AN ASSESSMENT OF PEOPLE MOVER TECHNOLOGIES FOR GEORGIA TECH

In Partial Fulfillment

of the Requirements for the Degree of

Master of Science in Civil Engineering

by

Robert Schreiber

GEORGIA INSTITUTE OF TECHNOLOGY
A UNIT OF THE UNIVERSITY SYSTEM OF GEORGIA
SCHOOL OF CIVIL ENGINEERING
ATLANTA, GEORGIA 30332
AN ASSESSMENT OF PEOPLE MOVER TECHNOLOGIES FOR GEORGIA TECH

A SPECIAL RESEARCH PROBLEM

PRESENTED TO

THE FACULTY OF THE SCHOOL OF CIVIL ENGINEERING

GEORGIA INSTITUTE OF TECHNOLOGY

by

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Approved:

Faculty Advisor/Date
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ABSTRACT

This analysis of "people mover" technologies addresses the comparative advantages and disadvantages of several fixed guideway transportation systems. The project was initiated as one part of an evaluation of transportation needs for the Georgia Institute of Technology. Manufacturers of people mover systems were asked to respond to a technical questionnaire with information describing their systems. Fifteen vendors replied, formally proposing 20 different systems for evaluation. Information from their responses was extracted and either entered into matrices of technical data or summarized and explained in descriptions of their systems. The report concludes that Personal Rapid Transit technology is most appropriate for further research, development, and eventual deployment for service on Tech's campus. The next most appropriate selection is the mass transit system supplied by Aeromovel. All other technologies are recommended with lesser degrees of appropriateness.
ASSESSMENT OF PEOPLE MOVER TECHNOLOGIES

FOR GEORGIA TECH

1.0 INTRODUCTION

This document is intended as one part of a larger assessment of the transportation needs for the Georgia Institute of Technology as it prepares for the 1996 Olympic Games. In particular, this analysis addresses the comparative advantages and disadvantages of several "people mover" systems. People movers are characterized as fixed guideway transportation systems that are designed to carry as many as 18,000 passengers per hour per direction, between stations that are usually spaced no further than a nominal 0.5 mile apart, in a limited geographic area (in contrast with line-haul or corridor systems).

Specific attention has been directed to the feasibility of implementing a system on Tech's campus with regard to the following possible scenarios;
- providing only on-campus transportation
- providing transportation on campus with the likelihood of expansion into the Midtown/Central Business District (CBD) of Atlanta
- accrued opportunities for conducting transportation research on a developing transit mode
- accrued opportunities for conducting transportation research on a developing transit technology.

2.0 ASSESSMENT PROCESS

The following list of characteristics represents one of the criteria used to evaluate the various proposed systems. The criteria are drawn from the technologies of other existing fixed guideway systems and their associated operating rules, regulations, and practices which have been accepted in the United States. In particular, the National Fire Protection Association, Inc. document 130 (NFPA 130) titled "Standard for Fixed Guideway Transit Systems", 1990 Edition, has been utilized as the most significant guideline for a number of assessment concerns. While a system may be promoted and/or designed to be technologically more sophisticated than other systems, the approach adopted for this assessment will not consider this system a "better" system than one which is technologically less sophisticated but better able to provide service which generally contributes to safer and more efficient operations.
Favorable evaluation of any system is increased if it can provide;

- **double track guideway with double crossover switches** which allow traffic to operate on either track in either a normal directional flow or a reverse flow, referred to as a "reverse run". This feature allows maximal flexibility of operations during failure management situations such as occur when stalled vehicles, failed right-of-way, or obstructed right-of-way prevents normal operations.
- **switches for either divergent route alignments away from or converging route alignments onto a separate right of way (ROW) alignment.** This allows routing options which serve a larger geographic area than can be served by a single line alignment.
- **individual vehicles which are capable of operating in two directions.** The bi-directional capability facilitates rapid and economical turnaround at a terminal. Rather than acquiring large real estate parcels for a loop turnaround, a narrow "tail track" can be provided for switching over to the track of return (opposite) directional flow. Furthermore, bi-directional operation allows high levels of routing and system flexibility for safety and failure management. If a transit unit (single vehicle or multi-unit consist) cannot proceed forward due to an obstructed guideway, the consist can be operated in the reverse direction to a station or switching area.
- **individual vehicles which can be coupled together to make trains.** More favorable evaluation also occurs if each vehicle is modular, meaning that any one vehicle can be positioned at the head, tail, or in the middle of a consist. In conjunction with adjusting headways (elapsed time between head ends of scheduled successive trains), the ability to quickly and easily adjust consist length, i.e. passenger capacity, contributes to maximizing the efficiency of the system during periods of fluctuating passenger demand.
- **train control which is implemented by wayside signals with manual vehicle operation, cab signals with full automatic vehicle control, or a combination of both.**
- **safe evacuation of passengers from a train at a non-station location.** Customarily, passengers can be evacuated through either 1) the normal entraining doors on either side of the train onto a walkway or another train or vehicle, or 2) by moving internally along the consist length, through vehicle end-doors, and then exiting the train through the last vehicle end-door, at either end of the train, onto the track bed, or onto an evacuation vehicle.
- **achievable headway minimums which are in the range of 50-120 seconds or less.** On-
time-performance (trips operating with delays less than 1 minute) is desired to be regularly in the range of 99+%.

- maximum operating speeds which are in the range of 15-30 mph or higher.
- the conventionally accepted standard for moving trains on the mainline, which calls for no less than 50% of the vital subsystems on a consist to be operational. Equipment for propulsion, braking, and air compressors is customarily designed to be in excess of twice the needed capability during a vehicle's normal operation. Equipment should be specified to meet this standard. The significance of this standard directly affects emergency/failure management. The variety of combinations of train lengths and their associated resulting redundancies of vital systems makes a detailed description of failure management difficult. However, a consist that operates normally with 100% of its vital subsystems (200+% of its needed capabilities) and then fails into less than "car-for-car" or less than 50% vital subsystems (100% of need) must be removed from the mainline by either a "rescue train" (which is usually the next following train, after passengers have been off-loaded) or some other specially designed piece of equipment. In either situation, normal traffic is interrupted and delays begin to develop.

- the preferred method of managing any single train failure between stations (a train unable to move) which is to reset, cut-out (disconnect), or correct the failed components, by remote control or, if available, by an operator or supervisor on the train, and then proceed. The next preferred method is to push or pull the disabled train, with the next available good train, to a station platform where passengers can be discharged. If these cannot be done, the next preferred method (on a vehicle without an operator) is to have controls on the vehicle which allow an authorized person to enter the failed vehicle and manually operate the vehicle to a safe refuge. If none of the preceding capabilities are available, provisions for the safe emergency evacuation of passengers must be designed into the system.

- vehicles and facilities which are designed to comply with the Americans with Disabilities Act (ADA). Federal law explicitly states specifications which must be adhered to in order for manufacturers to comply with ADA legislation for fixed guideway systems (Federal Register, Volume 56, #173, Friday, September 6, 1991, Rules and Regulations & Federal Register Part 4, Section 49, CFR Parts 27, 37, 38. 11-6-91). Any eventual performance specification for a people mover system on Tech's campus should stipulate that vendors are responsible for compliance with ADA regulations.
3.0 VENDOR SELECTION PROCEDURE

The selection of vendors was made by first researching marketing literature, books, and articles. A small group of fixed guideway consulting professionals, government officials, and developers provided further assistance in locating potential vendors. After the vendors were identified, a questionnaire and two feasible alignments were generated (see Appendix B, Page 140). Of the two alignments, one was a simple double track alignment (pinched loop) laid out through the diagonal center of campus. The other was a double track alignment on the Southwest part of campus connected to a single track loop through the Northwest part of campus providing more convenient service to campus activity centers (as determined by a separate travel-demand survey). Vendors were then contacted to determine if they would like to receive the questionnaire/alignment.

In the process of distributing the questionnaire, several more vendors expressed interest in submitting materials. Finally, after the questionnaire had been "on the street" for several weeks, several other vendors expressed interest in the project. Considering that an article, which referenced Atlanta and the Olympics, mentioning Tech's project, appeared in "Transit Pulse" (a bi-monthly periodical that provides news about people mover projects), it is likely that any potential vendor of a viable system was made aware of Tech's interests, and as such, those who responded represent a comprehensive list of viable suppliers.

The final vendor group represents a cross-section of technologies which can be categorized along the parameters of, a) innovative versus established systems, b) mass transit people movers versus personal rapid transit systems, c) bottom supported, topside supported, or guideway-side/vehicle-side supported systems, d) manually controlled operation versus fully automatically controlled vehicle operation, and e) car-born mounted propulsion versus wayside mounted propulsion system location (linear induction, cable, or pneumatic pressure). When received, the responses were reviewed, and each vendor was contacted to acknowledge receipt of their response, as well as to attempt to clarify any potential misunderstandings or apparent ambiguities in their responses. Statistical technological information has been extracted and entered into matrices. Information regarding system descriptions, operating characteristics, and areas of special concern are addressed in written evaluations which follow the matrices section.

1Readers who are marginally familiar with rail operations are advised to read Appendix A, Part I, Page 117, in order to gain an appreciation of the distinctions between Mass Transit, Group Transit, and Personal Transit as well as gain an initial appreciation of the role that technology plays in fixed guideway systems.
4.0 RECOMMENDATIONS

The decision criteria for selecting a fixed guideway technology for construction and operation have not yet been identified by Tech's administration. As such, the scenarios described in the introduction section will be used as the primary guidelines for the recommendations which follow. Additionally, the recommendations are made without complete engineering studies of the various suppliers regarding their ability to perform as described and without financial cost estimates of any proposed system. This information can only be generated after performance specifications are determined by Tech. Performance specifications include data such as exact route alignment and station locations, desired frequency of service, more accurate ridership forecasts, and a variety of other pertinent information all of which is required from any potential owner before a vendor can engineer a system and provide meaningful cost estimates. In the absence of the preceding, the following recommendations are based on a system's anticipated ability to provide service as proposed by the supplier.

The four scenarios from the introduction are:

- providing only on-campus transportation
- providing transportation on campus with the likelihood of expansion into the Midtown/Central Business District (CBD) of Atlanta
- accrued opportunities for conducting transportation research on a developing transit mode
- accrued opportunities for conducting transportation research on a developing transit technology.

Conventional systems which provide only transportation and have limited or no opportunity for conducting research in transportation are eliminated from the following recommendations. The expense of such a transportation system is difficult to justify, given the relatively small geographic area of campus. If financial commitment from the private sector can be obtained prior to embarking on a campus construction project, the feasibility of such a system is changed dramatically. The conventional systems in this project include AEG Westinghouse, Bombardier/UTDC, Soule', Von Roll, VSL, and Poma. VSL and Bombardier/UTDC have proposed a downtown people mover system to local Atlanta government and private sector groups. Maintaining contact with these groups is advisable as their proposal continues to receive further evaluation from the local sector.
Personal Rapid Transit (PRT), as an emerging mode of public transportation, is most likely to provide solutions to both contemporary and future public transportation needs in unprecedented ways. A more comprehensive discussion of PRT appears in Appendix A, Part II, Page 131. PRT offers attractive and economical solutions to both mobility and accessibility problems brought on by the changing demographic growth patterns of society. PRT offers passenger capacities and average-travel-speeds which are equal or higher than conventional bus-integrated Heavy and Light Rail metropolitan transit systems. The same benefits apply for PRT systems deployed in urban activity centers, such as either of Tech's alignment scenarios. Additionally, the research and development required to refine PRT, such as automatic vehicle control and computer neural networks are applicable to other areas of technology and transportation, especially IVHS research.

PRT is also likely to be the most expensive of the proposed concepts since, with the exception of CabinTaxi, many research and development costs will be encountered before any system can become operational. In particular, the ability of a supplier to provide car-born switching is anticipated as crucial to development of a truly competitive PRT system.

PRT SYSTEMS, Rank Ordered

- CABINTAXI is the system with the largest number of technological benefits and varieties of operational configurations, especially the ability to operate both Group and Personal transit on one guideway. By operating vehicles in opposite directions on the top and bottom of one guideway beam, it is the only system that can provide guideway redundancy in the event of vehicle or specific guideway failures. This approximates the benefits of reverse run capabilities of conventional dual guideway systems. CabinTaxi has a proven car-born switch which allows safe alternate routing selections when headways of three seconds or less are utilized. CabinTaxi has been demonstrated in full scale and has been recognized as ready for urban demonstration by the Federal German Railway. The vendor estimates being able to construct a system in 18-24 months and be ready for revenue service upon completion. At least two principals in the CabinTaxi organization have direct construction experience with the original CabinTaxi project and other more recent state-of-the-art transit projects. CabinTaxi has already been through an R&D phase during which a reported $70 million dollars (1978 dollars) was expended, however, additional R&D is necessary to upgrade systems which will benefit from improvements in technology since the original demonstration project was dismantled. Offsetting
this necessary expenditure is the desire of CabinTaxi to enter into a relationship with Tech, which would allow for continued urban transportation research and also allow for the distribution of eventual profits if the potential benefits of CabinTaxi come to fruition.

- **TAXI 2000** lacks guideway redundancy but utilizes carbon switching to provide only Personal Rapid Transit on its guideway (no CRT). The Taxi 2000 proposal represents many years of engineering refinement and has the support of Stone and Webster engineers, and may be able to provide financial capital through a recently completed relationship with Raytheon. Taxi 2000 has not yet operated a test track, and as such is likely to take four years after construction to become ready for passenger service.

- **SWEPETRACK FLYWAY** utilizes carbon switching and is being promoted as being able to provide guideway redundancy in limited applications. The benefits of topside suspension and the lowering cabins to the ground in lieu of elevated stations need independent engineering evaluation beyond the capabilities available herein. There is no indication of SwedeTrack's organizational structure nor any experience with other transportation projects and their reported relationship with Siemens is uncertain.

- **TITAN PRT** has construction experience with several mass transit projects. They have an existing financial strength through their involvement with other transit and non-transit related projects. They are also the only vendor to promote the concept of using the construction of a transportation system on campus for instructional coursework with upperclass students. Technologically, their subsystems and designs are conducive to PRT with the exception of the inability to provide carbon switching with their current guideway configuration. This limitation is assessed as a significant obstacle to developing a truly competitive PRT system.

- **INTAMIN** also lacks a carbon switch. Although they have construction experience with conventional mass transit systems, and have a parent company with a significant estimated financial stability, their level of technical refinement is assessed as incapable of providing the hardware necessary to support the short headways that PRT requires.

4.2 HIGHLY RECOMMENDED

- **AEROMOVE** propos a system (Type I, short vehicle) that can provide all requirements, except coupling, for either of the two mass transit alignment alternatives. The inability to provide coupling is negated by the systems ability
to provide less than 60 second headways with vehicles that can be sized in a variety of passenger capacities. Its design indicates that it can provide significantly lower construction, operation, and maintenance costs, relative to systems that can provide similar services. The levels of safety engineering and redundancy of systems are assessed as very high for a system of the people mover class. A test track, two demonstration projects, and one operating revenue service system indicates that a system for Tech can be built and placed in service in 24 months or less.

4.3 RECOMMENDED

- TITAN PRT's mass transit top-side supported system is proven in several American installations. Further evaluation of the cost/benefits of top-side supported suspension systems relative to other suspension systems is required before more thorough comparisons can be generated.
- SWEDETRACK S1PEM is operationally proven, however, the system has been deployed in only one application in Germany. The organization of SwedeTrack and their interests in maintaining operations and maintenance support is not evident. Their relationship with Siemens is uncertain.

4.4 NOT RECOMMENDED

Evaluated as unsuitable are all of the three vendors who are proposing side-supported systems: Futrex-System 21, HighRoad, and Continental Transit, Inc.’s InstaGlide. Although the systems could conceivably provide transportation, they are assessed as not being able to demonstrate benefits that exceed their limitations.

All three;
- lack reverse run switching capability, which is vital for vehicle and/or guideway failure management.
- terminate in a loop, making system extension difficult.
- are restricted in their ability to provide both center and side mounted platforms.
- are variations of mass transit modes with insufficient advantages to make them attractive relative to the anticipated costs of other emerging and comparably priced technologies.
- have not been demonstrated in a scale model test or full scale test, in a form as needed by Tech. If the systems offered greater potential advantages, the risk of selecting an untested technology for research might be justifiable.
5.0 MATRICES WITH TECHNICAL DATA

The following section includes matrices of technical data from each of the vendors. Preceding each matrix is an explanation of the abbreviations used in that matrices' column headings. All information in the matrices is drawn from the individual vendor responses and is a reflection of their designs, beliefs, and experience. Verification of the ability or inability of a vendor to supply a specific system characteristic is the responsibility of a prospective owner. Blank entries in the matrices indicate that a vendor did not supply information to that particular question.

Two of the matrices, the Planning Matrix-5.4 and Planning Matrix Supplement-5.5, are composites of information which can be found in other matrices. They have been generated as an aid for easily accessing basic data which is used in designing system operating and construction parameters.

The following abbreviations have been used to identify individual vendors:

AEGW- AEG Westinghouse, System C-10, C-45, or C-100
ARMV- Aeromovel, Type I-a or II-a
ARBS- Aerobus of Texas
CBTX- CabinTaxi, USA
FTRX- Futrex System-21
HIRD- Highroad
ITMN- Intamin
SULE- Soule' SK
SWDT FLWY- SwedeTrack, Flyway
SWDT SIPM- SwedeTrack, Sipem
TITN- Titan FRT Systems
UTDC- Bombardier, UTDC Transportation Systems Division
VNRL- Von Roll, Type II or III
VSL- VSL Corporation
POMA- Poma, Urban Transportation Systems
CIVIL AND SWITCH MATRIX - 5.1

1) SUPPORT-Position of the guideway support structure relative to the vehicle.

2) MINIMUM HORIZONTAL/VERTICAL CURVE-The smallest horizontal/vertical curvature through which the vehicle or trainset can be guided in normal operations.

3) STANDARD SPAN LENGTH-The most economical distance between support columns.

4) MAXIMUM SPAN LENGTH-The longest distance between columns before encountering excessive or unusual costs. Some vendors can provide cable stayed spans or special beam construction if designs require unusually long spans.

5) COST DIFFERENTIAL-The cost penalty for building maximum length spans relative to the cost for building standard length spans.

6) GRADE-A train's maximum sustainable rate of climb, expressed as feet/100 feet.

SWITCHES

7) LOCK-TO-LOCK TIME-The amount of time required for an automatic switch to throw (change routing alignment) and be properly aligned and locked for traffic.

8) MAXIMUM SPEED-The highest rate of travel through a switch which is positioned for diverging or merging traffic. Tangent moves are "straight through" and seldomly require speed reductions.

9) CURVE RADII RANGE-The range of curve radii which can be built into a switch for diverging/merging alignments. Higher radii along with spirals allow for higher speeds and higher passenger comfort when entering diverging routes.

10) TYPE-A description of the operating characteristics of a given switch;
   • Pivot- an entire beam section shifts laterally around a central pivot point to meet either of two routing options.
   • Rotary Beam- an entire beam section rotates on a longitudinal axis to provide routing on either of two alignments.
   • Flexible Point (conventional railroad switch)- a flexible length of rail is moved laterally by a switch machine to create a route between one of two available routes.
   • Flexible Point with Flexible Frog- both a long flexible length of rail, and a short flexible length rail where the two routes merge, are moved to create one route.
   • Turntable- a length of track is mounted on a device which can be rotated, horizontally, while a train is on it, to a different route. Turntables are limited to moving short consists on non-operational routes i.e. into yards or storage facilities.
   • Transfertable- after a train operates onto an independent section of track, the section slides laterally with the train on it, and aligns with any of several parallel tracks for further downstream or upstream movement (used only for maintenance).
   • Sliding Beam- a tangent and a curve beam are mounted on one piece of sliding apparatus which can be positioned to allow routing to either of two alignments.
   • Beam Replacement- a compound pivot switch where two or more beam sections shift to provide a alternate routing.

11) MANUAL CRANKING CAPABILITY-In the event of a power or control failure at the switch, a person can manually operate the switch with a crank or other device.
<table>
<thead>
<tr>
<th>VENDOR</th>
<th>SUPPORT</th>
<th>MIN HOR CRV ft</th>
<th>MIN VER CRV ft</th>
<th>STD SPAN LENGTH ft</th>
<th>MAX SPAN LENGTH ft</th>
<th>LOCK TIME sec.</th>
<th>MAX SPEED LIMIT mph</th>
<th>CURVE RADIUS RANGE</th>
<th>TYPE</th>
<th>MANL CRANK CAPABILITY</th>
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<td>50-60</td>
<td>50-60</td>
<td>var</td>
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<td>15</td>
<td>8</td>
<td>75</td>
<td>pivot</td>
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<tr>
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<td>BOTT 75</td>
<td>s 675 c 225</td>
<td>80</td>
<td>100-120</td>
<td>var</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>75+</td>
<td>pivot</td>
</tr>
<tr>
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<td>BOTT 75</td>
<td>s 350 c 450</td>
<td>80</td>
<td>100-120</td>
<td>var</td>
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<td>10</td>
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<td>75+</td>
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<td>328</td>
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<td>124</td>
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<td>10</td>
<td>6</td>
<td>7.5-14</td>
<td>78</td>
<td>FLEXIBLE POINT WITH FLEXIBLE FOG</td>
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<td>BOTT appx 75</td>
<td>328</td>
<td>82</td>
<td>124</td>
<td>80</td>
<td>10</td>
<td>6</td>
<td>7.5-14</td>
<td>78</td>
<td>FLEXIBLE POINT WITH FLEXIBLE FOG</td>
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<tr>
<td>ARBS TOP</td>
<td>TECHNICAL INFORMATION IS NOT AVAILABLE</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CBTX</td>
<td>BOTH 100</td>
<td>105+ w/ cable stay</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>carbon</td>
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<tr>
<td>FTRX</td>
<td>SIDE 90</td>
<td>300 '70-98'03.5' incr</td>
<td>10</td>
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<td></td>
<td>FLEXIBLE POINT w/ FLEXIBLE FOG, TURNTABLE</td>
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<td>3</td>
<td>130+</td>
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<td>49</td>
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<td>SWDT FLWY</td>
<td>TOP 16 SLOW</td>
<td>300 98-131+w/ cable stay</td>
<td>0 w/ PENALTY</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td>100</td>
<td>125</td>
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<td>120 (EX.)</td>
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<td>30</td>
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<td>10</td>
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<td>9</td>
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<td>70-90</td>
<td>110-120</td>
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<td>10</td>
<td>8</td>
<td>var</td>
<td>50+</td>
<td>sliding beam, pivot</td>
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<td>164</td>
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<td>6</td>
<td>15</td>
<td>none</td>
<td>45</td>
<td>sliding beam, transferable, etc.</td>
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<tr>
<td>VNRL III</td>
<td>BOTT 65.5</td>
<td>1000</td>
<td>98</td>
<td>164</td>
<td>var</td>
<td>6</td>
<td>15</td>
<td>none</td>
<td>65</td>
<td>sliding beam, transferable, etc.</td>
</tr>
<tr>
<td>VSL</td>
<td>BOTT 100</td>
<td>250</td>
<td>140</td>
<td>160</td>
<td>20</td>
<td>12</td>
<td>7</td>
<td>30</td>
<td></td>
<td>rotary beam</td>
</tr>
<tr>
<td>POMA</td>
<td>50</td>
<td>165</td>
<td>65-100</td>
<td>120</td>
<td>20</td>
<td>15</td>
<td>3</td>
<td>28</td>
<td>var</td>
<td>flexible point</td>
</tr>
</tbody>
</table>
Dynamic Envelope refers to the widest and highest dimensions of clearance required to allow a car or trainset to safely move along the ROW without striking any fixed objects. Attention is given to failed suspension which may cause a vehicle to lean to the left or right, or tip with either the lead or tail end assuming a taller position than during normal operations. Also, the front-end, rear-end, and the middle of the car body often pass outside the path of the wheeltrucks when the vehicle runs on curved track sections.

Horizontal-

SINGLE TRACK, STRAIGHT ROUTE-width requirements for a single track alignment on a straight section of ROW.

DOUBLE TRACK, STRAIGHT ROUTE-width requirements for a double track alignment on a straight section of ROW, including recommended space between the two tracks.

SINGLE TRACK, CURVE ROUTE-width requirements for a single track alignment on a minimum curve radius section of ROW.

DOUBLE TRACK, CURVE ROUTE-width requirements for a double track alignment on a minimum curve radius section of ROW.

Vertical-

SINGLE TRACK, STRAIGHT ROUTE-height requirements for a single track alignment on a straight section of ROW.

DOUBLE TRACK, STRAIGHT ROUTE-height requirements for a double track alignment on a straight section of ROW, including recommended space between the two tracks.

SINGLE TRACK, CURVE ROUTE-height requirements for a single track alignment on a minimum curve radius section (sag or crest) of ROW.

DOUBLE TRACK, CURVE ROUTE-height requirements for a double track alignment on a minimum curve radius section (sag or crest) of ROW.
# Dynamic Envelope Matrix - 5.2

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Single Straight</td>
<td>Double Straight</td>
</tr>
<tr>
<td>AEGW C-10</td>
<td>BOTT</td>
<td>vehicle is currently being redesigned</td>
<td></td>
</tr>
<tr>
<td>AEGW C-45</td>
<td>BOTT</td>
<td>9' 5&quot;</td>
<td>9' 10&quot;</td>
</tr>
<tr>
<td>AEGW C-100</td>
<td>BOTT</td>
<td>11' 0&quot;</td>
<td>13' 6&quot;</td>
</tr>
<tr>
<td>ARMY TP-I</td>
<td>BOTT</td>
<td>8' 7&quot;</td>
<td>9' 11&quot;</td>
</tr>
<tr>
<td>ARMY TP-II</td>
<td>BOTT</td>
<td>9' 9&quot;</td>
<td>10' 6&quot;</td>
</tr>
<tr>
<td>ARBS TOP</td>
<td>TECHNICAL INFORMATION IS NOT CURRENTLY AVAILABLE</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CBTX BOTH</td>
<td>TECHNICAL INFORMATION IS NOT CURRENTLY AVAILABLE</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FTRX SIDE</td>
<td>20' +</td>
<td>8'+</td>
<td></td>
</tr>
<tr>
<td>HIRD SIDE</td>
<td>25' 6&quot; est.</td>
<td>9'+</td>
<td></td>
</tr>
<tr>
<td>ITMN BOTH</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SULE BOTH</td>
<td>8' ?</td>
<td>14' 9&quot;</td>
<td>11' 4&quot;</td>
</tr>
<tr>
<td>SWDT TOP</td>
<td>23'+</td>
<td>37'</td>
<td>34' 6&quot;</td>
</tr>
<tr>
<td>FLWY</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SWDT TOP</td>
<td>24'+</td>
<td>37'</td>
<td>34' 6&quot;</td>
</tr>
<tr>
<td>SIPM</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TX20 BOTT</td>
<td>5' 6&quot;</td>
<td>2X 5' 6&quot; CLEARANCE</td>
<td>5' 8.5&quot;</td>
</tr>
<tr>
<td>TITN TOP</td>
<td>12' 4&quot;</td>
<td>20' 7&quot;</td>
<td>12' 4&quot;</td>
</tr>
<tr>
<td>UM-3 BOTT</td>
<td>7' 4&quot;</td>
<td>17' 8&quot;</td>
<td>8' 3&quot;</td>
</tr>
<tr>
<td>UM-3 INCL. WALKWAY</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VNRL T-II</td>
<td>BOTT</td>
<td>6' 3&quot;</td>
<td>14' 1&quot;</td>
</tr>
<tr>
<td>VNRL T-III</td>
<td>BOTT</td>
<td>7' 1&quot;</td>
<td>15' 4&quot;</td>
</tr>
<tr>
<td>VNRL III</td>
<td>BOTT</td>
<td>9' 4&quot;</td>
<td></td>
</tr>
<tr>
<td>VSL</td>
<td>BOTT</td>
<td></td>
<td></td>
</tr>
<tr>
<td>POMA</td>
<td>BOTT</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
1) CENTER/SIDE- Indicates whether a system can provide service to stations with platforms that are in the middle of a double track ROW (center platform), to stations with platforms that straddle the ROW (side platform), or whether a system can serve both types of station platforms.

2) PLATFORM DOORS- Indicates the availability of barriers or platform mounted doors that open and close in synchrony with the doors on a stopped vehicle. Such systems are not usually deployed if Obstruction Detection systems are installed.

3) OBSTRUCTION DETECTION- Indicates the availability of subsystems to detect the presence of a person or other types of obstructions on the ROW at a station. Such systems are not usually deployed if platform doors are installed.

4) STAFF REQUIRED- Indicates the need to provide station staffing for normal operation of the vehicles. Aeromovel allows for the elimination of Automatic Train Control subsystems if station staffing is utilized. Other vendors require operators in the vehicles if fully automatic operation is not installed.

5) NEW ARCHITECTURE- Indicates the feasibility of incorporating a station into a new building (one under construction), either in a lobby or abutting the side of a new or existing structure.

6) GAP, NORMAL/WORST- Indicates the horizontal distance between the platform edge and a vehicle's door threshold. Satisfying ADA requirements, and precision construction of platforms relative to vehicle guidance structures are dependent on this information.

7) PLATFORM & CAR THRESHOLD ALIGNMENT- Indicates the vertical distance between the platform edge and a vehicle's door threshold. Satisfying ADA requirements and introducing a possible "tripping hazard" to patrons is dependent on this information.

8) PLATFORM LENGTH- indicates the length that a platform edge must be built to accommodate a specific vehicle, trainset, or train consist.

9) TERMINAL RUN-THROUGH- indicates the need for an additional length of track at a terminal, beyond the platform length, to allow for safe braking in the event of a failure of the automatic stopping subsystem.
<table>
<thead>
<tr>
<th>VENDOR</th>
<th>CNTR/SIDE</th>
<th>PLTFM DOORS</th>
<th>OBSTR DETCT</th>
<th>STFF REQD</th>
<th>NEW ARCH</th>
<th>GAP NORML/WRST in.</th>
<th>PLTFM &amp; CAR THRSH ALIGN</th>
<th>PLATFORM LENGTH</th>
<th>TERMINAL RUN-THRU</th>
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<tbody>
<tr>
<td>AEGW C-10</td>
<td>both</td>
<td>avl</td>
<td>avl</td>
<td>no</td>
<td>yes</td>
<td>1&quot;±0.5</td>
<td>8 car - 47' 6&quot; 4 car - 61'6&quot;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AEGW C-45</td>
<td>both</td>
<td>avl</td>
<td>avl</td>
<td>no</td>
<td>yes</td>
<td>1.5&quot;</td>
<td>1 car - 20' 2 car - 43' 25' + buffer</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AEGW C-100</td>
<td>both</td>
<td>avl</td>
<td>avl</td>
<td>no</td>
<td>yes</td>
<td>1&quot;±0.5</td>
<td>36' per car</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ARMV TP-I</td>
<td>both</td>
<td>avl</td>
<td>avl</td>
<td>yes/no</td>
<td>yes</td>
<td>1.25&quot;</td>
<td>38&quot;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ARMV TP-II</td>
<td>both</td>
<td>avl</td>
<td>avl</td>
<td>yes/no</td>
<td>yes</td>
<td>1.25&quot;</td>
<td>38&quot;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ARBS</td>
<td>TECHNICAL INFORMATION IS NOT CURRENTLY AVAILABLE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CBTX</td>
<td>both</td>
<td>avl</td>
<td>avl</td>
<td>no</td>
<td>yes</td>
<td>variable</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FTRX</td>
<td>cntr only</td>
<td>yes</td>
<td>no</td>
<td>no</td>
<td>prob not</td>
<td>1.5&quot;</td>
<td>0.5&quot;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HIRED</td>
<td>side only</td>
<td>yes</td>
<td>no</td>
<td>no</td>
<td>yes</td>
<td>2&quot;</td>
<td>1/8&quot; 40', single car only</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ITMN</td>
<td>both</td>
<td>avl</td>
<td>no</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SULE</td>
<td>both</td>
<td>no</td>
<td>avl</td>
<td>no</td>
<td>yes</td>
<td>1.25</td>
<td>3/8&quot; 1 car 26'</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SWOT FLWY</td>
<td>both - SEE TEXT</td>
<td>avl</td>
<td>not nec.</td>
<td>no</td>
<td>yes</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SWOT SIPM</td>
<td>both</td>
<td>yes</td>
<td>not nec.</td>
<td>no</td>
<td>yes</td>
<td>2 car - 50'</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TX20</td>
<td>both</td>
<td>no</td>
<td>no</td>
<td>yes</td>
<td>0.5&quot;</td>
<td>1/8&quot; 12 feet/car/platform side</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TITN</td>
<td>both</td>
<td>yes</td>
<td>yes</td>
<td>no</td>
<td>yes</td>
<td>0.5&quot;</td>
<td>0.5&quot; appx. 24'/car</td>
<td></td>
<td></td>
</tr>
<tr>
<td>UTDC UM-3</td>
<td>both</td>
<td>avl</td>
<td>avl</td>
<td>no</td>
<td>yes</td>
<td>1.5&quot;/2.0&quot;</td>
<td>70'/3 car trn 160'/6 car trn buffer only</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VNRL T-II</td>
<td>both</td>
<td>avl</td>
<td>no</td>
<td>yes</td>
<td>1&quot;/1.6&quot;</td>
<td>0.8&quot; 9 car - appx 120' 13'-26'</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VNRL TIII</td>
<td>both</td>
<td>yes</td>
<td>avl</td>
<td>no</td>
<td>yes</td>
<td>1&quot;/1.6&quot;</td>
<td>0.8&quot; 7 car - 106'</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VSL</td>
<td>both</td>
<td>avl</td>
<td>avl</td>
<td>no</td>
<td>yes</td>
<td>2.0&quot;±0.5&quot;</td>
<td>45' per vehicle</td>
<td></td>
<td></td>
</tr>
<tr>
<td>POMA</td>
<td>both</td>
<td>yes</td>
<td>yes</td>
<td>no</td>
<td>yes</td>
<td>1.5&quot;±1.0&quot;</td>
<td>1 car - 16' 2 car - 32'</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
1) VEHICLE LENGTH- Indicates the longest external dimension of a vehicle. If couplers or bumpers are a part of a vehicle, then they are included in total vehicle length.

2) AUTOMATIC OR MANUAL- Indicates whether a system is designed to be operated on the mainline as a primarily driverless (automatic) system or one which requires a driver (manual). Aeromovel allows for a system to be operated manually with station attendants, but not with drivers on individual vehicles.

3) MINIMUM HEADWAY- Indicates the minimal timing between the head ends of successive trains, as limited by the safe capabilities of automatic train control systems and vehicle control systems (not civil requirements). Scheduled operations are not advised to be created utilizing Minimum Headway capability.

4) DWELL TIME- indicates a recommended duration that a vehicle is allowed to sit at a platform with doors open and be available for passenger boarding.

5 & 6) ACCELERATION AND DECELERATION RATE- indicates the maximum recommended rates for vehicle performance considering first, passenger comfort and second, vehicle capability. Some vendors provided information which indicates that the rates can be adjusted, as specified by the owner. All rates are listed in "g.'s"/"gravity".

7) MAXIMUM SPEED- indicates highest design speed of a vehicle or train. Scheduled operations are not advised to be created utilizing Maximum Speed capability.

8) CARS PER TRAIN- Indicates the maximum train length that a system can accommodate. The term "fixed" indicates that a train is not designed to be easily lengthened or shortened once it is constructed. The term "variable" indicates that individual cars can be coupled or uncoupled with relative ease, as may be needed to accommodate daily (not hourly) fluctuations in passenger demand.

SEATS- NOTE: Conventional car seating designs allow for three categories of passenger load configurations; Seated Load, Standing Load, and Crush Load.

9) SEATS PER CAR + WHEEL CHAIR SPACES- Indicates the number of seats available for able-bodied patrons and the number of spaces available for disabled patrons in wheelchairs. Sometimes, wheelchair spaces are available by reducing the spaces available to able-bodied standees and so totals may add up with an apparent error of 1. Sometimes WC spaces are available without reducing able-bodied seating. A "+" indicates a specific number of available spaces, and "ADA" indicates multiple spaces.

10) STANDEES PER CAR- indicates the number of people who can "comfortably" be accommodated, usually allowing an average of 2-3 square feet of floor space per person. Seats per car + Standees = (Standing Load).

11) MAXIMUM CAPACITY PER CAR- indicates the Crush Load Capacity of a car, usually allowing an average of 1.5-2.2 square feet per standee. Seats per car + Standees + additional patrons = (Crush Load). Wheelchair spaces are included in the total number.
### Conversion Chart for 1 g = 32.17 Feet per Second per Second

0.10g = 3.22 Feet per Second squared  
0.10g = 2.19 Miles per Hour per Second  
0.10g = 0.98 Meters per Second squared

### Planning Matrix - 5.4

<table>
<thead>
<tr>
<th>VENDOR</th>
<th>VEH LENGTH</th>
<th>AUTO or MANL</th>
<th>MIN HDW TIME</th>
<th>ACCEL RATE g.'s</th>
<th>DECEL RATE g.'s</th>
<th>MAX SPD</th>
<th>CARS / TRN</th>
<th>SEATS / CAR</th>
<th>STND / CAR</th>
<th>MAX CAP / CAR</th>
</tr>
</thead>
<tbody>
<tr>
<td>AEGW C-10</td>
<td>A 16'8&quot; B 12'9&quot;</td>
<td>auto</td>
<td>70</td>
<td>0.09</td>
<td>0.09</td>
<td>15</td>
<td>fixed 1-10</td>
<td>4 + 0 (4)</td>
<td>6 (10)</td>
<td>5 (5)</td>
</tr>
<tr>
<td>AEGW C-45</td>
<td>A 28'0&quot; B 26'5&quot; C 26'5&quot;</td>
<td>auto</td>
<td>70</td>
<td>20</td>
<td>0.09</td>
<td>0.09</td>
<td>32</td>
<td>var. 1-3</td>
<td>12 + ADA (45)</td>
<td>10 (57)</td>
</tr>
<tr>
<td>AEGW C-100</td>
<td>A 36'4&quot; 33'8&quot; B C 39'0&quot;</td>
<td>auto</td>
<td>70</td>
<td>20</td>
<td>0.09</td>
<td>0.09</td>
<td>50</td>
<td>var. 1-3</td>
<td>appx 20 + ADA</td>
<td>80 (100)</td>
</tr>
<tr>
<td>ARMY TP-I</td>
<td>var. 26&quot;</td>
<td>auto or station attendant</td>
<td>var &lt; 60</td>
<td>0.10</td>
<td>0.10</td>
<td>50+</td>
<td>1</td>
<td>16 + ADA</td>
<td>44 (64)</td>
<td></td>
</tr>
<tr>
<td>ARMY TP-II</td>
<td>var. 26&quot;</td>
<td>auto or station attendant</td>
<td>var &lt; 60</td>
<td>0.10</td>
<td>0.10</td>
<td>50+</td>
<td>1</td>
<td>46 + ADA</td>
<td>142 (180)</td>
<td>50 (238)</td>
</tr>
<tr>
<td>ARBS</td>
<td>TECHNICAL INFORMATION IS NOT CURRENTLY AVAILABLE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>VENDOR</th>
<th>VEH LENGTH</th>
<th>AUTO or MANL</th>
<th>MIN HDW TIME</th>
<th>ACCEL RATE g.'s</th>
<th>DECEL RATE g.'s</th>
<th>MAX SPD</th>
<th>CARS / TRN</th>
<th>SEATS / CAR</th>
<th>STND / CAR</th>
<th>MAX CAP / CAR</th>
</tr>
</thead>
<tbody>
<tr>
<td>CBTX</td>
<td>6px 10' 12px18-6</td>
<td>auto</td>
<td>0.25</td>
<td>0.25</td>
<td>30</td>
<td>1</td>
<td>6 or 9+1 12 or 10 + 2</td>
<td>none</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FTRX</td>
<td>A 30'3&quot; B 26'7&quot;</td>
<td>manual</td>
<td>60</td>
<td>.15</td>
<td>.15</td>
<td>55</td>
<td>var. 1-4</td>
<td>22+ 1</td>
<td>20 (42)</td>
<td>4 (46)</td>
</tr>
<tr>
<td>HRID</td>
<td>45&quot;</td>
<td>auto</td>
<td>30</td>
<td>20</td>
<td>0.10</td>
<td>0.10</td>
<td>60-120</td>
<td>1</td>
<td>28+ ADA (52)</td>
<td>50 (80)</td>
</tr>
<tr>
<td>ITMN</td>
<td>15' 9&quot;</td>
<td>both avl.</td>
<td>60</td>
<td>15</td>
<td>0.31</td>
<td>0.31</td>
<td>30</td>
<td>fixed 10</td>
<td>5 + 1 or 6</td>
<td></td>
</tr>
<tr>
<td>SULE</td>
<td>10.25 var.</td>
<td>both avl.</td>
<td>15</td>
<td>1fps 25sec</td>
<td>0.10</td>
<td>0.10</td>
<td>20</td>
<td>1</td>
<td>4 + ADA var. var. (20)</td>
<td></td>
</tr>
<tr>
<td>SWDT FLWY</td>
<td>10' 9&quot;</td>
<td>auto</td>
<td>0.5</td>
<td>25</td>
<td>.15</td>
<td>.15</td>
<td>34</td>
<td>1</td>
<td>4 or 2+1ADA</td>
<td></td>
</tr>
<tr>
<td>SWDT SIPP</td>
<td>27&quot;</td>
<td>auto</td>
<td>50</td>
<td>0.10</td>
<td>0.10</td>
<td>38</td>
<td>1-2</td>
<td>20 + ADA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TX20</td>
<td>13&quot;</td>
<td>auto</td>
<td>0.5-3.0</td>
<td>11</td>
<td>0.10</td>
<td>0.10</td>
<td>30</td>
<td>1</td>
<td>3 + 2 aux.</td>
<td>none 5 or</td>
</tr>
<tr>
<td>TITN</td>
<td>24&quot;</td>
<td>both avl.</td>
<td>7.5</td>
<td>20</td>
<td>0.10</td>
<td>0.10</td>
<td>50</td>
<td>1</td>
<td>3 + ADA (30)</td>
<td>26 (30)</td>
</tr>
<tr>
<td>UTDCC UM-3</td>
<td>26' 4&quot;</td>
<td>auto</td>
<td>90</td>
<td>15</td>
<td>0.08-0.10</td>
<td>0.06-0.10</td>
<td>20</td>
<td>fixed 1-10</td>
<td>8 + ADA (10)</td>
<td>17 (35)</td>
</tr>
<tr>
<td>VNRL T-II</td>
<td>18'11&quot; CTR 13'6&quot;</td>
<td>both avl.</td>
<td>110</td>
<td>25</td>
<td>0.15</td>
<td>0.30</td>
<td>13.6</td>
<td>fixed 2-10</td>
<td>LO/TRL 9+1 CTR 12+4</td>
<td>none</td>
</tr>
<tr>
<td>VNRL TIII</td>
<td>18'11&quot; CTR 13'6&quot;</td>
<td>both avl.</td>
<td>105</td>
<td>20</td>
<td>0.15</td>
<td>0.30</td>
<td>31</td>
<td>fixed 2-10</td>
<td>LO/TRL 8+ADA CTR 8+ADA</td>
<td>var.</td>
</tr>
<tr>
<td>VSL</td>
<td>39' 5&quot;</td>
<td>both avl.</td>
<td>20</td>
<td>20</td>
<td>0.09</td>
<td>0.09</td>
<td>35</td>
<td>var.</td>
<td>8 + ADA</td>
<td>60?</td>
</tr>
<tr>
<td>POMA</td>
<td>18' 4&quot;</td>
<td>auto</td>
<td>30?</td>
<td>25</td>
<td>0.14</td>
<td>0.14</td>
<td>30</td>
<td>1-2</td>
<td>8 + ADA</td>
<td>32 (40)</td>
</tr>
</tbody>
</table>
PLANNING MATRIX SUPPLEMENT - 5.5

1) TYPE OF VEHICLE SUPPORT ON TYPE OF GUIDEWAY SURFACE- indicates A) the material used to make vehicle wheels or tires, i.e. steel, rubber with air-fill, rubber with foam-fill, or synthetic-clad-tire over a steel wheel base, and then B) the material used for constructing the surface on the guideway that directly bears the load of the wheel, i.e. steel tracks or concrete.

2) PROPULSION TYPE- indicates whether the propulsion system is A) conventional electric rotary motor, B) Linear Induction Motor (LIM), or C) powered by forced air (air).

3) OPERATIONAL DIRECTION- indicates whether a vehicle or train can be operated in only one direction or in two directions. CabinTaxi and Taxi 2000 operate vehicles primarily in one direction but can operate in the reverse direction for emergency management.

4) COUPLING CAPABILITIES- indicates the ability to make multi-car trains with individual cars:
   • n/a- no coupling, single car operation only.
   • manual- indicates that trains can be formed with manual involvement needed to make coupling connections.
   • semi-automatic- indicates that the coupling connections can be completed automatically with some amount of manual involvement at the coupling site.
   • fully automatic- indicates that coupling connections can be made without manual intervention at the coupling site, but only under direction from persons in a control facility.
   • push- indicates that a following vehicle can push a preceding disabled vehicle to a refuge area, but that pushing is not a normal operating procedure.
   • electronic- mechanical linkage does not occur, but distance between vehicles is controlled to allow minimal spacing between vehicles.

5) MEAN TIME BETWEEN FAILURES (in excess of 5 Minutes)- indicates the average amount of elapsed time between subsystem failures on the mainline that required more than 5 minutes to correct.

6) CENTRAL CONTROL TO/FROM TRAIN, VOICE COMMUNICATIONS- describes the technology used to transmit or receive information to patrons on a vehicle. This is required in order to satisfy NFPA 130 guidelines; A) duplex radio and loss-E line-allows concurrent transmission and reception of signals, B) cellular phone-allows concurrent transmission and reception of signals, using telephone technology, and bar and inductive loop are for vehicle control communications).

7) INTERIOR NOISE- indicates noise levels inside a car

8) EXTERIOR NOISE- indicates noise levels on the outside of a car.
<table>
<thead>
<tr>
<th>VENDOR</th>
<th>VEH SUPPORT</th>
<th>PROP TYPE</th>
<th>OPER DIRECTION</th>
<th>SMALL / LRG CONS SIZE</th>
<th>COUPL CAPAB AUTO / MAN</th>
<th>MTBF OVER 5 MIN</th>
<th>CENTRAL TO TRN COMMUNICATION</th>
<th>INT NOISE @ MPH</th>
<th>EXT NOISE @ MPH</th>
</tr>
</thead>
<tbody>
<tr>
<td>AEGW C-10</td>
<td>rubber/concrete</td>
<td>rotary motor</td>
<td>2</td>
<td>fixed 1-10</td>
<td>manual</td>
<td>120</td>
<td>duplex radio</td>
<td>75 @ 30</td>
<td>74dba 30mph</td>
</tr>
<tr>
<td>AEGW C-45</td>
<td>rubber/concrete</td>
<td>rotary motor</td>
<td>2</td>
<td>var. 1-3</td>
<td>manual</td>
<td>120</td>
<td>duplex radio</td>
<td>75 @ 30</td>
<td>74dba 30mph</td>
</tr>
<tr>
<td>AEGW C-100</td>
<td>rubber/concrete</td>
<td>rotary motor</td>
<td>2</td>
<td>var. 1-3</td>
<td>manual</td>
<td>120</td>
<td>duplex radio</td>
<td>75 @ 30</td>
<td>74dba 30mph</td>
</tr>
<tr>
<td>ARMV TP-I</td>
<td>steel on steel</td>
<td>air</td>
<td>2</td>
<td>1</td>
<td>n/a</td>
<td>duplex radio</td>
<td>77 @ 25</td>
<td>75dba 25mph</td>
<td></td>
</tr>
<tr>
<td>ARMV TP-II</td>
<td>steel on steel</td>
<td>air</td>
<td>2</td>
<td>1</td>
<td>n/a</td>
<td>duplex radio</td>
<td>77 @ 25</td>
<td>75dba 25mph</td>
<td></td>
</tr>
<tr>
<td>ARBS</td>
<td>TECHNICAL INFORMATION IS NOT CURRENTLY AVAILABLE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CBTX SYNTH CLAD STEEL W/HL. OR STEEL</td>
<td>LIM</td>
<td>2 only</td>
<td>emerg.</td>
<td>1</td>
<td></td>
<td>duplex radio</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FTRX steel on steel</td>
<td>rotary motor</td>
<td>1</td>
<td>var. 1-4</td>
<td>manual</td>
<td></td>
<td>duplex radio</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HIRD steel on steel</td>
<td>rotary motor</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td>cellular phone</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ITMN rubber/concrete</td>
<td>rotary motor</td>
<td>2</td>
<td>2-10</td>
<td>manual &amp; semi-auto</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SULE SYNTH CLAD STEEL W/HL. OR STEEL</td>
<td>cable</td>
<td>1</td>
<td>1</td>
<td>n/a</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SWDT FLWY SYNTH CLAD STEEL W/HL. OR STEEL</td>
<td>rotary motor</td>
<td>2</td>
<td>1</td>
<td>n/a</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SWDT SIPM rubber/concrete</td>
<td>rotary motor</td>
<td>2</td>
<td>var. 1-2</td>
<td></td>
<td></td>
<td>duplex radio</td>
<td>65dba @ 25mph</td>
<td></td>
<td>25 ft</td>
</tr>
<tr>
<td>TX20 FOAM FILLED PNEUMATIC OR METAL AIR</td>
<td>LIM</td>
<td>2 only</td>
<td>emerg</td>
<td>1</td>
<td>push (emerg.)</td>
<td>loss-E line</td>
<td>&lt;65</td>
<td>&lt;65</td>
<td></td>
</tr>
<tr>
<td>TITN SYNTH CLAD STEEL W/HL. OR STEEL</td>
<td>LIM</td>
<td>2</td>
<td>var. electronic 7.3 sec.</td>
<td></td>
<td></td>
<td>avl</td>
<td>71 @ 50</td>
<td>72dba 50mph</td>
<td></td>
</tr>
<tr>
<td>UTDCC UM-3 rubber/concrete</td>
<td>rotary motor</td>
<td>2</td>
<td>fixed 1-10 man., semi, full auto</td>
<td></td>
<td></td>
<td>duplex radio</td>
<td>74 @ 0</td>
<td>70dba 16ft 70dba 16ft</td>
<td></td>
</tr>
<tr>
<td>VNRL T-II rubber/concrete</td>
<td>rotary motor</td>
<td>2</td>
<td>2-10 for mnt only</td>
<td></td>
<td></td>
<td>duplex radio</td>
<td>71 @ 20</td>
<td>80dba 23ft</td>
<td></td>
</tr>
<tr>
<td>VNRL TIII rubber/concrete</td>
<td>rotary motor</td>
<td>2</td>
<td>2-10 for mnt only</td>
<td></td>
<td></td>
<td>duplex radio</td>
<td>71 @ 20</td>
<td>80dba 23ft</td>
<td></td>
</tr>
<tr>
<td>VSL rubber/concrete</td>
<td>rotary motor</td>
<td>2</td>
<td>1-?</td>
<td>fully auto</td>
<td></td>
<td></td>
<td>69 @ 20</td>
<td>72dba 20mph</td>
<td></td>
</tr>
<tr>
<td>POMA RUBBER ON STL OR RUBBER ON CONC</td>
<td>cable</td>
<td>1</td>
<td>1-2</td>
<td>yes-by cable</td>
<td></td>
<td>duplex radio</td>
<td>60 @ 30</td>
<td>65dba 30mph</td>
<td></td>
</tr>
</tbody>
</table>

23
1) EXTERNAL LENGTH- The longest distance between the outermost parts of a car.

2) EXTERNAL WIDTH- The widest distance between the outermost parts of a car.

3) INTERIOR LENGTH- The longest interior distance between vehicle ends.

4) INTERIOR WIDTH- The longest interior distance between vehicle sides.

5) GUIDEWAY TO ROOF HEIGHT- The total external distance between the guideway surface and the external top of the vehicle roof.

6) GUIDEWAY TO FLOOR HEIGHT- The total distance between the guideway surface and the upper surface of the vehicle floor upper-surface.

7) CENTER AISLE HEADROOM- The height of the floor surface to the bottom of the ceiling along the vehicle's longitudinal centerline.

8) MINIMUM HEADROOM- The height of the floor surface to the lowest point of the vehicle ceiling.

9) VEHICLE EMPTY WEIGHT- The weight of the vehicle without any passengers.

10) CRUSH LOAD WEIGHT- The total weight of the vehicle plus the design capacity weight of a crush passenger load (assuming 160 pounds per passenger).

11) EMPTY VEHICLE WEIGHT DIVIDED BY THE CRUSH LOAD WEIGHT- A ratio indicative of the possible energy efficiency of a vehicle by being able to carry a maximal number of passengers with the least amount of vehicle mass.
<table>
<thead>
<tr>
<th>VENDOR</th>
<th>EXT LENGTH</th>
<th>EXT WDH</th>
<th>INT LNCH</th>
<th>INT WDH</th>
<th>GDWY -RF HGH</th>
<th>GDWY -FLR HGH</th>
<th>CTR AISL HDRM HGH</th>
<th>MIN HDRM HGH</th>
<th>VEH EMPTY WEIGHT</th>
<th>CRUSH LOAD WEIGHT</th>
<th>EMPTY CRUSH DIVID.</th>
</tr>
</thead>
<tbody>
<tr>
<td>AEGW C-10</td>
<td>in design</td>
<td>6.67</td>
<td>9.41</td>
<td>5.41</td>
<td>in design</td>
<td>3 car 16.0</td>
<td>3 car 20.16</td>
<td>.56</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AEGW C-45</td>
<td>A 28.0 B 26.5</td>
<td>8.0</td>
<td>23.11</td>
<td>6.91</td>
<td>10.5</td>
<td>3.0</td>
<td>6.67</td>
<td>6.67</td>
<td>20.0</td>
<td>30.16</td>
<td>.65</td>
</tr>
<tr>
<td>AEGW C-100</td>
<td>A 36.33 B 33.67 C 39.0</td>
<td>9.33</td>
<td>appx. 33.0</td>
<td>7.83</td>
<td>11.08</td>
<td>3.58</td>
<td>6.83</td>
<td>6.67</td>
<td>32.6</td>
<td>58.7</td>
<td>.56</td>
</tr>
<tr>
<td>ARMV TP-I</td>
<td>26.25</td>
<td>8.16</td>
<td>22.91</td>
<td>7.58</td>
<td>9.91</td>
<td>2.25</td>
<td>7.16</td>
<td>7.16</td>
<td>7.716</td>
<td>1.796</td>
<td>.43</td>
</tr>
<tr>
<td>ARMV TP-II</td>
<td>83.67</td>
<td>9.16</td>
<td>75.41</td>
<td>7.5</td>
<td>9.91</td>
<td>2.25</td>
<td>7.16</td>
<td>6.83</td>
<td>24.25</td>
<td>62.33</td>
<td>.39</td>
</tr>
</tbody>
</table>

**ARBS**
TECHNICAL INFORMATION IS NOT CURRENTLY AVAILABLE

| CBTX | 6p 10.0 | 5.67 | 5.41 | 6p 3.2 |
| FTRX | A 30.2 B 26.7 | 7.7 | 8.0 | 6.83 | 6.83 | 10.1 | 17.35 | .58 |
| HIRD | 45.0 | 8.0 | 37.67 | 7.33 | 7.0 | 7.0 | 20.0 | 40.8 | .49 |
| ITMN | 15.75 | 5.91 | 5.91 | 4.91 | 5.67 | 5.0 | 4.75 | 3.57 | 4.45 | .80 |
| SULE | 10.25 | 5.25 | 5.91 | 7.15 | 2.42 | 5.06 | .48 |
| SEDOT FLWY | 11.0 | 5.41 | 3.5 | 4.4 | .79 |
| SWDT SPM | 27.0 | appx. 7.0 | 6.5 | 18.7 |
| TX20 | 13.0 | 8.0 | 4.67 | 8.0 | 3.0 | 5.0 | 1.575 | 2.325 | .60 |
| TITN | 24.0 | 5.1 | 19.0 | 6.67 | 2.0 | 9.08 | 6.33 | 6.33 | 7.5 | 17.74 | .42 |
| UTDC UM-3 | 26.33 | 7.0 | 13.58 | 6.25 | 7.91 | 0.75 | 6.5 | 6.5 | 9.15 | 14.75 | .62 |
| VNRL T-II | 18.91 | 5.91 | 12.16 | 5.08 | 7.33 | 0.58 | 5.91 | 5.58 | 5.4 | 7.38 | .73 |
| VNRL TIII | 18.91 | 5.91 | 12.16 | 5.91 | 8.83 | 0.70 | 7.25 | 6.58 | 7.194 | 11.19 | est. |
| VSL | 39.41 | 8.25 | 26.25 | 7.33 | 12.08 | 3.16 | 6.83 | 6.75 | 17.64 | 28.22 | .63 |
| POMA | 18.37 | 8.56 | 16.40 | 8.53 | 9.51 | 2.95 | 6.89 | 6.89 | 11.44 | 20.06 | .57 |
ELECTRICAL REQUIREMENTS MATRIX - 5.7

1) PRIMARY VOLTAGE, AC OR DC, AND PHASE REQUIREMENTS- Voltage requirements for electrical propulsion systems.

2) PRIMARY POWER SUPPLY GRID- Systems supply primary electric propulsion power to vehicles by third rail or buss bar (similar to third rail). Aeromovel does not transmit primary electric power on the guideway, and neither do the cable drawn systems.

3) COLLECTOR TYPE- The method used to gather primary power from the supply grid. Generally, systems use a solid steel "collector shoe" or a collector shoe with a sacrificial graphite or carbon insert.

4) AUXILIARY VOLTAGE, AC OR DC, AND PHASE REQUIREMENTS- Voltage requirements for carborn lights, control systems, communications, door operators, etc.

5) AUXILIARY POWER SUPPLY GRID- The method used to supply Auxiliary power to the car; A) third rail, B) carborn battery, C) running rail, D) or primary power conditioned on the car and distributed to secondary systems.

6) BATTERY BACKUP DURATION- The length of time that carborn batteries can support secondary systems in the event of a loss of primary power.

7) LOAD SHEDDING RETAINED SYSTEMS- The list of subsystems that are supported by battery backup.

PROPULSION SYSTEM

8) LOCATION- The location of the propulsion motors; A) carborn-completely on the vehicle, B) wayside-completely off of the vehicle, or C) linear induction motor-shared by the vehicle and the guideway.

9) ACCELERATION CONTROL (some vendors understood this to mean "How is power transmitted to the wheels?" and others understood it to mean "How is acceleration power controlled?"

   A) direct transmission- from motor, through transmission, to wheels
   B) computer and valves- Aeromovel governs acceleration by varying the pressure of the air which is either behind or ahead of the vehicle.
   C) carborn computer
   D) electromagnetic clutch- hysteresis clutch
   E) inverted to DC- implies either cam control or thyristor/chopper
   F) digital- implies thyristor/chopper
   G) velocity loop- loop detectors in the guideway assess acceleration and moderate vehicle rates.
   H) thyristor-silicon controlled rectifier/chopper.

10) LOAD COMPENSATION- A method for detecting total passenger weight and adjusting acceleration in a way that maintains consistently even headway between heavily loaded vehicles and lightly loaded vehicles.
<table>
<thead>
<tr>
<th>VENDOR</th>
<th>PRIM VOLT AC/DC PHASE</th>
<th>PRIM POWER SUPPL GRID</th>
<th>COLL TYPE</th>
<th>AUX VOLT AC/DC PHASE</th>
<th>AUX PWR SUPPLY GRID</th>
<th>BATT BACKUP DURAT min</th>
<th>LOAD SHEDDING SYSTEMS</th>
<th>PROPULSION SYSTEM LOCAT</th>
<th>ACCEL CONTR</th>
<th>LOAD COMP</th>
</tr>
</thead>
<tbody>
<tr>
<td>AEGW C-10</td>
<td>CURRENTLY BEING REDESIGNED</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AEGW C-45</td>
<td>480/3 AC rail 3rd shoe</td>
<td>120AC lowDC</td>
<td>3rl&amp; batt</td>
<td>30</td>
<td>ATC, communicat. lites, ventilat.</td>
<td>car born</td>
<td>DIRECT TRNSNT</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AEGW C-100</td>
<td>575/3 AC rail 3rd shoe</td>
<td>120AC lowDC</td>
<td>3rl&amp; batt</td>
<td>30</td>
<td>ATC, communicat. lites, ventilat.</td>
<td>car born</td>
<td>DIRECT TRNSNT</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ARMV TP-I</td>
<td>220/33 Ga Power n/a</td>
<td>55 v run DC rail</td>
<td>180</td>
<td>controls, lites communication</td>
<td>way side</td>
<td>COMPUTER &amp; VALVES</td>
<td>yes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ARMV TP-II</td>
<td>220/33 Ga Power n/a</td>
<td>55 v run DC rail</td>
<td>180</td>
<td>controls, lites communication</td>
<td>way side</td>
<td>COMPUTER &amp; VALVES</td>
<td>yes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ARBS</td>
<td>TECHNICAL INFORMATION IS NOT CURRENTLY AVAILABLE</td>
<td></td>
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</tr>
<tr>
<td>CBTX</td>
<td>550/3 AC rail 3rd shoe</td>
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<tr>
<td>FTRX</td>
<td>750/DC rail 3rd shoe</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>HIRD</td>
<td>460/3 AC rail 3rd shoe</td>
<td>277/3 AC 3rd rail</td>
<td>60</td>
<td>controls, lites communications</td>
<td>car born</td>
<td>ELECTROMAG CLUTCH</td>
<td>yes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ITMN</td>
<td></td>
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<td></td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>SWDT FLWY</td>
<td>600or 750DC rail 3rd shoe</td>
<td>12V DC 3rd rail</td>
<td>120</td>
<td>COMPUTER, LITES, VENTILAT. ALARMS, BRAKE, COMM.</td>
<td>car born</td>
<td>INVERTED TO DC</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SWDT SIMH</td>
<td>400/3 AC rail 3rd shoe</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>TX20</td>
<td>600 V DC rail 3rd shoe</td>
<td>in design</td>
<td></td>
<td>COMMUNICATIONS, LITES CONTROLS, VENTILATION</td>
<td>LIM</td>
<td>DIGITAL</td>
<td>yes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TNTN</td>
<td>480/3 AC rail 3rd shoe</td>
<td>DC</td>
<td>yes</td>
<td></td>
<td>LIM</td>
<td>VELOCITY LOOP</td>
<td>yes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>UTDCC UM-3</td>
<td>480/3 AC rail 3rd shoe</td>
<td>28 V batt</td>
<td>60</td>
<td>controls, lites communication</td>
<td>car born</td>
<td>4 QUADRANT AC to DC</td>
<td>yes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VNRL T-II</td>
<td>500or 600AC rail 3rd shoe</td>
<td>24 DC 120AC</td>
<td>30</td>
<td>communication lites, ventilat.</td>
<td>car born</td>
<td>THYRISTOR</td>
<td>no</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VNRL T-III</td>
<td>500or 600AC rail 3rd shoe</td>
<td>24 DC 120AC</td>
<td>30</td>
<td>communication lites, ventilat.</td>
<td>car born</td>
<td>THYRISTOR</td>
<td>no</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>VSL</td>
<td>480/3 AC rail 3rd shoe</td>
<td>24 DC 120AC</td>
<td>120</td>
<td>communication lites, ventilat.</td>
<td>car born</td>
<td>THYRISTOR</td>
<td>no</td>
<td></td>
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<tr>
<td>POMA</td>
<td>?/3 AC Ga Power n/a</td>
<td>3rd rail &amp; commut on car</td>
<td>120</td>
<td>communication lites, ventilat.</td>
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</tbody>
</table>

27
CAR BODY CONSTRUCTION MATRIX - 5.8

All vendors currently comply or will modify their vehicles to comply with NFPA 130 Standards, Section 4-1. In particular Table 4-2.4 of the Standards specifies the various ASTM tests. The floor tests and requirements reference national standard ASTM E-119.

1) BODY SHELL- A) fiberglass on welded steel, B) body-on-frame, C) monocoque construction, and D) monocoque and welded.

2) FASTENERS- bolts, rivets, or welds.

3) FRAMING MATERIAL- Steel or Aluminum (Al).

4-9) MATERIALS FOR EXTERNAL SIDES, ROOFS, EXTERIOR ENDS, INTERIOR SIDES, CEILINGS, AND INTERIOR ENDS - A) fiberglass, B) Aluminum, C) Steel, D) galvanized steel panels, or E) FRP-fiberglass reinforced plastic.

10) FLOOR MATERIAL- A) Aluminum, B) Steel, C) Rubber, D) carpet, E) plywood, F) synthetics, or G) wood.

11) BURN THROUGH RATING- as per NFPA 130.
<table>
<thead>
<tr>
<th>VENDOR</th>
<th>BODY SHELL</th>
<th>FAST ENER</th>
<th>FRAMING</th>
<th>EXTINGUISHER</th>
<th>END</th>
<th>END</th>
<th>EXT</th>
<th>ROOF</th>
<th>EXTR SID</th>
<th>INTR SID</th>
<th>CEIL</th>
<th>INT END</th>
<th>FLOOR MATERL</th>
<th>BURN THRU</th>
</tr>
</thead>
<tbody>
<tr>
<td>AEGW C-10</td>
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<td></td>
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<td></td>
</tr>
<tr>
<td></td>
<td>FIBERGLASS</td>
<td>n/a</td>
<td>Al &amp; Stl</td>
<td></td>
<td></td>
<td></td>
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<td>AEGW C-45</td>
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<td>n/a</td>
<td>Al &amp; Stl</td>
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<tr>
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<td>FIBERGLASS</td>
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<td></td>
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</tr>
<tr>
<td>ARMV TP-I</td>
<td>BODY ON FRAME</td>
<td>rivet</td>
<td>Stl</td>
<td>ALUMINUM OR AS PER SPECIFICATION WILL BE NFPA 130 COMPLIANT</td>
<td></td>
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</tr>
<tr>
<td>ARMV TP-II</td>
<td>BODY ON FRAME</td>
<td>rivet</td>
<td>Stl</td>
<td>ALUMINUM OR AS PER SPECIFICATION WILL BE NFPA 130 COMPLIANT</td>
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</table>

**ARBS TECHNICAL INFORMATION IS NOT CURRENTLY AVAILABLE**

<table>
<thead>
<tr>
<th>VENDOR</th>
<th>BODY SHELL</th>
<th>FAST ENER</th>
<th>FRAMING</th>
<th>EXTINGUISHER</th>
<th>END</th>
<th>END</th>
<th>EXT</th>
<th>ROOF</th>
<th>EXTR SID</th>
<th>INTR SID</th>
<th>CEIL</th>
<th>INT END</th>
<th>FLOOR MATERL</th>
<th>BURN THRU</th>
</tr>
</thead>
<tbody>
<tr>
<td>CBTX</td>
<td>Steel, and Aluminum or Fiberglass</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>FTRX</td>
<td>Al &amp; Stl</td>
<td></td>
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</tr>
<tr>
<td>HIRD</td>
<td>MONOCOCUDE</td>
<td></td>
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<tr>
<td>SULE</td>
<td>Steel-Aluminum-Glass</td>
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</tr>
<tr>
<td>SWDT FLWY</td>
<td>MONOCOCUDE AND WELDED</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>SWDT SIPM</td>
<td>MONOCOCUDE AND WELDED</td>
<td></td>
<td></td>
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<tr>
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<td>currently in design will be NFPA 130 compliant</td>
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</tr>
<tr>
<td>UTDG UM-3</td>
<td>BODY ON FRAME</td>
<td>bolt</td>
<td>fiberglass reinforced plastic (FRP)</td>
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<td></td>
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</tr>
<tr>
<td>VNRRL T-II</td>
<td>MONOCOCUDE</td>
<td>bolt, riveted</td>
<td>Aluminum</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>VNRRL TIII</td>
<td>MONOCOCUDE</td>
<td>bolt, riveted</td>
<td>Aluminum</td>
<td></td>
<td></td>
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<tr>
<td>VSL</td>
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<td>bolt, riveted</td>
<td>Stl Al Al FRP FRP Al FRP</td>
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</tr>
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<td>POMA</td>
<td>MONOCOCUDE</td>
<td>bolt, glue</td>
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</table>

Vehicle is being redesigned - will be NFPA-130 compliant
HEATING, VENTILATION, AIR CONDITIONING, AND COMMUNICATIONS MATRIX - 5.9

1) TYPE- indicates the type of ventilation system supplied-either generic or Sutrak, an industry leader of integrated heating, ventilation, and air conditioning equipment.

2) NUMBER OF AIR HANDLERS PER VEHICLE

3) NUMBER OF AIR EXCHANGES PER HOUR- the number of times that a vehicle's interior air is exchanged with outside air; usually excluding exchanges that occur while doors are open at station platforms.

4) SMOKE DETECTORS- refers to the presence of carbon interior smoke detection systems and the ability to detect if a specified threshold is exceeded, and then shut down a vehicle's HVAC system while simultaneously sending an alarm to Central Control.

5) HEAT TYPE- Type of heating system (Sutrak uses electric resistive heat, often drawn from the dynamic braking resistor grid).

6) COMMUNICATIONS TO PASSENGERS- the method used to communicate to passengers from Central Control.
<table>
<thead>
<tr>
<th>VENDOR</th>
<th>TYPE</th>
<th># AIR HNDLR per CAR</th>
<th>AIR EXCHNG per hr</th>
<th>SMOKE DETEC</th>
<th>HEAT TYPE</th>
<th>COMMUNICATIONS TO PASSENGERS</th>
</tr>
</thead>
<tbody>
<tr>
<td>AEGW C-10</td>
<td>generic</td>
<td>1</td>
<td></td>
<td>avl</td>
<td>resistive</td>
<td>duplex radio</td>
</tr>
<tr>
<td>AEGW C-45</td>
<td>generic</td>
<td>2</td>
<td>40</td>
<td>avl</td>
<td>resistive</td>
<td>duplex radio</td>
</tr>
<tr>
<td>AEGW C-100</td>
<td>generic</td>
<td>2</td>
<td>40</td>
<td>avl</td>
<td>resistive</td>
<td>duplex radio</td>
</tr>
<tr>
<td>ARMV TP-I</td>
<td>VENDOR NT</td>
<td>to be determined</td>
<td></td>
<td></td>
<td></td>
<td>radio</td>
</tr>
<tr>
<td>ARMV TP-II</td>
<td>VENDOR NT</td>
<td>to be determined</td>
<td></td>
<td></td>
<td></td>
<td>radio</td>
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<td>ARBS</td>
<td>TECHNICAL INFORMATION IS NOT CURRENTLY AVAILABLE</td>
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</tr>
<tr>
<td>CBTX</td>
<td>generic</td>
<td>1</td>
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<td>yes</td>
<td>resistive</td>
<td>duplex radio</td>
</tr>
<tr>
<td>FTRX</td>
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<td></td>
<td></td>
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<tr>
<td>HIRD</td>
<td>generic</td>
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<td>107</td>
<td>smoke stat</td>
<td>resistive</td>
<td>cellular phone linked to Public Address</td>
</tr>
<tr>
<td>ITMN</td>
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<td></td>
<td></td>
<td>yes</td>
<td>electric</td>
<td>buss bar or radio</td>
</tr>
<tr>
<td>SULE</td>
<td>optional</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SWDT FLW</td>
<td>n/a</td>
<td>1</td>
<td></td>
<td>avl</td>
<td>resistive</td>
<td>duplex radio</td>
</tr>
<tr>
<td>SWDT SIPH</td>
<td>generic</td>
<td>to be determined</td>
<td></td>
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<td>duplex radio</td>
</tr>
<tr>
<td>TX20</td>
<td>generic</td>
<td>in design</td>
<td></td>
<td>yes</td>
<td>resistive</td>
<td>radio Loss-E line</td>
</tr>
<tr>
<td>TITN</td>
<td>Sutrak</td>
<td>2</td>
<td></td>
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<tr>
<td>UTDC UM-3</td>
<td>generic</td>
<td>2</td>
<td>26</td>
<td>avl</td>
<td>resistive</td>
<td>duplex radio</td>
</tr>
<tr>
<td>VNRL T-II</td>
<td>Sutrak</td>
<td></td>
<td></td>
<td>ASHRAE</td>
<td>yes</td>
<td>resistive</td>
</tr>
<tr>
<td>VNRL T-III</td>
<td>Sutrak</td>
<td></td>
<td></td>
<td>ASHRAE</td>
<td>yes</td>
<td>resistive</td>
</tr>
<tr>
<td>VSL</td>
<td>Sutrak</td>
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<td>25%</td>
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<td>resistive</td>
<td>inductive loop</td>
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<td>POMA</td>
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<td>4</td>
<td>30</td>
<td>yes</td>
<td>resistive</td>
<td>duplex radio</td>
</tr>
</tbody>
</table>
VEHICLE DOOR CONFIGURATIONS AND EMERGENCY EXITS MATRIX - 5.10

1) DOOR WIDTH- the clearance width of any single normal service entry way.

2) DOOR HEIGHT- the clearance height of any single normal service entry way.

3) DOORS PER SIDE- the number of doorways (openings) per vehicle side,

4) LEAVES PER DOORWAY- the number of individual door leaves per doorway that close or open to allow entry.

5) DOOR TYPE- the type of door leaf system; A) sliding- similar to a residential pocket-door, B) sliding plug- similar to a conventional passenger van sliding door, or C) Double bi-fold- similar to the doors of older buses which had two hinged-folding-sections per leaf.

6) CONTROL TYPE- the type of mechanism which activates the door leaf.

7) CUT-OUT CAPABILITY- the ability to manually lock a malfunctioning door without having to take the entire car or train out of service.

8) EMERGENCY EGRESS- a brief description of the emergency evacuation capability of the system.
## VEHICLE DOOR CONFIGURATIONS AND EMERGENCY EXITS MATRIX - 5.10

<table>
<thead>
<tr>
<th>VENDOR</th>
<th>DOOR W/D ft-in</th>
<th>DOOR HGT ft-in</th>
<th>DOORS SIDE</th>
<th>LVS / DR</th>
<th>DOOR TYPE</th>
<th>CONT TYPE</th>
<th>CUT OUT</th>
<th>EMERGENCY EGRESS</th>
</tr>
</thead>
<tbody>
<tr>
<td>AEGW C-10</td>
<td>3'-10</td>
<td>5'-5&quot;</td>
<td>1 2</td>
<td>slide</td>
<td>elect</td>
<td>yes</td>
<td>SIDE DOORS OPEN ONTO WALKWAY, CONTROLS ALLOW OPENING ONLY ON SIDE WHERE WALKWAY EXISTS</td>
<td></td>
</tr>
<tr>
<td>AEGW C-45</td>
<td>6'-2&quot;</td>
<td>appx 7'-0&quot;</td>
<td>1 2</td>
<td>slide</td>
<td>elect</td>
<td>yes</td>
<td>VEHICLE EMS OPEN, STAIRS UNFOLD, EGRESS IS ON THE GUIDEWAY SURFACE</td>
<td></td>
</tr>
<tr>
<td>AEGW C-100</td>
<td>3'-10</td>
<td>5'-5&quot;</td>
<td>1 2</td>
<td>slide</td>
<td>elect</td>
<td>yes</td>
<td>SIDE DOORS OPEN ONTO WALKWAY, CONTROLS ALLOW OPENING ONLY ON SIDE WHERE WALKWAY EXISTS</td>
<td></td>
</tr>
<tr>
<td>ARMV TP-I</td>
<td>5'-10</td>
<td>appx 7'-0&quot;</td>
<td>2 2</td>
<td>slide</td>
<td>pneum</td>
<td>yes</td>
<td>VEHICLE EMS OPEN, STAIRS UNFOLD, EGRESS IS ON THE GUIDEWAY SURFACE</td>
<td></td>
</tr>
<tr>
<td>ARMV TP-II</td>
<td>5'-10</td>
<td>appx 7'-0&quot;</td>
<td>4 2</td>
<td>slide</td>
<td>pneum</td>
<td>yes</td>
<td>VEHICLE EMS OPEN, STAIRS UNFOLD, EGRESS IS ON THE GUIDEWAY SURFACE</td>
<td></td>
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</tbody>
</table>

### ARBS

TECHNICAL INFORMATION IS NOT CURRENTLY AVAILABLE

<table>
<thead>
<tr>
<th>VENDOR</th>
<th>DOOR W/D ft-in</th>
<th>DOOR HGT ft-in</th>
<th>DOORS SIDE</th>
<th>LVS / DR</th>
<th>DOOR TYPE</th>
<th>CONT TYPE</th>
<th>CUT OUT</th>
<th>EMERGENCY EGRESS</th>
</tr>
</thead>
<tbody>
<tr>
<td>CBTX</td>
<td>6p-1 12p-2</td>
<td>slidg plug</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>RESCUE VEHICLE ON OPPOSITE GUIDEWAY - RESCUE VEHICLE ON THE GROUND</td>
</tr>
<tr>
<td>FTRX</td>
<td>4'-5&quot; 6'-3&quot;</td>
<td>1 1</td>
<td>DOL Bi-Fold</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>20' CATWALK ON PEAK OF BEAM ACCESS BY LADDER IN VEH, ELEVATOR FROM CAR TO GROUND IS IN DESIGN</td>
</tr>
<tr>
<td>HIRD</td>
<td>4'-0&quot; 7'-0&quot;</td>
<td>2 2</td>
<td>slide</td>
<td>screw</td>
<td>motor</td>
<td>yes</td>
<td></td>
<td>LADDER ON BEAM SIDE OF VEH ARE HINGED ON BOTH AND OPEN OUTWARD TO FORM A WALKWAY TO TOP OF THE MAIN BEAM/GROUND VEH</td>
</tr>
<tr>
<td>ITMN</td>
<td>4'-1&quot; 4'-9&quot;</td>
<td>1 2</td>
<td>slide</td>
<td>pneum</td>
<td></td>
<td></td>
<td></td>
<td>VEHICLES CAN BE PUSHED/TOCHED BY OTHER VEH., OR BY RESCUE VEHICLE ON THE GROUND</td>
</tr>
<tr>
<td>SULE</td>
<td>1 or 2</td>
<td>2</td>
<td>slide</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>CATWALK ON GUIDEWAY</td>
</tr>
<tr>
<td>SWDT FLNY</td>
<td>3'-3&quot; 5'-0&quot;</td>
<td>1 2</td>
<td>slide</td>
<td>elect</td>
<td></td>
<td></td>
<td></td>
<td>VEHICLE LOWERS TO THE GROUND, BY RESCUE VEHICLE ON THE GROUND, BY ROPE LADDER FROM VEHICLE</td>
</tr>
<tr>
<td>SWDT SIPM</td>
<td>4'-5&quot;</td>
<td>2 2</td>
<td>slide</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>NOT INCLUDED IN RESPONSE, HOWEVER THE SYSTEM WAS ACCEPTED BY THE F.B.R. IN GERMANY</td>
</tr>
<tr>
<td>TX20</td>
<td>2'-10 5'-0&quot;</td>
<td>1 1</td>
<td>slidg plug</td>
<td>electro</td>
<td>mchn</td>
<td>yes</td>
<td></td>
<td>A WALKWAY IS AVAILABLE BUT NOT STD, BY VEH., PUSHING OTHER VEH., BY RESCUE VEH ON OR TRANSFER TO TOP OF THE MAIN BEAM/GROUND VEH</td>
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<tr>
<td>TITN</td>
<td>4'-2&quot; 6'-4&quot;</td>
<td>2 2</td>
<td>slidg plug</td>
<td>electro</td>
<td>mchn</td>
<td>yes</td>
<td></td>
<td>WALKWAYS ARE AVAILABLE, VEHICLES PUSH VEHICLES, OR BY RESCUE VEHICLE ON THE GROUND</td>
</tr>
<tr>
<td>UTDC UM-3</td>
<td>4'-0&quot; 6'-6&quot;</td>
<td>1 2</td>
<td>slide</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>SIDE DOORS OPEN ONTO WALKWAY, CONTROLS ALLOW OPENING ONLY ON SIDE WHERE WALKWAY EXISTS</td>
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<tr>
<td>VNRL T-III</td>
<td>10 3'-4&quot; CTR.</td>
<td>5'-7&quot;</td>
<td>2 1</td>
<td>slide</td>
<td>belt</td>
<td></td>
<td></td>
<td>MOVEMENT IN THE TRAIN IS BY CLIMBING THRU HATCHES BETWEEN INDIVIDUAL CARS, EGRESS IS ONTO A CATWALK BETWEEN BEAMS OR ON BEAM SIDE</td>
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<tr>
<td>VNRL TIII</td>
<td>3'-6&quot; 6'-7&quot;</td>
<td>1 1</td>
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<td>MOVEMENT IN THE TRAIN IS BY CLIMBING THRU HATCHES BETWEEN INDIVIDUAL CARS, EGRESS IS ONTO A CATWALK BETWEEN BEAMS OR ON BEAM SIDE</td>
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<tr>
<td>VSL</td>
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<td>slide var.</td>
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<td>UNLOCK WINDOWS ON LEAD OR TRAILING ENDS AND CLIMB TO GUIDEWAY</td>
</tr>
<tr>
<td>POMA</td>
<td>7' 3&quot; 6' 4&quot;</td>
<td>1 2</td>
<td>slide</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>ONE END OF EACH VEHICLE HAS AN EMERGENCY DOOR WHICH ALLOWS EGRESS TO THE GUIDEWAY</td>
</tr>
</tbody>
</table>

33
1) **LOAD COMPENSATION** - the ability of the vehicle to detect high passenger loads and compensate with increased brake pressure to maintain uniform brake rates among all trains.

2) **SLIP/SLIDE** - the ability of the vehicle to detect slipping (wheel spin during acceleration) or sliding (loss or traction during braking) and correct for the condition.

3) **DYNAMIC BRAKING/REGENERATIVE BRAKING** - the electrical conversion of propulsion motors to electrical generators which provides braking resistance and voltage generation.

4) **PRIMARY SERVICE BRAKE** - the first and most frequently used brake system; 
   A) Dynamic - field reversal of rotary motors creates a generator braking effect.  
   B) friction shoe on wheel drum.  
   C) Air - Aeromovel uses piston effect in its air plenum.  
   D) LIM - linear induction motors use induced fields to create braking.  
   E) Track - a spring loaded/electromagnetically activated length of steel creates friction on the steel guidance surface or an electromagnetic braking field is induced in the tracks by a born component.

5) **SECONDARY SERVICE BRAKE** - the type of braking used to backup the primary system and/or to be used as a blended brake for final stopping and precision stopping  
   A) disc (or rotor) - similar to a conventional automobile disc brake.  
   B) friction/drum - similar to a conventional automobile drum and shoe arrangement.  
   C) tread - similar to conventional rail brakes utilizing a friction shoe that applies pressure to the wheel tread of a flanged steel wheel.  
   D) friction on motor shaft - is used by Poma.

6) **SERVICE (BRAKE) RATE** - the brake rate under normal (non-emergency) conditions. PRT is high due to all-seated passengers. Primary and Secondary Service Brakes are usually designed to operate in a way that causes the primary to activate first and for a longer duration, and then slowly release as a secondary service brake provides precision braking (blended braking).

7) **EMERGENCY BRAKE** - the type of emergency brake;  
   A) friction (drum) or disc,  
   B) air flow and disc combination (Aeromovel)  
   C) track brake,  
   D) pinch beam - a system which utilizes the beam as a disc rotor,  
   E) LIM, or  
   F) an undesignated type but spring applied brake.

8) **BRAKE ACTIVATION** - the type of mechanism used to activate primary and/or secondary brake systems.

9) **BRAKE CONTROL** - the type of system used to control the brake action.

10)**EMERGENCY RATE** - the brake rate of a vehicle under emergency braking conditions, usually higher than service brake rate. PRT is high since all passengers are seated.

11) **JERK RATE** - the rate of change of acceleration/deceleration, indicating how much force a passenger will experience as a vehicle accelerates (g.'s).

12) **PRECISION STOP** - the ability of a brake system to precisely stop a vehicle at a platform within a longitudinal "window".
CONVERSION CHART FOR 1 g = 32.17 feet per second per second

0.10g = 3.22 feet per second squared
0.10g = 2.19 miles per hour per second
0.10g = 0.98 meters per second squared

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<th>SLIP /SLD</th>
<th>DYNAM /REGN</th>
<th>PRIM SERV BRAK</th>
<th>2nd SERV BRAK</th>
<th>2nd RATE g.'s</th>
<th>EMERG BRAKE</th>
<th>BRAKE ACTIVATION</th>
<th>BRAKE CONTROL</th>
<th>EMERG RATE g.'s</th>
<th>JERK RATE g.'s</th>
<th>PREC STOP</th>
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<td>yes</td>
<td>frictn drum</td>
<td>0.09</td>
<td>frictn</td>
<td>spring</td>
<td>elect</td>
<td>0.18</td>
<td>0.045</td>
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<td>frictn</td>
<td>spring</td>
<td>elect</td>
<td>0.18</td>
<td>0.045</td>
<td>+6''</td>
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<td>n/a</td>
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<td>air/ disc</td>
<td>air &amp; elect</td>
<td>hydraulic</td>
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<td>var.</td>
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<td>air &amp; disc</td>
<td>air &amp; elect</td>
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<td>eddy curr</td>
<td>LIM</td>
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<td>mech</td>
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<td>rotor</td>
<td>0.15</td>
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<td>beam</td>
<td>hydraulic</td>
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<td>regn</td>
<td>modifd</td>
<td>disc</td>
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<td>yes</td>
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<td>spring</td>
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<td>0.26</td>
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</table>

35
NOTE: Conventional car seating designs allow for three categories of passenger load configurations; Seated Load, Standing Load, and Crush Load.

1) SEATS PER CAR + WHEEL CHAIR SPACES- Indicates the number of seats available for able-bodied patrons and the number of spaces available for disabled patrons in wheelchairs. Sometimes, wheelchair spaces are available by reducing the spaces available to able-bodied standees and so totals may add up with an apparent error of 1. Sometimes several spaces are available without reducing able-bodied spacing. A "+" indicates a specific number of available spaces, and "ADA" indicates multiple spaces.

2) SQUARE FEET PER SEAT- the amount of interior floor space allotted to seated passengers.

3) STANDEES PER CAR (Total)- indicates the number of people who can "comfortably" be accommodated, usually allowing an average of 2-3 square feet of floor space per person. Seats per car + Standees = (Total standing load).

4) SQUARE FEET PER STANDEE- the amount of interior floor space allotted to standing passengers.

5) CRUSH LOAD (Total)- indicates the Crush Load Capacity of a car, usually allowing an average of 1.5-2.2 square feet per standee. Seats per car + Standees + additional patrons = (Total crush load). Wheelchair spaces are included in the total crush load number.

6) SQUARE FEET PER CRUSH LOAD STANDEE- the amount of interior floor space allotted to standing (crowded) passengers.

7) VARIABLE ARRANGEMENTS- an indication of the flexibility of seating layouts and the ability to easily remove seats to increase vehicle capacity.

8) LONGITUDINAL SEATING- the ability to position seats so that passenger shoulders are parallel with the direction of travel (backs alongside vehicle sides).

9) TRANSVERSE SEATING- the ability to position seats so that passenger shoulders are perpendicular to the direction of travel (forward or rearward facing).
<table>
<thead>
<tr>
<th>VENDOR</th>
<th>SEATS / VEH + WHLCH</th>
<th>SQR FEET / ST</th>
<th>STAND LOAD TOTAL</th>
<th>SQR FEET STND</th>
<th>CRUSH LOAD TOTAL</th>
<th>SQR FEET / CRSH</th>
<th>VAR ARR</th>
<th>LONG SEAT ARR</th>
<th>TRANS SEAT ARR</th>
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<td>AEGW C-10</td>
<td>4 + 0</td>
<td>4.5</td>
<td>6 (10)</td>
<td>5 (15)</td>
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<td>AEGW C-45</td>
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<td>45 (57)</td>
<td>10 (67)</td>
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<td>yes</td>
<td>yes</td>
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<td>80 (100)</td>
<td>50 (150)</td>
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<td>yes</td>
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<td>4.4</td>
<td>46 (64)</td>
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<td>142 (188)</td>
<td>50 (238)</td>
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6.0 SYSTEM EVALUATIONS

6.1 PERSONAL RAPID TRANSIT

PICTURE EXPLANATIONS AND CREDITS

1) CabinTaxi- Hagen, Germany demonstration track. Upper picture shows bi-directional operation with three passenger cars. In the distance, a car is operating on a cable-stayed section of guideway. The curved tower is supporting the cables. Lower picture shows complex switching capability. (Pictures from Automated Guideway Transit - An Assessment of PRT and Other New Systems, prepared at the request of the Senate Committee on Appropriations, Transportation Subcommittee, June 1975.)

2) "Filling the Need"- Artist's rendition of a designed three passenger vehicle for Taxi 2000. Bogie is completely obscured by the guideway, and only the vehicle body is visible to the general public. (Pictures from marketing literature provided by Taxi 2000 Corp.)

3) SwedeTrack Flyway proposes small vehicles for individuals and vehicles large enough to transport cars, all operating on the same guideway. Vehicles are supported from elevated guideways. Rather than have elevated platforms, Flyway is conceived to have vehicles that lower to the ground for boarding. (Pictures from marketing literature provided by SwedeTrack AB, Flyway).

4) Intamin did not respond with a formal proposal for PRT on Tech's campus, however, they did submit several drawings from their Chicago RTA submittal. Their vehicle is essentially a small vehicle operating on a bottom-side supported monorail beam. The significant limitation of this particular guideway/suspension relationship is that switching is restricted to systems which move the beam, and as such, is likely to be too time consuming for a competitive PRT system. Other PRT systems have carbon switches which permit 1.0 second headways and less. (Drawing from Intamin Corporation, 1990)
Cabinet taxi: Suspended and Supported Vehicles
FILLING THE NEED

A new approach to urban transportation is required – one that is sufficiently low in cost and high in service quality that it will be accepted as an attractive alternative to the automobile. It must have adequate speed, capacity, safety, and reliability. It must operate in all weather conditions and be fully accessible to the elderly and handicapped.

The system must be visually unobtrusive, generate no noise or air pollution, and require very little land. And it must be easy to install, easy to maintain, energy efficient to run, and comparable in service life to present modes of transportation.

Taxi 2000 is just such a revolutionary new system concept for public transit . . . it fills the need.

TAXI 2000 IS UNIQUE

Taxi 2000 is the product of 18 years of evolutionary engineering effort. It builds on the work of all earlier developers. The product of analytical studies and practical experience, every element of the design is the result of minimizing cost per passenger-mile and maximizing accessibility and public acceptance of the system. The most significant features that characterize the concept are:

- three-passenger, lightweight vehicles operating in small (3 x 3-ft cross section) guideways ensure minimum visual impact
FLYWAY

Harmonizing.....

For everybody..... Even for cars!
Personal Rapid Transit (PRT) is completely distinct from Mass Rapid Transit. It is not, as often misunderstood, another mode of Mass Transit and therefore, although some of the evaluating parameters may be similar to Mass Transit, only rarely should PRT be assessed using the same parameters of evaluation in the same way as they are used for Mass Transit.

PRT systems achieve their passenger capacities by operating a large number of small capacity vehicles (3-6 passengers) on close headways (1-3 seconds). As a result, the different proposed system capacities are sensitive to vehicle passenger capacity and to minimum achievable headways. When evaluating PRT, the concept of passenger capacity per hour per direction should be considered along with "slots" (on the guideway) per hour or "available vehicles" per hour. For example, 200 vehicles on a campus network, each with a capacity of 3 people, might serve an area one mile long X 0.33 miles wide (total guideway mileage might be 2.75 miles) with a mainline network speed of 20 mph. The longest trip might take 8.5 minutes. At the Destination station, the vehicle becomes available for an Origin trip, or may be dispatched to another station (consuming 1.5 minutes) where demand requires additional vehicles. Total time elapsed is 10 minutes. This can be extended to 200 vehicles X 6 trips per hour = 1200 vehicles per hour of network capacity or 3600 pph. A system that can provide headways of 3 seconds or less can allow mainline operations to satisfy this demand. If campus users learn to share vehicles, perhaps one fourth of all trips will be two persons per vehicle yielding a network usage of 1500 pph. This example considers most trips to be "longest" trips. Presumably, some trips will be shorter, making vehicle availability higher, and further increasing network usage. By extending Tech's alignment Alternative #2 to include a loop alignment that serves the south and east side of campus, a double overlapping-loop alignment can be created. This allows for a more efficient basic network for PRT feasibility on campus as well as serving a larger campus area.

In general, system planning for PRT is a challenge. The conventional concept of links (sections of uninterrupted travel lanes) intersected by other links at nodes (points where stations and/or terminals cross each other, i.e. transfer points) is modified and expanded upon. With PRT, guideway planning is one task and locating stations is separate. Stations DO NOT necessarily exist near nodes, but rather can exist anywhere on a link where a sufficient amount of space for deceleration and acceleration lanes to an off-line station is available. This added flexibility dramatically expands the potential effectiveness and efficiency of the system and makes planning an art. With the exception of CabinTaxi (CT), most PRT
systems are based on one directional guideways. The flexibility of the PRT network concept allows a wide degree of latitude for selecting station locations. CabinTaxi utilizes its guideway in a manner that allows one direction of travel on top of the guideway and an opposite direction of travel hanging under the guideway. This essentially creates two separate networks in the horizontal space required by one network. The networks are interfaced at stations, if desired, and a degree of guideway redundancy is created that is unique to the Cabin Taxi design. This redundancy is analogous to the capability provided by mass transit reverse run switching scenarios.

A special station requirement of any PRT system involves an interface for passengers to communicate their destination selection to vehicles and/or the network. While different vendors may approach the task in a variety of manners, the task must be addressed at each and every Origin station.

With the exception of CT, stations tend to be off-line. CT offers the possibility of initiating service with 12 passenger vehicles at 15 second headways (2800 pphpd) with on-line stations, and then growing to off-line stations with shorter headways as demand increases. Off-line stations introduce a cost penalty to PRT relative to on-line station systems, namely, separate deceleration and acceleration lanes (similar to expressway ramps) must be built. Additionally, if a station is sized for large capacity, conceivably, two decel/accel lanes would be needed, further increasing costs. The major operational advantage of off-line stations is that vehicle speed on the mainline is maintained at a constant rate, which increases average trip speed. A "macro" evaluation of off-line stations would likely indicate total benefits that exceed those of costs relative to on-line station systems.

SPECIAL NOTE 1: Selection of PRT for Tech will undoubtedly be a controversial and more risky decision than a conventional system. The ground-based transit establishment tends to be conservative. This contributes to safe design of systems at the expense of innovative systems which are comparably safe. Attention to projected risk analysis statistics for system failure events and attention to system design considerations which address the areas of safety and cost effectiveness is vital in a detailed evaluation of PRT. As improvements in technology contribute to statistically reducing a variety of potential hazards to "non-events", the feasibility of PRT increases. Additionally, evaluation of subsystems from a micro "costs" perspective often overlooks macro "benefits" in several areas (ex. LIMs, small vehicles and small stations (convenience), close headways (capacities) and overall system capacity (network feasibility), etc.) Offsetting the controversy and
risk is the certainty that PRT on Tech's campus will draw many transportation-related visitors and will make Tech the subject of research and curiosity for decades. The Morgantown, W. VA. project (1975) has done so for that school. Although institutional issues from the original Morgantown project combined to cast negative perceptions of Group and Personal Rapid Transit, the technology is successful. Advances in technology that would undoubtedly evolve from further research would greatly contribute to further acceptance of the PRT concept, if a similar, but more wisely planned venture would be attempted today.

SPECIAL NOTE 2: Rates of vehicle acceleration, deceleration, and jerk are much higher than conventional mass transit systems since standees are not permitted and seated passengers can comfortably withstand the higher rates. However, no vendor addresses the possible scenario where young children may be standing on the floor or a seat while the vehicle is in motion.

COMMON ADVANTAGES

• off-line stations allow for uninterrupted flow on the mainline. This can result in lower average travel times than conventional mass transit.
• a mature network offers multiple routing choices for failure management or congestion management.
• overall energy consumption per vehicle trip should be very low since vehicles maintain a constant speed and do not repeatedly accelerate and decelerate.
• stations can be economically sized according to demand and not according to "longest train" on the mainline.
• large crowds can be handled with greater efficiency than with mass transit.
• small vehicles transporting personal groups provide an element of security greater than mass transit.
• system extensions are likely to be more economically built than most conventional people mover systems since the guideways are narrow and light weight.
• networks are designed to provide demand responsive service and thereby provide more convenient service than fixed schedule systems. Night operations are very economical.
• in a mature PRT network, the adverse effects of transfers can be greatly reduced or eliminated.
• if selected for campus implementation, research opportunities in the areas of advanced controls such as needed for IVHS, computer neural networks, and advanced transportation planning and city planning, etc. will become available.
• There may be a potential market for up-graded control technology at Morgantown and AirTrans (Dallas), and this could be a revenue source. These systems have been operational for more than 15 years with no known major changes.

COMMON DISADVANTAGES

• large fleet size maintenance costs have not been established (research indicates that they may be less than mass transit.)
• some people will object to visual intrusion of a mature elevated network.
• R&D will be expensive.
• problems from previous PRT or Group RT (GRT) projects adversely "color" the concept. PRT is misunderstood and controversial.
• PRT requires a completely new infrastructure for regional implementation. In an area which is already served by bus, rail, and auto, the cost effectiveness will have to be closely evaluated. Good planning is needed to determine the efficacy of PRT in Atlanta.
• all of the vendors depend on having all passengers in a vehicle seated while in motion in order to achieve their acceleration/deceleration/jerk/ and speed around curves specifications. None of the vendors address the likely issue of a child standing on a seat or the vehicle floor while in motion.
• NOTE WELL: emergency management procedures for removing passengers from stalled vehicles between stations, will provide the basis of technical controversy. NFPA-130, 4-5.2, states "A means to allow passengers to evacuate the vehicle safely to a walk surface or other suitable area under the supervision of authorized employees in case of emergency shall be provided." NFPA-130, 1-1.3, states "Nothing in this standard is intended to prevent or discourage the use of new methods, materials, or devices, provided that sufficient technical data are submitted to the authority having jurisdiction to demonstrate that the new method, material, or device is equivalent to or superior to the requirements of this standard with respect to fire resistance and safety." The approach that any vendor applies for emergency evacuation will likely be guided by these two NFPA sections.
Five vendors responding to Tech's questionnaire have been involved in PRT research, but only three have proposed PRT systems. The three are CabinTaxi, SwedeTrack Flyway, and Taxi 2000. Intamin and Titan PRT did not propose PRT but both have expressed interest if PRT is selected as a mode for deployment.

CabinTaxi, USA (CT) did not respond to the questionnaire. After placing 6-7 telephone calls to Terrill Hill between August 25 and September 30, 1992, no return calls were received by him. During a chance meeting with him, he explained that CT basically has an exclusive marketing agreement with Demag, a major German industrial engineering and manufacturing group with a specialty in fully automated materials handling systems, and one of two partners in the original German CabinTaxi demonstration project. Also, some of the engineers involved with the original CabinTaxi demonstration would be able to come to the U.S. and lead the team for the necessary up-grade of systems and installation of the Tech CabinTaxi project. A later conversation with Marsden Burger indicated that CT is proposing a joint-ownership business with Tech for the creation of a new American-made product. Additionally, Marsden Burger would likely be Manager of Systems or higher, and he brings field experience of high management-level involvement in the state-of-the-art fully automated Vancouver SkyTrain and Detroit DPM projects. By considering the German CabinTaxi demonstration project (c.1972-80) and the Ziegenhain system (continuously since 1976) as accepted demonstration projects, construction of a system on Tech's campus, with similar but improved technology, could be expedited. The Tech installation would become a site for on-going research, provide transportation on campus, and serve as a PRT sales tool for the newly formed joint-ownership. During November 7-9, Marsden and Terrill were available in Atlanta and much valuable information was conveyed. Nonetheless, the sophistication of their organizational structure must be further considered.

Intamin responded to the questionnaire with proposals other than PRT technology. Considering that the name of CabinTaxi was listed on the original questionnaire, Intamin was aware that PRT was being considered, especially since they claim to have some of the original CabinTaxi engineers in their employ. They later contacted Tech and requested that they be included in the group of vendors if PRT is selected as the mode for campus deployment.

Titan PRT learned of Tech's evaluation questionnaire substantially later than the other vendors. They submitted technology for a people mover type system. They have PRT capability if PRT is selected, and would be interested in submitting a PRT proposal.
Only Cabin Taxi has been through a full demonstration project. It is considered by the Federal German Railway to be "ready for implementation in an urban setting".

**CABINTAXI - SYSTEM DESCRIPTION**

The assessment that follows is a compilation of information gathered from interviews with Terrill Hill and Marsden Burger and from documents that reference CabinTaxi (CT). Marsden Burger, in particular, brings a background in urban geography and management level field experience to the CT proposal.

The system design work that has gone into CT is beyond full appreciation in this evaluation. The varieties of redundancy, and areas where fail safe logic have been incorporated, have been demonstrated in two projects, the CT demonstration track at Hagen, Germany, and a smaller demonstration shuttle, in Ziegenhain, West Germany. As a result of the R&D at these locations, the Federal German Railway concluded that CT was ready for installation in an urban environment. This represents a considerable level of development beyond the other PRT vendors. Although some of the control components for the original system are obsolete, replacements with state of the art components are available and would meet or exceed specifications from the original demonstration project. As conceived for full scale implementation, CT provides the capability of providing a level of service which is unsurpassed by any existing or proposed system in this entire assessment (or any known system in its class), and provides the service with proven components and logical conceptual design for expanding a system beyond Tech’s immediate needs (referred to herein as a "mature network"). Of particular importance is the utilization of the horizontal beam for both top and bottom supported vehicles. At the heart of the design is the idea that urban horizontal space is available at a higher premium than vertical space. The concept also allows for double capacity on the horizontal beams and a level of redundancy that other one-way PRT systems do not provide.

The CT design also incorporates the ability to provide both PRT and CRT on one guideway. This ability contributes to the possibility of installing a relatively less expensive initial system on Tech’s campus when compared to other PRT systems. Vehicles

As conceived for a mature network, vehicle capacities are for 3, 6, or 12 passengers. Six passenger vehicles are 10 feet long and 12 passenger vehicles would be 15 feet long. Vehicles are capable of bi-directional operation. The Hagen vehicles were steel and aluminum, however, new composites would likely be used for
new vehicles. NFPA 130 standards would be met or exceeded. Mechanical coupling is not utilized, but a "push" capability can be installed if desired. Load compensation is controlled by carbon computer. HVAC and smoke detection are included in each vehicle. Seating arrangements on the three vehicles allow for no standees and are designed to have A) 3 passengers (pax) facing forward, B) 3 pax facing 3 pax, or C) for CRT, two sets of 3 pax facing 3 pax (total-12).

Propulsion, Suspension, Guidance

The 3 and 6 passenger vehicles have one bogie, the 12 passenger vehicle has 2 bogies. Each bogie has four rubber-clad steel wheels and each wheel is mounted on its own independent spindle. Guidance is provided by the beam, which is straddled by the bogie. Horizontal wheels for guidance were not discussed, but seem likely. Independent wheel mountings reduce hunting and minimize guideway maintenance.

Vehicle suspension is provided by infinitely adjustable hydraulic cylinders. The cylinders are utilized for superelevating the bottom-supported vehicle in curves. They are also used for leveling the vehicles to match the platform level at stations when wheelchairs or strollers must enter the vehicles. (Vehicle entry is achieved by stooping into the doorway. To make the entry more comfortable, the normal vehicle floor position is approximately 9 inches above the platform level.)

Propulsion is achieved by two double-sided linear induction motors (LIMs) on each bogie interfacing with a guideway mounted reactor rail. The bogies are mounted in the guideway in such a manner (in conjunction with auxiliary equipment) as to make fire hazard almost nil. A series of baffles in the beam minimizes the effects of inclement weather on the upper guideway and the lower guideway is immune to weather.

Brakes

Three brake systems are installed on each bogie. Primary braking is accomplished by creating eddy currents with the LIMs and the reactor rails. Blended braking with a drum brake provides precision braking and parking brakes. Emergency brakes are spring applied track brakes.

Doors

Each 3 or 6 passenger vehicle has one sliding-plug door per side (similar to the side sliding doors on passenger vans). Each 12 passenger vehicle has two sliding-plug doors per side. The use of sliding plug doors in US fixed guideway transit is unusual, and requires further evaluation.

Train Control

Train control was not included as part of our discussions. The CT Hagen project demonstrated a 3 second headway with reliability. By limiting headway
initially to 3 sec., CT can maintain safe "brick wall" stopping capability (ability to stop as if a preceding vehicle can stop instantly and create a brick wall hazard) without jeopardizing conventionally accepted safety. The long term goal of the designers is to reduce the headway to 0.5 seconds @ 22-30 mph. This will result in the need to challenge conventional standards since brickwall stopping will not be capable, but will be demonstrated as not necessary. At that time, the train control system will be changed from quasi-synchronous to an asynchronous vehicle-follower system. A carborn destination storage register allows vehicles to proceed to their destination, even if data communication with central control is lost.

Wayside train control is presumed to be very similar to Taxi 2000, since the two systems have similar origins.

(From Taxi 2000 - Quasi synchronous control is used on the guideway network. A hierarchy of vehicle, zone, station, and central control results in a coordinated, redundant, and flexible system which fails gracefully. Minimum headways of 0.5 seconds with nominal headways of 1.0 seconds are anticipated. Vital control functions are distributed amongst the four control systems. The central control computer coordinates administrative functions such as fare collection, empty vehicle routing, and congestion management. Zone control computers make local decisions regarding merge/diverge decisions and send signals to individual vehicles which control minor acceleration and deceleration adjustments for maintaining headways and assuring that merges occur smoothly. Note: Taxi 2000 is already providing basic computer modelling to FTA for Intelligent Vehicle Highway Systems, Advanced Vehicle Control Systems scenarios. Wayside-to-Vehicle communication is achieved by slotted coaxial cable and radio frequency signals.)

The modular nature of the control system allows for easy additions if network capacity expansions are desired.

Switches

CT switches are carborn and have been successfully demonstrated in the Hagen project.

Station Design

Since the CT network utilizes both top and bottom supported vehicles, stations have platforms to accommodate both guideways. The Hagen project demonstrated simple stations that are supported by a central elevator shaft. Low capacity station shafts support off-line platforms on one side of the shaft and support the mainline guideway on the other side. Higher capacity stations have platforms on both sides of the shaft and the mainline requires its own vertical support. Estimating station capacity for Tech's initial phase is difficult with the information provided. Simplistically, with a 3 second headway, 1,200 slots per hour are available on each of two guideways. If only 6-passenger vehicles are deployed, system capacity of
2,000 or 6,000 pph can easily be achieved. The flexibility provided by the CT system allows for the provision of service which is unprecedented and mind-boggling. Station designs can accommodate the 2,000 or 6,000 capacities and are ADA compliant. One strategy that CT proposes is to initially provide group rapid transit with 12 pax vehicles every 15 seconds (2,880 pax/hr). Stations for the start-up project can be easily utilized for eventual PRT operations.

Emergency Management

CT has designed fire resistance into their vehicle to a level that satisfied German standards and is believed to meet or exceed NFPA 130. The LiMs are isolated from the vehicles by a series of baffles in the guideway. Heat sensors and smoke detectors are combined to monitor motor health, so that motors which begin to exceed specified safety parameters are automatically routed to the nearest station and removed from service before a hazard is created. Similar systems have been implemented on the Vancouver SkyTrain system and have reportedly resulted in unprecedented high performance records. Carbon controls are inside the vehicle cabin and are isolated from the passengers. The Hagen project demonstrated that a blowtorch in the section where controls are located could be directed at the section wall for 30 minutes without burn-through. Inside the passenger compartment, heat and smoke detectors combine to route a vehicle to the nearest station if specified parameters are exceeded.

A system rescue-vehicle was demonstrated in Hagen. If an emergency develops on the upper beam, a rescue vehicle can access the trouble-car from the lower beam and visa-versa. The decision to provide "push" capability for stalled vehicles has not been finalized.

CT's top/bottom support system provides a level of guideway redundancy for emergency management that the other vendors have not matched.

Structures

The horizontal beams are steel and are designed with inspection panels in the sides to allow easy access to the various systems installed in their interiors. The panels contribute to smooth lines for aesthetic enhancement and also provide sound insulation for the vehicles. The beams can also be designed to incorporate space for utility lines such as fiber optic data cables, steam lines, etc. Columns are likely to be steel clad concrete and are designed to allow guideway sections to be supported by direct fixation to the beam sides, or cantilevered over road traffic such as may be need if routes along tree-lined sidewalks are desired.
TAXI 2000 – SYSTEM DESCRIPTION

Taxi 2000 (T2) was founded by J. Edward Anderson in June, 1983. Ed Anderson is an MIT Ph.D. (1962) and currently teaches Aerospace and Mechanical Engineering at Boston University. He has been a proponent of PRT since before founding Taxi 2000 and, since then, has been consistently researching, designing, and promoting the concept. T2 and Intamin were the two shortlisted competitors in the Chicago RTA competition. There is some kind of relationship between T2 and Raytheon, and T2 and Stone Webster. Further exploration of the relationship with Raytheon may lead to financial benefits for deploying a system on Tech's campus. Information about T2’s financial statement was not provided.

Vehicle

The T2 vehicle is designed as a self-propelled vehicle. Although the primary operating mode is one directional, the ability to reverse directions exists for emergency management. Basic design is for three passengers, but two jump seats for children or wheel chair attendants raise the capacity to 3'. Transporting a wheel chair passenger limits the vehicle capacity to one WC plus one able-bodied attendant. At its current level of development, a hydraulic bumper at either end allows vehicles to push or be pushed by other vehicles. A simple mechanical coupler is under design which would allow a good vehicle to backup to a disabled vehicle, couple up, and proceed to a station while pulling the disabled vehicle.

Construction materials for the vehicle are still being selected and will be NFPA 130 compliant. Communication between the vehicle and central control is by loss-E line. HVAC and smoke detection is available. The seating arrangements are fixed and an airbag option is available (however, controversial in view of potential extended insurance liability). Carbon batteries are reported to provide 12 hours of uninterruptable power to all vehicle systems, but this seems to be a long period if ventilation is included as a backed-up system. The issue of emergency ventilation, and its effect on UPS duration must be clarified.

Propulsion, Suspension, and Guidance

Two Linear Induction Motors (LIMs) are mounted on each vehicle. The LIMs provide redundant propulsion and redundant service braking. Four dual durometer tires (foam filled rubber) provide vertical support by riding on two aluminum or copper clad running rails. Guidance is achieved with eight horizontally mounted wheels which run inside the guideway. Failure of one of the load bearing wheels is overcome by the resulting load being directed by the guidance wheels onto the remaining three good load bearing wheels.
Brakes

Primary service braking is 100% LIM. An electrically actuated spring applied friction brake is available for emergency braking and as a parking brake.

Doors

One doorway with one sliding plug door is located on each side of the vehicle. (sliding plug doors are used on the rear-side of most conventional passenger vans.)

Train Control

Quasi synchronous control is used on the guideway network. A hierarchy of vehicle, zone, station, and central control results in a coordinated, redundant, and flexible system which fails gracefully. Minimum headways of 0.5 seconds with nominal headways of 1.0 seconds are anticipated. Vital control functions are distributed amongst the four control systems. The central control computer coordinates administrative functions such as fare collection, empty vehicle routing, and congestion management. Zone control computers make local decisions regarding merge/diverge decisions and send signals to individual vehicles which control minor acceleration and deceleration adjustments for maintaining headways and assuring that merges occur smoothly. Note: T2 is already providing basic computer modelling to FTA for IVHS AVCS scenarios. Wayside-to-Vehicle communication is achieved by slotted coaxial cable and radio frequency signals.

The modular nature of the control system allows for easy additions if network capacity expansions are desired.

Switches

A carbon switch engages a guideway mounted length of angle-rail which is permanently affixed to the guideway. Throw time is 0.4 seconds. Switch design is simple, effective, unaffected by weather, manually operable, and fail-safe. When in the selected position, the switch arm is "locked" in place and cannot be accidentally disengaged.

Station Design

Adding new stations between existing stations or expanding the network is complicated by having to remove one-way guideway sections and replace them with sections that have switches for a diverging or converging route. However, the guideway segments are modular, can be fabricated off-site, and can be installed more easily than having to interrupt service for several days of construction-on-site. Platform doors or barriers are required, and station design is fairly simple. T2 stations are similar to CabinTaxi with the exception that T2 operates vehicles only on the topside of the beam.
Emergency Management

The single situation of greatest concern is vehicle evacuation. Accessibility of the vehicles by a ladder truck is a function of the terrain over which the guideway is constructed. T2 designers are reluctant to include walkways, however, walkways can be mounted to the sides of a guideway. Sufficient safety concern in design is demonstrated in their responses to conceptually resolve emergencies which can be anticipated, however, the solutions themselves must be further evaluated.

Structures

Tapered vertical columns, presumed to be 3/4" thick steel, are 28 inches wide at the base and 20 inches wide at the top. Hollow steel columns must be further evaluated for survivability after being struck by a car, truck, etc. Horizontal sections are of welded and bolted truss construction 38 inches wide and 36 inches tall. The vehicle rides inside an enclosed "U" guideway. For aesthetics and for sound insulation, a fascia can be mounted on the external guideway surfaces and can be painted any color desired.

SwedeTrack Flyway - System Description

SwedeTrack (ST) is farsighted in their vision and is proposing a system which can eventually carry small (1 pax), medium (4 pax), and large (24 pax) personal vehicles, freight modules, and platforms upon which automobiles can be driven and then transported long distances. However they do not specify how much of this vision they propose to achieve in an initial demonstration project. Attempting to provide even the simplest of the various services will require several years of construction and pre-revenue testing, before even one person can be transported. If ST has the support of Siemens in the development of the vital electronic subsystems for Flyway (as they claim to have for their Sipem system - see page 75), then what comes across as ST’s lack of familiarity in transportation engineering is less significant. Difficulties in translation from Swedish to English result in difficulty determining how extensively some systems have been conceived. Information about ST’s organizational size and financial strength were not included. Also, no statement was made regarding their intentions to provide on-going service, maintenance, or research on their system after final acceptance.

Vehicle

Each Flyway (FY) vehicle is an individual, bi-directional, 4 pax vehicle. No written reference or pictured reference indicates the ability of a vehicle to push or be pushed by another. This may be a significant limitation, but, depending on the bogie design, might be easily overcome. Details of car construction have not
been formalized, but will be designed to comply with NFPA 130 and Tech's requests. Communications is by fiber optic cable in the guideway beam and by radio. Air conditioning is neither proposed nor apparently available, but heating and ventilation is. Seat positions have 2 passengers facing 2 passengers with (sufficient?) space between the seats for wheelchairs. Battery backup on the vehicle provides 120 minutes of uninterruptable power for controls, alarms, lights, low speed ventilation, and emergency braking.

Propulsion, Suspension, and Guidance

Each cabin is supported from an overhead beam by a single bogie. Each bogie has two steerable axles with two rubber clad metal wheels per axle. Propulsion is accomplished by one rotary motor per axle. An important part of the suspension system includes what seems to be a sintered ball joint or some form of pivot hinge on the suspension arm, just below the guideway. This is intended to allow the hanging vehicle to sway outward when traversing curves and thereby allow higher speeds without superelevation of the guideway. No reference is made to controlling sway with a damper such as may be needed during gusty winds or when approaching stations near curves, and no reference is made to a method for controlling sway during an emergency stop. No control for horizontal guidance of the bogie is referred to, other than through a diagram which shows a lip on the running rail which surrounds a lower portion of the load wheels. Further clarification and acceptability of both sway and guidance control is required. A critical component of the suspension system is a proposed sub-system for raising and lowering the vehicle approximately 16 feet, between ground level stations and an elevated running position, before motion begins. This seems to be a concept which is completely new to transit suspension. SwedeTrack claims that the system is economically less expensive than building elevated stations. Numerous safety concerns are raised and further assessment is impossible without more highly detailed information.

Brakes

Primary service braking is dynamic, secondary service braking is by two separate hydraulically actuated disc brakes, and emergency braking is by a "pinching" device that interacts with a clamping action on the beam, presumably with the same action as conventional disc brakes. Brake rate is determined in part by the distance to the vehicle ahead, but no mention is made as to how this information is conveyed to the vehicle's on-board sensor.

Doors

Each vehicle has one doorway on each side with two door leaves per doorway.
Train Control

The total complexity of the proposed train control system is described too generally for accurate evaluation by this assessor. Quasi-synchronous control is anticipated to be the form of moving block control utilized by any introductory PRT system, and is, in fact, proposed by ST. The vendor’s reference to "object oriented" control is not clearly described. Other elements of the system are construed as appropriate for the requirements of a PRT system, however, more detail will be necessary.

Switches

ST utilizes a carbon switch which was developed by Siemens-Duewag in their prototype H-Bahn installation (similar to the proposed Sipem system). However, this design is not known to be in use in any other transit application and seems to have been discontinued by Siemens. As shown in drawings, the switch seems to require continuous activation throughout the duration of its being called upon, i.e. a loss of power during the period of traversing a switch might create a hazard. This concept is in conflict with conventional switch design, which requires a route to be aligned and switches to be mechanically locked before a vehicle is allowed to proceed. Further, the switch design transfers the weight of the suspended mass from four wheels to two wheels. This requires a "hefty" suspension system for the time when the switch is active. If the design is, in fact, determined to be safer than it seems to be, then SwedeTrack suggests that it could be used at stations and other locations in a manner that allows a following vehicle to pass a leading vehicle on the same beam. This would be novel and workable.

Station Design

Station design decisions will be determined by selecting either the lowering/raising suspension device or the fixed-length suspending arm concept. The lowering/raising concept is claimed to involve less overall expense than tall stations with elevators. The time required to lower, load, and raise a cabin is estimated at 25 seconds. Information about the duration of the lower/raise cycle time, independent of station dwell time, is not provided. With off-line stations and the inclusion of the "passing" capability of the switch concept described above, this seems workable. The vehicle is described as having a detection device which is sensitive to obstructions on the bottom side of the vehicle, nonetheless, provisions on the ground must be made to prevent people from accessing the area immediately below a descending cabin.

If a fixed-length suspension arm is used, then station design requires platform doors or barriers. Further evaluation, with SwedeTrack, of the impact on
boarding times imposed by this more conventional station design is required.

Adding stations between existing stations to an off-line system requires long term planning so that real estate for deceleration and acceleration lanes can be acquired. Also, switches must be installed in the mainline beams. The duration of this process and its impact on existing service is undetermined.

Extending the system is most easily accomplished if the future extension is predicted during original construction and switching provisions are included at that time. There is a price penalty for this. Extensions after service is started is similar to adding lanes for off-line stations.

Emergency Management

Several general concerns are raised by the ST proposal regarding emergency management. A number of subsystems seem to be either not yet designed or are still in development.

The ability of pushing disabled vehicles is discussed, and acceptable. Although the idea may meet the letter of NFPA 130, evacuation of a vehicle using a rope or rope ladder, as described, is of questionable utility. Accessibility of the vehicles by a ladder truck is a function of the terrain over which the guideway is constructed.

The switch design requires further clarification before a fair assessment can be conducted. The lowering/raising concept for replacing complex stations needs to be evaluated much more closely than discussed in the proposal. Especially, fail-safe design of the system must be detailed.

Finally, the costs/benefits of the pivot hinge on the suspension arm must be evaluated more closely.

Structures

Steel column and steel beam construction is proposed. Further technical information is required regarding 1) the use of one beam side as a by-pass lane of the other beam side, 2) the anticipated construction time of the guideway and the modularity of its components, and 3) the dimensions of the beam and limitations of the system if small capacity vehicles (1-4 pax), moderate capacity vehicles (24 pax), and freight laden vehicles are deployed on one guideway with the short headways that are necessary for PRT and CRT.
6.2 AEROMOVEL

PICTURE EXPLANATIONS AND CREDITS

1) This article and accompanying drawings appeared in Popular Science, October 1991.
Every Saturday, Sunday, and holiday, thousands of revelers in Jakarta, the steamy, teeming capital of Indonesia, throng to Taman Mini Park. Since 1989, 700,000 of them have traveled on a three-car unmanned people mover that glides along a two-mile elevated track in an endless loop, circling a lagoon dotted with islands.

So far, no surprises. Many fair grounds and theme parks have people movers. But this one is unique—it runs on air.

It’s called Aeromovel, and its developer, Sur Coerster of Sao Paulo, Brazil, claims that it improves the safety and economy of people movers. The first Aeromovel, a 3,200-foot-long pilot project, was built in 1987 in Sao Paulo. The Sur Coerster group is now designing another system to run for six miles along Sukumvit Highway, a major downtown artery in Bangkok, Thailand.

Lee H. Rogers, a Baltimore-based, much traveled transportation consultant, is promoting the use of Aeromovel for commuters in the Washington, D.C.—Baltimore area and other cities. The basic concept for Aeromovel, he explains, is simple and deceptively low-tech. The cars roll on steel rails supported on an elevated concrete guideway. Underneath the rails is a box-shaped, hollow, concrete air duct 39 inches on a side. This air duct is fed by ground-based external blowers. The pressure they generate provides the driving force by acting on two square propulsion “sails.” The sails hang from the front and rear of the cars and fit comfortably into the air duct.

Although the blower pressure is very low—only 2 pounds per square inch—the total thrust it exerts on the 1,600-square-inch surface of the sail is a hefty 3,200 pounds. If one blower is used to suck air from the portion of the duct directly in front of the leading sail, the thrust is doubled, and a top speed of 50 mph is possible. Speed, acceleration, and deceleration at stations is controlled by regulating the blowers’ output and by opening and closing air valves along the system.

A typical Aeromovel line is divided into a string of elevated guideway sections, each served by individual blowers. As a car passes over a given section it can be isolated from the rest of the circuit by large flap valves that block off a length of air duct. Electric blowers, capable of moving 50,000 cubic feet of air per minute, and their distribution valves are housed in sound-proofed 20-foot modules; motor speed and valve operations are regulated by a central computerized control system.

Rogers explains the process: “A vehicle’s approach to the station is signaled by a track-side sensor. As it enters the guideway section, a flap valve seals off the air duct behind it, and the downstream blower revs up to compress air against the trailing sail. If extra power is needed here, the isolation valve at the far end of the section also closes, and the upstream blower, with valves set for negative pressure, draws the leading sail forward.” All this is computerized.

As cars near a station, they are first slowed by opposing air pressure likewise programmed into the system and are finally stopped by hydraulic disc brakes on all the wheels. For brisk acceleration away from a stop, power is boosted by applying double-ended, push-pull air pressure until normal cruise speed is reached.

The Jakarta system, with its three 80-foot-long cars, has six stations and includes sharp 90-degree curves and a section with a 10 percent grade. That grade is manageable uphill, says Rogers, even though the cars’ path currently runs downhill over that section. Two of the stations have no blowers, three have one blower, and one station has two blowers, one to push, one to pull. On that stretch, the cars zip along at 42 mph. On the rest of the loop, they amble at a sightseeing rate of 12 to 15 mph.

To explain why this system sharply lowers costs, Rogers
ON AIR

This pilotless people mover uses air power for safety, reliability, and low cost.

By DAVID SCOTT

compares it to another simple, economical people mover—the San Francisco cable car system. "The cable car is also a passive vehicle," Rogers says, "externally powered by an underground dragline so it carries no heavy electric motor or other drive gear. That means a high payload to dead-weight ratio for added passenger capacity with a given energy input." For example, the passenger payload of a fully loaded car in the Indonesian system is 70 percent of the car's weight; in the New York City subway system, the passenger payload is only 33 percent.

Furthermore, the wheels of passive vehicles merely support and guide the car and are not needed for traction or braking on the steep hills. "We figure the capital cost of Aeromovel is under half that of any conventional people mover," says Rogers, "and likewise for operating costs.

(Continued on page 93)

HOW TO RUN ON AIR

Aeromovel's two-car articulated vehicle runs on steel rails in a troughlike concrete guideway elevated 14.7 feet above ground. Motor-driven blowers provide air pressure for propelling sails slung under the wheel assemblies. The sails, whose edges are sealed with rubber strips to prevent air leakage, protrude into an underslung hollow air duct. A segment of the guideway's air duct can be sealed off by upstream and downstream isolation valves. In the illustration above, the left-hand blower pushes against the rear sail, and the right-hand blower pulls the forward sail by suction. The combined thrust and suction move the vehicle forward to the next section, where other valves and blowers take over. A central computer switches the blowers between pressure and suction modes as needed.
cost per passenger.” He estimates that Aeromovel is cheaper than systems such as maglev (magnetically levitated) trains, as well as electric systems. Shifting all the drive equipment from the cars to fixed positions, he says, cuts the load on the track, guideway, and support columns. Therefore, the equipment can be of lighter, cheaper construction—only nine tons per car—while wear and maintenance are reduced. The steel wheels on steel rails have only one-tenth the rolling resistance of rubber tires and serve only as support and guidance.

“Energy needs are cut both by the cars’ low weight and their off-track propulsion,” Rogers says. “A self-propelled vehicle like a passenger bus might have a big two-hundred-eighty-horsepower engine because that much power would be needed for a standing start under full load on a steep hill, whereas level cruising takes only sixty horsepower.” Because with Aeromovel the power is fed to the guideway, the power requirements for each individual route segment are determined by local conditions—sharpness of the grade, for example—and increased over the normal level-ground requirement only for gradients and special high-speed sections.

The Aeromovel system has significant safety features. Tail-end collisions are prevented by the column of compressed air that always separates two vehicles on adjacent route segments and maintains a minimum headway, or distance, between them. Derailment risks are eliminated, since the front and rear propulsion sails are slotted into the guideway. A similarly fastened retaining bar beneath the central wheels also prevents derailments. In case of a power failure, the air duct valves close automatically, thus stopping all vehicles on the circuit. With no third rail or exposed electrical equipment there is, of course, no shock hazard.

19th-century air power

The idea for air-powered mass transit is not new. It was advanced and crystallized by the 19th-century British engineer Isambard Kingdom Brunel, a.k.a. “the Little Giant,” a diminutive figure best known for grandiose projects, such as the 1858 Great Eastern, the largest steam vessel of its time.

In 1847, Brunel built something he called “the Atmospheric Railway.” It was a 52-mile rail system strung along England’s Dover Coast, running past the foothills of Dartmoor. The trains were air-powered in a manner uncannily like that of Aeromovel. Between the rails lay a continuous 15-inch tube with a slot through which a leather-cupped piston reached down from the leading car. Stationary pumping engines along the way created a vacuum in the tube, and the train was sucked forward. The slot in the air tube had a leather flap that was opened by the advancing piston and then closed to maintain a relatively airtight seal.

The Atmospheric Railway not only worked, but propelled passengers at a remarkable 68 mph. Unfortunately, the leather flaps deteriorated under the assault of fog, salt spray, and the persistent gnawing of rats, and could not be adequately maintained. Brunel was forced to suspend operations after eight months, and the investors lost their capital.

Amazingly, the developers of the Aeromovel system had no knowledge of Brunel’s pioneering work until some three years after their design was complete.
AEROMOVEL - SYSTEM DESCRIPTION

The uniqueness of Aeromovel places it in an evaluation class of its own. In many ways, it is identical to conventional heavy rail technology, with the one significant distinction being its pneumatic propulsion system. The vehicle is essentially "blown along the tracks".

The Aeromovel (AM) design and development was performed by Oscar Coester in Puerto Alegre, Brazil. He holds all patents and rights. His personal background was originally aviation safety and his primary business is currently electronic marine navigation equipment manufacturing. Marketing rights for Aeromovel were granted to Marsha Feliciano, owner of Intermass Corporation, West Palm Beach, Florida. No information about either corporation's financial statement was submitted. In March of 1993, marketing rights were transferred to Aeromovel International, of Indianapolis, Indiana.

Cost estimates for the proposed alignment alternatives were not submitted, however, since AM's visit to Tech's campus during summer, 1992, additional financing options have become available.

A test track operation for AM was built in Puerto Alegre as well as a demonstration project. Two other demonstration projects have been built, but were not referenced in the questionnaire response. A two mile single-track loop in Jakarta, Indonesia has been in revenue service since December, 1989. It has a 2,000 pphpd capacity and recently carried its one millionth passenger.

AM is being reviewed by the Lenox Park developers as one of two short listed systems for possible installation in the Buckhead area (the other being Von Roll). The developers have expressed interest in developing a close relationship with Tech to mutually benefit all parties if both Tech and they select the same technology for implementation.

AM has proposed three different vehicles, each one configured in one of two different ways. Of the two configurations, one involves an "all seats - no standees" design. These have been considered as providing too little capacity for an economical Tech application, and as such have been eliminated from this assessment. The other configuration includes "few seats - many standees" and in fact can be configured with infinite seating/standing arrangements. Of the three vehicles so configured, the largest of the three provides capacity far in excess of the 6,000 pax scenario, and as such, has been eliminated from this assessment. The two vehicles being evaluated are arbitrarily designated Type I-a, the smaller of the two, and Type II-a, a larger, articulated vehicle.
System Advantages

- Propulsion is derived from guideway mounted power supplies. AM has the "lowest vehicle-weight-to-crush-load-weight ratio - without sustaining an energy consumption penalty" of any of the vendors. Theoretically, this should contribute significantly to conservation of energy for vehicle operations.
- The motors/blowers used to create air pressure in the beams are conventional heavy-duty industrial units. Maintenance on the units can be performed by persons with conventional electric motor maintenance skills. "High-tech" electronic skills are not needed, as might be the case with propulsion units from other vendors.
- In the no-HVAC design, AM has only a 55 VDC power supply on the guideway. All high voltage is completely isolated from the vehicle and the guideway. This reduces the possibility of an on-board fire, simplifies vehicle maintenance, and eliminates the need and expense of installing a high voltage power supply distribution system.
- AM is generally a relatively low-technology system utilizing many "off the shelf" components. Acquisition of replacement parts will likely be less dependent on proprietary vendors than other proposed systems. Acceptance of AM by Tech would create an opportunity to refine a technology which would likely have significant value to developing nations.
- Emergency egress from the vehicle is achieved by exiting the vehicle through special doors and then utilizing the upper surface of the guideway beam as a walkway.
- Forced air propulsion is anticipated as being able to provide unusually smooth acceleration and deceleration curves. Additionally, the possibility of head-on collisions is virtually impossible since any single block cannot have air blowing in two conflicting directions.
- Aeormovel claims that the system has been accepted by the Federal German Railway, a recognized stringent-standards organization.
- The need to install future primary propulsion units (fan rooms) can be facilitated by building horizontal beams that incorporate concrete "knock-outs" to accommodate the ducting for the units.
- With little or no modification to its existing level of development, AM is able to provide line-haul service and much higher passenger capacities than needed for Tech's requirements. Integrating AM into an intermodal scenario would be easier than the other vendor's systems due to AM's ability of operating vehicles at higher speeds than other systems.
System Disadvantages

• at its current level of development, a number of subsystems are likely to not meet U.S. standards, however, modifying those subsystems is anticipated as being relatively easy with conventional, existing technology.

• in the system design stage, close attention to possible future increases of service or addition of stations is critical. After implementation, insufficient capacity can only be corrected by modifications to the structural guideway and addition/removal of propulsion supply units.

• rescuing disabled vehicles (between stations) with a following vehicle may be difficult, but the probability of a vehicle needing rescuing is significantly lower than all other systems.

Vehicle

The AM vehicle is essentially a "people box" on wheels. It can operate in either direction as a single car unit only. The I-a vehicle is 26 feet long and is built on a rigid frame. The II-a vehicle is 83 feet long and is articulated. Designed into the articulated II-a vehicle is an element of safety which allows unimpeded passenger movement in the vehicle interior. The Jakarta vehicle is basically constructed on a steel frame with aluminum body parts. For U.S. implementation, NFPA 130 guidelines will likely result in some modifications in materials specifications, but this is anticipated as being without significant consequence. Load compensation for acceleration and braking is achieved by computer monitoring of the vehicle and adjusting of the valves which control the pressure of forced air in the beam. Voice communication is achieved by VHF-FM radio. HVAC is a subsystem which requires much closer scrutiny. Readily available is a carborn system which can only be powered by high voltage electricity (220+). However, the electricity can only be supplied by adding a third rail subsystem on the guideway and collector shoe to the vehicle. AM is reluctant to do this as it would be expensive and would eliminate a desirable safety feature, i.e. no high voltage on the guideway or vehicle. An alternate concept has been developed which is believed to involve the charging of a carborn heat pump by making a 10 second automatic connection, during station stops, with a refrigerant compressor unit. Although the components may be "off the shelf", this concept is not known to be in application in any situation, transit or otherwise. Vehicle interior smoke detection is available. Seating in either vehicle is variable according to Tech specifications. The vehicle is wheelchair accessible. Batteries supply 120 minutes of uninterruptable power to doors, lights, and communications.
Propulsion, Suspension, and Guidance

The I-a vehicle has two bogies and the II-a vehicle has three bogies, the middle one being shared as an articulating joint. Each bogie has four steel wheels, each with a synthetic liner between a conventionally flanged steel tire and the wheel. Guidance is provided by the flanged tires running on steel rails. Each wheel rotates around its own spindle, i.e. there are no axles joining wheel pairs. This reduces hunting and reduces wheel and rail maintenance costs. Vehicle suspension is provided by pneumatic springs and load leveling is not provided. Maximum deflection of the vehicle floor relative to a platform threshold is 5/8".

Suspended below each of the end bogies is a steel pylon which protrudes into the horizontal box beam through a 6.75 inch wide slot in the beam's top surface. The slot is sealed by two flexible gaskets which can be separated by the pylon as it passes by. Life cycle of the gaskets is approximately 10 years and replacement is designed to be an easy modular task. In the beam, the pylon supports a steel propulsion plate which is sized to fill the hollow area of the beam. Two double edged gaskets surround the propulsion plate and create a 5 mm gap between the edge of the plate and the guideway wall. Air loss per one mile of beam length is claimed to be 6% or less. A system for preventing overturning derailments has been developed and is attached to the pylons, just below the upper beam interior surface. Consequential damage to the beam caused by this system if a vehicle splits a switch is not addressed, but is anticipated to be minimal or non-existent.

Housed in 20 foot ISO containers (standard shipping containers), are the electric motor-driven blowers and hydraulically actuated control valves. This equipment can supply or exhaust air to either of two contiguous beam sections. The installations are referred to as Primary Propulsion Units (PPUs). The PPUs are installed under the elevated guideway at locations which are determined by desired headways and station locations. Noise level information regarding PPU operation was not provided. Reported MTBF for the blower motors is 100,000 hours. The reported distance that one PPU can propel one vehicle is 2 miles.

Propulsion is achieved predominantly by increasing or decreasing the air pressure behind a vehicle's pressure plate, thereby pushing the vehicle downstream. Acceleration, cruising speed, deceleration, and jerk rate are controlled by computer commands which open or close PPU valves (PPUVs), Section Isolation Valves (SIVs), or Atmospheric Valves (AVs). Propulsion is not dependent on friction between wheel and rail. This makes propulsion virtually immune to adverse effects of inclement weather and further reduces maintenance requirements on wheels and rails.
Propulsion fan design most likely involves keeping the motors in a continuous "power on" or no less than a continuous "idling" mode. This results in an economy of operation which leans toward requiring short headways of relatively smaller vehicles. In the event of a regional power failure, vehicle momentum and air already in motion in the beam can be supplemented with residual energy from the spinning fans. This provides for an element of reserve propulsion capacity to assist vehicles coasting into stations. The battery powered uninterruptable power supply on the vehicle provides control for braking at a station stop.

Brakes

Primary braking is achieved by reducing the air pressure behind any one vehicle. Additional braking is available by increasing air pressure in the beam area ahead of a vehicle. In a regional power failure, section isolation valves can be closed and produce a "piston effect" braking action. A secondary brake system involves hydraulically actuated double-sided disc brakes on the vehicles. The disc brake system is blended with the pneumatic flow system at station stops. The disc brake is used for emergency and parking functions and is sufficiently sized to provide complete braking capability independent of pneumatic flow braking. Emergency brakes have conventional A-1 reservoirs.

Doors

The I-a vehicle has two doorways per vehicle side. Each doorway has two door leaves. The II-a vehicle has two doorways per side of each of the two articulated sections. Each doorway has two leaves. Doors are manufactured by Vapor, a leading manufacturer. Cut-out capability is available.

Train Control

Checked redundant computers receive information from wayside vehicle detectors positioned at 37 foot intervals along the guideway. This provides a fixed block control system. Conceivably, the fixed block is permissive and train separation within a permissive block is controlled by computer and backed up by the "piston effect" which would prevent two vehicles from having a same-direction collision. Traffic direction is established by the direction of air flow between Section Isolation Valves, Atmosphere Valves, and PFU valves in the beam. The vehicle is completely passive in the train control subsystem. Bunching and headway adjustment is completely computer controlled. Control can be completely automatic or semi-automatic, i.e. Central control personnel can intervene in the automatic functions. Another level of manual control is installed which provides back-up to the functions at Central. The system involves "local control" equipment positioned at stations and operated by trained station attendants or system supervisors.
Switches

AM utilizes a switch which is comparable to conventional railroad switches. The design incorporates a flexible-point/flexible-frog design. In its current level of development, the switch will most likely not meet US standards. However, modifying a conventional General Railway Signal or Union Switch and Signal machine should be simple and acceptable for U.S. use. Oscar Coester is already aware of this condition and anticipates no problems with installation of such machines. Evaluation of the necessity of switch heaters is advised in view of the narrow guideway, short headways, and automatic vehicle operation. Customary practice at Marta involves deploying maintenance personnel at switch locations during snow/ice conditions. These persons use brooms and de-icing chemicals to keep switches operable and the procedure is not recommended for the Aeromovel guideway. Vehicle speed through a switch is a function of passenger comfort rather than mechanical capabilities.

Station Design

Stations can be constructed with either side mounted or center mounted platforms. Platform doors are available as a subcontracted option. Installation of new stations between existing stations is relatively complex. If original design has not allowed for expansion, new PFUs have to be installed and new beams with appropriate valves may have to be installed. Simplifying the expansion process is the availability of cast-off-site modular beams. Conceivably, if the "short headway scenario" is employed, then new stations can be more easily installed if they are in the vicinity of an existing PPU. Additionally, if expansion has been anticipated in the original phase, "knock-outs" facilitate installation of new valves in original concrete beams. Presumably, steel beams can be cut with torches and valves can be installed. The entire issue of system expansion requires close scrutiny. Extending the alignment is no more complex than building original guideway.

Emergency Management

Much effort in the system design has been directed toward emergency prevention. Events requiring emergency evacuation of a disabled vehicle between stations have nonetheless been anticipated. The forward and rearward facing windows on the ends of each vehicle are hinged on top and open upward. A set of stairs which is integrated into the interior nose of the vehicle pivot outward and form an emergency staircase (three steps?) to the guideway. Vehicle height above the guideway is only 27 inches. Both I-a and II-a vehicles have "walk-through" capability.
Structures

The guideway structures can be fabricated from steel or concrete. Steel is less capital intensive and likely to be more maintenance intensive. Concrete is the opposite. Either system is fabricated off site and installed in sections. The Primary Propulsion Units are fabricated off site and field installed as completed units which require only the completion of electrical connections. Further clarification is required regarding sound transmission through the hollow steel beam. The internal cross sectional area of a beam is a function of the anticipated air flow required to propel the vehicles. Both I-a and II-a vehicles are anticipated as requiring a 1 square meter interior beam dimension.
6.3 CABLE PROPELLED SYSTEMS

PICTURE EXPLANATIONS AND CREDITS

1) Upper Left-Soule' system at the YES 89 Exposition. Note "open guideway" surface between running rails. Upper Right-Note two vehicles at the platform, both in continuous motion. Platform length is a standard 25 feet. Lower Pictures-Three different available vehicle designs. (Pictures from marketing literature provided by Soule' Corporation).

2) POMA U.T.S. has coupling and full switching capabilities with cable propulsion. (Pictures provided by POMA, in response to Tech's questionnaire).
SK AUTOMATED CONTINUOUS TRANSPORTATION SYSTEM

- URBAN AREAS
- PARKING LOTS
- AIRPORTS
- UNIVERSITIES
- SHOPPING CENTERS
- THEME PARKS
LAON PEOPLE MOVER
CABLE PROPELLED SYSTEMS
Soule', Otis, Poma

The Soule' SK (SK) system and Otis were selected to compete with each other as cable propelled systems. Both systems are supported from the bottom. Otis supplied sales literature, but did not respond to the questionnaire. The Otis system operates as a shuttle system only, and is not compatible with Tech's needs. SK supplied literature, expressed interest in being further considered, but was involved with a new contract and was unable to complete a questionnaire. Shortly before completing this document for final presentation, a completed questionnaire was received by Poma, Urban Transportation Systems. In view of the thoroughness of the submitted information and the potential viability of their product for a Tech application, an analysis of their system has been included.

COMMON ADVANTAGES - SK and Otis

• since vehicles are cable drawn, there are no propulsion motors, cooling blowers, or transmissions on the vehicle. This greatly simplifies vehicle maintenance, contributes to narrower elevated spans since the vehicles are relatively light weight, and contributes to energy conservation.
• with propulsion motors located away from the ROW, reserve motor capacity and/or redundancy of the motors is easily designed without adverse impact to the vehicles or guideway, and maintenance can be performed easily in the motor room.
• the only significant source of vehicle noise is from the ventilation system.
• both systems utilize a detachable grip (clutch) to allow vehicles to disengage from one cable and engage another cable. This allows different vehicles on the same alignment to be operated at different speeds (unlike ski lifts).
• vehicles which are cable drawn do not have propulsion overloads (occurrences where propulsion motors overheat and circuit breakers interrupt the motor's power generation) or a variety of brake problems, both of which tend to interrupt revenue service.
• if air conditioning is not included, the only electricity on the guideway is low voltage. This is recognized as a safety feature.
• cable technology is among the oldest forms in transit and has been time-tested in many installations.
• since vehicles are not dependent on friction between the guideway and drive wheels, revenue service is minimally effected by adverse weather.

COMMON DISADVANTAGES

• if a cable motor stops, all vehicles attached to the cable are stopped until the condition is corrected.
SOULE' SK · SYSTEM DESCRIPTION

Original information in this assessment was extracted from marketing literature, and from articles, information, and a video tape referencing SK, and is therefore incomplete. Several weeks after completing the original assessment, a representative from SK visited Atlanta, came to Tech, and expressed interest in being further considered as the most appropriate vendor for Tech's requirements. A copy of the original analysis that had been completed at that time was given to the representative with the anticipation that complete detailed information, as requested in the original questionnaire, would be submitted. Approximately two weeks later, no detailed information was submitted, but rather Soule' edited the original analysis. The following assessment is a combination of the original document and the one submitted by the vendor.

SK is a French based privately owned company with assets of $75 million dollars and 750 worldwide employees. It has two divisions, one specializing in transportation and industrial automation equipment, and the other specializing in low, medium, and high voltage overhead (materials handling?) equipment and overvoltage equipment.

The SK system is essentially an upgraded horizontal elevator. A basic rectangular box on wheels is drawn by a cable from station to station. A significant difference between SK and cable funiculars or ski lifts is that the system is designed to be able to disengage from the long cables that provide propulsion from station threshold to station threshold. The disengaging is accomplished by a carbon cable clutch. On approach to a station, the clutch disengages one cable, grabs onto a "station" cable, and then the vehicle is slowed to a continuous speed of approximately 1 foot per second (.70 mph). At this speed, passengers embark/disembark while the vehicle remains in motion as it passes by the platform edge. Large double doors facilitate the transfers within the time available along any one platform. Acceleration is achieved by increasing the speed of the "station" cable until it equals the speed of the propulsion cable between stations and then the clutch release process is reversed. The manufacturer states that during the YES 89 Yokohama Centennial World's Fair, a total of 1 million people were carried with a reliability of 99.7%. The manufacturer also indicated that 10 million passengers have been transported with no major incidents in the past 6 years (presumably on all SK systems.) Furthermore, at YES 89, the system carried "an average of 20 handicapped passengers daily...without once having to stop the system." The Handicapped Association of France, reporting on the Paris-Nord
exhibition installation claimed that "no difficulty whatsoever was encountered by handicapped passengers with or without wheelchairs using the SK system"

Conceivably, this system could be among the lowest cost systems available i.e. capital, O&M, for the campus-only alternative. Feasibility for expansion into Midtown would have to be further evaluated.

Vehicle

The vehicles are rectangular in shape and run on steel wheels fitted with regular (pneumatic?) tires. Cars travel as single units in one direction only. "Since the safety mechanisms are built in and programmed along the track (see the section on Train Control), the cable direction cannot be reversed." This creates an operating problem if a vehicle at a station is delayed, and following vehicles cannot proceed. Ideally, cables can be stopped, and then reversed to allow passengers to debark vehicles at station platforms rather than evacuate onto a guideway. Most of the equipment and off-the-shelf components are procured in the US and all are in compliance with the NFPA 130 guidelines. Maximum passenger capacity of 28 is the highest of what seems to be several different available vehicle sizes. Coupling is not available. Maximum speed is 20 mph. Communication devices in cars, HVAC capacity, and smoke detectors in vehicles are installed upon request. Note: All vehicle configurations have large expanses of glass which enhances passenger security and enjoyment. This benefit is also a liability to summertime operation as well as to janitorial maintenance. The windows are custom designed to accommodate the client's preferences and requirements.

Propulsion, Suspension, and Guidance

"Vertical, longitudinal, and transversal suspensions are provided to the cars through elastomer suspension blocks (linking the body and the chassis to the cars)."

"Wheels fitted with tires provide propulsion for cars while they are in stations (embarking and disembarking modes). These wheels are mounted on bevel gears linked together by shafts and universal Cagdan joints."

"Direct current motors controlled by electronic variable speed drives regulate deceleration and acceleration of the cars."

Brakes

The cars are cable drawn and are therefore not fitted with a braking system. "It must be noted that the lightweight cars result in a very low kinetic energy and quick-stops if necessary. When cars are in a station there are three possible causes for stopping:

• an object falls on the track which is equipped with weight sensitive floors.
• doors are not completely closed.
• the sensitive panel at the end of the platform is hit by an object and/or person. In such cases, the platform driving wheels are stopped, completely stopping the car within 2 inches (manufacturer indicates that this has very rarely occurred).

Doors

One doorway with two large sliding leaves is available on each side of the vehicle. Door control mechanisms are located on pylons, at platform thresholds, and not on the vehicles. Each pylon has a "sensitive edge" which, if activated, stops the vehicle before injuries can occur. There is a method of manually opening the doors from the outside and the inside in the event of an emergency or a prolonged stoppage of the system.

Train Control

Train control is provided primarily by the inter-station cables. "The guideways to the SK system are equipped with 'fixed block controls' and detectors which are installed every 100 yards in the tracks to ensure that cars are travelling a safe distance from one another and to prevent collisions between cars in the case of an emergency stop. After a delay has occurred at the platform, an operator ensures that safe conditions have been restored before resuming normal operations." There is no reference to a method for controlling bunching after a delay. The only way is to reduce turn-around time at a terminal.

Switches

Although no applications have been built to date, the manufacturer claims that it is possible to design switches for routing vehicles. However, the manufacturer does not address the significant additional complexity of up-grading the train control subsystem of cable propelled vehicles so that merges of traffic can be achieved without collisions. SK uses an automatic terminal turntable (similar to San Francisco cable cars) for rotating vehicles for a return trip. The turntable diameter is approximately 10 feet. They also use what seems to be a transfer table for routing into a maintenance area. While the absence of on-line switching may be a detriment to operations and emergency management, the reliability of a system which is cable propelled reduces the vehicle complexity and reduces the probability of needing switches. Also, insurance requirements may necessitate "no passengers!" on vehicles during turnarounds on the turntables. This too must be clarified and, if necessary, controlled.

Stations

"Passenger exchanging" occurs at a speed of one foot per second, therefore a 20-25 foot long platform is standard. Pictures in the literature confirm this.
Pictures indicate an extremely simple station concept. Adding new stations between existing stations is complicated by having to install station cables for platform-long line sections plus acceleration and deceleration lengths. The manufacturer claims that actual construction of a new station should not be unusually difficult. Extension of a system beyond existing terminals is complicated by having to remove the turntable and install a new acceleration cable and a new propulsion cable. Planning for eventual extensions is advised during the design stage of any original installation. This will result in reduced interruptions of eventual normal service. (The new information from the vendor claims that only a short interruption of normal service is caused by system extensions.)

Emergency Management

Since there is no high voltage to vehicles that do not have HVAC subsystems, fire hazard is reduced significantly. Low voltage current is adequate to supply lighting, communications, controls, and ventilation. If air conditioning is desired, 220-240 volt third rail is required (the rail is already in place.)

If a vehicle becomes disabled between stations, the elevated guideway, with some complications, can become an emergency egress facility. Further information is required.

Structures

The elevated guideway is constructed of either concrete or steel. Further clarification is required.

POMA, U.T.S. - SYSTEM DESCRIPTION

Poma, Urban Transportation Systems is one of several divisions of its parent company, Pomagalski, S.A., in Grenoble, France. The company began in 1934 when its first ski lift was erected in France. Since that time, it has built more than 7,000 cable systems in ski areas, amusement parks, mines, etc., throughout the world. The French companies SGTE (established 1898, original engineers on the Paris subway), and The Schneider Group (multi-billion dollar engineering and financial group) have partial ownership of Poma. Poma is currently performing engineering design work for a new system being considered by Stone Mountain Park.

Poma has built or upgraded 15 cable drawn people movers, primarily in France or Italy. The development of a switching capability that allows their system to be designed very similarly to conventional rail systems if a customer so chooses, is notably significant. Also, many of the subsystems are very easily customized according to customer wishes.
Poma proposes a comprehensive turnkey project utilizing their Poma-2000 vehicle system. Their proposal specifically addresses their ability to contract O&M of their system or provide formal training of an O&M staff that is designated by Tech. They also specifically address the availability of a Poma team for annual maintenance inspections and reports.

**Vehicle**

The proposed vehicle is a Poma 2040 and is essentially a "people box on wheels". Since it is cable drawn, it primarily operates in one direction, but is not restricted to one direction of travel. Trains can be formed using coupling devices on the vehicles as back-ups to cable clutches which directly and securely grab a propulsion cable. Vehicle construction is simple and is NFPA 130 compliant. Load compensation for acceleration and braking is provided by the cables. Communication between passengers and Central Control is by duplex radio. Smoke detection is integrated into the ventilation system which utilizes four air handlers per vehicle. Batteries provide 120 minutes of electrical UPS to lights, doors, communications, and controls. Seating is intentionally minimal and longitudinally arranged. The vehicle is ADA compliant.

**Propulsion, Suspension, Guidance**

The configuration of the bogies is difficult to determine from the information provided. Each vehicle has two bogies, and each bogie has two steerable axles. Each axle has two wheels with Michelin pneumatic rubber tires. Horizontal guidance is provided by a configuration of horizontally mounted wheels which also provide anti-tipping protection. A set of vertical wheels is also utilized to provide a secure attachment of the vehicle to the guideway. Suspension is limited to "rubber blocks", however, air springs are available.

Propulsion is provided by thyristor controlled DC electric motors which drive a "bullwheel" (a device which directly accepts the windings of cable in a manner that prevents slippage) The liner of the bullwheel which receives the wear of the cables is rated with a ten year useful life and the bullwheel and bearings useful life is rated at 50,000 hours. A cable tensioner assures steady adhesion of the cable on the bullwheel and at the same time allows for some slack as various rates of acceleration and deceleration occur. Motors are capable of bi-directional operation. There seems to be redundancy of propulsion motors to reduce the impact of a single motor failure. There seems to be two types of propulsion cable systems deployed on the guideway. The first is a primary cable, used to propel vehicles along continuous sections of track, such as between stations. The cable is continuous along the length of the alignment and is powered by one motor room. The
other is type is deployed at stations and at switches, and is used to provide acceleration, braking, and transitional power between the primary cable and other cables. These secondary cables are controlled by motors at the local position of the cable. Safety features of the propulsion system detect broken strands of wire in the cables and detect corrosion or wear of the cable. Vehicles grab the cable with two cable grips. Either one is adequately sized to withstand the entire load of a vehicle. The same grips can engage/disengage a cable at stations or switches.

**Brakes**

Braking seems to be primarily achieved by the cable system. There is likely to be a tread brake on the vehicle, but this is not specifically stated. Primary service braking is achieved by dynamic/regenerative action of the drive motors. Secondary service braking is possibly achieved by a blended carbon brake and/or a friction brake acting on the propulsion motor drive shaft. Emergency braking is achieved by friction shoes on the bullwheels. A disadvantage of cable systems is that if an emergency brake application is required on the long primary propulsion cable, then all vehicles on the line are stopped, even if they are past the area where a problem exists. This is partially offset by the reliability of cable systems.

**Doors**

Each vehicle has one doorway per side and two leaves per doorway. On one end of each vehicle is a doorway for emergency egress to the guideway. Unless a doorway is included into the other end of the vehicle, caution must be used when assembling trains so that each emergency door is facing the outside of a consist. Upon arrival at a station, doors are released to patron control and remain closed unless a button is pressed by patrons on the inside or outside which triggers a door-opening cycle. This contributes to economical operation of a vehicle’s climate control equipment.

**Train Control**

The system is designed to operate fully automatically on the mainline, with the capability of being overridden by system controllers at the central control facility. High degrees of redundancy are built into the fault-tolerant microprocessor based controllers. Information regarding the type of block control is not provided, however, considering that full switching is available, some form of block control is required. System capacity can be increased or decreased by adding/removing vehicles to accommodate fluctuations in passenger demand.

**Switches**

Poma utilizes conventional flexible point switch design which is accepted by the French rail industry. Information provided in the response is incomplete.
regarding the switch operation and the various mechanical changes that occur in regard to cable/grip interactions.

Stations

Both center and side mounted platforms can be built at stations. Poma offers platform doors and also guideway obstruction detection systems. Adding a station between two existing stations is complicated by having to install the station cabling for acceleration and braking. Extending a system beyond existing terminals is no more complicated than original construction. It is simplified if the original terminals were built with adequate lengths of station cables to allow for accelerating vehicles onto new extensions, however, the extra lengths of ROW may be considered visually intrusive until the extensions are completed.

Emergency Management

Poma explicitly references the availability of training materials for system operation and the management of failures and emergencies. The degree of safety that a Poma system can have is determined primarily by the variety of subsystems that a prospective owner selects in the system design. Emergency evacuation of vehicles is achieved either by passengers utilizing vehicle side doors and accessing a walkway on the guideway or by utilizing vehicle end doors and accessing the guideway itself. Double track alignments have walkways installed between the two tracks.

Since one long primary propulsion cable can be designed to provide power to vehicles which operate in opposite directions of a double track alignment, the installation of no less than one back-up propulsion motor is highly advised. This can be easily accomplished, considering the design flexibilities of the system and the propulsion motor rooms.

Structures

The horizontal beams and vertical columns can be constructed from concrete, steel, or a combination of the two. No information regarding cast-in-place or cast-off-site is given, but presumably either construction type is available.
6.4 TOPSIDE SUPPORTED SYSTEMS

PICTURE EXPLANATIONS AND CREDITS

1) Originally built in 1901, the Wuppertal vehicles were upgraded most recently in the 1970's. (Picture from The New Electric Railway Journal, Winter 1992.)

2) Aerobus of Texas proposes a suspension cable system which supports two tracks. Vehicles are suspended from the overhead tracks. Long spans between towers and full switching are the advantages of the Aerobus design. (Picture from Aerobus of Texas, Intermountain Design Incorporated, 1993).

3) SwedeTrack AB proposes acting as an agent or distributor for the Siemens-Duewag H-Bahn system. (Picture from marketing literature provided by Siemens)

4) Titan PRT formally proposes a mass transit system that is suspended from a mono-I-Beam. (Pictures 4 and 5 are from Titan's response to Tech's questionnaire).

5) Titan's guideway provides more stability than Aerobus of Texas with minimal visual intrusion.
The Wuppertal Schwebebahn uses these articulated cars delivered in the early 1970s. Older single units operated in two-car trains were retired.
The H-Bahn system in Dortmund joins two sites of the university. The guideway is 1.05 km long and has a station at each end. Two cabins, each able to carry 42 passengers, give a maximum line capacity of 1000 passengers/hour/direction. The system is intended primarily for students and university staff, although parcels can also be transported (e.g. to the library). A special cabin with autonomous drive (battery) is available for maintenance and rescue.

The possibility of extending the system to form a link between residential areas and the S-Bahn is being investigated.

Construction and acceptance of the H-Bahn system was in accordance with the Personenförderungsgesetz (Public Transportation Act) and the Bau- und Betriebsordnung für Straßenbahnen (Federal German Construction and Operating Code for Tramways).

This is the first fully automatic rapid transit system in the Federal Republic of Germany and meets the strict safety and fire protection requirements.

The system is operated by the H-Bahn Gesellschaft Dortmund mbH with operations being managed jointly with the technical services of the University of Dortmund.

The system has been funded by the Federal German Ministry for Research and Technology and the Ministry for the Economy, Mediumsized firms and Transportation of the state of North Rhine-Westphalia.
Custom Sized/Advanced Styled Vehicles...
Slim and Cost Effective Guideways...
Aerobus of Texas, Swedetrack Sipem, and Titan

The systems in this section are similar in that they are all supported by structures that are above the vehicles. The Wuppertal system, in Germany, is probably the oldest top-side supported system in continuous operation (since 1901), and was built by Siemens. Only one incident, following a collision, has resulted in a vehicle falling to the ground (no deaths, some injuries). Modern automatic signalling would likely further reduce the possibility of a repeat similar incident. The Wuppertal is installed primarily over the Wupper river. Support columns, arched perpendicularly over the river and anchored in the river banks, allow river traffic to proceed uninterrupted. Heavy congestion alongside the river made right of way acquisition expensive for a land-based system. The primary benefit of top-side support is that it results in an inherently stable ride since the vehicle's center of gravity is below the point of suspension. A secondary benefit is that pedestrians on the ground are able to observe the vehicles as they pass. This contributes to the sense of the transit system as being a part of the city-scape and the surrounding environment.

Three vendors propose systems suspended from overhead guideways. The Sipem system is proposed by SwedeTrack (ST) with support of Siemens, the Aerobus system is proposed by Aerobus of Texas (AT), and the Astroglide system is proposed by Titan PRT (TP).

Lack of direct personal experience with topside suspended systems makes assessment difficult. A more than casual review of over 225 articles and several books indicates that topside systems are installed worldwide in only a few locations, often where geographically imposed limitations contribute to system feasibility.

COMMUN ADVANTAGES

• superelevation of the guideway can be eliminated if the vehicle suspension system allows a train to sway around curves.
• an inherently smooth ride, since center of gravity is below the point of suspension.
• passengers and pedestrians may perceive the system as being an integrated part of the city-scape since both can easily observe the system while it is "working".
• passenger exposure to fire/smoke hazard is reduced by having all high voltage electrical supply lines and equipment positioned above the vehicle.
• after providing platform doors or barriers at stations, there is little opportunity for people to access the guideway between stations.
• walk-through capability with egress through ends of vehicles allows added benefit for emergency evacuation.
• all three systems have full switching, including reverse run capabilities.

COMMON DISADVANTAGES
• train speed approaching and/or departing curves, especially near stations, must be controlled to prevent excessive sway. Sway dampers are likely to be advisable.
• wind velocity becomes a factor to be considered during normal operations and could easily become a reason to discontinue operations sooner than if a bottomside supported system is selected.
• installing emergency walkways can be done, most effectively, only below the vehicle. This contributes to visual intrusion.
• right-of-way acquisition for the alignment may be complicated. Land for column placement must be purchased in addition to obtaining air rights over the land which the vehicles will travel.
• planning for emergency evacuation of passengers must consider the system's height above the ground, and the land use below the guideway must be restricted when the system is being designed.
• melting chunks of ice may be a hazard to traffic or pedestrians below the guideway.
• columns must be taller than those of bottomside supported systems, introducing a cost penalty of an undetermined magnitude. If vehicle bottoms must be a nominal 16 feet above the ground then columns will have to be approximately 12 feet taller.
• conventional positions of subsystem cutouts for brakes and propulsion, which are most easily located on a bogie, are accessible only by accessing areas above the vehicle. Conceivably, the cutouts could be located in the vehicle and be made accessible to a maintainer who would have to access a disabled vehicle from a ladder truck or catwalk.
• platform doors or barriers are a necessity.
• a "tray" under the guideway at station platforms is advisable to prevent objects from falling to the ground below.
AERBUS OF TEXAS - SYSTEM DESCRIPTION

Prior to receiving Tech's questionnaire, Aerobus of Texas (AT) had submitted a proposal for the Milwaukee Suspended Light Rail demonstration project. Shortly after receiving Tech’s questionnaire, they were notified of being selected as the winning vendor for Milwaukee. As such, they did not complete a questionnaire or provide any specific detailed information for Tech’s alternatives other than marketing literature and a copy of the UMTA report which evaluated the Mannheim demonstration project, an early generation of the AT system.

The AT concept is unique in transit. Suspender cables are strung from tower to tower. Normal span distances between towers can be 650-1000 feet, and maximum spans can be 3,000-4,000 feet. Hanger cables drop from the suspenders and support a steel trackway. Vehicles with steel wheels are suspended from the trackway. The following information is composed from the information which was submitted in lieu of a response to the questionnaire.

After demonstrating his system’s feasibility with a prototype test track in Zurich (1970), a Swiss inventor secured a two mile demonstration project at a six month long German garden show in Mannheim (1975). The show was held in two locations which were separated by the Neckar river. Presumably, the longest span between pylons was over the river, a distance of 885 feet. Mean Time Between Failures (MTBF) for the first six weeks of service was 31.5 hours and Mean Time To Restore Service (MTTR) was 2.8 hours. A problem with the power distribution grid was solved in the first six weeks and this resulted in dramatically improved reliability. For the remainder of the show, MTBF was 183.1 hours and MTTR was 1.0 hours. The second most frequent cause of overall system downtime was wind in excess of 36 mph. This caused 18% of the system downtime events. System availability during the first six weeks was 93.1% and for the remainder of the show increased to 99.6%. An assessment of this system was conducted by UMTA (September, 1979) and provides an extensive in-depth evaluation. The UMTA document is available to Tech. The Mannheim system was dismantled after the show. Vevey Engineering Works, Ltd. purchased all rights to the system (1983) and engineered improvements prior to a proposal for Kuala Lampur. Funding for the project has not materialized. Fred Parks, a Houston attorney, purchased all rights in April, 1987. In Fall of 1992, AT was reportedly accepted as the winner of the competition for the Milwaukee Suspended Light Rail demonstration project.

Advantages of Aerobus

- span length between vertical support towers of the AT system is longer than other systems (650-1000 feet).
• full switching capabilities exists, including reverse run operations.
• the system of suspender cables and hanger cables which support the horizontal running track may be perceived as less visually intrusive than the "picket fence" intrusion of conventional column-and-beam elevated systems.
• in conjunction with the long spans between columns and the suspended rails, interference with ground based traffic and pedestrians is greatly reduced.
• the system is particularly conducive to installations over hilly terrain.
• spans between short runs might conceivably be accomplished with one or no vertical supports other than at station thresholds.

Disadvantages
• visual intrusion occurs from support towers being very tall and/or complex structures. Long spans require tall towers in valleys or extra towers when building curves at locations other than near stations.
• adding stations between existing original stations is potentially very complicated. Conceivably, extending an alignment is very complicated, also.
• reducing headways after a system opens is difficult or impossible unless original design allows for additional weight between towers.
• wind sway, ice build-up on vehicle roofs, and electrical grounding concerns in severe weather may limit safe operating parameters.

SIPEM and TITAN
The remaining two topside supported systems are similar in that the vehicles are suspended below horizontal beams which are supported by columns.

SIPEM SYSTEM DESCRIPTION
SwedeTrack AB, a Swiss firm responded to the questionnaire with two different systems, one, a PRT design, and the other, the Sipem system. Many items in the questionnaire were answered briefly or not at all, making full assessment difficult. Direct quotes are used to indicate all information that was supplied in a response.

SwedeTrack (ST) claims that it has a "cooperation agreement with Siemens, which is valid only in Sweden". The nature of the relationship and the amount of invested support of ST by Siemens is uncertain. A question is raised by the respondent as to whether Siemens is interested in competing against AEG Westinghouse in the U.S., (and this was submitted before the AEG Westinghouse acquisition of Von Roll). Clarification of the relationship as well as Siemens' long term interest in the project should be obtained, in writing, from Swedetrack and separately from Siemens. SwedeTrack seems to be marketing a Siemens-Duewag system originally
demonstrated at a university in Dortmund, Germany. The availability of ST and Siemens (in the U.S.) to provide technical maintenance support must be clarified. Finally, a financial statement from SwedeTrack is highly recommended.

Additional Advantages of Sipem
- vehicle bogies operate inside an inverted-U guideway and are therefore unaffected by snow and ice.
- the system has been accepted by rigid German railway standards.
- any noise from the propulsion system is contained in the box beam.
- there is reduced visual intrusion of horizontal steel structures relative to some bottomside support structures (Westinghouse, Aeromovel, concrete).

Additional Disadvantages of Sipem
- ice build-up on the vehicle roofs and the associated additional suspended weight must be considered in system and vehicle suspension design.
- maintenance on any subsystem which is installed inside the beam is complicated by having to work in a confined space.

Vehicle

The Sipem vehicle is a self propelled bi-directional vehicle and can be coupled to another vehicle at either end. The ST proposal calls for two car train consists in order to satisfy the 6000 pphpd scenario. The basic vehicle which is welded-body-on-frame will be manufactured by Siemens. Finish materials are to be specified by Tech as required by NFPA 130. Conceivably, the Siemens-Duewag facilities in California will be able to provide assistance. "A two way communication link is installed between the central dispatch and all cabins and stations" but reference to whether the link is radio or buss-bar technology is omitted. Load compensation, HVAC, and other minor vehicle systems are not clearly addressed in the questionnaire response. The standard and spaciously arranged 16 seat configuration allows for 1-2 wheelchairs and an additional 29 standees/vehicle. Seating arrangements are variable.

Propulsion, Suspension, and Guidance

Each vehicle has two bogies. Each bogie has two axles with two hard rubber-tired steel wheels per axle. Propulsion is provided by one rotary motor per axle, but LIMs have been used at one location in Germany. Suspension and guidance information was not provided.

Brakes

A total of four brake systems are referenced in the response, but all four are not clearly described. Primary braking by the rotary motor is regenerative. A secondary friction brake is referenced as reacting with (pinching) the guideway in a
manner similar to a disc brake, however the issue of maintaining the surface of the beam which acts as a "disc rotor" is not discussed. The LIM version has dynamic braking and presumably is backed up by the same secondary brake as used with the rotary motor configuration.

Doors

The Dortmund system has two doorways on each side of the vehicle and two sliding door leaves in each doorway. For emergency egress, "There is a special battery operated guideway vehicle which can approach the (disabled) vehicle in emergency and take over the passengers." Vehicles have emergency doors in the cabin ends to allow passenger transfer to the rescue vehicle. This concept does not address the scenarios where more than one vehicle is stranded such as by a regional electrical outage. Presumably, accessibility from the ground with special trucks is also used, and this requires that the alignment be accessible.

Train Control

A 50 second minimum design headway is provided by a Siemens manufactured, moving block, inductive loop system, installed in the guideway. "The ATC system has been operationally proven."

Switches

A switch with a single, long, flexible point rail allows full switching. Acceptance of the switch design by German regulators is a strong point in its favor, however, reference to manual switch operation capabilities in the questionnaire is not clearly obvious from the supplied materials. Considering that the Dortmund system was expanded in 1991, switch operation is presumed to be adequate, but, reliability data and a more thorough understanding of the switch is strongly recommended.

Station Design

Both island and center platform stations are available. Platform doors or barriers are required for safety purposes. A tray, below the guideway, at stations, is advisable, in order to prevent debris from falling to the ground. Adding stations between existing stations is restricted only by the availability of level guideway and sufficient available land for a station footprint. Extending a system is no more complex than building original structures and attaching the new and old together.

Emergency Management

NFPA 130 guidelines do not specifically address topside support emergency egress issues. Presumably, a catwalk between horizontal beams must be built, or some form of egress from the vehicle to the ground or to another vehicle must be
available. A catwalk would have to be installed below a vehicle's operating path so that vehicle sway would not cause collisions with the catwalk. Vehicle coupling, if automatic, may allow for only limited emergency retrieval capabilities since the guideway is enclosed. For example, coupling on a curve is difficult, if not impossible, when a coupler's centering springs are not removed. If the coupling systems are manual, emergency vehicle retrieval may be limited to only pushing a stranded vehicle. Siemens literature shows a picture of a battery powered rescue vehicle which can be used to push/pull stranded vehicles or receive passengers if a train must be evacuated. Considering that German safety guidelines are considered to be more stringent than American guidelines, further research may indicate that emergency management is less complex than evaluated above.

Structures

"The interior of the guideway is (44 inches) high and (30 inches) broad. The supports can be made in different sizes and shapes." Obtaining detailed information regarding guideway loading with more than two car consists between columns is recommended if "car-for-car" emergency operations are anticipated. Steel beams are manufactured and welded off-site, train control equipment is installed inside the beams, and then the units are transported to the site for installation.

Installation is expedited by the modularity of the individual columns and beams.

**TITAN PRT SYSTEM DESCRIPTION**

Titan PRT (TP) is a 100% American company. The current proposal is for their "Astroglide" topside supported people mover. However, they can manufacture group or personal rapid transit systems as well. Their test track in Hammond, Indiana has been dismantled. There are nine various Titan mass transit systems in revenue service, and a PRT system has been designed and is awaiting funding for construction at a Compaq Computers facility in Texas. (CabinTaxi claims to have had significant input on the design of the Compaq system before TP became involved. CT decided to remove itself from the project when funding was assessed as unlikely.) TP claims UMTA verification of 99.8% operating efficiency over a 20 year span of systems in operation. Some of the TP subsystems are subcontracted to other transit systems.

No financial statement information was provided.

Of particular interest is TP's desire to build a system in conjunction with student involvement. This not only becomes a course credit learning experience but is claimed to permit project financing on a "tax exempt" bonding basis, and qualifies for grants from ISTEA. TP is willing to work on a cost + fee basis with its profit retained until project completion.
Estimated cost for Tech's Alternate #1 is 16.5M and includes all double track, three switches (less than specified), 5 stations, and 9 vehicles, each with 60 pax capacity.

Additional Advantages of Titan
• the horizontal guideway beams are steel I-beams and result in minimal visual intrusion.

Additional Disadvantages of Titan
• none, beyond the Common Disadvantages of topside systems.

Vehicles
Each vehicle is a bi-directional, fully automatic unit with an estimated life of 25 years. Mechanical coupling is not available but electronic coupling is. The electronic coupling is a function of automatic train control and allows trains to operate with 7.3 second headways. General vehicle construction is NFPA 130 compliant. Load compensation is controlled through computer logic. Communications is two way and methods of transmission and reception are available and dependent on several factors before finalizing a selection. Two HVAC units per car are supplied by Sutrac and smoke detection is optional. Seating is minimal with much space retained for wheel chairs and for standees. A special insulating panel isolates the cabin from possible heat generated by an overhead fire in the LIMs. Carborn batteries provide 12 hour power for brakes, in the event of a power failure. Battery power for ventilation, brakes, lights, etc. is not mentioned. Vehicles have energy absorbing bumpers in the event of a collision with an object.

Propulsion, Suspension, and Guidance
Each vehicle is suspended from a steel "I" beam girder by two separate bogies. Each bogie has one LIM motor, four free-wheeling load bearing wheels, four horizontal guidance wheels, and two vertical guidance wheels. Load bearing wheels ride on the upper surface of the lower flange of the I-beam. Horizontal wheels run in the webbing of the beam. The bottom of the beam is the location of the reactor rail of the LIM and is also the running surface for the vertical guidance wheels. When the vehicle is at rest, the load bearing wheels accept the weight of the vehicle. In motion, the vehicle is elevated, and the load bearing wheels do not contact the rail. This creates a type of magnetic levitation and a "floating on air" suspension. The manufacturer claims that the energy consumption penalty for levitating the vehicle for motion is offset by savings in maintenance of other systems. This should be further analyzed.
Brakes

Primary service braking is 100% LIM reverse thrust. Emergency braking is achieved by independent disc brakes. The high rate of deceleration for emergency braking (0.25g) should be analyzed for suitability with a system that carries passengers predominantly as standees.

Doors

Door systems are supplied by Vapor, an industry leader. Each vehicle has two doorways per side, with two sliding leaves per doorway. Vapor has cut-out controls as an available option.

Train Control

Automatic train control is based on a fixed block concept. Vehicles can be dispatched on a fixed-schedule basis or manually dispatched by the operators in Central Control on a variable schedule. The variable scheduling allows for economical operations during light ridership periods. Signal transmission is via buss bar and contact pickup. In the event that a land based vehicle encroaches into the vehicle operating space, a separate transponder system on each vehicle detects encroachment and stops the vehicle.

Switches

TP utilizes a sliding beam replacement concept for its switching. The beams are mounted on an overhead frame and are positioned by sliding the frame perpendicularly to the guideway. An advantage of this concept is that a cover can be mounted over the entire switch and thereby protect the mechanisms from snow and ice.

Station Design

Stations can be built either as center or straddle platform structures. Platform doors or barriers are required. An estimated 24 feet per car is required for each platform. Although cars enter the station individually, a 48 foot platform allows two cars to be at a station at one time. No unusual difficulties are anticipated for adding stations between existing stations or extending the guideway.

Emergency Management

TP designs high levels of redundancy into their vital systems. Emergency generators are a standard item for the total system and provide limited capacity to move a vehicle to a station during a regional power outage. An independently powered vehicle is available for emergency evacuations. Vehicles have one 450 square inch sliding window which allows additional emergency egress.
Structures

Horizontal "I" beams are made of 110#/foot steel, and vertical columns are fabricated as either round cylinders or from "I" beams. Power supply and communication rail is affixed to the webbing of the beam. A unique feature of Titan is the turning capability afforded by their short minimum horizontal curve of 15 feet. Conceivably, a Titan system can be aligned down one side of a two lane street, can be turned 180°, and the return route can be aligned down the other side of the same street.
6.4 SIDE SUPPORTED SYSTEMS

PICTURE EXPLANATIONS AND CREDITS

1) Drawing H-9 shows the HighRoad Intercity vehicle. For local transit, the overhead luggage bin, restroom, and baggage area are removed and seating is added where baggage is currently stored. Stations can only be served with side mounted platforms and system does not have operational switching. (Drawing from HighRoad's response to Tech's questionnaire).

2) "Figure 17", Futrex, shows operational switching for diverging and converging routes, but the system cannot execute reverse runs.

3) This page shows several pictures of a model mock-up and drawings of the Futrex vehicle cross section. As the vehicle approaches a station, the outrigger slides upward on the bulge of the upper rail, thus allowing passengers to board without the obstruction of an upper rail. (Pictures 2 and 3 are provided by Futrex marketing literature which predates modifications to the system specifications, as described in their response to Tech's questionnaire).

4) "Typical Cross Section Guideway" of Continental Transit's vehicle/guideway drawing shows the tube within which a helical drive propels the vehicle. No known full scale test track of this system, as proposed for Tech, diminishes the acceptability of this concept. (Drawing provided by Continental Transit in marketing literature).
Returning now to the car-to-switch interface, figure 17 illustrates one side of the branch as seen from alongside the "common" track. In the foreground, at A, is one end of the switch module. This module extends 75 feet to a point just beyond D. Diverging traffic passes along this side, while converging traffic is on symmetrically opposite tracks. Rails are "fixed" from A to B and beyond C, except for a movable frog at D.

Between B and C, a length of 17 feet, both the upper and lower rails flex through a very limited range as supported and controlled by a rugged internal mechanism, details of which will be covered in a future paper. Switching action entails a motion of 4.5 inches at C. The outrigger and the lower safety hooks (fig 5) are compatible with the small but adequate clearances at C, both top and bottom.

As elsewhere, the third rail is just beneath the top rail and mounted to it; however the scale of figure 16 does not permit illustrating the third rail per se. But one can readily imagine it flexing with the top rail, aligning either with the fixed turnout rail or the fixed trunk line rail that continues to D. Thus, practically speaking, there is no interruption in mechanical engagement of the collector shoe blade as it passes through the switch -- satisfying one of the basic objectives.

At D there is a movable frog, which serves two quite different needs. First, in the "turnout" position shown, it provides a lower rail with strength and rigidity to support the car and resist traction/braking loads. It must also resist loads imposed by the safety hooks in a mishap. In the second position the frog gives continuity to the top rail of the trunk line, with a mechanical interface for the collector shoe. Being only 6 feet long, this length need not be "hot". A scale model of this active frog was illustrated in the original paper (1). Clearances in and around the frog are consistent with those at C, as discussed above.

Beyond the switch module the trunk line continues to bulge as illustrated in figures 15 and 17. The current design, which provides for 35 mph speed on the trunk line, has a maximum width of 12.5 feet in this bulge. Mounts for the curving branch line, illustrated at E in figure 17, impose additional loads on the lower guideway in this area. To carry these loads efficiently over a 99-foot span above the cross street, this long span is made deeper than the normal guideway depth. Such variations are possible by virtue of the adaptable mounting of the car's outrigger, as already discussed in connection with the station interface.

**POWER AND PERFORMANCE**

Design criteria for the Project 21 system are that cars/trains operate normally up to 55 mph, and that this be virtually unaffected by crush loads, grades to 1 percent, or headwinds to 15 mph. Acceleration typical of modern rapid transit is an additional requirement.
Each outrigger has a group of eight rollers that engage a special upper rail. As shown in figs 3 and 4, the rollers ride on the inner flange of the railhead. Thus the car/train imposes both bending and torsional loads on the beam.

At stations, the upper rail is placed above the passageway doors as shown in fig 5. This requires that the outrigger "swing up" relative to the car as it approaches a station; this is accomplished by a progressively deepening guideway beam adjacent to the station (fig 5) and by incorporating a movable attachment between the outrigger and the car structure (fig 6).

This paper presents results of a preliminary assessment of the above features by FUTREX and four subcontractors, sponsored by the Department of Energy under a Grant identified as DE-FG01-89CE15439.

Results of the individual studies/assessments will be presented in the following sequence:

1. Strength and rigidity of the guideway beams for spans of 75 to 99 feet, by Dr. Powell and Prof. Mouton.
2. Dynamics of the ride over spans from 75 to 99 feet at speeds of 55 to 100 mph, by Dr. Lissaman.
3. Integrity of the outrigger per se, by Mr. Ahlbeck.

System parameters used in all of the analyses included the following:

- Car length/wheelbase: 28 feet/18 feet
- Empty weight: 11,000 pounds
- Crush-loaded weight: 17,500 pounds
- Car C.G. - offset from center of beam: 64.5 inches
- Lower rail slope: 30° from vertical
- Outrigger slope (except in stations): 5° from horizontal

0.5 g earthquake with a crush-loaded train on one side
0.3 g earthquake with normal-loaded trains on both sides
40 psf winds (approx 120 mph) with a train on the beam
60 psf winds (approx 150 mph) on the beam alone.
TYPICAL CROSS SECTION
GUIDEWAY

PASSenger CAR

STABIZING WHEELS

24" STEEL TUBE

DRIVE UNIT

VEHICLE SUPPORT ARM

ELECTRICAL "BUSS" BARS

STEEL/CONCRETE SUPPORT STANCHIONS

STEEL/CONCRETE SUPPORT STANCHIONS
Highroad, Futrex, and Insta-Glide

Two vendors propose systems which support vehicles mechanically by side-mounted structures affixed to single beam guideways. This configuration allows two directional travel on opposite sides of one beam. The two are Highroad, designed by the Owen Transportation Group (Bill Owen), and System 21, designed by Futrex, Inc., (Larry Edwards). Both have developed to the point of having extensive conceptual and engineering documentation. Neither one has a scale test track, a full size test track, or a system in operation. Futrex has a non-operational 1/4 scale model. Additionally, neither indicates having the direct support of a nationally recognized transportation engineering corporate-backer. The lack of corporate support at this level of development might be an indication of lack of "faith" in the concept as a viable transportation mode by professional groups with a broader technical perspective. Both systems utilize a single monobeam (as distinct from monorail) to provide a relatively narrow right-of-way upon which two-directional traffic can operate. Both claim generalized costs of $15-20 million dollars/mile (only HighRoad specifies that the $20 million dollar figure includes all beams, 2 vehicles per mile, one station per mile, maintenance and administration facilities, electrical power connections, utility relocation, some ROW acquisition, and one turntable for every 2 miles of main guideway.

A third vendor, Continental Transit, Inc. (CTI), located in Canada, submitted information (but not a completed questionnaire) about its Insta-Glide system which is operationally similar to the Futrex System 21 concept, but with significant differences in guideway structures and vehicle propulsion, suspension, and braking systems. This system is being closely evaluated for implementation in Cobb County's Platinum Triangle district. Since the CTI submittal was made shortly before final preparation of this document, full assessment has not been included. If side-mounted systems are selected for the short list by Tech, a detailed analysis will be provided. The common advantages and disadvantages below do not necessarily apply to Continental Transit, Inc.

**COMMON ADVANTAGES**

- ability to provide two-directional traffic on one guideway beam (Insta-glide uses a double guideway structure, unlike HighRoad or Futrex).
- American designed, owned, engineered, and will be American manufactured.
- minimum design operational headways in the range of 60-120 seconds, and speeds in the range of 50+ mph.
- all three claim a rapid construction rate due to modularity of components.
• projected operating costs that allow for vendor claims of 100% recovery of capital and O&M costs from the farebox, based on a reasonable fare.

COMMON DISADVANTAGES

• all three are unable to provide reverse run service for failure management or guideway maintenance (see HighRoad-Switches for an exception). This is assessed as a serious and insurmountable design deficiency. A single vehicle failure, wayside guideway failure, or damage to only one side of the guideway effectively incapacitates large sections of alignment, if not the entire system.
• none of the three can provide both side and center platform station design. This limits the ability to design ROW in established dense urban areas.
• as a demonstration of exemplary new technology, all three systems possess questionable marketability based on their limited operational flexibility and comparable cost competitiveness of newly developing technologies.
• extending a system in the vicinity of an existing loop turnaround is complex.
• all three systems require a loop-turnaround at terminals in order to route trains back along the guideway. HighRoad's minimum radius curve requires 131 feet (262 foot diameter loop) and System 21's minimum radius curve requires 90 feet (180 foot diameter loop). HighRoad promotes an alternative to the small loop turnaround, i.e. make the loop large enough to service a geographic area. Favorably, this allows for providing revenue service by operating vehicles on the inside guideway of the turnaround. Unfavorably, this requires utilization of a turntable in order to add or remove vehicles from the large inner loop so they can be routed to a maintenance facility, such as required during adjustment of service levels for peak ridership or when removing disabled equipment. If a storage track is built on the inside loop, it is readily accessible only to the vehicles on the inside loop, rather than being available to vehicles on both sides of a guideway.
HIGHROAD - SYSTEM DESCRIPTION

The Owen Transportation Group (OTG) is located in Marietta, GA. Conversations with Bill Owen and responses to the questionnaire indicate a sincere desire to make the Highroad system a Georgia based industry and they have projected 1,850 full time jobs over a ten year period if a proposed 38 mile system is selected and built in Cobb County. He has negotiated agreements with Grumman Aerospace (Bethpage, NY) to manufacture the vehicle in the Grumman plant in Milledgeville and has made arrangements with a respected Atlanta minority contractor to perform construction activities. Moreland-Altobelli Engineers has reviewed the structure design and assisted in its further development. Reportedly, they are fully involved. Owen has also pursued state legislative support. Financial information about OTG was not supplied. NOTE: The HighRoad has been designed to perform analogously to aerospace vehicles. In those vehicles, the probability of failure has been reduced in design and proven in operation to be virtually non-existent events. The primary causes of failure in a Highroad-type system would be reduced to mechanical systems, such as a door failing to close due to an obstruction, or a guideway structural failure.

Vehicle

The Highroad vehicle is a fully self contained single unit. It is planned to be capable of operation as a lead or trailing car in a two car maximum train. The train is capable of one directional operation. Advanced composite materials are used throughout the vehicle body and design concepts borrow heavily from the aviation industry. All specified materials are in conformance with NFPA-130 guidelines. Load compensation for suspension, propulsion, and braking is included in the design. Communications between central control and passengers is by cellular telephone and interlocked public address. Full HVAC is included in the design and is tied in with a smoke detection subsystem. One hour battery backup supports lighting, communications, and controls. Seating is minimally variable with transverse seating being most readily installed.

Propulsion, Suspension, and Guidance

Each vehicle has two bogies. Each bogie has one 460 volt, 3 phase rotary motor linked to a hysteresis (electromagnetic) clutch for transmitting power through a gearbox to one 12 inch steel drive wheel which contacts a steel rail. The clutch system, manufactured by a separate supplier, is not known to be currently in use in a transit application as proposed by OTG. Historically, the hysteresis clutch is generally less efficient than a conventional motor-direct-drive-gearbox arrangement, however, advances in the technology may have improved the concept to a level of acceptability for transit applications. Conceptually, either of the propulsion
motors has the capacity to power the vehicle if the other motor fails, however, adequate friction for transmitting tractive and braking forces is questionable in even the normal two-motor operating mode. Conceivably, the extra loads imposed on the drive wheel by the unconventional vectors of the side supported vehicle may eliminate any traction problem. Demonstration of the capability to provide normal acceleration with one motor, from a standing start, on the steepest design incline, with a crush passenger load, on wet rail is advised. A combination of additional wheels interface with the beam to secure the vehicle on the guideway and provide guidance.

The propulsion units are isolated away from the vehicle, thereby reducing an element of fire hazard in the passenger cabin. Automatic control of propulsion overload reset and propulsion cut-out capabilities is considered to be not necessary.

Brakes
Each vehicle has two identical but separate air-controlled and spring-applied friction-type track brake systems. The maximum emergency brake rate capability of 6.4 fpsps is accomplished with 100% brake application and is controlled by a carborn decelerometer. Activation of the system seems to be an automatic function only, and eliminates mechanical trippers. Friction track brakes for primary braking are not known to be utilized in any transit application. Although the brake "pad" is presumed to be manufactured of sacrificial material, the effect of the friction on the shape of the rail crown should be further investigated.

Train Control
OTG proposes a moving block train control system that has its base in infra-red fiber optic technology. Moving block technology is sophisticated and complex relative to fixed block technologies. No reference is made to Automatic Train Control design assistance from industry leaders such as General Railway Signal, Union Switch and Signal, Alcatel, etc. Additional information about the train control design is recommended. Manual vehicle operation for emergency management and maintenance operation is intended. Carborn systems are monitored and controlled by checked-redundant microcomputers.

Doors
The door system is manufactured by Vapor, a recognized leader in the transit industry, and is similar to the door on Marta vehicles. Two doorways per vehicle, each with two leaves, provide redundant entrance/egress to any one vehicle. Further investigation is required regarding the capacity to automatically cut-out disabled leaves in order to clear a false door-open indication or automatically bypass a
false vehicle-motion indication. These capabilities are anticipated as being available by Vapor.

Switches

The Highroad system is designed for geographically large loop alignment applications or for layouts with loop turnarounds. Operational switching has not been developed. The lack of operational switching is assessed as a serious system deficiency. Switching into maintenance areas and for emergency management is accomplished with turntables or transfer tables. The use of turntables to provide reverse run capability is conceptually feasible, but cumbersome. All switch design concepts call for one minute automatic lock-to-lock operating time, and could presumably be longer if operated manually. The maximum speed into any of the switches is 3 mph, further slowing any operation which requires switch usage. Additionally, if more than one car is used to make up a consist, either the turntable will require a wide area to accommodate its rotation, or trains will have to be uncoupled and cars will have to be turned one at a time.

Station Design

Station design is restricted to side platforms only. From an operations perspective, side platforms are the less preferred of either the side or center mounted options. Side platforms require passengers to move either up or down one station level in order to catch a train travelling in the opposite direction of the passenger’s original travel (such as after accidentally travelling one station beyond one’s intended station, or, when one station side is closed due to the need to "single track" for emergency management and then normal service is restored). Free-standing station costs are increased by requiring one elevator on each side of the station in order to be ADA compliant. As a benefit, side platforms can be more easily designed to be as deep as necessary, in order to comply with NFPA 130 2-5. Means of Egress guidelines. Additionally, construction of new stations between existing stations is facilitated by not having to create major interruptions in service while new platforms are cantilevered toward the existing guideway.

A peripheral safety feature of the OTC side platforms at stations arises by having vehicle doorways on the opposite side of the vehicle’s propulsion and traction power equipment. This isolates high voltage equipment to the opposite side of the area where passengers board the vehicle.

Emergency Management

OTC complies with evacuation capabilities for failure management as described in NFPA 130, 4-5. Windows on the beam side of the vehicle are hinged at the bottom and can be pivoted outward so as to create a "gang plank" access to the top of the
horizontal beam. The top of the beam is approximately six feet wide and makes for a stable walkway to a waiting train on the other side of the beam or to a nearby station. Additionally, mounted on top of the beam center is a single guide rail. OTG proposes a specially outfitted, independently-fueled vehicle which can operate on top of the beam, guided by the single rail, and can function as a rescue vehicle. The vehicle would be outfitted with an inverted "L" arm, which could be lowered and used to push a transit vehicle in the event of a complete loss of traction power. However, the effectiveness of this concept is limited by the response time of an operator, the distance of the failed transit vehicle from the storage location of the rescue vehicle, the 10 mph speed limit of the rescue vehicle/rail vehicle pair (due to maintaining safe braking standards), and the conditions of the beam surface i.e. ice, snow, etc. Further limiting the effectiveness of this concept is that removing a failed vehicle from the mainline, especially if suspended on an inner loop, is likely to be very time consuming and creates a time period during which no reasonable revenue service can be provided.

Structures

The OTG columns are concrete and the horizontal beams are post tensioned and pre-cast concrete to enable easy, minimally-intrusive construction. The beam is shaped similarly to a letter "T". The overhang of an upper horizontal bar affords a moderate amount of weather protection to the steel rails. All components are custom manufactured according to civil specification.

SYSTEM 21- FUTREX - SYSTEM DESCRIPTION

Futrex is located in Herndon, VA. Larry Edwards, Vice President and Treasurer, explained by letter that a 60 mph demonstration system is currently being proposed and their efforts are directed toward completing that proposal. Therefore, a questionnaire was not completed, and instead, a System 21 Design Guide was submitted. The information from the Design Guide, in conjunction with literature obtained in mid-1990 from a marketing and engineering brochure, forms the body of available literature upon which this assessment is based. Both Boris Pushkarev and Vukan Vuchic, nationally recognized transportation professionals, heartily endorse System 21.

Vehicle

The Futrex system utilizes an "A" car/"R" car concept. Each A car has an operator's console in its nose and is capable of independent one directional operation. B cars are shorter than A cars and do not have operator's consoles. As many as three B cars can be coupled behind one A car and all four vehicles can be
controlled by one operator. While introducing the economy of saving the expense of multiple operator consoles in multi-car consists, the absence of a control panel in the B car introduces a serious operational limitation. If a failure on the A car disables that car, then the entire train is disabled. Conventional heavy and light rail systems (excluding BART) utilize a system of double-ended single cars or double-ended married pairs with operator consoles on each end. If a lead vehicle fails, it can be uncoupled, removed from revenue service onto a siding, and the remaining good cars can complete a scheduled trip. Also, if a train's head end console fails or if for any reason the train must be reversed, an operator can move to the tail end and move the train backwards. The Futrex concept requires removal of the entire consist. Conventional rail procedure requires "car-for-car" disabled train movement, i.e. a good four car train is required to push or pull a disabled four car train. The Futrex concept requires that all trains in service at one time be of equal length. This requires a large reserve fleet, and introduces an operations nightmare when building/breaking trains for peak service. Multi-car consists are only judiciously used during peak hours and a failure of one System 21 consist could cause large scale system-wide delays. Multi-car consists are strongly discouraged from deployment on an inner loop segment of track for reasons which are more complicated than easily described in this assessment. The Futrex A/B concept introduces a serious risk to maintaining scheduled service during vehicle malfunctions.

Communications between central control and passengers is radio linked. The literature makes reference to load compensation for suspension and braking but not for propulsion. The vehicle is constructed of aluminum and steel. No reference is made to NFPA-130 materials. HVAC, smoke detection, battery backups, or variable seating arrangements.

Finally, the A car is designed to have the operator sitting opposite the beamside of the vehicle and open to the public. While this promotes a modicum of security to the A car passengers, it introduces a hazard by encouraging operator/passenger conversations in a system which is particularly sensitive to the need for full operator attention being directed toward the signal system and to the approaches of both straight-through and diverging switching moves.

Propulsion, Suspension, and Guidance

Each vehicle has two bogies. Each bogie has one 750 volt DC rotary motor directly linked to a transmission for transmitting power to one drive wheel. Concerns of adequate friction for transmitting tractive and braking forces are dismissed by the designer with comparisons to several early streetcars. However.
the designer fails to consider that streetcars traditionally used a two wheeled axle for transmitting traction to the rails and that there were two and often four powered axles per car.

Suspension of the vehicle has been skeptically reviewed by other evaluators, and the designers claim that they have all been eventually satisfied with further detailed explanations of the unconventional vehicle suspension and guidance systems.

Propulsion motors protrude into the passenger cabin and require extensive insulation to comply with NFPA-130 requirements.

Brakes

Braking is presumed to be accomplished by blended regenerative brakes fading to disc or tread brakes. Load compensation is referred to. No other information is available.

Doors

Each A car has one doorway per side with two bi-fold leaves and one rear end vertically-hinged door. Each B car has one doorway per side with two bi-fold leaves and one vertically-hinged end door on each end. Bi-fold doors were popular in transit vehicles for a long time but have generally been discontinued due to the tendency of passengers getting caught in the folds. Side doors are trainlined and controlled by the operator while end doors are opened manually. Manually troubleshooting side door failures (or vehicle malfunctions) on multi-car consists will be time consuming when conducted from outside a consist. a strategy which is strongly discouraged for the Futrex vehicle/guideway configuration. Troubleshooting a door failure from inside the vehicle is hindered, especially when an operator must make his way through a standing load of passengers. Door malfunctions, in general, are not uncommon. The single door per side combined with the lack of ability to execute reverse-runs, introduces a serious detriment to providing timely scheduled service. The ability of passenger movement between cars, through end doors, provides a desirable and mandatory safety feature.

Train Control

Train control is manual-with-wayside-signal only and current pricing reflects manual signalling and control only. Plans to provide cab signalling are being developed. Manual signalling is currently used on several LRT systems without adverse consequences to maintaining headways and the Futrex design prevents head-on collisions.

Switches

A significant advantage of Futrex over Highroad is the development of an operational switch which allows divergent and convergent routing between different
lines (not reverse runs on the same line.) Speeds through the normal (tangent) switch position are designed to be 35 mph and speeds through the reverse position are designed to be 15 mph. No information is available regarding the availability of a manual cranking capability in the event of switch machine failure, but the design appears to not be conducive to such ability.

Station Design

Station design is restricted to center platforms only. From an operations perspective, this is preferred. Center platforms require only one elevator and are generally less costly to build. However, the Futrex design may not conform to NFPA-130 2-5. Means of Egress. Drawings of the modular station segments, which do not contain dimensions, indicate that it is narrow and might not be able to provide the required platform area for accommodating both a full load of passengers wanting to board a train on both platform sides plus two fully loaded trains entering the platform at the same time. Further information must be obtained. Additionally, stations cannot be built between existing stations without significant interruptions of the entire system. Since stations are shipped as modules, construction of a new station requires removal of a beam segment and precision installation of the new station module. Also, vehicle speeds must be reduced prior to entering the horizontal curves that are before each platform.

Emergency Management

Compliance with NFPA 130, 4-5 (Vehicle Emergency Egress Facilities) is a problem for Futrex. Vehicle evacuation can only be accomplished A) through one side door per A or B car, B) through one end door per A car (the operator's control console interferes with installing an emergency door in the A car nose) or C) through either of two end doors per B car. into another car or out of the train through the last B car. Quoting from the Futrex literature (section GT-8) "If the train stops at the right position along the beam..." access to a catwalk is available. The condition of the train stopping at other than the "right position" is not addressed for catwalk access. Reference is made to development of an emergency elevator on the A cars for one-at-a-time passenger egress to the ground. This seems to require a dedicated clear area under the vehicle along the entire ROW length. Evacuation will likely be restricted to the end door of the end car, provided that it is not made inaccessible by fire or other obstructions. A boom truck or ladders will have to be used to lower passengers from the vehicle to the ground. Complicating emergency evacuation is the location of propulsion motors in wheel wells which protrude into the passenger cabin. If the emergency involves fire in the propulsion motors, they are located near the side doors which might have to
be used for evacuation. The possibility of smoke or flame from a propulsion motor may eliminate that doorway for evacuation purposes.

Structures

Futrex guideway construction is likely to be the most modular of any conceived system. Steel columns, beams, curved sections, stations, and switches are available in "catalog" form at various incremental sizes. Feasibility of standardized components for such large civil projects has not knowingly been demonstrated. Theoretically, the need for any custom sections can be satisfied with custom manufacturing. Overall costs could conceivably be lower when compared to all-custom fabrication.

APPLICABILITY

None of these concepts will satisfy the existing alignments for Tech. Alternative 2 could be modified on the southeast end to include a loop turnaround. Such a modification would conceivably provide service to a larger geographic area. Additionally, the limitation of no reverse run capability requires serious evaluation before accepting the concept for further development.

EXAMPLE- A system is designed to provide 20 trips/hour X 18 hours of service. This equals 360 trips per day. Even if a respectable 99.9% on-time-performance is achieved, 99.9% X 360 trips/day results in an average of 2 failures/week. Emergency management capabilities are vital for system efficiency.
6.6 MONORAIL BOTTOM-SUPPORTED SYSTEMS

PICTURE EXPLANATIONS AND CREDITS

1) Bombardier's new monorail system uses rotary switches. Note the diverging route beam that becomes available when the upstream section of beam, immediately behind the pictured vehicle, is rotated on a longitudinal axis to complete the turn-out move. (Picture provided by Bombardier, copyright 1991).

2) Intamin's steep grades are demonstrated at their test track. The bottom-side supported vehicle lacks wheelchair accessibility. Their top-side supported vehicle, not pictured, is wheelchair accessible. (Picture provided by Intamin Corporation in their response to Tech's questionnaire).

3) Von Roll has several systems in operation throughout the world. Their simple guideway contributes to minimal visual intrusion. However, their trainset cannot be lengthened, shortened, or coupled to when fluctuations in passenger demand require variable system capacity. Capacity can only be adjusted by increasing or decreasing headways. (Picture from The New Electric Railway Journal, Winter 1992).

4) VSL's Primadonna system is currently a cable drawn system. However, VSL has modified the vehicle so that it can be a self-propelled rotary motor vehicle, operating on the same guideway as the cable drawn system. Note the window in the nose of the vehicle. This is part of the emergency evacuation system in which the window opens, stairs unfold to the guideway, and egress can occur into a trough between the guideway walls. (Picture supplied by VSL in their marketing literature).
The Swiss-designed Von Roll system is in use as a circulator in Sydney, Australia. A 6000-rider per hour capacity is claimed for the small cars. A Von Roll monorail is also being built at the Newark, NJ airport.
The Primadonna
METRO-SHUTTLE 6000™
Transit System

VSL Operating Unit Headquarters

Australia
VSL Prestressing (Aust) Pty. Ltd.
6 Pioneer Avenue
Thornleigh, NSW 2120
61-2-484-5944

USA West
VSL Corporation
1077 Dell Avenue
Campbell, California 95008
1-408-866-5000

USA East
VSL Corporation
8006 Haute Court
Springfield, Virginia 22150
1-703-451-4300

Europe/Middle East
VSL International AG
Bernstrasse 9
CH 3421 Lyssach
Switzerland
41-34-47 99 11

Far East
VSL Far East Pte. Ltd.
151 Chin Swee Road
#11-01 to #11-10
Manhattan House
Singapore 0316
65-235-7548
Bombardier-UTDC Systems, Intamin, Von Roll, and VSL

Four vendors are proposing bottomsided supported monorail systems. They are Bombardier-UTDC Systems Division (UTDC), Intamin, Von Roll (VR), and VSL.

Common Advantages

- low visual intrusion, modular off-site fabrication, and simple on-site construction of vertical and horizontal structures
- sizzle and public acceptance, from having been popularized at the Disney and other amusement parks.
- high levels of redundant propulsion and braking systems on each trainset
- smooth and quiet ride on pneumatic tires
- emergency walkways are easily installed between double track alignments (VSL has integrated walkway!)
- relatively easy station additions and alignment extensions if preliminary planning has allowed for the possibility.

Common Disadvantages

- if semi-permanent coupling is utilized to form trainsets, then consist lengths cannot be reasonably lengthened or shortened to accommodate daily fluctuations in passenger demand. This limits the system capacity and flexibility, necessitates close attention to fleet size, and demands entire trainsets for reserve capacity, rather than just single cars.
- rubber-wheels running on steel or concrete surfaces, along with massive switches, may require track and switch heaters to prevent ice and snow accumulation. This is expensive to build and operate.
- gap between platform edge and beam almost requires platform doors and/or a safety platform structure beneath the beam at stations.
- emergency walkways, especially on single track sections, adversely impact horizontal visual intrusion (except VSL).
Bombardier-UTDC employs over 30,000 people in seven countries and has annual revenue in excess of $3 billion dollars. Since 1942, the company has built systems and acquired other manufacturers of fixed guideway systems until today, it can supply what is one of the largest variety of fixed guideway vehicles and systems in the world. The UM III system is being proposed for Tech with the possibility of a slight upgrading of the system to a UM III+ (a slightly larger passenger capacity and 10 mph faster version). The UM III is based on the acquired experience of nine previous, but slightly different installations. The company is almost ready to introduce a new system, the UM IV, and might be willing to negotiate an introductory price for a showcase installation.

Vehicle

Each vehicle is fully self contained, bi-directional, and fully automatic. Trainsets can be formed with optional manual or automatic coupling to a maximum length of 10 cars. Recommended by the manufacturer is A) a three car trainset every 90 seconds yielding a capacity of 3000 pphpd or B) a 6 car trainset every 90 seconds, yielding 6000 pphpd. Vehicle construction is NFPA 130 compliant. Load compensation for seated and standing loads is provided for both acceleration and braking. Load compensation for suspension is not available. Both data and voice communications is accomplished by full duplex radio signal. Two fully independent HVAC systems serve each car and heat is provided by electric resistance. Seating in each car is variable (8-12 + ADA) with both transverse and longitudinal arrangements available. Carborn batteries supply 60 minutes of uninterruptable power for communications, light, and ATC. No reference to battery power for ventilation is made.

Propulsion, Suspension, Guidance

Each vehicle has two bogies. Each bogie has one axle with two pneumatic tires per axle. Each load tire has a solid steel safety wheel. No reference is made to suspension beyond the pneumatic tire, but it is presumed to be provided directly by pneumatic springs. Each axle has one traction motor. Middle cars share common bogies, which become the articulated joints of the trainsets. Each trainset is semi-permanently coupled at the articulation. Guidance is provided by horizontal wheels running in the webbing of an I-beam rail.

Brakes

Primary braking is achieved by a dynamic regenerative system through the propulsion motor, and is utilized for 100% service braking. Secondary braking is
achieved by electrically controlled and spring applied disc brakes. Load compensation is an included feature.

Doors

Each vehicle has one doorway with two electrically operated sliding door leaves. Sensitive edge obstruction detection is utilized and can range from 5 to 10 cycles per closing. Manual door releases allow for emergency evacuation. The releases are located for easy access to wheelchair passengers.

Train Control

The UM III can be installed with either fixed or moving block automatic train control (ATC). Minimum design headway at the Tampa airport is 90 seconds with recommended dwell time set at 15 seconds. Bunching is corrected by computer commands to lengthen or shorten vehicle dwell times or by accelerating a consist above the system's programmed cruise speed. ATC can be subcontracted by Alcatel (an industry leader) or by other vendors. An "overtravel buffer" is installed at terminals in the event of a station run, but no extra track length is required.

Switches

A horizontally rotating beam combined with sliding pivot sections is the only switch deployed for normal operational switching in pinched loop configurations. At Tampa, this switch operates 40 times per hour during a 21 hour service day. Rotation time is 8 seconds and manual cranking can be performed if necessary. Pivot switches are used to access a maintenance area.

Station and Platform Design

Stations can be designed with either center or side mounted platforms. Design is ADA compliant. Coordinated platform doors are recommended but not required. Platform length is 70 feet for a 3 car train and 160 feet for a 6 car train. The UM III is similar to the Epcot monorail and can be installed into new architecture. Additional stations and system extensions are relatively easy to accomplish with appropriate safety precautions and planning.

Emergency Management

UTDC has employed high levels of redundancy in their design. Pushing capability is apparently available for failure management. Additionally, catwalks can be installed alongside single guideways or between double guideways. Of concern is the concept of utilizing only one doorway per vehicle side. If a single leaf fails and must be locked, this greatly impedes passenger flow.
Structures

Steel box beams, 29 inches wide, are used for horizontal support. Presumably, they can be installed on concrete vertical columns. Span length is determined by the depth of the steel beam.

INTAMIN - SYSTEM DESCRIPTION

NOTE: Intamin offers a trainset concept which can either be bottomside or topside supported. With the exception of internal structural differences and the bottomside system not being ADA compliant, the trainsets are basically identical. They have one bottomside system operating in Korea and one topside system operating in Busch Gardens, Florida. A second bottomside system is due to open in Stuttgart, Germany in 1993.

Intamin AG is a Swiss based manufacturer of heavy industrial and commercial fabricated steel products. They have offices in Switzerland, Germany, Liechtenstein, Japan, Korea, and the United States. Their transportation division is apparently an outgrowth of a well established amusement park ride division. They operate a test track in Switzerland and claim to be able to provide turnkey design, build, operate, maintain services.

Intamin responded to the questionnaire by proposing both top and bottom systems without clearly distinguishing between the two in their answers. Attempts to clarify several points were further complicated by the marketing director who is not exceptionally familiar with the monorail systems. She also made a blanket statement that Intamin can provide greater system flexibility than is apparently capable as analyzed from the material that they submitted.

Vehicle

Both top and bottom supported trainsets are bi-directional, fully self contained, and can be designed to be manually or automatically operated. Each trainset seems to be configured with an A car at either end and as many as 8 B cars in the middle. Middle cars share common bogies which become the articulated joints of the trainsets. Each trainset is semi-permanently coupled at the articulation. Coupling of trainsets is available as either a manual or semi-automatic function. Push bumpers are also an available option. Reference to construction materials is omitted, and the applicability of NFPA 130 standards to amusement park rides is not known. HVAC and smoke detection is available. Communication is via buss bar or radio. Seating on both systems is limited to two forward facing bench seats per car. Each bench can accommodate three passengers. Wheel chair accessibility seems to be available on the topside supported system A cars only.
Propulsion, Suspension, and Guidance

Each bogie seems to have one dual-axle set. Each of the two axles seem to have one load bearing drive wheel powered by its own traction motor. The system can be AC or DC powered. Suspension of the bottomside system seems to be primarily through the pneumatic tires with sliding-blocks available in the event of tire deflation. The topside system is suspended on solid (?) wheels. Guidance of each bogie is achieved with four horizontally mounted wheels running on the webbing of the box beam guideway. A pair of wheels mounted on the opposite side of the running surface assures strong positive contact between the propulsion wheel and its running surface.

Brakes

Primary braking is dynamic regenerative, and a secondary system is conventional disc. A spring applied parking brake is provided. Additional information was not supplied.

Doors

Doors on the bottomside supported system are not ADA compliant. Each bench seat in each car is served by a door on either side of the vehicle. Doors are pneumatically driven and have an obstruction detection feature. The topside supported system is ADA accessible, but no information about doors, other than inconclusive pictures, was provided.

Train Control

The train control system utilizes what seems to be a simple fixed block system. Additional information is not available.

Switches

Operational switching seems to be achieved by a sliding beam and switching in a maintenance area seems to be achieved by transfer table. Either a buss bar system or radio wave system can be used for transmitting signals, and fail-safe checked-redundant computers are used for processing information. Additional material is not available.

Station Design

Stations are to be procured by the owner. Design seems to be accepting of both center or straddle platforms. The inability to provide stations, in particular platform doors, creates a source for potential problems. Other transit system vendors have historically encountered interface problems when allowing subcontractors to build station facilities.
Emergency Management

The topside system has a permanently attached drawbar coupler at each end of a trainset. This facilitates pushing and pulling, however, no explanation of how coupling can be achieved in an emergency is offered. Reference is made to being able to provide catwalks at strategic locations, however, no additional information is offered. Reference is made to an emergency diesel-driven evacuation vehicle, but no indication is given as to whether the vehicle operates on the guideway or independently of the guideway.

Structures

"An ST-37 steel I-beam provides both running and guidance surfaces."

VON ROLL - SYSTEM DESCRIPTION

Founded in 1823, Von Roll, AG (VR) is a Swiss industrial engineering and manufacturing firm specializing in A) steel, cast iron, and piping, B) environmental systems, C) transportation systems, D) and products for the electrical and electronics industry. For the last 100 years, they have been involved in more than 1500 transportation systems around the world ranging from cable-cars, gondolas, funiculars, and monorails. Preliminary merger negotiations between AEG Westinghouse and VR have resulted in a November, 1992 press release announcing the acquisition of VR by AEG.

VR is being reviewed by the Lenox Park developers as one of two short listed systems (the other being Aeromovel) for possible installation between Lenox park and the Marta Lenox station. The developers have expressed interest in developing a close relationship with Tech to mutually benefit all parties if both Tech and they select the same technology for implementation.

While the two systems proposed in response to Tech's questionnaire are full scale monorails, VR builds smaller systems for amusement parks and conceivably, for a campus only system, a smaller and less sophisticated system could be supplied.

VR is proposing two different systems for Tech. The Type II system is operationally less flexible and has a smaller capacity than the Type III system.

VON ROLL - TYPE II SYSTEM

Vehicle

Individual cars are designed to be operated in conjunction with at least one other car. The lead end and tail end cars are designed with aerodynamic bodies which have bumpers on the outside for pushing. Center cars are "box" ended and are designed to share a bogie, forming an articulated joint, with whichever car they
abut. Lead/tail cars can seat 8 pax and center cars seat 12 pax (four rows of three abreast). No standees are permitted in any cars and wheel chairs can be accommodated in the lead/tail cars only. Trainsets are constructed in such a way as to make disconnecting individual cars possible but not timely (adjusting line capacity by adjusting train length is not possible). Materials for the vehicles are NFPA 130 compliant, and are comprised primarily of Aluminum and fiberglass reinforced plastic. Load compensation for maintaining evenly spaced headways is controlled by computer adjustments of vehicle speed and not with carboron load sensors. HVAC is provided by Sutrac and smoke detection is available. Voice communications is achieved best by duplex radio, but other systems are available. Carboron batteries supply 30 minutes of uninterruptable power for lights, communications, and ventilation.

Propulsion, Suspension, and Guidance

Each vehicle end is supported by a single axle, dual pneumatic tire, single DC motor bogie. Tires have inner liners for run-flat operation. Each bogie has one pneumatic spring for suspension and load leveling is not provided. Load bearing tires run on top of the beam and contact a special concrete track which has heating wires embedded in the concrete. Four guidance wheels per bogie are mounted horizontally and run in the webbing of the boxed I-beam. Two vertical guidance wheels run on the bottom of the upper lip of the I-beam and provide a clamping action to assure good traction between the load bearing tires and the beam. The bogie is of steerable design. The cars are mounted on the bogies in a manner that lowers vehicle centers of gravity and thereby minimizes roll and sway.

Brakes

Three brake systems are provided. The Primary system is dynamic regenerative and provides almost 100% service braking. At the final stages of a station stop, the dynamic fades out (this is known as "blended braking") and an automotive type disc brake provides final braking and prevents trainsets from rolling while stopped. A spring applied emergency brake activates if the other two are not available. No reference is made to cut-out capability.

Doors

Lead/tail cars have one doorway per side and one sliding door leaf per doorway. The door is wide enough to create a wheelchair passageway. Center cars have two doorways per side and one sliding door per doorway. Center cars are not wheelchair accessible. Interior seating accommodations are not conducive to passengers moving from the front of the car to the rear of the car, so that locking-out a door malfunction on one vehicle side requires locking-out the door on the
opposite side, with a resultant loss of passenger capacity. Passage between cars during emergencies is achieved by removing an emergency hatch and crawling over the vehicle bogie compartments, into another car. Sensitive edges and emergency releases are available on all side doors. Between stations, doors can only be opened on the side where a walkway is available.

Train Control

Automatic train separation is provided by a VR patented control system. Other components of the ATC system seem to be manufactured by Alcatel (an industry leader) or now, with the AEG merger, the ATC system will likely be completely AEG designed. Fully automatic operation is based on a moving block concept and allows operating headways of 90 seconds for loops and 105 seconds for shuttle operations. Approximately 13-26 feet of track is required at terminals to allow for station run-throughs (failed automatic stops).

Switches

A variety of switch types are available, including pivot beam, beam replacement, turntable, transfer table, etc. Selection is a function of the type of routing required, the frequency of switch operation, the amount of available space alongside the guideway, and other parameters. Switch prices vary with the complexity of the switch.

Station Design

The longer trains of the Type II system with their lower passenger capacity will require longer platforms and therefore more expensive stations than the Type III system.

<table>
<thead>
<tr>
<th>TRAINSET</th>
<th>TYPE II</th>
<th>TYPE III</th>
</tr>
</thead>
<tbody>
<tr>
<td>TRAIN/PLATFORM LENGTH</td>
<td>9 CAR - 132' 5&quot;</td>
<td>7 CAR - 105' 5&quot;</td>
</tr>
<tr>
<td>SEATED CAPACITY</td>
<td>100</td>
<td>56</td>
</tr>
<tr>
<td>STANDING CAPACITY (SEATED+STANDEES)</td>
<td>0(100)</td>
<td>95 (151)</td>
</tr>
<tr>
<td>CRUSH LOAD CAPACITY (STANDING+CRUSH)</td>
<td>0(100)</td>
<td>31 (182)</td>
</tr>
</tbody>
</table>

VR has extensive experience with integrating guideways into new or existing buildings and stations. Platforms can be of center or side mounted design. Platform doors are recommended. A protective steel pan is installed below the beam, at stations, to prevent objects from falling onto the ground below. Adding stations or extending a line does not incur any unusual problems.
Emergency Management

VR has built high levels of redundancy into their system. They are faced with the difficulty and expense of any monorail system, i.e. adding walkways to single or double track sections between stations. The single door leaf per doorway in the center cars creates more of an operational problem and not so much a safety hazard. Passage between cars, through the emergency hatch, is probably cumbersome but is NFPA 130 compliant. Tow bars between trains can be attached for retrieving vehicles but the process is too time consuming to be used for emergencies which have imminent threat to life. Rubber tires and the rubber bellows at the articulation are reported as not being NFPA-130 compliant (but this is not anticipated as being a problem in view of other existing systems in this country.)

Structures

All columns and beams are fabricated off-site and then installed in the field with minimal traffic disruption. The steel box beams are constructed by welding steel plates into the beam shape. Internal diaphragms provide added rigidity and all welds are air tight to prevent internal rusting of the beam. Beams can be painted per customer specification. Columns can be finish painted and crash barriers can be added at the base to reduce the effects of auto impacts.

VON ROLL - TYPE III SYSTEM

Vehicle

The Type III vehicles are the same length as the Type II vehicles, however, they are wider and tall enough to allow standees. Trainset configuration is similar to Type II vehicles. One set of four abreast seats are mounted with their backs against the car bulkheads and this clears a large area in the middle of the car for standees. Vehicle construction and sub systems are similar to the Type II car.

Propulsion, Suspension, and Guidance

All systems are similar to the Type II system.

Brakes

All systems are similar to the Type II system.

Doors

A significant difference exists between Type II and Type III doors. The Type III cars have only one doorway with one sliding door leaf per side. Even with the emergency hatch between cars, the single leaf door may create more than just an operational difficulty. Although the concept was accepted for the New Jersey airport system, the operating characteristics of the airport are significantly different than what will occur at Tech. Even at amusement parks, the number of
skilled persons who can be trained and available for emergency evacuations is higher than will likely be available at Tech. The door system needs to be more thoroughly evaluated and the possibility of installing 2 leaves per doorway should be considered.

Train Control

Minor differences in the Automatic Train Control system may exist between the Type II and Type III. This is not anticipated as a significant difference, but should be evaluated in more detail if VR is short listed.

Switches
All systems are similar to the Type II system.

Station Design
All systems are similar to the Type II system.

Emergency Management
All systems are similar to the Type II system with the exception of the door configuration discussed above.

Structures
All systems are similar to the Type II system.

VSL - SYSTEM DESCRIPTION

VSL is a member of the Bouygues Group, a French company with revenues in excess of 10 billion US dollars (1990). Bouygues is involved in construction, energy, engineering, communication, and transportation. Since its 1974 inception, VSL has designed and built 19 passenger transportation systems of which at least 8 have been automated guideways. VSL builds cable propelled, cable suspended, and self propelled systems. In response to Tech's questionnaire, three different systems are referred to, however, only one is detailed. The one is a variation of a cable propelled system in Las Vegas and although operationally similar to the Westinghouse C-100 or C-45 systems, it is more similar in appearance to monorails. Two significant features of the system are noteworthy. First, the VSL Tech proposal indicates that a self propelled modification of the existing cable drawn vehicle has occurred, and second, the guideway has a self-contained emergency walkway. The VSL guideway/walkway concept is unique in the industry of systems that give the visual appearance of monorail design.

VSL also specifically addresses the development of an operations procedures plan which will provide a variety of normal and emergency operating procedures and schedules.
Vehicle

Each fully self contained vehicle is bi-directional and fully automatic. Trains can be formed with either completely automatic or semi-automatic couplers. The vehicles are primarily constructed from aluminum, steel, and fiberglass reinforced plastic and are fully NFPA 130 compliant. Noise and sound insulation is installed between inner and outer walls. Communications for voice and data is by inductive loop. One HVAC unit per car is subcontracted to Sutrac and smoke detection is available. Seating is flexible and capacity per vehicle is estimated at 60 pax crush (maybe more). Vehicle construction is often subcontracted to CWA, a European railcar manufacturer. Carbon batteries provide 120 minutes of uninterruptable power for doors, lights, and ventilation. Windows are shatterproof, tinted, tempered, and installed with airtight and watertight seals.

Propulsion, Suspension, and Guidance

Each vehicle has two bogies. Each bogie has two pneumatic tires mounted vertically on one load bearing axle. Either one or two motors per axle is available as a customer option. Suspension and load leveling is provided by pneumatic springs. Four spring-loaded horizontally-mounted guide wheels run on the inner sides of the U-shaped guide beam. Loss of air in the load tires causes the vehicle to lower onto teflon skid pads. Pneumatic springs with load leveling provide suspension.

Brakes

Primary braking is provided by a dynamic regenerative system which provides 100% service brake to 0 mph. A disc brake provides emergency braking and holds the vehicle in a stationary position when completely stopped. Emergency braking parameters are maintained with as little as 50% system availability. Passenger activation of emergency brakes from inside the vehicle is available.

Doors

Doors are manufactured by either SWN, Vapor or Bode, industry leaders. Vehicle design can be specified to include single or double doorways per side with single or double leaves per doorway. Cutout capability is probable.

Train Control

Automatic Train Control is based on fixed block logic which allows 20 second minimum headways and design and manufacturing is subcontracted to Frey AG. Operation can be fully automatic, controlled by operators at Central Control or, accomplished by a maintenance technician on board the train. Fail safe logic and redundancy of computers is employed to provide extensive safety features. The
vendor claims that their system is easier to maintain than network systems. Further clarification is necessary.

Switches

VSL's response makes reference to rotary beam switches and not to any other type. The rotary switch is an 18,000 pound unit and is designed with alignment locking safety devices. If no other switch is available, then construction of a maintenance yard is likely to be expensive, relative to transfer tables, especially if expansion into Midtown is anticipated. Further clarification is needed.

Station Design

Both center mounted and side mounted platforms can be utilized with VSL's vehicle and platform doors seem to be required by the manufacturer. Platform doors are subcontracted (creating a potential for interface problems) obstruction detection is optional. Guideway intrusion detection by passengers at stations is available. Construction of new stations between existing stations or extensions of an original alignment do not seem to require any unusually difficult procedures.

Emergency Management

VSL is unique in that its guideway is built like an open-at-the-top box beam. External dimensions at the base are 5'0". The external vertical walls of the beam are 3'0" tall and are 12" thick. The load bearing wheels run on the top of the 12" wide vertical walls. Inside the open beam is a 36" wide trough which is available to passengers as an emergency walkway. Egress from the vehicle is through a hinged window in the front and back of the vehicle's noses. If a train of two or more vehicles is operating, egress from one vehicle to another is cumbersome but available. VSL also designs for push and pull capabilities in emergencies but only if fully automatic couplers are a part of the vehicle design.

Structures

In addition to the description of the beam in Emergency Management, post tensioned beams can be cast in place or cast off site. Also, the guideway is available in steel. VSL indicates a preference to casting in place. The beams have 4" drain holes which allow for rain water and melting snow to run off of the guideway interior. Heater elements are an option for the track surface of the vertical beam walls upon which the tires make contact. Spans longer than 140 feet require beam depths greater than 5 feet.
6.7 AEG WESTINGHOUSE

PICTURE EXPLANATIONS AND CREDITS

1) AEG C-45 Vehicle Dimensions A, B, and C cars.

2) AEG C-45 Vehicle Guidance bogie drawing.

3) AEG C-100 Vehicle Dimensions A, B, and C cars.

4) AEG C-100 Vehicle Guidance bogie drawing.

(All drawings provided by AEG Westinghouse in their response to Tech's questionnaire.)
The major components located on the C-45 bogie are shown in this illustration. Current collector shoes, also attached to the bogie, are not shown.
Vehicle

Car Dimensions
Vehicles are available in C-100 and C-45 sizes with the same basic technology used in both. The major differences between the C-100 and C-45 vehicles are passenger capacity and the width between wheel centers. Because that width difference affects guideway dimensions, C-100 and C-45 cars cannot be mixed on the same system.

Doors
Biparting doors on both vehicles and stations open together from the center, retracting horizontally outside the side walls. The floors of the vehicle are automatically leveled to within ± 1 inch (± 25 millimeters) of the station floors.

In normal operation, the doors are automatically closed and locked. A manual override is provided, however, to open and close the doors from inside or out in the event of an emergency, such as loss of power.
The major components located on the C-100 bogie are shown in this illustration. Current collector shoes, also attached to the bogie, are not shown.
WESTINGHOUSE AND MATRA

The original design of this assessment intended to put AEG Westinghouse (AEG) into direct competition with Matra.

After the first call to Matra on August 24, 1992, John Marino was identified as the appropriate person with whom to speak regarding sales, and a message was left, asking Mr. Marino to contact Tech. Three additional calls were placed attempting to contact John Marino. During the last call, Mr. Marino's secretary was asked to convey Tech's request for an informational package describing Matra's capabilities. She was also informed that a questionnaire would be sent to Mr. Marino. No informational package was sent from Matra and no acknowledgement of having received the questionnaire was issued by Matra. On October 7, 1992, an informational package was received from Matra with a note from John Marino, "I hope this information is helpful. Sorry we were unable to connect on the telephone." No reference was made to filling out the questionnaire. The entirety of these events are construed as a "no bid" response. In view of Matra's failure to respond, Westinghouse is without direct competition.

AEG WESTINGHOUSE – SYSTEM DESCRIPTION

AEG has numerous installations of people movers around the world and is recognized as an industry leader. They also have a reputation for being one of the higher priced vendors, but they also provide a system that has minimal limitations on design flexibility. In view of their November, 1992 press release announcing the agreement to acquire Von Roll, their position in the industry and the variety of systems that they can supply is significantly increased. System availability is consistently above 99% and most commonly in the range of 99.8+% AEG operates its own test track in Pittsburgh (complete with snow making equipment) and offers turnkey project involvement i.e. design, build, operate, and maintain, and will guarantee system availability. The three systems that AEG offers are their models C-100, C-45, and C-10. Since AEG has the operate/maintain contract at Hartsfield, there may be a variety of economies as well as available technical backup if AEG is selected by Tech. Additionally, if Tech selects an identical vehicle to one that is currently in production for one of three existing AEG contracts elsewhere, there may be further economy. The new contracts seem to be based on vehicles with a slightly aesthetically modernized body on a C-100 chassis, and with improvements to carborne train control resulting from the utilization of microcomputers.
THE C-100 SYSTEM
Vehicle

The C-100 is the vehicle in use at Hartsfield airport, which is also AEG's most complex existing system. There are 12 other systems in operation and 3 contracts for new installations. Most are operating in environments where high passenger demand and high reliability are crucial, i.e. airports.

The C-100 is available in three vehicle configurations, an A, B, or C car. All three have complete capability to operate independently, automatically, bidirectionally or as part of a larger consist. The A car has a head end and a box end, intended to have another box end vehicle coupled to it. The B car is double box ended, intended as a middle car between two A cars. The C car is double head ended but can be coupled to other C cars to form a train. Small differences in the vehicle's lengths result from these variations. If platform doors are desired, then all vehicles in a fleet must be of the same length, and then the A cars are the most reasonable selection, although for what will likely be a small price premium. If platform doors are not desired, any combination of vehicles can be selected to comprise a fleet (the Miami DPM is an outdoor, elevated system that does not use platform doors). Coupling any of the three vehicles is accomplished with manual vehicle operation. However, all mechanical and electrical connections are made automatically by the coupler. This capability facilitates making/breaking trains to accommodate passenger load fluctuations or service cutbacks. Vehicle construction is essentially a welded steel frame with an aluminum body. An aluminum skin is riveted to the aluminum frame and vehicle end-caps are fiberglass. Interiors are aluminum and fiberglass. With propulsion motors mounted under the passenger floor, fire protection and burn through times are vital, and AEG complies with ASTM E-119, which is the NFPA 130 minimum standard. Glass is used in large fixed-in-the-frame windows. All other components are designed to meet NFPA 130 standards. Suspension includes load compensation features but acceleration and braking do not. Data transmission and communication between passengers and central control is by full duplex radio. HVAC on all cars is provided by dual independent systems with smoke detection optional. Individual car passenger capacity is 20 seated (around the vehicle sides), an additional 80 standing, and an additional 50 crush (total 150). Abundant wheelchair space is available in the open area of the car. Carborn batteries supply 30 minutes of uninterruptable power for communications, controls, lights and ventilation.
Propulsion, Suspension, Guidance

Each vehicle has two bogies. Each bogie has one axle with two pairs of air-filled rubber tires. An aluminum disc, which is mounted between each of the dual wheel pairs, provides emergency vehicle support if one or both tires lose air pressure. Each axle is powered by one rotary motor through a highway type axle and differential. Motor control is provided by on-board computer. Dead load (empty) suspension is provided by leaf springs and live load is supplemented with load compensating pneumatic springs. In the event of a pneumatic spring failure, an alarm is activated in Central Control and the leaf springs accept the total vehicle load. The entire bogie pivots under a king pin which tends to extend tire life. Guidance and anti-derailment safety is provided by four horizontal wheels on each bogie which engage a track-bed-mounted "I" beam.

Brakes

The brake system is fully redundant. Primary regenerative braking is blended with secondary friction drum brakes. Drum brakes are electrically controlled and pneumatically activated. An emergency and parking brake is spring applied. Precision braking is ± 6 inches.

Doors

Each vehicle has two doorways on each side, with two leaves per doorway providing redundant access/egress to any one vehicle. Sensitive edges cause both vehicle and platform doors to open if activated. Individual door leaves can be manually locked for failure management. Emergency egress is accomplished by normal door operation or by passenger activation of an emergency door release. Activation while a vehicle is already in motion automatically initiates an emergency stop. Doors open only on the side where an emergency walkway is available. Vehicles do not have walk-through capability (doors creating passage from one car to another). This is accepted by NFPA 130 standards, but is less than maximally safe.

Train Control

Fully automatic operation includes acceleration, coast (energy conserving) and braking modes, with partial Automatic Line Supervision (headway maintenance) based on a comparison between commanded and actual speed. AEG provides its own in-house signal system which is proven reliable in other installations. Minimum headway is a function of alignment, but several systems operate in the 70-120 second range. Carborundum and wayside signalling is achieved through checked redundant microcomputers. Of importance is the capability of manual vehicle control, by authorized personnel, from the inside of the vehicle, during failure management. Note: AEG seems to be going through a technology transition. Reference is made to wayside equipment being
relay based and new equipment being computer based. This transition is similar to conventional line haul changes and is similar to changes for future Marta extensions.

The wayside signal system is based on conventional fixed block logic. Occupied blocks are followed by "zero speed" blocks assuring adequate safe following distances. Head-on anti-collision protection is provided by what seems to be inclusion of conventional traffic directional logic. Bunching is controlled by adjusting the standard 20 second dwell time.

A 25 foot length of track is required beyond terminal platforms in the unlikely event of a station run-through. A hydraulic damper is mounted at the end of the track to aid in absorbing kinetic energy.

Switches

Primarily two types of switches are available. Both are hydraulically operated and have a manual operation backup capability. One switch is a horizontally pivoting guidebeam switch and operates similarly to conventional railroad flexible point switches, offering straight-through and divergent routes. The other is a longitudinally "rotating" guidebeam switch offering "wye" (Y) route alternatives. Both have cycle times in the range of 10-12 seconds and are proven reliable in operations requiring throws as frequently as every one or two minutes. The need for switch heaters should be analyzed closely.

Station Design

Both island and center platform stations can be accommodated by the C-100 vehicle. Platform doors are available as a recommended option. Station staffing is not required. AEG has experience with the difficulties involved in adding a guideway and platforms into existing structures. New stations between existing stations can be easily constructed provided that proper planning during the initial construction includes allowances for the additions (such as sufficient level track or available space for the desired type of platform. Extensions beyond the initial phase are no more complicated than original construction. Adding on to the 25 foot tail track does not interfere with existing operations and expanding the traction power grid and signal systems is fairly straight forward. Noise and vibration are isolated from the station by the rubber tires and by barrier walls if platform doors are installed. If platform doors are not installed, noise levels will have to be assessed, however, they are not expected to be at undesirable levels for an outdoor installation.

Eventual expansion of this system into Midtown is relatively easy. If a 5 minute headway with two car trains produces a 2400 pph capacity, then a 2 minute
headway produces a 6000 pph capacity. If higher levels of service are preferred, then the possible need for longer trains and associated longer platforms must be analyzed. While it is common to operate 1 or 2 car trains in a system designed with 3 car platforms, an operational difficulty is introduced if Midtown capacities require 3 car trains which must be isolated from Tech’s 2 car platforms. Long term planning is advised.

**Emergency Management**

AEG offers many features for emergency management, some being standard and others being optional. The C-100 system is designed to perform very much like heavy rail systems, however there is likely to be a price premium. Tech will have to evaluate the number and types of safety systems it will deem appropriate. Literature does not indicate whether catwalks for elevated structures are standard features in either single or double track elevated alignments. For Tech, the pinched loop Alternative Alignment #1 affords a location for installation of a catwalk between the parallel tracks. If C-100 two-car consists operate on a 5 minute headway, a capacity of 2400 pph is created. The two car consist provides very high levels of safety and increases the variety of options available for emergency management.

**Structures**

The most frequently used construction scheme utilizes concrete piers, steel superstructure, and concrete running surfaces that are poured in place. The structure is claimed to be virtually maintenance free. This type of construction is relatively intrusive during construction when compared to cast-off-site systems. Standard spans are 80 feet with maximum spans in the range of 100-120 feet.

**THE C-45 SYSTEM**

**Vehicle**

The C-45 vehicle is in use at Las Colinas and at one other Dallas-Fort Worth location. In Las Colinas, two car trains with a capacity of 90 people (crush) can operate on 70-75 second headways and carry 4800 pph.

Much of the C-100 design is carried over into the C-45 design. If AEG is short listed, a detailed evaluation of the tradeoffs between the two systems will be necessary. The C-100 requires a heavier, more costly guideway. It also provides higher capacities which facilitate extension into Midtown. The C-45 requires a lighter and less costly guideway. System capacity will likely be achieved by trains operating at closer headways, and therefore, a larger fleet is required.
Theoretically, the smaller vehicles are designed to be operated independently, allowing for overall O&M savings during off peak periods.

The C-45 has A, B, and C cars. The A car has an aerodynamically designed head end with a box tail. The C car is double box ended and is designed to be coupled between two A cars, operate independently, or operate in a consist of C cars. The B car outwardly appears to be identical to a C car in that it is double box ended. However, while it has powered bogies, it does not have automatic train control equipment. This provides an up front capital savings with the associated potential operational problems of not being able to function at the head of a train. This can adversely effect fleet availability and failure/emergency management. If the operating head end of an A-B-A consist fails, special problems are introduced when trying to remove the consist from the guideway. Also, emergency egress is affected (see Doors). Otherwise, coupling capability, vehicle construction, glazing, NFPA-130 compliance, HVAC, and data and voice communications are similar, if not identical to the C-100. Seating is primarily longitudinal, although other arrangements can be designed. Carborn batteries provide 30 minutes of uninterruptable power for communications, controls, lights, and ventilation.

Propulsion, Suspension, Guidance

Each vehicle has two bogies. Each bogie has one axle with two pneumatic rubber tires with run-flat liners. N.B. Only one axle per vehicle is powered. This creates an operating dilemma. Failure of that motor leaves a single operating vehicle without propulsion and without primary regenerative braking. In order to minimize service interruptions, a minimum of two cars per train is deemed appropriate. Using C-45s in two car train operations erodes the economies of selecting the smaller system. AEG would have to be consulted for further guidance regarding their recommended operating guidelines.

Vehicle suspension is achieved primarily by load compensating pneumatic springs, with an alternate back-up system for safety. Guidance is similar to the C-100.

Brakes

Brake systems are similar to the C-100 with the one exception being that the secondary blended brake is disc rather than friction drum, as on the C-100 vehicle.

Doors

Each A, B, or C car has one doorway on each side. Each doorway has two leaves. The doors can be activated in emergencies similarly to the C-100 vehicles. The A cars have an additional emergency exit through the vehicle head end. The
center windshield pivots outward on a sloped-vertical hinge and a staircase can be manually pivoted over the coupler to form an egress to the guideway.

Train Control

Automatic train control is identical to the C-100 system, with similar high reliability.

Switches

Rotary beam, "wye", and pivot beam switches are identical to the C-100 system, with similar high reliability.

Station Design

Station layout possibilities are similar to the C-100 system. Extending a C-45 system into Midtown would require planning in the initial Tech construction phase.

Emergency Management.

As denoted previously, several important questions regarding recommended operating practices during propulsion, brake and air compressor failures must be determined before selecting the C-45 system. Additionally, guideway width requirements and the position of catwalks must be clarified in order to properly assess the safety of C-45 consists with more than two A cars.

Structures

Presumably, a system based on consists of 2 A cars can have a narrower and less expensive guideway than those required for consists of three or more C-45s or any of the C-100 configurations. AEG would have to be consulted for design guidance.

Construction techniques similar to the C-100 are available. However, the lighter weight of the C-45 system requirements allow for cast-off-site construction. AEG must further clarify guideway requirements for different emergency egress scenarios.

THE C-10 SYSTEM

Only one C-10 installation has been built, and it is in Pearl Harbor, Hawaii. The system is 0.23 miles long and is operated as a single track monorail-type shuttle. A single four car train operates at a speed of 8 miles per hour. Operation is automatic, however, attendants at each station monitor loads, close doors, and dispatch trains into service. The system was originally built by Rohr industries, which was later acquired by Westinghouse. System costs were (1978 dollars) 2 million to construct and $300,000 annually, to operate.

The C-10 system, as originally conceived, is strikingly similar to the Von Roll monorail. The C-10 questionnaire response by AEG makes numerous reference to
various subsystems being "redesigned" and in view of the recent Von Roll acquisition, will combine advantages of the C-10 with advantages of the Von Roll systems.

Vehicle

The new vehicle is intended to be constructed as a fixed length trainset utilizing A and B cars. A cars have an aerodynamic end and a box end. They are intended for the heads and tails of trainsets which are planned to be bi-directional. The B cars are box ended on both sides and are intended for placement between A cars. As many as eight B cars can be incorporated between two A cars. All permanently coupled ends share a common dual axled bogie at the articulation. No walk-through capability is available between individual cars. According to the questionnaire (and in conflict with the sales rep's comments) individual trainsets can be manually coupled. Therefore, five A-A trainsets could be coupled to make a 10 car train or three A-B-A trainsets could be coupled to make a 9 car train. This provides economy for energy consumption and controlling O&M costs as well as providing scheduling flexibility and significantly improved failure management logistical capabilities. Von Roll does not currently have coupling capabilities.

Only one HVAC system is planned for each cabin, and data and voice communication will be by full duplex radio. The majority of other vehicle subsystems are under redesign and will be NFPA compliant.

Propulsion, Suspension, Guidance

Bogie s are positioned at each end of a train and at each articulation. Each bogie has two short axles with two pneumatic tires on each axle. One axle, on articulated bogies only, is powered by a propulsion motor. All other axles are idlers. An aluminum safety disc supports the vehicle if a pneumatic tire fails.

Suspension is by load compensating pneumatic spring. Failure management of a spring malfunction is not directly addressed.

The single motor per articulated truck implies that, for safety reasons, the smallest consist would have to be a three car trainset. This would allow for one propulsion motor to malfunction and still have a second functional propulsion motor on the trainset. Further information regarding the intended operating strategies will have to be obtained from AEG. Von Roll design allows powered bogies at any position in the trainset.

Guidance and anti-derailment safety is provided by four horizontal wheels on each bogie which engage horizontal, 30" wide "I" guidebeam.
Brakes

The planned vehicle speed is to be a maximum of 15 mph. Regenerative braking is not planned. Service braking is accomplished with friction drum brakes. Emergency and parking brake activation is accomplished by a spring applied brake.

Doors

Each cabin has one doorway on each side of the vehicle. Each doorway has two leaves. Door functions and controls will be standard AEG design. A walk-through capability between cars does not seem to be included in the new plans. A potential safety hazard is created if a door malfunction occurs on a car which is stopped between stations, and requires evacuation from the vehicle side where a walkway is not installed.

Train Control

Automatic train control is identical to the C-100 system, with similar high reliability.

Switches

The questionnaire response claims that pivot switches, similar to the C-100 system are used. However, this is not likely, given the nature of the guidance system.

Station Design

Station platform layout possibilities are similar to the C-100 system. The minimal safe trainset consists of an A-B-A configuration. This gives flexibility for operating in Midtown. Extending guideway and adding stations is similar to new construction. AEG must be consulted with for more details.

Emergency Management

Due to the number of subsystems being redesigned, assessment of the emergency management capabilities would be speculative.

Structures.

The 30 inch wide I-beam is supported by concrete columns. No other information was provided.
APPENDIX A

The Interrelationship of Advances in Fixed Guideway Technology and Urban Growth
THE INTERRELATIONSHIP OF ADVANCES IN FIXED GUIDEWAY TECHNOLOGY AND URBAN GROWTH

This paper examines fixed guideway technology and its interrelationship with urban growth. The first part reviews improvements in urban transportation as a result of advances in technology. A novel manner for categorizing different systems is then proposed. The second part briefly examines concerns and impacts of Personal Rapid Transit as a potential new form of urban transportation.

PART I

FIXED GUIDEWAY DEVELOPMENT and CATEGORIES OF SYSTEMS

As technological advances have been applied to fixed guideway transportation systems, improvements in service quality and safety have followed. The improvements also allow for the provision of more reliable and dependable transportation to the public. Historically, the improvements have also contributed to different urban growth patterns and allowed a greater flexibility for developers and urban planners to coordinate transportation and planning within a geographic area. At the same time, the improvements have combined to introduce an element of misunderstanding when attempting to accurately categorize the increased varieties of transportation systems which have become available. This misunderstanding exists amongst manufacturers, design engineers, consultants, planners, educators, and owners (operators). This section will examine two issues. First, in order to illustrate the interrelationship of fixed guideways with urban development and also, to illustrate the origin of the current difficulties in categorizing systems, some of the historically significant technological advances in the fixed guideway industry will be described. Second, an examination of some prevailing categorization systems will illustrate their shortcomings and a new system of categorization will be proposed.
A Brief History of Fixed Guideway Technology

"All cities, throughout history, have been shaped by the state-of-the-art transportation device of the time" - Joel Garreau, Edge City

Steam powered locomotives were invented before the American Civil War. They were used to pull multiple cars, filled with passengers or freight, in a train formation. Prior to 1876, operations on a track were governed primarily by a timetable. Track switches were operated at their local position by persons who could only assume that train service was operating as scheduled. Acceleration of a train was controlled by an engineer in the locomotive cab. Braking was controlled by the engineer blowing a coded series of "toots" on the whistle, and individual brakemen on each car would hopefully apply their brakes in a coordinated manner that lead to safe braking. This level of service was unequaled by any previously developed transportation system, and as such, was readily accepted by society as state-of-the-art. However, although tolerated, there were several serious safety problems. Switchmen could not determine whether one of two tracks was available for service or was occupied by a train, especially if delays in service had occurred. Abrupt acceleration and other conditions lead to the possibility of a train separation (broken coupler). The safe braking distance of trains often exceeded the distance that an engineer could see. And achieving smooth stops without separating a train was difficult. If the cars or the brakemen in the rear sections of a train were able to respond faster than the front sections, separations would occur. These inadequacies, when combined, lead to head-on collisions, tail-end collisions, jerky acceleration and braking, and, on long inclines, sections of trains that might separate and begin rolling backwards at a rate that exceeded the stopping capability of the brake system. In 1876, after experimenting with a progression of iterations, George Westinghouse introduced the air brake. The significance of the invention is noteworthy for a few reasons. First, the air system lead to uniform brake application pressure on each of the wheel sets on a train. Smoother braking resulted in reduced passenger discomfort or injury. Second, the air system resulted in the ability of the engineer to control braking from the locomotive cab. This control capability safely eliminated the necessity and the expense of the brakemen. Third, in an earlier developmental stage, Westinghouse had used air pressure to force brake shoes onto the treads of the steel wheels. This created braking friction. If the brake pipe that directed the air from car to car were to rupture, the reduced air pressure resulted in a "no brakes" or "fail-to-danger" condition.
Westinghouse refined his system whereby air pressure was used to hold brakes off of the wheels. A reduction of air pressure was required to achieve a brake application. Loss of air pressure resulting from an engineer operating a valve in a controlled manner, a train separation, ruptured brake pipes, failed air compressors, or any other similar reason resulted in a brake application, or a "fail-to-safety" condition. This is the first documented application of fail-safe logic to a mechanical system.

Westinghouse's interest in rail safety continued. By 1880, he had invented an automatic system for signalling engineers with visual aspects that would convey downstream track availability. The signalling system was not designed to stop trains so much as it was designed to maintain fluid operations as well as establish "traffic direction" on a track segment. This system, with some modifications, is still in use today and is referred to as "line of sight signalling" or "wayside signalling". This was also the beginning of "fixed block" control. Predetermined lengths of track could now be designed to accommodate the braking characteristics of trains. With the improved train braking performance of the air brake, stopping distances could be calculated for specific train speeds, and lengths of blocks could be designed to maximize the number of train operations on any given length of track, i.e. capacity could be maximized. WABCO (Westinghouse Air Brake Company) and Union Switch and Signal Company are both companies that were started by George Westinghouse and survive today.

In the late 1800's, railroad companies realized that they could schedule their inter-city trains to arrive on the outskirts of a city in the early morning and then proceed into the city in time for workers to begin their daytime jobs. Since many railroad companies had already been granted rural land ownership rights, they decided to develop some of that land as residential property. To encourage housing sales, they offered to discount or "commute" the fare to persons who elected to live in the distant developments and shuttle to the downtown on a daily basis; hence, the term "commuter". Contemporary commuter rail lines utilize diesel-electric or electric locomotives to achieve maximum speeds of 70-75 mph and on rare occasion 100 mph. Line lengths of 50 miles are not uncommon and average speeds (travel speed including dwell time for station stops) range between 45-55 mph or higher.

Steam powered locomotives were excellent for long haul operations and their contribution to the settling of the West is well known in American history. However, they caused problems when utilized in urban transportation applications.
They were dirty and noisy. If used under ground, the soot would fill the tunnels and soil passenger's clothing. And if implemented on elevated structures, the ashes and clinkers would fall onto the pedestrians and traffic below. Further, their acceleration characteristics limited economical operations to minimum distances of 2-3 miles between stations.

Prior to 1888, urban transit was provided primarily by horse drawn transit cars, and eventually, cable cars. Both played significant roles in the urbanization and suburbanization of the larger American cities. However, in 1888, Frank J. Sprague introduced modifications to the fledgling electric railway industry that revolutionized public transit. In general, his improvements to motors and car design lead to efficiencies that were greater than horse drawn or cable drawn technologies. In particular, he introduced a method whereby one operator in a lead operating cab could control the acceleration of all motors on each wheel truck of a multi-car train and also control the braking of each car in a uniform manner. This concept is known as "trainline" or "multi-unit" operations. The significance is that, by operating longer electric trains, line capacity could once again be increased without jeopardizing safety. Electric railroading became the state-of-the-art for public transit and during the next two years, more than 1200 miles of electric transit were built in the U.S. Average speeds of 10 miles per hour allowed developers to build subdivisions on the outskirts of a city and then use electric streetcars to provide mobility to the downtown. Atlanta's Inman Park is an example of combining the new electric train technology with real estate development. From 1905 through 1940, electric streetcar mass transit systems proliferated in American cities.

As improved technology raised maximum speeds to the range of 50 mph and as passenger demand increased, electric rapid rail became feasible. Rapid rail depends on large numbers of passengers travelling along a dedicated right of way corridor. The dedicated right of way (ROW) allowed for higher average speeds (20-25 mph) than was safe with streetcars, since interference with regular vehicular and pedestrian traffic could be eliminated. Whether at grade, elevated, or below ground, rapid rail was, and continues to be, the most capital expensive of the fixed guideway systems. With few exceptions, rapid rail did not shape urbanization. Rather, because of its expense, it followed already established growth patterns.

As early as the 1910's, transportation planners in New York City anticipated passenger demands that would exceed their subway capacities. To accommodate the
anticipated demand, when building new rapid rail lines, three and four track ROWs were installed. The idea was to implement express and skip-stop service. Express service allowed passengers at the extreme ends of long routes to board a train and then travel, without stopping, to a Central Business District (CBD) where local service would begin. Skip-stop service calls for the designation of stations as (ex.) A, B, C, and D stations. Trains stop at the A and D, B and D, or C and D stations. The D station, being served by all trains, become a transfer zone. Anyone wanting to travel from any station to another would have to transfer no more than once on that particular line. Express and skip-stop service increased average travel speeds and also again, increased line capacities. While the New York planners were not likely to have been the first to do so, their farsighted planning illustrates an early strategy to operate a variety of service types on one guideway system.

In the 1950's a new advance in technology, automatic cab signalling, was first implemented in Europe. The first American transit system to install cab signalling was the Port Authority Transit Corp. (PATCO), sometimes referred to as the "Philadelphia high speed line" or the "Lindenwold line". Automatic cab signalling allows for electro-magnetic signals (speed commands) to be transmitted through the running rails and be received by apparatus on a train. Using Marta as an example, seven different speed commands are utilized. The absence of a signal results in "zero" speed, while different frequencies can limit a train's speed to 15, 25, 37, 50, 60, or 70 mph. Even with continuous welded rail, insulated joints can be installed to create "blocks" for train control. The civil geometry of several blocks of track may allow for 70 mph operation. However, the presence of a slower or stalled train, in a downstream position relative to a following train, automatically causes the 70 mph speed command to the following train to be reduced in progressive blocks. Eventually, one or two empty blocks are created where a "zero" speed command causes the following train to stop before a rear end collision can occur. Head-on collisions are prevented by transmitting the speed commands in a manner that creates "traffic" directional flow, against which opposing traffic receives only a "zero" speed command and into which routes cannot be aligned. The hard-wired, relay logic of cab signalling is installed using fail-safe design and operates independently of any central computers (even if Central Control computers crash, speed commands and the safety that they provide are not jeopardized). Although a train operator can defeat the system by overriding the carborn automatic
features or, control circuitry can be designed or installed improperly to allow unsafe moves, the hardware itself is time-tested to be 100% fail-safe reliable. Cab signalling, when combined with other electronic vehicle control improvements can lead to on-time performance in the range of 99.0%+ in heavy rail applications.

Since their first implementation, cab signal control systems have been referred to as "automatic train control". In conjunction with their implementation, maximum speeds were raised to 70-80 mph, and this lead to increased average speeds. Again, using Marta as an example, average speed from terminal to terminal on the East/West line is 30 mph and on the North/South line is 35 mph. First PATCO, then BART, WMATA, MARTA, Baltimore, and Miami were implemented as what became referred to as "automated, high-speed, heavy rail systems". An element of misunderstanding creeps into terminology at this point. First, "high speed" refers to high maximum speed, not high average speed. Second, the term "heavy" rail refers to the passenger capacity of a line (light rail-17,000 pphpd, and heavy rail—above 17,000 pphpd) and does not refer to any weight characteristics of the systems. And third, although train control is automatic, the above mentioned systems, as a whole, are semi-automated, since, by policy, all of the different city's systems require operators in the head ends of the trains while they are being operated on the mainline (with speed commands and wayside signals) or in the yard areas (wayside signals only). These systems allow for transporting as many as 45,000+ passengers—per-hour-per-direction,(pphpd). The advantage of cab signalling is that high speed operations can be designed for 90 second headways and realistically be operated at 120-180 second headways with the assurance of almost completely eliminating the possibility of collisions. This is compared to (ex.) New York, which operates with wayside signalling and headways of 120-180 seconds, but without the reliability of a cab signal control system and without other electronic vehicle control features. As a result, New York's on-time performance suffers and the possibility of collisions is controlled primarily by the motorman.

Contrary to popular belief, the costs of vehicle procurement or energy consumption are not the largest expenses of rail transit. Rather, it is ROW acquisition, construction of elevated guideways or tunnels, and construction of stations, shops, and other facilities that make the systems costly. In an attempt to reduce the expense of dedicated ROWs, several Canadian cities embarked on new construction of Light Rail Transit systems (LRT) in the late 1960's and early 1970's. These were designed to be similar to systems that had already been proven...
in several European cities. First Pittsburgh, in the U.S., then Buffalo, San Diego, and several other cities implemented LRT systems. LRT can reduce capital costs by operating on existing or abandoned rail ROWs, or by sharing ROWs with automobiles on existing streets (similar to the original streetcars). Operating in city streets is often referred to as "street running" and speeds are governed by the traffic signals used by automobile traffic. When routed in an area that allows for barriers which restrict pedestrians or vehicular traffic from crossing the ROW, speeds can be raised to 55-60 mph and wayside or cab signalling can be used.

However, two concerns limit the line capacities of LRT to 17,000+ pphpd. First, since the trains street-run, LRT is limited to 2 or, on occasion, 3 car consists (180-270 ft.) Longer trains would be likely to interfere with automobile traffic at intersections. Second, since LRT often operates at-grade, through crossings with gates that stop automobile traffic, minimum headways are limited to 3 to 5 minutes (averaging 1.5 - 2.5 minutes per direction) so that automobile traffic can flow across the ROW. Using the Los Angeles Blue Line as an example, a trip from downtown L.A. to the end of the line in Long Beach covers 21 miles, with 21 stations, and takes 59 minutes. Average speed between the stations near the L.A. downtown is less than 21 mph since stations are spaced more closely together and trains have to street-run. LRT, in general, operates with average speeds in the range of 15-22 mph. Nonetheless, LRT has become the system which is most often implemented during the current resurgence of rail transit in the U.S. On-time performance is usually in the range of 98-99%. Occasional collisions with automobile drivers who violate the lowered crossing gates or pedestrians who try to "beat the train" result in accidents and deaths. Rarely is there serious injury to passengers on the train.

Commuter, heavy, and light rail corridors are often served with connecting bus service at stations. Average speeds for local service bus operations in the U.S range between 10-15 mph. Bus/rail interfaces enable people to traverse a regional transit network, albeit, with the penalty of having to make 2 or 3 undesirable transfers, often to modes with slower average speeds than trains.

In the mid 1960's a different form of fixed guideway transit began to emerge. Addressing the demand to transport large numbers of passengers for short distances with access to any of several stations, small systems were developed to handle capacities in the range of <1,000-18,000 pphpd. These systems have been lumped together and are mistakenly interchangeably referred to as "people movers", PRT.
(personal rapid transit), CRT (group rapid transit) and AGT (automated guideway transit). Applications have initially been at airports and amusement parks, however, urban activity centers and university complexes are becoming target markets. The capabilities that these systems have for reliably transporting large numbers of people are beginning to be recognized as possible solutions to automobile congestion in small geographic areas. Additionally, when integrated with existing transit service, they can provide reliable transportation for the last link of a commuter's journey.

Dallas/Ft. Worth airport's AirTrans system is one of the earliest and largest systems, while systems at the university at Morgantown, West Virginia, Hartsfield airport, and Disneyland (Anaheim) and Disney World (Orlando) are each early examples of similar but different types of these systems.

Although all of the above systems are similar in geographic service area, route length, and can be configured to be similar in capacity, they are different in some distinct ways. AirTrans is automated i.e. no operator is on board a vehicle, and vehicles operate as 1-3 car units. Additionally, the original design called for a mainline loop track, and 5 secondary loops with multiple stops, that serve individual air terminals. Each secondary loop is served by vehicles which circulate along that loop and then around the mainline loop. Passengers at terminal "A" can ride to the mainline on an "A" car, disembark, and then catch a different car to any of the other loops. The advantage is that each passenger does not have to stop at all stations on all loops. This results in a time savings for the passengers. The disadvantage is that a transfer is introduced into a single, short Origin-Destination trip.

The Morgantown project uses off-line stations and fully automatic vehicles to achieve an operation similar to AirTrans. Since all vehicles do not stop at all stations, a time savings is provided to passengers. However, all vehicles are of smaller capacity and operate only as single car units.

At Hartsfield, automatic trains with as many as three cars operate along a one mile route. However, formation of trains is still a manual operation. The individual vehicles must be assembled into trains by personnel in a maintenance area. As a result, increasing or decreasing consist lengths to maximize efficiency during periods of brief peak passenger demand is not a normal activity. On the mainline, all trains stop at each station on the route. Prior to the demise of Eastern Airlines, the Hartsfield system was among the 10 busiest transit systems in
the U.S. and provided service headways in the range of 120-180 seconds with on-time performance in the range of 99.5+\%.

The Disney systems are examples of monorail guideway technology. The elevated guideways are relatively simple to construct and as a result can be relatively less costly than the more expansive guideways of conventional systems. While they reduce the impact of visual intrusion, they are criticized for introducing difficulty with emergency evacuation capabilities. And, although trainsets are longer than one car, the way they are built makes adding or removing cars impractical for accommodating fluctuations in passenger demand. Train control is automatic and, by owner preference, operators are used on each train.

In the last 15 years, several significant innovations in applied technology have produced a new state of the art for automated guideway transportation operations. The innovations include "moving block" train control and Linear Induction Motors (LIMs). Cab signalling with fixed block control prevents collisions, however, coupling operations have to be conducted manually. Moving block train control provides collision protection similar to fixed block control, but also allows trains to be coupled (controlled collisions) without manual intervention. LIMs have no moving parts, and as a result, when combined with reduced maintenance requirements and reduced probability of mechanical failure, they can result in higher reliability with lower costs. Moving block control, LIMs, advances in computer monitoring of vehicle subsystems, and other advances in technology contribute to making systems such as VAL by Matra at Lille, France (rotary motor, fixed block control) and SkyTrain at Vancouver B.C. practical systems. Both are line-haul systems with no operator on a train. Although supervisors circulate through the system and monitor each train periodically, the expense of a "bull-pen" of operators standing by to operate extra trains when passenger demand increases can be eliminated along with the expense of operators for each regularly scheduled train or for yard operations. Reliability of both systems is in excess of 99.5+\% on-time. Both systems rely on short trains operating at short headways to achieve their line capacities. VAL (phase 1) is an 8.3 mile double track system with 18 stations. Married pair units, 84 feet long, operate every 60 seconds during peak travel times to provide a line capacity of 12,000 pphpd. Average scheduled speed is 21.8 mph. A productivity index statistic which indicates achievable labor savings with fully automatic control is the ratio of "passengers carried per staff person per year (ppspy)". In 1988 VAL carried 160,000
ppspy, Montreal carried 100,000 ppspy, and Marta carried approximately 55,000 ppspy. Even after an expansion in 1990, VAL O&M costs of $23.3M were exceeded with farebox revenues of $26.7M. Another benefit of the concepts utilized in the VAL system is that consistently high on-time performance with short headways has contributed to actual ridership counts being significantly higher than even the highest forecasted predictions. Passenger reports specify a "relaxed" attitude about riding VAL since "if a train just departed, another one will be by in a minute".

VAL and SkyTrain are examples of an evolutionary change utilizing short headway, moderate capacity vehicles, and sophisticated full automation to provide more economical system operation than previously availability. However, the emerging technology of Aeromovel, from Brazil, is an example of an advancement with the potential for lower capital and O&M costs relative to VAL and SkyTrain. Horizontal box beams provide support for a conventional steel track guideway. The beam also creates an air plenum through which air is forced at a pressure of two pounds per square inch. Apparatus which is attached to the train extends into the hollow of the beam and functions as a "sail" which transfers energy for propulsion to the train. The system is fully automated and favorable operating economies are maximized with short, convenient headways. Favorable economy is enhanced by reducing vehicle weight through locating the heavy propulsion motors, transmissions, and primary braking system off of the moving vehicles. Additionally, by not having to construct a high voltage power distribution system along the guideway, significant additional capital and maintenance cost savings are achieved. Vehicle speeds in the range of 45-50 miles per hour have been demonstrated, with the demonstration of higher speeds limited only by the availability of a sufficient length of straight test track. Line capacities in the range of 18,000 pphpd are achievable with a one meter square air plenum, and larger capacity vehicles require only modest increases to the hollow space of the box beam. Relative to conventional cast-in-place guideway construction, Aeromovel's off-site column and beam fabrication results in less obtrusive and lower construction capital expenditures. Acceptance of Aeromovel's "low tech" approach to transportation could result in significant economical changes for fixed guideway systems with the passenger capacities in light rail range.

In the mid-1960's, transportation engineers began to give serious consideration to the concept of personal rapid transit (PRT). Previously popularized by science fiction authors for several decades, advances in technology
made real development of the concept feasible. By the late 1960's several groups had begun research and design of systems. Eventually, the Japanese operated a demonstration track called the Computer-Controlled Vehicle System (CCVS) and two other projects. The French demonstrated the Aramis project. And the West German government operated a demonstration project called CabinTaxi.

A more detailed discussion of PRT follows in the second section of this paper, however, for the purpose of clarifying fixed guideway categories, some basic information is pertinent. First, PRT concepts and systems use vehicles of 1-6 seated-passenger capacities. There are no standees. Second, PRT utilizes a fully automated guideway. Third, stations are usually off-line which allows traffic on the mainline to flow at a steady controlled speed of 20-30 mph. Capacities are achieved by maintaining headways of 3 seconds (proven in demonstration) with long range design calling for 0.5-1.0 second. Fourth, PRT utilizes a network of links to provide service throughout an area. This is in contrast to conventional systems which, even if spur lines are used, utilize the concept of providing service through a densely populated corridor with supplemental connecting bus service to the less densely populated areas. The concept of a "mature PRT network" implies a large network on which small stations are so closely spaced that a large majority of trips are Origin-Destination, i.e. they can be completed without transferring to another transportation mode and that walking distances to stations are no more than 0.25 miles. And last, a mature network is stocked with a sufficient number of vehicles so that they are waiting for passengers at stations during off-peak hours, and during peak hours, wait times are no more than 2-3 minutes. A mature PRT system provides vehicle availability, average travel times, and passenger comfort at levels that exceed capabilities of the systems previously described.

"Categorically Confusing"

Arriving at an easily comprehensible system for categorizing and describing fixed guideway systems has been difficult.

Vuchic (1992) uses an analytically complex system that focuses on ROW category, technology, and type of service.

ROW can be Category A, mixed traffic (street cars), Category B, longitudinally separated (LRT on separate ROW with grade crossings), or Category C, dedicated (exclusive) ROW.

Technology is classified by support, guidance, propulsion system, and control system.
Type of service has three classes; 1) short haul, city transit, and regional transit, 2) local service, accelerated service (skip-stop, limited stop, etc), or express service, and 3) the time of operation, i.e all-day, peak, or irregular.

Other categories address capacity, speed, and other characteristics associated with transportation in general.

Elms (1989) addresses only AGT systems and subcategorizes them into line-haul, people movers, CRT, and PRT.

Talley, Ernst, and Jackson (1989) restrict their categories to service type, minimum travelling unit, and maximum operating speed.

Generally, consumer concerns are focused on convenience, 1) how much time is needed to complete an entire Origin-Destination and return trip, 2) how comfortable is the trip, 3) how safe is the mode (probability of vehicle accidents or probability of being personally assaulted), and 4) how much will the trip cost (primarily out-of-pocket, and secondarily long term). In view of these parameters, the following passenger-oriented system for technologically categorizing fixed guideway systems is proposed.

The first and most important level of distinction addresses issues of comfort, personal safety, and speed. Service Type, 1) Mass transit (MT)—where all passengers ride with many strangers and stop at all available stations on a line. Access is usually by some other mode of transportation. 2) Group Transit (GT)—where all passengers will likely ride with a few strangers and stop at only a few of the available stations on the line or in the network. Access may be by another transportation mode, or because of a network of guideways, trip origins and final destinations are more likely to be within walking distance of a station, and 3) Personal Transit (PT)—where passengers travel non-stop as individuals, or with other persons of their own choosing, from their origin station to their destination station. Access to the network is primarily by walking to a station not further than 0.25 miles from Origin or Destination.

The following categories are not rank ordered, but rather help to further specify certain important characteristics.

The second category addresses levels of comfort which is an operating policy. Vehicle Capacity, (not to be confused with Line-Capacity) 1) High—where the number of standees in a vehicle is designed to be twice, or more, the number of seated passengers, 2) Moderate—where the number of standees is designed to equal or
slightly exceed the number of seated passengers, and 3) Small—where no standees are allowed, i.e., all passengers are seated.

The third category is Speed, which is a technical constraint 1) High—where average travel speed is faster than 35 mph, 2) Rapid—where the average travel speed is 20–35 mph, and 3) Low—where the average travel speed is less than 20 mph.

The final category addresses reliability, safety and operating costs. Type of Control, 1) Fully automated—where all mainline and yard functions are conducted without operators. This category is divided into “fully automated-single car train” and “fully automated-multi-car train”, 2) Automated—where mainline operations are conducted without operators but yard operations require vehicle-operating personnel, 3) Semi-automated—where cab signalling automatically governs certain mainline functions but operators are still required to control other train functions, and 4) Manual—where operators have primary control of the train in all situations.

The efficacy of this method is demonstrated with the following questions and answers.

Q 1) What is the NYCTA transit system? A) NYCTA operates manually controlled mass transit and group transit (express and skip-stop service) on one heavy rail capacity fixed guideway. They operate high capacity vehicles and provide rapid service. However, overall average trip time is likely to be low speed when combined with transferring to buses.

Q 2) Is PRT an AGT? A) Personal Rapid Transit on a fixed guideway is likely to always require full automation and as such is only one type of ACT. An automated guideway can currently be utilized to provide personal transit, group transit, or mass transit services with automatic or fully automatic vehicles of small or moderate capacity, travelling at low or rapid speeds. PRT is fully automated personal transit which uses small capacity vehicles and operates at rapid speeds.

Q 3) What about the term People Mover? A) In its current usage, the term People Mover is used to describe mass transit that uses high and moderate capacity vehicles. People movers usually serve a small geographic area relative to heavy or light rail systems. Because stations tend to be closely spaced, people movers operate at low speed. Line capacities range between 1,000 pphpd and go as high as 18,000 pphpd. Current systems are usually automated in some manner which contributes to their efficiency. However, some systems are deployed which are semi-automatic (Disney monorails), while the Detroit Downtown PM is the first fully...
automated multi-car train system in this country (all normal mainline and yard coupling moves are performed without operators).

Q 4) What is the VAL system? A) VAL is fully automated, light rail, mass transit using high capacity vehicles for rapid speeds.

Q 5) What about the Disney systems? A) Epcot is a rapid (?) semi-automated mass transit system that uses moderate (?) capacity vehicles. Monorail ROW is not a major concern for the passengers or for this categorizing system.

Q 6) What are some examples of CRT? A) NYCTA skip-stop and express service is CRT, as is the service at Morgantown. The two are different in that NYCTA uses manually operated high capacity vehicles and Morgantown uses fully automated, moderate capacity vehicles. Also, the size of the geographic area being served is different.

Q 7) Can LRT be Automated Group Transit? A) Yes and no. For economical capital and operating costs, LRT is usually deployed on double track ROW and skip-stop or express service can be difficult to implement without a readily available middle track or off-line stations, so Light Rail Group Transit is not likely, although it is available. However, automated and fully automated guideways can be used to provide line capacities similar to LRT. The fully automated Vancouver Skytrain, even though it operates on a dedicated ROW, is appropriately referred to as Advanced LRT (ALRT) since the "Light" term is an indication of line capacity and not ROW type or vehicle weight.

Q 8) What about cable drawn systems like San Francisco? A) The type of propulsion is not important to a passenger. Cable cars are mass transit semi-automated (the cable controls maximum speed and traffic direction), moderate capacity vehicles operated at low speeds. PCMA 2000, a manufacturer of cable propelled systems, has developed a full switching capability that allows for the development of cable propelled group transit.

Q 9) What is commuter rail? A) Commuter rail provides longer distance, local service, and is high speed mass transit utilizing moderate or high capacity vehicles in a semi-automated or manually controlled manner. Stations are usually at least 2 miles apart and often more. Commuter rail is contrasted with High Speed Rail in that High Speed Rail will operate in excess of 100 mph but will not achieve those speeds for commuter operation. A High Speed train may operate High Speed from Chattanooga to Kennesaw, and then begin commuter operation into Atlanta.

Q 10) Why isn't PRT mass rapid transit? A) Large numbers of people riding a system that serves a large area does not make a system mass transit. A common mistake is
to use the terms "mass transit" and "public transit" interchangeably. By the definitions above, personal and mass transit are two completely different modes of public transportation. Even though PRT maximum vehicle speeds are only 20-30 mph while mass rapid transit can be 70 mph, the average trip time of PRT is designed to be significantly less than mass transit, and PRT provides more desirable conveniences.

Q 11) Why isn't PRT or small vehicle CRT a people mover. A) They can be. However, both can be designed in a way that serve larger areas and have higher system capacities than people movers or even LRT, or heavy rail.

PART II
POTENTIAL IMPACTS AND FEASIBILITY of SMALL VEHICLE URBAN RAPID TRANSIT

If a man's only tool is a key, he will imagine every problem to be a lock.  
-Abraham Maslow

In the mid-1970's Time magazine reported on a group of Japanese businessmen who had come to the U.S. to observe American factories and business practices. When asked to list their observations, the leading comment was focused on long-range planning; in America, long-range is no more than 25 years, while in Japan, 100-300 years is more common.

In June, 1975, the United States Congress-Office of Technology Assessment (OTA) published "Automated Guideway Transit, An Assessment of PRT and Other New Systems". All of the characteristics of PRT and CRT as described previously are recognized in the report.

In the section reviewing PRT, a series of issues are raised, focusing on technical, economic, social, and institutional concerns.

Technical Concerns

The OTA technical concerns were focused on 1) the need to further develop the necessary computer control capabilities that are required for vehicle routing, vehicle headway spacing, merges and diverges on the guideways, and administrative functions of storing and distributing empty vehicles, 2) development of advanced control and braking systems that assure safe operation at close headways, 3) the need for major improvements in reliability—far beyond levels which had been achieved by any other existing transit equipment in operation, 4) demonstrating crash survivability tests similar to NHTSA tests and demonstrating a
means for emergency evacuation, and 5) a study of alternative engineering approaches in order to develop cost effective systems and components.

Since 1975, solutions to the majority of technical concerns of the OTA have been demonstrated by PRT/QRT research in Japan, France, the U.S., and Germany. All four countries discontinued their research in the late 1970's or early 1980's for political or financial reasons. Japan and Germany dismantled their demonstration projects and France reportedly modified their system to perform more like conventional mass transit (the system may have been dismantled.) Of noteworthy importance is that the German Federal Railway (a conservative, standards-setting organization) has reportedly recognized that CabinTaxi was designed to fully comply with all of its certification requirements. If properly constructed, in compliance with the specifications and standards of the original demonstration project in a small urban setting, it would theoretically have little or no difficulty acquiring German "certification". The U.S. Morgantown system still operates as CRT. During the period that has followed, new applied research came to a standstill. J. Edward Anderson, with Taxi 2000, and a few other transportation engineers continued conceptual design work, but no new systems have been built.

Advances in technology since the early 1980's, especially in the areas that are vital to fully automated transit, make PRT even more feasible today. One need only look to the VAL, Detroit DPM, and SkyTrain systems and the new O'Hare airport system by Matra, for evidence. And pertinent technical advances which are already well into development are likely to be available in the near term future. These will further contribute to resolving issues focused on computer control, safety, light weight construction materials, etc.

Inadequate technology is no longer a valid reason to oppose PRT.

Economic Concerns

The OTA report focused on the technical economic feasibility of developing PRT. Costs for subsystems development, operations and maintenance, and vehicle acquisition were reported as being so unclear that "meaningful analysis is difficult". At the time the report was issued, the Morgantown project was only partially completed, and well on its way to encountering cost-overruns, which, for the completed project, were approximately seven times the predicted costs. However, the Morgantown project, in particular, was hurried and as a result had to be managed in a manner that goes against conventionally accepted incremental research. Admittedly, projecting the capital and O&M costs for a mature PRT system from ones
that have only been deployed in a few unrelated demonstration projects is difficult. The final OTA finding was to defer major financial commitment until further studies could be conducted. An analysis of alternatives to PRT was discussed, but these were based on the costs, travel patterns, and highway traffic of the mid-1970’s. A broad analysis of the future context was not undertaken. Proponents of PRT claim the potential for PRT profitability by providing regional transit system savings made possible by serving large areas with one high quality level of technology and service. This is contrasted with the expenses of the variety of technologies currently used to provide interconnecting modes of technology, each with varying levels of service.

Social Concerns

Four social issues were defined. First, uncertainty was raised as to what would be the urban objectives served by PRT. In the mid-1970’s the focus on urban planning was to radially connect suburbs to downtown districts. The current trend toward urban activity centers was not established sufficiently to be a concern at that time. However, today, transportation within and between activity centers has become the focus of much attention. The characteristics of conventional mass transit networks make them too costly to deploy as LRT or HRT and too time consuming for passengers if deployed with buses. PRT provides rapid levels of service with much greater flexibility than other fixed guideway systems. PRT lends itself to implementation in areas of low-density development and in areas where development will eventually be moderate to heavy, but are currently low. And as a PRT network grows larger, it becomes more efficient and flexible, since alternate guideways become available for congestion or failure management. These attributes of PRT go far to reducing the variety and complexity of transit services needed in an activity center, such as envisioned by Meyer (1992).

Second, the social acceptability of PRT is questioned. Concern over the proliferation of elevated guideways and numerous stations in residential neighborhoods is raised. The concern is a valid one today. However, with urban horizontal at-grade space at a premium, the only alternatives for fixed guideway or steerable mode ROWs (streets) is elevated, below ground, or more urban sprawl. Historically, new transportation technologies have been greeted with resistance, until they could prove their benefits above and beyond the existing state of the art modes. Iron horses, horseless carriages, heavier-than-air machines, and iron-clad ships each had to overcome initial antagonistic static inertia of societal mind-sets.
with the individual efficiencies that each mode had to offer. Once proven, each one was quickly grasped by society. PRT guideways, as proposed by CabinTaxi or Taxi 2000 use horizontal beams that are only one lane wide. Taxi 2000 beams are only 36 inches wide and 36 inches tall since their vehicles operate only on top of beams. CabinTaxi vehicles can operate in opposite directions on the top and bottom of a beam (or on only the top or bottom), and therefore the beams are approximately 72 inches wide and 63 inches tall. The technical requirements of average stations allow for relatively small footprints, taking only enough ground space to accommodate an elevator shaft to the elevated platforms and enough mass around the shaft to support the platform and guideways. A five car platform would likely be in the range of 55 feet long and be able to accommodate an estimated 800 vehicles per hour. Additionally, a significant benefit of PRT station design is its intended installation, not as free-standing structures, but rather adjoined to existing buildings or incorporated into a building as part of new construction. Ironically, a significant issue that was not addressed by OTA, is what would likely be the exorbitant costs for ROW acquisition and air rights. This particular issue is one which seems to have been overlooked by both the evaluating groups and PRT proponents, and is the one question which should be closely scrutinized before further developing the technology with the intent of constructing a mature network.

The third and fourth social concerns are focused on environmental impacts and whether providing such a high level of transportation at public expense would result in benefits accruing only to the "well-to-do", or whether the benefits would be available to provide for "the needs of the transit disadvantaged".

Evaluating the grand-scale costs of the alternatives to PRT is likely to make PRT more acceptable. For example, even if a totally non-polluting motor for automobiles is available tomorrow, and the current IVHS projects are successful and available for implementation in one fourth of the 30 year estimates (for some of the more effective Advanced Vehicle Control Systems), air quality would be greatly improved, but congestion would likely increase due to society's perceived reduction of any need to limit Single Occupant Vehicle trips. What are the projections for auto ownership and "number of licensed drivers" during the next 30 years, and how might they relate to future congestion, and the resultant expenditures for road construction, and highway maintenance.

Also, IVHS is currently designed to be deployed in a manner that is funded similarly to the current aviation industry, a method which does not reflect
equitable allocation of resources. Aviation is heavily subsidized by federal funds and economically accessible, readily, only by the upper-middle class, upper class, and business. A significant flaw in the IVHS concept is that the systems will be funded with federal money but individuals will have to purchase specially equipped vehicles and maintain them in a manner that makes them able to interface with IVHS technology. How likely is it that the middle class and below will be able to afford maintenance costs associated with IVHS equipment as well as be able to maintain their vehicles in a road worthy condition? If an IVHS vehicle is being operated on a special freeway lane at 65 mph and is automatically controlled to follow a downstream vehicle within (ex.) 5 feet, what happens to a stream of traffic when something as simple as someone’s "bald tire" goes flat or a radiator overheats? And how will "spot weather conditions" be efficiently managed by IVHS. Icy and wet highways may result in highway-side IVHS equipment automatically reducing speeds through an area, but a variety of carbon control systems are necessary to prevent skids. In contrast, a privately or publicly owned and operated PRT system can assure that preventive and predictive maintenance is conducted in a manner that promotes system efficiency. PRT designs incorporate guideways that economically eliminate the effects of adverse weather. And PRT guideways, by design, eliminate the need for concern with lateral control.

Institutional Issues

The OTA report focused on the possibility of international joint-development potentials. However, since almost all research has ceased since 1980, the current feasibility of such agreements is not likely. Currently, CabinTaxi, Inc. (USA) has direct access to the research conducted by the German CabinTaxi project, one with estimated expenditures in the range of $70 million (1975).

PRT FEASIBILITY

Why has further PRT evaluation not been promoted by consultants, design engineers, or urban planners?

Promoters of the systems believe that many well-respected persons in the transportation field were against PRT/CRT in its early stages of development, claiming that it was not technically or economically feasible, Having committed themselves to a position of opposition, they are reluctant to change their positions.

Both Vuchic (1992) and Henderson (1992) were involved in the initial OTA assessment. Vuchic currently dismisses PRT as being incapable of meeting urban
needs because of the investment intensive nature of the necessary infrastructure and the low transporting capacity of small vehicles. While the expense of the infrastructure may be a valid concern, the capacity of a mature PRT network can handle greater volumes of passengers with a higher quality of service than conventional systems. Henderson refers to a theoretical PRT system, designed in 1968 for San Francisco, to dismiss PRT as too expensive for practical deployment. The theoretical system was generated by the Aerospace Corporation, and has not been refined to reflect the real geographic conditions of the proposed service area. It uses a grid, which is useful for conveying the PRT concept, but is not likely to be realistically practical. As a result, the cost estimate is likely to be high.

Another explanation for lack of interest in PRT is based in the belief of promoters that those who oppose PRT have not taken the time to closely scrutinize it and learn how the apparent microcosmic disadvantages are offset by the real macrocosmic advantages. The beliefs of the promoters can be supported. In the 1983 International Transit Compendium (formerly the Lea Transit Compendium), Japanese CCVS and German CabinTaxi were reported as;

"...ready for small urban demonstration projects. As of 1983, however, there is no PRT system in passenger service in the world and no plans to implement one in the future."

Then, in the January 1989 Houston Connector System Technology Assessment by Lea+Elliott, PRT is eliminated in one paragraph in which the 1983 quote appears again. Further reason is given;

"(because)...Its development has not proceeded beyond the test track and there are no known suppliers..."

This is true, and jumping from the test track to regional deployment would not be "uncertainty avoiding", and therefore is politically ill advised. However, the technical reasons provided for dismissing PRT seem to indicate a miscomprehension of PRT theory;

"In addition, the PRT technology, at a maximum line capacity of 4,800 pphpd, will not meet even the required initial line capacity of 8,000 pphpd, and its maximum cruise speed at 30 mph falls short of the required 50 mph."

While one PRT link may carry only 4,800 people, the network capacity is much higher and a mature network, as would be required for Houston, would not have all vehicles routed onto one link. And the maximum PRT cruise speed (which is slightly
faster than the average cruise speed) rivals systems with 70 mph maximum speeds, as described previously in this paper.

Local Planning Issues

While the OTA assessment evaluated PRT from a federal funding perspective, little was written regarding the local planning issues and potential impacts. As mentioned earlier, the cost of ROW acquisition must be thoroughly assessed, and this can only be performed at the local level on a case by case basis.

Local institutional issues regarding PRT ownership and political issues resulting from a mature network being able to maximize its efficiency by operating in many different political jurisdictions have to be addressed.

A comprehensive evaluation of PRT feasibility must recognize that it will not replace all automobile trips. PRT does well at accommodating single purpose trips such as home to work or school, and some home to shop/recreation trips. Multi-purpose trips often require an automobile to provide temporary secure storage, such as dropping off a TV for repair, then picking up dry cleaning, then going shopping at the "mall", and finally going to the grocery store.

Implementation of PRT will alter land use planning and densities. Current mass transit systems often create congestion near major stations or corridors. They also contribute to high land costs for parcels within the "magic" 0.25 mile perimeter surrounding a station (the average American will not walk more than 0.25 miles to access public transportation). PRT would tend to disperse development and can economically serve already dispersed development in a way that would contribute to reducing congestion in narrow corridors.

In conjunction with elevated stations that can adjoin buildings, a change in retail space allocation would appropriately occur. Issues of second and third story building design/usage/privacy would have to be addressed.

An adverse component of PRT would likely be the impact of installing support columns along existing sidewalks. Close attention to how closely the columns could safely be placed near existing roads or how far from a curbline a column should be placed is necessary. Also, fire safety codes and vehicle proximity to buildings must be evaluated.

Environmental

Environmental impacts of elevated PRT guideways are likely to be significantly different than roads or other mass transit guideways. The high vehicle capacities of a narrow, light-weight, single beam can replace two lanes of freeway capacity,
not to mention the capacity of an entire PRT network deployed throughout a region. PRT requires no de-icing chemicals in winter, and uses steel and concrete for major repair, not volatile petroleum based asphalt products.

As an electrified system, air pollution is confined to increases at electrical generating plants where efficiencies of combustion can be controlled and raised to much higher levels than the levels of individual power generating systems on many personal vehicles. And by utilizing back-up generators, both uninterruptable power supply and peak electrical demand leveling can be provided. Further, the PRT operating characteristic of Origin-Destination non-stop transit contributes to energy efficiency. Energy losses from repetitive acceleration and deceleration of heavy vehicles is eliminated. In fact, energy consumption is so low, that CabinTaxi design allows for the possibility of implementing PRT and CRT on the same network. Since one person in a continuously moving twelve passenger vehicle requires insignificantly more energy than one person in a six passenger vehicle the two modes can operate simultaneously, and thereby increase network capacity. During peak travel, the network would operate in a CRT mode, and during base and evening hours, the same vehicles can operate in a PRT mode.

Noise from traffic horns, train horns, rubber tire squeal, steel wheel squeal, vehicle exhaust systems, and heavy vehicle rumble (vibration) are significantly if not completely eliminated. Additionally, several PRT guideway systems "nest" the suspension systems of the vehicles inside the guideway in a manner that utilizes the beam as a sound barrier.

Conclusion

Urban transportation planning, growth patterns, and technologies interact with each other as society and technology evolve. Transportation planners can provide better services if minimizing a passenger's total trip time is emphasized over the current emphasis of minimizing trip time on a series of multi-modal trip links.

PRT and small vehicle CRT are overdue for another close evaluation. The advances in technology during the last 20 years combined with changing American urban growth patterns indicate that PRT benefits seem to be improving and concerns are less valid. A new demonstration project will provide data upon which an up-to-date evaluation can be based. Although a thorough evaluation will be difficult, a best-effort attempt utilizing teams of a variety of professional experts, comprised of PRT proponents as well as PRT opponents, is the best way to determine the current viability of PRT as a new urban transportation mode.
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