TECHNOLOGY SELECTION REPORT

California MAGLEV Deployment Project

Final Report

for
California Business, Transportation and Housing Agency
California High Speed Rail Authority
and
Southern California Association of Governments

prepared by

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At its regularly scheduled meeting on December 16, 1999, the SCAG MAGLEV Task Force formally approved the selection of the Transrapid technology as the basis for the development of system design, cost, and performance parameters for the California MAGLEV Deployment Program. The selection of a technology supplier, which can offer technology that performs at least as well or better than the design basis technology, may be deemed appropriate at the time a solicitation is issued for implementation of the project.

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LIST OF TERMS AND ACRONYMS

A

AMT	American Maglev Technology

B

BT&H	(State of California) Business, Transportation and Housing Agency

C

CDF	cumulative distribution function
CFS	Commercial Feasibility Study
CHSRA	California High Speed Rail Authority
cm	centimeters
consist	A railroad/technical term, a noun meaning what the components of a train are, i.e., how many locomotives and cars, or in the case of MAGLEV technology, how many vehicle sections in a train

E

EA	Environmental Assessment
EDS	electrodynamic system (uses *repulsive* magnetic levitation forces)
EMF	electromagnetic field
EMS	electromagnetic system (uses *attractive* magnetic levitation forces)
EMSA	Eurotren Monoviga SA

F

FRA	Federal Railroad Administration

G

GIS	geographical information system
GPS	global positioning system

H

HRT	heavy rail transit

I

ICE	InterCity Express

J

JPA	Joint Powers Authority

K

kW	kilowatt

L

LIM	linear induction motor
LM	linear motor
LRT	light rail transit
LSM	linear synchronous motor

M

MDI	Japanese Maglev Development Institute
m/s	meters per second
MGT	million gross tons
mm	millimeters
mph	miles per hour
MTIR	MAGLEV Technology Information Request

N

NMI	National Maglev Initiative

O

O&M	operating and maintenance
OCC	Operations Control Center
OCS	Operations Control System

P

PD	(MAGLEV) Project Description
PTG	Parsons Transportation Group
PTS	positive train separation

R

RSH	revenue seat-hour
RSK	revenue seat-km

S

SCAG	Southern California Association of Governments
SCDs	system concept definitions from the National Maglev Initiative

T

TRI	Transrapid International

Section

1

TECHNOLOGY EVALUATION CRITERIA AND SELECTION PROCESS

Introduction and Background

As part of its charter, the Southern California Association of Governments (SCAG) monitors both existing and proposed transportation in Southern California. Community Link 21, the Regional Transportation Plan (RTP) adopted by the SCAG Regional Council in April 1998, provides a framework for future transportation improvement projects in the SCAG region. Implementing the elements of this landmark RTP will allow the region to meet its mobility goals and to demonstrate air quality conformity in a financially constrained environment. At the same time, the elements allow flexibility to implementing agencies as they develop and refine their transportation infrastructure strategies.

Through the RTP, SCAG is proposing an intra-regional MAGLEV system that will connect major regional activity centers and significant multimodal transportation facilities in Los Angeles, Orange, Riverside, and San Bernardino counties. The completed system will connect to the San Diego region and will be a collection system for the state's proposed high-speed rail system extending to northern California. It will also provide an opportunity for future corridor expansion into the high desert portions of Los Angeles and San Bernardino counties.

The initial SCAG-proposed corridor to be analyzed in this study extends from Los Angeles International Airport (LAX) through Union Station in downtown Los Angeles, then on to Ontario International Airport (Ontario Airport) and March Air Reserve Base (March Field), a distance of approximately 75 miles.

The Transportation Efficiency Act of 1998 (TEA 21) includes provisions for the deployment of a MAGLEV project in the United States. Under these provisions, the Federal Railroad Administration (FRA) selected the SCAG MAGLEV project as one of seven proposed projects in the nation to receive federal funding for MAGLEV preconstruction planning. The California Business, Transportation and Housing Agency (BT&H),

California High Speed Rail Authority (CHSRA), and SCAG have joined together to prepare the California MAGLEV Deployment Program proposal to be submitted to FRA on June 30, 2000. The FRA will review this proposal and the six other competing state proposals, and select one project for full deployment. The work program consists of 11 interrelated tasks, as shown in Figure 1-1.

These tasks will be described more fully in the program's Project Description and Environmental Assessment. They address the requirements of section 268.11, Project Eligibility Standards, and section 268.17, Project Selection Criteria, of the Interim Final Rule governing the Federal MAGLEV Deployment Program (the Program).

Task	Description
1	Transportation purpose and significance
2	System design – engineering factors
3	Technology sourcing and transfer
4	System design – operational and economic factors
5	Project benefits
6	Cost estimates
7	Partnership potential
8	Management documentation
9	Environmental Assessment
10	Participation and submission requirements
11	Project management and administration

Figure 1-1 – MAGLEV Deployment Program Tasks

The Parsons Transportation Group (PTG) project team will provide full project management, planning, engineering, financial, and other technical skills required to fully document and present a MAGLEV Deployment Program for Southern California capable of advancing the project into the next phase of the Federal Railroad Administration national implementation competition.

As with all major transportation corridor studies, the analysis and evaluation of MAGLEV deployment concepts within the 75-mile corridor will consist of a series of complex technical disciplines, all of which are interrelated and codependent.

As a product of Task 3, this technical report describes the evaluation of potential MAGLEV technologies.

Effective development of the Project Description (PD) for the intra-regional MAGLEV corridor envisioned by SCAG requires early selection of a technology. Such selection allows for solid conceptual development of the proposed MAGLEV system. The identification of a specific prospective technology, potentially provided by commercial interests desirous of eventual sale of product, establishes alignment criteria, station concepts, maintenance facility requirements, sizing of power and communication facilities, and myriad other details needed to bring a new transportation system into service.

In compliance with the Federal Railroad Administration guidelines, partnerships must be formed to finance, construct, operate, and maintain the proposed system.

This report describes the basis for PTG's recommendations on selection of a MAGLEV technology.

The selected technology should be the one which:

- Best satisfies the FRA's selection criteria for the Program.
- Best satisfies state, regional, and corridor goals and requirements not already included in the FRA's criteria for the Program.
- Is a good operational match to the requirements of SCAG's intra-regional corridor, planned to extend from Los Angeles International Airport (LAX) to March Air Reserve Base via Los Angeles Union Passenger Terminal (LAUPT) and Ontario International Airport.
- Has design criteria and environmental effects sufficiently well established to readily prepare a Project Description meeting the Program's requirements.

These considerations are listed in what PTG considers a descending order of importance, and were used as the basis for a 100-point rating system for candidate technologies. Of the total 100 points, 60 were assigned to meeting Program selection criteria, 30 to meeting the corridor's requirements, and 10 to the degree to which the development of the Project Description would be supported. This point distribution reflects PTG's view that the FRA's point of view as decision-maker for the Program should be about twice as important as local considerations, and that for non-FRA considerations, the ultimate issues of economics for SCAG and its partners should be about twice as important as the more immediate issues of producing the Project Description. The split implicit in these assumptions (67–22–11) was rounded to 60–30–10. Within each area, points were assigned based on evaluation criteria defined by PTG as described in subsection 1.1.

The overall selection process is described in subsection 1.1.2. Subsequent sections of this report address the characteristics of the candidate technologies, evaluation of the criteria for each candidate technology, and the recommendation of a technology for further development of the corridor. Technical Appendix A and Technical Appendix B provide further information on the techniques used to evaluate the criteria. Technical Appendix C presents the findings of an independent Technology Assessment Panel (TAP) established to review the technology selection process.

1.1 Evaluation Criteria and Rating Basis

1.1.1 Criteria for Program Effectiveness

Section 268.17 of the Interim Final Rule for the Magnetic Levitation Transportation Technology Deployment Program describes project selection criteria for the Program. For some of these criteria, PTG found that the choice of technology supplier was a not significant factor in the performance of the project under the criterion. For other selection criteria, a significant potential relationship with the choice of technology supplier was identified, and PTG assigned both a specific measure of effectiveness and a point value for rating purposes.

The Program's selection criteria include "*the degree to which the project description demonstrates attractiveness to travelers, as measured in passengers and passengers-miles*"[1]. MAGLEV technologies adhering to consistent ride comfort criteria along generally comparable alignments will offer slightly different travel times, and may operate at or above 240 mph (386 km/hour, often rounded to 400 km/hr for general discussions) for different fractions of the route. At this stage in the development of the Project Description, the relationship between speed and potential ridership in the corridor has not been well established. Given the history of the Program to date, PTG established the following

[1] This criterion, and all others established through similar quotations, are drawn from 49 CFR 268, Section 268.17, as published in the Federal Register of Tuesday, October 13, 1998.

Criterion	Maximum Points
Average Speed (ridership)	10
240-mph capability	5
240-mph alignment	5
Total	20

measures of effectiveness and point assignments to represent this criterion:

- Average operating speed over a representative alignment: 10 points (10 = an ideal average speed of 194 mph[2], 0 = 55 mph)
- Ability to meet or exceed 240 mph along the representative alignment: 5 points (awarded if 240 mph is attained)
- Fraction of representative alignment operated at 240 mph or greater: 5 points (5 = highest fraction among the candidate technologies; 0 = lowest).

The Program criterion of "*the extent to which implementation…will reduce congestion and attendant delay costs*" will be determined to a much greater extent by specifics of the project (e.g., station locations and fare structures) than by the technology selected. Therefore, no points were assigned to this criterion.

"The degree to which the project will demonstrate the variety of operating conditions which are to be expected in the United States," another Program selection criterion, is determined by the general location of the corridor, which does not depend on the technology selected. No rating points were assigned to this criterion.

"*The degree to which the project will augment a MAGLEV corridor or network that has been identified*" is determined exclusively by the general location of the corridor and statewide transportation plans, which do not depend on the technology selected. Again, no rating points were assigned to this criterion.

The Program's selection criteria attach considerable weight to *timely implementation*, but do not provide strict guidelines for evaluating this criterion. The enabling legislation for the Program[3] authorizes funding that would be expended by the end of the 2003 Federal fiscal year (i.e., September 30, 2003). The intent appears to be a project for which the infrastructure would be substantially in place by the end of 2003, and with a reasonable allowance for testing and commissioning, might see service as early as 2004.

[2] Estimated average speed including two one-minute stops, assuming constant acceleration and deceleration of 0.986 m/s2 (0.1 g), and a maximum speed of 134 m/s (300 mph), unconstrained by curves, grades, air resistance, or power availability.
[3] Transportation Equity Act for the 21st Century, section 1218, paragraph 322(h).

Because the authorization is in current dollars, PTG assumed that a project going into service later than this date would be assessed negatively. At a minimum, the value of the Federal funding lost to inflation should be considered. The risks SCAG and its partners might assume in developing the corridor are taken into consideration as described in subsection 1.1.2. PTG established the following measures of effectiveness and point assignments to represent this criterion:

Criterion	Maximum Points
Start date	15
Federal contribution	10
Total	25

- Median (50th percentile) date for start of revenue service: 15 points (median date for an “ideal” no-risk MAGLEV technology = 15, latest median date for candidate technologies = 0*)*

- Expected fraction of Federal contribution to the Program lost to inflation for infrastructure investment: 10 points (lowest fraction among candidate technologies = 10 points, highest fraction among candidate technologies = 0)

Economic benefit to the U.S. is another Federal evaluation criterion.

The FRA indicates that “*the extent to which the project is expected to create new jobs in traditional and emerging industries in the United States*” is a project selection criterion. The Program’s requirement for U.S. participation will ensure significant U.S. job creation, particularly in the more traditional infrastructure-related industries. A longer-term consideration will be the potential for technology transfer to the U.S. Should a non-U.S. technology be selected, the ability of U.S. industry to be in an equivalent position for subsequent MAGLEV implementations is an important consideration. PTG established the following measures of effectiveness and point assignments to represent this criterion:

Criterion	Maximum Points
Supplier site	5
U.S. jobs	10
Total	15

- The supplier is U.S.-owned and U.S.-sited: 5 points; if a non-U.S. supplier indicates the ability to conform to the Program’s U.S. content and technology transfer requirements: 3 points

- Estimated fraction of future MAGLEV “emerging industry” jobs in U.S.: 10 points (70 percent = 0; 100 percent = 10)

The FRA will consider *“the degree to which the project description demonstrates partnership potential for the corridor…and/or for the project independently.”* This will depend to a large extent on the characteristics of the route and services offered, and on financing and funding decisions. These factors do not depend directly on the technology selection. Therefore, no points were assigned to this criterion.

The FRA will consider *"the extent and proportion to which States, regions, and localities commit to financially contributing to the project…"* This criterion is a matter of public policy, and cannot meaningfully be applied to technology selection. Therefore, no points were assigned to this criterion.

1.1.2 Criteria for Operational Requirements

The appropriateness of a technology for a corridor, as well as its commercial feasibility, are both strongly reflected in the expected operating and maintenance (O&M) costs for the intended service in that specific corridor. The relative importance of energy savings or other operational advantages may be small or large, depending on the scale and nature of the corridor. PTG assigned the 15 points for this consideration based on the estimated operating margin, including consideration of capital costs.

Criterion	Maximum Points
O&M costs	15
Potential risk	15
Total	30

Recognizing the technological and administrative uncertainties for the Program, as well as the risk-averse nature of SCAG's potential private-sector partners, PTG assigned 15 points to a measure of financial risk; 0 points were assigned to the worst technology's performance, and 15 to the best.

1.1.3 Criteria for Project Description Support

Criterion	Maximum Points
Data quality and supplier responsive-ness	5
Character-istics published	5
Total Points	10

PTG considered two factors in assigning the 10 points under this category. Five points were assigned based on PTG's assessment of the quality of responses to MAGLEV Technology Information Requests (MTIRs) sent to four suppliers: 5 points to the best, 4 to the second best, etc. Quality, timeliness, and completeness of the responses were considered. It will be in SCAG's best interest to have a supplier who can rapidly and effectively respond to information requests.

Five points were also assigned based on the extent to which basic vehicle characteristics (1 point), alignment design criteria (2 points), and environmental effects such as noise and electromagnetic interference (2 points) have previously been published or made available under the Program. Uncertainties in any of these areas will complicate the production of the Project Description and environmental information required by the Program.

1.2 Technology Selection Process

The process for technology selection consisted of three distinct steps:

- Identifying and screening possible suppliers
- Sending MTIRs to candidate suppliers
- Evaluating candidate suppliers based on their responses to the MTIRs and other available information

From previous MAGLEV work and attendance at FRA-sponsored Program workshops, PTG developed a list of possible MAGLEV technology suppliers. SCAG also identified one additional possible supplier (Dr. Raymond Paulson) based on communications directly concerning the corridor. Because of the wide range in development status among these suppliers and the short timeframe necessary to meet the Program schedule, PTG short-listed candidate suppliers based on the four criteria listed below. As a result of the application of these criteria, PTG sent MTIRs to four candidate MAGLEV technology suppliers selected from a list of eight potential suppliers. The MTIRs were sent to those suppliers meeting two or more of these criteria:

- The supplier has operated a full-size test or demonstration vehicle employing the proposed methods of levitation and propulsion.
- The supplier has operated a full-size test or demonstration vehicle at a speed equal to or greater than 240 mph.
- The supplier is American-sited and American-owned
- The supplier is associated with another application for the FRA's Magnetic Levitation Transportation Technology Deployment Program which was selected for funding.

Table 1-1 shows the long list of potential suppliers considered under these criteria, and indicates the short-listed four who received a MAGLEV Technology Information Request.

The MTIRs asked prospective suppliers to indicate their interest in SCAG's program and their ability to supply, at a later date, the information necessary to fully support completion of the technology portions of the Project Description. They also requested specific information to determine the three issues critical to technology selection: technology system performance, technological maturity, and the level of American participation.

Evaluation of the candidate suppliers was the result of assigning points to each measure of effectiveness as described in subsection 1.1. The results of the evaluation are described in section 3.

Table 1-1 – Selection of Candidate Technology Suppliers to Receive MTIRs

Technology Supplier	Full Size Vehicle Demonstration	Vehicle Operation at 240 mph	American-sited or American-owned	Associated with FRA Selection Process	Sent MTIR
HSST Development Corporation (Japan)	Yes	No[4]	No	No	No
Transrapid International (Germany)	Yes	Yes	No	Yes	Yes
American Maglev Technology	Yes	No	Yes	No	Yes
Maglev 2000 of Florida Corporation	No	No	Yes	Yes	Yes
Meneren Corporation	Yes[5]	No	Yes	No	Yes
Maglev Development Institute (Japan)	Yes	Yes	No	No	No[6]
Magneplane	No	No	Yes	No	No
Dr. Raymond Paulson	No	No	Yes	No	No

[4] This technology is designed for lower-speed applications, and is not planned to operate at over 55 meters per second (approximately 120 miles per hour).

[5] Operation with the intended prototype vehicle under a different propulsion arrangement was interpreted as a “yes”.

[6] This supplier wrote the FRA to say that it does not intend to participate in the MAGLEV Technology Deployment Program.

Section

2

CANDIDATE TECHNOLOGY SUPPLIERS

This section describes the key characteristics of the four candidate MAGLEV technologies. It contains a subsection describing each technology and a subsection comparing their physical properties. Comparisons against the evaluation criteria are presented in section 3.

A brief introductory discussion of MAGLEV technology is appropriate at this point. The term “MAGLEV” applied to this Program refers to a class of surface transportation systems using electromagnetic forces to support and propel individual vehicles or trains. These systems fall into two categories in terms of their basic operating principles and into two other categories in terms of their allocation of propulsion system components between the vehicle and the guideway (or track).

All proposed MAGLEV systems rely on the principle of the *linear motor (LM)*, that in effect is a conventional rotary electric motor “unrolled” so that either the armature or the field is continuous with the guideway and the other component is on the vehicle. In *long-stator* systems (one of the two classifications according to allocation of components) the armature, or stator, is continuous along the guideway and the field is located on the vehicle. *Short-stator* systems reverse this arrangement. An advantage of the short-stator approach is that the guideway magnetics can be less expensive, because the control and power conditioning elements can be concentrated on the vehicle. This feature has proven to be a challenge for high-speed operation, however, because electrical contact (e.g., via shoes or brushes) is required between the vehicle and the guideway to transfer the large (3 MW and up) power loads to the vehicle.

MAGLEV systems operating on the electromagnetic system (EMS) use what is called *attractive* forces to lift the vehicle toward an underrunning component of the guideway. These forces must be actively managed in real-time to avoid contact between the field and stator. The electrodynamic (EDS) operating principle uses *repulsive* forces, which increase as the distance between field and stator decreases; this provides less of a challenge to levitation control. The less control-intensive aspects of EDS have made it attractive as a potential application for superconducting magnets, and make it possible to operate with a wider air gap, thereby offering the possibility of maintenance and construction cost savings.

Various combinations of the two basic classifications have been developed or proposed, as shown in Table 2-1. MAGLEV developments undertaken so far reveal a number of technical hurdles or challenges for high-speed application. Research and development for the longer term appears to be focused on superconducting long-stator EDS technology (Maglev 2000 and the Japanese Maglev Development Institute, MDI), and in the nearer term, on higher-speed applications of short-stator EDS.

Table 2-1 – Comparison of MAGLEV Technologies

Technology	Principle	Stator	Super-conduct-ing	Status (as of October 1999)
Transrapid (TRI)	EMS	Long	No	Operational to 110 m/s (260 mph). Preproduction vehicles in demonstration service with passengers. Planned to be applied in Berlin-Hamburg corridor in Germany.
High Speed Surface Transportation (HSST)	EMS	Short	No	Operational to about 50 m/s (120 mph). Power pickup difficulties have prevented deployment at higher speeds. Proposed local transit applications in Japan are on hold.
Maglev Development Institute (Japan)	EDS	Long	Yes	Developmental; has operated at high speeds (115 m/s or 272 mph), but has experienced reliability and other difficulties with superconducting magnets.
Grumman	EMS	Long	Yes	One of four “paper” system concept definitions (SCDs) proposed to the U.S. Department of Transportation as part of the National Maglev Initiative (NMI) in 1992
Foster-Miller	EDS	Long	Yes	An SCD for the NMI.
Bechtel	EDS	Long	Yes	An SCD for the NMI.
Magneplane	EDS	Long	Yes	An SCD for the NMI.
American Maglev Technology	EDS	Short	No	Prototype vehicle has been demonstrated at low speed.
Meneren Corporation	EDS	Short	No	A prototype vehicle has been operated at low speeds with a motor other than that proposed for the Program. Some vertical support and all guidance are provided by wheels which contact the guideway.

Technology	Principle	Stator	Super-conduct-ing	Status (as of October 1999)
Maglev 2000 of Florida	EDS	Long	Yes	Prototype demonstration under construction. No vehicle has been operated.

Following completion of the National Maglev Initiative in 1993, the Federal government decided not to pursue potentially expensive research and development into long-stator superconducting EDS MAGLEV technology, which had been chosen by three of the SCD contractors. Since that time, attention in the U.S. has focused to some extent on the potentially less expensive short-stator technologies. One U.S. supplier, Maglev 2000 of Florida, is continuing to pursue the long-stator EDS approach.

2.1 American Maglev Technology (AMT)

American Maglev Technology (AMT) will employ short-stator technology in pursuit of its inherent economies. The technology employs a linear induction motor (LIM), which relies on the induction of passive lift and guidance forces in aluminum coils embedded in a pair of vertically mounted reaction rails and guiderails in the guideway. It shares the use of the electrodynamic system (EDS) of levitation with the other two U.S. technologies, and the use of LIM propulsion with the Meneren Corporation’s technology.

Each relatively large vehicle will have two swiveling bogies. Each bogie contains an array of permanent magnets straddling the guiderails. Even when levitated, the vehicle will maintain contact with the guideway. There will be an electrical contact with power rails mounted outboard and/or between the reaction rails, and a contact via brushes held against the guiderail by a linear spring. Power conditioning will occur on the vehicle. The conditioned power will flow to the fixed coils in the guiderails, and will form a LIM with the on-board permanent magnets.

An active suspension system will allow the vehicles to bank relative to the guideway, increasing their ability to negotiate horizontal curves at speed. At low speeds (below 9 meters per second or approximately 20 mph) the vehicle will roll on unpowered wheels, because the induced magnetic lift will no longer be sufficient to support it.

AMT’s technology was demonstrated at low speeds in the 1980s at a short test track in Edgewater, Florida.

Although some documents provided by AMT indicate the possible application of electronic switching, it is more likely that mechanical switching will be used for the first commercial application.

AMT did not provide operational control details, but the intent expressed in AMT documents previously-submitted appears to be to design a control system from off-the-shelf train control products to provide automatic train protection, automatic train operation, and route supervision. Vehicle location would be determined by a multiply redundant system including on-board GPS and inertial guidance systems and sensors incorporated in the guideway. PTG believes that the resulting control capability should be generally comparable to the other MAGLEV technologies.

PTG Assessment of AMT Technology

PTG considers this technology to have a relatively high technological risk. First and foremost, short-stator technology has yet to be proven sustainable for speeds over 50 m/s. The developers of the Japanese HSST technology, which had the express goal of achieving over 100 m/s (HSST-300 and HSST-400), have discovered that the wear on the mechanical brushes necessary to transfer the high power loads causes unreliability and is economically prohibitive. Although a concerted research and development effort may solve this problem, this cannot be taken for granted in the near term.

AMT also proposes to use an active-tilt suspension, which has taken considerable time to engineer into railroad equipment. While in principle there is nothing to prevent such engineering in a MAGLEV system, it is an additional risk factor.

Finally, AMT proposes to use aerodynamic braking at high speeds, blending it with electrodynamic braking at lower speeds. This blending has been achieved by the Japanese MDI technology, but will require time to engineer into a new vehicle.

2.2 Maglev 2000 of Florida Corporation (Maglev 2000)

At the FRA’s third MAGLEV workshop on August 24, 1999, Maglev 2000’s proponents characterized their technology as a simpler and more cost-effective “second generation” application of the long-stator EDS principle used in the high-speed system being developed by MDI in Japan. The supplier’s principals include the pioneers of MAGLEV technology, American professors Danby and Powell. Similar to the Japanese technology, the vehicle-borne magnets will employ superconducting technology, and will require on-board cryogenics to maintain the very low temperatures required.

Guideways could be constructed in either a planar configuration or a narrower beam, employing one of two sets of vehicle-mounted magnets. The use of the EDS principle and a linear synchronous motor (LSM) would permit relatively wide air gaps between the magnets and reaction rails, on the order of 15 cm. Given the efficiency and power of the linear motor design, grades as high as 25 percent could in principle be negotiated.

Unique among the technologies under consideration for the SCAG corridor is the use of electronic switching, relying on magnetic fields rather than movable mechanical switches.

As of October 1999, Maglev 2000 was constructing a 600-meter test guideway in Florida, and had fabricated a prototype guideway panel.

Maglev 2000 has not identified a particular control strategy as yet. PTG believes that one or more of the ideas employed by the other suppliers could readily be adapted to it.

PTG Assessment of Maglev 2000 Technology

PTG considers this technology to have high technological risk. As the least developed of the candidate technologies, a tremendous amount of systems integration effort will be needed to reach the concept demonstration stage, let alone commercial feasibility. The electronic switching concept, while both elegant and efficient, is unproven for full-size vehicles. The development of a reliable superconducting magnet has also been shown by the Japanese EDS effort to be a considerable technical challenge.

2.3 The Meneren Corporation (Meneren)

The short-stator technology offered by the Meneren Corporation as the “Maglift Monorail” will be built around the high-thrust Seraphim (Segmented Rail Phased Induction Motor) developed by Sandia Laboratories for potential space launch applications. This LIM offers the capability, in principle, to operate a vehicle on grades as high as 25 or 30 percent. The Maglift Monorail will incorporate this technology into a vehicle adapted from a conventionally powered monorail system developed by the Spanish firm Eurotren Monoviga SA (EMSA) in the 1980s. The monorail vehicle relies on unpowered wheelsets to provide both lateral guidance and levitation to carry about 20 percent of the vehicle’s vertical load. The flangeless wheels will also provide full vertical support when the vehicle is operating at low speeds or is stopped, or in the event of power failure.

The Seraphim motor creates thrust under the EDS principle by pulsing an alternating current through a driving coil on the vehicle when it is properly positioned over an unpowered reaction element on the top of the guideway. The reaction element is not continuous as with other linear motors. The operation with segmented reaction rails generates a vertical “maglift” component that can support about 80 percent of the vehicle weight. The gap between the vehicle’s driving coils and the passive reaction rail will be about 25 cm. Maglift Monorail will be a “contact” system; in addition to the load-bearing wheelsets and guidance wheels, electrical power will be drawn by contact with a guideway-mounted rail.

The short vehicle sections and wheelbases of the basic EMSA vehicle, in conjunction with the lack of vertical reaction rails, will permit the negotiation of very tight vertical and horizontal curves. In conjunction with its high gradeability, this feature makes it attractive for mountainous terrain. The technology has been selected for the Colorado Intermountain Fixed Guideway Authority’s system connecting Denver to mountain resorts along the I–70 corridor.

The system’s Operations Control Center (OCC) will include a conventional “moving block” train control system, evolved as necessary to handle the high operating speeds. The OCC and the control system design evolved from off-the-shelf train control products will provide automatic train protection, automatic train operation, and route supervision.

PTG Assessment of Meneren Technology

PTG considers this technology to have high technological risk for high-speed operation. It shares the power transfer and active tilt design challenges of the AMT technology. An additional area of uncertainty is the performance of its load-bearing and guidance wheels at very high speeds. The development of an appropriate secondary suspension system and means to ensure that wear will not become a prohibitive expense is required.

2.4 Transrapid International (TRI)

Transrapid technology relies on four actively controlled magnets along the guideway for both propulsion and levitation. It is a fully noncontact (magnetically levitated) system at all speeds, and recently achieved a speed slightly exceeding its intended maximum design speed of 138 m/s (approximately 300 mph). Both the levitation and the guidance magnets use the electromagnetic (EMS) principle. This means that these forces must be continuously monitored and controlled. A synchronous long-stator linear motor is formed by propulsion windings in stator packs mounted underneath the guideway, interacting with levitation magnets mounted in two bogies at the end of each vehicle section. The bogies, or levitation frames, are joined to the vehicle body (in the TR08 preproduction vehicle) via a self-leveling air suspension and pendulum suspension. The normal operating air gap between the levitation magnets and the propulsion stator pack on the vehicle is 8 mm.

The Transrapid vehicle wraps around a T-shaped guideway, virtually eliminating the risk of derailment. The vehicle guidance rails are mounted on the outside edge of the guideway; operating gaps for guidance are several times larger than for levitation.

Transrapid's Operations Control System (OCS) is a radio-based, decentralized command and control system that provides positive train separation (PTS), safe speed enforcement, route integrity checking, and route supervision (dispatching). Train operation is fully automatic. In the event of an external power failure, on-board batteries automatically provide levitation to a safe stop at a designated refuge location.

Germany requires two levels of certification before commercial operation of a new transportation technology is authorized. Transrapid received the first, Certification of Technical Readiness for Application, in late 1991. The final certification, Type Approval, is expected by 2004. Factors related to system integration, train control, safety, and reliability were thoroughly explored while obtaining certification, and considerable operating experience has been acquired in trial service (220,000 passengers and over 600,000 vehicle-km). As part of preparing for possible applications in the U.S., Transrapid has investigated requirements that must to be met for an FRA Rule of Particular Applicability in the U.S.

PTG Assessment of TRI Technology

PTG considers this technology to have low technological risk. The technical issues currently being addressed by the Transrapid developers are characteristic of the late development and early operational phases of system development.

2.5 Summary Comparison

Table 2-2 compares the basic physical characteristics of the candidate technologies' vehicles.

A fair comparison among the candidate technologies must take into account the fact that practical considerations often limit the extent to which a technology's inherent (or nominal) capabilities can be exploited in a practical transportation system. This is particularly true for both passenger comfort criteria and power consumption. In the first case, acceptable longitudinal accelerations, unbalanced lateral accelerations, and floor slopes when stopped can pose significant limits to alignment design.

In the second case, demand charges for electric power and the size of substations required will place a practical limit on the power available to linear motors.

Table 2-2 – Comparison of Vehicle Characteristics

	AMT	Maglev 2000	Meneren	TRI
Vehicle section length (m)	36.6	30.5	6.40	27.0 (end) 24.8 (middle)
Vehicle section width (m)	3.8	3.2	3.20	3.70
Vehicle section height (m)	3.5	3.8	3.55	4.16
Nominal unloaded section mass (kg)	30,500	20,000	8,500	45,000
Practical unloaded section mass[7] (kg)	34,500	22,600	9,600	45,000
Load factor assumed	51.4%	53.8%	55.5%	54.3%
Passenger seats (intercity/airport)	120	60	20	62 (end) 84 (middle)
Loaded weight per passenger (kg)	637	778	943	1,134[8]

Of the candidate technologies, TRI has gone the farthest to determine practical engineering limits and alignment design criteria for applications. Table 2-3 compares practical design characteristics of the Transrapid technology to both practical and nominal values for the less developed technologies. In all cases, information obtained from the suppliers is indicated in plain text, and information estimated by PTG is shown in italics. The following conclusions can be reached:

- The technologies with active tilt suspension relative to the guideway (Meneren and AMT) can travel at significantly higher speeds through curves than TRI or Maglev 2000. However, practical limitations on floor slope while stopped (11–12 degrees), in conjunction with the limits of the tilt suspension, can be expected to place a similar constraint on the total effective superelevation for both active-tilt systems.

[7] For technologies that have not reached the trial service stage, an upward adjustment of 13 percent was made to estimated vehicle mass. This represents the average increase for the Japanese MDI and the TRI technologies for corresponding stages of development.
[8] Average for a five-unit train (2 end units, 3 middle units).

- The Maglev 2000 and AMT technologies appear to offer superior maximum practical grade-climbing ability. The 10 percent practical value for Meneren and TRI, however, is unlikely to be exceeded for alignments closely following existing interstate or railroad routes in the SCAG corridor.

- All the suppliers indicate that indicate that they expect their technologies to be able to attain 134 m/s (300 mph). PTG's modeling based on information from the suppliers indicates that this should be the case, provided all technological risks are resolved. TRI is the only candidate technology to have demonstrated performance in this speed range, however.

The performance characteristics themselves do not give a clear picture of their value in an actual application. The practical advantages of the technologies in different respects were assessed in combination by evaluating their performance over a representative alignment for the SCAG corridor, as described in section 3.

Table 2-3 – Summary of Technology Performance Characteristics
(italics = PTG estimate)

	TRI	AMT		Meneren		Maglev 2000	
Characteristics*	Practical	Nominal	Practical	Nominal	Practical	Nominal	Practical
Maximum superelevation of guideway (degrees)	12[9]	11	11	30	*11*[10]	> = 30	*12*[11]
Maximum vehicle tilt relative to guideway (degrees)	0	15	15	15	15	*0*	*0*
Maximum effective superelevation (degrees)	12	*11*	24	45	*26*	> = 30	*12*
Minimum[12] horizontal curve radius (m)	374[13]	244	*341*	*N/A*	*173*	92	*374*
Maximum grade[14] (%)	10	N/A	*12*	30	*10*	25	*14*
Maximum speed on level tangent[15] (m/s – mph)	139–311[16]	*151–339*	134–300	*141–314*	134–300	*188–421*	134–300

*Table values in italics represent values PTG derived from information provided by the suppliers.

[9] TRI indicated that 16 degrees could be used in unspecified “special circumstances.”
[10] AMT’s nominal/practical limit was imposed; this value also corresponds to a criterion the Japanese government determined for temporary habitability of high-rise structures which have tilted due to soil liquefaction during earthquakes.
[11] TRI’s practical limit was imposed; the supplier suggests that up to 15 degrees may be acceptable for passenger comfort.
[12] Practical values represent a curve on which a speed of 25 m/s can be sustained with fully compensated lateral acceleration at the maximum practical superelevation.
[13] TRI’s nominal minimum radius is 350 m.
[14] Practical values represent PTG’s estimate of a grade on which a typical train as defined in section 3 could sustain at least 25 m/s without requiring a larger electrical supply system than would be required for a maximum cruising speed of 134 m/s.
[15] The nominal values represent the speed at which, according to PTG’s models, aerodynamic drag and other resistance components would consume all available tractive effort.
[16] PTG’s estimated nominal maximum speed for TRI is 167 m/s (374 mph).

Section

3

EVALUATION OF CANDIDATE TECHNOLOGIES

This section describes and evaluates the criteria for technology selection. Separate subsections discuss operating performance over a representative route, likely date for start of revenue service, economic benefits to the U.S., operating and construction costs, and ability to support development of the Project Description.

3.1 Operating Performance Over Representative Route

To fairly assess the performance of each technology in the SCAG corridor, PTG modeled the performance of each along a representative alignment of 129.6 km, as follows:

- From LAX to LAUPT via railroad right-of-way 24.4 km
- From LAUPT to Ontario Airport via I-10 62.6 km
- From Ontario Airport to March AFB via State Route 60 and I–215 42.6 km

PTG laid out preliminary horizontal curves and average grades for this alignment, and set speed limits in curves to yield no uncompensated lateral accelerations on passengers, while keeping within the “practical” effective total superelevations shown in Table 2-2. Vehicle performance was established using a time-advanced spreadsheet simulation incorporating the effects of available acceleration, passenger comfort, grade and curve resistance, aerodynamic drag, and magnetic drag or rolling resistance as applicable. These evaluations were independently reviewed as described in Technical Appendix C.

For comparisons on the preliminary alignment, PTG assumed that the maximum guideway superelevation would be 12 degrees (for passenger comfort when a train is stopped in a curve), and that vehicle acceleration and deceleration would be restricted to no more than 0.1 g (0.986 m/s/s). The model for each technology was calibrated to specific case results provided by the technology suppliers. For each technology, a representative consist[17] was selected to provide an economical consist for the assumed passenger demand and a 20-minute maximum headway: 8 vehicle sections for AMT and TRI, 11 sections for Maglev 2000, and 20 sections for Meneren.

Figure 3-1 shows the estimated speed versus distance profile along the representative alignment for each of the candidate technologies. Table 3-1 summarizes the results and shows the points assigned for evaluation purposes. The average speeds shown also include a one-minute dwell time at each of two intermediate stations, LAUPT and Ontario International Airport. The most significant differences among the technologies are:

- Lower speeds for TRI and Maglev 2000 in curves, versus the active-tilt technologies (AMT and Meneren). Typical speed differences are on the order of 15–20 m/s (33–45 mph).
- Achievable accelerations at higher speeds (100 m/s and up, i.e., above 240 mph). Maglev 2000 appears best in this regard, with AMT and TRI at an intermediate level. The Meneren technology is expected to have the lowest available acceleration rate at speeds above 100 m/s, in part because of the rolling resistance of its load-bearing wheels at high speed.

[17] "Consist" as used here is a railroad/technical term, a noun meaning what a train consists of, i.e., how many locomotives and cars, or in the case of MAGLEV technology, how many vehicle sections in a train.

Figure 3-1 - Operational Comparison over Representative Alignment

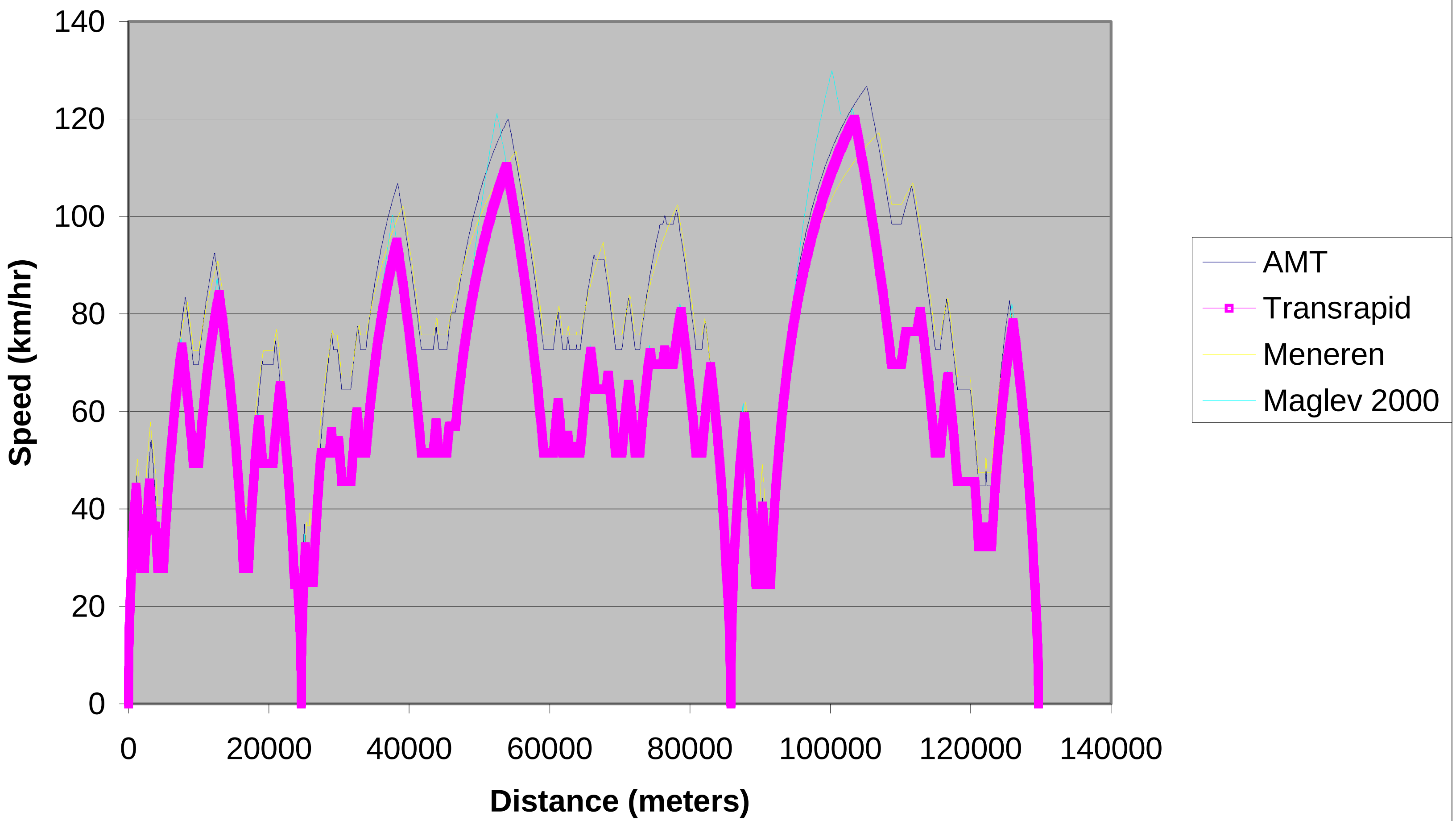


Table 3-1 – Operational Comparison Over Representative Route

	Maximum Points	AMT	Maglev 2000	Meneren	TRI
Average operating speed (m/s – mph)		58.3–130	51.2–115	60.8–136	50.1–112
Points assigned for operating speed	10	10	4	10	4
Points assigned for operation over 240 mph	5	5	5	5	5
Fraction of route operated at over 240 mph		11%	9%	8%	5%
Points assigned for fraction of route over 240 mph	5	5	3	2	0
Total points for Operational Comparison	20	15	12	13	9

3.2 Start of Revenue Service

Given that at present, no commercial MAGLEV transportation system is in operation, any forecast of a revenue service date will have considerable technological uncertainty associated with it. When this uncertainty is combined with possible delays attributable to administrative and approval processes, and with construction contingencies, the resulting range in likely revenue service dates becomes substantial. To account for this variability, PTG used a stochastic critical path method to estimate the cumulative distribution function (CDF) of the likely revenue service date, rather than only a single most likely date.

In effect, a large number of cases of sample project implementations were tested to identify the typical result. An analogy might be to rolling a six-sided die 100 times and averaging the result to estimate the “typical” roll. In the case of the die, the expected result is readily calculated (i.e., (1+2+3+4+5+6)/6 = 3.5). In the case of the model, the determination of each sample’s outcome is sufficiently complex (see Figure A-1 in Technical Appendix A) that the “Monte Carlo” approach is simpler than attempting an analytical solution. The Revenue Service Attainment Model is described in detail in Technical Appendix A.

The results of the forecast for each technology are shown in Figure 3-2, as well as results for a hypothetical “ideal” MAGLEV technology with no technological risk associated with it. TRI exhibits the lowest level of overall risk of the candidate technologies, less than three years later than the "ideal." For the 10th percentile and median, the U.S. technologies are expected to lag about five years behind TRI. At the 90th percentile, the less-developed technologies exhibit a wider gap of five-and-one-half to almost eight years. According to the model, there is an outside possibility that the gap could be 10 years or more. The independent review of PTG's methods in Technical Appendix C concludes that there is a significant risk of "outright technical failure" with the three U.S. technologies. PTG has extended these technologies the benefit of the doubt by assuming that these technical challenges can be resolved.

Table 3-2 shows the expected revenue service date (the average of 500 cases of the model for each technology) and the corresponding estimated fraction of the Federal contribution ($950 million current dollars in fiscal 2000 through fiscal 2003) lost to inflation[18.] Table 3-2 also shows the rating points assigned each technology based on these values.

3.3 Economic Benefits to U.S.

Three of the candidate technology suppliers identify themselves as American-owned and American-based: AMT, Meneren, and Maglev 2000. As such, they would not be required to prepare a technology transfer plan under the Program, and were assigned 5 points for evaluation purposes.

PTG is of the opinion that these three suppliers are "American" for this purpose. The Meneren Corporation proposes to develop its prototype from a vehicle placed in storage by a Spanish firm in the late 1980s. Meneren notes that the vehicle "is being 'Americanized' as it is being redesigned within the US to have steel wheels, bullet profile, LIM propulsion, and tilting cabin for high speeds." The Meneren Corporation also says that it has worldwide rights to the predecessor technology. The cornerstone of its propulsion system, the Seraphim motor, was developed by the U.S. Department of Energy's Sandia National Laboratories. The guideway will also likely need to be re-engineered for high-speed applications. This is sufficient to qualify the Meneren technology as essentially American.

[18] Inflation and carrying costs were computed from estimated midpoint of construction, using rates recommended at the FRA workshop in August 1999 (3% for inflation, 7% for carrying costs).

Figure 3-2 - Comparison of Revenue Service Start Probabilities

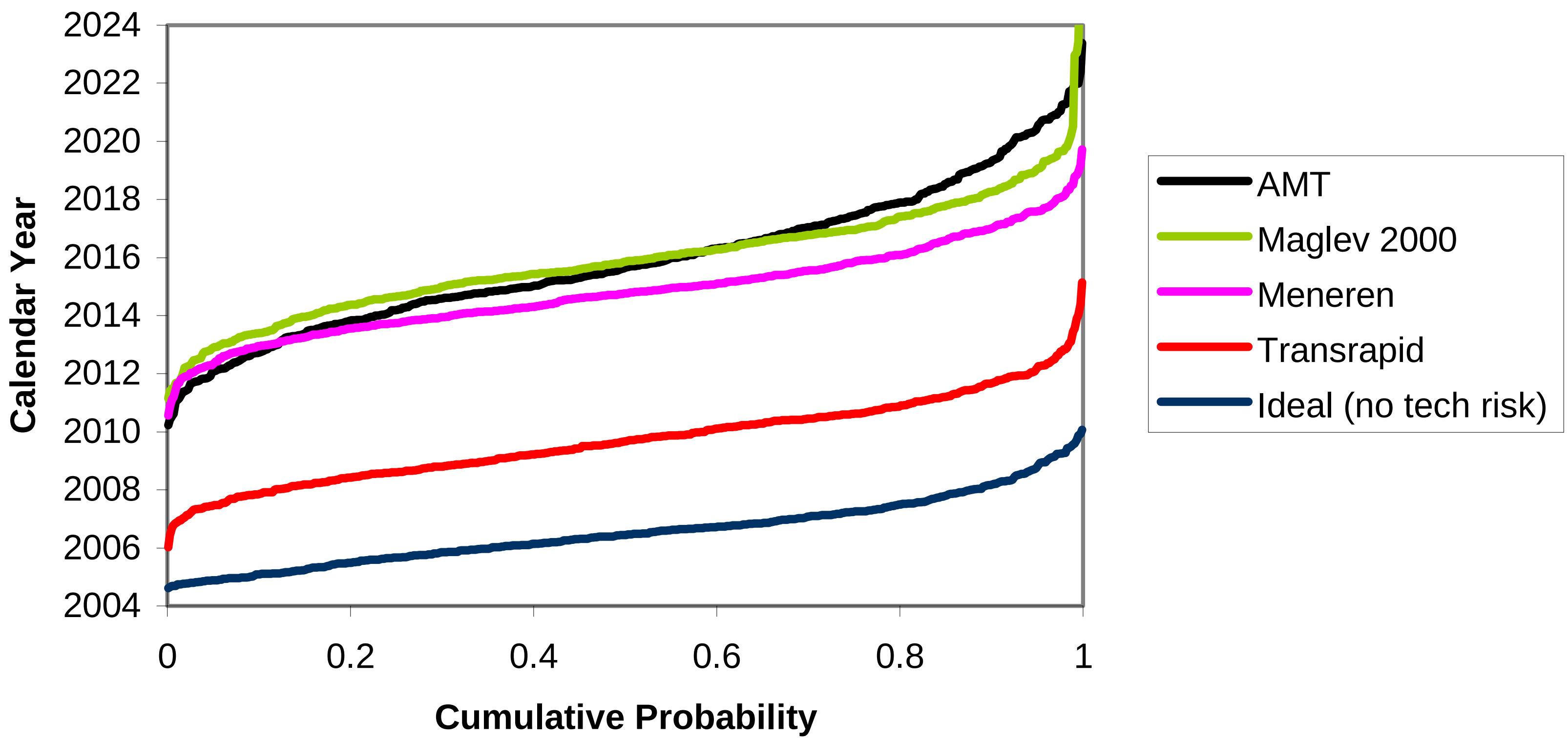


Table 3-2 – Comparisons Relating to Start of Revenue Service

	Maximum Points	AMT	Maglev 2000	Meneren	TRI
Median Revenue Service Date (50th percentile)		August 2015	October 2015	September 2014	August 2009
10th percentile (early) Revenue Service Date		September 2012	May 2013	November 2012	October 2007
90th percentile (late) Revenue Service Date		April 2019	March 2018	January 2017	August 2011
Rating Points for Revenue Service Date	15	0	0	1	10
Fraction loss of Federal contribution due to schedule		12%	11%	10%	3%
Rating Points for loss of Federal contribution	10	0	1	2	10

The Transrapid technology evolved in Germany as a natural outgrowth of Western Europe's need for a new generation of high-speed ground transportation. It is intended to complement, and in some instances ultimately replace, high-speed rail technology like the InterCity Express (ICE) services there. As such, it will need to meet the technology transfer requirements of the FRA's program.

Transrapid addressed this issue directly in its response to the MTIR:

"For the federal Maglev Deployment Program, TRI-USA [Transrapid International - USA] and Transrapid International GmbH & Co, KG [the German management and marketing company for the technology] are committed to develop the required technology transfer program that will result in the establishment of a Transrapid manufacturing base in the United States. In the preconstruction phase of the project, TRI-USA will cultivate professional relationships with qualified U.S. companies to acquire manufacturing services including (at a minimum) guideway construction, transportation and erection; transportation engineering; specialty concrete/steel fabrication and production…"

Transrapid has indicated that it will provide the 70 percent certification required by FRA, "most of which can be consumed by guideway construction and civil works." Based on comparison with other recently proposed MAGLEV projects, PTG believes that this achievable.

In PTG's opinion, as evidenced in part by the completeness of its response to the request for information, and in part by its stability and size[19], Transrapid is able (as well as willing) to respond to the FRA's requirements. TRI was therefore assigned 3 points for evaluation purposes.

As identified in subsection 1.1.1, however, a major consideration should also be the potential for U.S. job creation in follow-on MAGLEV implementations. PTG considered two factors in this regard: the possibility that selection of a non-U.S. supplier would deter the development of a wholly American MAGLEV industry, and the effective U.S. content of subsequent MAGLEV projects if a non-U.S. supplier's technology were to become dominant.

In PTG's opinion, selection of Transrapid for application in the SCAG corridor would provide a clear advantage for Transrapid, but would not ensure that this technology dominates the MAGLEV market in the U.S. thereafter. MAGLEV is still in its infancy, and the market forces and demands in the U.S., Japan, and Germany will continue to shape the transportation technologies that become available. The apparent operational advantages of the U.S. technologies are sufficient to let them remain candidate successor technologies even if Transrapid is built in the SCAG corridor. For investments considerably less than the size of this program, the U.S. could assure itself that at least one or two U.S. technologies enter trial service.

The SCAG corridor is positioned in a strategic location in an area more likely than most to be able to support longer-distance extensions of MAGLEV service. The ultimate requirement for a much longer line, as part of a nationwide network, is likely to require decades to emerge. In the meantime, the technology selected by SCAG would be at a competitive advantage in the Southwest. PTG estimates that MAGLEV vehicles (which TRI has not suggested would be manufactured in the U.S.) represent about 15 percent of the high-technology employment base for MAGLEV, and that the areas contiguous to Southern California may represent about one-quarter of the U.S. potential for MAGLEV. Assuming that TRI effects technology transfer and establishes a manufacturing base for MAGLEV guideway in the U.S., about 4 percent of the possible U.S. high-technology job growth in MAGLEV might be at risk if Transrapid is selected. Therefore, Transrapid was assigned 9 of the 10 points available for this consideration.

[19] The Transrapid consortium was established by some of Germany's leading industrial firms: Thyssen Industrie AG, Siemens AG, and Daimler-Benz AG/AEG AG.

3.4 Operating and Construction Costs

PTG estimated operating costs for the representative alignment from an internal "placeholder" preliminary demand estimate[20], adjusted for changes in travel times[21] for each technology and station location[22]. The representative alignment and its assumed characteristics as shown in Table 3-3 will not necessarily closely resemble the corridor ultimately developed by SCAG. The generally low load factors (compared with intercity transport at 65 to 70 percent) reflect the relatively high peaks characteristic of intra-regional transportation as well as the fixed length of MAGLEV train consists operating under a maximum headway of 20 minutes.

Table 3-3 – Preliminary Placeholder Operations Results for a Representative Alignment

Operations Results	AMT	Maglev 2000	Meneren	TRI
Annual Passenger Boardings (000)	37,689	34,315	38,017	34,417
Annual passenger-km (millions)	2,271	2,065	2,293	2,072
Net change in operating margin ($ million)	11.8	5.9	15.5	0.0
Annual value of construction savings ($ million)	10.1	10.7	24.1	0.0
Average operating expense per passenger-km ($)	0.116	0.117	0.115	0.120
Annualized cost of vehicles ($ million)	55.85	71.90	115.74	96.35
Annual operating and vehicle expenses per passenger-km ($), including construction cost savings	0.160	0.152	0.165	0.166
Points assigned for O&M costs	15	9	1	0
Net equivalent annualized value of expected developmental risks ($ million)	68.0	61.0	49.6	27.0
Points assigned for risk	0	3	7	15
Total points assigned for operational considerations	**15**	**12**	**8**	**15**

[20] Correspondence from L. Wesemann, "Placeholder Estimates for MagLev Forecasts for internal use only," October 22, 1999.

[21] A mode split model calibrated for Connecticut DOT's 1994 study of the I–95 crossing of New Haven Harbor was applied to the placeholder ridership.

[22] To correspond with the representative alignment, placeholder ridership for stations at Riverside, Mid-Corridor and West LA was removed from the estimate used for operating costs.

The technologies with smaller section sizes generally can achieve a higher load factor at their economically optimal size because of “rounding”; i.e., a fixed consist closer to the economic optimum is more likely to be achievable. Over a specific alignment, average load factor could also be improved by tailoring the service to demand by turning back some trains short of the termini. Because of the very preliminary nature of the assumed ridership, it was not appropriate to attempt such an adjustment for this comparison.

The operating costs for the representative alignment were estimated using equations developed to approximate the results of the FRA’s Commercial Feasibility Study (CFS) for intercity service[23]. The costs were adjusted to 1998 dollars and assumed a saving of $5.33 per originating trip for passenger service-related expenses, relative to the standard “intercity” service assumptions in the CFS. This reduction represents decreased expenses for ticketing, reservations, marketing and service planning, and baggage handling. Other cost adjustments were made for specific technologies, as follows:

- Additional expenses were added for AMT and Meneren for the ongoing maintenance of their active tilt mechanisms.
- Additional expenses were added for Meneren for maintenance of the load-bearing (vertical) and guidance (horizontal) wheels.
- Electrical energy power cost savings relative to Transrapid were applied for each of the three other technologies, based on power consumption as estimated by PTG.
- Guideway maintenance cost savings relative to Transrapid were applied for each of the three other technologies.

The specifics of the above assumptions are in Appendix B. Table 3-3 shows the following estimated operational statistics (in 1998 dollars) for the representative route for all four candidate technologies:

- The net change in operating margin, i.e., passenger revenues less operating expenses. An increase in this amount would be available to offset investment in the fixed facilities. It accounts for differences including passenger revenue, passenger service expense, energy consumption, and maintenance of vehicles and guideway.

[23] Allen, Duncan W., “Cross-Corridor Comparison of Operating Costs for High-Speed Ground Transportation,” *Transportation Research Record 1584*, Transportation Research Board, 1997, p.8.

- Annualized value of potential savings in guideway construction This was estimated as seven percent of the construction cost savings relative to TRI, as described in Appendix B. Seven percent is the primary discount rate suggested by FRA for use in the Program.[24]

- Average operating expense per passenger-km.

- Annualized cost of vehicles, as estimated in Appendix B, assuming a 25-year service life for vehicles.

- Annual operating and vehicle expenses per passenger-km, including construction cost savings. This measure was the basis for assigning O&M points.

- Annualized value of the expected financial risk, including carrying costs of infrastructure between construction and revenue service, and loss of value of the Federal contribution, in accordance with assumptions in Appendix B.

In general, the direct annual contributions from changes in the operating margin are of the same order as the annualized savings in guideway construction. Treated on a per passenger-km basis, the combined relative annual operating savings estimated by PTG for the three U.S. technologies, if they perform as indicated by the suppliers, would be: 6.6% for AMT; 6.8% for Maglev 2000; and 12.8% for Meneren.

These potential savings are significant relative to an intercity travel market now dominated by airlines, whose aggregate annual productivity change of 1 to 2 percent continues to stimulate considerable change in the airline industry. If any of the candidate U.S. technologies were already proven at 240 mph or more, and if the cost savings were substantiated by actual construction and operating experience, the savings would make a strong case for that technology. As it now stands, a fair comparison requires taking into account the technological risk associated with the unproven systems. PTG's primary tool for doing this was to develop stochastic forecasts of a revenue service date, as described in subsection 3.2. The inherent assumption in PTG's evaluation was that each of the U.S. technologies can ultimately be proven; there can be, of course, no guarantee that this is the case (see Technical Appendix C).

[24] Handout provided at FRA Workshop III, August 24, 1999.

3.5 Ability to Support Development of the Project Description

Because of unforeseen difficulties with delivering MTIRs to suppliers, responses were provided well after the date originally requested. PTG made follow-up calls to suppliers from which no response had been received as of October 31, 1999 (TRI and AMT). TRI indicated that it was completing a response, which was received November 1, 1999. AMT did not indicate that it planned to respond. To avoid having to eliminate a candidate supplier, information provided to PTG by AMT for another corridor (Atlanta Regional Commission’s proposed Atlanta–Chattanooga project) was borrowed with permission for evaluation purposes.

All responses defined the vehicle and guideway systems adequately, and were assigned 1 point; AMT and Meneren provided good information on design parameters, and were assigned 2 points; Maglev 2000’s response in this area was incomplete, and was assigned only 1 point. Only TRI has measured environmental (e.g., noise) data available; 2 points were assigned.

Points for overall quality, completeness, and timeliness were assigned as follows: TRI, 5; Maglev 2000, 4; Meneren, 3; and AMT, 2.

Section

4

EVALUATION SUMMARY AND RECOMMENDATIONS

Table 4-1 sums the rating points assigned for each criterion for each candidate technology in section 3. Overall, Transrapid ranks highest, with AMT in second place, and the other two U.S. technologies close behind. Although Transrapid is outperformed "by the numbers" in terms of the FRA operational criteria, its advantage in terms of revenue service availability put it in first place from an FRA perspective, even when U.S. economic benefits were considered.

In terms of local considerations, AMT and Transrapid tied; the U.S. technology's likely (but unproven) superior economics are at least balanced by its considerably higher technological risk.

TRI has demonstrated a superior ability to provide necessary information for the SCAG corridor's Project Description.

Table 4-1 – Summary of Candidate Technology Evaluation

	AMT	Maglev 2000	Meneren	TRI
Total points for operational comparison on FRA criteria (from Table 3-1)	15	12	13	9
Total points for "timely implementation" (from Table 3-2)	0	1	3	20
Total points for economic benefits to the U.S. (from section 3.3.)[25]	15	15	15	12
Total points for operational considerations (see Table 3-3)	15	12	8	15
Rating of MTIR	2	4	3	5
Detail of available information	3	2	3	5
Total Points	**50**	**46**	**45**	**66**

[25] Includes points for compliance with Program's technology transfer requirements.

In summary, then, PTG recommends that SCAG select the Transrapid technology for the corridor. The key considerations are:

- Transrapid can be implemented much sooner than the other technologies, and has no significant risk of outright technical failure.
- Transrapid is the only candidate technology which has demonstrated operation at greater than 240 mph.
- Transrapid can provide field measurements of many environmental effects, rather than simulations or analytical estimates.
- Transrapid has indicated an ability to meet the Program's requirements for technology sourcing and transfer.
- The expected operating cost advantage of the U.S. technologies is not dramatic in overall terms, and could therefore be reduced or eliminated by unexpected delays to technology developments.

Technical Appendix

A

REVENUE SERVICE ATTAINMENT MODEL

The model for estimating the cumulative probability distribution of the start of revenue service (as a function of calendar time) was a stochastic or "Monte Carlo" critical path method. PTG defined a sequence of 14 events (designated A through N) necessary for revenue service. For each event for each candidate technology (as well as for a baseline "ideal" technology), a cumulative distribution of event duration was assigned, and any other events that were necessary predecessors were identified. The total duration until the start of revenue service was designated by a "dummy" event, O. The information for each event is described here, with supporting information for its assumed duration distribution. Unless otherwise noted in the event descriptions, the duration distributions assigned for the four candidate technologies were identical.

A graphical summary of the model sequence appears in Figure A-1. Where two or more arrows lead to one event, the start of the event is assumed to occur at the conclusion of the later (or latest) of the preceding events.

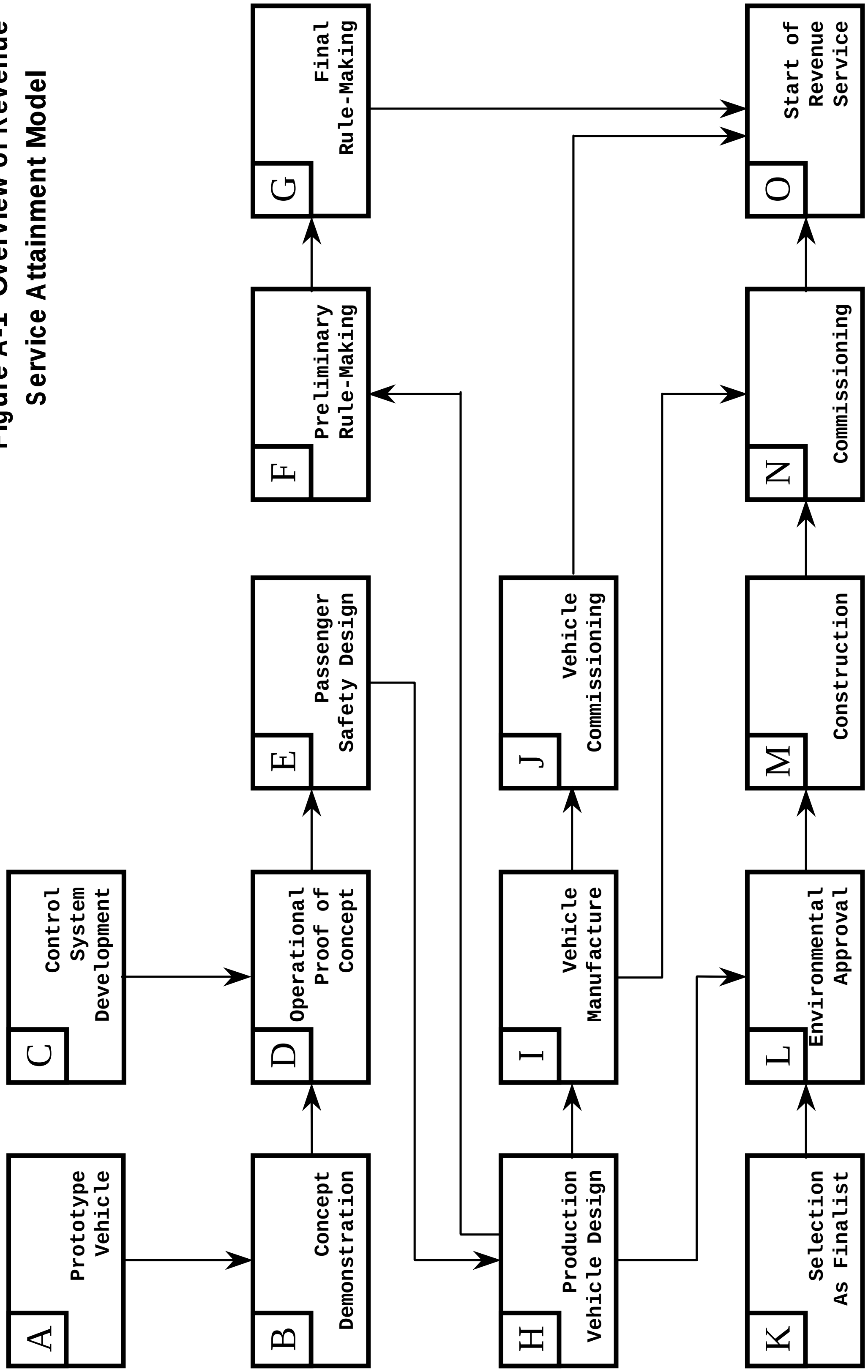
The general form of the cumulative duration distribution for an individual event was a *logit* curve of the form:

$$\text{Cumulative probability (duration} <= t) = 1.0/[1.0 + \exp(At + B)]$$

where t is the event duration in months, and A and B are parameters calibrated for each event. The general form was also subject to both a minimum (floor) value of t, and a maximum (ceiling) value of t.

The following sections describe how the model was constructed for each candidate technology and for a baseline ideal technology. The results of the model are described in section 3.2 of the Technology Selection Report.

Figure A-1 Overview of Revenue Service Attainment Model



Event A Prototype Vehicle Development

Event Definition: This event represents the completion of a full-scale version of a working vehicle, which can be demonstrated to reach a significant fraction of its intended design speed on a test guideway.

Event Duration: The duration distribution parameters and expected durations were as shown in Table A-1. These figures were derived from a combination of information provided by suppliers, and by PTG's assessment of engineering issues that require resolution before this event can be completed. Because of the skewed nature of the distributions to be calibrated, a third parameter, C, was added to the logit expression for this event; the expression "At + B" in the logit formula for this event should be replaced by "$At + B + Ct^{0.25}$". For Transrapid, the duration was set to zero for all cases, because this event has already occurred.

Table A-1 – Characteristics of Duration Distributions for Prototype Vehicle Development

	AMT	Maglev 2000	Meneren	Transrapid
A	0.1322	0.1799	0.1162	N/A
B	33.2266	49.8600	44.9515	N/A
C	-15.9251	-22.8157	-21.3677	N/A
Floor (months)	10.2	20.4	15.3	0.0
Ceiling (months)	84.0	144.0	108.0	0.0
Expected Value (months)	32.8	41.3	25.7	0.0

For the undeveloped U.S. technologies, the duration distribution parameters were calibrated from the following assumptions:

- The basic time required to develop the vehicle would be normally distributed, with a mean equal to that identified by the suppliers (shown in Table A-2), with a standard deviation equal to 25 percent of the mean.
- The minimum (floor) duration would be 85 percent of the time identified by the suppliers.
- The maximum (ceiling) duration would be four times the sum of the duration identified by the suppliers and the average time for technical issue resolutions.

- Additional time would be required to any resolve major technical issues which PTG associated with the technology, as shown in Table A-2. The natural logarithm of the resolution time for each issue was assumed to be normally distributed around the logarithm of the mean values shown in Table A-2, with a standard deviation of 30 percent of the logarithm of the mean. The result was further constrained to be not less than half the mean, nor more than five times the mean. Where two or more issues applied, it was assumed that the longest of the resolution times would be added to the basic duration of prototype development.

Table A-2 – Basis for Parameter Estimation for Prototype Vehicle Development

	AMT	Maglev 2000	Meneren
Mean development time (months)	12	24	18
Additional time to resolve high-speed power pickup	12	N/A	12
Additional time to resolve superconducting magnet operation	N/A	12	N/A
Additional time to resolve active tilt mechanism operation	6	N/A	6
Additional time to resolve blended multimode braking	9	N/A	N/A

Predecessor Event(s): None

Event B Concept Demonstration

Event Definition: This event represents a point at which all the key functions of an individual vehicle or train can be reliably demonstrated, including starting from and stopping at station platforms, switching, and operation at the intended design speed.

Event Duration: The duration distribution parameters and expected durations were as shown in Table A-3. The basis for deriving the parameters was similar to Event A as shown in Table A-4. For Transrapid, the duration was set to zero for all cases, because this event has already occurred.

Table A-3 – Characteristics of Duration Distributions for Concept Demonstration

	AMT	Maglev 2000	Meneren	Transrapid
A	0.7839	0.1285	0.5836	N/A
B	53.3664	24.5321	84.8169	N/A
C	-36.9410	-12.9381	-45.0291	N/A
Floor (months)	2.55	5.1	15.3	0.0
Ceiling (months)	24.0	36.0	84.0	0.0
Expected Value (months)	6.3	20.1	23.3	0.0

Table A-4 – Basis for Parameter Estimation for Concept Demonstration

	AMT	Maglev 2000	Meneren
Mean development time (months)	3	6	18
Additional time to resolve high-speed wheel dynamics	N/A	N/A	3
Additional time to refine secondary suspension	3	3	3
Additional time to resolve electromagnetic switching	N/A	12	N/A

Predecessor Event(s): A

Event C Control System Development

Event Definition: This event represents the development and validation of a control system meeting modern safety requirements and providing automatic train operation, automatic train protection, route integrity checking, and route supervision with multiple trains.

Event Duration: The duration distribution parameters and expected durations were as shown in Table A-5. They are derived from the experience of train control system development and reflect the assumption that a completely new control system built “from scratch” has often taken about 10 years to develop and install (e.g., London Transport’s Jubilee Line, BART’s AATC system, or BC Transit’s Skytrain). About half this time is typically necessary to bring such a system to a pilot demonstration, essentially the point represented by this event in the model. For modern systems that adapt or are rooted in mature commercial product lines (such as Adtranz, Alcatel, or MATRA), total design and implementation time can be on the order of five years, so that 30 months might be considered a typical value for this event. The principal assumptions made about each technology to derive a mean duration for this event are as follows:

- AMT's proposed train control system incorporates many new elements and ideas; it is essentially "from scratch" (i.e., 60 months).
- Maglev 2000 proposes to adapt a control system from existing commercial products. PTG added 6 months to the mean duration, however, because this technology proposes to incorporate electronic switching, which means that time-tested approaches to electromechanical switching will have to be revised.
- Meneren proposes to adapt available commercial technology, so was assigned the expected duration of 30 months.
- TRI will use a proprietary control system developed for MAGLEV. Given the advanced status of this system (many functions have been tested at the Emsland test track), PTG applied a 36-month adjustment to the expected mean, resulting in 24 months.

The distribution of event duration around the mean was based on the experience of nine selected control system development projects, whose estimated time to the pilot stage ranged from one-half to twice the mean. All technologies were assumed to have the same distribution relative to their means, which accounts for the values of parameter B in Table A-2 having the same value. Because Maglev 2000 and Meneren had the same assumed means, all their parameters are identical.

Table A-5 – Characteristics of Duration Distributions for Control System Development

	AMT	Maglev 2000	Meneren	Transrapid
A	-0.0554	-0.0923	-0.0923	-0.1384
B	3.3220	3.3220	3.3220	3.3220
Floor (months)	30	18	18	12
Ceiling (months)	120	72	72	48
Expected Value (months)	62.5	37.5	37.5	25.0

Predecessor Event(s): None

Event D Operational Proof of Concept

Event Definition: This event represents a point at which all system functions can be reliably demonstrated and shown to be safe. Demonstration passenger service using a section of guideway with two or more stations may commence after this point, but not as a certificated common carrier.

Event Duration: The estimated duration parameters are shown in Table A-6. The common B coefficient represents a characteristic distribution shape derived from the development history of selected transportation technologies. The basic value used for the U.S. technologies was the geometric mean (22.58 months) of values derived by information supplied by AMT and Meneren. These suppliers have experience with actual prototype vehicles, and PTG considered their assessment more realistic than Maglev 2000's much lower value. For Maglev 2000, PTG assigned 2 additional months to the base value, resulting in 24.58 months. Given the status of TRI's development, its corresponding value of 8 months was applied.

Table A-6 – Characteristics of Duration Distributions for Operational Proof of Concept

	AMT	Maglev 2000	Meneren	Transrapid
A	-0.12816	-0.11773	-0.12816	-0.36173
B	2.89385	2.89385	2.89385	2.89385
Floor (months)	17	19	17	6
Ceiling (months)	60	64	60	16
Expected Value (months)	25.7	28.0	25.7	8.9

Predecessor Event(s): B and C

Event E Passenger Safety Design

Event Definition: This event represents the design and validation of measures to ensure passenger safety within the envelope of the design vehicle, including location and operation of emergency devices, passenger evacuation procedures and equipment, failure modes and effects analysis, and vehicle crashworthiness and collision energy management analyses.

Event Duration: The duration distribution for the non-baseline technologies was calibrated around a most likely value of 8 months, with a standard deviation of 2.4 months. For TRI, the values were assumed to be only one-half of these values, because a preproduction safety design has already been designed and installed in the TR08 vehicle. Minimum (floor) values were set at half the most likely value, and maximum (ceiling) values at twice the most likely value. For TRI, the ceiling value was kept at 16 months to reflect the risk that U.S. safety requirements might pose a challenge not already addressed in the TR08 design.

Table A-7 – Characteristics of Duration Distributions for Passenger Safety Design

	AMT	Maglev 2000	Meneren	Transrapid
A	-0.66325	-0.66325	-0.66325	-1.3795
B	5.9499	5.9499	5.9499	5.5436
Floor (months)	6.0	6.0	6.0	3.0
Ceiling (months)	16	16	16	16
Expected Value (months)	9.15	9.15	9.15	4.18

Predecessor Event(s): D

Event F Preliminary Rule-Making

Event Definition: This event represents the development and publication of a preliminary FRA Rule of Particular Applicability for the technology in a specific corridor.

Event Duration: The duration distribution parameters were: A = -0.7013; B = 6.201; floor = 4.5 months; ceiling = 18 months. These values were calibrated from an assumption of a most likely value of 9 months, with a standard deviation of 2.7 months. The expected value of the duration with this distribution is about 8.9 months. For Transrapid, a reduction to two-thirds of the duration estimated by the distribution was made if the later of the event's two predecessors was later than June 2004, by which time TRI expects to have German approvals substantially complete. The test results supporting these approvals will probably speed the FRA rules development process.

Predecessor Event(s): H

Event G Final Rule-Making

Event Definition: This event represents the development and publication of a final FRA Rule of Particular Applicability for the technology in a specific corridor, including the incorporation of any comments or hearings input on the preliminary rule.

Event Duration: The duration distribution parameters were: A = -0.6002; B= 6.559; floor = 6 months; ceiling = 18 months. The expected value of the duration with this distribution is about 11 months.

As summarized in Table A-8, the duration distribution was calibrated from the experience of recent FRA rules development.

Table A-8 – Supporting Data for Final Rule-Making

FRA Rule or Order	Date of Preliminary Rule	Months from Notice of Preliminary to Publication of Final
Two-way end of train devices	02/21/96	10.3
Passenger safety standards	09/27/97	8.5
Railroad communications	06/26/97	14.5
Emergency preparedness	02/24/97	14.3
Track standards	07/03/97	11.6
Northeast corridor 150 mph operation	11/20/97	10.0
Locomotive “ditch lights”	08/28/95	7.3

Predecessor Event(s): F

Event H Production Vehicle Design

Event Definition: This event represents the evolution of the development vehicle design into one for fully operational and safe vehicles intended for operation in the SCAG corridor, including incorporation of passenger safety features, with the seating configuration and passenger amenities suitable for the intended service.

Event Duration: The duration distribution was given a shape to correspond to the distribution of the estimated design periods for actual high-speed rail and MAGLEV vehicles around an assumed central value of 24 months. The duration distribution parameters were: A = -0.1822; B = 4.9259; floor = 11.0 months; ceiling = 36.0 months. The expected value of the duration with this distribution is about 26.3 months. For Transrapid, the estimated value was reduced by 50 percent to reflect that supplier’s prior experience with vehicle prototyping and manufacturing. This is approximately the ratio of “evolutionary” high-speed rail designs (such as the British ATP, French TGV, and German ICE) to a single generation of MAGLEV project vehicles (Transrapid, HSST, and the Japanese MDI technology).

Predecessor Event(s): E

Event I Vehicle Manufacture

Event Definition: This event begins with execution of a contract to purchase vehicles and ends with the delivery of the total fleet of initial production vehicles for the SCAG corridor.

Event Duration: For each technology, a similarly-shaped duration distribution (i.e., equal value of B) was assumed to apply around a base value. In each case, the floor was set at 75 percent of the base value, the ceiling was set at twice[1] the base value, and the basic distribution for calibration was a normal distribution with a mean equal to the base value and a standard deviation equal to 20 percent of the base value. Table A-9 shows the assumptions underlying the base values and the parameters for the distributions.

Table A-9 – Characteristics of Duration Distributions for Vehicle Production

	AMT	Maglev 2000	Meneren	Transrapid
Production effort per train in equivalent TRI vehicle sections[2]	8.79	6.16	4.75	8.0
Sections per train (consist)	8	11	20	8
Trains required for service[3]	20	26	45	26
Months per TRI equivalent section	0.185	0.200	0.175	0.150
Base value (months)	30	30	45	30
A	-0.3005	-0.3005	-0.2003	-0.3005
B	8.8915	8.8915	8.8915	8.8915
Floor (months)	22.5	22.5	33.75	22.5
Ceiling (months)	60	60	75	60
Expected Value (months)	30.0	30.0	44.9	30.0

Data supporting the assumed values of production time per TRI section equivalent is shown in Table A-10. For initial production runs of vehicles,

[1] A slight downward adjustment was made for ceilings over 60 months.
[2] 6.25% of relative effort is assumed to vary with the number of sections per consist, the remainder in proportion to seats per consist.
[3] To carry estimated passengers at the estimated load factor (see Table 2-1), including 10 percent spares.

production rates are generally lower than for succeeding series. Similarly, production rates are lower for smaller quantities.

Table A-10 – Supporting Data for Vehicle Production

Technology	TRI Section Equivalents[4] per Month – first production run	TRI Section Equivalents per Month – second production run	Months per Section Equivalent – first run	Months per Section Equivalent – second run
British High Speed Train (HST)	6.0	9.2	0.167	0.109
German InterCity Express A	5.9	N/A	0.169	N/A
Italian ETR-450	3.6	N/A	0.278	N/A
French TGV-A	N/A	8.75	N/A	0.114
Proposed Texas TGV	5.4	N/A	0.185	N/A
Average (mean)	5.225	8.975	0.200	0.112
Standard Deviation	1.115	N/A	0.053	N/A
Coefficient of Variation[5]	0.213	N/A	0.263	N/A

Predecessor Event(s): H

Event J Vehicle Commissioning

Event Definition: This event represents the acceptance of the total production vehicle fleet by the operating entity, including full-speed testing in the corridor. In practice, only the acceptance of the final "batch" of production vehicles will count toward the revenue service date, because the acceptance testing of earlier deliveries is assumed to be parallel with the production of later vehicles.

Event Duration: The duration distribution parameters were. A = -1.3362; B= 5.2550; floor = 3 months; ceiling = 8 months. The basic underlying assumption is a normal distribution with a mean of 4.0 months and a standard deviation of 1.2 months, for all technologies. The expected value of the duration with this distribution is about 4.2 months.

[4] Power car counted as 2.0 section equivalents, trailing coach as 0.75, electric multiple unit (EMU) as 1.0.
[5] Ratio of standard deviation to the mean.

Predecessor Event(s): I

Event K Selection as Finalist

Event Definition: This event represents the time at which the FRA is assumed to select SCAG's corridor for implementation. The minimum value of 12 months represents a 9-month allowance to prepare the Project Description, counting from October 1999, and three months for the FRA to make a decision. The parameters were calibrated to fit a total duration of 12 months plus the larger of two exponentially distributed delays with a mean of one month each (one for the Project Description process, one for the FRA decision). This assumption is intended to reflect two processes with a high internal incentive for avoiding delays, and some ability to accommodate for delay in the Project Description by accelerating the decision-making process. The likelihood of the total duration exceeding 20 months under these assumptions is vanishingly small; therefore a 20-month maximum was assumed.

Event Duration: The duration distribution parameters were: A = -1.6259; B= 21.981; floor = 12 months; ceiling = 20 months. The expected value of the duration with this distribution is about 13.6 months.

Predecessor Event(s): None

Event L Environmental Approval

Event Definition: This event represents the time necessary to obtain the required environmental approvals for construction of the corridor, including local environmental studies and construction permitting.

The duration distribution assumed a most likely planned duration of 12 months, and that the distribution of the actual duration would have a similar relationship to this planned value as does the system construction (see Event M). This was based on an assumed approval of 18 to 24 months of environmental study work being complete before the predecessor events. It represents a typical planned environmental permitting timeframe for a large transportation project.

Event Duration: The duration distribution parameters were: A = -0.3653; B = 6.3563; floor = 10.0 months; ceiling = 36.0 months. The expected value of the duration with this distribution is about 17.6 months.

Predecessor Event(s): K and H

Event M System Construction

Event Definition: This event represents the time required to construct a guideway-based transportation system, from environmental approval to the substantial completion of construction and the ability to begin full system testing.

Event Duration: The duration distribution parameters were: A = -0.1212; B = 6.2177; floor = 32 months; ceiling = 80 months. The expected value of the duration with this distribution is about 51.8 months; which reflects the reality that most large public projects require longer to construct than even the most careful preconstruction estimates.

The duration distribution was derived from the experience of 16 transit projects, as summarized in Table A-11. The expected ratio of actual to planned construction timeframes was applied to an assumed construction period of 36 months, based on the three-year sequence of major expenditure anticipated in the FRA program.

Table A-11 – Supporting Data for System Construction

Project	Planned Construction (years)	Actual Construction (years)	Ratio of Planned to Actual
WMATA rapid transit	8	15	1.875
MARTA rapid transit	6	12	2.000
MTA (Baltimore) RT	6	12	2.000
Miami rapid transit	6	7	1.167
Buffalo LRRT	5	8	1.600
PAT LRT (Pittsburgh)	5	8	1.600
Portland Tri-Met LRT	5	6	1.200
Sacramento LRT	3	5	1.667
Miami people-mover	3	5	1.667
Detroit people-mover	3	5	1.667
Edmonton LRT	5	4.8	0.960
Calgary South LRT	4	4	1.000
San Diego South LRT	2.25	2.25	1.000
Baltimore CLRL	3.1	4.2	1.355
Denver starter LRT	3	2.9	0.967
Dallas starter LRT	6.5	7	1.077

Predecessor Event(s): L

Event N Commissioning

Event Definition: This event represents the time required from substantial completion of construction to readiness for revenue service. It includes activities such as control system and auxiliary system (e.g., fare collection and public address) testing, verifying the dynamic clearance envelope, and acceptance testing of fixed infrastructure.

Event Duration: The duration distribution parameters were: A = -1.1311; B = 6.8588; floor = 5.0 months; ceiling = 12.0 months. The expected value of the duration with this distribution is about 6.3 months.

The duration distribution was calibrated from the experience of urban transit projects, and was based on an assumed most likely duration of 6 months, normally distributed with a standard deviation of 1.5 months. It was assumed, however, that no less than 5 months would be required and that the duration would in no case exceed 12 months.

Predecessor Event(s): I and M

Event O Start of Revenue Service

Event Definition: This event represents the commencement of MAGLEV service "for hire," i.e., collecting fares for passenger transportation on the initial "project" portion of the SCAG corridor.

Event Duration: The duration of this event is assumed to be zero. It is a logical or "dummy" event used to collect the latest of its three predecessors to determine the total duration from October 1999 to the start of revenue service.

Predecessor Event(s): G, J and N

Model Application to an "Ideal" Technology

An ideal situation for the Program would be for a mature, commercially-proven MAGLEV technology already to be available in the U.S. To provide a basis for a maximum ranking value for the FRA criteria, PTG applied the Revenue Service Attainment Model to estimate the revenue service date distribution assuming such a technology existed. To do this, PTG made one of the following assumptions for each event for the "ideal" technology as shown in Table A-12.

- The event would have zero duration because it would already have occurred or would not be applicable to the ideal technology (“Zero” in Table A-12).
- The event would have the characteristics of the baseline technology (“TRI” in Table A-12).
- The event would have the same distribution as all the other technologies (“General” in Table A-12).

Table A-12 – Assumed Characteristics of “Ideal” MAGLEV Technology

Event	“Ideal” Assumption
A	Zero
B	Zero
C	Zero
D	Zero
E	Zero
F	Zero
G	Zero
H	TRI
I	TRI
J	General
K	Zero
L	General
M	General
N	General

Technical Appendix

B

OPERATING, MAINTENANCE AND CONSTRUCTION COSTS

The choice of a MAGLEV technology will influence both the annual operating and maintenance (O&M) expenses of the system, which will consume revenues that could otherwise be applied toward the initial system investment and the size of the initial investment itself. In addition to the direct initial cost for guideway infrastructure and vehicles, the potential risk of development costs and carrying costs for the less mature MAGLEV technologies must be considered.

Operating Costs

Operating costs for high-speed ground transportation are strongly determined by factors other than the specifics of the technology selected:

"Such factors as traffic volume, route length, passenger-miles per train-hour, and average trip length strongly influence the…expense levels"[1].

To make a fair comparison among these technologies, these factors should be considered to establish a baseline for comparison, and then the differences attributable to the technologies should be isolated. PTG implemented this approach by constructing a baseline as follows:

- Made a preliminary "placeholder" estimate of system passenger boardings and annual passenger-km from the early work on passenger demand. According to this estimate, for a 129.6-km system from March Air Reserve Base to LAX, with intermediate stops at LAUPT and Ontario International Airport, annual boardings in the year 2020 will be about 34 million, generating about 2 billion passenger-km.
- Estimated baseline annual operating costs in 1993 dollars using a formula shown to track closely with the typical results of the FRA's

[1] U.S. Department of Transportation, Federal Railroad Administration, *High-speed Ground Transportation for America*, September 1997, pp. 7–13.

Commercial Feasibility Study (CFS)[2]. Applying this formula directly[3] with an adjustment for passenger service expense, annual costs for maintenance of way were estimated at $10 million, and for all other expenses, $201 million. PTG adjusted the estimated expenses for passenger service downward by $5.33 (1993) per boarding passenger, to reflect that the expenses for ticketing, reservations, and baggage service on SCAG's intra-regional system will probably not be so high as those for typical intercity services modeled in the CFS.

- Converted 1993 dollars to 1998 dollars by applying a factor of 1.129, based on the Consumer Price Index between June 1993 and June 1998.

In 1998 dollars, baseline operating and maintenance costs were estimated at $238 million, or about $0.12 per passenger-km. Additional reductions from this level would probably be attainable as services and stations are tailored to the estimated demand. However, these changes would not significantly change the relative positions among the candidate technologies.

PTG examined the potential for the effects of technology on three significant components of operating expense: energy consumption, transportation costs related to average speed, and guideway maintenance expense.

Energy Consumption

The models used to estimate operating speeds for the candidate technologies over the representative route also estimated trains' electric power consumption at the vehicle. Power factors and transmission and distribution of the energy result in an efficiency of less than 100 percent; previous research has suggested that electrodynamics (EDS) systems such as those proposed by the U.S. suppliers may be able to achieve a higher efficiency than TRI. Table B-1 shows the average unit power consumption and energy cost (in 1998 dollars at a rate of 9.74 cents per kilowatt-hour, the average rate paid in 1998 for operation of Los Angeles area rapid transit and LRT services) as estimated by these models.

[2] Allen, Duncan W., "Cross Corridor Comparison of Operating Costs for High-speed Ground Transportation," *Transportation Research Record 1584*, Transportation Research Board, p. 8.

[3] Assuming a route length of 127 km, an average operating speed of 50.1 m/s (TRI's value in Table 3-1), and an average load factor of 54.3 percent.

Table B-1 – Estimated Unit Energy Consumption and Costs for Representative Alignment

	AMT	Maglev 2000	Meneren	TRI
Energy consumption per seat-km (kW)	0.031	0.037	0.031	0.047
Transmission and distribution efficiency [4] (%)	88%	88%	88%	83%
Energy cost per passenger-km (1998 cents)	0.67	0.77	0.63	1.03

To compare operating costs, PTG assumed that TRI will exhibit costs equivalent to the baseline, and that net changes for the other technologies relative to TRI will represent their differences from the baseline.

Transportation Costs Related to Speed

The higher average speeds offered by the U.S. technologies would allow more revenue seat-km (RSK) to be delivered per revenue seat-hour (RSH) in service. Because the formula used to generate costs for the baseline explicitly uses both quantities, they were substituted for the baseline (TRI) values to estimate changes in costs.

Increases in average speed will also likely lead to increased system ridership, which in turn will reduce unit costs by spreading fixed system costs over a larger ridership base. Baseline station-to-station ridership was assumed to be equal to the preliminary placeholder ridership estimate developed in the first few weeks of the project. To represent the differences among technologies, PTG made assumptions about typical access times to and from the MAGLEV line for each of the five trip purposes[5] used in the placeholder estimates. A mode split model from a previous PTG project[6] was applied to estimate a MAGLEV "utility" for the average trip length for each purpose. The same formula was used to estimate the utility of each purpose for each nonbaseline technology, by substituting the MAGLEV travel times for that technology. The adjusted ridership for each purpose for each nonbaseline technology was estimated as the baseline ridership times the ratio of the utility for the nonbaseline technology to the baseline utility.

[4] Values borrowed from U.S. Army Corps of Engineers Report 98–12, "Technical Assessment of Maglev System Concepts," Table 28, p. 87. The value for the U.S. technologies is the average of the table's values for the Bechtel and Foster-Miller system concept designs.

[5] The investment-grade forecasts under development for the corridor will likely employ as many as 12 trip purposes and will make use of detailed network and land use data.

[6] The alternatives screening process for the EIS for the I–95 New Haven Harbor Crossing, Connecticut DOT.

Table B-2 shows the estimated changes in ridership and unit transportation and maintenance of equipment operating costs[7]. The higher-speed (active tilt) technologies may attract as much as 10 percent additional ridership, according to PTG's methods. The change in transportation and maintenance of equipment operating cost per passenger-km appears to be of the same order, a 10 to 15 percent reduction. The generally low cost is consistent with the high passenger traffic density inherent in the placeholder demand estimates. In the CFS MAGLEV case studies[8], for example, these unit costs ranged between $0.021 and $0.042 per passenger-km (1998 dollars).

Table B-2 – Transportation Cost Comparison for Representative Alignment

	AMT	Maglev 2000	Meneren	TRI
Annual boardings (thousands)	37,698	34,315	38,017	34,416
Transportation and maintenance of equipment cost ($1998 thousands)	49,609	43,793	48,856	48,985
Transportation and maintenance of equipment cost per passenger-km ($1998)	0.022	0.021	0.021	0.024

Guideway Maintenance Expense

The technology selected can be expected to affect three components of maintenance-of-way expense:

- Inspection of the guideway to ensure that it is within required mechanical tolerances. These tolerances vary among the candidate suppliers.
- Routine maintenance and repair of guideway components.
- Programmed replacement of guideway components.

PTG assessed possible cost reductions from a TRI baseline for six categories of expense, as shown in Table B-3. The proportions of total expense were based on cost estimating relationships from the CFS; the identifying activity number (four digits in parentheses) is shown for

[7] Excluding maintenance of way, passenger service, and general and administrative expenses.
[8] U.S. DOT, *op. cit.*, statistical supplement pages 1–33.

reference[9]. For two of these activities, PTG applied a rule for scaling the relative costs, as follows:

- Program maintenance was reduced based on the relative annual millions of gross tons (MGT)[10] on the guideway, according to a typical relationship from the CFS, whereby cost is assumed to be proportional to the expression

$$67.3 + (5 + MGT)^{0.7}$$

Table B-3 – Guideway Maintenance Cost Breakdown Comparison

Item and CFS Activity Code	TRI (Baseline) (%)	AMT (%)	Maglev 2000 (%)	Meneren (%)
Program maintenance of structures (1403)	42.2	38.7	39.8	41.0
Routine repair (1205)	24.1	21.9	21.8	18.9
Power repair (1604)	16.7	16.7	16.7	16.7
Control ducts and backbone (1803)	2.3	2.3	2.3	2.3
Continuous control elements (1814)	6.6	6.6	6.6	6.6
Physical inspection (1201)	8.1	3.2	0.3	3.2
Total	**100.0**	**89.4**	**87.5**	**88.7**

- Routine repair expense was assumed to be proportional to unit construction cost as described below.

- Physical inspection requirements were assumed to be inversely proportional to the vertical air gap normally maintained between the magnets and stator when operating.

Other activities were assumed to remain at the baseline level. The estimated MGT for each technology was based on the average loaded weight of each technology's assumed consist[11] and a number of daily departures yielding the lowest unit operating cost for that technology while

[9] U.S. DOT, Draft Appendix EXP, Commercial Feasibility Study, Operations and Maintenance Cost Model, June 1995.

[10] The use of this traditional railroad unit, based on English units, was retained from the CFS.

[11] "Consist" as used here is a railroad/technical term, a noun meaning what a train consists of, i.e., how many locomotives and cars, or in the case of MAGLEV technology, how many vehicle sections in a train.

maintaining a 20-minute maximum headway: 22 MGT for AMT; 27 MGT for Maglev 2000; 33 MGT for Meneren; and 40 MGT for TRI.

The total results in Table B-3 indicate a potential savings of 11 to 13 percent in guideway maintenance expenses for the U.S. technologies. These factors were applied to the baseline maintenance of way cost factor in the baseline estimate.

System Construction Costs

The U.S technologies offer the prospect of initial construction cost savings as well as reduced operating costs per passenger-km. Direct costs for vehicles will have a small effect on overall system costs, which could be increased depending on how development costs for the less developed technologies are assigned.

Guideway Construction Costs

Reductions in guideway costs relative to the baseline (TRI) will result primarily from a less complex electrical and electronic arrangement of the guideway. The lower unit weights of these vehicles will also permit a less massive structure to be constructed.

The NMI and subsequent work by the U.S. Army Corps of Engineers has established that a baseline dual elevated guideway for the TRI technology can be expected to cost about $12.4 million (1998) per kilometer to construct, exclusive of right-of-way, stations, and support facilities. This will most likely be distributed among various components as shown in the “Baseline” column in Table B-4.

Although some U.S. suppliers have offered estimates of the construction costs for their systems, these do not have the benefit of significant actual construction history to validate them. PTG chose to adjust the baseline costs as follows:

Table B-4 – Construction Cost Breakdown Comparison

	TRI (Baseline)	AMT	Maglev 2000	Meneren
Structural	54%	48%	53.0%	43.0%
Magnetics	21%	18%	12.5%	10.5%
Electrical (power)	18%	18%	18.0%	18.0%
Communications and signals	7%	7%	7.0%	7.0%
Total	**100%**	**90%**	**89.5%**	**78.5%**
Estimated construction cost per km (thousands $1998)	12,370	11,260	11,190	9,710

- Adjust the structural portion of the baseline cost for the reduced vehicle loadings of the U.S. technologies
- Adjust the magnetics portion of the baseline cost for the simpler wayside arrangements of the U.S. technologies

The results shown for the U.S. technologies in Table B-4 are expressed as fractions of the total baseline cost allocated for each component. In PTG's opinion, no significant change to the unit cost for the electrical (traction power) or communications and signal components can be presumed based on the differences among the technologies. Therefore, the "Total" line in Table B-4 should indicate the potential construction costs that could reasonably be associated with the U.S. technologies relative to TRI.

Costs for the guideway structure (superstructure, supporting structure, and foundations) will be related to the vehicle characteristics, chiefly weight and length. A study from Carnegie-Mellon[12] University developed an applicable parametric model for estimating transit guideway construction costs.

PTG applied this relationship, using the vehicle characteristics in Table 2-1. The resulting values are shown in Table B-4. They indicate savings of about 11% for AMT, 2% for Maglev 2000, and 20% for Meneren. These results are generally consistent with the savings of 18.7 percent implied by estimates by the U.S. Army Corps of Engineers for a generic "U.S. MAGLEV" on elevated guideway[13], assuming the best

[12] Hoel, Lester A., et. al., *Urban Rapid Transit Concepts and Evaluation*, Transportation Research Institute, Carnegie-Mellon University, 1968, pp. 31 ff.
[13] U.S. Army Corps of Engineers, *op cit* ., Table 53, p. 165

characteristics of four system concept designs offered to the government in 1993.

The relative cost reduction assumed for the magnetics component was based on analogy with the U.S. Army Corps of Engineers' itemized cost estimates for TRI and three U.S. MAGLEV system concept designs. A typical LSM winding unit cost derived from the Corps' work ($1,195,100 per km per meter width) was prorated by winding width. Power rail costs were added, assuming the same costs as for brake rails in the Corps study. TRI was used as a baseline for structural costs. The resulting reductions are significant, and are more likely to overstate than to understate the savings achievable: 16% for AMT; 40% for Maglev 2000; and 51% for Meneren. The values in Table B-4 reflect these savings applied to the 21 percent of baseline construction cost allocated to magnetics.

Vehicle Costs

The significant differences in the sizes and operating principles among the candidate technologies will result in differences in initial costs for the vehicles. Although this cost may be small relative to the total for fixed facilities, it is worth considering.

Vehicle costs for MAGLEV technologies are a matter of some conjecture. In the U.S. Army Corps of Engineers report, costs for TRI and three U.S. technologies generally similar to the candidate technologies were estimated to cost between $69,300 and $141,200 per metric ton (1998 dollars); the estimated unit cost for the TR07 was $111,813. One candidate supplier, Maglev 2000, provided an indication of its expected costs. In Table B-5, these costs are compared with a "comparison value" computed by applying a formula derived from the Corps of Engineers' results to the train weight for the other technologies.

In PTG's opinion, these comparison costs may be on the low side because they do not include provisions to recover the very significant development costs for MAGLEV technologies. The section prices are only about twice (per ton) the cost of proven modern light rail transit (LRT) vehicles, for example.

Table B-5 – Comparison of Estimated Vehicle Capital Costs

	AMT	Maglev 2000	Meneren	Transrapid
Supplier-identified cost per metric ton	N/A	$140,000[14]	N/A	$111,813[15]
PTG comparison value [16] per metric ton	$116,631	$129,594	$160,525	$120,005
Sections per train	8	11	20	8
Estimated cost per train ($millions)	32.14	32.22	30.82	43.20
Number of trains	20	26	45	26
Scale factor for quantity purchase	1.020	1.000	0.978	1.000
Total direct vehicle cost ($ millions 1998)	651	838	1,349	1,123

To some extent, the additional costs for developing the technology will likely be borne by the purchaser, especially for the unproven systems. The German government has already invested on the order of $2 billion in the TRI technology, and private industry has provided hundreds of millions more. The moderate level of German testing and certification activity in late 1999 appears to be costing on the order of $650,000 per month. A recent proposal by AMT for a demonstration project including a 5–7 km test guideway indicated average monthly costs of a similar order.

To indicate the extent to which these costs might find their way into SCAG's ultimate cost, PTG estimated the 10th and 90th percentile number of months until the start of vehicle manufacture for each technology (refer to Appendix A), and applied a $650,000 monthly cost to this time.

For the less developed technologies which have not yet built test tracks for sustained high-speed testing, PTG estimated the cost of such a track (24-km guideway length), and added $45 million for test vehicles, right-of-way, and support facilities. PTG assumed that a share of these costs would be borne by the SCAG project. The possible values of the share would depend on the level of investment by the suppliers themselves, in respect of future sales, and the possible participation of states or agencies using the technology for other corridors. PTG's assumptions of the range of shares for each technology are shown in Table B-6.

[14] Derived from estimated costs presented by Maglev 2000 at the third Program workshop on August 24, 1999.
[15] Derived from data published in U.S. Army Corps of Engineers, *op.cit*., pp. 15–16.
[16] From formula fitted to above data and three other technologies evaluated by the National Maglev Initiative in 1993: Cost per MT = $282,560 F_{stator} / (MT^0.25), where F_{stator} is 1.10 for long-stator systems, 1.0 otherwise.

Table B-6 – Assumptions on Sharing of Test Track and Support Facilities Risk (for Nonbaseline Technologies)

	AMT	Maglev 2000	Meneren
Range in industry share[17]	0 – 35%	0 – 35%	0 – 35%
Range in remaining share by other agencies	0 – 25%[18]	25 – 50%[19]	25 – 50%[19]
Assumed range in SCAG share of costs	49.75 – 100.0 %	32.5% – 75.0%	32.5% – 75.0%

The risk ranges representing the above assumptions are shown in Table B-7. For the evaluation in the main body of the Technology Selection Report, the development risk was explicitly modeled by the Revenue Service Attainment Model described in Appendix A, by applying $650,000 to the number of months required up to Event I. The test track and support facility risks were assumed to be uniformly distributed between the minimum and maximum values shown in Table B-7.

Table B-7 – Vehicle Costs and Demonstration Cost Risks

	AMT	Maglev 2000	Meneren	Transrapid
Direct vehicle cost ($M) from Table B-5	651	838	1,349	1,123
Representative development risk range ($M)	87–135	79–108	79–108	38–59
Test track and support facility cost ($M)	315	314	278	342
Test track and support facility risk range ($M)	157–315	102–236	90–209	0[20]

[17] The 35% level represents German industry's contribution to the later development phases of Transrapid.
[18] Maximum assumes a second corridor would choose to underwrite 50% of the development costs of the technology at the mid-point of development.
[19] Assumes a second corridor (e.g., Maglev 2000 in Florida, or Meneren in Colorado) has a 50% chance of being built.
[20] Test track and support facilities are already in place in Emsland, Germany.

Technical Appendix

C

TECHNOLOGY ASSESSMENT PANEL

PTG's findings and recommendations on technology selection for the SCAG corridor were reviewed by an independent three-person Technology Assessment Panel (TAP). This appendix provides information on the TAP members, their individual roles and opinions, and the conclusions of the TAP as a group. No members of the TAP are employees of PTG or are employed by, or have a financial interest in, any of the candidate technology suppliers.

Members of the TAP

Christopher J. Boon
President
Boon, Jones, and Associates, Inc.
Glenburnie, Ontario, Canada

TAP Assignments:
TAP Chair, General Review, Specialty Review of Operating Costs and Technological Risks

Mr. Boon is an expert on project management, transportation systems evaluation, technology assessment and commercial proposal preparation, with over 25 years consulting experience. He established Boon, Jones, and Associates with Dr. Joseph Jones as an extension of a career of over 20 years with the Canadian Institute of Guided Ground Transport (CIGGT), a leader in the evaluation and research of high-speed rail and MAGLEV transportation in potential North American corridors. Mr. Boon held the following positions with CIGGT: Manager of Transportation Systems Research (1987–1994); Manager of Passenger Systems Development (1985–1987); and Manager of Track Structures Research (1979–1982). Before these management assignments, he served as both Research Assistant and Research Associate.

Mr. Boon's range and breadth of experience makes him an ideal choice for chairing the TAP. As a *project manager*, he has organized multidisciplined teams for assessment of technology options and life-cycle costs for complete and incremental high-speed rail (HSR), MAGLEV, and conventional passenger railroad systems. Between 1978 and 1997, he planned and executed *assessment of technology* capabilities, development status, and operational history for HSR, MAGLEV, rail transit, and people-mover systems. Mr. Boon has conducted complete *transportation systems evaluations*; he is currently a member of a World Bank Panel of Experts, advising China Railways on the proposed Beijing-Shanghai HSR. With another member of this panel, Mr. Boon developed an outline parametric model to structure the many tradeoffs among alignment criteria, rolling stock characteristics and performance, operating strategies, system capacity, and life-cycle costs.

Mr. Boon is the author of numerous papers and presentations on high-speed ground transportation to the TRB and other professional and research organizations. His prior experience in California includes being the project leader for technology assessment for the Las-Vegas–Southern California Corridor in 1986.

David N. Wormley
Dean, College of Engineering
Professor of Mechanical Engineering
Pennsylvania State University

TAP Assignments:
General Review, Specialty Review of Performance Comparison

David Wormley was named Dean of the College of Engineering at Penn State on July 1, 1992. He holds bachelors, masters, and doctoral degrees in Mechanical Engineering from MIT. Prior to joining Penn State, Dr. Wormley headed the Department of Mechanical Engineering at MIT from 1982 to 1991 and served as Associate Dean of Engineering at MIT from February 1991 through June 1992.

Professor Wormley's research focuses on the dynamic analysis, optimization and design of advanced control systems, transportation systems, and fossil fuel energy systems. His research has included the development of sensors and actuators for advanced control systems, control, modeling and simulation techniques and experimental evaluation technologies for both urban and intercity transportation vehicle and guideway systems. Recent research has focused on vehicle-track interaction analysis techniques for both magnetic vehicle systems and rail vehicles. His research is described in more than 100 papers and technical reports. He has served as a consultant to more than 25 companies in vehicle dynamics and advanced control systems.

Dr. Wormley serves on the Executive Committee of the National Research Council's Transportation Research Board. He served as chair of the Transportation Research Board Advisory Committee on the 1993 Railroad Research Needs Conference. He has served on the National Science Foundation Engineering Directorate Advisory Board. Dr. Wormley was the first director of the American Association of Railroads' Affiliated Research Laboratory at MIT.

Professor Wormley is a member of ASME, Sigma Xi, and Pi Tau Sigma, and serves on the editorial board of the *International Journal of Vehicle Mechanics and Mobility* and is associate editor of the *Journal of Engineering Education*. He received the 1997 ASME Dynamic Systems and Control Division Education Award. He has been the recipient of the ASME Lewis Moody Award, a NASA Certificate of Recognition, and is a Fellow in the American Society of Mechanical Engineers. He has co-authored two books, *Automated-Transit Guideways: Analysis and Design* and *System Dynamics: An Introduction*, a textbook published in 1996.

Steven P. Erie
Associate Professor of Political Science
University of California, San Diego

TAP Assignments:
General Review from a California perspective

In addition to his faculty position at UCSD, Steven P. Erie is a Senior Fellow at the Southern California Studies Center, University of Southern California. An authority on Southern California's trade infrastructure, Professor Erie recently has published:

- *International Trade and Job Creation in Southern California: Facilitating Los Angeles/Long Beach Port, Rail, and Airport Development* (1996)
- *Facing the Challenges of Expanding Southern California's Global Gateways* (with Edward Rodriquez, 1998)
- *A New Orange County Airport at El Toro: An Economic Benefits Study* (with John Kasarda and Andrew McKenzie, 1998)
- *Toward a Trade Infrastructure Strategy for the San Diego/Tijuana Region* (1999)

He currently is completing:

- *The LAX Master Plan: Facing the Challenges of Community, Environmental and Regional Airport Planning* (with Thomas P. Kim and Gregory Freeman)

- *A New Orange County Airport at El Toro: Catalyst for High-Wage, High-Tech Development* (with John Kasarda, Andrew McKenzie and Michael Molloy)

- *Global High-Speed Rail Projects: Lessons for California* (with Harold Brackman and Gregory Freeman)

- *Global Los Angeles: Growth and Crisis of a Developmental City-State.*

He is a member of the Governor's Commission on Building for the 21st Century, the Pacific Council on International Policy, and San Diego Dialogue.

TAP Opinions and Findings

The following documents are annexed to this appendix:

- Mr. Christopher Boon's specialty review of technological risk and operating costs
- Prof. David Wormley's specialty review of performance comparison
- Mr. Christopher Boon's review of the draft technology selection memorandum
- Prof. David Wormley's review of the draft technology selection memorandum
- Prof. Steven Erie's review of the draft technology selection memorandum
- TAP Chair's letter report on the Panel's findings

PTG is of the opinion that these documents speak for themselves, and that they confirm that the recommendation of Transrapid for the corridor is a sound one. In particular, the TAP's conclusions that the rating system employed is reasonable (see Prof. Erie's letter), and that PTG may have been generous in extending "credit" for unproven capabilities (see Mr. Boon's and Prof. Wormley's memoranda), provide additional support for the decision.

PTG has added footnotes to the appended documents to either address points raised therein, or to indicate how they were dealt with in this final version of the report.

EVALUATIONS BY TECHNOLOGY ASSESSMENT PANEL

BOON, JONES AND ASSOCIATES, INC.

MEMORANDUM

November 22, 1999

FROM: **Chris Boon**
TO: **DUNCAN ALLEN, PTG**
SUBJECT: **Comments arising from Review of Maglev 2000, MAGLIFT monorail, American Maglev and Transrapid International USA information packages**

1. I have completed my review of the material concerning Maglev 2000, MAGLIFT Monorail, American Maglev, and TRI you sent me. My comments in this memo concern the apparent development status of each of these concepts and the consequent levels of risk of technical failure, delay, and cost overruns attendant on each, as specifically mandated under Task A, Concept Review.

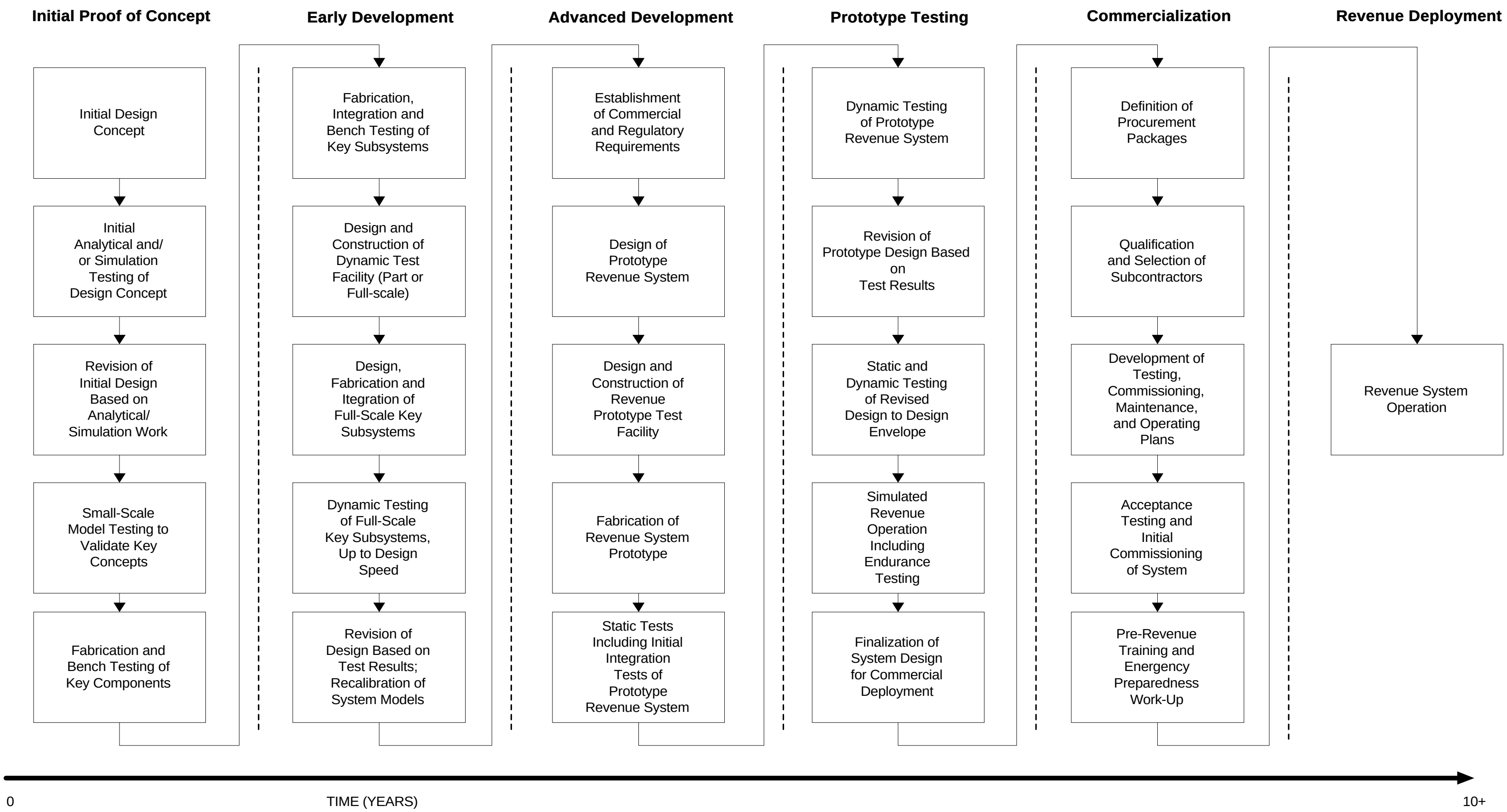
   To put my assessment in context, I have prepared the following generic diagram summarizing a typical development, testing, commercialization, and deployment process for an advanced ground transportation system. Note that this focuses on the technical development process and does not include institutional processes such as environmental permitting and other regulatory approvals, as these vary dramatically from jurisdiction to jurisdiction. This is based on my knowledge of the actual processes followed by SNCF and GEC-Alstholm with the TGV, by Transrapid with the TR-07/08, by JNR and its successor companies with the JR EDS system, and by Kawasaki with several recent versions of Shinkansen rolling stock.

   Note that for the steel-wheel-on steel-rail developments, there were existing operators with specific performance requirements and other specifications, while Transrapid was essentially a national "blue-sky" science-driven process, especially in the conceptual design and early development stages.

   The lessons from these development processes are three-fold, at least in my opinion.

   - Successful development of a commercial product requires a clear understanding of the competitive market conditions that necessitate technological innovation (TGV and Shinkansen).
   - Even with *incremental* changes to *proven* technologies, it is essential to verify and validate innovations through experimental programs (e.g., the TGV articulated bogie, improved pantograph, trainline power distribution, and train control system; new

GENERALIZED FLOW OF DESIGN, TESTING AND DEVELOPMENT ACTIVITIES FOR AN ADVANCED HIGH-SPEED GROUND TRANSPORTATION SYSTEM



construction standards for track and structures; the greatly reduced unsprung mass and axle loads of later generation Shinkansen and the improvements to pantograph design and power distribution for these EMU trainsets).

- Analysis and simulation in the absence of validating experimental results typically demonstrate little except the consequences of the assumed input parameter values.

2. Material Reviewed

In preparing this memorandum, I reviewed the material summarized in Table 1 below, pertaining to the four candidate technologies:

Table 1 – Materials Reviewed

American Maglev	Document titled *Intelligent High-Speed Transportation Demonstration Project,* dated May 1996
Maglev 2000	Letter from Mr. C.H. Smith of Maglev 2000 to Mr. C.De Weese of PTG, dated Oct 20, 1999, including a 13-page attachment titled *Maglev 2000 of Florida Corporation -Technology Validation*
Maglift Monorail	Letter from Mr. T.H. Hopkins of Meneren Corporation, to Mr. C.C. De Weese of PTG, dated October 15, 1999; Letter from Mr. Hopkins to Dr. John Harding of FRA, dated 26 April 1999, and response from Dr. Harding to Mr. Hopkins dated May 11, 1999; Undated paper titled *Maglift Monorail - Signals, Control and Safety"* Undated paper titled *Maglift Monorail-Communications - Including Fire Protection and Intrusion Detection* Paper by Messrs Hopkins, Silva, Marder, Turman and Kelley, presented to HSGTA 1999 Conference, June 6-9, titled *Maglift Monorail - A High-Performance, Low Cost and Low Risk Solution for High-Speed Ground Transportation*
Transrapid International USA	Letter from Mr. L.E. Blow, US Projects Manager, TRI USA, to Mr. Brent Lacy of PTG, dated August 26, 1999 Attachment titled *Technology Sourcing and Transfer Discussion,* same date Paper titled *Transrapid System Overview,* dated August 1999 Book titled *Transrapid Maglev System,* dated 1990

I also drew on material in my personal files on the development processes for Transrapid, the TGV, the JR[1] EDS MAGLEV and recent versions of Shinkansen EMU rolling stock, on CRREL Special Report 98-12, *"Technical Assessment of Maglev System Concepts - Final*

[1] JR = Japanese Railways, predecessor developer of the Maglev Development Institute's technology.

Report of the Government Maglev System Assessment Team" dated October 1998, and on material downloaded from the FRA's website pertaining to the *Interim Final Rule-49 CFR Part 268*.

3. Apparent Development Status, Comments and Questions

3.1 AMERICAN MAGLEV

This technology uses powerful permanent magnets to provide induced levitation and guidance forces at speeds above 40 mph; to reduce the cost of the guideway, American Maglev (AMT) proposes to transmit propulsion power from the vehicle to the immediately adjacent portion of the guideway-mounted propulsion coils (p 13, "*Intelligent High-Speed Transportation Demonstration Project"*). Propulsion power is picked up at wayside using sliding contacts on steel rails, then distributed back to the guideway by means of Be-Cu Brushes (Table 3.3.1-1; Figure 3.3.1-7, *op.cit.*).

The information provided indicates that the concept was tested using a full-scale vehicle and test track at low speed during the spring and early summer of 1995. This information states that levitation and propulsion were tested but braking was not.

The proposed approach for power collection and distribution is especially troublesome, inasmuch as it depends on reliable and cost-effective brush-based pickup and distribution of power in excess of 5 MW. While the concept of a short-stator propulsion system has always had considerable appeal, for the very reasons cited by AMT, the only previous attempt to develop this type of technology for high-speed applications (the JAL HSST-300 and 400) foundered on its inability to demonstrate reliable and cost-effective brush-based power pick-up. The brush life of the HSST 400, based on measured wear on a short test track, was calculated to be less than 1000 miles (CIGGT Report 86-10, *Maglev Technology assessment, Task 5, Development Status of Major Maglev Subsystems and Critical Components*, Boon, Hayes, Eastham et al, March 1986), leading to unacceptable maintenance down-time and parts costs—and that design involved only one such brushed contact.

Note that brush pickups do perform very well at lower speeds, even up to 120 mph as proposed for the AMT demonstration vehicle. The problems of wear rates and reliable contact really only start at genuinely high speeds and high transmitted power levels. Accordingly, this key aspect of the AMT technology must be regarded as entirely unproven; as such it constitutes a potential "Fatal Flaw" in the system concept. Also, I am of the opinion that the proposed demonstration program, which would only see 120 mph operation, would not be sufficient to prove out the power collection and distribution aspects of the design. Endurance testing at the full design speed will be essential before accepting the reliability and cost-effectiveness of brush-based power collection and distribution.

This concept also incorporates active tilt to improve passenger comfort at high speeds in curves. This tilt is apparently to be provided by airbag suspension elements. The use of tilt at 240 mph remains an entirely unproven concept. The maximum commercial tilt operation is limited to about 160 mph (260 km/h), and there are a whole host of passenger comfort issues related to tilt motion parameters while traversing transition curves, even with an unbalanced lateral acceleration of less than the generally applied ride quality limit of 0.08*g*, The key factors, in order of significance to passengers, are:

- The rate of change in lateral acceleration, or lateral *jerk;*
- The tilt roll velocity; and
- The tilt roll acceleration.

There is also the technical issue of timely curve detection at high speed. Since it is necessary to filter accelerometer signals to eliminate the noise from minor guideway irregularities, or even from external sources such as wind buffeting, the accelerometer signal will not reach the tilt control system for some delay time. Consequently, tilt actuation may not be effected until the vehicle is actually on the transition curve, which exacerbates the passenger comfort issues mentioned above. Accelerometer-based sensor and tilt actuation systems have proven to be relatively high maintenance items in HSR applications. For a complete discussion of these systems and the issues surrounding them, see *High Speed Rail Tilt Train Technology A state of the Art Survey, ENSCO Inc and CIGGT, for FRA Office of R&D, May 1992, Appendix B.*

On a more positive note, the presence on the AMT team of Lockheed Martin provides some reassurance that there is ability to manage a high-technology development and testing program and that the required systems integration and interface management capabilities are, or at least could be, available.

Also, the proposed test plan, although stopping well short of the performance level required under IFR CFR-49-268, demonstrates a realistic understanding of what is required to bring an innovative technology to the marketplace. I suggest that AMT be approached with a request to re-do the demonstration program[2] to carry it through to the required level of performance.

Risk Assessment

On the basis of the information provided, I am of the opinion that this technology has a high risk of outright technical failure (stemming largely from its dependence on brush pick-up and distribution of 5 MW+ power), a high risk of inability to achieve its proposed schedule (due to its truncation at 120 mph rather than 240 mph as required) and a high risk of significant cost increases over the course of the development process (again stemming from the need to deal with power pick-up and distribution issues).

3.2 MAGLEV 2000 OF FLORIDA

This technology is still at the conceptual “paper” design stage, although the information submitted asserts that “688 feet of planar guideway has [sic] been constructed.” Apparently no testing of either a vehicle or of guideway-mounted subsystems has been initiated as of the date of submission.

It is important to recognize that although the specific technology configuration proposed by Maglev 2000 (hereafter abbreviated to ML2000) has not yet progressed beyond paper, the

[2] PTG is of the opinion that such a reconstruction of the demonstration program would not result in a revenue service availability earlier than indicated in Appendix A, and in light of Mr. Boon’s overall risk assessment and in view of the FRA’s timeframe for preparing Project Descriptions, did not suggest that SCAG pursue this course of action.

feasibility of many of the key subsystems for levitation, propulsion and guidance have been proven in the course of the EDS MAGLEV development program undertaken by initially by JNR and laterally by its privatized successor companies. However, while the JR results give some confidence that the ML2000 concept should ultimately be workable, the fact remains that ML2000 is at the initial activity in Figure 1, and faces the entire sequence of development and testing activities to prove out the practicality and performance capabilities of the design.

The information provided by ML2000 also gives no indication of the team composition and thus of the capabilities of team members. I am especially concerned with respect to system integration capabilities, as the management of this process will be a critical importance in achieving any kind of success path for the development and proving out of ML2000.

It should also be noted that development of the Transrapid EMS and JR EDS MAGLEV systems has, in each case, required close to 15 years of concerted effort and the expenditure of well over $1 billion US. It is not at all clear how ML2000 expects to go from paper to revenue deployment in four years.

Risk Assessment

On the basis of the information provided, I am of the opinion that this technology has a moderate risk of outright technical failure (largely stemming from systems integration issues), a very high risk of inability to achieve its proposed schedule and a high risk of significant cost increases over the course of the development process.

3.3 Maglift Monorail

This is an unusual hybrid technology employing partial magnetic levitation, partial (20%) support on unflanged steel wheels, partial magnetic guidance using lateral wheels (also steel) and propulsion using a short-stator phase-segmented LIM developed by Sandia National Labs as part of the (now defunct) railgun program.

This technology also falls foul of the problem or reliable and cost-effective brush-based collection of MW power (between 5 and 10 MW depending on speed and acceleration). As noted above, this is a potential fatal flaw for any short-stator system I am also of the opinion that the developers are significantly underestimating the problems and challenges associated with using unflanged steel-wheels-on-steel rails for partial vertical support and lateral guidance at high speeds. Even granting the low load levels, the excitation of the steel-wheel suspension systems by irregularities in steel rails produced to normal tolerances and installed to normal construction standards, not to mention that caused by expansion joints at segment interfaces, will almost certainly produce vibration and noise problems requiring quite sophisticated (and expensive) mitigation. There is also the question of the level of dynamic increment created by the unsprung mass of these wheels. While the mass will be small relative to the unsprung mass of classic wheel-on-rail technologies, the forces are largely proportional to the square of the speed, so even small irregularities can result in substantial force increments at 240 mph and above.

The heroic assertion that "*we are using refinements to existing technologies and there are* ***no significant technological unknowns or issues***" (Letter of Oct 15/99 from T.H. Hopkins, Meneren Corp, to C. De Weese, PTG, page 5, section II.A(2), my emphasis added) is simply not supported by any experimental or operational evidence.

From the information provided, it appears that the only subsystem component that has actually been built and tested is the phase-segmented LIM, which was developed and tested by Sandia Labs as part of the railgun development program. However, the data from that program have never been published, and it is unclear whether the adaptations of the PS-LIM for the Maglift Monorail have ever been physically tested. However, perhaps the input parameters for the PS-LIM in the "*Performer*" simulation model are based on experimental evidence rather than assumptions.

There is also an apparent misstatement in the material provided by Meneren with respect to the maximum acceptable bank angle (superelevation plus tilt) for a vehicle based on passenger comfort concerns. On pages 2–3 of the document titled "*Maglift Monorail Performance Summary*" the statement is made that "*The maximum total banking (track bank plus vehicle tilt) is set at 45^o, per advice from the FRA based on studies of what passengers are comfortable with (unpublished).*" I was part of the FRA working group that initiated the study cited, and this was at odds with my recollection of the results, so I spoke with John Harding. He stated that this was not the conclusion of that study at all, and that in fact when the simulated highway-alignment-following flights were made, the first person to ask for relief was the most avid proponent of the 45-degree bank maximum. Following a flight path corresponding to the New York State Throughway alignment geometry resulted in the rapid onset or airsickness in all but the most hardy of participants (a notable exception was a veteran blue-water sailor). As stated in appendix A of CRREL 98-12, the design bank angle is only 24^o; 45 degrees is included for use if riders are seated and belted in only.

There also seems to be a lack of recognition that the ability to climb steep grades is only of value to the extent that the transitions at crest or trough can be made without exceeding passenger comfort limits. The objective must not be to replicate the experience of a flight on the "Vomit Comet."

The issues associated with active tilt noted in the discussion of AMT also apply to the Meneren concept.

Risk Assessment

On the basis of the information provided, I am of the opinion that this technology has a high risk of outright technical failure (stemming from the dependence on brush pick-up of 5- to 10-MW power), a high risk of inability to achieve its proposed schedule (due to significant underestimation of the level of technical issues to be overcome during detail design and testing), and a high risk of significant cost increases over the course of the development process (again stemming from the need to deal with power pick-up issues and underestimation of the technical complexity and unproven status of some key subsystems of the proposed design).

3.4 Transrapid International USA TR-07

The status of the TR-07 can best be summed up with quotations from the Executive Summary (page xiv) of CRREL 98-12:

"The Transrapid 07 (TR07) is a commercially ready electromagnetic suspension (EMS system…"

and from Section 2.2.4 -Status of the same report:

"TR07 is a proven technology …."

Based on the information provided for this assessment and on the wealth of data previously published and subject to peer review and critical assessment, it is clear that TRI is offering a technology that has attained the final stage before revenue system deployment (refer to Figure 1). It is the only candidate technology that is doing so. All the others are at best offering an opportunity to invest in a development program, with entirely uncertain outcomes.

Risk Assessment

On the basis of the information provided, I am of the opinion that Transrapid has essentially zero risk of outright technical failure, a low risk of inability to achieve its proposed schedule, and a low to moderate risk of significant cost increases over the course of the commercial deployment process (stemming from site-specific environmental and geotechnical conditions and from regulatory uncertainties).

BOON, JONES AND ASSOCIATES, INC.
MEMORANDUM
November 15, 1999

FROM: **Chris Boon**
TO: **DUNCAN ALLEN, PTG**
SUBJECT: **Review of Relative Operating Cost Estimates**

1. I have completed my review of the material concerning O&M costs for American Maglev, Maglev 2000, MAGLIFT Monorail, and TRI which you sent to me (Technical Appendix B). My comments in this memo address the requirements as specifically mandated under Task C, Review of Relative Operating Cost Estimates.

2. General Comments and Observations

From my long experience in developing life-cycle cost estimates and financial and economic analyses for alternative high speed ground transportation investment options, there are two key principles which stand out as essential in the development of credible, comparable and consistent relative O&M costs:

- For each major subsystem of each candidate technology, there must be a clear and explicit definition of the physical process or processes (the *cost drivers*) which cause costs to be incurred; and
- For each cost driver, there must be an explicit estimate of the nature and frequency of maintenance or operational activities required to sustain the system.

With respect to the first point, understanding the nature of the physical process causing cost to be incurred is fundamental to selecting the correct metric for the independent variable or variables to be used in the cost calculation equation. As an example, a fully- levitated MAGLEV system does not impose any frictional wear on its guideway, However, the guideway structure and attached or embedded coils are subject to repetitive fatigue loads is which are a function of the number of vehicle passes. Thus, while the gross ton miles (GTM) metric is a reasonable predictor of required guideway maintenance for a wheel-supported system, I believe that the number of load cycles is a better predictor for non-contact systems. For a blended system such as Maglift Monorail, there should be components of both elements used, inasmuch as there will both contact-based mechanical wear and load-cycle based fatigue.

With respect to the second point, there needs to be an explicit attempt to estimate the activities that would be involved in overcoming the physical degradation of each subsystem arising from its use, the quantity and type of labor involved, and the materials that would be consumed. At this level of analysis, relatively aggregated estimates are acceptable, but these should always be explicitly documented so as to permit easy refinement at later stages or as more credible numbers become available from full-scale testing or simulated system operation.

It is also important to recognize that more complex systems always require more maintenance than simple ones. Commercial aircraft, such as the B-737, while by no means simple in an absolute sense, are quite simple compared to advanced high-performance military aircraft such as the B-2, and require orders of magnitude less maintenance input per flight hour that do their military counterparts.

The location of subsystems can also have an impact on maintainability and required maintenance inputs. For example, wayside power conditioning equipment can be made as robust as required, inasmuch as there will be little or no constraint on weight and volume, whereas vehicle mounted equipment always faces weight and volume constraints, which will typically affect both initial cost (smaller and lighter are more expensive, even with cheap chips-consider the relative prices of desktop and laptop computers with similar processor speed and memory) and the ease of maintenance and consequent required maintenance hours (it is much easier to change out a circuit board in an electrical cabinet than one buried in a confined and hard-to reach installation under the floorboards of a vehicle).

2.1 Subsystem Comparison of the Candidate Technologies

To assist in the discussion that follows, Table 1 below lists the number and location of the major subsystems for each of the four candidate technologies. This is based on material drawn from the documents submitted by the four candidate suppliers, except for TRI, where I have drawn on CRREL 98-12 and on other detailed design information from my files. To simplify the analysis and interpretation, I have included only those subsystems where there appear to be substantive differences among the technologies. Thus, subsystems such as the vehicle structure, passenger accommodation and HVAC are not listed, but power supply, levitation, propulsion, lateral guidance and switching are.

As can be seen from the foregoing table, there are major differences amongst the candidate technologies in terms of the characteristics of the key subsystems and the extent to which the design and realization of these subsystems has been proven in full-scale test at the design speed. This latter aspect is of major concern with respect to the estimation of relative maintenance costs. Insofar as the lack of experimental evidence necessitates attachment of a much broader error of estimate to any nominal cost.

2.2 Relative Magnitude of Error of Estimate and Form of Cost Distribution

Based on the characteristics noted above, I am of the opinion that were one to develop distributions of cumulative probability for O&M cost for the four candidate systems, these distributions would take the following forms:

- The lowest error of estimate (and least skewed) distribution of probable O&M cost will be associated with TRI, for which all key subsystems have been proven in full-scale and

Table 1 – Subsystem Comparison of Candidate Technologies

Subsystem	American Maglev	Maglev 2000	Maglift Monorail	TRI	Comments
Power supply	Wayside 3-phase third rail with vehicle-mounted brush pick-up and also brushed distribution to guideway-mounted reaction coils to generate propulsion force; unproven at full scale and full speed especially with regard to brush life	VF 60Hz block-switched to supply guideway-mounted LSM; active guideway long stator; concept proven elsewhere at and above nominal design speed but specific design as yet untested and unproven	3 single-phase brushed power pickups per trainset from wayside power rail with on-train distribution of all phases to all powered vehicles; unproven at full scale and full speed especially with regard to brush life	Wayside block-switched to LSM; non-contact inductive generator for on-board power; fully proven at full scale and full speed	Reliability and cost-effectiveness of brushed power pick-up and distribution not proven at speeds above about 120 mph; could have major maintenance impact and also affect vehicle availability and reliability
Propulsion	Short-stator LIM; technology proven elsewhere at lower speeds	Longstator LSM; concept proven elsewhere at and above nominal design speed but specific design as yet untested and unproven	Short-stator Phase-segmented LIM; concept investigated at Sandia; may have been proven in test for other application but that is unclear from documentation	Longstator LSM; fully proven in full-scale and full-speed testing at Emsland facility including endurance testing	
Levitation	Permanent magnet EDS; rubber-tired wheels at low speed	Superconducting EDS; wheels at low speed; concepts proven elsewhere but untested in specific design	Partial permanent magnet EDS; unflanged steel wheels on steel rails for about 20% of static load; Unproven at design speed and no documentation on dynamic increment due to unsprung mass	EMS suspension; proven in full-scale, full-speed test at Emsland; skids for use in event of loss of suspension power	

Table 1 – Subsystem Comparison of Candidate Technologies

Subsystem	American Maglev	Maglev 2000	Maglift Monorail	TRI	Comments
Lateral Guidance	Passive null-flux coils; concepts proven elsewhere and tested in specific design at low speed	Passive null-flux coils; concepts proven elsewhere but untested in specific design	Blend of null-flux forces generated by LIM and steel wheel on steel rail lateral guidance wheels; Unproven at design speed and no documentation on split of forces between null-flux coils and wheels or on dynamic increment due to unsprung mass	Interaction with lateral guidance rails and on-vehicle magnets; Proven in full-scale, full-speed test at Emsland;	
Active Tilt	Yes, using air springs	Not fitted	Yes; up to 15°	Not fitted	
Switching	Electronic ; based on activation or deactivation of adjacent sets of guidance coils in planar guideway; unproven	High speed-electronic; unproven. low speed (40 mph) mechanical using pivoting concrete slab; unproven	Essentially a transfer table with tangent and turnout guideway segments; unproven; lock-to lock time issue?	Flexible steel beam; hydraulic actuation; about 30 second lock-to lock for 125 mph design; proven up to 125 mph	

- full-speed tests. The distribution for Maglev 2000 will have a larger error of estimate (due to the absence of test validation for the specific designs that are proposed and the lack of any specific design for its electronic switch) and will be somewhat skewed to the right (i.e., a greater cumulative probability of high rather than lower costs relative to the nominal mean);
- the distribution for American Maglev will have a significantly larger error of estimate (due to the use of not one but two brushed contacts for power pickup and distribution and the absence of even a conceptual design for a high-speed switch) and will be more skewed to the right; and
- Maglift Monorail will have the highest error of estimate (due to the use of brushed contacts for power pickup [unproven at speed]; the use of partial steel-wheel on rail suspension and guidance [unproven at speed] ; the proposed use of a transfer-table type switch [lock to lock time unknown]; and the use of the segmented phase LIM [development status and characteristics undocumented] and will be most heavily skewed to the right.

3. Comments on Specific Technologies

3.1 American Maglev

This technology uses powerful permanent magnets to provide induced levitation and guidance forces at speeds above 40 mph; to reduce the cost of the guideway, American Maglev (referred to as AM hereafter) proposes to transmit propulsion power from the vehicle to the immediately adjacent portion of the guideway-mounted propulsion coils (p13, "*Intelligent High-Speed Transportation Demonstration Project*"). Propulsion power appears to be picked up at wayside using a sliding contact on a steel rail (used conventional railroad rail was used for the short test facility), then distributed back to the guideway by means of Beryllium-Copper Brushes (Table 3.3.1-1; Figure 3.3.1-7, *op.cit*).

The information provided indicates that the concept was tested using a full-scale vehicle and test track at low speed during the spring and early summer of 1995. This information states that levitation and propulsion were tested but braking was not.

The proposed approach for power collection and distribution is likely to have a significant impact on operations and maintenance costs, inasmuch as it depends on reliable brush-based pickup and distribution of power in excess of 5 MW. While the concept of a short-stator propulsion system has always had considerable appeal , for the very reasons cited by AM, the only previous attempt to develop this type of technology for high-speed applications (the JAL HSST-300 and 400) foundered on the inability to develop a reliable and cost-effective brush-based power pick-up. The brush life of the HSST 400, based on measured wear on a short test track, was less than 1000 miles (CIGGT Report 86-10, *Maglev Technology assessment, Task 5, Development Status of Major Maglev Subsystems and Critical Components,* Boon, Hayes, Eastham et al, March 1986), leading to unacceptable maintenance down-time and parts costs—and that design involved only one such brushed contact.

Note that brush pickups do perform very well at lower speeds, even up to 120 mph as proposed for the AM demonstration vehicle. The problems really only start at genuinely high speeds. ***I strongly recommend that the vehicle O&M costs be augmented to reflect the likelihood that these brushed contacts will require maintenance or change-out at frequent intervals during commercial operation.***

3.2 Maglev 2000 of Florida

This technology is still at the conceptual 'paper' design stage, although the information submitted asserts that "688 feet of planar guideway has [sic] been constructed". Apparently no testing of either a vehicle or of guideway-mounted subsystems has been initiated as of the date of submission.

It is important to recognize that although the specific technology configuration proposed by Maglev 2000 (ML2000) has not yet progressed beyond paper, the feasibility of many of the key subsystems for levitation, propulsion and guidance have been proven in the course of the EDS MAGLEV development program undertaken by initially by JNR and laterally by its privatized successor companies. However, while the JR results give some confidence that the ML 2000 concept should ultimately be workable, the fact remains ML2000 is at the initial activity in Figure 1, and faces the entire sequence of development and testing activities to prove out the practicality and performance capabilities of the design.

In terms of O&M costs, the major uncertainly will stem from the availability of an effective high-speed switch, for which even the earliest of conceptual designs is not offered. This has the potential to have an impact on system operability, achievable average speed and annual vehicle utilization, and thus on both initial capital cost and on annual O&M cost.

3.3 Maglift Monorail

This is an unusual hybrid technology employing partial magnetic levitation, partial (20%) support on unflanged steel wheels, partial magnetic guidance using lateral wheels (also steel) and propulsion using a short-stator phase-segmented LIM developed by Sandia National Labs as part of the (now defunct) railgun program.

This technology also falls foul of the problem or reliable and cost-effective brush-based collection of MW power (between 5 and 10 MW depending on speed and acceleration). As noted above, this is a potential fatal flaw for any short-stator system. ***I strongly recommend that the vehicle O&M costs be augmented to reflect the likelihood that these brushed contact power pickups will require maintenance or change-out at frequent intervals during commercial operation.***

I am also of the opinion that the developers are significantly underestimating the problems and challenges associated with using unflanged steel-wheels-on-steel rails for partial vertical support and partial lateral guidance at high speeds. Even granting the asserted low static load levels, at the design speed the excitation of the steel-wheel suspension systems by irregularities in steel rails produced to normal tolerances and installed to normal construction standards, not to mention that caused by expansion joints at segment interfaces, will almost certainly produce vibration and noise problems requiring quite sophisticated (and expensive) mitigation. There is also the question of the level of dynamic increment created by the unsprung mass of these wheels. While the mass will be small relative to the unsprung mass of classic wheel-on-rail technologies, the forces are largely proportional to the square of the speed, so even small irregularities can result in substantial force increments at 240 mph and above.

The use of a switch based on a transfer table to move segments of tangent or turnout guideway into place may be feasible in concept, but no details are given regarding the method of actuation or the expected lock-to-lock time. Given the relatively small consist capacity (400 seats), and using the ridership and other assumptions in Technical Appendix B-I estimate that the nominal average headway for this technology to provide the required level of capacity at the specified load factor would be about 4.6 minutes. The question then becomes whether a transfer table design could achieve a lock to lock cycle in 4.6 minutes, less whatever time would be required to assure failsafe stopping in the event that the switch did not cycle, align and lock correctly.

3.4 Transrapid International USA TR-07

In my judgement, the only really significant issue surrounding the TR07 that would affect maintenance costs is the ability to maintain the necessary alignment tolerances for the guideway-mounted long-stator packs, TRI has shown that it can fabricate and Field-erect to these tolerances during different phases of construction at the Emsland test facility, but Emsland, though located in a boggy area, is tectonically stable. While there has never been a problem with misalignment at Emsland, the ability of the TRI guideway design to remain in alignment in a seismically active area like southern California, without an unacceptable level of maintenance input, is still unproven. Note that I am not concerned about the consequences of a major earthquake. Any design is vulnerable to a large-magnitude seismic shock. The issue with TRI is whether the almost constant microshock regime that typifies that area will result in small-scale misalignments requiring frequent maintenance. In my opinion, this could be resolved by the erection of a couple of unpowered but instrumented guideway segments in an appropriately shaky location, on footings representing the design to be used for the commercial construction of the system, and collecting data for a few months. If there is no movement, the issue can be put to rest once and for all.

MEMORANDUM

To: Duncan W. Allen
Parsons Transportation Group

From: David Wormley

Subject: Review of Analyses of MAGLEV System Concepts

Date: November 11,1999

1. Introduction

A review of the methodology and selection of parameter values to evaluate four MAGLEV system concepts with respect to energy requirements and time and distance performance has been performed. The trip scenario simulator has been reviewed, as well as descriptions of the four candidate systems provided by PTG.

2. Trip Scenario Simulator

The trip scenario simulator has been reviewed to determine whether its predictions of train time-distance profiles and energy consumption are reasonable and consistent with data available in COE 98-12 (1). The scenario simulator results for the cases reviewed were consistent with other available data and in general reflected in an integrated fashion the detailed system performance data. It is noted that a detailed review of the equations embedded in the simulator was not performed because this type of effort was not within the scope of the review.

3. Vehicle Concept Representation

Reports provided by PTG (2–5) described the four MAGLEV system concepts for which trip scenario evaluation data were available. The four concepts varied substantially in the technologies employed to achieve system performance.

System A: Transrapid International-USA

- Attractive electromagnetic suspension for levitation and guidance
- Linear synchronous motor propulsion

System B: Maglev 2000

- Repulsive superconducting magnet suspension for levitation and guidance
- Linear synchronous motor propulsion

System C: American Magnetic Technologies

- Vehicle permanent magnet – guideway coil suspension

- Locally activated guideway coils for propulsion

System D: Meneren Corporation

- Wheel-based suspension with partial levitation
- Linear induction motor propulsion

4. System Performance Parameters

For each of the systems, the parameters describing the vehicle performance which are used as inputs to the trip scenario simulator were reviewed including:

- Vehicle mass properties
- Aerodynamic and magnetic drag
- Propulsion force and power
- “Hotel” power (for interior lights, climate control, etc.)

For each of the systems these parameters were found to be consistent with the performance data available in the reports cited as references 2–5.

5. Trip Scenario Simulation Results

Results of simulations for each of the four systems were reviewed for the hypothetical trip considered. The simulated scenarios indicated that the power requirements of the four systems are:

- System A: 0.043 kW/seat-km
- System B; 0.037 kw/seat-km
- System C: 0.031 kw/seat-km
- System D: 0.031 kw/seat-km

These trip scenario results for the respective system power requirements for the trip profile considered are consistent with the basic parameters of each system and reflect the differences in the system technologies employed.

6. Accuracy of the Power Requirement Simulations

The certainty of the determination of the performance of each system is strongly influenced by the degree of certainty of the performance parameters of the individual system vehicles and vehicle subsystems. For the four systems, significant differences exist in their stages of development and in the verification of the performance parameters with full scale, at speed tests. Therefore, while the parameters which have been used to represent vehicle performance for each of the systems appear to be reasonable engineering estimates, only after further tests could they be verified with a high degree of certainty for the systems (Systems B, C, D) for which at speed, field test data are not available.

References

1. "Technical Assessment of Maglev System Concepts," U.S. Army Corps of Engineers, Special Report 98–12, October 1998.

2. Maglev 2000 letter to Mr. C. W. De Weese and attachments, October 20,1999.

3. Meneren Corporation Letter to Mr. C.W. De Weese and attachments, October 15, 1999.

4. American Maglev Technology Inc. letter to Mr. B. Lacy and attachments, August 23, 1999.

5. Transrapid International–USA Inc. letter to Mr. B. Lacy and attachments, August 26, 1999.

BOON, JONES AND ASSOCIATES, INC.
MEMORANDUM
November 22, 1999

FROM: **Chris Boon**
TO: **DUNCAN ALLEN, PTG**
SUBJECT: **Task D, Overall Review of Technology Selection Memorandum**

1. As required under the terms of reference for Task D, I have completed my review of the draft Technology Selection Memorandum, paying particular attention to the following aspects of that document:

   - Reasonableness of criteria for meeting both FRA and Corridor requirements
   - Objectivity and fairness of treatment of each supplier given the information supplied
   - Accuracy of application of the evaluation to each supplier
   - Reasonableness of the final recommendation.

2. In carrying out this review, I referred to the document itself (*Technology Selection Report - California MAGLEV Deployment Project, Parsons Transportation Group, Nov 12, 1999)*; and also to *49 CFR part 268, Federal Register, V63 No. 197, Oct 13, 1998* and to *Magnetic Levitation Transportation Technology Deployment Program, Interim Final Rule-49 CFR part 268, Informal Questions and Answers, Nov 4, 1998,* both as downloaded from the FRA website at http://www.fra.dot.gov/s/regs/maglev

3. Based on my review, I offer the following oversight comments pertaining to the specific requirements of my scope:

   - The evaluation process defined and applied by PTG in ITS selection analysis is transparent and specifically responsive to the criteria established by the FRA and applicable state. regional and local requirements, objectives and goals.
   - The criteria used in the evaluation process are reasonable and appropriate given the Program objectives and criteria, and the apparent prioritization of these criteria as reflected in 49 CFR 268 and the "Questions" document cited above.
   - The criteria and process have been applied with scrupulous fairness and objectivity as regards the three U.S. design concepts. In fact, I believe that these three have been given *more* than any reasonable *benefit of the doubt* in the absence of reproducible and published experimental results.
   - The evaluation process has been applied accurately and in accordance with the process set out in section 1 of the Technology Selection Report; however, the application of this

process would be strengthened by the addition of the rationale for assigning a "zero" score to the lowest performer in categories where the metric has a continuous distribution.

- The final recommendation, of Transrapid, is appropriate, reasonable, and fully supported by the evaluation process.

4. I have also provided detailed comments and editorial suggestions on the body of the TS Report and the three appendices[3]. I have also attached a final version of my memorandum[4] addressing Task A.

[3] PTG has incorporated these comments and suggestions in the final report as PTG deemed appropriate.
[4] This memorandum is included separately in this Appendix.

MEMORANDUM

To: Mr. Christopher Boon
Chair, Technology Assessment Panel

From: David N. Wormley

Subject: Review of Draft Technology Selection Report
California MAGLEV Deployment Project

Date: November 24, 1999

1. Introduction

A review of the draft report, *Technology Selection Report California MAGLEV Deployment Project*, has been conducted. In the review, primary attention has been devoted to the overall methodology and the way in which the methodology employs system technical performance data.

2. Selection Methodology

The study utilizes a systematic and well-accepted selection methodology.

1. Relevant system technical, cost, time and deployment risk.
2. Parameters are identified.
3. Their relative levels of importance are established.
4. A weighted summation of the principal factors influencing the selection of competing technologies to determine the relative overall ranking of competing technologies for the transportation corridor is performed.

The rationale for the weighting factors is clearly described.

The parameters characterizing the four technologies are established in a consistent manner using available performance data from the developers of the technologies and engineering judgement.

3. Selection Process Results

The results of the selection process leading to the ranking of the four competing technologies are strongly influenced by the technical and fiscal risk associated with the deployment of the technologies in the near future, i.e., 4–7 years. With this constraint as a dominant factor, the overall selection process has resulted in a final ranking that strongly reflects the relative development and deployment risks of the technologies.

4. Employment of Performance Measures

The differences in the characteristics of the four technologies influence a number of primary system performance measures directly including:

1. Trip travel time
2. Trip energy consumption and the associated energy cost
3. System construction and maintenance costs

The latter two of these are incorporated directly in the selection methodology, while travel time is represented in terms of trip average speed for the complete trip. Travel times are often a factor in transportation demand studies and would nominally be used in detailed corridor demand studies. The travel times for the three corridor segments are summarized in Table 1, determined from the trip simulator. For the shortest trip segment, i.e., the segment from LAX to Union Station, the relative variations in travel time are less than two minutes, and the differences in the abilities of the four technologies to influence travel demand for these segments is reduced in comparison to the longer segments. For the total trip, the maximum travel time differences approach 7.1 minutes. It is noted that travel time is highly route specific depending on specific passenger origin-destination pairs, and would be coupled with other data in a detailed segment by segment travel demand study[5].

The comments on travel time and its use in the methodology do not alter the results presented in the selection study. It is recommended, however, that some travel time data be included in the report, simply for convenience of the reader in gaining an overall understanding of the relative differences in the performance of the four technologies.

Table 1 – Corridor Route Segment Travel Times in Minutes

System	Segment LAX–Union	Segment Union–Ontario	Segment Ontario–March AFB	Total Full Trip Time (Not Including Stop Times)
AMT	8.6	14.6	11.85	35.1
Maglev 2000	9.56	17.51	13.1	40.2
Meneren	8.09	14.1	11.4	33.5
TRI	9.83	17.8	13.3	40.6

[5] PTG notes that potential changes in the "placeholder" travel demand presented in Table 3-3 were estimated between station pairs based on the travel times shown in Table 1 of this memorandum (plus 1-minute station dwells).

November 30, 1999

TO: Duncan W. Allen, Parsons Transportation Group
Christopher J. Boon, Chair, Technology Assessment Panel

FROM: Professor Steven P. Erie, University of California, San Diego

RE: Review of Draft Technology Selection Memorandum, California MAGLEV Deployment Project

I now have had the opportunity to review and evaluate:

- The draft Technology Selection memorandum prepared by Parsons Transportation Group for the Southern California Association of Governments, recommending a choice of a MAGLEV technology supplier for the proposed SCAG intra-regional corridor.
- The responses from the four candidate technology suppliers to the request for information.
- The FRA Interim Final Rule and associated Informal Questions and Answers.

My evaluation follows:

Reasonableness of criteria for meeting both FRA and corridor requirements

The relative weighting of FRA, corridor, and project description elements appears reasonable given FRA's recognition in the Interim Final Rule that there may not be sufficient detailed information provided about the various project selection criteria. Considering that the Federal share of full project costs will be no greater than 2/3s, it is reasonable to weight FRA criteria at roughly double the value of corridor and program description criteria.

The criteria, maximum point assignments, and measures of effectiveness proposed *within* the three overall evaluation components also seem reasonable. In particular, because the FRA selection criteria attach considerable weight to *timely implementation*, the 25 maximum points assigned here seems appropriate.

Overall, the weighting and criteria chosen that meet FRA and corridor requirements seem reasonable. The FRA project selection criteria excluded from the draft selection report because they do not depend on the choice of technology supplier also appear appropriate. In addition, the selection criteria for short-listing candidate technology suppliers appear appropriate.

Objectivity and fairness of treatment of each supplier given the information supplied

Considering variation in both the quantity and quality of technological, operational and financial data provided by the four candidate suppliers, the Draft Selection Memorandum's treatment of each seems fair and reasonable.

Accuracy of application of the evaluation to each supplier

In general, the applications were reasonable. One concern, however, was the assignment of 9 out of a possible 10 points to Transrapid (pages 3–6, 3–7) in terms of technology transfer and U.S. job growth. The draft memo's measure of effectiveness and its application both need to reflect uncertainties regarding the evolving U.S. MAGLEV market and technology transfer impacts. The selection of the SCAG corridor and TRI as the candidate supplier could in fact affect the entire U.S. high-speed rail market. If the operational advantages of remaining U.S.-based candidate suppliers are sufficient (page 3–6) for them to remain candidate successor technologies should TRI and the SCAG corridor be selected, then those advantages should be reflected in their relative ratings for operational considerations (see Table 3-1 and 3-3). Here the draft report might benefit by erring on the side of caution[6]. TRI's overall U.S. economic benefit score may be somewhat less than the 12 currently assigned (see Table 4-1).

Reasonableness of the final recommendation

All things considered, the recommendation of Transrapid appears appropriate in terms of its distinct advantage regarding earlier revenue service availability, notwithstanding TRI's generation of fewer U.S. economic benefits relative to U.S.-based technology suppliers. Even if TRI were assigned somewhat fewer points for U.S. economic benefits because of attendant market and technology transfer uncertainties, its demonstrated superiority in terms of timely implementation, coupled with the Interim Rule's considerable weighting of this factor, makes it the superior candidate technology supplier.

Overall, the draft Technology Selection Memorandum appears reasonable, technically sound, and comprehensive. I trust you will find these comments and suggestions useful.

[6] If the ratings were adjusted along the lines suggested here, e.g., to assume that 100% rather than 25% of the US MAGLEV market would be affected, then the points awarded TRI would decrease from 9 to 6. As Prof. Erie notes in the following paragraphs, this would not affect the overall ranking of the suppliers, because TRI would remain the best choice at a total of 63 points.

December 2, 1999.

Mr. Duncan W. Allen
PTG Transportation Group
50 Milk St., 10th Floor
Boston, MA 02109

Dear Mr. Allen:

RE: REPORT OF THE TECHNOLOGY ASSESSMENT PANEL FOR THE SCAG MAGLEV CORRIDOR

On behalf of my colleagues, Drs. David Wormley of PSU and Steven Erie of UCSD, I am pleased to submit this letter report summarizing our findings with respect to the Draft Technology Selection Memorandum [DTSM] (our Task D) and the precedent Tasks (A, Concept Review and Advice in Development of Technology Forecasting Tool - Boon; Task B, Review of Travel Time and Power Consumption Estimates - Wormley; and Task C, Review of Relative Operating Cost Estimates - Boon).

With respect to the DTSM, we are unanimous in offering the following comments:

- The selection process developed and applied by PTG is transparent, clearly defined, objective and consistently and equitably applied.
- The criteria employed in the selection process are reasonable and appropriate, and explicitly map to the criteria established for the FRA's MAGLEV Technology Deployment Program.
- The selection process was applied correctly and fairly.
- Each candidate technology supplier was treated fairly and equitably.
- The recommended technology selection is appropriate and well-supported by the results of the analysis.

The individual memoranda dealing with Tasks A, B, C and D are attached as Annexes A, B, C, and D1 (Boon), D2 (Wormley), and D3 (Erie) to this letter report[7]. The points below summarize the highlights from these memoranda.

[7] These documents are included in this Appendix; any PTG comments on these documents are footnoted therein.

Task A (Boon)

AMT Risk Assessment

"On the basis of the information provided . . . this technology has a high risk of outright technical failure (stemming largely from its dependence on brush pick-up and distribution of 5MW+ power), a high risk of inability to achieve its proposed schedule (due to its truncation at 120 mph rather than 240 mph as required) and a high risk of significant cost increases over the course of the development process (again stemming from the need to deal with power pick-up and distribution issues)."

Maglev 2000 Risk Assessment

"On the basis of the information provided . . . this technology has a moderate risk of outright technical failure (largely stemming from systems integration issues), a very high risk of inability to achieve its proposed schedule and a high risk of significant cost increases over the course of the development process."

Meneren Risk Assessment

"On the basis of the information provided . . . this technology has a high risk of outright technical failure (stemming from the dependence on brush pick-up of 5 to 10MW power), a high risk of inability to achieve its proposed schedule (due to significant underestimation of the level of technical issues to be overcome during detail design and testing), and a high risk of significant cost increases over the course of the development process (again stemming from the need to deal with power pick-up issues and underestimation of the technical complexity and unproven status of some key subsystems of the proposed design)."

TRI Risk Assessment

"On the basis of the information provided . . . Transrapid has essentially zero risk of outright technical failure, a low risk of inability to achieve its proposed schedule, and a low to moderate risk of significant cost increases over the course of the commercial deployment process (stemming from site-specific environmental and geotechnical conditions and from regulatory uncertainties)."

Finally, as a general comment pertaining to assessment of performance and other claims for technologies in the early stages of development.

> "Analysis and simulation in the absence of validating experimental results typically demonstrate little except the consequences of the assumed input parameter values."

Task B (Wormley)

From his review, Dr. Wormley reported the following:

> "The trip scenario simulator has been reviewed to determine whether its predictions of train time-distance profiles and energy consumption are reasonable and consistent with data available in COE 98–12. The scenario simulator results for the cases reviewed were consistent with other available data and in general reflected in an integrated fashion the detailed system performance data. It is noted that detailed review of the equations embedded in the simulator was not performed as this type of effort was not within the scope of the review."
>
> "For each of the systems, the parameters describing the vehicle performance which are used as inputs to the trip scenario simulator were reviewed including:
>
> - Vehicle mass properties
> - Aerodynamic and magnetic drag
> - Propulsion force and power
> - Hotel power
>
> For each of the systems these parameters were found to be consistent with the performance data available . . ."
>
> "Results of simulations for each of the four systems were reviewed for the hypothetical trip considered. The simulated scenarios indicated that the power requirements of the four systems are:
>
> System A: 0.043 kWh/seat-km
> System B; 0.037 kWh/seat-km
> System C: 0.031 kWh/seat-km
> System D: 0.031 kWh/seat-km
>
> These trip scenario results for the respective system power requirements for the trip profile considered are consistent with the basic parameters of each system and reflect the differences in the system technologies employed"; and
>
> "The certainty of the determination of the performance of each system is strongly influenced by the degree of certainty of the performance parameters of the individual system vehicles and vehicle subsystems. For the four systems, significant variations exist in their stages of development and in the verification of the performance parameters with full-scale, at-speed tests. Thus, while the parameters used to represent vehicle performance for each system appear to be reasonable engineering estimates, only after further tests could they be verified with a high degree of certainty for the systems (Systems B, C, D) for which at speed, field test data are not available."

Task C (Boon)

"There are major differences amongst the candidate technologies in terms of the characteristics of the key subsystems and the extent to which the design and realization of these subsystems has been proven in full-scale test at the design speed. This latter aspect [the absence of experimental results] is of major concern with respect to the estimation of relative maintenance costs. Insofar as the lack of experimental evidence necessitates attachment of a much broader error of estimate to any nominal cost."

"Were one to develop distributions of cumulative probability for O&M cost for the four candidate systems, these distributions would take the following forms:

- "The lowest error of estimate (and least skewed) distribution of probable O&M cost will be associated with TRI, for which all key subsystems have been proven in full-scale and full-speed tests."
- "The distribution for Maglev 2000 would have a larger error of estimate (due to the absence of test validation for the specific designs that are proposed and the lack of any specific design for its electronic switch) and will be somewhat skewed to the right (i.e., a greater cumulative probability of higher rather than lower costs relative to the nominal mean)."
- "The distribution for American Maglev would have a significantly larger error of estimate (due to the use of not one but two brushed contacts for power pickup and distribution and the absence of even a conceptual design for a high-speed switch) and will be more skewed to the right."
- "Maglift Monorail would have the highest error of estimate (due to the use of brushed contacts for power pickup [unproven at speed]; the use of partial steel-wheel on rail suspension and guidance [unproven at speed]; the proposed use of a transfer-table type switch [lock to lock time unknown]; and the use of the segmented phase LIM [development status and characteristics undocumented] and will be most heavily skewed to the right."

Task D (Boon, Erie, Wormley)

Boon comments:

"The evaluation process defined and applied by PTG in their selection analysis is transparent and specifically responsive to the criteria established by the FRA and applicable state. regional and local requirements, objectives and goals."

"The criteria used in the evaluation process are reasonable and appropriate given the stated Program objectives and criteria, and the apparent prioritization of these criteria as reflected in 49 CFR 268 and the "Questions" document cited above."

"The criteria and process have been applied with scrupulous fairness and objectivity as regards the three U.S. design concepts. In fact, I believe that these three have been given *more* than any reasonable *benefit of the doubt* in the absence of reproducible and published experimental results."

"The evaluation process has been applied accurately and in accordance with the process set out in section 1 of the Technology Selection Report."

"The final recommendation, of Transrapid, is appropriate, reasonable and fully supported by the evaluation process."

Erie comments:

"The relative weighting of FRA, corridor and project description elements appears reasonable…. Considering that the Federal share of full project costs will be no greater than 2/3s, it is reasonable to weight FRA criteria at roughly double the value of corridor and program [criteria]."

"The criteria, maximum point assignments and measures of effectiveness proposed *within* the three overall evaluation components also seem reasonable. In particular, because the FRA selection criteria attach considerable weight to *timely implementation*, the 25 maximum points assigned here seems appropriate."

"Overall, the weighting and criteria chosen meeting FRA and corridor requirements seem reasonable. The FRA project selection criteria excluded from the draft selection report because they do not depend upon the choice of technology supplier also appear appropriate. In addition, the selection criteria for short-listing candidate technology suppliers appear appropriate."

"Considering variation in both the quantity and quality of technological, operational and financial data provided by the four candidate suppliers, the Draft Selection Memorandum's treatment of each seems fair and reasonable."

Dr. Erie does raise one concern, namely:

"The assignment of 9 out of a possible 10 points to Transrapid in terms of technology transfer and U.S. job growth."

> "The draft Memo's measure of effectiveness and its application both need to reflect uncertainties regarding the evolving U.S. MAGLEV market and technology transfer impacts. The selection of the SCAG corridor and TRI as the candidate supplier could in fact affect the entire U.S. high-speed rail market. If the operational advantages of remaining U.S.-based candidate suppliers are sufficient for them to remain candidate successor technologies should TRI and the SCAG corridor be selected, then those advantages should be reflected in their relative ratings for operational considerations. Here the draft report might benefit by erring on the side of caution. TRI's overall U.S. economic benefit score may be somewhat less than the 12 currently assigned."

However, this concern not withstanding, he concludes:

> "All things considered, the recommendation of Transrapid appears appropriate in terms of its distinct advantage regarding earlier revenue service availability."
>
> "Overall, the draft Technology Selection Memorandum appears reasonable, technically sound and comprehensive."

Dr. Wormley comments:

> "The study utilizes a systematic and well-accepted selection methodology."
>
> "The rationale for the weighting factors is clearly described."
>
> "The parameters characterizing the four technologies are established in a consistent manner using available performance date from the developers of the technologies and engineering judgment."
>
> "The results of the selection process leading to the ranking of the four competing technologies [are] strongly influenced by the technical and fiscal risk associated with the deployment of the technologies in the near future, i.e., 4-7 years. With this constraint as a dominant factor, the overall selection process has resulted in a final ranking that strongly reflects the relative development and deployment risk of the technologies."

We trust that the comments provided above and in the Annexes to this letter will assist SCAG and PTG in obtaining the desired designation as the Federal Maglev Deployment Corridor.

Yours sincerely,

Christopher J Boon
Chair, Technology Assessment Panel
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