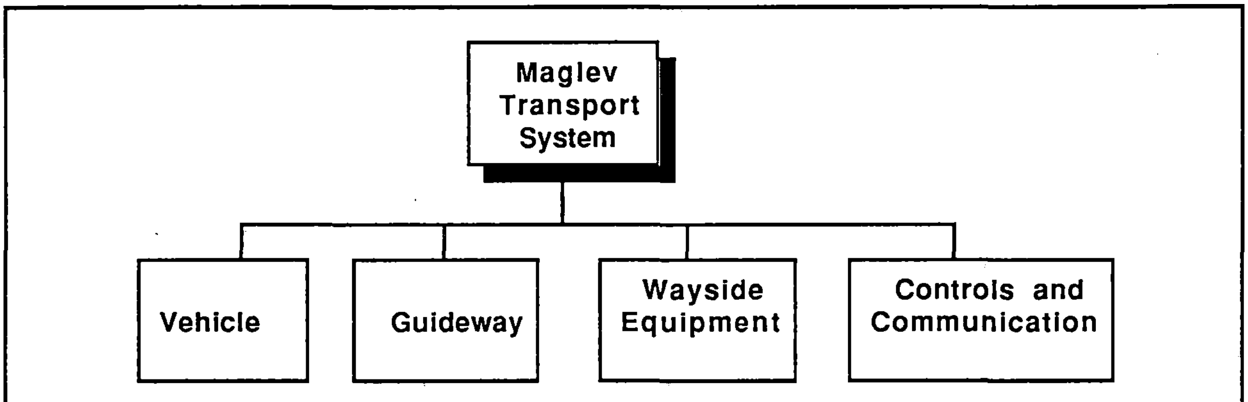

Figure 3.3-1 Definition of Major Subsystems of High-Speed Maglev Transport System As Identified In the CIGGT Maglev Technology Assessment, Task 5

This is not viewed as an oversight but rather a recognition that the architecture of vehicles, guideway, control and communications will ultimately define major portions of the requirements for terminals. In recognition of the preliminary state of maglev systems development in the U.S. and the magnitude of influence that vehicles/guideway configurations have on terminal requirements, this study likewise will not address this issue.

Figure 3.3-2 is a block diagram of a portion of the system defined by CIGGT and clearly illustrates the inter-relationship of subsystems, and subassemblies and, accordingly, it was concluded that this approach would be used as a point-of-departure for this study. Modifications, made by this study, of the CIGGT point-of-departure were considered appropriate in the following areas:

1. **Governing Documentation**—The investigation team performing this study view that the ultimate design, manufacture, test, and activation of a revenue maglev system will require a collaborative effort that will include national and local governments and multiple industrial partners. Collaborations of this magnitude give rise to the need for a clear definition of requirements and constraints to preclude redundancies and inconsistencies between elements of the system. Further, in order to ensure passenger and equipment safety certain governing regulations must be imposed on all critical system elements. Accordingly, this study has identified a series of hierarchical documents that should be considered as a necessary ingredient of any maglev system architecture.

This structure is illustrated in Figure 3.3-3. Four major documentation areas have been identified in Figure 3.3-3 the most critical of which is the "System Specification". This document is the cornerstone necessary for the orderly development of a complex system since, properly structured, it will provide definition of system performance parameters, governing regulations, and applicable government and industry standards to assure system safety, reliability, maintainability and availability. Figure 3.3-4 presents a capsule summary of the relationship of the system specification to the governing "Operational Concept" and the resulting "System Architecture" or "Product Structure".

2. **Architecture Nomenclature and Updates**—The architecture identified by CIGGT has been updated to include additional system elements and current nomenclature, where appropriate, as identified during the course of the literature search and interview of industry sources.

   This architecture is presented in Table 3.3-1 in an indented parts list format. Notation is made in the selected areas where two alternative components and or subassemblies are identified as a result of the differences between electromagnetic and electrodynamic systems. These notations are (R) for repulsive, and (A) for attractive systems, respectively. The elements in Table 3.3-1 are to be viewed as a "slice in time" and will be updated as the results of the System Concept Definition Studies are made available.

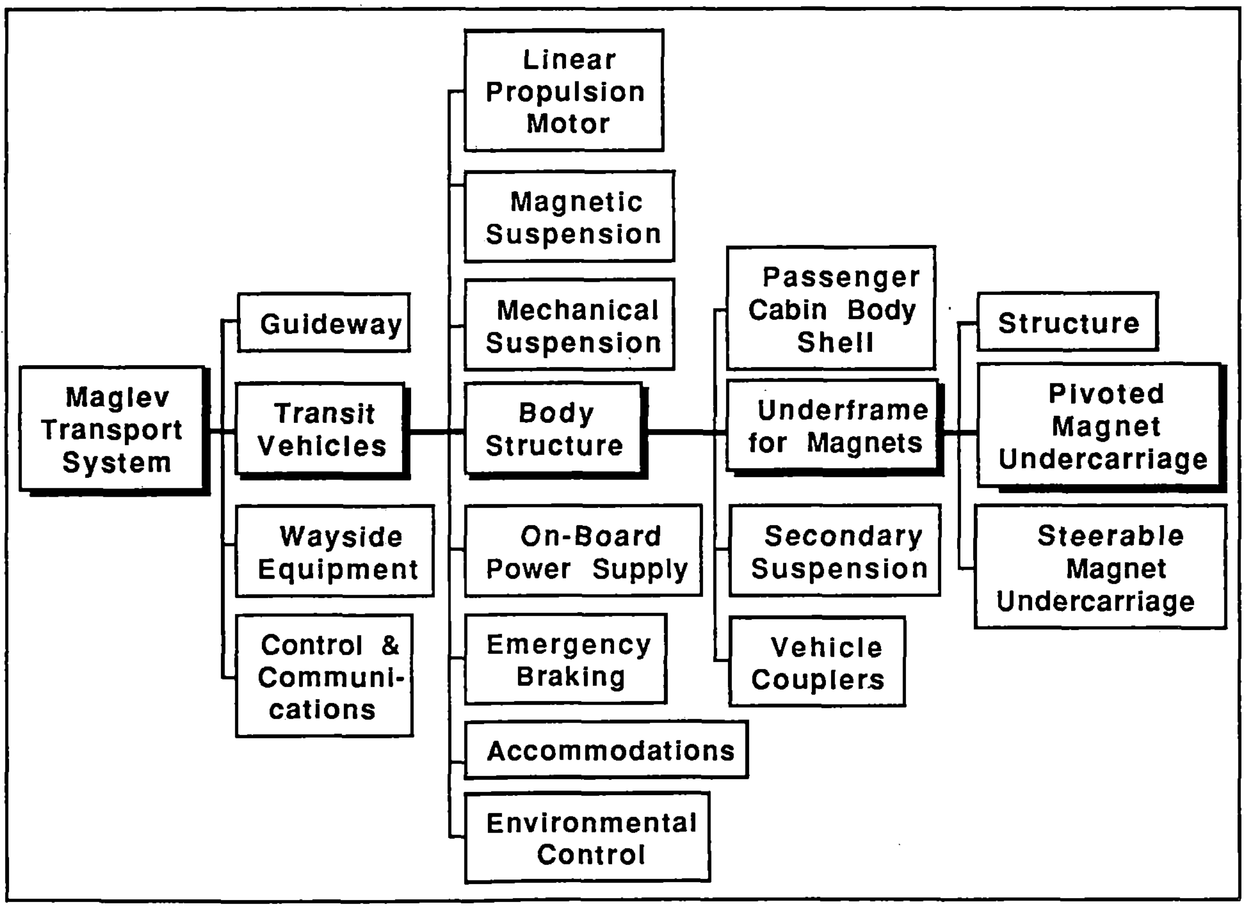

Figure 3.3-2 Typical Element of CIGGT Maglev System Architecture

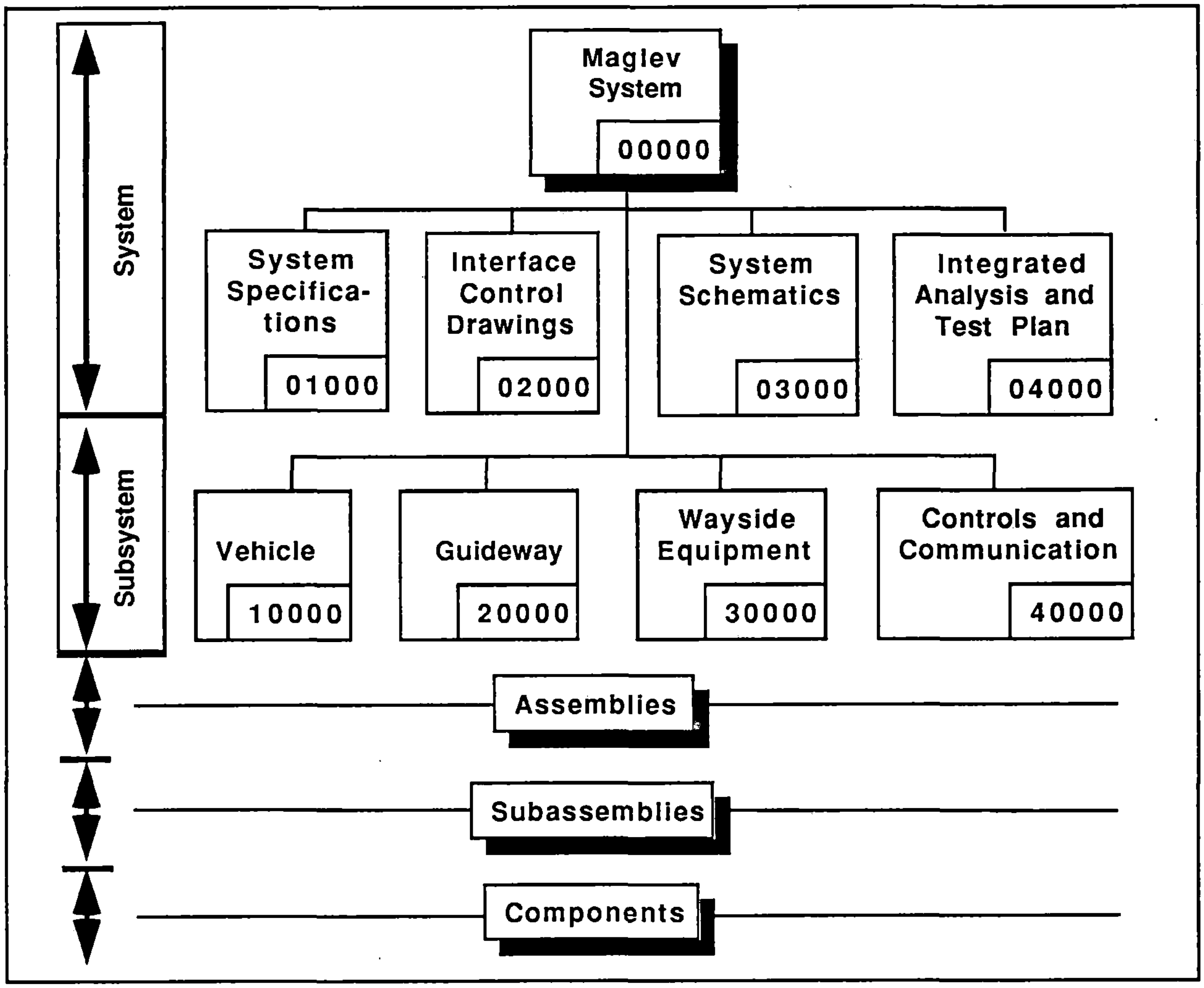

Figure 3.3-3 Recommended Maglev System Architecture Framework

System Operational Concept	• Describes the user's perception of the function, workings, and management of the system or service. • Identifies how people will interface with the system at a top level. • Establishes policy in the form of a mission statement to which all system requirements are traceable. • Defines the economic, societal, timing, and benefits expectations for a system or service.
System Specifications	• Defines top-level system performance requirements. • Allocates system performance requirements to major subsystems. • Defines major subsystem interface constraints. • Establishes hardware and software performance verification methods and requirements.
Architecture or Product Structure	• Establishes inter-relationship of subsystems, assemblies, subassemblies, and components. • Provides vehicle for overall system configuration control. • Establishes framework for suballocation of major subsystem requirements. • Provides a baseline for manufacture, test, and activation.

Figure 3.3-4 Relationship of system specifications to operational concepts and product structure

Table 3.3-1 Point-of-Departure Maglev System Architecture

Maglev System

- System Specification
- Interface Control Drawings
  - Vehicle
  - Guideway
  - Wayside Equipment
  - Control and Communications
- System Schematics
- Integrated Analysis and Test Plan

Vehicle

- Subsystem Specification
- Subsystem Interface Control Drawings
- Subsystem Design Criteria Document
- Body Structure
  - Magnet Underframe Assembly
    - Underframe Structure
    - Steerable Magnet Undercarriage
    - Pivoted Bogie Magnet Undercarriage (R)
  - Cabin Structural Assembly
    - Floor Subassembly
    - Aero-shell Subassembly
      - Normal Access/Egress
      - Emergency Egress
  - Secondary Suspension Assembly
    - Suspension Active Tilting Mechanism
  - Between Vehicle Couplers
- Linear Propulsion Motor and Magnetic Suspension Assembly (R)
  - Superconducting Magnet Subassembly (R)
    - Liquid Helium Cryocooler (R)
    - Superconducting Winding & Persistent Switch (R)
    - Helium Reservoir and Heat Exchanger (R)
    - Magnet Cryostat (R)
    - Cryogenic Distribution (R)
  - Electromagnet Subassembly (A)
    - Iron-core Electromagnets
    - Magnet Feedback Control Equipment
    - Feedback Control Sensors
  - On-board Power Conditioning Equipment
  - Stator Windings
- Mechanical Suspension Assembly
  - Low-Speed Support and Guidance Wheels (R)
  - Emergency Landing Skids

Table 3.3-1 Point-of-Departure Maglev System Architecture (Continued)

- On-board Power Supply Equipment
  - Sliding Contact Propulsion Power Pickup
  - On-board Emergency Batteries
  - Non-contact Linear Generator
  - Non-propulsion On-board Power Conditioning
- Emergency Braking Assembly)
  - Brake Shoe Sliding On Guideway
  - Brake Shoe Clamping On Brake Rail or Guidance Wheel Rotor (R)
  - Air Spoiler Subassembly
- Passenger Accommodations
  - Cabin Furnishings
  - Magnet Field Shielding
  - Air-conditioning/Heating

Guideway

- Subsystem Specification
- Subsystem Interface Control Drawings
- Subsystem Design Criteria Document
- Guideway Substructure
  - Elevated Guideway Footing
    - Piled Footings
    - Spread Footings
  - Simply-supported At-grade Footings
- Guideway Superstructure
  - At-grade Simply Supported Beams
    - Non-magnetic/Electrically Isolated Concrete (R)
    - Position Adjustment Subassembly
  - Elevated Guideway
    - Pier Supported Beams
      - Non-magnetic/Electrically Isolated Concrete (R)
      - Position Adjustment Subassembly
    - Vertical Piers
- Linear Motor Component Attachments
  - Air-core Linear Synchronous Motor Stator Winding (R)
  - Linear Synchronous Motor Stator Winding/Iron Core (A)
  - Adjustment Fittings
- Magnetic Suspension Guideway Attachments
  - Passive Air-core Levitation Coils (R)
  - Ferromagnetic Guidance Rails (A)
  - Adjustment Fittings
- Switch Assembly
  - Horizontal Bending Flexible Beam
  - Lateral Transfer Beam Segment
  - Multiple Jointed Beam Subassembly

Table 3.3-1 Point-of-Departure Maglev System Architecture (Continued)

Wayside Equipment

- Subsystem Specification
- Subsystem Interface Control Drawings
- Subsystem Schematics
- Subsystem Design Criteria Document
- Power Conditioning Substations
  - Transformers
  - Variable Frequency Cyclo-converters or Inverters
  - Reactive Power Compensation
  - Regenerative Braking Subassembly
- Power Distribution Subsystem
  - Input Power Distribution Lines
  - Feeder Power Distribution Lines
  - Section Switch Feeder Power

Control and Communications

- Subsystem Specification
- Subsystem Interface Control Drawings
- Subsystem Schematics
- Subsystem Design Criteria
- Vehicle Subsystems
  - Transmission/Reception Antennae
  - Vehicle Position Sensor
  - On-board Diagnostic Assembly
- Guideway Subsystems
  - Telemetry Link
  - Position Reflectors
- Wayside Subsystems
  - Linear Synchronization Control Assembly
  - Phase Angle and Current Regulation Assembly
  - Centralized System Computer Control Assembly
  - Speed Regulation Assembly

3.4 IDENTIFICATION OF MAGLEV DEVELOPMENT RISKS

3.4.1 Objectives

The purpose of this activity was to compile an authoritative list of risks inherent in a maglev development program. Emphasis was placed on identifying risk that could have significant program impact regarding cost, schedule, technical, and architectural approach. Significant unmitigated risk in this case is characterized as potential for:

- Cost overrun in excess of approximately $10,000,000
- Schedule impact in excess of 6 months, or
- Proceeding with a non-compliant technical approach.

A comprehensive identification of program risk is desired to:

- Estimate realistic program cost,
- Establish an achievable program schedule,
- Define system requirements,
- Identify technology requirements currently beyond the state-of-the-art, and
- Plan mitigation activities and facilities.

3.4.2 Approach

The literature search, described in Section 3.1 provided a basis for satisfying several objectives. In relationship to the task of identifying risk, the literature search supported identification of:

- Governmental, academic, and industrial leaders in the field,
- Maglev system architectures,
- Generally accepted maglev risks,
- Risk mitigation techniques, and
- Lessons learned.

Having identified maglev experts and compiled an initial list of development risk, interviews were conducted with knowledgeable sources, as described in Section 3.2 to:

- Expand the list of risks,
- Substantiate risk identified in the literature,
- Support characterization of risk severity, and

- Support allocation of risk to a subsystem within the architecture.

The summary of risks identified through interviews with knowledgeable sources has been presented in Table 3.2-2. Interviews were conducted with 31 experts resulting in identification of a total of 140 risks. Many of the experts practice in multiple disciplines and many of the risks apply to more than one discipline; therefore, redundancies exist in the list. The risks were analyzed to:

- Eliminate redundancies and insignificant risks,
- Assess and assign severity,
- Allocate and assign the risk to a subsystem, if possible, and
- Aggregate the risks by subsystem and type.

The results of the analysis are shown in Table 3.4-1, Summary of Risks Sorted By Severity and Risk Type. Insignificant risks are those that, upon judgement by the Test Requirements Analysis Team, do not satisfy the criteria for "significant" defined in Section 3.4.1.

Severity was subjectively assigned based on an assessment of technical challenge, relationship to safety, and propensity for cost overrun and schedule impact if not properly mitigated. Risks rated with a severity of "high", if unmitigated, can have dramatic impact on the program, one or more orders of magnitude in excess of the definition for "significant" (reference Section 3.4.1). Risks rated "medium" can have impact up to one order of magnitude in excess of the definition for "significant". Risks rated "low" can have impacts on the order of the definition for "significant".Risks were allocated to 1 of 4 subsystems:

- Guideway,
- Vehicle,
- Control and Communications, or
- Wayside.

If a risk is intricately tied to a physical relationship between 2 or more subsystems, then the risk is assigned to "System", the next higher level in the architecture hierarchy (refer to Section 3.3). This allocation was performed to facilitate using the list as a cross-check of completeness when drafting system and subsystem specifications.

Based on analysis of interrelationships and common attributes among the risk elements, the basic risk types identified in Table 3.2-4 were developed. The risk types are tailored to the specifics of the maglev program and define distinct lines of activity that remain consistent throughout the verification and validation program. They represent generally different techniques for risk mitigation (and ultimately define the various testing strategies). Dynamics risks, for example, are mitigated in a fundamentally different way from Reliability, Maintainability, and Availability (RMA) risks, and from Electromagnetic (EM) Fields risks, etc. Each risk was accordingly assigned to the appropriate risk type.

Table 3.4-2 contains the same risks as Table 3.4-1; however, it is sorted first by risk type and then by severity. This sort is used to identify all risks within a particular risk type and forms

Table 3.4-1 Summary of Risks Sorted By Severity and Risk Type

Item	Risk Type	Risk	Requirements Allocation Level*	1 = Low 2 = Med. 3 = High Severity
1	Aging	Guideway Misalignment Due to Weather and Geotech	Guideway	3
2		Guideway Degradation Due to Fatigue	Guideway	3
3		Robust, Long-Life Vehicle/Guideway Interface Standard	System	3
4	Construction	Tolerance Build-Up in Guideway Construction	Guideway	3
5	Control	Vehicle Collision With Foreign Objects	System	3
6		Vehicle Collision With Vehicle	System	3
7	Cryogenics	Thermal Effects of Not Maintaining Constant Levitation Clearance (EDS)	Vehicle	3
8	Dynamics	High Speed Turnouts	System	3
9		Vehicle-Guideway Interface Tolerances (EMS)	System	3
10		High Speed Intolerance to Control Failures	System	3
11		Control of Vertical Dynamics	System	3
12		Dynamic Linkage Between Vertical and Longitudinal Motion (Surging)	System	3
13		Control of Lateral Dynamics	System	3
14		Switching and Service Braking in a Trough Shaped Guideway	System	3
15		Operational Use of Landing Gear	System	3
16		Effects of Cross-Wind and Headwind on Vehicle Dynamics (Incl Ride Comfort	Vehicle	3
17		Active Suspension Systems	Vehicle	3
18	E-M Fields	Biological Effects of Electromagnetic Fields	System	3
19		Active Cancellation of Magnetic Fields	Vehicle	3
20	Electrodynamics	Maintenance of Levitation Gap	System	3
21		Superconducting Magnet Quench Management	Vehicle	3
22	Emergency	Crashworthiness and Survivability	System	3
23	Human Factors	Provide Satisfactory Passenger Ride Comfort (Lat Accel, Roll, Vibrations)	System	3
24	Programmatic	Inadequate Provision of Development Testing Facilities	System	3
25	RMA	Guideway Availability and Modularity	Guideway	3
26		Superconducting Magnet Functionality	Vehicle	3
27		Cryostat Functionality	Vehicle	3
28		Vehicle Functionality	Vehicle	3
29		Power Conditioning Functionality	Wayside	3
30	Sensor	Obstruction Detection	Control & Comm	3
31	Software	Control Software Compatibility	Control & Comm	3
32		Software Reliability	System	3

Table 3.4-1 Summary of Risks Sorted By Severity and Risk Type (Continued)

Item	Risk Type	Risk	Requirements Allocation Level*	1 = Low 2 = Med. 3 = High Severity
33	Weather & Geotech	Guideway Degradation Due to Environment	Guideway	3
34	Acoustics	Noise, Startle Effects	System	2
35	Aerodynamics	Pressure Effects of Passing Vehicles	System	2
36		Overpressure Effects in Tunnels	System	2
37	Aging	Fatigue Failure of Guideway Mounted Aluminum Sheet	Guideway	2
38		Long Term Loss of Coil Field Strength	System	2
39	Construction	Tight Tolerances in Moving Switch Elements	Guideway	2
40	Dynamics	Active/Passive Tilt Demands on Lateral Guidance	System	2
41		Active Tilt Systems	System	2
42		Operating Non-Tilt Systems at Other than Design Velocity	System	2
43	E-M Fields	Mass Required to Mitigate Biological Effects of Electromagnetic Fields	System	2
44		Electromagnetic Compatibility of On-Board and Encountered Systems	System	2
45	Electrodynamics	Null Flux Performance Uncertainties	System	2
46		Eddy Current Losses In Magnets	Vehicle	2
47	Human Factors	Passenger Perception of Speed	System	2
48	Materials	Weight of Cryogenically Cooled Superconducting Magnets	Vehicle	2
49		Vehicle Fire Supression	Vehicle	2
50	Programmatic	Environmental Acceptability	System	2
51	RMA	Control System Functionality	Control & Comm	2
52		Power Distribution Systems Functionality	Wayside	2
53	Sensor	Obstruction Detection False Alarm	Control & Comm	2
54	Software	Adequate Software Test	System	2
55	Structures	Non-Magnetic Structural Components in Guideway (EDS Systems)	Guideway	2
56		Propulsion and Suspension Coil Attachment to Guideway	Guideway	2
57		Thermal Loads and Deflection of Guideway Mounted Aluminum Sheet	Guideway	2
58	Weather & Geotech	Guideway Suitability for All Domestic Geotechnical and Weather Conditions	Guideway	2
59		Environmental Effects on Guideway-Mounted Sensors	System	2
60	Acoustics	Interior Noise	System	1
61	Aging	Thermal Stress Mismatch of LSM Components Causing Attachment Fatigue	Guideway	1
62	Construction	Guideway Manufacture, Assembly, and Field Erection	Guideway	1
63		Guideway Positional Adjustability	Guideway	1
64	Dynamics	Dynamics of Simple vs Continuous Guideway Support	Guideway	1

Table 3.4-1 Summary of Risks Sorted By Severity and Risk Type (Concluded)

Item	Risk Type	Risk	Requirements Allocation Level*	1 = Low 2 = Med. 3 = High Severity
65	Dynamics (cont'd)	Mismatching Structural and Crossing Frequencies at All Operational Speeds	System	1
66		Vehicle Tolerance of Pre-Lift-Off Dynamics (EDS)	Vehicle	1
67	E-M Fields	Fidelity of Flux Simulations	System	1
68	Human Factors	Technical Community Agreement on Excessive Decelerations (0.5g)	System	1
69		Passenger Emergency Egress	System	1
70	Materials	Suitability of Concrete for Use as Guideway Material (Tolerance Failures)	Guideway	1
71		Controlling Content of Concrete Components with Magnetic Properties	Guideway	1
72		Electrostatic Corrosion of LSM Components	Guideway	1
73		Aluminum Combustability	System	1
74		Superconducting Magnet Manufacturing Flaws	Vehicle	1
75		Lightweight and Environmentally Benign Air Conditioning	Vehicle	1
76	Operations	Degree of Incorporating Man-In-The-Loop for Vehicle Control	Control & Comm	1
77		Central Control with Man-In-The-Loop	Control & Comm	1
78	Power	Adequate Inductive Power Transfer for Hotel Functions	System	1
79		Efficient Regenerative Braking	System	1
80	Programmatic	Control System Verification and Validation	Control & Comm	1
81		Aluminum Production Capacity	Guideway	1
82		Adaptation to Existing Rights-of-Way	Guideway	1
83		Availability of GTO Thyristors	System	1
84	RMA	Reliability of Continuous Welds in Guideway Mounted Aluminum Sheet	Guideway	1
85		Adequate Preventive and Predictive Maintenance	System	1
86		Vehicle Health Management	Vehicle	1
87	Sensor	Obstruction Detection Sensor Effectiveness Under Operating Conditions	Control & Comm	1
88		Guideway Integrity Sensor Function In High Magnetic Field Environment	System	1
89	Software	Control System Test Thoroughness and Fidelity	Control & Comm	1
90	Structures	Superconducting Magnet Mechanical Integrity	Vehicle	1
91	Weather & Geotech	Wind Effects on Spans	Guideway	1
92		Seismic Effects on Guideway Integrity	Guideway	1
93		Ice and Snow Accumulation in Trough Shaped Guideway	Guideway	1
94		Operation Under Severe Weather Conditions	System	1

(Notes: Redundant Risks Have Been Eliminated and Other Risks Have Been Generalized in this Sort
*** = Allocated to 'System' if Risk Applies to More than 1 Subsystem)**

Table 3.4-2 Summary of Risks Sorted By Risk Type and Severity

Item	Risk Type	Risk	Requirements Allocation Level*	1 = Low 2 = Med. 3 = High Severity
1	Acoustics	Noise, Startle Effects	System	2
2		Interior Noise	System	1
3	Aerodynamics	Pressure Effects of Passing Vehicles	System	2
4		Overpressure Effects in Tunnels	System	2
5	Aging	Guideway Misalignment Due to Weather and Geotech	Guideway	3
6		Guideway Degradation Due to Fatigue	Guideway	3
7		Robust, Long-Life Vehicle/Guideway Interface Standard	System	3
8		Fatigue Failure of Guideway Mounted Aluminum Sheet	Guideway	2
9		Long Term Loss of Coil Field Strength	System	2
10		Thermal Stress Mismatch of LSM Components Causing Attachment Fatigue	Guideway	1
11	Construction	Tolerance Build-Up in Guideway Construction	Guideway	3
12		Tight Tolerances in Moving Switch Elements	Guideway	2
13		Guideway Manufacture, Assembly, and Field Erection	Guideway	1
14		Guideway Positional Adjustability	Guideway	1
15	Control	Vehicle Collision With Foreign Objects	System	3
16		Vehicle Collision With Vehicle	System	3
17	Cryogenics	Thermal Effects of Not Maintaining Constant Levitation Clearance (EDS)	Vehicle	3
18	Dynamics	High Speed Turnouts	System	3
19		Vehicle-Guideway Interface Tolerances (EMS)	System	3
20		High Speed Intolerance to Control Failures	System	3
21		Control of Vertical Dynamics	System	3
22		Dynamic Linkage Between Vertical and Longitudinal Motion (Surging)	System	3
23		Control of Lateral Dynamics	System	3
24		Switching and Service Braking in a Trough Shaped Guideway	System	3
25		Operational Use of Landing Gear	System	3
26		Effects of Cross-Wind and Headwind on Vehicle Dynamics (Incl Ride Comfort	Vehicle	3
27		Active Suspension Systems	Vehicle	3
28		Active/Passive Tilt Demands on Lateral Guidance	System	2
29		Active Tilt Systems	System	2
30		Operating Non-Tilt Systems at Other than Design Velocity	System	2
31		Dynamics of Simple vs Continuous Guideway Support	Guideway	1
32		Mismatching Structural and Crossing Frequencies at All Operational Speeds	System	1

Table 3.4-2 Summary of Risks Sorted By Risk Type and Severity (Continued)

Item	Risk Type	Risk	Requirements Allocation Level*	1 = Low 2 = Med. 3 = High Severity
33	Dynamics (cont'd)	Vehicle Tolerance of Pre-Lift-Off Dynamics (EDS)	Vehicle	1
34	E-M Fields	Biological Effects of Electromagnetic Fields	System	3
35		Active Cancellation of Magnetic Fields	Vehicle	3
36		Mass Required to Mitigate Biological Effects of Electromagnetic Fields	System	2
37		Electromagnetic Compatibility of On-Board and Encountered Systems	System	2
38		Fidelity of Flux Simulations	System	1
39	Electrodynamics	Maintenance of Levitation Gap	System	3
40		Superconducting Magnet Quench Management	Vehicle	3
41		Null Flux Performance Uncertainties	System	2
42		Eddy Current Losses In Magnets	Vehicle	2
43	Emergency	Crashworthiness and Survivability	System	3
44	Human Factors	Provide Satisfactory Passenger Ride Comfort (Lat Accel, Roll, Vibrations)	System	3
45		Passenger Perception of Speed	System	2
46		Technical Community Agreement on Excessive Decelerations (0.5g)	System	1
47		Passenger Emergency Egress	System	1
48	Materials	Weight of Cryogenically Cooled Superconducting Magnets	Vehicle	2
49		Vehicle Fire Supression	Vehicle	2
50		Suitability of Concrete for Use as Guideway Material (Tolerance Failures)	Guideway	1
51		Controlling Content of Concrete Components with Magnetic Properties	Guideway	1
52		Electrostatic Corrosion of LSM Components	Guideway	1
53		Aluminum Combustability	System	1
54		Superconducting Magnet Manufacturing Flaws	Vehicle	1
55		Lightweight and Environmentally Benign Air Conditioning	Vehicle	1
56	Operations	Degree of Incorporating Man-In-The-Loop for Vehicle Control	Control & Comm	1
57		Central Control with Man-In-The-Loop	Control & Comm	1
58	Power	Adequate Inductive Power Transfer for Hotel Functions	System	1
59		Efficient Regenerative Braking	System	1
60	Programmatic	Inadequate Provision of Development Testing Facilities		3
61		Environmental Acceptability	System	2
62		Control System Verification and Validation	Control & Comm	1
63		Aluminum Production Capacity	Guideway	1
64		Adaptation to Existing Rights-of-Way	Guideway	1

Table 3.4-2 Summary of Risks Sorted By Risk Type and Severity (Concluded)

Item	Risk Type	Risk	Requirements Allocation Level*	1 = Low 2 = Med. 3 = High Severity
65	Programmatic (cont'd)	Availability of GTO Thyristors	System	1
66	RMA	Guideway Availability and Modularity	Guideway	3
67		Superconducting Magnet Functionality	Vehicle	3
68		Cryostat Functionality	Vehicle	3
69		Vehicle Functionality	Vehicle	3
70		Power Conditioning Functionality	Wayside	3
71		Control System Functionality	Control & Comm	2
72		Power Distribution Systems Functionality	Wayside	2
73		Reliability of Continuous Welds in Guideway Mounted Aluminum Sheet	Guideway	1
74		Adequate Preventive and Predictive Maintenance	System	1
75		Vehicle Health Management	Vehicle	1
76	Sensor	Obstruction Detection	Control & Comm	3
77		Obstruction Detection False Alarm	Control & Comm	2
78		Obstruction Detection Sensor Effectiveness Under Operating Conditions	Control & Comm	1
79		Guideway Integrity Sensor Function In High Magnetic Field Environment	System	1
80	Software	Control Software Compatibility	Control & Comm	3
81		Software Reliability	System	3
82		Adequate Software Test	System	2
83		Control System Test Thoroughness and Fidelity	Control & Comm	1
84	Structures	Non-Magnetic Structural Components in Guideway (EDS Systems)	Guideway	2
85		Propulsion and Suspension Coil Attachment to Guideway	Guideway	2
86		Thermal Loads and Deflection of Guideway Mounted Aluminum Sheet	Guideway	2
87		Superconducting Magnet Mechanical Integrity	Vehicle	1
88	Weather & Geotech	Guideway Degradation Due to Environment	Guideway	3
89		Guideway Suitability for All Domestic Geotechnical and Weather Conditions	Guideway	2
90		Environmental Effects on Guideway-Mounted Sensors	System	2
91		Wind Effects on Spans	Guideway	1
92		Seismic Effects on Guideway Integrity	Guideway	1
93		Ice and Snow Accumulation in Trough Shaped Guideway	Guideway	1
94		Operation Under Severe Weather Conditions	System	1

(Notes: Redundant Risks Have Been Eliminated and Other Risks Have Been Generalized in this Sort

*** = Allocated to 'System' if Risk Applies to More than 1 Subsystem)**

the basis for choosing risk mitigation methods and assignment of the timing of mitigation to the development schedule (described in Section 3.5).

The maglev system architecture defined in Section 3.3 was used to cross-check the list of risks and build confidence that all components of the system were represented and considered in identifying risk.

3.4.3 Results

Risk is relatively evenly balanced in terms of severity (refer to Table 3.4-2):

- 33 risks are high,
- 26 risks are medium, and
- 35 risks are low severity.

Tables 3.4-3 and 3.4-4 list statistics of risk severity by risk type. Dynamics and RMA risks dominate the maglev program not only in total number of risks but risk severity as well. Aging and EM field risks are also numerous and severe. Control, cryogenics and emergency, although few in total number of risks, are high severity and warrant close attention in the development program.

These 7 risk types constitute 41 of the 94 total risks (24 of which are high severity) and will require a carefully crafted mitigation program in which high-fidelity testing at full scale is required intensively and early in the program. The greatest maglev program risks are in these categories.

Programmatic, electrodynamics, software, construction, human factors, sensor, and structures risks fill the midrange with 4 to 6 total risks. These risks will require a relatively balanced program of analysis and test with test timeframes chosen on a risk-by-risk basis.

Materials, weather, and geotechnical risks are numerous but relatively low risk. These risks will require a program of early analysis with possible deferral of testing to timeframes later in the program, if at all.

Aerodynamics, acoustics, operations, and power are at the low end of the risk scale. Mitigation of these risks can generally be accomplished through analysis.

Table 3.4-3 Analysis of Risk Sorted by Number of Total Risk Elements

Sort By Total Risks				
		Risk Severity		
Risk Type	High	Medium	Low	Total
Dynamics	10	3	3	16
RMA	5	2	3	10
Materials	0	2	6	8
Weather & Geotech	1	2	4	7
Aging	3	2	1	6
Programmatic	1	1	4	6
E-M Fields	2	2	1	5
Electrodynamics	2	2	0	4
Software	2	1	1	4
Construction	1	1	2	4
Human Factors	1	1	2	4
Sensor	1	1	2	4
Structures	0	3	1	4
Control	2	0	0	2
Aerodynamics	0	2	0	2
Acoustics	0	1	1	2
Operations	0	0	2	2
Power	0	0	2	2
Cryogenics	1	0	0	1
Emergency	1	0	0	1
Total	**33**	**26**	**35**	**94**

Table 3.4-4 Analysis of Risk Sorted by Number of High Severity Risk Elements

Sort By Highest Risks				
		Risk Severity		
Risk Type	High	Medium	Low	Total
Dynamics	10	3	3	16
RMA	5	2	3	10
Aging	3	2	1	6
E-M Fields	2	2	1	5
Electrodynamics	2	2	0	4
Software	2	1	1	4
Control	2	0	0	2
Weather & Geotech	1	2	4	7
Programmatic	1	1	4	6
Construction	1	1	2	4
Human Factors	1	1	2	4
Sensor	1	1	2	4
Cryogenics	1	0	0	1
Emergency	1	0	0	1
Structures	0	3	1	4
Materials	0	2	6	8
Aerodynamics	0	2	0	2
Acoustics	0	1	1	2
Operations	0	0	2	2
Power	0	0	2	2
Total	**33**	**26**	**35**	**94**

3.5 TEST PROGRAM REQUIREMENTS AND SCOPE

The final report for this contract will address test program planning and test facility requirements. Included with the interim report is a preliminary assignment of each risk to a particular risk mitigation method (analysis or test) and recommendation for assignment of the mitigation activity to a particular point in the development program schedule. Also included is a brief discourse on test activities performed by prior and current developers of transportation systems.

3.5.1 Risk Mitigation Methods and Timeframes

With the progress to date, analysis has only been performed to identify timeframes in which various risk mitigation activities can be integrated into the Maglev Prototype Development Program (PDP). Figure 3.5-1 shows the relationships and timing of the various phases of the Maglev PDP. The relationships of the phases and their names were derived from the ISTEA of 1991. For the purpose of this study, the terms "Phase 3", "Phase 4", and "Phase 5" are assigned to the three final activities outlined in the law (the three activities are not assigned phase numbers in the ISTEA).

If an activity similar to what is termed Preliminary Design Review (PDR) in development programs is desired at the close of Phase 1 (System Concept Definition) then certain tests and analyses should be required of the competing teams in satisfaction of PDR requirements. Similarly, if what is commonly termed a Critical Design Review (CDR) is desired at the close of Phase 2, Detailed Design, then certain tests and analyses should be required of the competing teams in satisfaction of CDR requirements. The Prototype Development, Construction, and Operational Testing (Phases 3, 4, and 5) will also require risk mitigation activities; however, these will predominantly (though not exclusively) be tests, analysis having been essentially completed in the earlier phases.

With these understandings as a baseline, the test requirements analysis team determined which risks should be mitigated by either analysis or test. The assignment of a mitigation method to analysis or test was performed on the basis of:

- Risk severity,
- Current state-of-the-art in analysis fidelity and sophistication,
- Cost of requiring test, and
- Engineering judgment.

The Test Requirements Analysis Team also determined the appropriate phase in the PDP for conducting the mitigating activity. The phasing determination was made on the basis of:

- Risk severity,
- Timing of analysis input availability and results requirements,
- Timing of economical test hardware or facilities availability, and
- Engineering judgment.

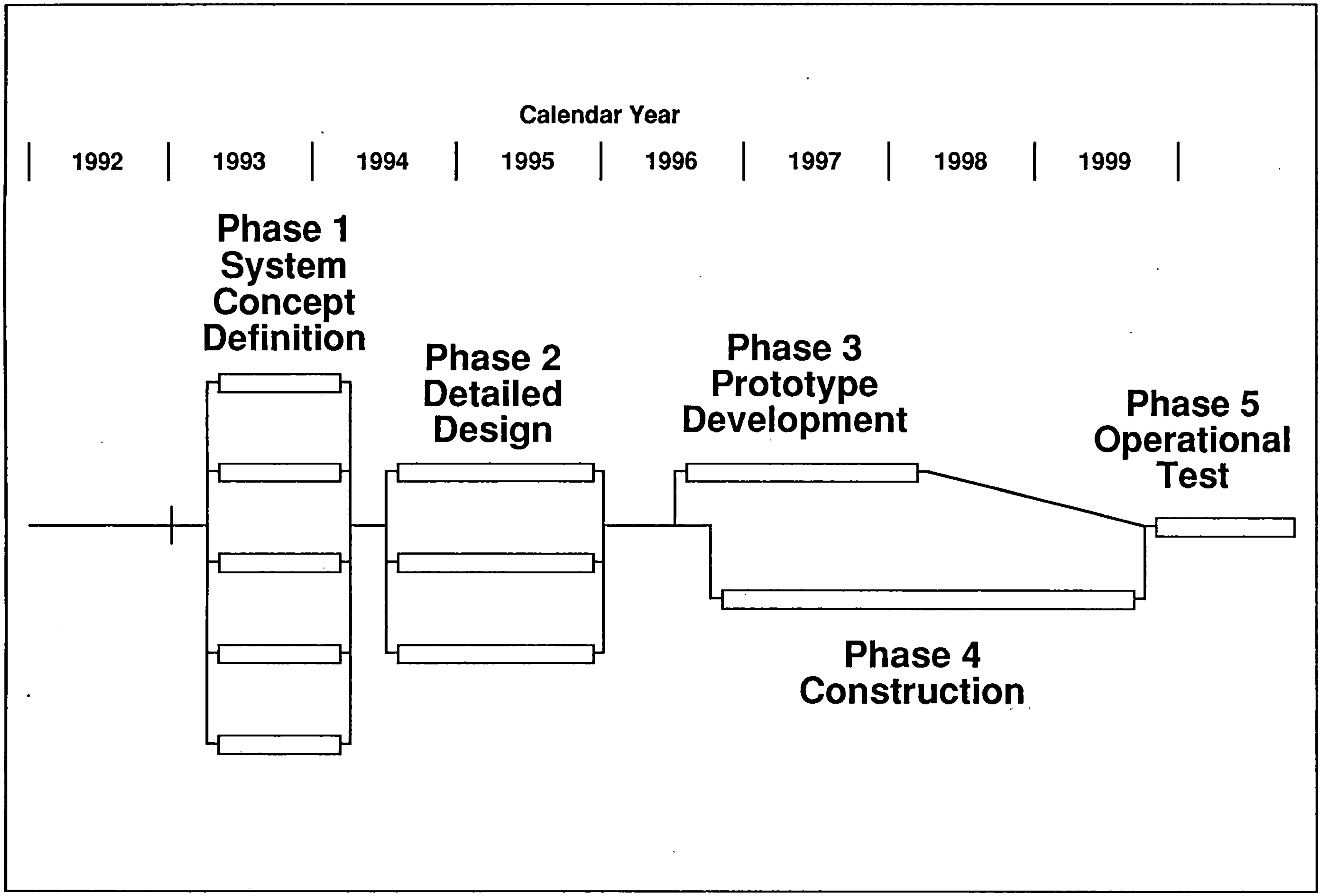

Figure 3.5-1 Maglev Prototype Development Program Phases

Not all identified risks will ultimately require test for risk mitigation. Some risks are mutually exclusive. Once an option has been selected, testing of the competing option is eliminated.

Under no circumstances should the assumption be made that these tests and analyses can be performed within the costs and timeframes associated with the ISTEA mandated PDP budget and schedule. Analysis of schedule requirements will be forthcoming in the final report of this contract.

The product of the required mitigation method and phasing analysis is Table 3.5-1 Suggested Risk Mitigation Verification Method by Prototype Development Phase and Risk Type. A list of risks by type and item number (Table 3.5-2) is included for use as a reference in identifying the item numbers used in Table 3.5-1.

3.5.2 Test Activities by Prior and Current Transportation System Developers

Information was obtained during the literature search and source interviews regarding test activities by prior and current developers of transportation systems. Existing test facilities and preliminary designs for proposed facilities were identified as potential resources for maglev testing. Capabilities and technologies most frequently cited were those of the Department of Transportation Test Center (TTC) and test facility designs proposed by Argonne National Laboratory.

The TTC, located on 52 square miles of open land in Pueblo, Colorado includes a number of facilities and capabilities applicable to full-scale testing of the maglev system. The Rail Dynamics Laboratory (RDL) at the TTC houses the following:

- Vibration Test Unit (VTU): Capable of recreating the dynamic effects of perturbed track on a moving vehicle. Consists of 12 electro-hydraulic actuators which apply vertical and lateral vibrations into the test vehicle within the frequency range of 0.2 to 30 Hz. Can be used to identify modal characteristics of transport vehicles.

- Roll Dynamics Unit (RDU): Simulates motion of powered or unpowered vehicles. Acceleration, adhesion, braking and curving forces can be investigated using the RDU.

- Simuloader (SMU): Applies vibration into a test vehicle through the vehicle body itself. Runs efficiently for long periods of time, making it applicable for fatigue or accelerated life tests. Earthquake simulation is another potential application of the SMU.

- RDL Computer Capabilities: Consist of a DEC 11/23 computer, two DEC 11/34 computers, a DEC 11/44 computer, and access to a VAX 11/780. The DEC 11/23 provides control to the shakers while acquiring and analyzing up to 64 channels of data. One DEC 11/34 provides input to the SMU while the other is a telemetry linked data acquisition system. The DEC 11/44 and VAX 11/780 are used for data processing.

- RDL Handling Capabilities: Two 100-ton traveling bridge cranes and pneumatic lifting devices are available to position test articles.

The TTC has power resources available for wayside and/or cantenary support. A significant amount of TTC land space is undeveloped, permitting construction of straight and curved guideway segments of sufficient length to conduct high-speed tests. A project management building, containing office space to accommodate up to 100 people, is available for long-term occupancy on-site at the TTC.

Extensive studies conducted by Argonne National Laboratory have resulted in the preliminary design of a proposed intermediate size development facility. The proposed design incorporates a modular component approach which allows users to replace entire sections of guideway and complete suspension and propulsion systems on the vehicle for experimentation with alternative concepts. The design includes elevated test guideways, one or more fully instrumented test vehicles, data acquisition, transmission and reduction facilities, power and power conditioning equipment, operational controls, a control and office building and a maintenance garage. The facility location would be in a region in which climatic conditions are varied for testing all weather operational capabilities of items or systems under development.

The facility proposed by Argonne would be operated as a National User Facility, available to all U.S. government, industrial and academic developers of the maglev system. The facility is not intended to evaluate full-scale systems, but to test integrated and discrete systems and components in sufficient sizes and under sufficiently realistic conditions that they can be extrapolated to operational configurations and speeds by using analytical models. Five major subsystems were studied to identify test facility requirements as follows:

- Vehicle/Train - The facility would be capable of evaluating single and coupled test vehicles at realistic speeds. The vehicles would be of such size and tested at such speeds that the results could be reasonably extrapolated to operational sizes and speeds. The test guideway would be constructed to simulate the operational periodic perturbations, thereby permitting assessments of ride quality. The vehicle would be accelerated at the approximate acceleration of a full-scale system, thereby permitting realistic assessments of the propulsion, power, and control systems. The test vehicle would be designed to interchangeably accommodate any suspension system. The facility would provide for the use of cryogens in the vehicle. The test vehicle body would be constructed of aluminum to minimize weight and to avoid masking the diagnostic measurement of magnetic fields from the propulsion and suspension systems.

- Guideway - The test guideway must be capable of evaluating alternative maglev systems. It would be designed to support the maximum vehicle weight anticipated with a deflection of less than 1 part in 1000 of the span. The guideway design would permit evaluation of both electromagnetic and electrodynamic systems. The proposed guideway is approximately 3.3 km (2.05 miles) long and would permit the performance of vehicle tests at speeds up to 67 m/s (150 mph). A section of the test guideway would be removable, permitting the capability to test sections having different rigidities, structural designs, structural tolerances, or materials. The guideway would incorporate various means of obstacle detection for evaluation.

- Propulsion System - The test facility would incorporate innovative strageties for controlling the propulsion system under conditions in which both the vehicle/guideway dynamics and wind gusts affect and interact with the motor. The guideway design provides for the replacement of the propulsion system in part or in its entirety.

- Control and Communications System - The proposed facility would be useful for evaluating the application of digital control strategies, such as dead-beat control and self-turning controls. The facility could be used to develop an expert dynamic control system and a database for accumulating test results. Control and communications response times in the test facility would vary depending on the particular control considered, but would not be less than one-half that of operational systems.

- Power Supply - The proposed facility would use gate-turn-off thyristors (GTOs) to convert power to the wide range of frequencies required for the EMS and EDS. Novel systems would be expected to have frequency and power requirements within the range provided by the test facility.

Other test facilities which were identified during the literature search and knowledgeable source interviews include the following:

- Langley Research Center—Reference was made to the Ride Quality Simulator which consists of a platform which can roll and translate in three axes with up to 1 in. maximum displacement. Langley also has the capability of introducing acoustic noise during simulation of accelerations.

- MIT—The wind tunnel was identified as a possible resource for conducting sub-scale aerodynamic testing.

- Draper Laboratory—Includes facilities for testing fault-tolerant, fail-safe computer control systems.

- Several sources identified test facilities located within their own organizations which, with modification, could be used in the development stages of the program to evaluate magnetic field levels, power loads, component sensitivity to dynamic environments, guideway material sensitivities and numerous other risks.

Available test facilities will be evaluated and assessed in accordance with various test scenarios to determine their adequacy and new facilities will be identified as required in the next phase of the study.

Table 3.5-1 Suggested Risk Mitigation Verification Method By Prototype Development Phase and Risk Type

	Phase 1		Phase 2		Phase 3	Phase 4	Phase 5
Risk Type	**Analysis**	**Test**	**Analysis**	**Test**	**Test**	**Test**	**Test**
Acoustics	1		1,2	1			1
Aerodynamics	3,4		3,4				3,4
Aging	5-10		5	6,8-10		5	5-10
Construction	11		12-14			11-14	12
Control	15,16		15*-16*				15,16
Cryogenics	17	17		17			17
Dynamics	18-33	21-23,26-29	21-23,27-32	18-23,25-29,33	19,21-23,27-29		18-29,33
E-M Fields	34-38	34,35,38	34-37		34-37		34-37
Electrodynamics	39-42	39	39	39,42	39,40		39-40
Emergency	43		43				43
Human Factors	46,47	44,45	44,47		44,47		44,45,47
Materials	48-55				54		
Operations	56,57						56,57
Power	58,59			58,59			58,59
Programmatic	60-65		62*		62		62
RMA	66-75		66-75		67-69,71,74	66,70	66-75
Sensor	76-80		80	76-79	80	72,73	76-80
Software	81-83		81*-83*		81-83		81-83
Structures	84-87			85,86	87	84	84-87
Weather & Geotech	88-94			90		93	88-91,93,94

(Note: * = Software Demonstration)

Table 3.5-2 Maglev Program Risks by Risk Type

Item	Risk Type	Risk
1	Acoustics	Noise, Startle Effects
2		Interior Noise
3	Aerodynamics	Pressure Effects of Passing Vehicles
4		Overpressure Effects in Tunnels
5	Aging	Guideway Misalignment Due to Weather and Geotech
6		Guideway Degradation Due to Fatigue
7		Robust, Long-Life Vehicle/Guideway Interface Standard
8		Fatigue Failure of Guideway Mounted Aluminum Sheet
9		Long Term Loss of Coil Field Strength
10		Thermal Stress Mismatch of LSM Components Causing Attachment Fatigue
11	Construction	Tolerance Build-Up in Guideway Construction
12		Tight Tolerances in Moving Switch Elements
13		Guideway Manufacture, Assembly, and Field Erection
14		Guideway Positional Adjustability
15	Control	Vehicle Collision With Foreign Objects
16		Vehicle Collision With Vehicle
17	Cryogenics	Thermal Effects of Not Maintaining Constant Levitation Clearance (EDS)
18	Dynamics	High Speed Turnouts
19		Vehicle-Guideway Interface Tolerances (EMS)
20		High Speed Intolerance to Control Failures
21		Control of Vertical Dynamics
22		Dynamic Linkage Between Vertical and Longitudinal Motion (Surging)
23		Control of Lateral Dynamics
24		Switching and Service Braking in a Trough Shaped Guideway
25		Operational Use of Landing Gear
26		Cross-Wind and Headwind Effects on Vehicle Dynamics (Incl Ride Comfort)
27		Active Suspension Systems
28		Active/Passive Tilt Demands on Lateral Guidance
29		Active Tilt Systems
30		Operating Non-Tilt Systems at Other than Design Velocity
31		Dynamics of Simple vs Continuous Guideway Support
32		Mismatching Structural and Crossing Frequencies at All Operational Speeds
33		Vehicle Tolerance of Pre-Lift-Off Dynamics (EDS)
34	E-M Fields	Biological Effects of Electromagnetic Fields
35		Active Cancellation of Magnetic Fields
36		Mass Required to Mitigate Biological Effects of Electromagnetic Fields
37		Electromagnetic Compatibility of On-Board and Encountered Systems
38		Fidelity of Flux Simulations
39	Electrodynamics	Maintenance of Levitation Gap
40		Superconducting Magnet Quench Management
41		Null Flux Performance Uncertainties
42		Eddy Current Losses In Magnets
43	Emergency	Crashworthiness and Survivability
44	Human Factors	Provide Satisfactory Passenger Ride Comfort (Lat Accel, Roll, Vibrations)
45		Passenger Perception of Speed
46		Technical Community Agreement on Excessive Decelerations (0.5g)
47		Passenger Emergency Egress
48	Materials	Weight of Cryogenically Cooled Superconducting Magnets
49		Vehicle Fire Supression
50		Suitability of Concrete for Use as Guideway Material (Tolerance Failures)
51		Controlling Content of Concrete Components with Magnetic Properties
52		Electrostatic Corrosion of LSM Components
53		Aluminum Combustability
54		Superconducting Magnet Manufacturing Flaws
55		Lightweight and Environmentally Benign Air Conditioning
56	Operations	Degree of Incorporating Man-In-The-Loop for Vehicle Control
57		Central Control with Man-In-The-Loop
58	Power	Adequate Inductive Power Transfer for Hotel Functions
59		Efficient Regenerative Braking
60	Programmatic	Inadequate Provision of Development Testing Facilities
61		Environmental Acceptability
62		Control System Verification and Validation
63		Aluminum Production Capacity
64		Adaptation to Existing Rights-of-Way
65		Availability of GTO Thyristors
66	RMA	Guideway Availability and Modularity
67		Superconducting Magnet Functionality
68		Cryostat Functionality
69		Vehicle Functionality
70		Power Conditioning Functionality
71		Control System Functionality
72		Power Distribution Systems Functionality
73		Reliability of Continuous Welds in Guideway Mounted Aluminum Sheet
74		Adequate Preventive and Predictive Maintenance
75		Vehicle Health Management
76	Sensor	Obstruction Detection
77		Obstruction Detection False Alarm
78		Obstruction Detection Sensor Effectiveness Under Operating Conditions
79		Guideway Integrity Sensor Function In High Magnetic Field Environment
80	Software	Control Software Compatibility
81		Software Reliability
82		Adequate Software Test
83		Control System Test Thoroughness and Fidelity
84	Structures	Non-Magnetic Structural Components in Guideway (EDS Systems)
85		Propulsion and Suspension Coil Attachment to Guideway
86		Thermal Loads and Deflection of Guideway Mounted Aluminum Sheet
87		Superconducting Magnet Mechanical Integrity
88	Weather/Geotech	Guideway Degradation Due to Environment
89		Guideway Suitability for All Domestic Geotechnical and Weather Conditions
90		Environmental Effects on Guideway-Mounted Sensors
91		Wind Effects on Spans
92		Seismic Effects on Guideway Integrity
93		Ice and Snow Accumulation in Trough Shaped Guideway
94		Operation Under Severe Weather Conditions

4.0 CONCLUSIONS AND RECOMMENDATIONS

Literature Research Conclusions—The Test Requirements Analysis Team concludes that the state-of-the-art in maglev development is overseas. The United States has been virtually dormant in maglev research and resultant publication volume for almost 20 years. Transrapid, Japanese Railroads, and the Canadian Institute for Guided Ground Transport (CIGGT) are the definitive maglev leaders. The CIGGT Maglev Technology Assessment contains the framework for a standardized architecture and nomenclature.

No references were found that address themselves to a current re-assessment of operational concepts appropriate for U.S. application. The literature search, however, was instrumental in advancing system definition. Leading architectures and developers have been comprehensively characterized. Literature referencing test planning and facilities exercised by prior or current developers is sparse; however, exceptions are references to test planning and facilities at the Transportation Test Center near Pueblo, Colorado, CIGGT, Argonne, Brookhaven, Oak Ridge, Langley Research Center, and Lincoln Laboratories, MIT, and Draper.

Literature Search Recommendation—The National Maglev Initiative should consider a program of translating German and Japanese maglev source information on a broad scale. The resulting literature will stimulate technology transfer and significantly mitigate high risk in areas such as dynamics, magnet design, and vehicle command and control functions.

Industry Expert Interviews Conclusions—This activity was particularly effective in identifying technical risk. The domestic technical community has a keen interest in identifying risk even at a distance from where actual development is occurring. After some time, the Test Requirements Analysis Team noticed an increasing redundancy in risks, suggesting sufficient sampling had occurred. Few interviewees identified novel operational concepts. The community appears content to permit coexistence of multiple competing concepts at this stage in the program. Few architecture clarifications exceeded the level of specificity found in the literature. Test planning and facilities concepts exercised by prior or future developers will be better comprehended upon completion of site visits to the Myazaki Prefecture, Japan and Emsland, Germany.

Architecture Conclusions—Differences exist with regard to levitation, guidance, propulsion, and braking techniques. Architecture classifications must be flexible enough to accommodate competing approaches. CIGGT architecture standards suffice. Although the prospect of competing hardware designs within a common architecture is desirable, competing operational concepts are not desirable. Significant differences currently exist in system operations concepts. One concept proposes vehicles making frequent stops, operating at short headways on a highly networked system requiring high-speed switching for viability. Another operational concept foresees maglev competing against short-hop air travel in more of a line-haul mode with high speeds, infrequent stops, and longer headways. One consistent operations concept will be required prior to contracting for a design fly-off to accurately discriminate between competing approaches.

Architecture Recommendations—The National Maglev Initiative should give strong consideration to an early development of a comprehensive operational concept and a consistent system specification in order to assure that the aims of the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991 are achieved within the constraints of cost and schedule.

Risk Conclusions—Dynamics and Reliability, Maintainability and Availability (RMA) risks dominate the maglev program not only in total number of risks but risk severity as well.

Aging and Electromagnetic (EM) field risks are also numerous and severe. Control, cryogenics and emergency, although few in total number of risks, are high severity and warrant close attention in the development program. These 7 risk types constitute 41 of the 94 total risks (24 of which are high severity) and will require a carefully crafted mitigation program in which testing is accomplished at a scale and degree of fidelity commensurate with the element under evaluation early in the program. The greatest maglev program risks are in these categories.

Programmatic, electrodynamics, software, construction, human factors, sensor, and structures risks fill the midrange with 4 or 5 total risks. These risks will require a relatively balanced program of analysis and test with test time frames chosen on a risk by risk basis.

Materials, weather, and geotechnical risks are numerous but relatively low risk. These risks will require a program of early analysis with possible deferral of testing to timeframes later in the program, if at all.

Aerodynamics, acoustics, operations, and power are at the low end of the risk scale. Mitigation of these risks can generally be accomplished through analysis.

Risk Recommendations—Maglev Prototype Development Program (PDP) requirements should incorporate preliminary and critical design reviews. Phase 1 contractors should perform tests and analyses as required to meet PDR requirements. Phase 2 contractors should perform tests and analyses as required to meet CDR requirements. Recommendations as to the specific tests and analyses necessary in each phase will be forthcoming in the Final Report of this study.

APPENDIX A: LITERATURE CATEGORIZATION AND ABSTRACTS

This appendix contains the listing of the abstracted literature and the review team categories in which they were reviewed. This is shown in Table A-1 along with the categories of results that were derived from each document or article. Reference Table A-1, the first three columns list the reference number, reference title and the publication date respectively. The next column indicates the review team by which the reference was reviewed. The categories and the abbreviations used on the table are shown below:

System Integration	SI
System Architecture	SA
Vehicle Subsystem	VS
Guideway Subsystem	GS
Electromagnetic Subsystem	ES
System & Subsystem Testing	ST
Control & Communications Subsystem	CC

The final three columns indicate the categories of results that were obtained from each of the references. These categories correlate with Statement of Work paragraph 4.1.1.c items 1, 2, and 3. and include development risks, operations concepts and system definition. The system definition subheadings refer to system architecture (SA), leading developers (LD), and test planning and facilities (TP).

Following the table each of the references are listed and abstracted in this appendix.

Table A-1 Literature References, Categories and Usage

REF#	Reference Title	Publication Date	Review Category	Risks	Operations Concepts	System Definition SA	System Definition LD	System Definition TP
1	A Comparison of Safety Considerations for High Speed Rail and Maglev Systems	Jan 16-91	SI, ST	•	•	•		
2	A Systems Approach to Safety from the Top Down	Jan-91	SI, SA	•	•	•		
3	Aero-Acoustic Investigations of the Magnetic Train Transrapid 06	Jul 7-11, 89	VS, ST	•		•		•
4	Amendment Submission for: The Maglev Levitation Demonstration Project to Florida High Speed Rail Transportation Commission	Apr-90	SI		•		•	
5	An Assessment of High-Speed Rail Safety Issues and Research Needs	Dec-90	SI	•	•	•		
6	An Update on the State of Maglev Technology and Its Prospects in North America	Nov-90	SI		•	•		
7	Applications of Superconductor Technologies to Transportation	Jun-89	VS, ES			•		
8	Assessment of the Potential for Magnetic Levitation Transportation Systems in the United States - Report Supplement	Jun-90	SI, SA		•	•		
9	Attractive Levitation for High-Speed Ground Transport with Large Guideway Clearance and Alternating-Gradient Stabilization	Mar-89	VS, GS	•		•		
10	Automated Operations Control System for High Speed Maglev Transportation	1987	CC	•	•	•		
11	Commercialization of Maglev Technology - Final Report	Aug-90	SI		•	•		
12	Costing of the Revised Canadian Maglev Guideway Design	Jul-86	GS			•		
13	Design Concept & Comparative Performance of an Electrodynamic Maglev Transportation System for Toronto-Montreal Corridor of Canada	-	VS, GS	•	•	•		
14	Design, Development and Test of a Wayside Power Distribution, and Collection System for the Tracked Levitated Research Vehicle	Apr 15-74	GS, ES, ST	•				•
15	Designing Micro-Based Systems for Fail-Safe Travel	Feb-87	CC	•	•	•		•
16	Draft Test Plan for Electric and Magnetic Field Measurements on the Northeast Corridor (NEC), Electric Research Management, Inc.	1987	ST	•		•		•
17	Dynamic Criteria in the Design of Maglev Suspension Systems	-	VS			•		•
18	Esperienze Nella Progettazione Della Sicurezza di un Sistema di Trasporto ad Automazione Integrale	Jul 4-5, 91	VS, ST				•	•
19	Experiments in Guideway Levitation Vehicle Interaction Dynamics	Jan-76	SI, SA	•		•		•
20	Federal Aviation Regulation 25.1309	Jan-89	VS, ES, ST					•
21	High Speed Transportation for the Year 2000 - CSAC Maglev 2000 Task Force	Feb 2-90	SI	•	•			
22	High-Speed Rail System Noise Assessment, Transportation Research Record 1255	-	SA, CC	•		•		
23	Human Vibration Standards - Sound and Vibration	Jul-91	SI, ST					•
24	Integrated Magnetic Propulsion and Suspension (IMPS) Final Report	Dec-86	SI, SA, CC	•		•	•	•
25	Interim Report on Magnetic Field Testing of TR07 Maglev Vehicle and System, Conducted August 1990, Electric Research Mgmt, Inc.	May-91	SI, SA	•		•		•
26	Japanese Superconducting Maglev: Present State and Future Perspective	Aug-89	ES, ST	•	•	•	•	
27	Maglev Guideway and Route Integrity Requirements - Draft Interim Risk Identification Report	Oct-91	SI	•				•
28	Maglev System Design Considerations - SAE Technical Paper - Future Transportation Technical Conference and Exposition	Aug 5-7,91	VS, GS	•		•		•
29	Maglev Transit Link for Birmingham Airport-Systems Engineering	-	SI, ST	•	•	•	•	•
30	Maglev: Transportation for the 21st Century-Civil Engineering, April 1987	Apr-87	SA, ES	-	•	•		
31	Magnetic and Electric Fields for Existing and Advanced Rail Transportation Systems, Electric Research Management, Inc.	-	CC	•				•
32	Magnetic Levitation Technology for Advanced Transit Systems-Future Transportation Technical Conference and Exposition, Vancouver	Aug-90	SI, SA	•	•	•	•	
33	Mathematical Modeling and Control System Design of Maglev Vehicles	Aug 7-10,89	SI	•		•		•
34	National Maglev Initiative - Government-Industry Workshop - Final Report 11/1/90	Nov-90	SI, CC		•			•
35	Preliminary Design for a Maglev Development Facility - Center for Transportation Research, Argonne National Laboratory	Apr-92	SI,ST					•
36	Recent Progress by JNR on Maglev-IEEE Transactions on Magnetics, Vol. 24, No. 2, March 1988	Mar-88	SI	•	•	•	•	•
37	Safety & Reliability of Synchronizable Digital Coding in Railway Track-Circuits - IEEE Trans on Reli, Vol.39,no.5,90 Dec	Dec-90	SI, ST	•		•		
38	Safety and Licensing Aspects of Transrapid and Maglev Systems	Dec 2-91	CC	•		•		•
39	Safety Effectiveness Evaluation of Rail Rapid Transit Safety	Jan 22-81	SV, ES	•	•	•		•
40	Safety of High Speed Magnetic Levitation Transportation Systems	Nov-90	ES	•	•	•	•	•
41	Super-Speed Ground Transportation System, Las Vegas/So. Calif. Corridor, Phase II-Maglev Tech. Assess. - Executive Summary	Jul-86	GS	•	•	•	•	
42	Super-Speed " " "- Summary of Experience	Nov-90	SI				•	•
43	Super-Speed " " "- Task 1: Review of Phase I Report	Jun 17-85	SI, SA			•	•	
44	Super-Speed " " "- Task 5: Development Status of Major Maglev Subsystem and Critical Component	Mar-86	SI, SA	•		•	•	•
45	Super-Speed " " "- Task 6: Maglev Vehicle Magnetic Fields	Sep-85	VS, ES	•		•	•	•
46	Super-Speed " " "- Task 7: Evaluation of Electromagnetic Interference(EMI) Effects on Wayside Installations	Jan-86	ES	•		•	•	•
47	Super-Speed " " "- Task 8.2: Guideway Tolerences and Foundation Conditions	Jan-86	GS	•		•	•	•
48	Super-Speed " " "- Task 9.1: Example of Estimated Costs, Initial Order of Magnitude Review	Jul-85	SI			•	•	
49	Superconducting Linear Synchronous Motor Propulsion and Magnetic Levitation for High Speed Guided Ground Transportation	Mar-76	VS, ES	•		•	•	•
50	Superconducting Magnetic Levitation and Linear Syncronous Motor Propulsion for High Speed Guided Ground Transportation	Mar-75	SA, VS, ES	•		•		
51	Test Facility for the Determination of Linear Induction Motor Performance	Aug-80	VS, ST			•		•
52	Transrapid Maglev System, Hestra-Verlag Darmstadt FRG	1989	SI, ST	•	•	•	•	•
53	Update of Super-Speed Ground Transportation Technology Development Status and Performance Capabilities	May-90	SI, ST	•	•	•	•	•

Abstracts

1. "A Comparison of Safety Considerations for High-Speed Rail and Maglev Systems," Paul Taylor, 70th Annual Meeting, Transportation Research Board, 16 January 1991.

   This is a bulletized viewgraph presentation comparing the safety issues for high speed rail and maglev systems. Overviews of the TGV wheel-on-rail and Transrapid EMS Maglev systems are given with descriptions of those features which impact safety. The safety risks are delineated, providing a basis for developing tests to improve safety and mitigate risk. Safety issues for maglev include vehicle structural strength, braking, communications, control, guideway structure and maintainability, degraded-mode operations, and emergency procedures.

2. "A Systems Approach to Safety from the Top Down," John A. Bachman, Presentation at Session 180: High Speed Rail and Maglev Safety Implications, Transportation Research Board Annual Meeting, 16 January 1991.

   This presentation addresses the need for a system approach to high-speed ground transportation (HSGT) safety and outlines one potential methodology to illustrate the approach. By system approach it is meant that safety issues must be addressed during the planning stage and addressed from the highest level of a system hierarchy downward. Specific planning should take place during the early stages of project preliminary design engineering.

   This is a departure from the traditional domestic approach of employing safety issues individually, for example, dependence on vehicle strength in isolation of other factors. Traditional specific domestic safety codes are not to be ignored, but their relevant importance to overall system safety objectives should be examined.

   There are six basic ideas conveyed in this paper as follows:

   - Integrate safety planning into HSGT system design
   - Define HSGT architecture
   - Identify critical interfaces
   - Structure interfaces schematically
   - Address formulation of HSGT safety standards at segment and element levels
   - Quantification and evaluation methodology is required

3. "Aero-Acoustic Investigations of the Magnetic Train Transrapid 06," Hans Alscher, International Conference on Magnetically Levitated Systems and Linear Drives, Maglev 89, Yokohama, Japan, Document No. UW-0009-89-PUB=OTN-031019, 7-11 July 1989.

   Minimizing aero-acoustic noise and aerodynamic drag are major aims in the development of high speed trains. For this purpose, dominant sources of aero-acoustic noise were identified on the surface of the magnetic train Transrapid 06 by microphone-array measurements. Dominant sources were the gaps between car body and bogies between the two cars of the train and a specific region near the nose of the train. The gaps are of no further interest, as they are closed by elastic fairings on the next generation vehicle, the Transrapid 07. Wind tunnel testing of the nose area led to local reshaping, which will lower aero-acoustic noise and aerodynamic drag.

4. "Amendment Submission for the Magnetic Levitation Demonstration Project," Maglev Transit, Inc., March/April 1990.

   This Amendment clarifies conflicting language in the original application to the Florida High Speed Rail Transportation Commission. It includes right-of-way, ridership, and technical requirements; environmental and community impacts; cost estimates, financing, and implementation.

5. "An Assessment of High-Speed Rail Safety Issues and Research Needs," Alan J. Bing, Report No. DOT/FRA/ORD-90/04, May 1990.

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

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

6. "An Update on the State of Maglev Technology and Its Prospects in North America," Christopher J. Boon and J. H. Parker, J. H. Parker and Associates, 15 November 1990.

   This report summarizes the current state of maglev technology and identifies prospective corridors for implementation. The Las Vegas - Southern California corridor study is detailed to illustrate the corridor evaluation process. Other corridor studies are summarized. Study emphasis is on gross revenue, intercity ridership, economic effects, land use impacts, environmental impacts, technology assessments, development potential, and energy impacts.

7. "Applications of Superconductor Technologies to Transportation," D. M. Rote, J. S. Herring, T. P. Sheahen, Argonne National Laboratory, ANL/CNSV-68, June 1989.

   This report assesses transportation applications of superconducting devices, such as rotary motors and generators, linear synchronous motors, energy storage devices, and magnets. Among conventional vehicles, ships appear to have the greatest potential for maximizing the technical benefits of superconductivity, such as smaller, lighter, and more-efficient motors and, possibly, more-efficient generators. Smaller-scale applications include motors for pipeline pumps, all-electric and diesel-electric locomotives, self-propelled rail cars, and electric highway vehicles. For diesel-electric locomotives, superconducting units would eliminate space limitations on tractive power. Superconducting magnetic energy storage devices appear most suitable for regenerative braking or power assistance in grade climbing, rather than for long-term energy storage. With toroidal devices (especially for on-board temporary energy storage), external fields would be eliminated. With regard to new vehicle technologies, the use of superconducting devices would only marginally enhance the benefits of inductive-power-coupled vehicles over conventional electric vehicles, but could enable magnetically levitated (maglev) vehicles to obtain speeds of 520 km/h or more. This feature, together with the quiet, smooth ride, might make maglev vehicles an attractive alternative to intercity highway-vehicle or airline trips in the range of 100-600 miles. Electromagnetic airport applications are not yet feasible.

8. "Assessment of the Potential for Magnetic Levitation Transportation Systems in the United States," Report Supplement, DOT/FRA TF1600.U52, June 1990.

   This report identifies seven endeavors to be emphasized in development of a U.S. Maglev System:

   1) Guideway construction cost reduction.

   2) Rights-of-way acquisition cost reduction.

   3) Propulsion system cost reduction.

   4) Development of high temperature superconducting magnets.

   5) Elimination of magnetic field hazard.

   6) Safety and reliability

   7) Operational considerations.

   Also discussed are significant trade studies to be accomplished and component/subsystem technical issues to be investigated includes propulsion systems and airport and highway investment cost savings as well as other economic impacts. The report addresses cost sensitivities and emphasizes importance of accurate estimates for fixed facility costs. Sensitivity to future growth in other transportation modes and optimum maglev routes is discussed. Competition with other HSGT technologies is also considered. Appendix IV - B discusses use of interstate highway and railroad rights-of-way, citing as an example a San Diego/Los Angeles route.

9. "Attractive Levitation for High-Speed Ground Transport With Large Guideway Clearance and Alternating Gradient Stabilization," John R. Hull, Presented at Intermag 89, Washington, D.C., 28-31 March 1989.

   This paper describes an attractive levitation concept that results in large guideway clearance and low magnetic drag and requires no feedback for stability. Dynamic stability is achieved by establishing alternating gradients of force, in which the spatial dependence of the attractive force between superconducting coils on the vehicle and iron rails in the guideway is altered by periodic changes in the rail configuration. For a vehicle velocity of 500 km/h, the appropriate lengths for each configuration are in the range of 5 to 40 m, and the guideway clearance is in the range of 50 to 100 mm, depending on the details of the rail and vehicle magnet design.

10. "Automated Operations Control System for High Speed Maglev Transportation," E. Schnieder, K. H. Kraft, and H. Guckel, IEEE, CH2443-181, 1987.

    To reduce the speed gap which still exists between trains and aeroplanes, a maglev transportation system is now under construction in Germany. This entails designing a control system which is able to take full responsibility for the operations and performance of the entire transportation system. To design an operations control for such an advanced transportation system, a specification must be drawn up of all operational requirements and the special technical features of maglev systems taken into consideration. In this paper, the objectives of maglev transportation are discussed in detail for these have an important bearing on operations control. A system overview is given. The operations control system, according to functional decomposition and spatial distribution, has a 3-level hierarchical arrangement. The operational functions are protection, control, and supervision which should be carried out continuously and automatically by the on-board, wayside and centrally located facilities.

11. "Commercialization of Maglev Technology -- Final Report," Richard A. Uher, Rail Systems Center, Carnegie Mellon University, UMTA-PA-06-0111-90-1, August 1990.

This report discusses conceptual regional and suburban maglev systems and explains the results of a preliminary feasibility study. The report identifies aspects of the transportation crisis which enhance the appeal of a high-speed ground transportation system. A review of maglev technologies is given. Appendix B of this report discusses a preliminary feasibility study of the Pittsburgh Maglev project.

12. "Costing of the Revised Canadian Maglev Guideway Design," T. I. Campbell, C. J. Boon, A. R. Eastham, C. Schwier, Canadian Institute of Guided Ground Transport (CIGGT), Report No. 86-20, July 1986.

The objective of this project was to develop construction specifications and commercial cost quotations for the manufacture of a revised guideway design, and, for reference, equivalent cost estimates for the original design.

Design drawings and specifications were prepared for the original design and for each of the revised design options, and submitted to three qualified large-scale manufacturers of precast concrete. These commercial quotes were then analyzed to identify sources of variance among quotes and assess the impact of the quoted prices on the capital costs of a maglev system.

Based on the findings of this study, it was concluded that both the box-section and channel-section beam designs would meet all technical and regulatory requirements for a maglev system. Conventional (magnetic) steel reinforcements can be used in construction of the guideway beams without causing adverse effects on vehicle operations or on guideway life expectancy. The channel section would cost between 10 and 25 percent less to fabricate than the box section. The channel section would also offer significant cost savings over the original trapezoidal trough/top slab design. Compared to the corresponding revised costs for the original design, the channel section would permit savings in the range of 15 to 35 percent. Price levels for the channel section correspond to a savings of about 42 percent (including the savings from fewer support structures), as compared to the revised estimates of the original beam design. The use of epoxy-coated reinforcing bars would increase the cost of the guideway girders by 10 to 20 percent.

13. "Design Concept and Comparative Performance of an Electrodynamic Maglev Transportation System for the Toronto-Montreal Corridor of Canada," W. F. Hayes, H. G. Tucker, Report No. C400/84.

The engineering design of a high-speed intercity electrodynamic maglev passenger transportation system suitable for the particular traffic density, route terrain, severe winter weather, and electrical power availability conditions of the 600 km Toronto-Ottawa-Montreal corridor in Canada is presented. The system design includes such features as combined linear synchronous motor propulsion and electrodynamic guidance; a primary magnetic and secondary mechanical suspension system; an elevated reinforced concrete dual-track guideway; a unique "vertical" switch design; light-weight superconducting magnets; very low level cabin magnetic fields without on-board shielding.

The predicted performance of this electrodynamic maglev transportation system operating in the specified corridor is compared with alternative air and ground transport modes.

14. "Design, Development and Test of a Wayside Power Distribution and Collection System for the Tracked Levitated Research Vehicle," J. O. Webster, M. Shapiro, C. Guenther, G. Kalman, J. Clemence, S. Mitchel, Federal Railroad Administration, Report No. FRA/ORD&D74-25, 15 April 1974.

    This document presents test activity description and results of the wayside power distribution and collection system designed for the TLRV, a high-speed ground transportation vehicle. The system was assembled at the U.S. Navy testing grounds, China Lake, California to prove the design concept and feasibility of transferring high-electrical power between rail and collector brushes at elevated speeds while subjected to prevailing environmental conditions. With minor modifications, the initial design conformed to specified requirements up to speeds in excess of 300 mph.

    Analysis of the rail configuration and test results indicated that distance between the wayside rail supports could be doubled (25 feet) lessening by half the number of supports required to maintain the rail's alignment integrity at design speeds. Installation of the wayside rail system at HSGTC, Pueblo, Colorado will be constructed using the 25-foot span configuration.

    Extensive testing was conducted to establish proper power distribution spacing under realistic environmental conditions. A materials evaluation subprogram was conducted on candidate power rail and brush materials to aid in material selection for the final power rail and brush configuration. An important tool used throughout the design process was an analog simulation, which through iteration with the design allowed continuous comparison of actual and required performance. The final iteration and analog simulation refinement occurred from dynamic testing of the prototype power collector.

15. "Designing Micro-Based Systems for Fail-Safe Travel," D. B. Turner, R. D. Burns, and H. Hecht, IEEE Spectrum, February 1987.

    This document addresses reliable control of railroads, aircraft, and space vehicles. Detection, isolation, and control of system faults is discussed in terms of redundancy in various forms - additional equipment, calculations or processing, information, or control actuation. Dual, triple, dual-dual, and quadruple redundant arrangements are described in terms of safety, fault detection, availability, economic, and maintenance characteristics. They are be classified according to their intended response - fail-safe, fail-passive, or fail-operational.

16. "Draft Test Plan for Electric and Magnetic Field Measurements on the Northeast Corridor (NEC)," Electric Research and Management, Inc., 1991.

    This test plan outlines the measurements to be taken on the Amtrak metroliner passenger train operating on the Northeast Corridor line between Washington, D.C. and Boston, MA. The measured data will be used to assess the electric and magnetic field environment on-board the train, at passenger stations, along the wayside and near electric substations supplying power to the catenary systems.

17. "Dynamic Criteria in the Design of Maglev Suspension Systems," R. M. Goodall, R. A. Williams, Report No. C393/84.

The fundamental requirements of a suspension system are discussed in relation to maglev suspensions. This includes the performance of the suspension, mainly in terms of ride comfort, and also the constraints within which this must be achieved. General conclusions regarding particular types of maglev suspensions are highlighted.

18. "Esperienze Nella Progettazione Della Sicurezza di un Sistema di Trasporto ad Automazione Integrale," J. H. Parker, Evoluzione del Trasporto di Mass Verso L'Automazione Integrale, Milan, 4-5 July 1991

This paper is a report on the experience gained during the development, design, manufacture, construction and delivery of three automated transit systems in North America from 1980 to 1986. The automatic train control technology utilized was proprietary to a particular company but the process and methodology used to assure safety are generally applicable, and in particular, for systems that use software to create vital functions.

The SkyTrain of Vancouver was the largest with 114 cars, 15 stations and 21.4 km of double track, and it involved driverless automation. The Detroit Central Automated Transit System has 12 cars, 4.7 km of single track and has driverless automation. Scarborough Rapid Transit has 28 cars, 6.9 km of double track and has an on-board operator who supervises the ATC and closes doors.

There are different regulatory processes for obtaining authorization to operate a railway in different countries and jurisdictions. For SkyTrain, there is a designated licensing authority for the province of British Columbia that has a mandate under the Railway Act. In contrast, the Scarborough Rapid Transit was self-regulating under the mandate of the Toronto Transit Commission. Nonetheless, the same process was used for verifying the safety of the automatic train control software even though for Scarborough, the roles of regulating authority and client were performed by the same organization.

The SkyTrain of Vancouver is used to exemplify the methodology and process employed to obtain and to verify the safety of the system.

19. "Experiments in Guideway-Levitation Vehicle Interaction Dynamics," James F. Wilson, Federal Railroad Administration, Report No. FRA-OR&D-76-259, January 1976.

This investigation involves the design and interpretation of laboratory-scale dynamic experiments of vehicles traversing multiple-span or cable-stayed guideways. The nondimensional responses of such systems, including critical span bending moments and vehicle heave accelerations, depend on the system parameters which are derived. A point load "vehicle" and two vehicles closely resembling advanced operational prototypes were designed and tested: the 150 mph Prototype Tracked Air Cushion Vehicle (PTACV), and the 300 mph Tracked Levitated Research Vehicle (TLRV). General experiments are designed, all based on these dimensionless system parameters and the capability of instrumentation and data processing minicomputers to measure and interpret response data. Also included are discussions and comparisons of response data for critical six and three-span guideway moments and for rms vehicle heave accelerations. It is demonstrated that this unique test facility is a very cost-effective way of generating non-dimensional system response data of quite general design applicability. With this facility, one can validate existing mathematical solutions of such systems as well as explore and optimize new alternative system designs for which there exist no mathematical analyses.

20. "Federal Aviation Regulation 25.1309 Advisory Circular," U. S. Department of Transportation, Federal Aviation Administration, January 1989.

This Advisory Circular (AC) describes various acceptable means for showing compliance with the requirements of Sections 25.1309(b), (c), and (d) for the Federal Aviation Regulations (FAR). Section 25.1309(b) provides general requirements for a logical and acceptable inverse relationship between the probability and the severity of each failure condition, and Section 25.1309(c) provides general requirements for system monitoring, failure warning, and capability for appropriate corrective crew action. The FAR regulation was updated because of an increase in system complexity, system integration, and in the number of safety-critical functions performed by systems.

21. "High Speed Transportation for the Year 2000," CSAC's Maglev 2000 Task Force, 2 February 1990.

This bulletized presentation is a top-level appeal for maglev development.

- Transportation is Emerging as a National Priority
  - Our decaying infrastructure is overburdened and ill-prepared for 21st century needs
  - Infrastructure impacts global competitiveness, economic health and national defense
  - Conventional transportation upgrades are reaching saturation
  - Environmental abuse and energy waste from transportation sources must be abated
- The U.S. Needs High Speed Transportation Systems Like Maglev
  - Many options exist, but few offer as many benefits
  - First generation vehicle technology is available
  - Rights of way and financing issues are being addressed
  - A national consensus is forming
- Long Term U.S. Competitiveness is at Stake
  - Maglev systems in Germany and Japan are being readied for commercial operation
- Window of Opportunity: 1 - 2 Years

22. "High Speed Rail System Noise Assessment," Carl E. Hanson, Transportation Research Record 1255.

This high-speed rail system noise assessment is in two parts: 1) a noise assessment procedure for the environmental impact analysis of high-speed rail systems and 2) a discussion of the noise characteristics of high-speed trains, including conventional steel wheel and steel rail trains and magnetically levitated (maglev) trains. Aerodynamic noise dominates the wayside noise levels at speeds above 150 mph. The result is that maglev and conventional tracked trains can have similar noise levels at high speeds. A procedure for estimating noise impact corridors for high-speed rail is used in an example.

The general environmental assessment procedure for new transportation projects and some of the noise information from high-speed rail systems that can be used for impact assessment purposes are described. Included in this paper are data on noise generated by operation of high-speed trains; the surprising result is that noise from maglev systems seems to be the same as that from conventional rail systems at high speeds.

23. "Human Vibration Standards," Donald E. Wasserman, Sound and Vibration, July 1991.

The medical, biological, epidemiological, performance, and other effects of whole-body and hand-arm vibration impinging on humans have been documented numerous times in the literature. These effects have resulted in a series of human vibration standards/guides. This article is intended to present some of the salient points of the major human vibration standards currently in use in the United States.

24. "Integrated Magnetic Propulsion and Suspension (IMPS) -- Final Report," R. G. Gilliland, D.D. Lyttle, G. W. Pearson, U.S. Department of Transportation, Report No. UMTA, Contract No. DTUM60-80-C-71009, December 1986.

This report describes the development of critical technology for an Integrated Magnetic Propulsion and Suspension (IMPS) system for automated guideway transportation. Baseline work begun by Rohr Industries, in 1970, was picked up by Boeing Aerospace, beginning in 1978 and continued to the present. Significant gains were demonstrated in the areas of linear motor development, power control and conditioning, and in non-contacting air gap sensor and control system development.

The IMPS technology is seen to be competitive with magnetically levitated machines being developed in Europe and Japan. With continued development, the Linear Synchronous Unipolar Motor (LSUM) can make the IMPS technology competitive with steel wheel and rail transit on an energy consumption basis. It can provide a higher level of service and lower overall operating and maintenance costs than competing systems.

The IMPS technology and the development of solid state electronics have matured to where it is completely feasible to develop a full-scale demonstration of the system.

25. "Interim Report on Magnetic Field Testing of TR07 Maglev Vehicle and System, Conducted August 1990," Electric Research and Management, Inc., August 1991.

This interim report describes the magnetic field measurements made by ERM, from 6-10 August 1990, within and in the vicinity of the TR07 vehicle operating at the Emsland Transrapid Test Facility. The measurements were intended to document the temporal and frequency spectral characteristics of the magnetic field (from static to 2 kHz) at the vehicle operators position, at the vehicle passengers' positions, at the station, near the guideway, and near the electrical substation. The interim report describes measurement procedures and equipment, tabulates the various conditions under which measurements were made, and reports some tentative observations of magnetic field characteristics based on a preliminary look at a small subset of the data.

26. "Japanese Superconducting Maglev: Present State and Future Perspective," Hiroshi Takeda, Society of Automotive Engineers, SP-792, Document No. 891718, August 1989.

    Maglev being developed as a new transportation means running at a speed of 500 km/h has various advantages in safety, mass transportation and less environment pollution as well as high speed. The development of this system is rapidly advancing into the practical stage, that is, commercial operation of maglev train as a mass transportation system for intercity highspeed service. This paper describes the present state of research and development as well as future prospects of maglev.

27. "Maglev Guideway and Route Integrity Requirements, Draft Interim Technology Assessment Report," FRA 31-91-0004, Martin Marietta Air Traffic Systems, October 1991.

    This report describes selection, characterization and evaluation of sensors for risk reduction in maglev systems. Risk profiles for four hazard categories (Obstruction and Fouling, Guideway Integrity, Physical Security and 'Other'), generated from the preliminary hazard assessment (PHA) performed in the previous Risk Identification task, are used to evaluate applicability of sensors to specific risk reduction. The PHA and the development of the risk profiles are documented in Maglev Guideway and Route Integrity Requirements, FRA31-91-0004.

    Sensors for risk mitigation are examined and include vehicle-mounted, guideway-mounted and wayside deployment options. Sensors are assessed for potential applicability, maturity and technological risk perspectives. A conceptual architecture is described representing a system-level combination of sensor and non-sensor mitigation methods. The conceptual architecture is evaluated in terms of the risk reductions achieved with respect to the initial risk profiles. New technology research initiatives are suggested based on the applicable sensor technology represented in the conceptual architecture and by the high potential, technologically mature sensors identified in the evaluation. These results are the basis for the final study task to develop a conceptual communications architecture.

    This study focuses on sensor-based mitigation and provides a conceptual architecture to indicate the necessary total systems viewpoint required to select the specific maglev system design. A desirable outcome of the design and selection process is the most cost-effective reduction of risk to acceptable levels through judicious trade-off of mitigation methods, such as: vehicle/guideway design, sensors, passive means, and operational procedures. New technology research is suggested to refine the specific application and the suggested configuration of sensors in more detail.

28. "Maglev System Design Considerations," Howard T. Coffey, Future Transportation Technology Conference and Exposition, Portland, Oregon, SAE Technical Papers Series, Document No. 911624, 5-7 August 1991.

    The characteristics of maglev systems being considered for implementation in the United States are speculative. A conference was held at Argonne National Laboratory on 28-29 November 1990, to discuss these characteristics and their implications for the design requirements of operational systems. This paper reviews some of the factors considered during that conference.

Although efforts are now being made to develop magnetic levitation technologies in the United States, they have been underway for two decades in Germany and Japan. The systems being developed there have been discussed extensively in the literature and are not repeated here. A National Maglev Initiative, led by the U.S. Department of Transportation and co-chaired by the U.S. Department of Energy and the U.S. Army Corps of Engineers, has been established to evaluate these technologies and to recommend a national maglev strategy. One possible recommendation would be to undertake the development of a new or modified maglev system. If that option is selected, test facilities for developing the technology would be required.

29. "Maglev Transit Link for Birmingham Airport - Systems Engineering," V. Nenadovic, (C396/84).

This paper outlines the systems engineering carried out by GEC Transportation Projects Limited for the maglev transit link at Birmingham Airport. The particular choices of configuration, control strategy, and devices are justified. The need for a system engineering approach from the initial design, to final testing and commissioning is emphasized. This document covers several aspects of the system including: track/vehicle interface, power supply system, vehicle design, suspension subsystem, and control and communications. Other functions that may need to be considered include closed-circuit TV, public address, fare collection, etc. Conclusions focused on the value of systems engineering in optimizing all system parameters to satisfy the technical specifications at a competitive cost.

30. "Maglev: Transportation for the 21st Century," G. Merrill Andrus and George T. Gillies, Civil Engineering, April 1987.

This article gives a brief history of maglev development as of the publication date. The authors then discuss prospects for maglev installation in Atlantic City, N.J. citing existing traffic congestion and demand for an efficient, environmentally sound transit system. The article proceeds to explain basic operation of the EMS and EDS configurations.

31. "Magnetic and Electric Fields for Existing and Advanced Rail Transportation Systems," F. M. Dietrich, W. E. Feero, D. C. Robertson, G. A. Steiner, and Aviva Brecher.

This paper describes a measurement protocol and the instrumentation used to characterize the intensity, spatial, temporal, and frequency characteristics of the magnetic and electrical fields on-board the vehicle or near the wayside. Magnetic field data for an advanced system (the German Transrapid TR07 Maglev Vehicle) are shown as an example of the complexity of the field conditions on-board electrified transportation systems.

32. "Magnetic Levitation Technology for Advanced Transit Systems," Floyd A. Wyczalek, Society of Automotive Engineers, Inc., Document No. SP-792, August 1989.

This collection of seven papers on Magnetic Levitation Transportation Technology was presented at the 1989 SAE Conference and Exposition on Future Transportation Technology held in Vancouver, B.C., Canada, 7-10 August 1989. The three goals of this special publication are: (1) review and assess the latest developments in magnetic levitation technology; (2) provide transportation policy planners and decision makers with a factual technical database; and (3) assist in developing a new integrated transportation policy strategy for North America by the beginning of the 21st century.

This publication includes recommendations by the most prominent authorities worldwide on magnetic levitation technology. In addition, it includes comparative assessments of the three magnetic levitation high-speed mass transportation systems currently under extensive development, and in the prototype vehicle demonstration stages, in the Federal Republic of Germany (FRG) and in Japan.

One approach, which is promoted by Transrapid International (TRI) in FRG, is based on the electromagnetic levitation (EML) concept; a second approach, which is promoted by the High Speed Surface Transport Corporation (HSST), is based on the EML concept developed and licensed from Japan Air Lines (JAL); a third approach, which is promoted by the Railroad Technology Research Institute (RTRI) (Sogo Tetsudo Gijutsu Kenkyusho), the developer of the Shinkansen train, is based on the super conductive electrodynamic levitation (EDI) concept. Also included is an outline of a new High Speed Transportation Strategy for North America (HSTSNA).

33. "Mathematical Modeling and Control System Design of Maglev Vehicles," K. Papp, Universitat Hannover, FRG, EIM 86-02 009441.

This article discusses evaluation of motion stability, ride comfort, and safety as well as overall system optimization through dynamic analysis of the vehicle, guideway, and suspension control. The author discusses results of a literature review conducted to identify applicable dynamic analyses and theory. Details are given in the modeling of the open-loop system, dynamics of multibody systems, control system design and analysis of the closed-loop system. An example model is considered to demonstrate approaches for analyzing stability and determining responses to deterministic and stochastic disturbances.

34. "National Maglev Initiative/Government-Industry Workshop," Argonne National Laboratory, 11-13 July 1990, Final Report, November 1990.

This report presents the results of the Government-Industry Maglev Workshop held at Argonne National Laboratory on July 11, 12 and 13, 1990. Attendees reviewed and evaluated the Draft Maglev System Parameters prepared by the Maglev Interagency Working Group. The system parameters include minimum requirements for performance specifications that a proposed maglev system must meet to be acceptable and design goals for target performance levels.

35. "Preliminary Design for a Maglev Development Facility," H.T. Coffey, J.L. He, S.L. Chang, J. Bouillard, S.S. Chen, Y. Cai, L.O. Hoppie, S.A. Lottes, D.M. Rote, Z.Y. Zhang, G. Myers, A. Cvercko, and J.R. Williams, Center for Transportation Research, Energy Systems Division, Argonne National Laboratory, April 1992.

This report details a study undertaken by Argonne National Laboratory to design a national user facility for the development of high-speed maglev technologies. The study identifies the requirements for such a facility and provides critical design characteristics. The proposed design is for an intermediate size development facility. The report details the facility requirements for five major maglev subsystems: vehicle, guideway, motor, power supply, and the control and communications subsystems. The stated purpose of the facility is to (1) verify experimentally the predicted performance of maglev vehicles propelled, suspended, and guided by means of different maglev technologies; (2) determine the dynamic interactions of these vehicles with guideways constructed using different materials, designs, and construction techniques; and (3) validate control and communication strategies and equipment. The facility design is not intended to accommodate testing of all aspects of full-scale vehicles, but to provide means for evaluating subsystems during the development of the maglev system.

36. "Recent Progress by JNR on Maglev," Yoshihiro Kyotani, IEEE Transactions on Magnetics, Vol. 24, No. 2, March 1988.

The magnetically levitated vehicles, or "maglev", now being researched and developed by JNR (Japanese National Railways) utilize superconducting magnet levitation and linear synchronous motor (LSM) propulsion. So far, the progress made has included a speed of 517 km/h reached by the experimental vehicle ML500, a three-car test run by the MLU001, manned test runs, and test runs with aberrations purposely introduced into the guideway. However, due to limitations in the capacity of the electric power supply facility, the maximum speed for the three-car train was 200 km/h.

Thus, the capacity of the electric power supply facility was increased and in December 1986, a maximum speed of 352 km/h was achieved for the three-car train. In addition, in February 1987, a two-car train achieved a speed of 400 km/h.

The 44-seat MLU002, measuring 22 m in length and weighing 17 tons, was completed in March 1987, and test run on the same 7-km long Miyazaki Test Track which had been used previously. The arrangement of the superconducting coils and the cooling method have been changed, and it has been designed to allow experiments using only Stirling cycle refrigerators for the helium refrigerators.

37. "Safety & Reliability of Synchronizable Digital Coding in Railway Track-Circuits," IEEE Transactions on Reliability, Vol. 39, No. 5, December 1990

The incorporation of digital error-control coding into railway track circuits represents a new approach for track-train data transmission for automatic train control. Methods based on error-probability analysis are presented for assessing the safety and reliability of synchronizable error-control coding in this application. The results for a sample coding scheme have been verified by experimentation using a calibrated source injecting audio-frequency Gaussian noise into a practical track circuit. Safety and reliability are compared in a example method whereby safety is increased by incorporating dictionary checking in the code-receiver algorithm and the reliability is enhanced by allowing single synchronization error correction. The technique demonstrates the possibility of designing a track-circuit data-transmission system to given target safety and reliability levels of the same order of magnitude as the known failure rates of existing equipment.

38. "Safety and Licensing Aspects of Transrapid and Maglev Systems," Joachim Blomerius, IEEE CH2443-205, 1987.

With regard to advanced wheel-on-rail technology, magnetic levitation offers significant merits due to the contact-free levitation, guidance and propulsion/brake system between the vehicle and the guideway. Use of these merits is only possible by considering maglev specific safety aspects.

Assisted by TUV Rheinland as an independent neutral expert, the high safety level of the Transrapid system has been achieved. At the International Conference on Maglev Transport '85, a report was given on the principles and aims of TUV safety work. The characteristics of magnetic levitation are active systems.

Some examples are presented to make safety problems of magnetic levitation and ways to their solution evident, as fail safe-techniques in the classical sense are out of question. In the Transrapid maglev train, the on-board energy supply and the levitation and guidance system are considered. As for the guideway, an active system in the form of a hydraulic drive is

used for positioning and locking a switch, with rail-safe behavior to meet requirements on vehicle safety in operation.

The ways to approve a maglev train in the Federal Republic of Germany and outlooks on approval in the United States of America are discussed.

39. "Safety Effectiveness Evaluation of Rail Rapid Transit Safety," National Transportation Safety Board, Office of Evaluations and Safety Objectives, Report No. NTSB-SEE-81-1, 22 January 1981.

On 28 and 29 July 1980, the National Transportation Safety Board held a public hearing on rail rapid transit safety. Twenty-five witnesses testified during the hearing on fire safety issues, emergency evacuation from rail rapid transit systems and safety oversight of transit systems. The Safety Board examined fire safety issues involving transit care design; emergency exit from cars; emergency tunnel ventilation; evacuation from tunnels; emergency procedures including training, drilling, and testing; emergency communications, equipment, and mobility; and local/State/Federal safety oversight of rail rapid transit properties.

The Safety Board issued urgent recommendations to the Urban Mass Transportation Administration for a survey of rail rapid transit systems to determine their capability for evacuation of passengers under various operational and passenger load conditions and to establish Federal guidelines for the elimination or minimization of combustible and toxic gas and smoke-generating materials in existing rail rapid transit cars. The Safety Board further recommended that the Secretary of Transportation propose Federal legislation which would explicitly authorize the establishment of safety standards for rail rapid transit systems. Other recommendations seek Federal guidelines for car and tunnel designs, safety equipment, and training; the need for five-year safety and research and development plans; a fire research and testing program; a study of the need for fire suppression systems; and improved training for tunnel rescue efforts for employees and emergency personnel.

40. "Safety of High Speed Magnetic Levitation Transportation Systems: Preliminary Safety Review of the Transrapid Maglev System," Robert M. Dorer and William T. Hathaway, DOT/FRA/ORD 90/09, Interim Report, November 1990.

The purpose of this report is to identify the adequacy of existing safety regulations and to identify potential modifications to support Transrapid TR-07 deployment in the United States. A safety evaluation concept is proposed and applied using a disciplined process of system definition, hazard identification, risk assessment, risk mitigation and follow-up. Application of historical data and existing railroad regulations is found inappropriate to new concepts such as: safe hovering, automatic train operations during emergencies and the procedures to remove disabled trains or vehicles from elevated guideways. Ten events are described in consequences must be reduced in spite of low occurrence probabilities. Remaining regulation issues to be resolved included: structure crashworthiness, emergency braking, window glazing requirements, signal and train control, interior and exterior noise, and electrical safety.

41. "Super Speed Ground Transportation System, Las Vegas/So. Calif. Corridor, Phase II-Maglev Technology Assessment, Executive Summary," CIGGT Report No. 86-19, July 1986.

This document summarizes the work done to assess the development status of available super-speed and high-speed train systems in the Las Vegas - Southern California corridor in the 1990s.

42. "Super Speed Ground Transportation System, Summary of Experience," CIGGT, November 1990.

This document describes the capabilities and activities of CIGGT since it was established in 1970. Capabilities range from propulsion system and guideway design to computer modeling, dynamic analysis, project planning, and extensive laboratory and field testing. Also described are the tools used at CIGGT to conduct financial analyses, technology assessment, education and training. Key CIGGT researchers are also identified.

43. "Super Speed Ground Transportation System, Maglev Technology Assessment, Task 1: Review of Phase 1 Report," CIGGT Report No. 86-06, June 17, 1985.

The purpose of the report is to review the Phase 1 work and to identify conceptual and specific issues for study in the Phase 2 work. Points of comparison between high-speed rail and maglev (circa 1982), differing route alignments, maglev technical advantages are appreciated while lack of supporting documentation was lamented. The conceptual issues center of efforts to strengthen the analysis by taking advantage of evolved knowledge of specific systems and reverifying projected costs. The resulting specific issues to be examined are organized in infrastructure, operations, technology and costing categories.

44. "Super Speed Ground Transportation System, Maglev Technology Assessment, Task 5: Development Status of Major Maglev Subsystems and Critical Components," CIGGT Report No. 86-10, January 1986.

This abstract covers the Communication and Control Equipment section. Four vehicle location systems, which are partially redundant (i.e. the systems independently duplicate the vehicle position detection function over at least part of the vehicle speed range) and have differing vehicle position resolution accuracies. These are: 1) a wayside vehicle-position-sensing passive inductive cable receiver which is excited by a vehicle on-board antenna; 2) a wayside motor phase angle detector based on the measurement of the stator voltage and current relationship at the power supply output terminal which, in combination with an analytical representation of the motor and a summation of the motor supply output waveform cycles, indicates vehicle position; 3) on-board vehicle-position-sensing inductor coils which detect the presence of the guideway stator winding poles; and 4) an on-board optical sensor which interrogates coded passive location markers attached to the guideway. The Transrapid control and communications system for both the TR-06 and TR-07, and the differences between them are discussed. The present development status and future potential of the control and communications equipment is also covered.

45. "Super Speed Ground Transportation System, Maglev Technology Assessment, Task 6: Maglev Vehicle Magnetic Fields," CIGGT and Division of Mechanical Engineering, National Research Council of Canada, CIGGT Report No. 86-11, September 1985.

This report addresses effects on the maglev transportation system, passenger, and crew due to magnetic field environments. Information is included related to magnetic field environments measured in and about the Transrapid TR-06 vehicle. The report concludes that the magnetic flux density induced in EMS vehicles is negligible. However, the magnetic field due to operation of an EDS is considerably higher and requires careful assessment. This report discusses the probable magnetic field tests to be conducted on the JNR test vehicle. Calculated magnetic flux densities are presented for the JNR EDS vehicle without

magnetic shielding. Although limited information is available regarding allowable exposure to magnetic fields, this report discusses past efforts to establish allowable levels. Possible techniques for magnetically shielding the maglev passenger cabin, including both passive and active shielding methods, and station platform shielding are also discussed.

46. "Super Speed Ground Transportation System, Maglev Technology Assessment, Task 7: Evaluation of Electromagnetic Interference (EMI) Effects on Wayside Installations," CIGGT Report No. 86-12, January 1986.

    This document summarizes studies conducted to evaluate EMI effects of the maglev system on wayside electrical and electronic installations. Since existing EMI test facilities are in relatively isolated areas (e.g., Emsland and Meyazaki), there is little experience with EMI effects which EMS or EDS Maglev might induce in an urban environment. The studies concentrate on two classes of potential EMI-related problems effecting wayside installations: 1) those induced by electromagnetic fields emanating from the track or guideway, and 2) those induced by EM fields emanating from the trainset during system operations.

47. "Super Speed Ground Transportation System, Maglev Technology Assessment, Task 8.2: Guideway Tolerances and Foundation Conditions," CIGGT Report No. 86-14, January 1986.

    In the Transrapid magnetically levitated system, the permissible deviation of the functional areas of the guideway from their normal positions is typically in the order of a few millimeters. These requirements are somewhat more stringent than previously applied in the construction industry. Consequently, they have an influence on the design and construction of the guideway. These influences, as related to a concrete guideway, are discussed in this report.

    The achievability of the required guideway tolerances will be influenced by the tolerances achieved in the following individual items of the guideway:

    - Fabrication of girders,
    - Attachment of hardware to girders,
    - Erection of girders on supports, and
    - Time-dependent deformations.

    Tolerances readily achievable in each of these items are discussed and their influences on the completed guideway structure are assessed.

48. "Super Speed Ground Transportation System, Maglev Technology Assessment, Task 9.1: Examination of Estimated Costs, Initial 'Order of Magnitude' Review," CIGGT Report No. 86-15, July 1985.

    This report presents the results of the initial "order of magnitude" review by the CIGGT study team of the costs of the "Las Vegas-Los Angeles High-Speed/Super-Speed Ground Transportation System Feasibility Study -- Final Report, Volumes I and II." This review was undertaken to determine the relative importance of individual cost categories to overall super-speed costs in order to allocate research effort.

49. "Superconducting Linear Synchronous Motor Propulsion and Magnetic Levitation for High Speed Guided Ground Transportation," Interim Phase III Contract Report - April 1975 - March 1976, A. R. Eastham, CIGGT Report No. 76-7, March 1976.

This report describes the results of the first year of Phase III of the Canadian Maglev program, the aims of which are: (1) to identify a technically feasible maglev system based on electrodynamic suspension and guidance and linear synchronous motor (LSM) propulsion principles; (2) to develop mathematical models describing levitation, guidance, propulsion and dynamic performance of the vehicle; and (3) to verify design proposals experimentally to the greatest extent practical.

50. "Superconducting Magnetic Levitation and Linear Synchronous Motor Propulsion for High Speed Guided Ground Transportation," Phase II Contract Report, March 1973 - March 1975, A. R. Eastham, CIGGT Report No. 75-5, March 1975.

This report describes the results of Phase II of the Canadian Maglev program, involving an investigation of the use of superconducting magnets for electrodynamic levitation and guidance and for linear synchronous motor (LSM) propulsion of high speed guided ground transportation.

The technical and operating characteristics of a maglev system with vehicles cruising at 480 km/hr (300 mph) have been investigated. Reference designs for the levitation, guidance and propulsion system and for the guideway have been compiled, and a first estimate of maglev vehicle characteristics, including a weight analysis, aerodynamic effects, noise and energy efficiency, has been made.

51. "Test Facility for the Determination of Linear Induction Motor Performance," A. R. Eastham, G. E. Dawson, D. L. Atherton, C. L. Schwalm, CIGGT Report No. 80-6, August 1980.

This report describes the experimental facilities and test equipment used to obtain the data for an assessment of the single-sided linear induction motor (SLIM) as an integrated suspension/propulsion system (ISPS), using either a squirrel-cage rail with laminated steel or a solid steel-only reaction rail. The performance of the SLIM over a wide range of operating conditions in the plugging, motoring, and regenerative braking modes was determined at CIGGT. The assessment of the SLIM in the ISPS mode of operation for high speed ground transportation was conducted by the MITRE Corporation.

52. "Transrapid Maglev System," Klaus Heinrich and Rolf Kretzschmar, Hestra-Verlag, Darmstadt, FRG, 1989.

This publication details the development of the German Transrapid Maglev System. The design processes for the guideway and vehicle are discussed. The test program is outlined and the Emsland Test Facility is discussed.

53. "Update of Super-Speed Ground Transportation Technology Development Status and Performance Capabilities," W. F. Hayes, C. J. Boon, A. R. Eastham, A. B. Hazell, The Canadian Institute of Guided Ground Transport, CIGGT Report No. 89-16, 25 May 1990.

This report presents an update of the Phase II assessment of development status and performance capabilities for four candidate super-speed ground transportation system alternatives for the Las Vegas - Southern California corridor. The four alternatives considered in this report are the TGV wheel-on-rail technology, the Transrapid TR-07 long-stator Electromagnetic Maglev (EMS) technology, the Japan Railways MLU Electrodynamic

Maglev (EDS) technology, and the HSST Corporation HSST-400 short-stator electromagnetic maglev technology.

The objectives of this update were fourfold:

- to confirm that the candidate technologies identified in Phase II remain the leading alternatives for deployment in the California-Nevada Corridor;

- to ascertain the current (first quarter 1990) development status, actual achieved level of performance, and future development potential of each candidate technology;

- to characterize the attributes and shortcomings of each candidate technology, with emphasis on identification of as-yet-unresolved development and/or operational issues, and on the plans and timetable of the developer/operator to deal with these issues;

- to create for the Commission an appropriately cross-referenced data base covering the key technical attributes, characteristics and unresolved issues for each qualified technology.

On the basis of the investigations, the basic conclusion of the Phase II Technology Assessment remains unchanged with respect to three of the four technologies identified as candidates for deployment in the Las Vegas - Southern California Corridor.

- The TGV wheel-on-rail technology is most developed and best proven, in terms of its operational history. It has recently demonstrated performance capabilities beyond those demonstrated in test by the Transrapid technology, and approaching that of the JR EDS maglev technology.

- The Transrapid electromagnetic maglev is the next most advanced technology, in terms of its readiness for deployment.

- The JR electrodynamic maglev technology remains in third place in terms of its readiness for deployment. Recent commitments for construction of a 24-mile-long test/revenue demonstration facility and pre-production prototype test trainset are significant, but an informed deployment decision cannot be made before the turn of the century.

The fourth technology considered in the Phase II work, the HSST-400 short-stator EMS maglev, is no longer even a remote possibility. Development of this version of the basic HSST design concept has been terminated. The slower-speed versions of HSST remain under development. There are two important issues that affect all three remaining technologies:

- None of these technologies meet existing U.S. standards with respect to vehicle structural strength. Redesign to achieve compliance is not possible without significant degradation in performance capabilities and/or imposition of significant capital and operating and maintenance cost penalties. Safe SST operation is not dependent on these standards, but rather on strict adherence to fail-safe design, construction and operating practices and rigorous preventative maintenance procedures.

- In the years since completion of the Phase II assessment, there has been growing concern about the possible adverse biomedical effects of exposure to even low-intensity power-frequency (60 Hz) AC electromagnetic fields and also to possible effects of interactions between AC electromagnetic and DC magnetic fields. It is unclear what, if any, public health issues may be caused by the reported effects.

The issue of AC fields and field interactions is much more complex than was apparent four years ago. Controlled measurements of AC and DC fields adjacent to all on-board and wayside electrical machines and transmission lines that form part of any SST system will be needed during the franchise award process.

APPENDIX B: STANDARD CONTACT INTERVIEW FORM

MAGLEV TEST PLAN
CONTACT FORM

Name of Contact________________________________ Phone______________
Contact's Affiliation____
Address____
Date of Contact__________ Initial Contact__________ Follow-up Contact__________
Name of Interviewer(s)____
Contact's Current Maglev Involvement____________________________________
____
____

INTERVIEW QUESTIONS:

1. Can you briefly summarize your Maglev R&D effort?

2. Have you identified development risk areas as part of your Maglev R&D as they relate to the following levels of development:
   Component?

   Subsystem?

   System?

3. Are you currently collecting test data as part of your Maglev R&D effort? If so, please explain.

4. Do you anticipate that your Maglev R&D effort will lead to future testing?

5. At what level can the development risk area you are researching be assessed? Component? Subsystem? Scale? Full-scale?

6. What other major subsystem interfaces are critical to the development of your subsystem?

7. What test facility requirements do you anticipate for the following test categories as they apply to your subsystem?

   Engineering Evaluation Tests:

   Concept Demonstration Tests:

   Full-scale Prototype Hardware Evaluation Tests:

   Other Anticipated Tests and Facility Requirements:

8. Which of the identified tests would be the responsibility of the development contractors and which would fall under the sponsorship of the government?

9. What existing test facilities would support your identified test requirements?

10. What do you recommend for the time phasing of your identified development testing with respect to other subsystem and system tests?