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Maglev Program Test Plan

National Maglev Initiative
Washington, D.C. 20590

DOT/FRA/NMI-92/11

July 1992
Final Report

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11 - Advanced Systems

METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

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

AREA (APPROXIMATE)

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

MASS - WEIGHT (APPROXIMATE)

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

VOLUME (APPROXIMATE)

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

TEMPERATURE (EXACT)

$[(x - 32)(5/9)]$ °F = y°C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

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

AREA (APPROXIMATE)

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

MASS - WEIGHT (APPROXIMATE)

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

VOLUME (APPROXIMATE)

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

TEMPERATURE (EXACT)

$[(9/5)y + 32]$ °C = x °F

QUICK INCH-CENTIMETER LENGTH CONVERSION

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

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

QUICK FAHRENHEIT-CELSIUS TEMPERATURE CONVERSION

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

For more exact and or other conversion factors, see NBS Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50. SD Catalog No. C13 10286.

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COTR: Tom Comparato, Volpe National Transportation Systems Center (VNTSC)

16. Abstract

Maglev systems represent a promising evolution in the high-speed ground transportation, offering speeds in excess of 300 mph along with the potential for low operating costs and minimal environmental impact. The goal of this effort is to investigate the feasibility and viability of maglev systems in the United States. The emergence of a sophisticated technology such as maglev requires a need for a coordinated research test program and the determination of test requirements to identify and mitigate development risk and to maximize the use of domestic resources.

This study is directed toward the identification and characterization of maglev systems development risks tied to a preliminary system architecture. Research objectives are accomplish by surveying experiences from previous maglev development programs, both foreign and domestic, and interviews with individuals involved with maglev research and testing. Findings include ninety-four distinct development risks and twenty risk types.

Planning and implementation requirements are identified for a maglev test program, including the development of a facilities strategy to meet any operational concepts that evolve out of early development effort. Also specified is the logical development flow and associated long-lead support needs for sub-scale and full-scale testing.

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FOREWORD

Martin Marietta Corporation, Air Traffic Systems submits this Final Maglev Program Test and Facilities Plan to the Federal Railroad Administration (FRA) as required under Contract No. DTFR53-91-C-00071, Maglev Program Test Plan. This document supersedes the Interim Test Requirements Analysis Report, in its entirety, (FRA45-92-003 submitted in April 1992) and forms the basis for completion of the referenced contract.

The nature of this study required the review of literature, interview of maglev industry and related institution representatives and the formulation of certain conclusions and recommendations regarding further efforts in support of the National Maglev Initiative. It should be noted that conclusions and recommendations included herein represent the views of the authors and do not necessarily represent positions of The Departments of Transportation and Energy and the Army Corps of Engineers which sponsored this study.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the important contributions made by others to the successful execution of this study and the preparation of this report.

Mr. Thomas F. Comparato, of the Volpe National Transportation Systems Center, Cambridge, Massachusetts, who served as the contracting officer's technical representative, provided technical oversight, encouragement and guidance throughout the study.

Dr. Howard T. Coffey and Laurence E. Blow, Argonne National Laboratory and James T. Ballard, U.S. Army Corps of Engineers, served as an advisory group attending periodic reviews during the performance of this study, reviewing the draft reports and imparting valuable insight to the program.

The industry and academic sources listed in Table 3.2-1 volunteered much helpful data on risks and facility needs and capabilities in their responses to our interviews. We sincerely thank them for the time and effort they took to answer our written and verbal questions.

Martin Marietta Air Traffic Systems, Washington, DC, contributed to this effort. David Kampsnider assisted in library development and literature review, Steve Carlton provided systems analysis and contract administration and Carl Sara furnished system and programmatic insights.

We wish to give very special thanks to other members of the Martin Marietta Astronautics Denver, CO team, namely Dr. Arthur Feldman, Sue Harris, Calvin Markwood and Dr. John Wollan, who gave long hours of their own time with special dedication to concept development and text preparation to assure the high quality and appropriate focus of this study.

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Linda A. Karanian

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APPENDICES

1.0 EXECUTIVE SUMMARY

The fundamental premise of this study is that successful development and implementation of an American maglev system will require the identification of the relevant development risks and the marshalling of appropriate testing and integration facilities to mitigate those development risks. Further, to obtain the technical data required to analyze and evaluate both electromagnetic and electrodynamic levitation and guidance systems, the development and construction of multiple levels of test facilities may be necessary, considering that:

- In the system concept design phase and technology assessment, laboratory-scale experimentation devices may be needed to establish proof-of-principle of a particular technology and to verify analytical findings.

- During the detailed design phase, the use of sub-scale or full-sized vehicle model and guideway component configurations may be needed to add confidence to the selection of a system configuration and to confirm the designs prior to making the significant investment in a full-scale prototype and with its associated testing facilities.

- In the prototype development phase, and even beyond, a full-scale test facility (or national test bed) may be required to ensure that all the associated subsystems are properly integrated and that the system functions in accordance with the pre-established performance parameters and operational safety requirements.

Based on this premise, this study was directed toward the identification and characterization of maglev system development risks tied to a preliminary system architecture, the definition of preliminary test planning and a recommendation for a system development flow and associated testing facility strategies. In addition, recommendations have been included for future activities that would augment this study and assist in the development of an American maglev system.

This is the final report associated with this effort and includes the following:

- Findings of a literature search in which 162 citations were reviewed. Of the 162 citations reviewed, 53 were selected for detailed assessment based on pertinence and being representative of current thinking in the development of maglev related components, subsystems and systems. Abstracts of the selected citations are included in Appendix A for reference.

- Interview results from 31 experts in the industrial and academic community who have made contributions in the recent past or are currently active in maglev related studies and/or hardware development. A complete list of individuals and their affiliations is included in Table 3.2-1.

- Identification of 94 distinct program development risks compiled from the review of literature and verified by the interviews of experts. These 94 risks were then grouped into 20 distinct risk types to assist in the definition of test planning activities. Delineation of the 94 risks and 20 risk types is presented in Tables 3.2-2 and 3.2-4 respectively.

- Characterization of risk by subsystem, severity, type and mitigation method in order to assist in the formulation of specific testing methodologies related to the various subsystems and particular phases of maglev system development. The summary results of this characterization are presented in Table 3.4-1.

- Definition of a preliminary maglev system architecture based on literature published to date, suggestions obtained from the interviews of industry and academic experts and inputs from principal investigators responsible for conducting concurrent technology studies. This architecture is presented in Section 3.3.

- Test Scope Data Sheets that propose typical tests and supporting analyses structured to mitigate the identified risks. Tests and analyses defined recognize the preliminary maglev system architecture and the recommended phases associated with the system development process. The total set of Test Scope Data Sheets is included in Appendix C.

- Recommendations for scheduling risk mitigation activities into four development phases consistent with traditional development methodologies for large multi-disciplined programs that require the advancment of the state-of-the-art within one or more technologies. A recommended development flow along with two alternatives, each with progressively higher risk, is presented in Section 3.5.2.

- Identification of existing and proposed component, subsystem and system level test capabilities available throughout the industrial complex that could be brought to bear for the development of a national maglev system. These capabilities are summarized in Section 3.5.3.

- Recommendations for future efforts related to this task in the areas of expanded risk assessment evaluations, detailed similitude studies to determine the degree of sub-scale testing that could be used to mitigate risks, the development of a total program integrated analysis and test plan and the preliminary design of a full-scale national test bed. These topics are presented in detail in Section 5.0.

A Test Requirements and Facilities Analysis Team, comprised of contractor personnel, successfully executed a process of identifying, documenting and analyzing the following maglev system aspects:

- Architecture,
- Operational concepts,
- Leading maglev system developers,
- Test planning and facilities exercised in prior related activities,
- Development risk,
- Typical tests formulated to mitigate a risk or group of risks,
- Facilities available (or proposed) to support maglev development and
- Risk mitigation methods and timeframes.

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 of components and electromagnetic field risks are also numerous and severe. Control, cryogenics and response to emergencies, although few in total number of risks, are high severity and warrant close attention in the development program. These seven 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 and its tractability. 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 turned to test planning and facilities utilization strategies. Based on the risk assessment, specific tests to mitigate the risks identified were documented and included in Appendix C. The data sheets provide top-level information required to build the point-of-departure test plan and facilities strategies. Each candidate test was assessed to determine at which phase of the development program the test could be conducted to most effectively mitigate the particular risk, or group of risks, and provide design and system integration support.

The approach to risk mitigation is critical to successful execution of a large-scale development program such as maglev. Accordingly, timeframes for risk mitigation have been assigned to specific phases in conjunction with discrete program milestones. This investigation has defined a recommended maglev system development flow that is illustrated in Figure 3.5-1. Included within this recommendation are critical milestones designed to segregate the development process into an orderly progression from the definition of top level system requirements and development of derived requirements through the completion of operational demonstrations. The critical milestones as described in Section 3.5.1 include:

- System Requirements Review (SRR)
- System Design Review (SDR)
- Preliminary Design Review (PDR)
- Critical Design Review (CDR)
- System Integration Complete (SIC)
- Initial Operational Capability (IOC)

The success criteria associated with the completion of each milestone have been defined, including identification of the types of testing required and associated testing facilities. Alternatives to the recommended development flow are included in Figures 3.5-2 and 3.5-3. These alternatives offer the possibility of a shorter development cycle. However, it is the view of the authors, the possibility of a shorter development cycle is offset by the potential cost escalation due to increased risk. The empirical evaluation of components and subsystems is decreased in the alternatives which tends to result in the need for late redesign.

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. It was determined that hardware component and software suppliers with an interest in participating in the development of a national maglev system have the necessary manufacturing and testing capabilities to provide components to an integration contractor for inclusion at the subassembly and subsystem level. However, with regard to the evaluation of major subsystems and associated development integration testing, capabilities and technologies most frequently cited were those of the test facility designs proposed by Argonne National Laboratory and the Transportation Test Center (TTC) near Pueblo, Colorado. Summary capabilities of these system level testing facilities and their application potential are included in Section 3.5 2 of this 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, number 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 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 included in this report, delineates test classifications and timing including engineering evaluation tests, concept demonstration tests and sub-scale and full-scale prototype hardware evaluation tests. Further, supporting analyses and test facility requirements have been included.

2.2 SCOPE

The Maglev Program Test Plan effort has three major objectives:

- To limit the programmatic risk associated with development of a maglev system by identifying and characterizing the technical risks,
- 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 efforts and
- To identify a logical development flow and associated long-lead support needs such as sub-scale and/or full-scale testing facilities.

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. Within these three major tasks, five sub-tasks were defined which include: the conduct of a literature search, interview of industry experts, development of a preliminary system architecture, conduct of point-of-departure test planning and the definition of point-of-departure facilities strategies. The relationship of all tasks is illustrated in Figure 2.2-1.

The first half of this study was dedicated to the completion of the first three sub-tasks and was documented in an interim report. The second half of the period of performance of this contract was dedicated to completing the last two sub-tasks and the preparation of this final report. It should be noted that the interim report is rendered obsolete with the publication of this document which includes all program findings.

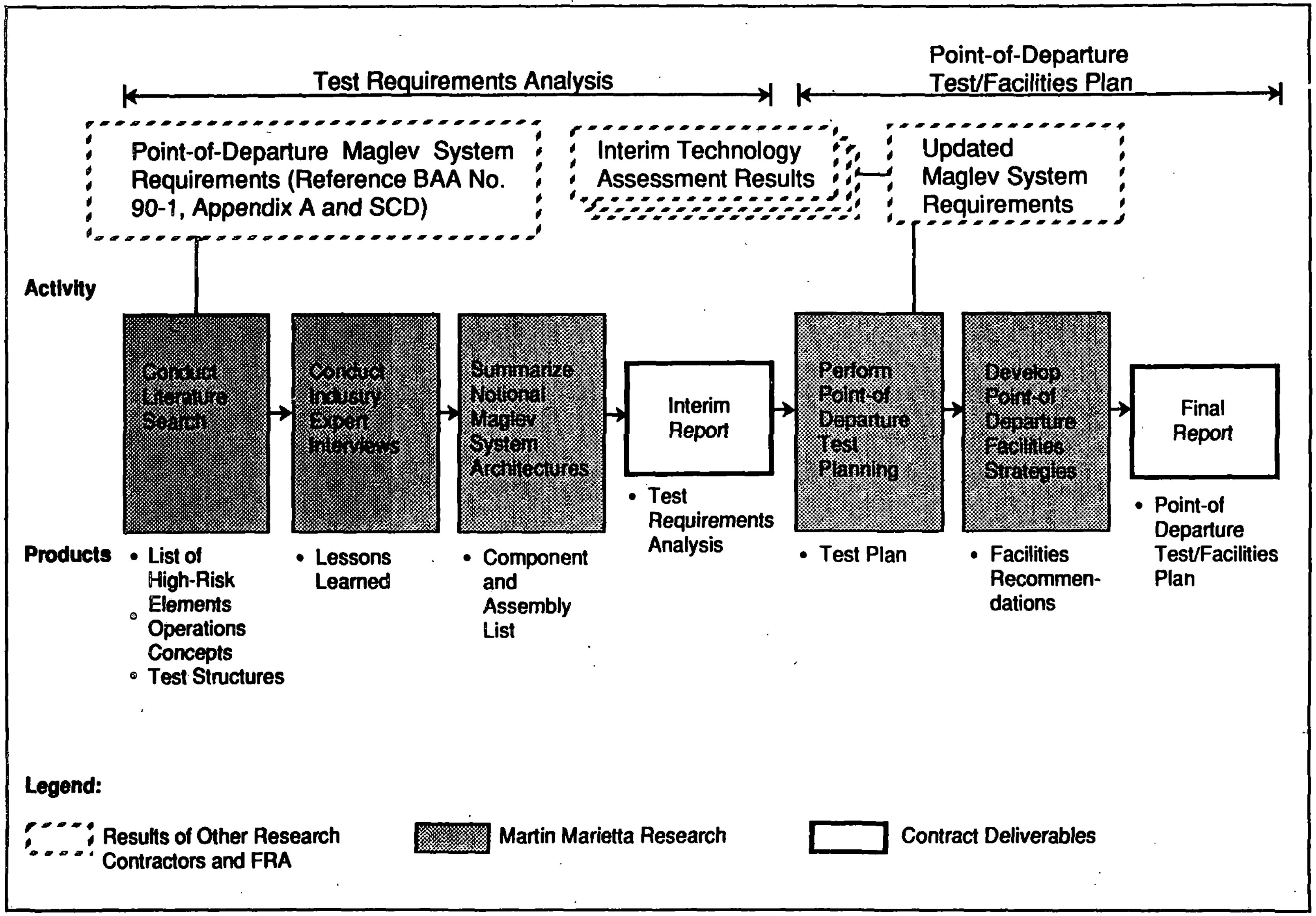

Figure 2.2-1 Maglev Program Test Plan

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 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, Japanese and Canadian 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. Analysis of findings from the literature review 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 and
- 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 a 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 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/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 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 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 Levitation 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 constituted 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 Number 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 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 hierarchical 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 bounds of the hazard are difficult to define. BAA Number 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 operation 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 implications of maglev, including 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 and integration of sensor information all involve a 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 1) establishing well defined software requirements and functionalities to avoid incompatibility between software modules and 2) 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 and system concept definition studies.

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, 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 Aeronautics 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 predominantly on the vehicle/guideway and associated power and control elements and does not address the elements of terminals.

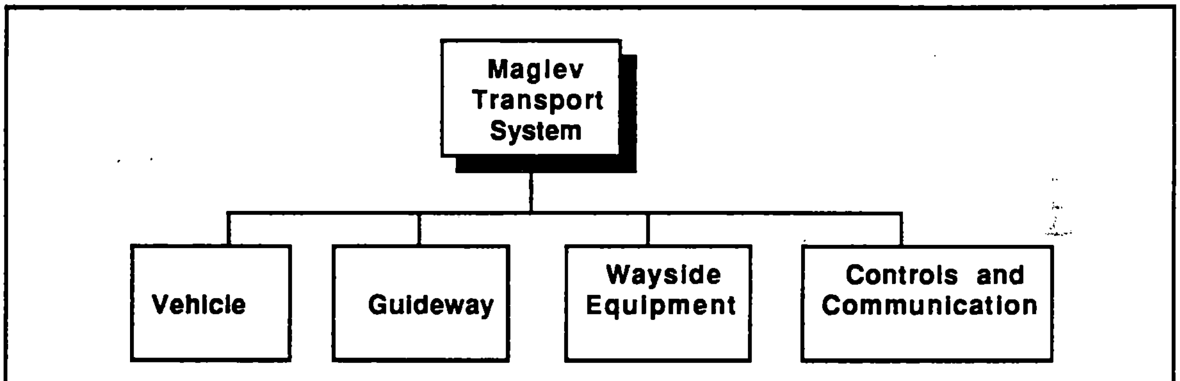

Figure 3.3-1 Definition of Major Subsystems of High-Speed Maglev Transport System As Identified In the CIGGT Maglev Technology Assessment, Task 5

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 vehicle/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. 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:

Governing Documentation—The investigation team performing this study recognize 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, 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".

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 interviews of industry sources. This architecture is presented in Figures 3.3-5, 3.3-6, 3.3-7 and 3.3-8. These figures depict the structure for the vehicle, guideway, wayside equipment and control and communications subsystems respectively. The architecture illustrated should be viewed as a "slice in time" and will obviously become more mature as the system proceeds through the development cycle.

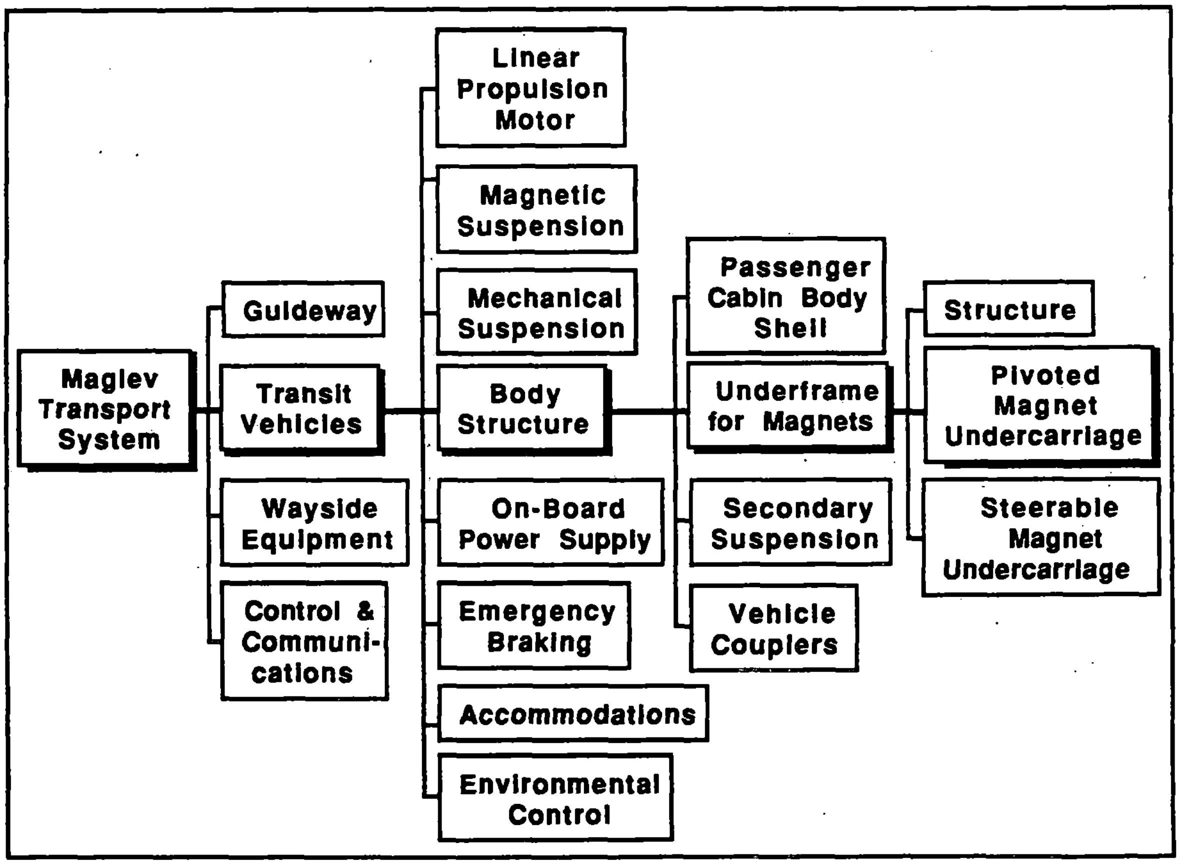

Figure 3.3-2 Typical Element of CIGGT Maglev System Architecture

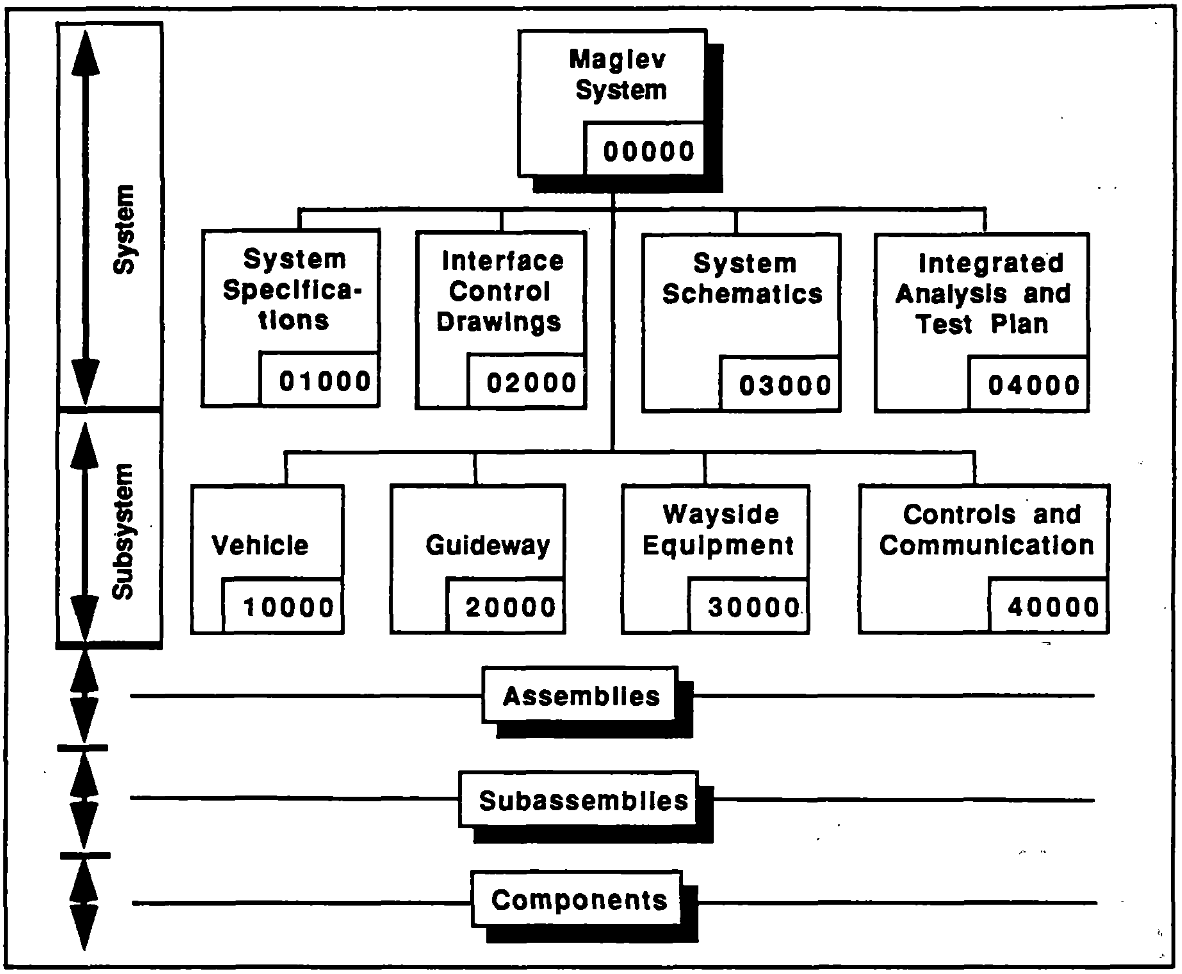

Figure 3.3-3 Recommended Maglev System Architecture Framework

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

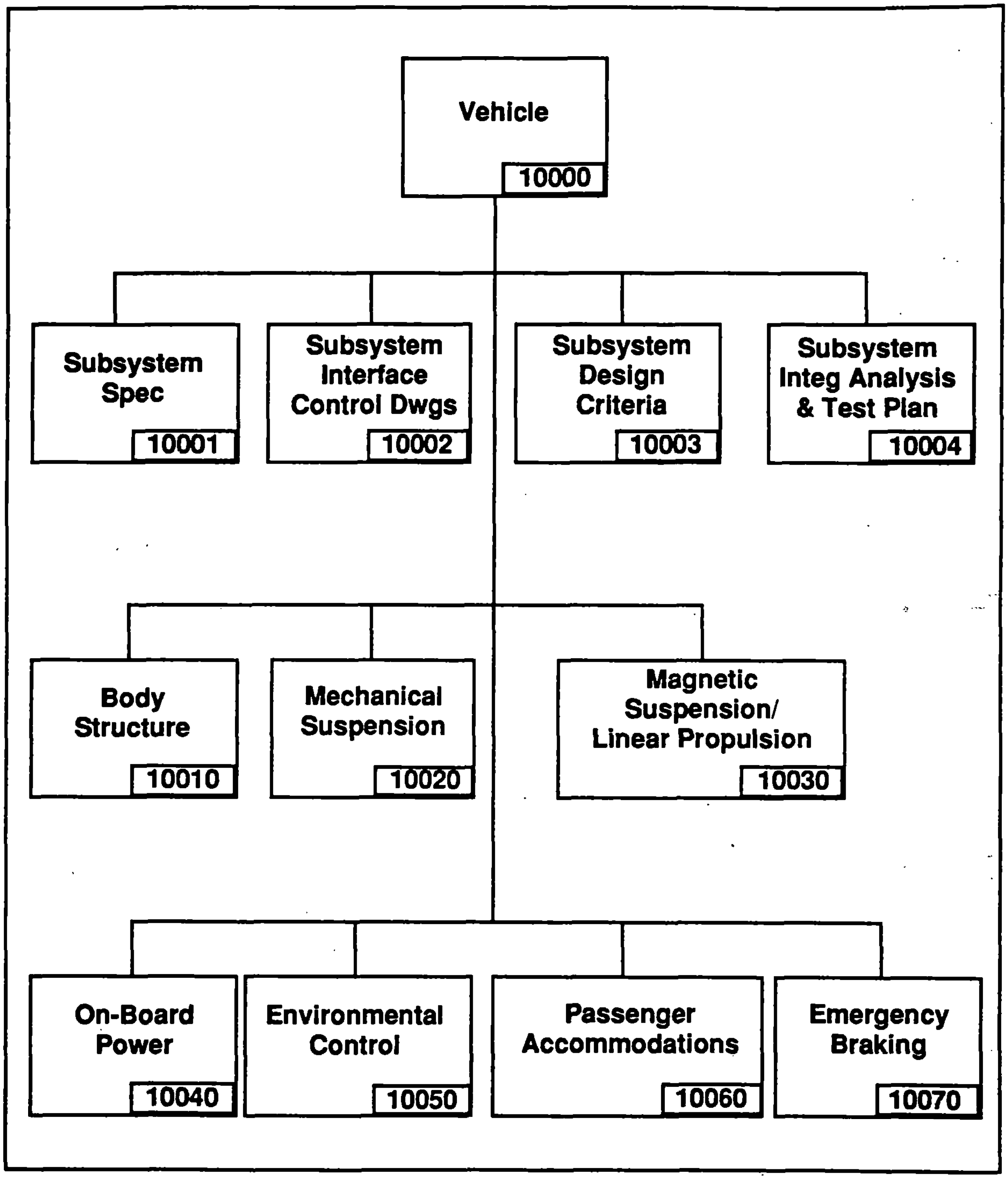

Figure 3.3-5 Vehicle Subsystem Architecture

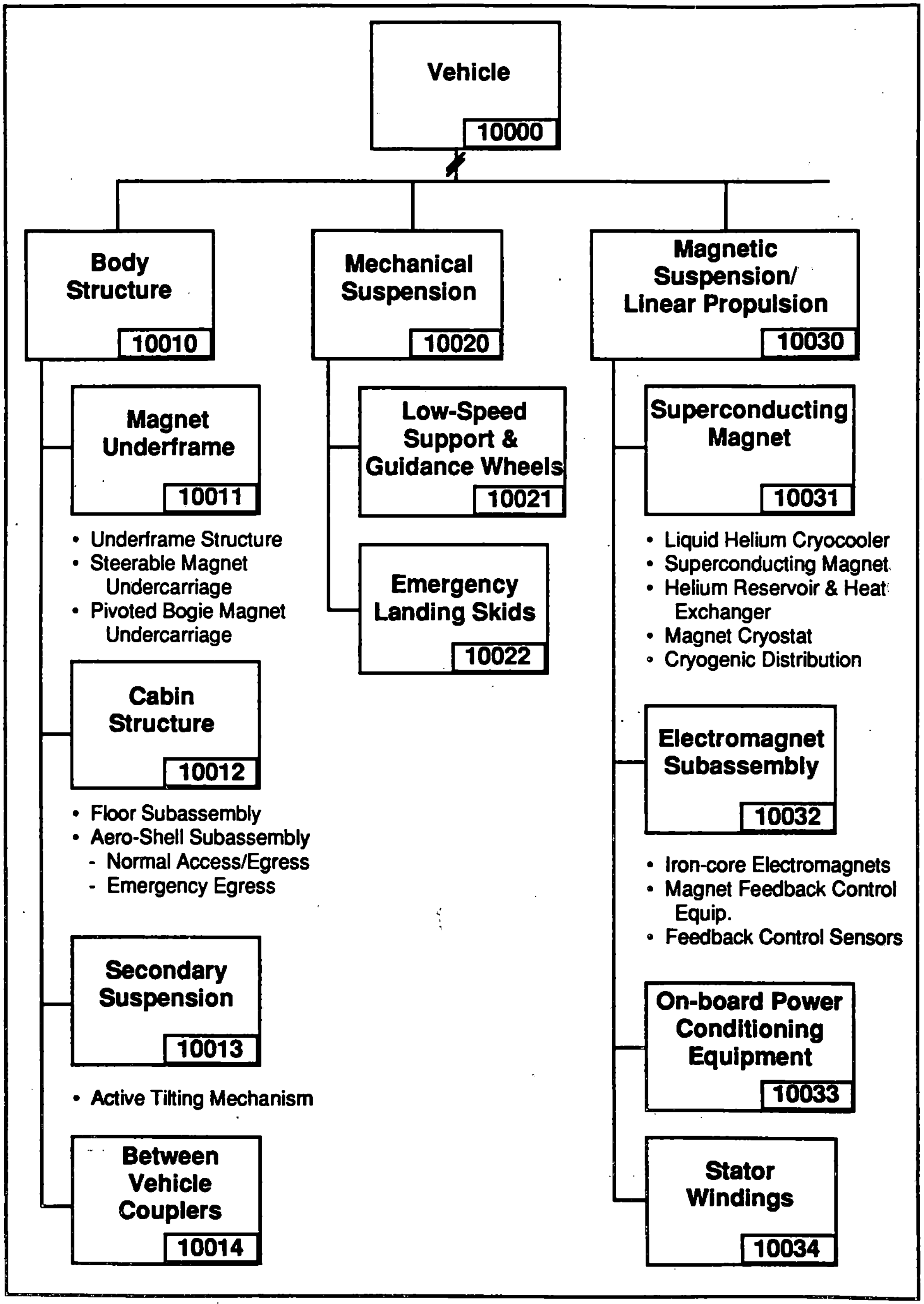

Figure 3.3-5 Vehicle Subsystem Architecture (Continued)

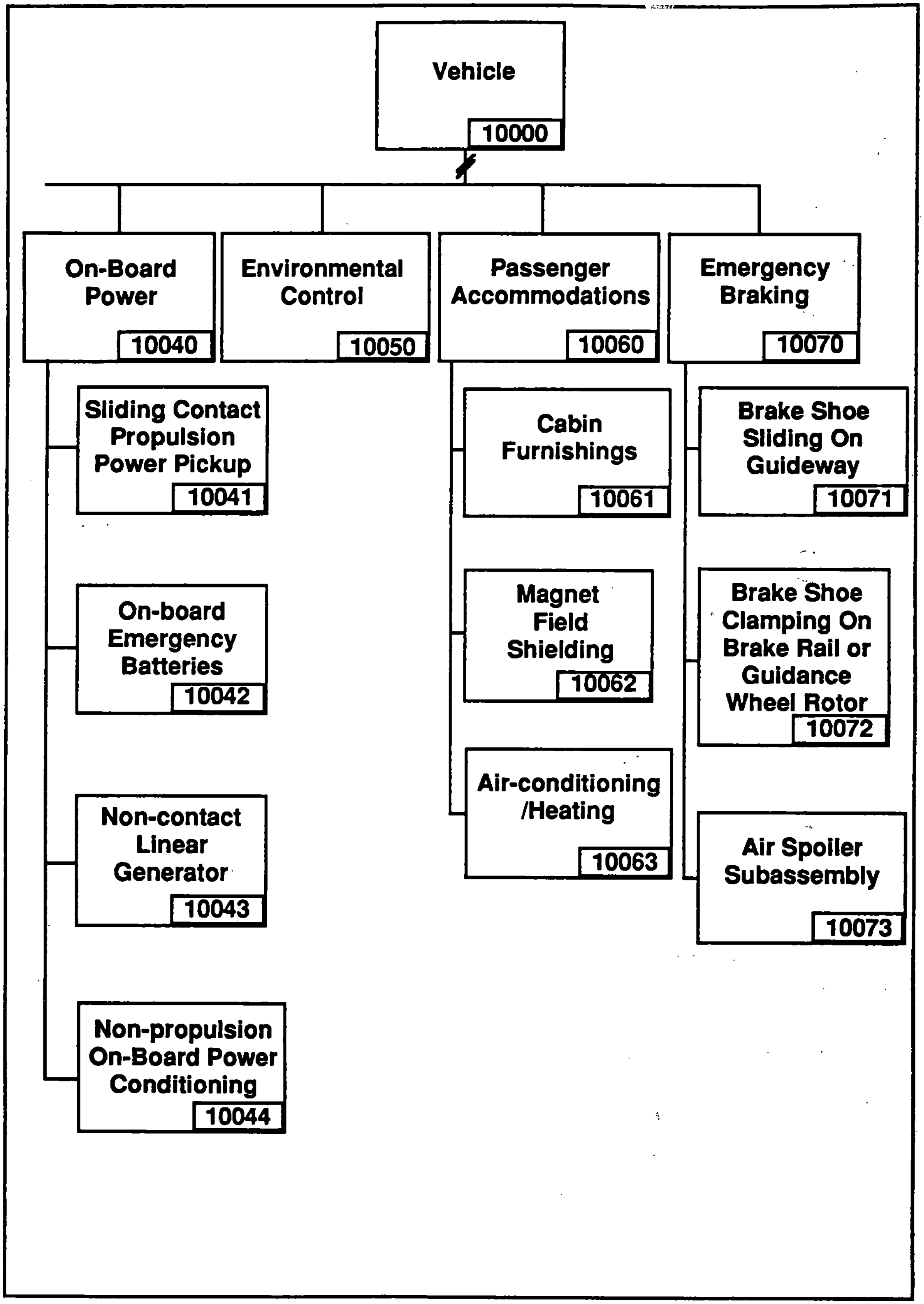

Figure 3.3-5 Vehicle Subsystem Architecture (Concluded)

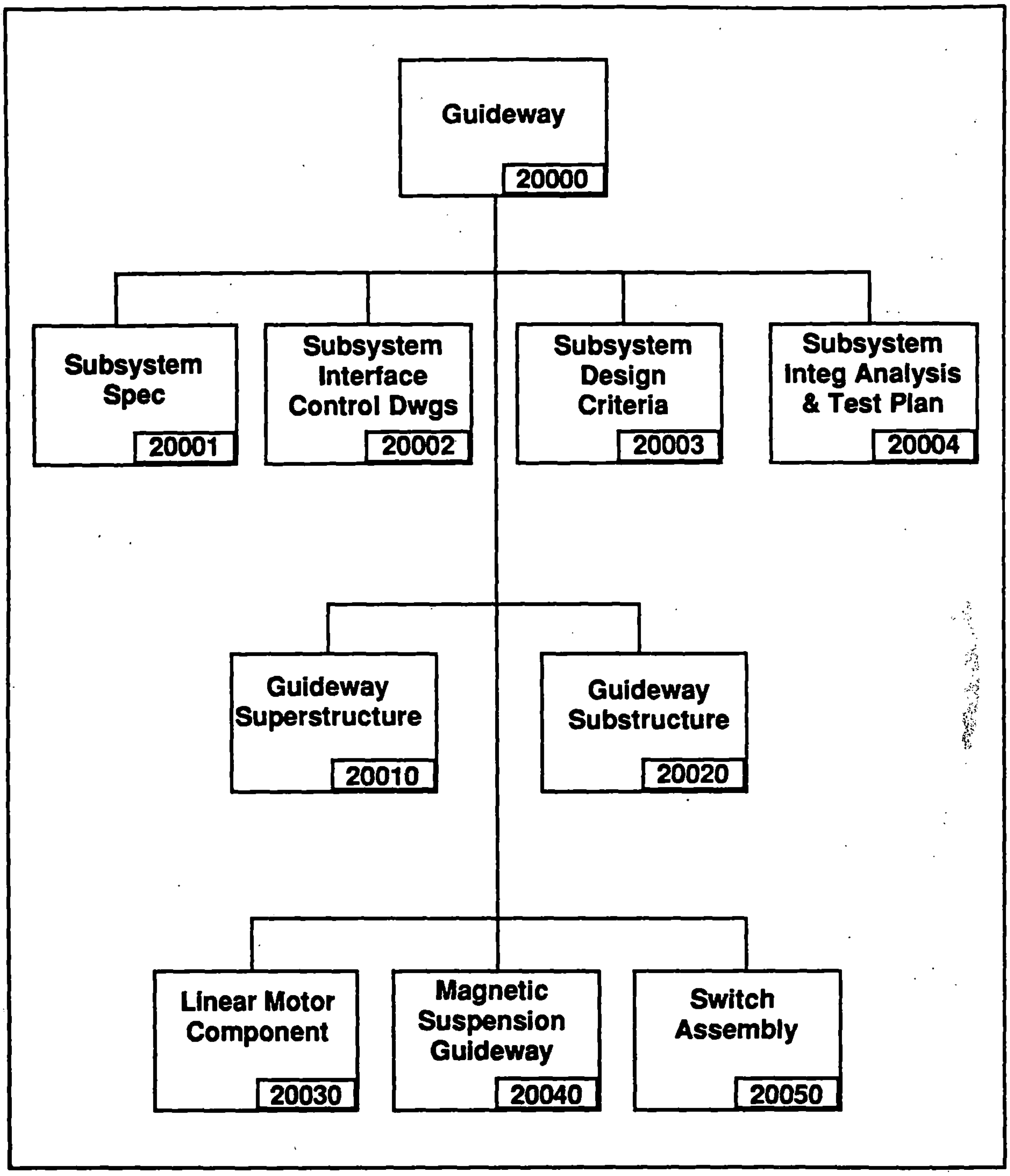

Figure 3.3-6 Guideway Subsystem Architecture

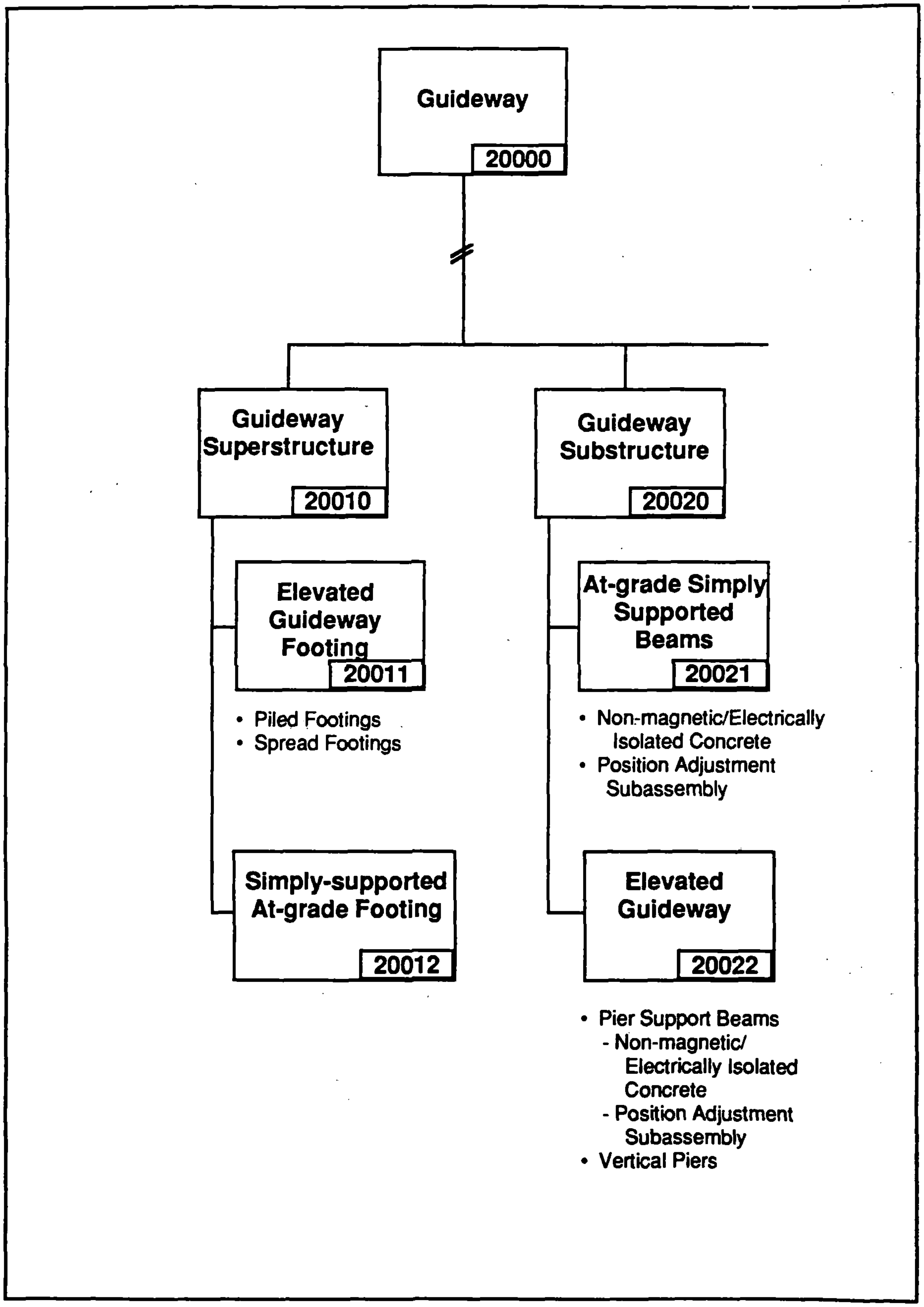

Figure 3.3-6 Guideway Subsystem Architecture (Continued)

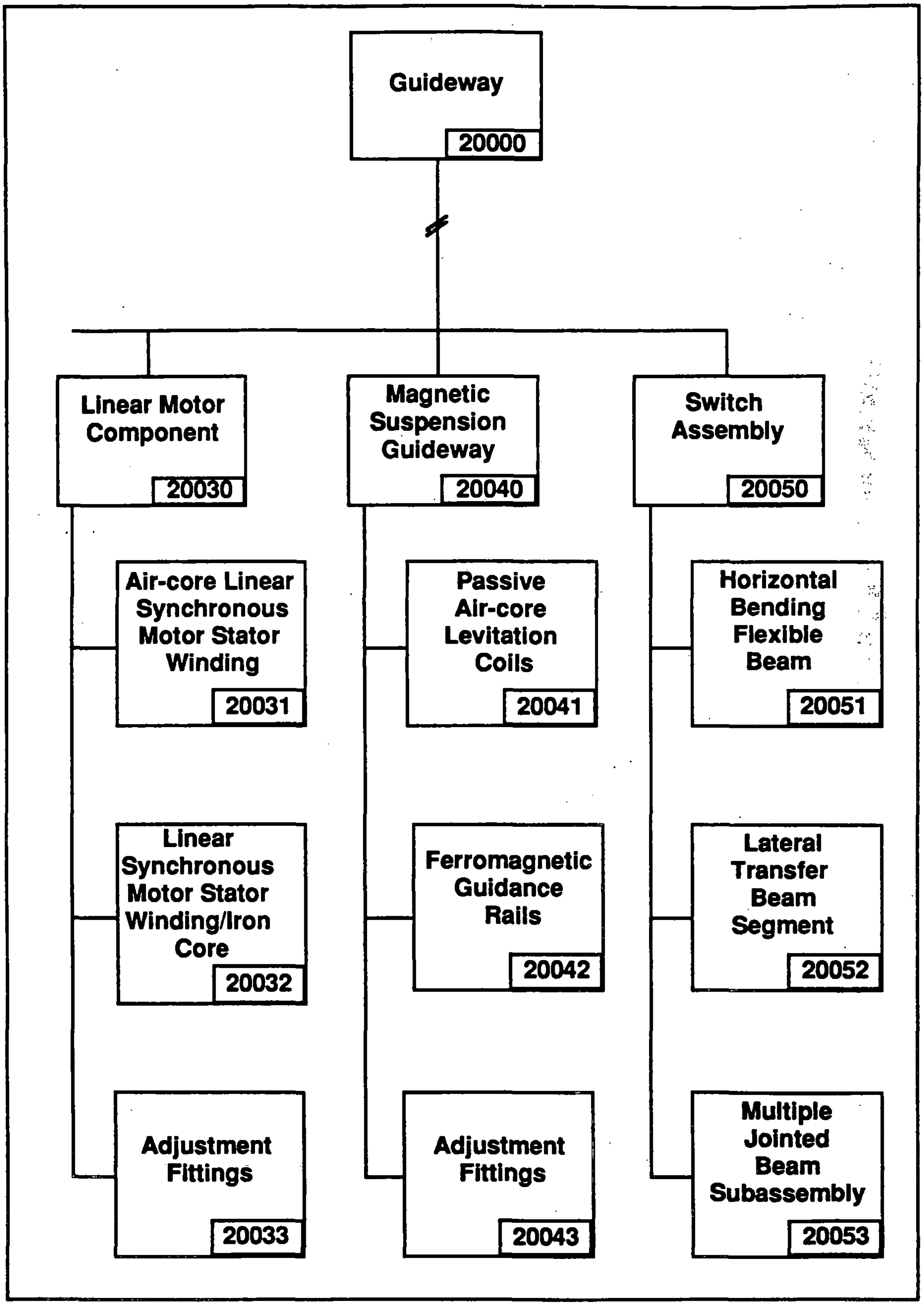

Figure 3.3-6 Guideway Subsystem Architecture (Concluded)

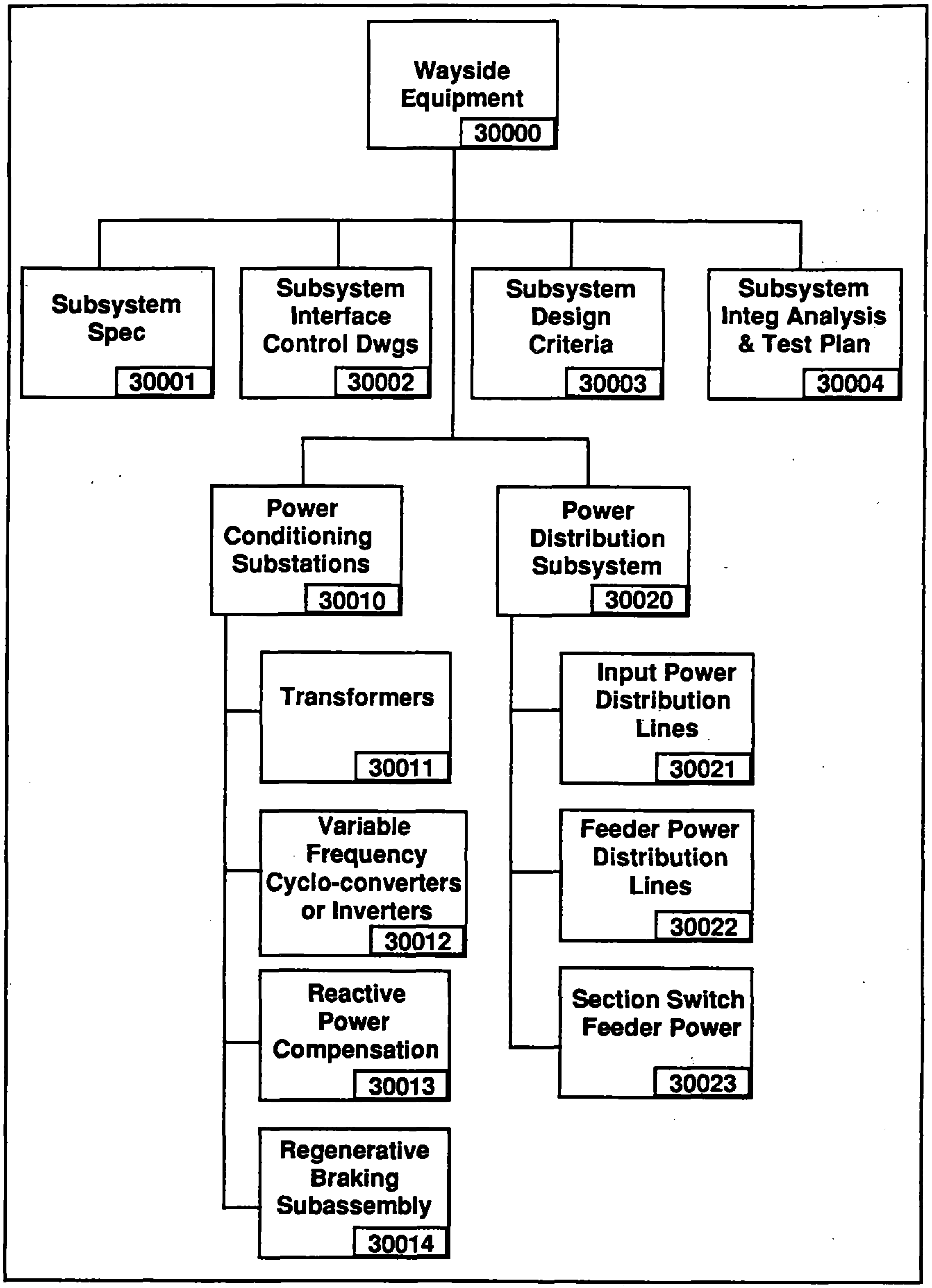

Figure 3.3-7 Wayside Equipment Subsystem Architecture

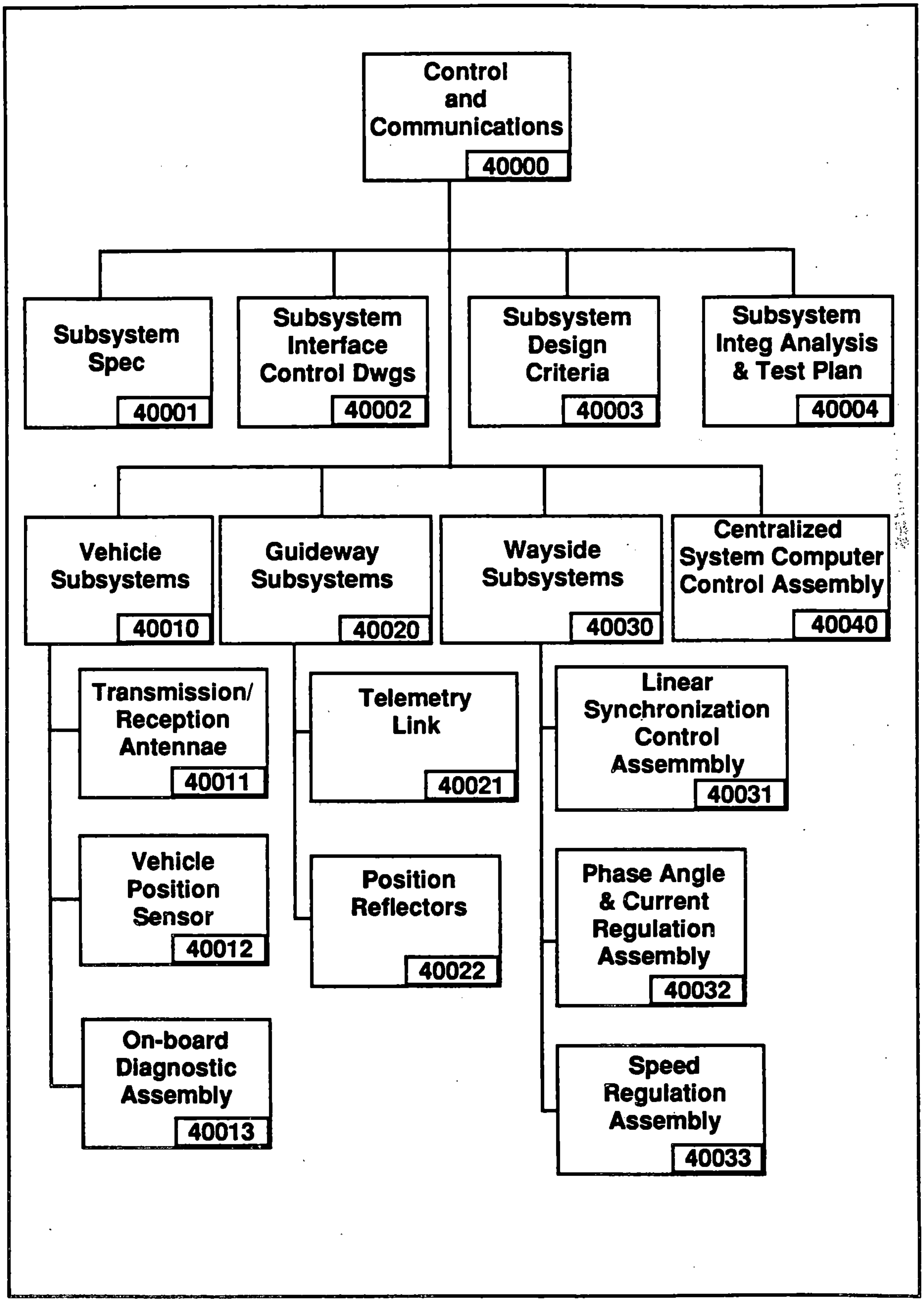

Figure 3.3-8 Control and Communication Subsystem Architecture

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 risks 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 ten million dollars,
- 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 recognized 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 risks identified in the literature,
- Support characterization of risk severity and
- Support allocation of risks 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. Confidence was gained in the completeness of the list of risks by monitoring results presented by BAA and System Concept Definition presentors at the April 1992 Maglev Technology Assessment Symposium. No new risks were identified from those presentations. Insignificant risks are those that, upon judgment 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 two 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 the future compilation of complete 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 3.4-1 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)**

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 formsthe 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 be accomplished in part 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 & Geotechnical	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 & Geotechnical	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

This section of the report addresses test program planning and test facility requirements. Section 3.5.1 provides explanations of terms related to key test program phases and milestones. Section 3.5.1 also explains how the integration and timing of key test program phases mitigate identified development risks. Section 3.5.2 introduces and explains the rationale for development of the Test Scope Data Sheets located in Appendix C. Section 3.5.3 discusses facilities requirements and categorizes existing capabilities and recommended upgrades to existing facilities.

3.5.1 Risk Mitigation Methods and Timeframes

The risk mitigation approach is critical to successful execution of a large-scale development program such as maglev. Thorough identification of the risks is necessary along with thoughtful planning of how and when those risks will be mitigated. Risk mitigation methods include analysis, demonstration, similarity and tests. Of those methods, the interrelationship of testing and analysis is especially strong in a development program. Many tests require analytical determination of expected performance, pass/fail criteria and results evaluation. Analysis, while often the primary method of demonstrating design adequacy or qualification, often requires the collection of empirical data as an input. Thus, in succeeding phases of the maglev program, the development of an integrated test and analysis plan is strongly recommended.

When dealing with complex system development, the timeframes for risk mitigation are customarily allocated to the following intervals with accompanying program milestones:

- Basic Research Phase—analysis and very preliminary tests including:
  - Analytical Studies—used to define appropriate requirements, assess applicability of mathematical tools and comprehend fundamental aspects of system and subsystem performance. (Current BAA and System Concept Definition research activities fall into this category.)
  - Proof-of-Principle Testing—conducted to demonstrate that the proposed technology is feasible and to verify the applicability of analytical tools and principles. Testing may be conducted with reduced fidelity hardware and at suitable scales to demonstrate fundamental phenomena under investigation.
- System Requirements Review (SRR)—a formal review to ensure that system requirements have been completely and properly identified.
- System Concept Design (SCD) Phase—additional analyses including the development of simulation capabilities, subsystem development tests pointing towards defining a system configuration which meets top level requirements.
- System Design Review (SDR)—top level system requirements defined.
- Preliminary Design Review (PDR)—system configuration defined but not mature pending additional analyses and tests.
- Detailed Design Phase—continued analysis dictating design specifics, component and subsystem development and development integration tests leading to specific design requirements.

- Development Testing—performed to support design choices and the develop high confidence that the hardware, as designed, will meet the established performance requirements. Testing may be performed at either sub-scale or full-scale depending on the results of analytical studies and the desired degree of confidence in the pertinent scaling laws.

- Critical Design Review (CDR)—final design review prior to release of detailed drawings for fabrication of prototype system elements. Detailed design requirements are all validated by analysis or test. Design changes after this point should be very rare.

- Prototype System Development Phase—final component and subsystem qualification testing, fabrication of components and assembly into subsystems and systems, substantial development of production methods and operational procedures.

  - Subsystem Integration Testing—performed at full-scale to demonstrate interactions between major subsystems leading eventually to full system integration. Validation of all subsystem performance requirements is accomplished.

  - Subsystem Integration Complete (SIC)—system test hardware is in place and checked out ready to begin system testing.

  - Operational Testing—the mature, full-scale prototype system undergoes evaluation in a simulated revenue environment. These simulated revenue environment tests are for the purpose of gathering reliability, maintainability and availability data in addition to continuous evaluation of other system performance parameters.

- Initiation of Operational Capability (IOC)—the system design has been fully tested against all system requirements and is ready to be commissioned for revenue service. Deployment of the system at other sites can be undertaken with only site specific considerations.

Recommended Maglev Development Program Phases—Within this customary system development framework, possible maglev development options have been examined. Figure 3.5-1 lays out a recommended development plan which has been conceived to offer the highest likelihood of successfully developing a national maglev system.

In the system development approach described in Figure 3.5-1, the current BAA and System Concept Definition activities within the NMI are consistent with a basic research phase. Many contractors have been involved in these early studies which have helped to define desired system attributes and explore feasibility of promising subsystem technologies. It is recommended that these studies culminate in a System Requirements Review (SRR) at which point consensus on key system requirements needs to be reached.

The plan then proceeds to System Concept Design (SCD). More detailed studies along with coordinated testing take place in this phase with the focus on the flow down of system requirements to determine appropriate design concepts and requirements for individual subsystems. Because the depth of analysis and testing increases through the SCD phase, it is likely that the number of contractors carried through that phase will be reduced from the large number involved in the BAA and System Concept Definition basic research activities. Typical of large-scale development programs, it is recommended that each contractor be required to develop

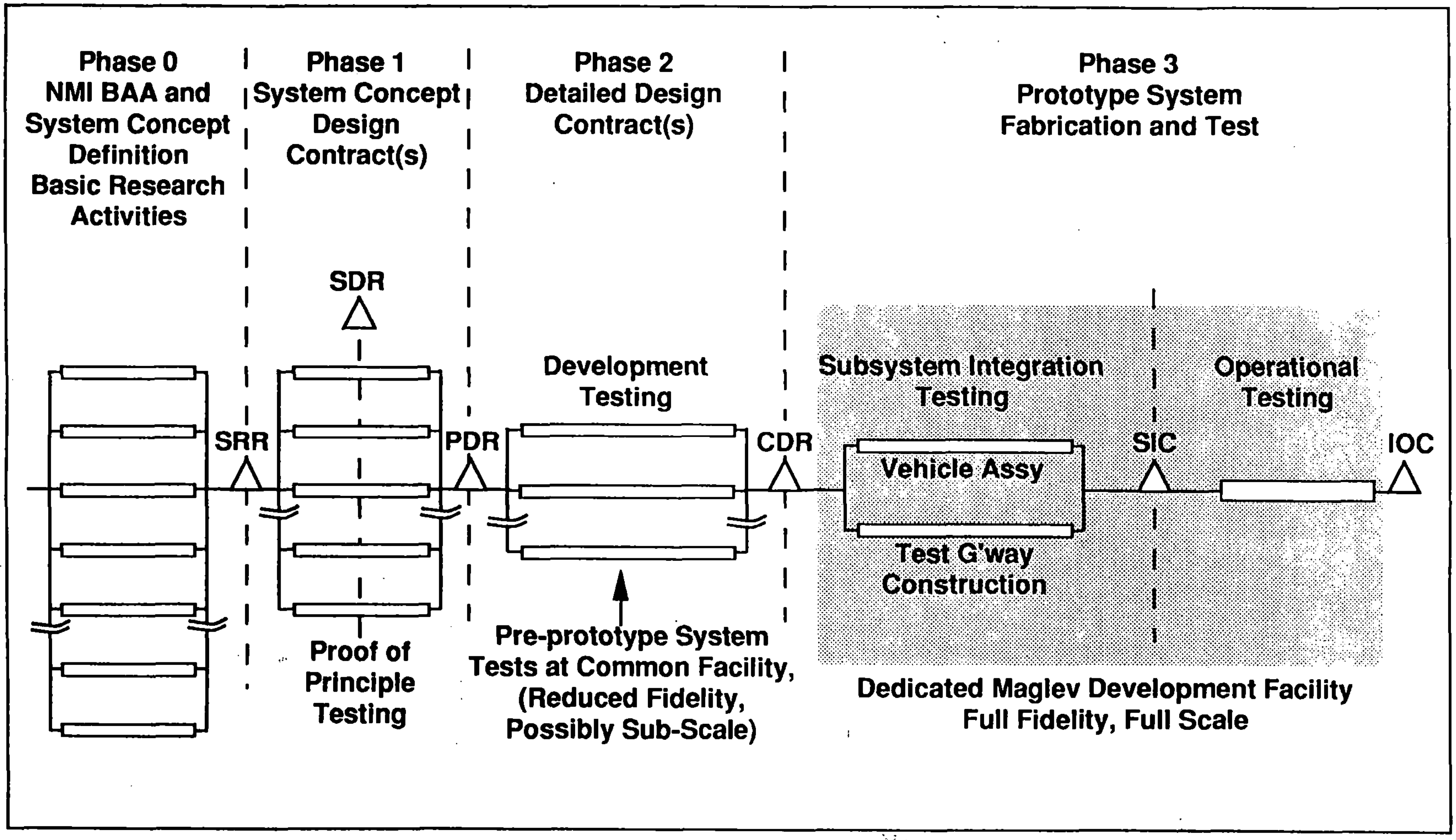

Figure 3.5-1 Recommended Maglev Development Program Phases

an Integrated Analysis/Testing Plan (IATP) which rigorously lays out the justification for and interrelationship of each test and study supporting the contractor's development scenario. The testing emphasis in this phase is on proof-of-principle, complementing the detailed feasibility studies also taking place. Midway through the SCD Phase a System Design Review (SDR) is recommended to establish detailed top level system requirements and scrutinize the integrated analysis and test plans. At the conclusion of the SCD Phase the development plan calls for a Preliminary Design Review (PDR). The purpose of the PDR is to verify that the system configuration selected on the basis of the Basic Research and SCD phases indeed is consistent with the established system requirements even though additional analysis and testing may be pending. The PDR is a milestone at which the decision is made on whether to commit to analysis and testing at an intensity consistent with the Detailed Design Phase.

The Detailed Design Phase is supported by Development Testing. It is desirable to perform as much development testing as possible at subsystem levels in order to defer the higher cost of system level testing to a time when a single, more mature design has evolved. However, in the case of maglev technologies there is such a high degree of interdependence of the major subsystems (levitation, guideway, vehicle etc.) that attacking maglev development testing at the subsystem level is judged to be a high risk approach. The principal risk is that without the benefit of some system level Development Testing a naive choice will be made for the system configuration to carry forward into the Prototype System Development Phase. Carrying out system level Development Testing in the Detailed Design Phase then shifts funding requirements forward. Costs could be contained by the use of scale and reduced fidelity system development tests. For example, a vehicle might preserve mass distribution and structural stiffness fidelity but not aero-shape, assuming aerodynamic effects have been established as being of secondary importance. In addition, costs could be controlled by limiting the number of contractors funded in parallel during the Detailed Design Phase (see Figure 3.5-1). The Detailed Design Phase leads to the Critical Design Review (CDR) milestone. CDR is a rigorous audit of design attributes and performance against the system and derived subsystem requirements. A successful CDR is required prior to releasing detailed drawings for acquisition or fabrication of prototype hardware.

The recommended sequence of studies, tests and reviews is laid out to reduce as much as possible the need to undergo design changes once into the Prototype System Development Phase. Changes at that stage tend to produce significant cost and/or schedule overruns. Prototype system development is divided into two stages. During the early stage, Subsystem Integration Testing is conducted with full-scale, full fidelity hardware. As development proceeds, more and more subsystems are integrated together leading to full system testing capability. Figure 3.5-1 indicates that vehicle assembly and testing can be carried out in parallel with the construction of the guideway. For example, a full-scale, full fidelity prototype vehicle could be assembled and subjected to dynamic excitation representing expected guideway interaction forces and displacements even before guideway construction is completed if a facility such as the Vertical Test Unit at the Transportation Test Center (TTC) were employed. At the Subsystem Integration Complete (SIC) milestone, the second stage of the Prototype System Development Phase begins, which is the first opportunity for full-scale, full fidelity, system level Operational Demonstration Testing. This final stage of testing is devoted to 1) verifying that each aspect of system performance meets the controlling requirement and 2) collecting data to support eventual revenue operation (e.g. reliability, maintainability and availability records).

It is important to note the recommendation to conduct the Prototype System Development Phase at a dedicated government facility. An alternative is to conduct that testing in a future revenue setting. Although such an alternative holds the promise of fielding the first revenue system in a shorter period, it has been judged to entail an untenable degree of risk. There is an inherent pressure in such an alternative scenario to curtail the acceptance and commissioning tests prematurely. The expediencies are to bring the system to revenue status and end disruptions to other infrastructure at the earliest juncture. Nothing would be more detrimental to maglev implementation than to have an accident or unreliable service resulting from premature commissioning. The additional cost and schedule time associated with the dedicated prototype development facility are considered to be offset by the reduction in risk exposure in eventual revenue operations and the value of the dedicated facility as a test bed for future enhancements in maglev technologies.

With the recommended development option as a baseline, the Test Requirements Analysis Team has made a preliminary determination of the division of risk mitigation between analysis and test and the designation of the program phases during which those activities would take place. The relationship between analysis and tests and the preliminary phasing is presented in Table 3.5-1. Table 3.5-2 is included as a convenience in identifying the risk item numbers used in Table 3.5-1. Scope and facilities for the identified tests are discussed in Sections 3.5-2, 3.5-3 and Appendix C.

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 for the required testing and
- Engineering judgment.

The Test Requirements Analysis Team also determined the appropriate phase in the development program 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.

Not all identified risks will ultimately require test for risk mitigation. Some risks are mutually exclusive. Once an option has been selected, testing of competing options can be eliminated. Other tests may be eliminated on the basis of favorable analytical findings.

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

	Phase 1		Phase 2		Phase 3		
	System Concept Design		Detailed Design		Subsystem Integration		Operational
Risk Type	**Analyses**	**Tests**	**Analyses**	**Tests**	**Vehicle Tests**	**G'way Tests**	**Tests**
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

Optional Maglev Development Program Phases—The recommended development option represents a minimum risk approach. As has been recognized earlier in this section, it is possible to gain cost and schedule advantages in return for higher development risk. Figure 3.5-2 illustrates an optional development plan. Through the Detailed Design Phase there are no differences to the recommended plan. The optional development plan, however, calls for the Prototype System Development to take place in a revenue setting. Such a plan would be to 1) construct the first segment of a revenue guideway system, 2) use it for the Subsystem Integration and Operational Demonstration Testing, and then at the completion of that testing, 3) turn the guideway and commissioned vehicles over to the revenue operations authority. Again the risk of such an approach derives from the inherent expediencies for the earliest commissioning. A second area of risk with conducting the prototype phase in a revenue setting is that difficulties encountered will be magnified as a result of closer public scrutiny which could erode public confidence and acceptance of maglev.

ISTEA Based Maglev Development Program Phases—Figure 3.5-3 illustrates the ISTEA plan and the relationship of its provisions to the typical development phases discussed in this section. It departs from the recommended plan in two important respects. First, within the constraints of the ISTEA provisions, the selection of the system to be carried into the prototype development phase will likely be made without the benefit of significant system level testing. Analysis of the funding levels of ISTEA indicates that it would not likely cover costly construction of vehicle/guideway test facilities at each of the three detailed design phase contractors. Thus, there is the risk that the one system singled out for prototype development on the basis of limited performance testing proves to be unsatisfactory as prototype system testing proceeds. The second risk corresponds to the same issue identified with the optional plan above in that the prototype phase is targeted for a revenue setting.

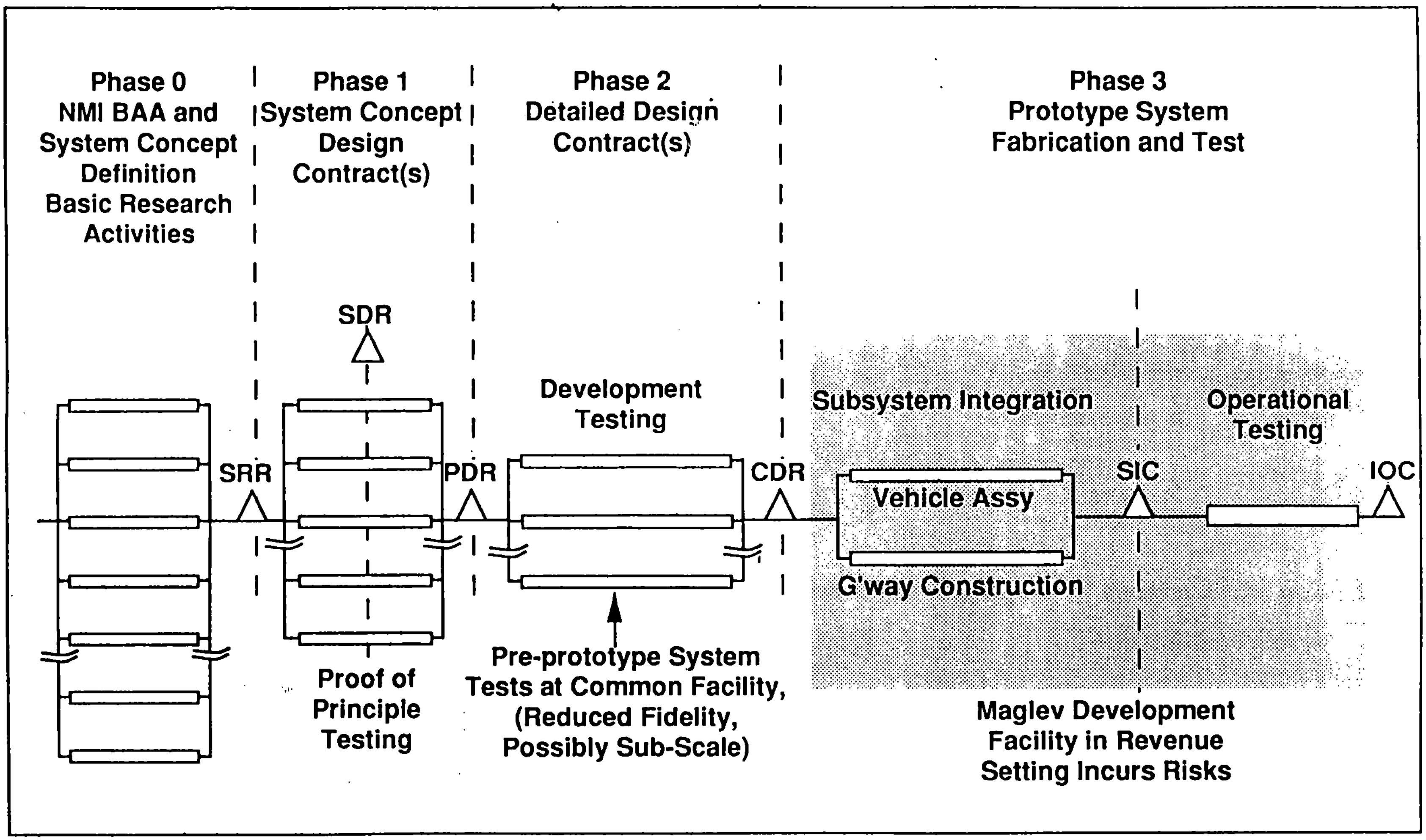

Figure 3.5-2 Optional Maglev Development Program Phases

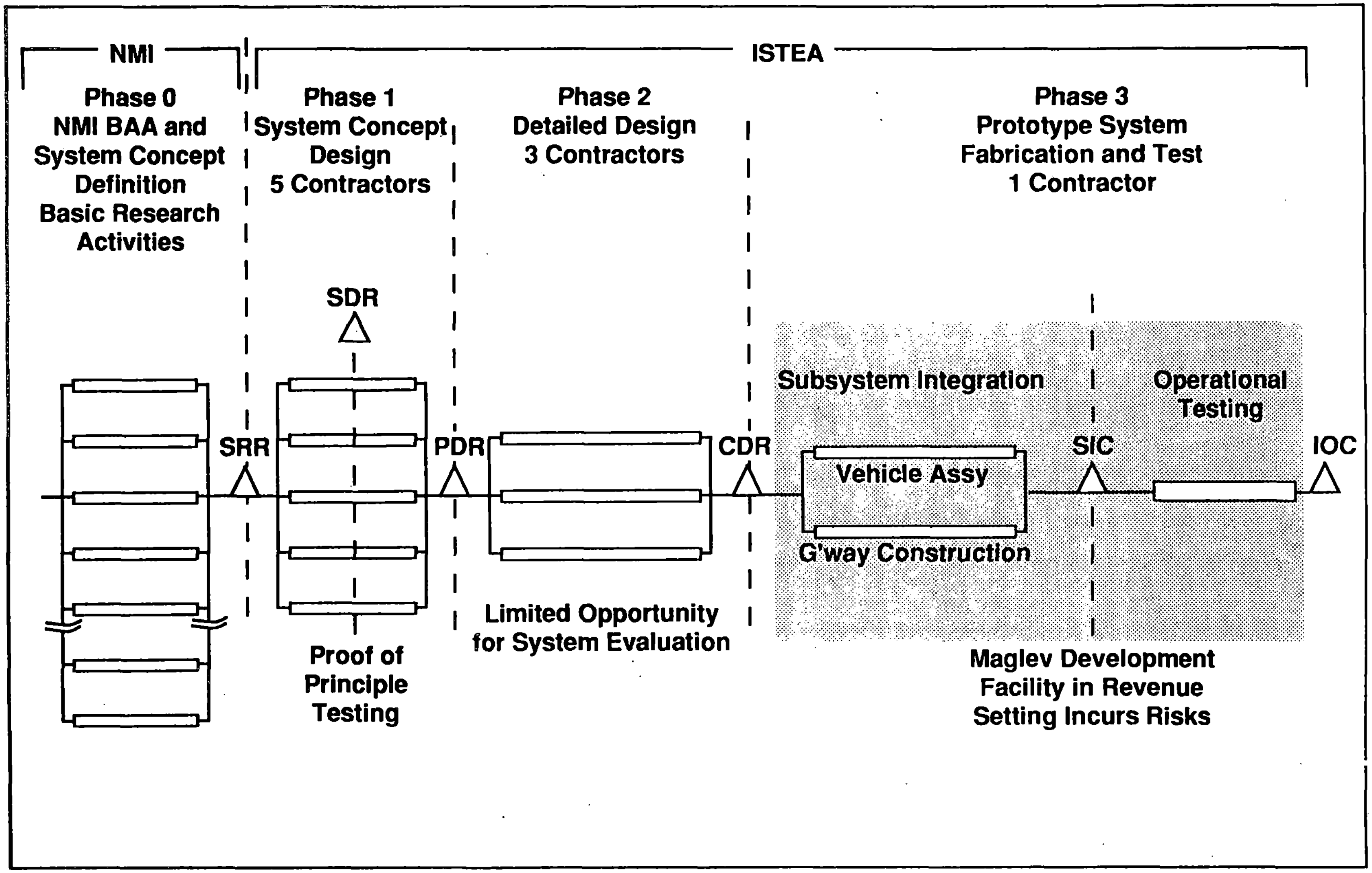

Figure 3.5-3 ISTEA Based Maglev Development Program Phases

3.5.2 Development of Test Scope Data Sheets

As a result of the previously discussed risk assessment, specific tests to mitigate the risks were identified. Appendix C contains Test Scope Data Sheets for all tests identified. The data sheets provide top-level information required to build the point-of-departure test plan and facilities strategy. Each candidate test was assessed to determine at which phase of the development program the test should be conducted to most effectively mitigate the risk and provide design and system integration support. The scope of each test was determined through identification of the potential test conductor(s), description of the test article, the test objectives and facility requirements. Each data sheet also provides a brief description of the candidate test and identifies any related analyses. This approach to defining recommended tests provides a "building block" approach to avoid duplication of effort and enables a systematic evolution in the development process.

The Test Scope Data Sheets are keyed to the applicable risks by the identifiers at the top of each sheet. Each identifier indicates the applicable risk category and the risk number(s) as listed in Table 3.5-2 as well as the development phase during which the test is to be conducted. Appendix C contains a detailed guide to using the Test Scope Data Sheets.

Table 3.5-1 was used to facilitate the identification of tests and analyses to afford risk mitigation in a timely manner. The time phasing of risk mitigation is based primarily on the risk severity and the effects on the system development program if the risk is not addressed early in the design stage. As Table 3.5-1 indicates, a significant number of risks can be assessed through analysis methods, particularly early in the development program when little hardware is available to support test activities. In some cases, such as risks associated with aerodynamics, analysis methods have been refined to the extent that testing is not necessary until final system validation. In other cases, such as risks categorized as dynamics risks, a fully integrated plan of analysis combined with test is essential. Analysis is often necessary in order to identify critical design characteristics before fabrication of a test article is possible. Math models are developed to predict responses to test environments prior to conduct of the test. Test results are then used to refine models and modify assumptions. Hence, an iterative analysis/test program evolves. Recognition of this process is reflected in the 'Related Analysis' section of the Test Scope Data Sheets included in Appendix C.

As indicated in the Test Scope Data Sheets, one test can often be designed to mitigate multiple risks. Inherently, multiple risks within a single risk type can be mitigated through one test. It is also true that, as the development program progresses and components can be combined to form sub-assemblies and sub-assemblies can be combined to form sub-systems, the ability to combine test activities is greatly enhanced. Through careful integration of the development process, various component and sub-assembly contractors can combine efforts to more effectively accomplish their respective test activities.

The Test Scope Data Sheets included in Appendix C were developed to reflect the recommended program time phasing as shown in Figure 3.5-1. As the program development plan evolves, it is recommended that participating contractors develop additional and/or modify the Test Scope Data Sheets to schedule risk mitigation activity as early in the program as possible, particularly for the high severity risks.

Prior to the Operational Demonstration Testing Phase, all risks have been mitigated at the component, sub-assembly and/or subsystem level and all that remains is to verify system operation. Therefore, one comprehensive test will be planned to verify that all risks have been sufficiently mitigated and system integrity meets all requirements. Since the planning and conduct of such a test is system concept- and site-specific, it is not possible to prepare a Test Scope Data Sheet to address the Operational Demonstration Test activity at this time. However, it is recommended that each SCD contractor prepare such a data sheet unique to the contractor's proposed concept.

3.5.3 Point-of-Departure Facilities Strategies

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. Based on the risks identified, the multiple potential concepts currently under development by the System Concept Definition contractors and the experience of the investigators in this study it has been concluded that the necessary facilities for the successful development of a national maglev system can be grouped into the following categories:

- Equipment Development/Supplier In-house Capabilities
- Proposed Sub-Scale Subsystem/System Capabilities
- Existing Full-Scale Subsystem/System Capabilities
- Supplementary Facilities
- Recommended Upgrades To Full-Scale Subsystem/System Capabilities

Equipment Development/Supplier In-house Capabilities — It has been determined that hardware and software developers and suppliers of components and subassemblies with an interest in participation in the development of a national maglev system have the necessary in-house manufacturing and testing capabilities to deliver fully qualified equipment to the subassembly and subsystem level. In general, the suppliers of applicable components or subassemblies have some or all of the laboratories for the evaluation of the following:

- Composites and Protective Coatings
- Chemical Technology
- Cryogenic and Vacuum Systems
- Electrical and Power Systems
- Failure Analysis
- Materials Analysis
- Microelectronics
- Metallography
- Materials
- Structures
- Vibration
- Shock

Further, many suppliers expressed the willingness to make the appropriate capital investment for equipment and tooling necessary to accommodate unique requirements associated with maglev system applications.

Proposed Sub-Scale Subsystem/System Capabilities — 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.

A facility like that proposed by Argonne National Laboratory, if constructed, could 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 deflections much less than typical bridge construction guidelines (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 strategies 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-tuning 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.

Existing Full-Scale Subsystem/System Capabilities — During the period of 1970 through 1980 the Federal Railroad Administration (FRA) sponsored the development of a Transportation Test Center (TTC) for the purpose of assisting in research and development of both conventional rail and advance ground based transportation systems. The TTC, located on 52 square miles of open land near 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 is one such facility and houses the following:

- Vibration Test Unit (VTU) — Capable of recreating the dynamic effects of perturbed track on a moving vehicle. Consists of 12 electrohydraulic 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 catenary support. A significant amount of TTC land space is undeveloped, permitting construction of straight and curved guideway segments of sufficient length to conduct full-scale 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.

Supplemental Facilities — 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 Laboratories — 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.

Full-Scale Subsystems/Systems Capabilities Upgrades — At this time it cannot be determined if the final selected option will use electromagnetic (attractive) or electrodynamic (repulsive) techniques for the generation of levitation and guidance forces. In the event that the electrodynamic technique is selected for the final product, consideration should be given to the construction of a full-scale test guideway given that this technique requires the vehicle to attain a velocity of between 18 to 27 m/s (40 to 60 mph) just to become levitated. This test guideway should be of sufficient length to allow for 1) the acceleration to maximum operating velocity of approximately 130 m/s (300 mph), 2) operation for a finite distance at maximum velocity and 3) to accommodate deceleration to a normal stop. This type of facility would allow for the critical evaluation of running gear performance during the approach to full levitation heights and emergency braking events. Further, all operational and safety systems could be clinically evaluated and modification incorporated and re-evaluated prior to delivery to a revenue environment.

It is recognized that a full-scale facility of this type represents a considerable expense to the development of a national maglev system. However, the success of any system is highly dependent on consumer perception of the reliability and safety of such a system. The conduct of first time system testing in a revenue environment represents a high risk for decreasing the public confidence in the event that early test results are less favorable than expected, minor malfunctions occur in a "first time out " situation or schedule delays arise due to component maintenance or replacement. Although these adverse events are all normal to the activation of a system, the possibility of undue or distorted publicity, focused on them, would lead to misperceptions on the part of future users and erode support for continuing funding actions at the federal, state and local levels. The overall expense can be somewhat mitigated by locating such a facility at the TTC which already has considerable infrastructure in place.

4.0 CONCLUSIONS

Literature Research—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 following:

- Transportation Test Center
- CIGGT
- National Laboratories (Argonne, Brookhaven and Oak Ridge)
- Langley Research Center
- Lincoln Laboratories
- MIT
- Draper Laboratories

Although several pertinent foreign publications were identified, primarily German in origin, no translations of the documents were located. Translated abstracts indicate that much of the identified foreign literature would be valuable in formulating a maglev development program in the United States.

Industry Expert Interviews—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—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 beyond the basic research phase. 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. Other operational concepts foresee maglev competing against short-hop air travel in more of a line-haul mode with high speeds, infrequent stops and longer headways. In order to accurately discriminate between competing system design approaches, one consistent operations concept must be defined no later than the beginning of the detailed design phase of development.

Risks—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.

The risk mitigation approach is critical to the success of the maglev development program. Risk mitigation methods include analysis, demonstration, similarity and tests. The careful integration of testing and analysis results in a timely and cost effective system development program.

Development Program Planning—The customary timeframe for accomplishing system development includes the following phases:

- Basic Research Phase during which analytical studies and some preliminary proof-of-principle tests are conducted. This phase concludes with the System Requirements Review.

- System Concept Design Phase during which more detailed analyses occur including development simulation capabilities. Definitive proof-of-principle and other subsystem development tests also take place during this phase, leading toward definition of a system configuration in compliance with top level requirements. This phase includes the System Design Review and concludes with the Preliminary Design Review.

- Detailed Design Phase during which continued analysis leads to design specifics. Development tests also take place during this phase. The Critical Design Review occurs at the end of the Detailed Design Phase.

- Prototype System Development Phase during which two activities take place which bring the system to a ready to be commissioned status. Full-scale Subsystem Integration Testing begins during this phase. Major subsystems are successively integrated leading eventually to full system integration. This phase concludes with Operational Testing of the complete system.

While alternatives to this development structure offer the possibility of a shorter development cycle, cost increase is possible due to increased risk since empirical evaluation of components and subsystems is decreased in the alternatives.

Test and Facilities Planning—Specific tests to mitigate risks identified during the course of the literature search and the interview of industry sources have been delineated and are included as Test Scope Data Sheets in Appendix C. In structuring these tests it was concluded that multiple risks could be mitigated by a single test configuration, thereby establishing the possibility of reducing costs and schedule time. In addition, it can be concluded that further cost and schedule savings can be gained by the conduct of mathematical model validation tests at the sub-scale level early in the development program. Properly validated models could then be used instead of the subsystem testing (acoustic environments for example) in order to achieve sufficient confidence to proceed directly to full-scale demonstration testing.

With regard to facilities that may be required to implement the development of a national maglev system, it was determined that sufficient capacity exists within the industry to develop and provide components and subassemblies associated with the maglev concepts. However, it was found that facilities necessary to properly evaluate prototypes at the subsystem and system level at either reduced-scale or full-scale do not exist. However, the extensive design work performed by Argonne National Laboratory for the construction of an intermediate size development facility represents a significant step in the definition of an appropriate subsystem/system level evaluation facility. No efforts were identified during this study that were directed toward the definition of requirements and design or implementation approach to full-scale development test facilities.

5.0 RECOMMENDATIONS

Literature Research—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.

Architecture—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 accurately discriminate between competing system designs. Further, each competing contractor should be required to identify a product structure consistent with the concept under development.

Risks—Recommendations as to the specific tests and analyses are as listed in Table 3.5-1. It is recognized that Table 3.5-1 will require a significant amount of modification and expansion as the program develops throughout Phase 1 and 2. Accordingly, it is recommended that this modification and expansion task be an integral part of the statement of work for the contractors associated with the maglev system development program. Maglev system development program 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.

Test and Facilities Planning—As the maglev program plan evolves, it is recommended that participating contractors build upon the Test Scope Data Sheets provided in Appendix C by developing additional test requirements as more specific designs evolve and further risks are identified. With regard to test facilities, it is recommended that sponsorship for a development test facility be obtained as early as possible such that participating contractors can maximize the utility of such a facility as they progress to their respective CDRs. In addition, it is recommended that a requirements definition and preliminary design study be initiated to define a limited full-scale facility to allow for the evaluation of the final prototype configuration prior to deployment to a revenue environment.

Future Studies and Activities—As a result of this preliminary test planning activity, future studies and activities have been identified which would significantly enhance the development of a national maglev system. Figure 5.0-1 shows the relative timeframes between the recommended future studies and the development program milestones. Recommended studies include the following:

- Expanded risk identification efforts by development contractors. As development of the system progresses, it will be necessary to identify concept- and site-specific risks.
- Conduct of a detailed study to determine which tests can be performed using sub-scale models. It is recommended that such a study be undertaken as soon as practical. Sub-scale testing can offer many advantages with respect to full-scale testing including reduced cost, shortened schedules and relative ease of changing parameter values. Each test or set of tests proposed to mitigate risk should be examined, subsystem by subsystem, to determine whether sub-scale testing is appropriate. An assessment should also be conducted to investigate a range of parameter values required such that full-scale testing becomes prohibitively expensive. Even when all parameters in a test cannot be exactly modeled and it is necessary to use a distorted model, valuable insight can be gained from a model test. Irrelevant parameters can be eliminated from the test program, the range

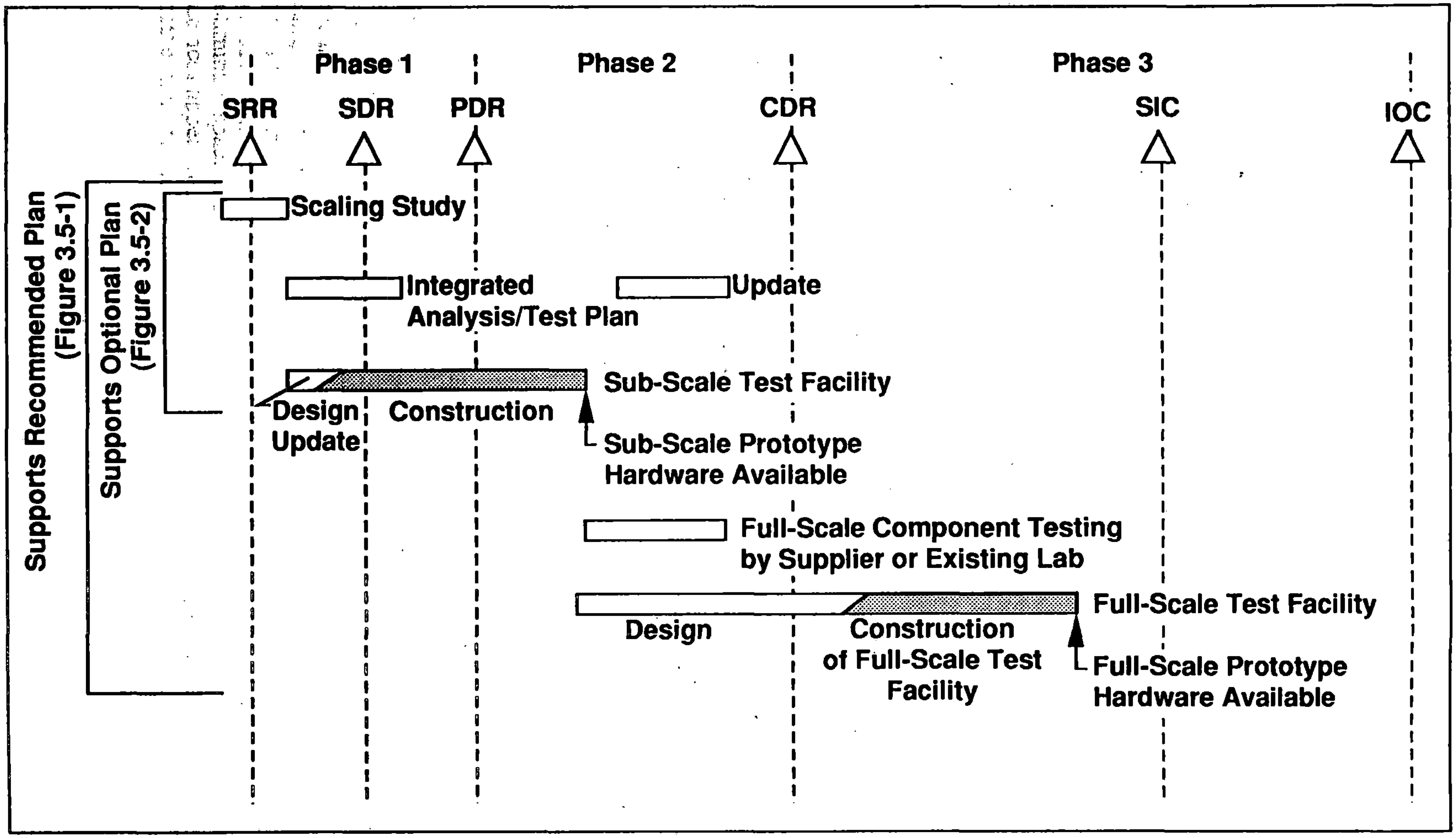

Figure 5.0-1 Test Planning and Facilities Support Element(s) Flow

of values of the test parameters can sometimes be reduced, and the location of sensors can be clarified. Used in this way, sub-scale testing is not a substitute for full-scale testing but becomes an important part of the full-scale test program, providing better focus and thus greater efficiency to the test effort. A preliminary examination of the tests proposed for mitigating risk indicates that noise testing, for example, can be pursued at sub-scale. Acoustic sub-scale testing is well-founded in the experience gained in auditorium design. Application of the principles of similitude to the scaling of tests for the determination of the propagation of noise due to maglev operations should yield a test program that is more cost effective and more comprehensive than any that could be accomplished at full-scale.

- Development of an integrated maglev system analysis and test plan. Due to the importance of the interrelationship between test and analysis in the development of a complex system such as maglev, it is critical that significant attention be directed toward efficiently planning such activity.

- Updated design and construction of a sub-scale test facility as cited in Section 3.5.3, if the scaling study dictates that such a facility is warranted.

- Conduct of a design study directed toward the development of a full-scale national test bed for maglev. It is recommended that this design study be initiated some period of time following the award of Phase 2 contract(s) in order to maximize the information transfer from these contract(s). Further, it is recommended that design activities extend beyond CDR in order to reflect specifics of the final concept selection in the design of the full-scale test facility .

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	LD	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 signaling 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?

APPENDIX C: TEST SCOPE DATA SHEETS

This appendix contains Test Scope Data Sheets for all recommended tests to mitigate program risks identified during this study. The Test Scope Data Sheets are keyed to the applicable risks by the identifiers at the top of each sheet.

Sample

Risk Category	Risk ID(s)	Test Phase(s)
DY	28,29	1,2,3SI

The risk categories have a two digit identifier:

AC - Acoustics
AD - Aerodynamics
AG - Aging
CN - Construction
CT - Control
CR - Cryogenics
DY - Dynamics
ED - Electrodynamics
EM - Electromagnetic Fields
EG - Emergencies
HF - Human Factors
MT - Materials
OP - Operations
PW - Power
PR - Programmatics
RM - Reliability, Maintainability, Availability
SN - Sensors
SW - Software
ST - Structures
WG - Weather and Geotechnical

Risks are identified by IDs in Table 3.5-2 of the report. Test Phases are identified according to the recommended Maglev Development Test strategy as follows:

- Phase 0 - Basic Research
- Phase 1 - System Concept Design
- Phase 2 - Detailed Design
- Phase 3C - Prototype Construction
- Phase 3SI - Prototype Subsystem Integration

TEST SCOPE DATA SHEET

Risk Category	Risk ID(s)	Test Phase(s)
AC	1	2

TITLE: Vehicle Aeroacoustics Test

APPLICABLE RISK(S):
Noise, Startle Effects (1)

DEVELOPMENT PROGRAM PHASE:
Phase 2: Detailed Design

TEST CONDUCTOR:
Vehicle development contractor(s)

TEST ARTICLE DESCRIPTION:
Sub-scale model of maglev vehicle simulating details of external profile.

TEST OBJECTIVES:

1) Measure baseline spectral noise phenomena generated by the following conditions:
   a) Oscillations in the turbulent boundary layer
   b) Flow separation
   c) Base pressure fluctuations
   d) Vehicle discontinuity/protuberance effects

2) Compile data to compare with previously obtained full-scale test/analysis results.
   a) Calibrate analytical models.
   b) Differentiate between aero-induced and structurally re-radiated noise.

TEST DESCRIPTION:
Mount test article in wind tunnel/acoustic chamber. Instrument test article using cluster and/or parabolic microphones. Simulate speeds of test article from 0 to 500 km/hr acquiring noise measurements at speed increments to be established in detailed test plan. May want to look at multi-vehicle effects.

FACILITY REQUIREMENTS:
Low turbulence, anechoic wind tunnel/acoustic chamber.

RELATED ANALYSIS:
Based on vehicle external noise measurements, internal noise levels can be calculated by determining noise attenuation characteristics of vehicle structure and passenger compartment acoustic treatments.

TEST SCOPE DATA SHEET

Risk Category	Risk ID(s)	Test Phase(s)
AG	5	4

TITLE: Guideway Aging Related to Weather and Geotechnical Effects

APPLICABLE RISK(S):
Guideway Misalignment Due to Weather and Geotechnical Effects (5)

DEVELOPMENT PROGRAM PHASE:
Phase 3C: Prototype Construction

TEST CONDUCTOR:
Prototype system developer

TEST ARTICLE DESCRIPTION:
Selected guideway segments subject to varying climatic conditions and site geologies

If possible, blind selection of the guideway segments to be evaluated is desirable so that findings truly represent typical construction rigor, tolerances etc.

TEST OBJECTIVES:
Observe settling behavior of prototype guideway construction techniques

Observe actual diurnal and seasonal temperature and deflection profiles within spans (See Phase 2 Aging)

Observe guideway susceptibility to salt corrosion

TEST DESCRIPTION:
Physical observations of guideway behavior

FACILITY REQUIREMENTS:
Guideway(s) constructed for prototype system(s)

RELATED ANALYSIS AND TESTS:
Phase 1 and Phase 2: Predictions of settling and thermal deflections based on simulation and comparative evaluations with other elevated transportation structures

Phase 3C: Construction Risk Mitigation Evaluation

Phase 3C: Weather and Geotechnical Risk Mitigation Tests

TEST SCOPE DATA SHEET

Risk Category	Risk ID(s)	Test Phase(s)
AG	6,8,10	2

TITLE: Guideway Accelerated Life Test

APPLICABLE RISK(S):
Guideway Degradation Due to Fatigue (6)
Fatigue Failure of Guideway Mounted Aluminum Sheet (8)
Thermal Stress Mismatch of LSM Components Causing Attachment Fatigue (10)

DEVELOPMENT PROGRAM PHASE:
Phase 2: Detailed Design

TEST CONDUCTOR:
Guideway developer with participation of developer of guideway mounted electromagnetic components

TEST ARTICLE(S) DESCRIPTION:
Candidate full-scale guideway span with integrated electromagnetic components

TEST OBJECTIVES:
Subject candidate guideway spans to accelerated loading schedules to investigate useful service life of guideway structure and attachments of guideway mounted components

Separate effects of repeated mechanical loading and thermal cycling

TEST DESCRIPTION:
Support the guideway span according to expected deployment methods

Provide means for repeated cyclic loading together with the option for accompanying thermal loading in appropriate components (eddy current heating in aluminum guideway sheets)

Provide means for inducing accelerated diurnal and seasonal thermal variations

Induce various separate and combined schedules of mechanical and temperature loading cycles

Inspect periodically through the loading schedules for evidence of fatigue, wear, debonding, etc.

FACILITY REQUIREMENTS:
A structural/environmental testing laboratory including:
Reliable cyclic loading equipment and fixturing
Thermal loading equipment, (e.g. resistive heating elements, brine circulation system)

RELATED ANALYSIS:
Investigation of fatigue behavior and other aging phenomena of similar type structures used in other transportation modes (elevated freeway, elevated rail)

TEST SCOPE DATA SHEET

Risk Category	Risk ID(s)	Test Phase(s)
AG	9	2

TITLE: Test of Field Coil Strength

APPLICABLE RISK(S):
Long Term Loss of Coil Field Strength (9)

DEVELOPMENT PROGRAM PHASE:
Phase 2: Detailed Design

TEST CONDUCTOR:
Magnet coil developer(s)

TEST ARTICLE DESCRIPTION:
Operational magnet coil, with appropriate current

TEST OBJECTIVES:
Assess coil field strength as a function of time

TEST DESCRIPTION:
Accelerate life of operational coil, providing operational current at an accelerated rate

FACILITY REQUIREMENTS:
To be determined by contractor

RELATED ANALYSIS:
Predicted life of magnet coil; analysis to determine most effective method of accelerating the simulation of magnet life

TEST SCOPE DATA SHEET

Risk Category	Risk ID(s)	Test Phase(s)
CN	11 thru 14	3C

TITLE: Construction Risk Mitigation Tests

APPLICABLE RISK(S):
Tolerance Build-up in Guideway Construction (11)
Tight Tolerances in Moving Switch Elements (12)
Guideway Manufacture, Assembly and Field Erection (13)
Guideway Positional Adjustability (14)

DEVELOPMENT PROGRAM PHASE:
Phase 3: Prototype Construction

TEST CONDUCTOR:
Prototype system developer

TEST ARTICLE DESCRIPTION:
Selected guideway segments subject to varying climatic conditions and site geologies

If possible, blind selection of the guideway segments to be evaluated is desirable so that findings truly represent typical construction rigor, tolerances etc.

TEST OBJECTIVES:
Evaluate representative as-built guideway construction tolerances, switch performance and guideway adjustability schemes

Evaluate representative guideway manufacture, assembly and field erection costs, learning curve trends, economies of scale etc.

TEST DESCRIPTION:
Phase 3C prototype guideway construction will be an opportunity to collect data on actual construction costs and construction quality as represented by as-built tolerances

FACILITY REQUIREMENTS:
Guideway(s) constructed for prototype system(s)

RELATED ANALYSIS:
Phase 1 and Phase 2: Construction Risk Analyses (tolerances, costs, adjustability, etc.)

Phase 3C: Aging Risk Mitigation Tests

Phase 3C: Weather and Geotechnical Risk Mitigation Tests

TEST SCOPE DATA SHEET

Risk Category	Risk ID(s)	Test Phase(s)
CR	17	1,2

TITLE Test of Thermal Effects on Levitation Clearance (EDS)

APPLICABLE RISK(S):
Thermal Effects of Not Maintaining Constant Levitation Clearance (EDS) (17)

DEVELOPMENT PROGRAM PHASE:
Phase 1: System Concept Definition

Phase 2: Detailed Design

TEST CONDUCTOR:
Levitation system subcontractor for EDS

TEST ARTICLE DESCRIPTION:
Phase 1: Guideway simulator (possibly rotating wheel) and superconducting coil

Phase 2: Sub-scale mock-up of guideway and coil

TEST OBJECTIVES:
Identify thermal effects on levitation system ability to maintain acceptable clearances. Identify temperature threshold for magnet quench.

TEST DESCRIPTION:
Phase 1: Suspend coil above rotating wheel. Power coil at operating current and adjust velocity by changing speed of rotating wheel. Monitor simulated velocity, gap between wheel and coil, force required to maintain gap and temperature of coil. Identify variations in clearance with respect to velocity and coil temperature. Continue operation until coil quench occurs. (Note: Efforts should be made to control temperature of rotating wheel thereby precluding quench due to test set-up.)

Phase 2: Operate sub-scale coil on sub-scale guideway, monitoring same parameters as in Phase 1 test activity.

FACILITY REQUIREMENTS:
Rotating wheel of sufficient size to simulate operational speeds. Temperature-controlled.

RELATED ANALYSIS:
Thermal modeling of coil should be accomplished prior to test. Test results should be used to validate model.

TEST SCOPE DATA SHEET

Risk Category	Risk ID(s)	Test Phase(s)
DY	18,20	2
PR	62	3SI

TITLE: Vehicle Control at High Speeds

APPLICABLE RISK(S):
High Speed Turnouts(18)
High Speed Intolerance to Control Failures(20)
Control System Verification and Validation(62)

DEVELOPMENT PROGRAM PHASE:
Phase 2: Detailed Design

Phase 3; Prototype Subsystem Integration

TEST CONDUCTOR:
Vehicle and Control System Contractors

TEST ARTICLE DESCRIPTION:
Vehicle mass and stiffness simulator/candidate control system.
Sub-scale model of vehicle is preferred.

TEST OBJECTIVES:
Determine control capabilities of vehicle at high speeds, assessing vehicle dynamic response and control system interaction requirements.

TEST DESCRIPTION:
Simulate high-speed operation of vehicle either with rotating drum or on sub-scale guideway.
Measure dynamic response of vehicle to control system inputs.

FACILITY REQUIREMENTS:
Sub-scale vehicle and guideway or rotating drum to simulate high-speed operation.

RELATED ANALYSIS:
Analyze dynamic response of vehicle to lateral accelerations using math model.

TEST SCOPE DATA SHEET

Risk Category	Risk ID(s)	Test Phase(s)
DY	19,21,22 23,26,27	1,2,3SI

TITLE: Vehicle Dynamics Simulation

APPLICABLE RISK(S):
Vehicle-Guideway Interface Tolerances (EMS)(19); Control of Vertical Dynamics(21); Dynamic Linkage between Vertical and Longitudinal Motion - Surging(22); Control of Lateral Dynamics(23); Cross-wind and Headwind Effects on Vehicle Dynamics (Incl. Ride Comfort)(26); Active Suspension Systems(27); Provide Satisfactory Passenger Ride Comfort - Vibrations(44)

DEVELOPMENT PROGRAM PHASE:
Phase 1: System Concept Definition
Phase 2: Detailed Design
Phase 3: Prototype Subsystem Integration

TEST CONDUCTOR:
Vehicle design contractor in coordination with suspension sub-contractor

TEST ARTICLE DESCRIPTION:
Phase 1: Low fidelity vehicle mass simulator with suspension stiffness/damping simulator.

Phase 2: Low fidelity vehicle mass and stiffness simulator with high fidelity suspension system - possibly sub-scale prototype.

Phase 3: High fidelity vehicle prototype with operational suspension system.

TEST OBJECTIVES:
Evaluate response of vehicle to guideway perturbations and periodic dynamic environments due to guideway support system. Assist in suspension and control system design. Evaluate ride comfort characteristics of coupled systems.

TEST DESCRIPTION:
Phases 1, 2 and 3: Simulate vertical, lateral and longitudinal dynamic environments imposed on suspension system through guideway perturbations and support system. Measure acceleration responses on suspension soft side due to vibration environments.

FACILITY REQUIREMENTS:
Phase 1: Dynamic test facility including shakers capable of imposing low frequency random and sinusoidal vibration levels to simulate guideway-imposed environments.
Phase 2: Same as Phase 1 or sub-scale guideway.
Phase 3: Sub-scale or full-scale guideway.

RELATED ANALYSIS:
Dynamic analysis of guideway-imposed environments to determine coupled random/sinusoidal environments for simulation in test. Modal analysis of vehicle to determine structural modes and design of suspension system.

TEST SCOPE DATA SHEET

Risk Category	Risk ID(s)	Test Phase(s)
DY	25	2

TITLE: Vehicle Pre-Lift-Off Dynamics Test

APPLICABLE RISK(S):
Operational Use of Landing Gear(25)

DEVELOPMENT PROGRAM PHASE:
Phase 2, Detailed Design

TEST CONDUCTOR:
Vehicle design contractor

TEST ARTICLE DESCRIPTION:
Vehicle mass and stiffness simulator. Sub-scale model is preferred.

TEST OBJECTIVES:
Evaluate response of vehicle to guideway-induced environments while vehicle is interfacing with guideway (at low speeds).

TEST DESCRIPTION:
Simulate guideway environments on vehicle and monitor dynamic response of vehicle.

FACILITY REQUIREMENTS:
Dynamic test facility including shakers capable of imposing low frequency random and sinusoidal vibration levels to simulate guideway-imposed environments.

RELATED ANALYSIS:
Modal analysis of vehicle. Dynamic analysis of guideway-imposed environments.

TEST SCOPE DATA SHEET

Risk Category	Risk ID(s)	Test Phase(s)
DY	28,29	1,2,3SI

TITLE: Tilt System Testing

APPLICABLE RISK(S):
Active/Passive Tilt Demands on Lateral Guidance(28)
Active Tilt Systems(29)

DEVELOPMENT PROGRAM PHASE:
Phase 1: System Concept Definition

Phase 2: Detailed Design

Phase 3: Prototype Subsystem Integration

TEST CONDUCTOR:
Vehicle design contractor in conjunction with tilt system sub-contractor

TEST ARTICLE DESCRIPTION:
Phase 1: Low-fidelity vehicle simulator with candidate tilt systems.

Phase 2: Mass and stiffness simulated vehicle with preferred tilt system.

Phase 3: Sub-scale prototype of vehicle with tilt system

TEST OBJECTIVES:
Evaluate tilt system responses due to predicted lateral accelerations.

TEST DESCRIPTION:
Simulate guideway lateral accelerations on vehicle and monitor response of candidate tilt systems.

FACILITY REQUIREMENTS:
Structural test facility, preferably with centrifuge test capabilities. For phase 3, requires guideway.

RELATED ANALYSIS:
Dynamic analysis of vehicle due to lateral accelerations.

TEST SCOPE DATA SHEET

Risk Category	Risk ID(s)	Test Phase(s)
EM	34 thru 38	1,3SI

TITLE: Electromagnetic Field Testing

APPLICABLE RISK(S):
Biological Effects of Electromagnetic Fields(34)
Active Cancellation of Magnetic Fields(35)
Mass Required to Mitigate Biological Effects of Electromagnetic Fields(36)
Electromagnetic Compatibility of On-Board and Encountered Systems(37)
Fidelity of Flux Simulations(38)

DEVELOPMENT PROGRAM PHASE:
Phase 1: System Concept Definition

Phase 3: Prototype Subsystem Integration

TEST CONDUCTOR:
Vehicle design contractor in conjunction with magnet coil sub-contractor

TEST ARTICLE DESCRIPTION:
Phase 1: Operational magnet coils

Phase 2: Mass and stiffness simulated vehicle with preferred tilt system.

Phase 3: Sub-scale prototype of vehicle with operational magnet coils

TEST OBJECTIVES:
Measure EM fields due to operation of magnet coils. Determine effects of measured levels on humans and on-board and wayside communications and control systems.

TEST DESCRIPTION:
Operate coils at operational current. Measure emitted EM fields. Upon development of vehicle prototype, measure internal and external EM fields.

FACILITY REQUIREMENTS:
Facility capable of permitting uncontaminated measurements of EM levels. During phase 3, requires guideway equipped with wayside EM measuring capabilities.

RELATED ANALYSIS:
Predictions of EM field levels.

TEST SCOPE DATA SHEET

Risk Category	Risk ID(s)	Test Phase(s)
ED	39	1

TITLE: Electromagnetic Levitation Gap Controllability Test

APPLICABLE RISK(S):
Maintenance of Levitation Gap (39)

DEVELOPMENT PROGRAM PHASE:
Phase 1: Concept Definition

TEST CONDUCTOR:
Levitation subsystem developer(s)

TEST ARTICLE DESCRIPTION:
Sub-scale levitation magnet and guideway sheet or coil elements—rotating wheels have been effectively used

TEST OBJECTIVES:
Provide proof-of-principle type demonstrations of levitation and levitation control schemes

Provide performance data for comparison to analytical predictions

TEST DESCRIPTION:
EDS type systems require rotating wheel, EMS systems can use stationary system with shaker drive for introducing disturbances

Levitation control system is evaluated for ability to maintain appropriate levitation gap in response to simulated guideway or aero disturbances

FACILITY REQUIREMENTS:
Rotating drum (EDS) or static test fixture with electrodynamic shakers (EMS)

RELATED ANALYSIS:
Phase 1 Electrodynamics, Dynamics and Aerodynamics

TEST SCOPE DATA SHEET

Risk Category	Risk ID(s)	Test Phase(s)
ED	39	2

TITLE:
Electromagnetic Levitation Gap Controllability Test (Phase 2)

APPLICABLE RISK(S):
Maintenance of Levitation Gap (39)

DEVELOPMENT PROGRAM PHASE:
Phase 2, Detailed Design

TEST CONDUCTOR:
Levitation subsystem developer(s)

TEST ARTICLE DESCRIPTION:
Sub-scale levitation magnet and guideway sheet or coil elements

Higher fidelity and/or larger scale than similar Phase 1 test

TEST OBJECTIVES:
Obtain performance data to support detailed levitation subsystem design

Provide performance data for continuing refinement of analytical predictions

TEST DESCRIPTION:
EDS type systems require moving system, EMS systems can use stationary system with shaker drive for introducing disturbances

Levitation control system is evaluated for ability to maintain appropriate levitation gap in response to simulated guideway or aero disturbances

Levitation gap variations, stability, power losses associated with gap variation are investigated

FACILITY REQUIREMENTS:
A large geotechnical centrifuge machine or a large-scale dynamometer may be adaptable for use as a test bed

Static test fixtures can be used for EMS evaluations

RELATED ANALYSIS:
Phase 1 and Phase 2 Electrodynamics, Dynamics and Aerodynamics

TEST SCOPE DATA SHEET

Risk Category	Risk ID(s)	Test Phase(s)
ED	39,40	3SI

TITLE: Levitation Subsystem Performance Tests

APPLICABLE RISK(S):
Maintenance of Levitation Gap (39)
Superconducting Magnet Quench Management (40)

DEVELOPMENT PROGRAM PHASE:
Phase 3: Prototype Subsystem Integration

TEST CONDUCTOR:
Prototype system developer(s)

TEST ARTICLE DESCRIPTION:
Prototype vehicle/guideway system—can be full-scale, low fidelity or possibly high fidelity sub-scale (e.g. the Argonne National Laboratory proposed test facility)

TEST OBJECTIVES:
Demonstrate prototype maturity of levitation control system, obtaining pertinent performance data on gap variation, efficiency, stability, etc.

Demonstrate graceful response to superconducting magnet quenches— shut down, heat management etc.

TEST DESCRIPTION:
Operational evaluation of levitation subsystem of the prototype vehicle/guideway system

FACILITY REQUIREMENTS:
See test article description

RELATED ANALYSIS:
Phase 1: Electrodynamics, Dynamics, Aerodynamics and Cryogenics

TEST SCOPE DATA SHEET

Risk Category	Risk ID(s)	Test Phase(s)
ED	42	2

TITLE: Levitation Subsystem Eddy Current Loss Test

APPLICABLE RISK(S):
Eddy Current Losses in Magnets (42)

DEVELOPMENT PROGRAM PHASE:
Phase 2: Detailed Design

TEST CONDUCTOR:
Levitation subsystem developer(s)

TEST ARTICLE DESCRIPTION:
Sub-scale levitation magnet and guideway sheet or coil elements—rotating wheels or drums have been effectively used

TEST OBJECTIVES:
Assess risks associated with time varying magnetic fields resulting in eddy current losses (EDS systems)

Provide performance data for comparison to analytical predictions

TEST DESCRIPTION:
Initiate disturbances to EDS levitation state and observe eddy current losses

FACILITY REQUIREMENTS:
Rotating wheel or drum (EDS), large geotechnical centrifuge or dynamometer may be adaptable for use as a test bed

RELATED ANALYSIS:
Phase 1: Electrodynamics, Dynamics and Aerodynamics

TEST SCOPE DATA SHEET

Risk Category	Risk ID(s)	Test Phase(s)
HF	44,45	1

TITLE: Human Factors:
Provide Satisfactory Passenger Ride Comfort (Lateral Acceleration., Roll, Vibrations) (44)
Passenger Perception of Speed (45)

TEST CATEGORY:
Phase 1: System Concept Definition

TEST LOCATION/FACILITY:
Contractors Facility

TEST CONDUCTOR:
Contractor

TEST ARTICLE DESCRIPTION:
Simulator, may either be a mock-up or computer based.

TEST OBJECTIVES:
Evaluate the preliminary passenger ride comfort requirements. Evaluate human factors issues which affect maglev viability.

TEST DESCRIPTION:
Evaluate the preliminary design requirements against human factors issues such as: passenger ride comfort, visual perceptions (speed), effect caused by lateral acceleration, roll and vibrations, etc. Simulate these design requirements and gather data to validate design concept.

PRETEST REQUIREMENTS:
Consider data already gathered on ride comfort parameters such as evaluations for Metro and AMTRAK passenger ride comfort.

INSTRUMENTATION-DATA REQUIREMENTS:
Measurement of acceleration/deceleration forces.

TEST EQUIPMENT/FIXTURES:
Prototype or simulator of vehicle passenger area.

GFE REQUIREMENTS:
Not determinable at this time.

RELATED ANALYSIS:
Control - Vehicle Collision testing.

TEST SCOPE DATA SHEET

Risk Category	Risk ID(s)	Test Phase(s)
HF	47	3SI

TITLE: Verification of Acceptable Emergency Egress

APPLICABLE RISK(S):
Passenger Emergency Egress

DEVELOPMENT PROGRAM PHASE:
Phase 3: Prototype Subsystem Integration

TEST CONDUCTOR:
Vehicle design contractor and guideway design contractor

TEST ARTICLE DESCRIPTION:
Spatial prototype of vehicle cabin and guideway segment

TEST OBJECTIVES:
Determine acceptable methods for emergency egress from vehicle on guideway.

TEST DESCRIPTION:
Use test and analysis to identify most critical vehicle/guideway attitude for passenger egress.

FACILITY REQUIREMENTS:
Guideway segment in most critical attitude for passenger evacuation.

RELATED ANALYSIS:
Human factors modeling of vehicle and guideway interfaces.

TEST SCOPE DATA SHEET

Risk Category	Risk ID(s)	Test Phase(s)
MT	54	3SI

TITLE: Test of Magnet Fabrication Processes

APPLICABLE RISK(S):
Superconducting Magnet Manufacturing Flaws(54)

DEVELOPMENT PROGRAM PHASE:
Phase 3: Prototype Subsystem Integration

TEST CONDUCTOR:
Magnet sub-contractor

TEST ARTICLE DESCRIPTION:
Operational Magnet

TEST OBJECTIVES:
Verify magnet fabrication process.

TEST DESCRIPTION:
Conduct destructive material testing on operational to identify process improvement actions.

FACILITY REQUIREMENTS:
Materials lab

RELATED ANALYSIS:

TEST SCOPE DATA SHEET

Risk Category	Risk ID(s)	Test Phase(s)
PW	58,59	2

TITLE: Power Transfer Testing

APPLICABLE RISK(S):
Adequate Inductive Power Transfer for Hotel Functions(58)
Efficient Regenerative Braking(59)

DEVELOPMENT PROGRAM PHASE:
Phase 2: Detailed Design

TEST CONDUCTOR:
Vehicle contractor and wayside power contractor

TEST ARTICLE DESCRIPTION:
Candidate power set-up

TEST OBJECTIVES:
Assess ability of power transfer system to adequately provide power for critical operational functions and hotel functions.

TEST DESCRIPTION:
Simulate power system configuration. Apply load on system which represents operational load. Measure system capacity and drain as various operations are introduced.

FACILITY REQUIREMENTS:
Power conditioning and transfer capabilities to be determined by contractor.

RELATED ANALYSIS:
Predicted total power requirements to support operation, including critical operations and hotel functions.

TEST SCOPE DATA SHEET

Risk Category	Risk ID(s)	Test Phase(s)
RM	66 thru 74	3C,3SI

TITLE: Prototype System Effectiveness Tests

APPLICABLE RISK(S):
Reliability, Maintainability and Availability (RMA, 66-74)

DEVELOPMENT PROGRAM PHASE:
Phases 3C and 3SI: Prototype Construction and Subsystem Integration

TEST CONDUCTOR:
Prototype system developer

TEST ARTICLE DESCRIPTION:
Full-scale prototype guideway sections (elevated and at-grade) with prototype vehicle operations

TEST OBJECTIVES:
First opportunity for evaluation of key RMA risks including:
- Guideway elements (modular windings connections, aluminum sheet, etc.)
- Vehicle elements (esp. superconducting magnets and cryo systems)
- Power distribution system elements (power conditioning, vehicle power collection)
- Control system elements (position, velocity sensing, communications)
- Vehicle Health Management (VHM) elements (diagnostics, fault tolerance)

TEST DESCRIPTION:
Compile records on system and component effectiveness—mean time between failures (MTBF), mean time to repair (MTTR), frequency of VHM actions, maturity trends etc.

FACILITY REQUIREMENTS:
Prototype system facility(ies)

RELATED ANALYSIS:
Phase 1 and 2: RMA analyses

TEST SCOPE DATA SHEET

Risk Category	Risk ID(s)	Test Phase(s)
SN	76,77,78	2,3C,3SI

TITLE: Obstruction Detection System Test

APPLICABLE RISK(S):
Obstruction Detection(76); Obstruction Detection False Alarm(77); Obstruction Detection Sensor Effectiveness Under Operating Conditions(78)

DEVELOPMENT PROGRAM PHASE:
Phase 2: Detailed Design
Phase 3: Prototype Construction, Prototype Subsystem Integration

TEST CONDUCTOR:
Phase 2: Sensor contractor(s)
Phase 3: Sensor contractor(s)

TEST ARTICLE DESCRIPTION:
Phase 2: Breadboard/laboratory sensors in laboratory environment.
Phase 3: Prototype sensors installed in representative operating environment.

TEST OBJECTIVES:
Phase 2: Demonstrate and characterize sensor capabilities.
Phase 3: Demonstrate sensor requirements achievable.

TEST DESCRIPTION:
Phase 2: Laboratory/Breadboard equipment will be used to demonstrate and characterize sensor performance in a 'laboratory' environment and in a 'synthesized' environment.
Phase 3: Prototype obstruction sensors will be installed in representative operating environment. Demonstrate that sensor requirements are achievable. Testing in environmental chamber may be desirable.

FACILITY REQUIREMENTS:
Phase 2: Standard electronic laboratory equipment. Specialized synthesizer may be required. Must record sensor responses, instrumented sensor results and provide necessary data to synthesized environment.
Phase 3: Representative operating environment mockup. Test hazards must be introduced and sensor responses recorded.

RELATED ANALYSIS:
Obstruction detection analysis

TEST SCOPE DATA SHEET

Risk Category	Risk ID(s)	Test Phase(s)
SN	79	2

TITLE: Sensor Operations Test

APPLICABLE RISK(S):
Guideway Integrity Sensor Function in High Magnetic Field Environment(79)

DEVELOPMENT PROGRAM PHASE::
Phase 2: Detailed Design

TEST CONDUCTOR:
Sensor development contractor

TEST ARTICLE DESCRIPTION:
Test Breadboard assembly in laboratory environment against magnetically produced field.

TEST OBJECTIVES:
Verify that breadboard assembly works as required in simulated environment. Determine design margins.

TEST DESCRIPTION:
Breadboard Guideway integrity assembly will be tested in laboratory magnetic field and design characteristics confirmed.

INSTRUMENTATION-DATA REQUIREMENTS:
Guideway integrity sensor must be instrumented. Capability to produce high magnetic field.

RELATED ANALYSIS:
Sensor - Guideway Integrity Sensor Function in High Magnetic Field Environment
Phase 1.

TEST SCOPE DATA SHEET

Risk Category	Risk ID(s)	Test Phase(s)
SW	80 thru 82	3SI

TITLE: Software/Hardware Integration Testing

APPLICABLE RISK(S):
Control Software Compatibility(80)
Software Reliability(81)
Adequate Software Test(82)

DEVELOPMENT PROGRAM PHASE::
Phase 3: Prototype Subsystem Integration

TEST CONDUCTOR:
Software Contractor

TEST ARTICLE DESCRIPTION:
Software installed in prototype

TEST OBJECTIVES:
Determine that software and hardware meet requirements when integrated.

TEST DESCRIPTION:
Software/hardware integration testing on the subsystem (prototype).

FACILITY REQUIREMENTS:
Prototype hardware/software available. Other requirements to be determined by contractor.

RELATED ANALYSIS:
Software Reliability.

TEST SCOPE DATA SHEET

Risk Category	Risk ID(s)	Test Phase(s)
SW	83	3SI

TITLE: Control System Test

APPLICABLE RISK(S);
Control System Test Thoroughness and Fidelity(83)

DEVELOPMENT PROGRAM PHASE:
Phase 3: Prototype Subsystem Integration

TEST CONDUCTOR:
Control System development contractor

TEST ARTICLE DESCRIPTION:
Sub-scale Maglev Vehicle and Guideway

TEST OBJECTIVES:
Determine that System and vehicle level control systems meet requirements.

TEST DESCRIPTION:
System will be exercised under an exhaustive set of conditions: normal operational object hazards introduced, component facilities induced, multiple consist interaction, etc.

FACILITY REQUIREMENTS:
Control system inputs and outputs must be recorded for analysis. System states must be recorded. Sub-scale guideway.

RELATED ANALYSIS:
Control System Test Thoroughness and Fidelity

TEST SCOPE DATA SHEET

Risk Category	Risk ID(s)	Test Phase(s)
ST	84 thru 86	2,3C

TITLE: Structural Test of Guideway Construction Methods

APPLICABLE RISK(S):
Non-Magnetic Structural Components in Guideway (EDS) (84)
Propulsion and Suspension Coil Attachment to Guideway (85)
Thermal Loads and Deflection of Guideway Mounted Aluminum Sheet (86)

DEVELOPMENT PROGRAM PHASE:
Phase 2: Detailed Design
Phase 3C: Prototype Construction

TEST CONDUCTOR:
Guideway contractor

TEST ARTICLE DESCRIPTION:
Phase 2: Section of guideway material with attachment mechanisms for propulsion and suspension coil components
Phase 3C: Section of operational guideway, configured for use by vehicle

TEST OBJECTIVES:
Verify integrity of attachments in guideway, investigate use of non-magnetic materials in guideway construction and evaluate effects of thermal loads on guideway integrity.

TEST DESCRIPTION:
During phase 2, subject mechanical attachments to loads predicted for operation. Also conduct thermal testing on aluminum sheets to be mounted on guideway.
During Phase 3C, evaluate the strength of non-magnetic materials used in guideway construction.

FACILITY REQUIREMENTS:
Thermal test chamber, static loads/stress test facilities, operational guideway.

RELATED ANALYSIS:
Conduct stress analysis to verify ability of guideway construction materials and fasteners to withstand predicted loads. Construct thermal model to evaluate effects of thermal loading.

TEST SCOPE DATA SHEET

Risk Category	Risk ID(s)	Test Phase(s)
ST	87	3SI

TITLE: Structural Test of Superconducting Magnets

APPLICABLE RISK(S):
Superconducting Magnet Mechanical Integrity (87)

DEVELOPMENT PROGRAM PHASE:
Phase 3: Prototype Subsystem Integration

TEST CONDUCTOR:
Vehicle Contractor

TEST ARTICLE DESCRIPTION:
Superconducting magnet

TEST OBJECTIVES:
Verify integrity of attachments and machining of magnet under load.

TEST DESCRIPTION:
Expose the magnet to loads predicted during operation. Test magnet material and fasteners for structural failure.

FACILITY REQUIREMENTS:
Structural test facility

RELATED ANALYSIS:
Conduct stress analysis to verify ability of magnet materials and fasteners to withstand predicted loads.

TEST SCOPE DATA SHEET

Risk Category	Risk ID(s)	Test Phase(s)
WG	90	2

TITLE: Guideway-Mounted Sensor Systems Evaluation Tests

APPLICABLE RISK(S):
Environmental Effects on Guideway-Mounted Sensors (90)

DEVELOPMENT PROGRAM PHASE:
Phase 2: Detailed Design

TEST CONDUCTOR:
Sensor system developers

TEST ARTICLE DESCRIPTION:
Sensor system developers should construct short, representative guideway segment (one or two spans)

Sensors for obstructions, ice and snow accumulation, guideway integrity etc. mounted on guideway

Follow-up testing possible at sub-scale, pre-prototype facility (e.g. Argonne National Laboratory proposed system)

TEST OBJECTIVES:
Early evaluation of effectiveness of guideway-mounted sensors for detecting hazards, obstructions, guideway structural degradation etc. under extreme weather conditions—rain (including electrical storm environments), snow, wind, ice, fog, temperature extremes, sun angles

System effectiveness is based on detection resolution, false detection rates etc. under the various weather extremes

TEST DESCRIPTION:
Collect sensor performance data by controlled introduction of stimuli under variety of weather conditions

FACILITY REQUIREMENTS:
Guideway(s) constructed for prototype system(s)

Extremes of weather conditions should be a consideration in selection of facility site(s)

RELATED ANALYSIS:
Phase 1 Sensor, Weather and Geotechnical and Operations Analyses

TEST SCOPE DATA SHEET

Risk Category	Risk ID(s)	Test Phase(s)
WG	93	3C

TITLE: Ice and Snow Accumulation Effects Test

APPLICABLE RISK(S):
Ice and Snow Accumulation in Trough Shaped Guideway (93)

DEVELOPMENT PROGRAM PHASE:
Phase 3: Prototype Construction

TEST CONDUCTOR:
Prototype system developer

TEST ARTICLE DESCRIPTION:
Full-scale prototype guideway sections (elevated and at-grade)

Sections should be at various angular orientations to prevailing winds and in varying terrains

TEST OBJECTIVES:
First opportunity for evaluation of ice and snow accumulation problems and adverse effects on operations

Follow-up opportunity for evaluating snow and ice detector systems

TEST DESCRIPTION:
Observe natural accumulations of ice and snow on guideways (especially) trough shaped sections

Assess effects on operations and effects of operation frequency on accumulation rates

FACILITY REQUIREMENTS:
Prototype system facility(ies)

Appropriateness of weather conditions should be a consideration in selection of facility site(s)

RELATED ANALYSIS:
Phase 1: Sensor, Weather and Geotechnical and Operations Analyses