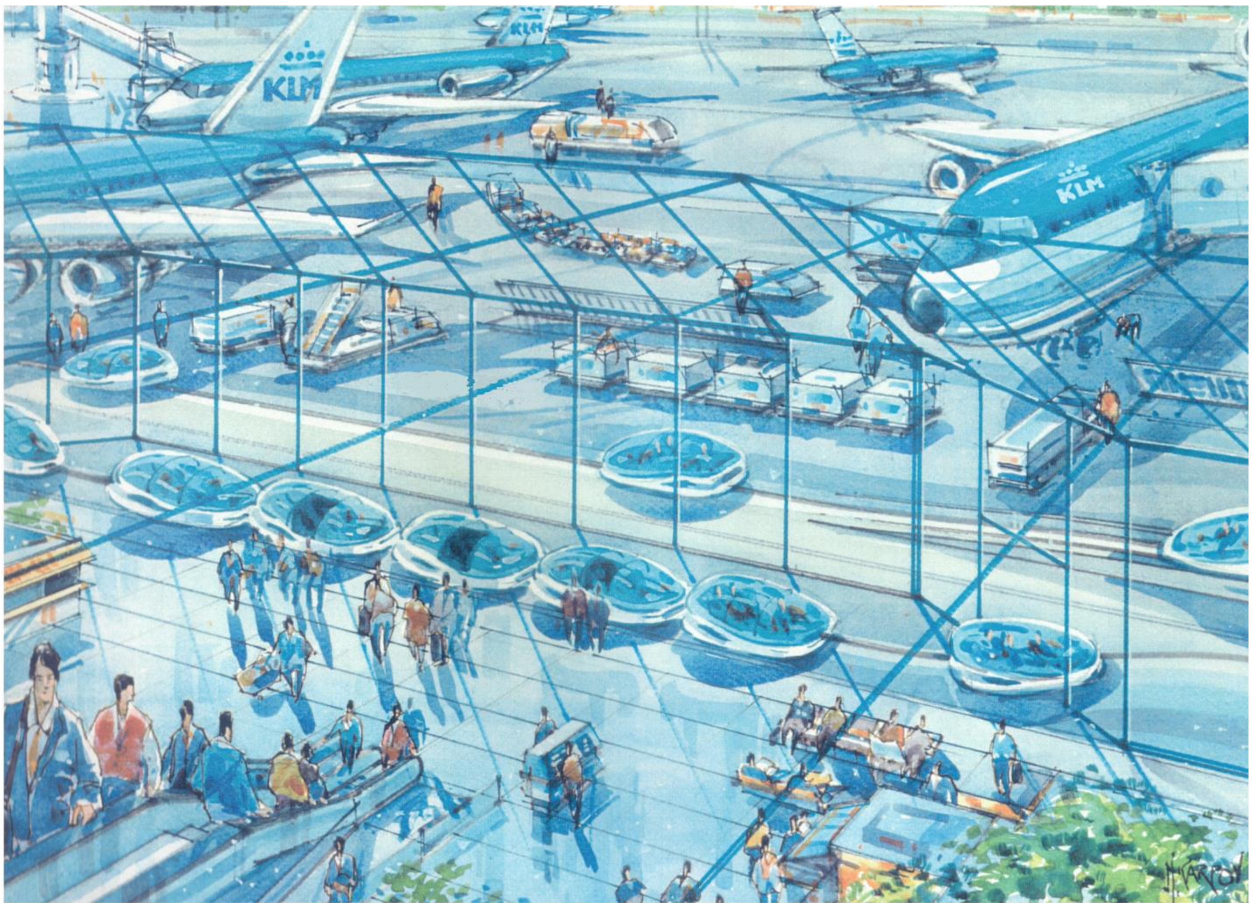
Business Plan

Commercialization of

An Intelligent Transportation Network System

"ITNS, LLC"



March 2019

Mission

To provide safe, reliable, and comfortable mobility while reducing congestion, air pollution, energy requirements, the need for oil, the land needed for transportation, and transportation costs.

Goal

To produce, install, and maintain the world's most system-engineered transit system in a variety of expandable applications in a highly competitive worldwide market.

Values – Follow the Engineers' Creed

- Give the utmost of performance,
- Participate in none but honest enterprise,
- Live and work according to the laws of man and the highest standards of professional conduct,
- Place service before profit, the honor and standing of the profession before personal advantage and the public welfare above all other considerations.

Contact

J. Edward Anderson, PhD, P. E.

Managing Director and Principle Developer

5164 Rainier Pass NE

Fridley, MN 55421

(763) 586-0877

jea.p.e.phd@gmail.com

Contributions to the Development of Personal Rapid Transit,

www.advancedtransit.org/Library/Books

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APPENDIX A: Detailed Task Descriptions

Executive Summary

ITNS is a totally new form of public transportation designed to provide a high level of service safely and reliably over an urban area of any extent in all reasonable weather conditions without the need for a driver's license, and both maximizes ridership and minimizes cost, energy use, material use, land use, and noise. Being electrically operated it does not emit carbon dioxide or any other air pollutant, and requires no oil.

This remarkable set of attributes is achieved by operating light-weight, sub-compact-auto-sized, automatically controlled vehicles on a network of minimum-weight, minimum-size, exclusive guideways with all stations off-line. To achieve reliable all-weather operation, the system uses non-contact linear induction motors.

Major Requirements for *ITNS*

The new system will

- Attract many more riders.
- Have adequate capacity.
- Reduce congestion.
- Increase access to the community.
- Operate where conventional transit can't operate.
- Not add to environmental pollution.
- Be as inexpensive as practical.
- Save energy.
- Be safe, reliable, and comfortable.
- Operate in all reasonable kinds of weather.

Dr. J. E. Anderson designed and supervised the construction of the fully automatic, linear-induction-motor powered ITNS vehicle shown here for a budget of only $600,000 and 6 months from the order to proceed to operation. The vehicle operated on a 60-ft section of covered-steel-truss guideway at the 2003 Minnesota State Fair 12 hours per day for 12 days with no failures. It worked exactly as designed.[1]

Here is the builder of the vertical chassis with the linear-induction-motor set not yet installed.

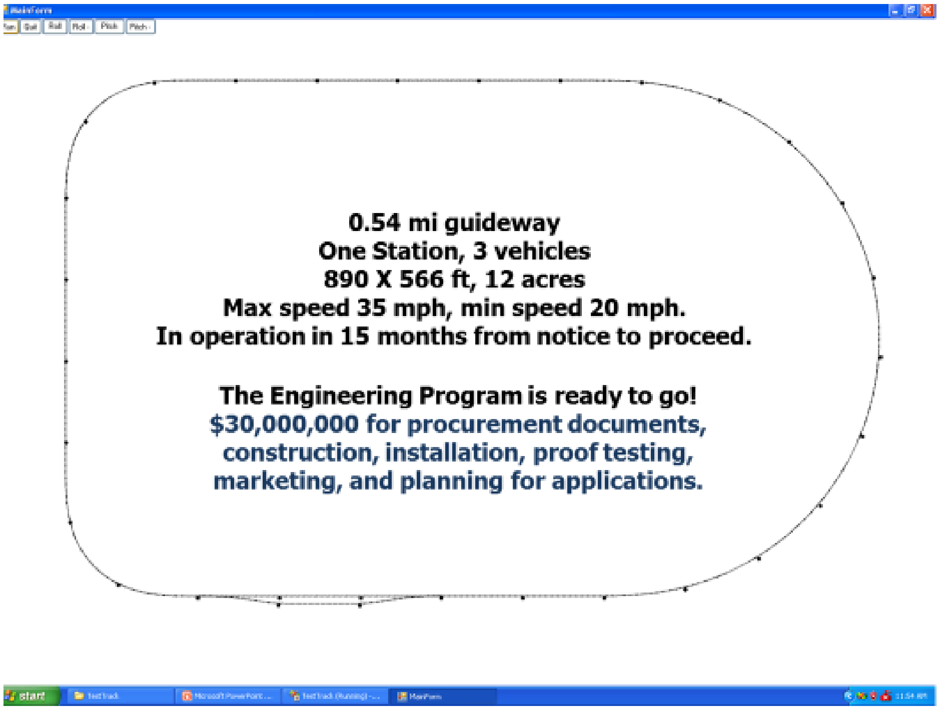
[1] The history of this project is given in the internal paper "How to Reduce Congestion and Save Energy."

Attributes of *ITNS*

- Off-line stations.
- Fully automatic control.
- Minimum-sized, minimum weight vehicles.
- Small, light-weight, generally elevated steel-truss guideways.
- Capable of operation in networks of guideways of any configuration.
- Vehicles ride above guideway to minimize cost and maximize both rider comfort and speed range.
- Hierarchical, modular, asynchronous control to permit indefinite system expansion.
- Dual duplex computers for high dependability and safety.
- Accurate, dual position and speed sensors.
- Dual linear-induction-motor propulsion and braking for all-weather operation.
- Smooth running surfaces for a comfortable ride.
- High-pressure, rubber-tired wheels to minimize guideway cross section and weight, and to minimize road resistance and noise.
- Switching with no moving track parts to permit reliable, no-transfer travel in networks.
- Guideway support-posts separated by at least 90 ft (27 m) to meet planning requirements.
- Propulsive power from dual wayside sources for high system reliability.
- Adaptable to all renewable energy sources.
- Well lit, television-surveyed stations to insure passenger security.
- Nonstop trips with known companions or alone.
- Adequate speed, variable with application and location in a network.
- Vehicle movement only when trips are requested.
- Automatic empty-vehicle rerouting to fill stations.
- Planned & unplanned maintenance *within the system.*
- Full compliance with the Americans with Disabilities Act.

These attributes are derived in my presentation entitled "How to Reduce Congestion and Save Energy," which should be the first of my papers studied by anyone seriously interested in commercializing my system. This paper gives references to details found in my three-volume 1500-page book *Contributions to the Development of Personal Rapid Transit.*

The Key to a New Multi-Billion-Dollar Industry



The Engineering Program for the Demonstration Facility is ready to go!

$45,000,000 for final design specifications, procurement engineering, manufacturing, assembly, test, marketing, and planning for the first system.

Why the Proof Testing and Demonstration Facility?

- To verify system capital and operating costs with a current team of engineers.
- To demonstrate safety and reliability in advance of the first application.
- To verify ride comfort before the first deployment.
- To allow time to organize for a large business.
- To provide a facility for training engineers, planners and technicians.
- To provide assurance that the first operating system will be successful.
- To correct errors before the first people-moving deployment.
- To provide a controlled environment in which artificially induced test conditions can exceed normal parameters.
- To enable an insurance company to establish a liability rate.
- To test possible improved and more cost-effective components in a controlled environment away from people-moving operations.
- To educate consulting firms asked to evaluate the system.
- To establish the system as “proven technology” for comparison with other transit technologies in major investment studies.

The Business Plan

1. Need for a New Solution to Ground Transportation

In their book *The Urban Transport Crisis in Europe and North America,* John Pucher and Christian Lefèvre, discussing only conventional transportation, concluded with this grim assessment: “The future looks bleak both for urban transport and for our cities: more traffic jams, more pollution, and reduced accessibility.”

During a luncheon attended by the Northeastern Illinois Regional Transportation Authority (RTA) Chairman it was agreed that “*We cannot solve the problems of transportation in the Chicago Area with just more highways and more conventional rail systems.* There must be a rocket scientist out there somewhere with a new idea!” The Illinois Legislative Act that established the RTA had given the new agency an obligation to “encourage experimentation in developing new public transportation technology.”

2. Systems Engineering Approach used by Rocket Scientists

Thoroughly understand the *Problem* and *Requirements* for a solution.
Let <u>System Requirements</u> dictate the technologies.
Identify all alternatives in all tradeoff issues <u>without prejudice</u> and with <u>absolute objectivity</u>.
<u>Thoroughly analyze</u> all reasonable alternatives for each issue until it is clear which best meets all technical, social, and environmental requirements.

This is Systems Engineering! More details are found in “16 Rules of Engineering Design.”[2]

ITNS is superior to alternatives because of rigorous application of these Rules.

3. Major Requirements

In more detail than given in the Executive Summary:

- Costs low enough to be recovered from fares and other revenue.
- Highly efficient operation in networks and with renewable energy sources.
- Time competitive with urban auto trips.
- Low air and noise pollution.
- Visually acceptable.
- Adequate capacity.
- Low material use.

[2] This paper and the others referenced can be found in a 1500-page, 3 volume work called “Contributions to the Development of Personal Rapid Transit” by Dr. Anderson. The first volume can be downloaded from the web site www.advancedtransit.org/Library/Books.

- Low energy use.
- Low land use.
- Safe.
- Secure.
- Reliable.
- Comfortable.
- Attractive for riders.
- Available always.
- Expandable in networks without limit.
- An unattractive target for terrorist attacks.
- Compliant with Americans with Disabilities Act.
- Operational in all kinds of weather, except for extremely high winds.

4. Major Tradeoffs (Available under footnote #2.)

1. Exclusive Guideway vs. Mixed Traffic
2. In Vehicle vs. In Track Switching
3. Small Vehicles vs. Large Vehicles
   J. E. Anderson, "Optimization of Transit System Characteristics."
4. Off-line vs. On-line Stations
   J. E. Anderson, "The Intelligent Transportation Network System."
5. Captive Vehicles vs. Dual Mode
   J. E. Anderson, "How does Dual Mode Compare with Personal Rapid Transit?"
6. Supported Vehicles vs. Hanging Vehicle
   J. E. Anderson, "The Tradeoff between Supported vs. Hanging Vehicles."
7. Suspension on Wheels vs. Magnetic Suspension (Maglev)
   J. E. Anderson, "Maglev vs. Wheeled PRT."
8. Propulsion by Linear Motors vs. Rotary Motors
   J. E. Anderson, "Safe Design of Personal Rapid Transit Systems."
9. Linear Induction Motors vs. Linear Synchronous Motors
   J. E. Anderson, "LIMs vs. LSMs for PRT."
10. Motors in Vehicles vs. Motors in the Guideway
    J. E. Anderson, "Motors on Board vs. Motors in Guideway"
11. Power Source at Wayside vs. On Board
    J. E. Anderson, "Power source on board vs. power source at wayside"
12. Guideway Narrow vs. Wide
    J. E. Anderson, *Transit Systems Theory,* Lexington Books, Chapter 10.
13. Control Asynchronous, Synchronous, Quasi-Synchronous, or Trans-Synchronous
    J. E. Anderson, "Control of Personal Rapid Transit Systems."
14. Control Point Follower vs. Car Follower
    J. E. Anderson, **"**Overcoming Headway Limitations in Personal Rapid Transit Systems."

Acknowledgement

Dr. Anderson's work on PRT has been inspired by a great deal of work of other engineers, which became known to him via chairing four international conferences on PRT, editing many of its papers, study of the work of every investigator known to him, and by visits to developers of almost every other PRT system under development anywhere in the world. He has often mentioned that the PRT work of The Aerospace Corporation led by its Vice President Dr. Jack Irving is particularly outstanding and that he would likely have stopped working in the PRT field long ago if it had not been for the work of Dr. Irving and his colleagues, which could not continue because of lack of government support. The references given above show that the author of this plan has contributed strongly to understanding of each tradeoff issues.

5. Result: *ITNS*

The background of, reasons for, and description of ITNS can be obtained from the following papers:

J. E. Anderson, "Optimization of Transit-System Characteristics," *Journal of Advanced Transportation*, 18:1(1984):77-111.
J. E. Anderson, "A Review of the State of the Art of Personal Rapid Transit." *JAT*, 34:1(2000):3-29.
J. E. Anderson, "The Future of High-Capacity Personal Rapid Transit," European Conference, Bologna, Italy, AATS 2005.
J. E. Anderson, "An Intelligent Transportation Network System."

These papers can be found in the document mentioned in footnote #2.

6. Benefits

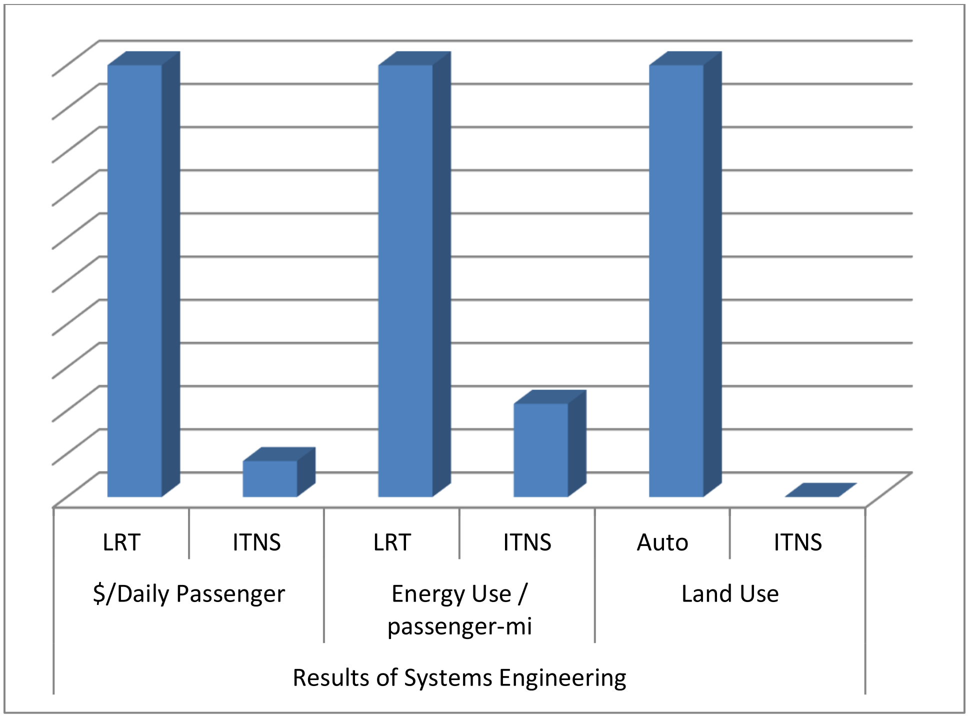
For the Individual User

- The system is easy for everyone to use. No driver's license is needed.
- The vehicle has room for three adults and two children.
- Vehicles wait for people, rather than people for vehicles.
- Travel is cost competitive.
- The trips are short, predictable, and nonstop.
- Average rush-period waiting less than a minute and off-peak waiting zero.
- Everyone has a seat.
- The system is available at any hour.
- The vehicles are heated, ventilated, and air conditioned.
- There is no crowding.
- There are no vehicle-to-vehicle transfers within the system.
- The ride is private and quiet.
- One can use a cell phone, text message, read, view scenery, or meditate.
- The chance of injury is extremely remote.

- Personal security is high.
- The ride is comfortable.
- There is space for luggage, a wheelchair, a baby carriage or a bicycle.

For the Community

- By using off-line stations and nonstop trips, the system will attract around 10 times the ridership achieved by conventional all-stop transit.
- By applying modern systems engineering to minimize costs, the revenue produced by the system through reasonable passenger fares, freight hauling and focused advertising will in many applications substantially exceed all costs.
- By use of linear induction motors, the all-weather level of safety achieved far exceeds that possible if acceleration and braking relies on friction of the running surface.
- **Land savings is huge** – 0.02% is required vs. 30-70% for the auto system, and only 3.5% of right of way needed for surface-level rail. This is the key factor in the ability of ITNS to reduce congestion.
- Energy use is very low.
- The system can use any kind of renewable energy.
- There is no direct air pollution. Being more than twice as energy efficient as the auto system and by using renewable energy, total air pollution will be reduced substantially.
- The system is attractive for many auto users, thus reducing congestion.
- Because every trip bypasses intermediate stations, stations can be spaced closer together without slowing the average speed, thus providing both increased access to the community and competitive trip times.
- Stations can be sized to demand, thus decreasing capital costs.
- As to accidents, no one can say that there will never be an accident, but the rate per hundred-million miles of travel will be less than one trillionth of that experienced with autos.
- Seniors, currently marooned, will have much needed mobility and independence.
- *ITNS will augment and increase ridership on existing rail or bus systems.*
- By spreading the service among many lines and stations, there are no significant high-value targets for terrorists.
- More livable high-density communities become possible.
- A pleasant ride is provided for commuting employees, thus permitting them to arrive at work rested and relaxed.
- More people-attracting parks and gardens become possible.
- Safe, swift movement of mail, goods and waste.
- Easier access to stores, clinics, offices and schools.
- Faster all-weather, inside-to-inside transportation.
- More efficient use of urban land.



7. Market-Opening Project

All the research and development work needed to define ITNS in detail has been completed. The necessary next step to prepare for entry into a very large market is to build and operate an ITNS system of sufficient but not excessive size to demonstrate continuous, safe, reliable, comfortable, and secure operation at expected speeds in all weather conditions except extreme winds. This requires construction of the oval guideway described in the **Executive Summary**, which is sufficient to attain continuous speeds up to 75 mph.[3] One off-line station and three vehicles are enough to prove all technical features of the system.

To complete the demonstration, it is necessary to recruit and educate a group of engineers who will develop procurement specifications for ITNS and its components, direct their procurement or manufacturing, direct the assembly and test of the first fully operational system. The project is divided into 12 parallel tasks so that each engineer involved need become familiar in detail with only a small portion of the entire project, thus making it practical to move quickly into a new area.

[3] If the client wants a different line speed, the test track can be revised in seconds.

8. Tasks that must be completed to Commercialize ITNS

Task #1: Management and Systems Engineering.

Task #2: Safety and Reliability assurance.

Task #3: Cabin.

This task will be subcontracted, likely to the Pasadena School of Design.

Task #4: Chassis.

The design and manufacturing will be done internally. Components will be obtained from known sources.

Task #5: Guideway and posts.

These components will be subcontracted. The posts are a specialty item that may be subcontracted to a firm such as Millerbernd, Winstead, MN.

Task #6: Guideway covers.

This is a specialty item that will be subcontracted.

Task #7: Control system.

Task #8: Propulsion and braking.

We intend to purchase LIMs from Force Engineering, Ltd.

Task #9: Wayside power.

Power rails will likely come from Insul-8.

Task #10: Civil works – station, maintenance facility, foundations.

Task #11: Test program.

Task #12: Planning and marketing for the first operational people-moving application.

The 1500 pages of analysis and specifications mentioned in Footnote #2 back up the program!

9. Technical Skills needed to Commercialize *ITNS*

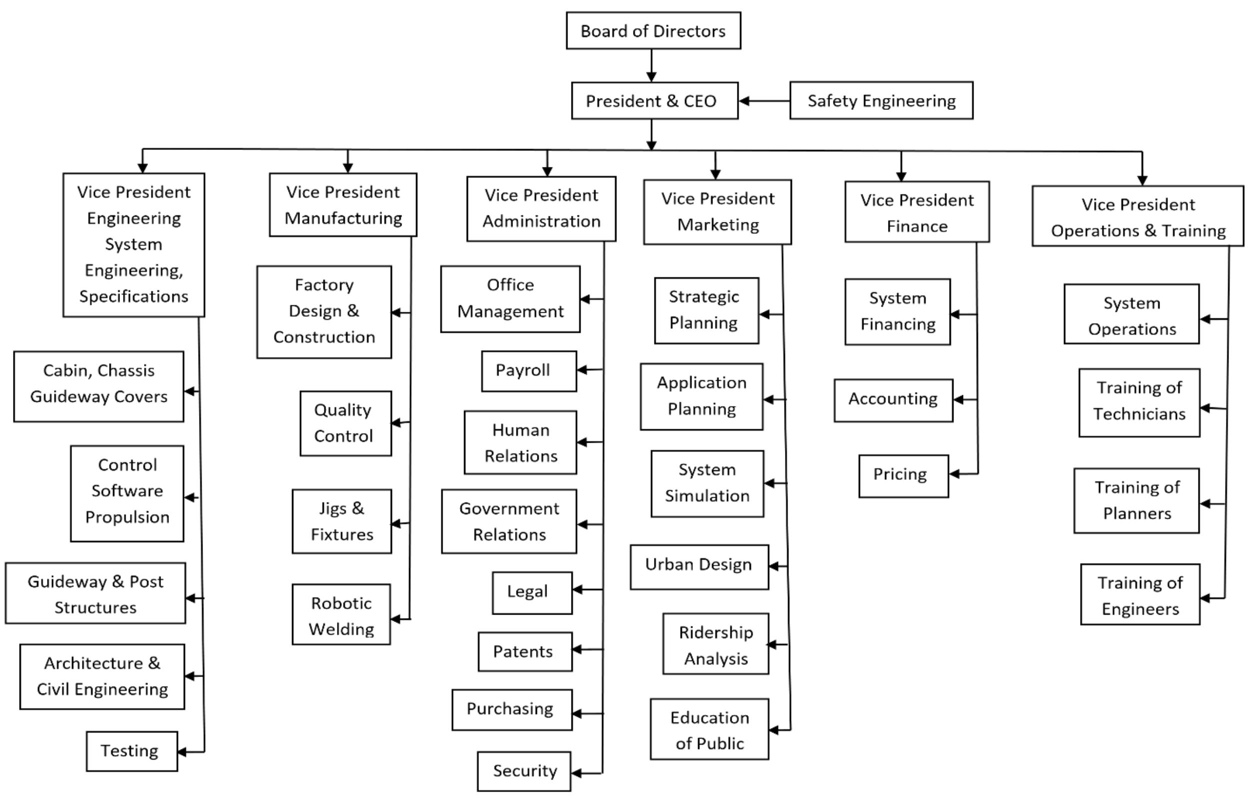
Area of Responsibility	Tasks	Skills Required
Systems Engineering	Responsibility for coordination of all aspects of the design.	Proven experience in systems engineering.
Standards	Review all applicable standards and report specific system and component requirements to the project managers.	Experience in dealing with engineering standards
Safety & Reliability	Responsibility for all aspects of system safety, dependability, hazard analysis, fault-tree analysis, and failure modes and effects analysis. Documentation of all procedures used to insure safety in keeping with accepted standards for operation of automated transit systems. Based on existing information and methodology, develop and maintain a model for calculating system dependability.	Strong experience in system safety and reliability engineering.
Weight & Cost Control	Develop computer models for weight control of the vehicle and cost control of the system. Maintain contact with all subsystems designers to keep models up to date. Report to project director and operations officer any deviations from target weight and cost. Develop model for calculating operation and maintenance costs.	Industrial engineer with at least five years of experience. Strong analytical ability required.
Vehicle Dynamics	Based on an available program, perform dynamic analysis of vehicle moving through merge and diverge sections of the guideway with the worst combination of side loading (wind + centrifugal) + maximum unbalanced load to verify the required maximum tire loads, tire stiffnesses, switch placement, flared switch rails, and ride comfort requirements.	Mechanical engineer having experience with computer tools for dynamic analysis.
Finite-Element Analysis	Perform FEA to finalize the specifications of the post-guideway bracket, the switch arm, and the chassis-cabin attachments.	Extensive experience with FEA tools.
Test Program	Review available descriptions of all necessary tests, define the test program, supervise all testing and document the results.	Engineer with proven experience in test engineering.
Control System	The software for the system and vehicle control has been defined and the required types of hardware have been identified. Based on this information,	Operational computer software and hardware experience. Understand-

	complete the design of the operational software and hardware, supervise procurement and installation of the components in the test system, update the test plan, and supervise testing.	ing of differential equations and engineering mechanics.
Propulsion & Power System	Specify LIM-VFD system and power-supply and distribution system, both on-board and at wayside. Identify suppliers and work with them to finalize the designs. Supervise installation in test system.	Electrical engineer with experience in power systems.
Guideway, Posts & Foundations	Perform computer verification of the guideway & post design. Develop post-foundation design. Coordinate space requirements inside guideway with the chassis designer. Develop the final design and drawings. Specify and supervise design of computerized jigs, fixtures, and robotic-welding equipment for guideway fabrication. Help select the fabricator & supervise fabrication.	Structural engineer with experience in use of computer structural analysis & design tools.
Vehicle Chassis	The chassis includes wheel-axle-bearing assemblies, LIM & VFD, shock absorbers, switch assembly, parking and emergency brake, mounting of power-pick-up shoes and transevers, equipment compartment for control and a/c components, frame, wiring, and interface with cabin. Develop final design drawings, find necessary suppliers, and supervise fabrication.	Mechanical engineer with vehicle-system experience including computer tools for dynamic analysis of vehicle systems.
Vehicle Cabin	Review the design requirements. Finalize bid documents and find cabin designer and fabricator. Work with fabricator to develop and build the final design. Supervise fabrication. Consider styling, structural design, thermal design, material selection, human factors, HVAC, aerodynamics, seat, automatic door operation and its fatigue testing, lighting, push-button controls, interface with chassis.	Mechanical engineer with experience in vehicle design.
System Planning & Design	Responsible for planning and design of specific applications including computer-graphics simulation of portions of system, and operational simulation to determine system performance, size and layout requirements. Estimate ridership. Coordinate and negotiate with clients. Market systems.	Transportation engineering preferably with prior experience with PRT systems. Strong analytical ability.
Director	Overall direction, supervision, and education of systems engineering team.	Extensive experience in quantitative PRT systems analysis, planning and design.

Operations Officer	Responsible for daily coordination, facilitation and expediting.	Engineering background with experience in project planning and expediting.
Contracts and Purchasing	Responsible for negotiating contracts and for purchasing of components and subsystems.	Experience with engineering contracts and purchasing.
Support	Develop and support for maintaining financial and accounting records and project controls. The human-resource functions also fall under this responsibility.	Previous experience in support management.

10. Organization for the Demonstration Program

The proposed organizational structure is as shown in following chart. Over the first six months, we expect the organization to grow to about 20 engineers plus about six to ten members of the support staff. In a year, we expect the staff to grow to a total of about 50 people.



11. The Industry

1. **System Owner**. This could be a public or private entity, and is responsible for seeing that the system is operated satisfactorily, which includes concern for safety, reliability, ride comfort, cleanliness, public relations, advertising, fare collection, etc. With a financial partner with substantial resources, the combined entity may wish to take on this role. The owner will of course enjoy much of the profit from all applications.

2. **Marketing**. Without marketing, there can be no business. Marketing will insure that knowledge and characteristics of *ITNS* become widespread. It will be necessary to prepare videos, CDs, print material, displays, virtual-reality presentations, etc.; attend and participate in conferences and trade shows; meet one-on-one with potential clients; arrange presentations; and do all that is necessary to find clients interested in purchasing an *ITNS* system so the site-planning-and-design team can go to work.

3. **Financing**. The function of this group is to locate, secure, and manage the financing necessary to build specific systems; and to set the system price.

4. **Site Planning and Design.** Each application will require a team of architects, engineers, and planners to work with local officials to locate lines and stations, perform ridership analysis, simulate the operation, and do the detailed design needed to provide plans to the general contractor, who will supervise the installation. There are many transportation-consulting firms that do this work under contract.

5. **Specification Development and Supervision.** This is the primary engineering task needed to insure safety, reliability, ride comfort, service and cost containment. It is a task that is never finished because there will be a continual stream of new ideas, products, procedures, and materials that must be considered and incorporated in specifications for new systems to stay ahead of competition and maximize profit for the owner. This function can also be called research and development. It encompasses the core engineering, and will include experts in all the hardware and software subsystems who will gather and analyze information on the performance of existing systems, recommend improvements, design and supervise testing, and follow new developments that may be advantageously incorporated into the system. People in this division will maintain cost, weight, and dependability models of the system.

6. **Manufacturing**.

   a. <u>Chassis</u>. This is a stainless-steel frame to which are attached the wheels, motors, control components, switch, parking brake, bumpers, and an air-conditioning compressor. The assembly and testing of the chassis is critical to performance and safety. The chassis frame and all its components will be subcontracted and will be assembled and tested internally.

b. Cabin. The design will be subcontracted to a firm experienced in vehicle design and construction, under our specifications.
c. Guideway. Subcontract to a structural design firm that will use computer tools to finalize the guideway and posts. With our concurrence, he will select a steel fabricator skilled in precision bending of steel and capable of using and possibly designing the necessary computerized jigs, fixtures, and robotic welding facilities. While the chassis and cabin are standard items, the shape of the guideway varies to match the curves, hills and speeds of each application. Thus, there will be a regular flow of data on the coordinates of guideways to the steel fabricator that will require close coordination, cooperation and inspection.
d. Station. There will be a wide variety of station designs depending on the needs of the owner or community in which the system is to be built; however, there needs to be a standardized prefabricated design for those who wish to minimize cost while meeting requirements, including those to accommodate persons in wheelchairs, blind, deaf, and other types of disability. We will be responsible for developing and maintaining specifications for the equipment needed in the station, which includes destination selection, fare collection, elevator, lights, video surveillance, motion detectors, voice communication system, and a standardized design of the station building with its details subcontracted to a qualified architect.
e. Ticketing System. Destination selection and fare collection are aspects of the ticketing system. Its specifications differ from those required in a conventional rail system.
f. Power Supply. This equipment is commercially available and will be specified by the consulting firm doing the site design.
g. Propulsion and Braking. Linear induction motors and variable-frequency drives are commercially available.
h. Communication and Control. The hardware is composed of available commodities. The system-control software has been simulated, proven, and must be maintained.
i. Maintenance Facilities. The maintenance operations, layout and use of automated equipment must be carefully designed. While preliminary designs have been developed, this task is best subcontracted to a firm expert in such operations. The facilities will be built under the supervision of a general contractor retained to install the whole system.
j. Vehicle-Storage Facilities. There are many configurations in which vehicles can be stored. The design is likely to be site-specific under the supervision of the general contractor. Storage need not be in heated buildings. Minimum storage can be along a siding with a low-cost roof and siding to keep snow and ice off the vehicles in the winter and the sun off them in the summer. There is ample time from retrieval from storage to the nearest station for the cabin interiors to reach the comfort-temperature range before passengers enter.
k. Administration Facilities. These will be built under supervision of the general contractor.

7. **Construction Contractor.** Takes the contract to do all the site preparation and system installation at each site.

8. **System Operator**. It is likely that separate companies will be set up to operate ITNS for a fee from the owner. These companies would do the actual work of maintaining safety, reliability, ride comfort, cleanliness, etc. The core company responsibility will be to set standards and oversee the operations.

9. **Training.** People will need training for system operations, planning and engineering all the way up to the graduate level. It will therefore be necessary to establish *Training Institutes*. Any person to be engaged in systems operations must be a graduate of such an institute. There is much information that a planner needs to know to plan ITNS successfully, so courses for planners will be developed and taken as a prerequisite to assignment to a specific project. Engineers will need more detailed training, so courses of a year or more in duration will be taught.

10. **Government Relations.** There are many regulations and standards that may affect the deployment and operation of ITNS. Thus, the core company needs people skilled in government relations to monitor and lobby to protect the company's interests.

11. **Legal.** There will be a great deal of work related to contracts and agreements, and to be certain that the company does not violate any applicable laws.

12. **Patents.** As the detailed engineering work proceeds, we will look for items that can be patented.

13. **Accounting.**

14. **Administration.**

12. Use of Proceeds

Expenses	$K
Organizing & Training	$1,200
Task #1: Management & System Engineering	$2,400
Task #2: Safety Engineering	$410
Task #3: Cabin	$3,250
Task #4: Chassis	$980
Task #5: Guideway & Posts	$19,800
Task #6: Guideway Covers	$450
Task #7: Control	$1,680

Task #8: Propulsion	$725	
Task #9: Wayside Power	$640	
Task # 10: Civil Works	$1,980	
Task #11: Test Program	$1,220	
Task #12: Application Marketing & Planning	$1,960	$36,295
Land for Demonstration System	$270	
Rent & Utilities	$90	
Travel	$80	
Public Relations	$560	
Legal	$370	
Insurance	$50	
Printing/Binding	$60	
Director Fees	$200	
Other Administrative	$95	$1,775
		$38,070
		$6,930
TOTAL		$45,000

We expect that the demonstration will be fully operational in 24 months from the notice to proceed, and that an additional 6 months will be needed to complete and document the test program. Planning for the first operational system will be initiated as soon as the planning team can be appropriately educated. The first operational segment will begin providing service within 36 months from the notice to proceed with full funding.

13. The Market

The Present State of Urban Mobility

Per ABC News (2014) congestion is the worst it has ever been and keeps getting worse year by year. Americans spend 74.5 million hours stuck in traffic every day. The Federal Highway Administration blames bad road design and conditions for 30% if highway fatalities. Idling cars and trucks emit environmentally unfriendly gases at an alarming rate, while the need to reduce greenhouse gases is more apparent every year. Since 1970, the U. S. population has grown by 32% while the number of licensed drivers has grown by 64%. The number of registered vehicles has grown by 91% and the vehicle-miles travelled by 131%. However, the total number of miles of roads has grown by only 6%. While congestion is bad here, the most congested U. S. city (Los Angeles) ranks only 13th internationally, indicating that the worldwide market for ITNS is very large.

Automated automobiles are much in the news, but they are no substitute for going to a new level on an exclusive guideway. ITNS requires only about 0.02% of the surface land while the auto system requires between 30% and 70%. Moreover, by using linear induction motors for acceleration and braking, the practical minimum safe headway reduces by a factor more than 10 and does not depend on the weather. The land required for each surface vehicle is the cruising speed multiplied by the safe headway. Thus, if the length of ITNS vehicles were the same as the length of self-driving vehicles (ITNS vehicles are shorter), the land required by self-driving vehicles is 10-times the land required for ITNS. These facts result in a huge reduction in land required for ITNS and reflect the need for ITNS rather than autonomous autos to reduce congestion. Moreover, once a trip on ITNS is complete, the vehicle is instantly available for another trip, thus reducing substantially the number of vehicles needed. Per an article in the Wednesday, March 16, 2016 issue of the St. Paul *Pioneer Press*: "Self-driving cars aren't yet able to handle bad weather, including standing water, drizzling rain, sudden downpours and snow, Missy Cummings, director of Duke University's robotics program, said . . . and they certainly aren't equipped to follow the directions of a police officer." In mixed traffic, self-driving automobiles will increase congestion because the minimum safe spacing must be set at the same value by each car company and a manually driven car will slip into the space between two autonomous cars and cause the rear car to slow into the traffic behind. The autonomous car control system must be much more complex than required for ITNS, and faces legal problems not yet solved. ITNS's greatest value is where the roads are congested and there is no room for a bus or train. Autonomous cars can complement ITNS.

Comparisons between Conventional Transit and ITNS

Land Use

Elevated ITNS requires surface land only for the foundations for its posts and for stations. With lines spaced half a mile apart and stations every half mile ITNS requires only 0.02% of the land, whereas the auto system requires about 30% of the land in residential areas and typically upwards of 50% of the land in central business districts. Line by line, surface-level street railways require more than ten times the width required for ITNS.

Figure 1. Surface Land Required for Right-of-Way for Equal Capacity

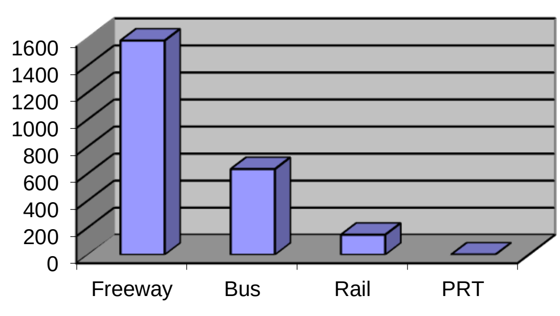


Figure 1[4] gives a comparison between surface-level right-of-way requirements along a single line for

[4] Figures 1 and 2 from Paul Hoffman and Jon Carnegie, *Viability of PRT in New Jersey,* FHWA-NJ-200x-00x, 2006.

three conventional urban transportation modes and ITNS (PRT).

1. A three-lane freeway. With its shoulders, a freeway is about 300 feet wide and can carry 6000 cars in each direction with typical rush-hour occupancies of about 1.1 people per vehicle, or 6600 people per hour per direction. The width requirement per mile is 300(5280) = 1,584,000 sq-ft.

2. A bus system. Assume 30 50-passenger buses per hour (a schedule frequency of 2 min) operating at 80% occupancy on lanes 12 feet wide. With five such lanes per direction the capacity would be 6000 people per hour per direction. A two-way system of that capacity would require 10 lanes, which would require a width per mile of 12(5280)(10) = 633,600 sq-ft.

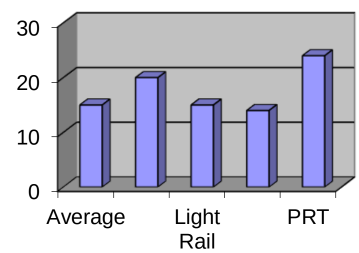
3. A light-rail system. Assume 10 200-passenger vehicles operating each hour in consists of 4 vehicles each at a load factor of 80%. The capacity per direction would be 6400 people per hour. A two-way light-rail line occupies a width of 28 ft, so the land requirement per mile would be 28(5280) = 147,840 sq-ft.

4. ITNS. A fleet of vehicles with an average occupancy of 1.1 persons operating at 0.6 sec headway gives 6600 people per hour. The surface-land requirement is 9 sq-ft for each post-foundation spaced 90 ft apart plus a 500 sq-ft station every half mile, giving a total land requirement per mile of 1528 sq-ft. Unlike the other systems, ITNS does not impede anything that may want to move under the guideway.

Average Speed

Figure 2 shows the reported average speeds of three conventional modes of transit compared with the estimated average speed of an urban PRT system. The speeds of the conventional modes have been obtained from APTA.

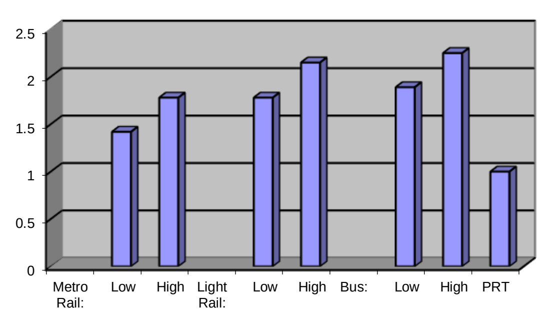
Figure 2. Average Speed, mph



Average Trip Time

The average trip times shown in Figure 3 include for the conventional transit systems typical minimum and maximum wait times including transfer times. Since the average wait time for PRT is very short, here assumed to be one minute, the contrast with conventional systems is even greater than the comparisons of Figure 3.

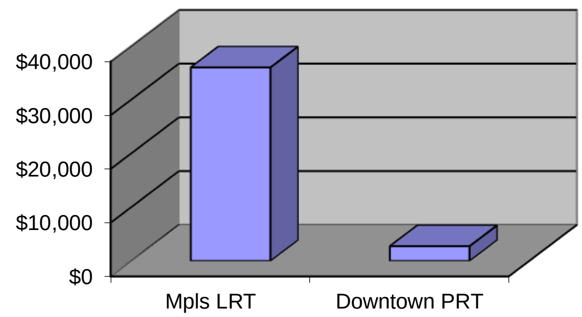
Figure 3. Relative Trip Time



Capital Cost per Daily Trip

The important economic factor in comparing conventional transit with ITNS is the cost per daily rider. The Minneapolis light rail system was reported to have a capital cost of $720,000,000 and it was announced that the ridership would be about 20,000 rides per day, which gives a cost per daily rider of $36,000. An 11-mile ITNS for Downtown Minneapolis was subject to a professional ridership analysis, which resulted in an average estimate of 73,000 rides per week day. A cost estimate, based on vendor estimates, was about $100,000,000 for this system. Since ITNS is new, suppose we estimate $200,000,000. Then its cost per daily rider would be $2740, showing that ITNS would come in at less than one twelfth (8.3%) of the cost per rider of the light rail system. The comparison is shown in Figure 4.

Figure 4. Capital Cost per Daily Rider



Energy Use

The energy use in kW-hr per passenger-mile of seven conventional modes of transit is compared with ITNS in Figure 5.[5] The names of these modes are abbreviated as follows:

HR = Heavy Rail

LR = Light Rail

TB = Trolley Bus

MB = Motor Bus

VP = Van Pool with high vehicle occupancy

DB = Dial-a-Bus

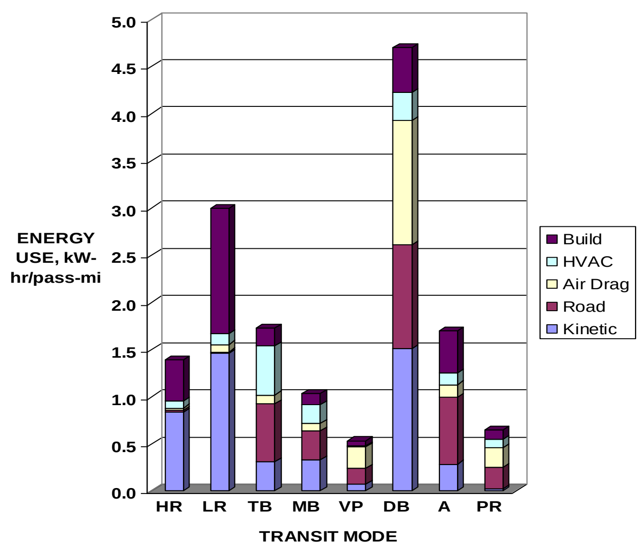


Figure 5. Energy Use.

[5] J. E. Anderson, What Determines Transit Energy Use? *Journal of Advanced Transportation*, 22:2(1988):108-132.

A = Automobile

PR = PRT(ITNS)

The energy input required supplies the kinetic energy of the vehicle; overcomes road resistance and air drag; supplies energy for heating, ventilation and air conditioning; and is needed to build the system.

Summary

ITNS is attractive because of

- Very small land requirement,
- High ridership potential, which together with its low capital and operating cost results in low cost per passenger-mile,
- Energy efficiency that results mainly by eliminating intermediate stops, which means that high average speed can be maintained without going to excessive cruising speed,
- Smaller trip time that results from eliminating intermediate stops,
- Ability to operate from sustainable energy sources, and
- Lack of emissions, which has become more and more important as the need to reduce CO_2 emissions has increased.

Market Size and Growth Rate

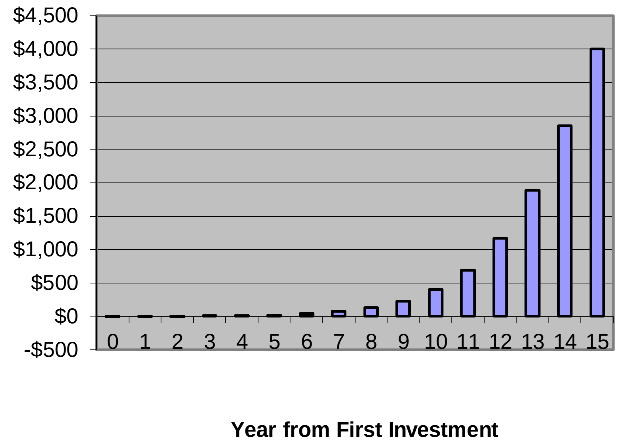
As one measure of market size, consider that in the United States about 8 billion trips are taken on transit every year[6]. Studies show that the ratio of trips per year to trips per weekday is about 300, and for a demand-responsive system the ratio of trips per weekday to the trips in a peak hour is about 10[7]. Thus, there are about $8000(10)^6/3000$ or $2.7(10)^6$ transit trips per peak hour. The number of vehicles required to carry a given number of trips in a peak hour is the peak hour flow multiplied by the average trip time and divided by the average vehicle occupancy. If these trips were to be carried by ITNS vehicles, a reasonable assumption is that the average vehicle occupancy counting empty vehicles is one. The average trip time is the average trip length divided by the average speed. It is fair to assume an average trip length of 4 miles and with ITNS an average speed of 25 mph, giving an average trip time of 0.16 hr. Thus, the number of ITNS vehicles required to carry the number of trips carried daily by conventional transit is approximately $2.7(10)^6$ (0.16) or 430,000. It is reasonable to assume an average of 40 vehicles per mile. Thus, the number of guideway miles required would be about 10,700. At a sale price of $15,000,000 per mile, this is a market of approximately $160 billion. Conventional transit in the United States attracts between 3% and 4% of the daily vehicle trips. Several studies have

[6] APTA 2005 Transit Fact Book.

[7] Boris S. Pushkarev & Jeffrey M. Zupan, *Public Transportation and Land Use Policy,* Indiana University Press, 1977.

shown that ITNS will attract at least five and possibly 10 times as many trips. Once the first operating ITNS system has had a few years of experience, it can be expected that new starts will take place more and more frequently, increasing per the well-known S-curve. It seems reasonable to suppose that in 30 years 10% of today's transit systems will be replaced or augmented by ITNS, but at five times the ridership. This would correspond to a market of about $80 billion. In any case, from this analysis, the projected growth of the company is shown in Figure 8. A market goal in ten years of $400 million seems attainable.

Figure 8. Cash Flow in $M



This market will develop slowly but exponentially until saturation is approached. With half the market developed in 15 years, likely no more than 5% will be developed in the first ten years, which is the time during which consultants and educators would be obtaining familiarity with ITNS. Major efforts on PRT are occurring mainly in Europe, where European PRT systems may dominate. It is difficult to say how much of this market or of the Asian market can be captured by an American PRT system. Since, now there is increased interest in reducing dependence on oil and reducing carbon dioxide emissions, ITNS may catch on more quickly.

Target Markets

The early markets, mainly for passenger movement, are expected to be found in highly congested business districts, airports, theme parks, office parks, hospital complexes, shopping centers, and retirement communities. There is interest known to us in these kinds of applications, characterized by two fundamental factors: 1) the decision-making process is relatively easy, and 2) there is a strong local champion.

The Competition

The most comprehensive web page devoted to Innovative Transportation Technologies is managed by Emeritus University of Washington Regional Planning Professor Jerry Schneider. The address of this web page is http://faculty.washington.edu/jbs/itrans/. There is a growing number of other web pages devoted to new transit technology, the most prominent of which are www.advancedtransit.org, www.gettherefast.org, http://kinetic.seattle.wa.us/prt. From these web pages, many web pages devoted to specific systems can be found.

While most of the systems shown on Professor Schneider's web page are not serious competitors, the few that may be are the following:

Figure 13.9, shows the ULTra PRT system, which has been under development at Bristol University in the United Kingdom and is now moving people and their luggage from parking lots into the terminals of Heathrow International Airport. This system uses a wide guideway, which has a large visual impact and is a snow-catcher in winter months. This system possesses the following characteristics, which will limit its use to fair weather, low-speed, low capacity, small systems:

Figure 13.9. ULTra.

- Rotary motor propulsion and wheel braking, which limits the headway to about 6 sec.
- Synchronous control, which limits the practical system size.
- On-board battery power, which limits speed and capacity.

Figure 13.10. Vectus

Figure 13.10 shows Korean steel company Posco's Vectus PRT system, a demonstration of which was built in Uppsala, Sweden. As seen in Figure 13.10, it uses a wide guideway. Moreover, the vehicles are propelled by linear induction motors mounted in the guideway. These motors must be placed quite close together to be able to emulate continuous thrust. Since at average flows there will typically be no more than about 40 vehicles per mile or one vehicle every 130 feet, the system will require about ten times as many motors as if they were mounted in the vehicles. This will make the guideway heavier and costlier than a system, such as ITNS, in which the motors are mounted in the vehicle – even considering the cost of power rails.

Figure 13.11 shows the third system we will illustrate. It is called "SkyWeb Express," offered by Taxi 2000 Corporation. This system was designed by Dr. Anderson, who found it necessary to resign from Taxi 2000 Corporation in early 2005. This system is not limited in the ways described above – it is an all-weather system designed to be indefinitely expandable. It was announced in June 2017 that Taxi 2000 has closed its doors – it is out of business.

Figure 13.11. Taxi 2000

14. Market Strategy

The sale of systems costing upwards of $100,000,000 is a complex process. Until the first real application is in operation, the major sales tool will be our demonstration system. It will be the tool needed to provide data on safety, reliability, comfort, and both capital and operating cost. As additional tools, we will develop 3-D virtual-reality simulations of specific applications, develop brochures and displays to be used at the many transportation and planning conferences, give presentations at these conferences, and maintain a web site. We can expect that, as has occurred previously, magazines, newspapers, and television stations will be anxious to describe our system at no cost to us. As we keep a growing number of people and institutions informed of our progress, we expect to make the first sales without the need for a worldwide marketing campaign. Indeed, at the end of this section is a table listing 12 applications, in each of which a prominent individual believes that the listed application will be ordered once testing is complete. This list was culled from almost 100 applications known to us. A great deal of the advertising needed will be provided by other groups and individuals that have already been watching our progress.

On any specific application, the process for making a sale is generally as follows:

- We make enough presentations and answer enough questions to convince the entity to look deeper.
- When the entity decides to proceed, the next step is a planning study in which detailed line and station layouts are made in cooperation with local planners, ridership is estimated typically by a specialty firm, a simulation of the application is made with a tool we have developed, three-dimensional visuals are developed to show how the system will appear in place, and costs are estimated. This work will be financed by the entity.
- If from this work the entity wishes to proceed further, having determined that the application can be financed, they may wish to prepare a request for proposals and solicit bids from various PRT companies. In that case, since the system designed by Dr. Anderson has already won competitions in Chicago, SeaTac, and Cincinnati, we are confident that we will be in a strong position to win.
- The selection of a specific PRT system constitutes the beginning of a sale, which generally goes in stages: First is preliminary engineering, in which remaining questions are answered, a more detailed design of the planned system is developed, and its costs are calculated. If the results of this preliminary-engineering process are satisfactory and the needed funds are secured, a contract is drawn for final design, construction, and test.

Pricing Policy

Once we are funded and underway, a critically important task of our management is to determine how to price our systems, considering all the project management costs, marketing and sales costs, education costs, lobbying costs, costs to negotiate and develop appropriate standards, legal costs, patent costs, continuing product-improvement costs, overhead, system-support costs, employee benefits, and profit. The price of our systems must be high enough to cover all costs and profit, but not so high that we discourage sales.

Optimal 10 Year ITNS Funding for 12 Projects

	City	Project Name	Miles Track; Stations/mi	Start Date	Capital Expense	Operating Expense net of Revenue
1	Rochester, MN	Urban Area	34 mi, 2 sta/mi	2022	$400M	$11M/yr
2	MSP, MN	Parking to Airport	20 mi, 2 sta/mi	2021	$300M	$10M/yr
3	Winnipeg, MN	Urban Area	25 mi, 1.6 sta/mi	2021	$300M	$11M/yr
4	San Jose, CA	A/P to Rail	34 mi, 2 sta/mi	2023	$510M	$15.3M/yr
5	Chicago, IL	O'Hare to Loop	35 mi, 1.5 sta/mi	2024	$525M	$17.9M/yr
6	Anaheim, CA	Disney and surroundings	25 mi, 2 sta/mi	2025	$400M	$12.0M/yr
7	Bloomington, MN	MSP to hotels and parking	23 mi, 2 sta/mi	2023	$345M	$10.4M/yr
8	Branson, MO	Tourist Center	15 mi, 4 sta/mi	2025	$270M	$8.1M/yr
9	Chicago	Hospital Connector	30 mi, 2 sta/mi	2025	$450M	$13.5M/yr
10	Nashville, TN	Medical Center	5 mi, 3.6 sta/mi	2025	$100M	$3M/yr
11	Kauai, HI	City Connector	90 mi, 1 sta/mi	2026	$1170M	$35M/yr
12	Auckland, NZ	Airport connector	16 mi, 1.5 sta/mi	2026	$240M	$7.2M/yr

15. Valuation

ITNS is a member of the class of transit systems called "Personal Rapid Transit" or PRT and is the leading embodiment of this class. Even before hardware was built, it won competitions in Chicago, SeaTac, and Cincinnati; and a Swedish report concluded that if it were tested full-scale it would be the preferred PRT system for Swedish cities. When hardware designed and supervised by its developer was built, it worked exactly as specified. *ITNS* represents *a paradigm shift* in the means for providing public transit. Therefore, efforts of the many inventors and engineers who have attempted to introduce this new and markedly superior form of public transportation had to overcome fierce opposition from practitioners of the conventional art. Almost all of them gave up. Compared on a per-passenger-mile basis with the average surface-level urban rail transit system, *ITNS* will cost for capital and operation a small fraction and will use a small fraction of the energy. Moreover, *ITNS*'s efficient use of urban land makes it ideal for applications in which there is no room for streetcars or buses.

How could this have happened? To understand requires that the reader gain some appreciation for the background and motivations of the principal developer of *ITNS*, Dr. J. Edward Anderson, whose biography is given in Appendix B and can be found in *Wikipedia*.

- His first professional job after receiving his Bachelor of Science in Mechanical Engineering had the title Aeronautical Research Scientist, Structures Research Laboratory, National Advisory Committee for Aeronautics, Langley Field, VA, where he received an education equivalent to a Master's Degree in Structural Engineering and contributed to the structural design of the wing of one of the Air Force's most advanced fighter aircraft.
- His second job was as a Senior Design Engineer at the Honeywell Aeronautical Division in Minneapolis, where his first design enabled Honeywell to totally dominate the Aircraft Fuel Gage Business, and his second design won the *Aviation Age* Product-of-the-Month Award.
- He transferred to the Research Department of Honeywell Aero where, after a year of study of the control of aircraft and missiles, he was put in charge of 15 Research Engineers working on autopilots for two of the Air Force's most important new fighter aircraft, and he was promoted to "principal engineer" at the time that only about 1% of the engineers at Honeywell held this title.
- To satisfy his desire to further his education, while working full time at Honeywell he earned a Master's Degree in Mechanical Engineering at the University of Minnesota, following which in successive years he took year-long graduate sequences in
    - Advanced Mathematics
    - Analytical Mechanics
    - Probability Theory
    - Theoretical Physics
- He was later assigned to Inertial Navigation where he invented and led the development of a new type of Inertial Navigator that is now standard equipment in most military and civilian aircraft.
- A year after Sputnik, he applied for and received a Fellowship to work on a PhD in Aeronautics and Astronautics at the Massachusetts Institute of Technology. His PhD thesis involved electromagnetics and was the only one out of 200 M. I. T. PhD theses that year

that was published by M.I.T. Press. It is used by physicists who study the containment of hot gasses by magnetic fields, and still produces royalty checks.

- Upon returning to Honeywell, he was appointed Manager of Space Systems in which role he directed a group of 25 senior engineers on the design of a spacecraft called a Solar Probe, which was to travel inside the orbit of Mercury to gather data on the particles and fields around the sun. After five months of work using only company funds, and after giving presentations and reports to NASA, NASA sent Honeywell a letter of commendation stating that they considered Honeywell as far advanced as funded contractors who had been working on the Solar Probe for several years. This project led to Honeywell's first spacecraft – an orbital infrared scanner.
- At this point, his yearning to teach led him to accept the position of Associate Professor of Mechanical Engineering at the University of Minnesota. In 1971 he was promoted to Full Professor.
- Every one of his engineering assignments, including teaching and research at the University, added to and rounded out the knowledge he would need to design a superior PRT system.

In 1968 the Urban Mass Transportation Administration (UMTA) released a report entitled "Tomorrow's Transportation" of work of 17 companies and research centers on the application of new technology to public transportation, which became possible only because of knowledge of the work of a few inventors and developers who had initiated and worked on PRT during the previous 15 years. Knowledge of U. S. government interest resulted in a rush of activity not only in the United States, but in all the major industrialized countries in the world. In almost all cases the rush to riches resulted in poorly designed systems that lacked even the most basic elements of systems engineering and caused a great deal of confusion in transit planning circles.

A successful PRT design required a firm and detailed understanding of the requirements of the design before detailed design could be initiated, which required seasoned understanding of every relevant engineering science, a strong grasp of engineering mathematics, and experience in laying out and promoting PRT systems in specific applications. Good systems engineering required strict objectivity in selecting components, but that required a great deal of research that most of those companies had neither the patience for nor resources to undertake. Such activity could take place in a Research University, and Dr. Anderson plunged in. PRT was the kind of project he had been looking for – one where he could apply his knowledge and skills toward great benefits for mankind.

The difference between Dr. Anderson's approach to PRT and the work of other PRT investigators is in the rigorous process of SYSTEMS ENGINEERING he has applied, and that was possible because of the many disciplinary engineering skills he had acquired.

The fact that we are where we are today, however, is a direct result of one outstanding exception: The Aerospace Corporation under the leadership of its Vice President, Dr. Jack Irving. He became interested in PRT in 1968. He and his team did the necessary research, because of which the PRT system developed under Dr. Irving's direction attracted the attention of Dr. Anderson and the University of Minnesota Task Force on New Concepts in Urban Transportation that he led. Under the above mentioned UMTA research and training grant and other grants, sufficient funds permitted Dr. Anderson to visit work going on in PRT in many cities in the United States and in Japan, England, France, Germany, Sweden, and Switzerland. These visits, coupled with the research he and his 15 colleagues did, showed unequivocally that the Aerospace PRT System was markedly superior to any other PRT design. Unfortunately, heavy lobbying stopped their work. Improvements made by Dr. Anderson and his team have been due to advances in technology and in continued research and development.

Under the auspices of the University of Minnesota's Department of Conferences, Dr. Anderson chaired International Conferences on PRT in 1971, 1973, and 1975 and edited the proceedings of the first two of these conferences. These conferences brought together 215 researchers, who shared and debated their ideas. It was estimated that by 1980 about $2 billion had been spent on a variety of types of automated guideway transit including PRT. That expenditure provided experimental evidence of features a PRT system should have and features it should not have. Only after 13 years of detailed study of PRT and of the work of other PRT investigators, engagement in PRT planning studies, giving hundreds of presentations and listing to and recording the feedback, work in a major study of transit alternatives in Denver, work on PRT as a consultant to Raytheon Company, serving as the first President of the Advanced Transit Association, work as U. S. Representative of the German PRT system called Cabintaxi, work on PRT as a consultant to the State of Indiana, and assembling findings in the first and only textbook in this field (*Transit Systems Theory,* Lexington Books, D. C. Heath and Company, available on www.advancedtransit.org/Library/Books) did Dr. Anderson initiate the design of the system now called *ITNS*.

To design *ITNS,* all the past work had to be assimilated and understood even though almost all those efforts had failed. The experimental evidence obtained showed most often how not to build a successful PRT system. Lessons from these activities have been invaluable. It took many years of study of all significant work on new forms of transit as well as detailed planning of them in a variety of specific settings to appreciate all the requirements of a successful design. There are many ways to design a PRT system, most of which are dead ends. Dr. Anderson used his knowledge of the engineering sciences, engineering mathematics, and economics (he taught Engineering Economics in the late 1970s) to study dozens of tradeoff issues. He aimed to do so with *absolute objectivity* until the approach to be taken in each issue became clear. Such a *Systems-Engineering Process* was possible only because of his in-depth prior involvement in all the branches of engineering required in the design of *ITNS*.

ITNS represents a culmination of research and development directed at achieving an economical and reliable solution to urban transportation that will minimize use of land, material and energy, will minimize pollution of all kinds, and will provide an unparalleled level of service. Remarkably, this combination of benefits minimizes capital and operating costs. The work that led to *ITNS* was conducted by Dr. Anderson and colleagues at two major research universities, in cooperation with three government agencies and five major private companies. A study of other PRT designs shows that without such experiences, mistakes are made and will continue to be made. It is unlikely that any engineering group working in a period acceptable today to a group of investors will have the patience needed to arrive at the comprehensive collection of requirements and technology that a successful PRT design requires. The drive to continue had to be self-motivated.

A NUMERICAL VALUATION of the intellectual knowledge and know-how that is represented in the 1500 pages of detailed plans and specifications of *ITNS* is not possible to derive. How much of the work of others, for example The Aerospace Corporation, should be included? Without that work *ITNS* would not exist. *ITNS* is unique. The experiences that led to it are not repeatable. Its value is not only a result of the direct activity that has gone into it, but in the associated work by many companies and governments, without which *ITNS* could never have been developed. The international demand for *ITNS* lies today in every corner of the civilized world, and the return to the investor will far exceed almost any other investment. A lead investigator estimated the worldwide market to be over $1 trillion.

16. Patents

The basic patents granted to the University of Minnesota on the system invented by Dr. Anderson have expired. Once we are underway, we will seek patentable ideas and file for patents as a priority of our development process. We have exhaustively searched for patents upon which we may infringe and have found only one – U. S. Patent 7,617,977 "Ticketing system for personal rapid transit," a method that has been common knowledge for decades. This patent can easily be circumvented and the company that owns it is out of business. The investors in *ITNS* will own the detailed plans and specifications needed to build systems.

17. How will the Enterprise make Money?

The company will own the detailed plans and specifications developed during the final design and test work summarized in the 12 Tasks of Appendix A. It will make its money from markup on system sales, from maintenance contracts, from fees for training, and as a fraction of the revenue from systems operated by franchisees or concessions. Concessions or franchises will make their money from revenue on ITNS directly from fares and advertising, and indirectly from the increased value of land freed up because of the very small amount of land required by the system. In many situations, all the costs will be recovered from revenues, making ITNS a profitable private business.

18. Risks

1. Management. We are a small start-up company that will consist of managers and engineers who thus far have little experience in working together. The investor must be satisfied that such a group, which must enlarge substantially, will work together cooperatively and successfully, and that new members will be provided opportunities to become thoroughly proficient in their assigned areas of the technology. The burden is on the company to be as certain as reasonably possible that new hires have the knowledge and commitment needed for success. As part of the process of selection of new employees, each will be subjected to a comprehensive psychological interview.

   By working in cooperation with established engineering companies that subcontract to us, we will satisfy the need for an established working environment. Experience with the Chicago RTA project showed that assigning the task of Prime Contractor to a company totally new to PRT produced a system much too expensive to find a market.

2. Technology. *ITNS* is a new configuration of technologies, albeit all existing technologies. These technologies must function economically day after day with less than one hour of delay for every 10,000 hours of operation for decades and with acceptable ride comfort, an outstanding safety record, and at a cost well under that required by competitors. Because computations practical only on digital computers are needed in planning, designing, manufacturing, operating, and managing PRT systems, the practicality of these systems has depended on advances in computer hardware, software, and fault tolerance. The investor must be satisfied that the necessary technical advancements will be used and that the systems engineering team assembled is sufficiently versed in such technologies.

   The technology proposed has been under development for over 30 years and the specific system proposed by the Company has been subject to extensive design reviews over the past decades that have shown that the technology is well within the state-of-the art.

3. Competition. Several companies are planning, designing, and building PRT systems. The investor must be satisfied that our approach to PRT will be strongly competitive and indeed superior to other approaches to PRT, either in the technology or in the people involved.

   None of the other PRT companies offering PRT systems have enjoyed the depth and breadth of experience that Dr. Anderson has had as the world's leading expert on PRT systems. The process that has been the foundation of that expertise is described in Section 15.

4. Code Requirements. Introducing a new system into the present complex fabric of industrial society requires compliance with a wide range of codes and standards. For example, late in the development cycle of the German Cabintaxi PRT system in the late 1970s a German railroad engineer found a standard that required all the plates in railroad bridges to be at least 12 mm thick, whereas the developers of Cabintaxi had specified 8 mm thickness as wholly ample for the plates of their guideway. The railroad engineers managed to get the elevated Cabintaxi guideway designated as a railroad bridge, and the time required for renegotiation of payment for the extra steel led to cancellation of the program.

   Mainly because of the Chicago PRT project (1990-1994), all the codes and standards required have been identified, the most important of which are the ASCE Automated People Mover Standards, the National Fire Safety Board standards for automated people movers, International Standards Organization ride-comfort standards, and the Americans with Disabilities Act. As our project begins, all the necessary standards will be assembled and reviewed.

5. Costs and Schedules. While our program plan has benefited over many years from a great deal of analysis, design, discussions with manufacturers, and operating experience, meeting the projected costs and schedule depends on securing the services of many skilled personnel and companies. Inability to obtain the services when needed could delay the effort and increase its costs.

   Our intention is to develop the project in an area where there is a great deal of high-tech talent and many small manufacturing firms from which to choose.

6. Marketing. An adequate return on investment requires that the company's marketing efforts have secured system orders with the expected frequency. The time required to complete necessary arrangements may be longer than anticipated and the economic situation may deteriorate. Thus, the projected program must be conducted in recognition of perpetually imperfect knowledge.

   We have already identified dozens of good applications, and are cognizant of the need to maintain a strong marketing effort.

7. Risk of Obsolescence. While every effort has been made to insure an optimum, adaptable design – one very difficult to improve or circumvent – other technological breakthroughs may shorten the life expectancy of our approach to PRT.

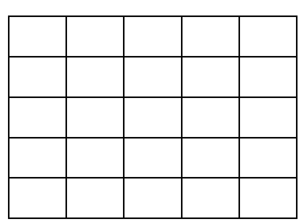
   An important strategy in the design of ITNS has been to use off-the-shelf components wherever possible and to review the state of the art for new ideas that will improve performance and/or lower cost. No one can ever assume that no new technology can render any system obsolete, but the basic ideas that led to the PRT concept and how to optimize it have been thoroughly researched and are amenable to change when new technologies become practical.

8. Possible Need for Additional Funds. While we believe that the estimated funding requirements are adequate to cover costs necessary to design, build, and prove its system to the degree needed to obtain orders and hence funding for projects, there can be no assurance that additional funds will not be needed.

   The cost estimates and schedules we have developed have benefited from review of similar costs and schedules estimated and achieved on similar projects going back to the early 1970s. The data, in addition to mature judgment, have let us to conclude that our estimates are conservative. Moreover, Dr. Anderson managed in six months the design and construction of a full-scale, automated, linear-induction-motor propelled vehicle that ran flawlessly for thousands of rides on a 60-ft section of guideway. The cost and schedule experience from this project have been incorporated into our current cost estimates and schedules.

19. Economics

Economic factors related to a first system deployed after the demonstration program has been approved are shown on the next page. In the calculations, it is assumed that the cost of the demonstration will be paid at the rate of $15,000,000 plus interest per year for each of the first two years and that the funds from the construction bond will be distributed over three years. Revenue is generated every year beginning three years after the notice to proceed to build the system. The operating system for this example is taken as a square network with six north-south guideways and six east-west guideways spaced a half mile apart, as shown below. The corresponding nine square mile transit service area extends a quarter of a mile out from each of the four sides of the network.



As an example, specific values are given for a range of parameters. In a detailed planning study for a first application, these values must be calculated from detailed planning information. In the second from the right-most column on the next page the year-by-year net cash flows (revenue minus payment on the bond and O&M expenses) are given. Beginning in the 31st year, after the bond is paid off, the net profit jumps. In the right-most column, the cash flows are discounted at 4.5% per year to allow summing to the total PRESENT VALUE of the profits over 40 years to the city that takes out the bond. The number in the sixth row of the last column, $286,374,730, is that PRESENT VALUE. By comparison, in conventional transit 100% of the capital cost and typically 2/3rds of the operating cost must be covered by taxes; hence the net Present Value of those systems is substantially negative.

City Purchases System & Demo via Bonding. Receives Net Profit every Year!

Application: A Square Network			O&M cost	
Transit Service Area, sq mi	9.0		reduces to	Present
Separation between lines, mi	0.5		95%	Value of
Guideway Length, mi	30.00		of previous year's	40 years of
Stations/mi	2.00		cost each year.	Profits
Total Number of Stations	60		CASH FLOW:	to the City:
Ridership		yr	($135,145,332)	**$286,374,730**
Peak Days/year	340	1	($135,145,332)	$0
People/sq mi	9,000	2	($120,145,332)	$0
Trips/person/day	3	3	$8,885,874	$7,786,661
Mode split to ITNS	20%	4	$9,507,507	$7,972,628
Passenger-Trips / Day/sq mi	5,400	5	$10,098,058	$8,103,197
Off-Peak Light-Freight trips/passenger-trips	0.50	6	$10,659,082	$8,185,064
Total Trips/ yr/ sq mi	2,754,000	7	$11,192,054	$8,224,240
Peak-hrs/Day	10	8	$11,698,378	$8,226,126
Passenger-Trips/ peak hr/sq mi	540	9	$12,179,386	$8,195,563
Performance		10	$12,636,343	$8,136,891
Passenger Trips/peak hr	4,860	11	$13,070,453	$8,053,996
Ave Trip Length, mi	1.60	12	$13,482,857	$7,950,353
Average speed, mph	25	13	$13,874,640	$7,829,066
People/occupied vehicle	1.35	14	$14,246,835	$7,692,904
Fraction of Vehicles empty	0.25	15	$14,600,420	$7,544,335
Percent of operating vehicle fleet in maintenance	0.04	16	$14,936,325	$7,385,555
Maintenance float, vehicles	13	17	$15,255,436	$7,218,512
Number of vehicles	321	18	$15,558,591	$7,044,936
Vehicle-miles/year	39,657,600	19	$15,846,588	$6,866,355
Number of operating vehicles/mi	10.27	20	$16,120,185	$6,684,120
Total number of vehicles /mi	10.70	21	$16,380,102	$6,499,419
Average headway, ft	514	22	$16,627,024	$6,313,296
Average headway, sec	14.0	23	$16,861,599	$6,126,664
System Cost		24	$17,084,446	$5,940,321
Cost of Demonstration	$30,000,000	25	$17,296,150	$5,754,958
Operating Guideway Cost/mi	$5,530,000	26	$17,497,269	$5,571,174
Cost of one station including bypass guideway	$718,511	27	$17,688,332	$5,389,482
Cost of one vehicle including storage guideway	$88,326	28	$17,869,842	$5,210,322
Cost of Control & Communication/mi	$300,000	29	$18,042,277	$5,034,066
Cost of Maintenance Facility/mi	$54,853	30	$18,206,089	$4,861,026
Construction Management Cost/mi	$314,841	31	$42,331,180	$10,815,718
Overhead, Fees and Taxes	40%	32	$42,479,021	$10,386,117
System Cost/mi	$12,014,533	33	$42,619,470	$9,971,729
Cost of Operating System + Demonstration	$390,435,996	34	$42,752,896	$9,572,198
Interest on Bonded Debt	4.50%	35	$42,879,651	$9,187,156
Time Horizon	30	36	$43,000,069	$8,816,226
Annual Payment on Bonded Debt/mi	$798,982	37	$43,114,465	$8,459,024
O&M Cost/vehicle-mile	$0.33	38	$43,223,142	$8,115,164
First year annual O&M cost (reduced with learning)	$13,087,008	39	$43,326,385	$7,784,256
Annual O&M as fraction of capital cost	3.35%	40	$43,424,466	$7,465,912
First-Year Total Annual Cost/guideway-mile	$1,235,216			
First-Year Total Annual Cost/vehicle-mile	$0.93			
Revenue				
Fare per vehicle trip	$2.50			
Fare per mile for freight	$1.00			

Advertising revenue/vehicle-trip	$0.40
Revenue/year	$45,288,000
Annual O&M Cost as % of Annual Revenue	28.9%
Annual Revenue/System Cost	11.6%
Break-Even Fare	**$1.10**

Appendix A. The Tasks[8]

Task #1. Management and Systems Engineering

The objective of this task is to show that all requirements and specifications for the Intelligent Transportation Network System (ITNS) have been met before building the first application. A prototype **Test Track** will be built and operated. Three vehicles, having functioning cabins, will be built and tested.

1. Resolve all policy issues with the client and thus agree on all design requirements.
2. Become familiar with all codes and standards, almost all of which are known, that may affect the design, and inform all the engineers working on the project of findings of importance.
3. Review and finalize the subsystem specifications.
4. Identify and negotiate contracts with subsystem suppliers.
5. Establish all design loads.
6. Frequently update the estimated vehicle weight and moments of inertia.
7. Frequently update the estimate of system life-cycle cost.
8. Maintain a library of relevant papers, reports, and books.
9. Using an available program and the correct vehicle mass and radii of gyration, perform dynamic analysis of the motion of a vehicle passing through a diverge sections of the guideway under maximum side wind load and unbalanced passenger load to reconfirm lateral tire loads and stiffnesses, position of the switch arm, and the flare length of the switch rails to meet ride-comfort criteria.
10. Weight & Cost Control
    Develop model for estimation and control of vehicle weight.
    Develop model for estimation and control of system capital cost.
    Develop model for estimation and control of O&M costs.
    Monitor all design tasks to keep within weight and cost targets.
11. Project Direction
    Educate and supervise all team members.
    Develop and maintain the over-all schedule.
    Provide inter-task coordination.
    Work with clients.
    Manage
        The office
        Procurement
        Engineering aids

[8] The papers referenced are included, as mentioned in Footnote #2, in the author's 1500-page, 3-volume book.

Task #2: Program of System Safety and Reliability

A major part of any engineering program related to automated guideway transit is to ensure that the system will be safe.[9] An agreed definition of safety will be developed.[10] The Automated People Mover Standards require that any APM program have on its staff at least one full-time person devoted to safety issues and who operates separate from the design teams. This person must be familiar with the analysis of safety problems in complex systems that include real-time, safety-critical software. Safety issues include fire safety, robustness and redundancy in the software, design loads and stresses, and all other issues involving safety. Safety was treated in detail in two reports from the Chicago RTA PRT Design Study.[11]

A great deal of systems engineering work[12,13] has been done to arrive at the current configuration of ITNS. The work under this task is to be sure that the hardware and the system-control protocols are safe and take advantage of the current state of the art. The safety engineering team will

1. Review prior work on hazards analysis, fault-tree analysis, and failure-modes-and-effects analysis.[14]
2. Tabulate data on component reliability from data sources such as www.e-reliability.com, from the AF Reliability Center at Griffiss Air Force Base, Rome, NY, and from other Internet sites. This work can be updated from the above-mentioned Chicago PRT Design Study.
3. Estimate system dependability and hence safety using an available model.[15]
4. Estimate the optimum component mean times to failure that meet the system dependability criterion at minimum life-cycle cost.[16]
5. Review the ASCE Automated People Mover Standards to be sure that they are complied with where relevant.
6. Examine in detail the safety implications of the component and subsystem design, and recommend changes when necessary.
7. Become conversant in safety technology, e.g. through the System Safety Society.

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[9] J. E. Anderson, "Safe Design of PRT Systems," *JAT*, 28:1(1994):1-15.

[10] See the definition suggested in J. E. Anderson, "Overcoming Headway Limitations in PRT."

[11] "Safety, Security & Failure Management Report" and "Fault-Tree Analysis and Reliability, Availability & Maintainability Analysis," PRT Design Study, Chicago RTA, 1991.

[12] J. E. Anderson, "A Review of the State of the Art of Personal Rapid Transit." *JAT*, 34:1(2000): 3-29.

[13] J. E. Anderson, "The Future of High-Capacity Personal Rapid Transit."

[14] J. E. Anderson, "Failures Modes and Effects."

[15] J. E. Anderson, "Dependability as a Measure of On-Time Performance of Personal Rapid Transit Systems," *JAT*, 26:3(1992):101-212.

[16] J. E. Anderson, "Life-Cycle Costs and Reliability Allocation in Automated Transit," *High Speed Ground Transportation*, 11:1(1977):1-18.

Task #3. Final Design, Construction and Assembly of the ITNS Cabin

This task is for the work needed for the final design and fabrication of the vehicle's cabin. The vehicle has a length/height ratio close to the famous Fibonacci ratio: 1.618. Three vehicles will be in the preliminary order for testing. The Company needs the assistance of an engineering company with the necessary computer tools and skills to

- Develop the cabin design,
- Produce drawings and specifications from which to fabricate the cabin,
- Select and procure the necessary components, and
- Fabricate or subcontract the fabrication of the cabins as finished units ready to be attached to the chassis.

1. Loading

1.1 Payload: The cabin shall be designed to accommodate a maximum payload weight of 800 lb (430 kg).

1.2 Wind: The cabin shall be designed to a maximum side wind of 70 mph (31 m/s).

1.3 Passenger loads: The cabin shall withstand the load of a 300-lb (136 kg) passenger pushing on the interior components of the cabin. The cabin floor at any point shall withstand a 200-lb (91 kg) concentrated load bearing on an area of one cm^2.

2. Exterior Dimensions

Subject to accepted reasons for change, the expected exterior dimensions of the cabin are: length 104"(2642 mm), height 64" (1633 mm), and width 63" (1600 mm). The walls shall be as thin as practical both from the view of structural strength and heat transfer.

3. Accommodations

The cabin is to be designed to accommodate either a person in a standard-sized wheelchair entering from the side and turning to face forward with an attendant, 3 adults and 2 children, a person with a bicycle, 2 people with large suitcases, or 2 persons with a baby carriage.

4. The Floor

The interior floor of the vehicle shall be at the same level ($\pm$ 0.5" or 12 mm) as the station floor. It shall be covered with a durable commercial grade material that will be easy to clean. The edge of the floor at the door shall be within half an inch of the edge of the station floor. Within the floor there shall be installed electrically conducing material that will shield the passengers from electromagnetic radiation from the chassis.

3. The Seats

There shall be a forward-facing bench seat at the rear interior of the vehicle in three equal sections that may be folded up individually, filling the interior width of the cabin, with seat backs extending to the interior top of the cabin and tilted backwards by 6^{o} (six degrees). The back of the seat back at the seat height shall be forward from the rear wall of the cabin 12” (300 mm) to permit space for the equipment described in Paragraph 9. The top of each seat shall be 17” (430 mm) from the interior floor and shall fold up to ease access of a wheelchair or other large object. These seats will have a spring constant of about 200 lb/in (350 N/cm). There shall be two backward-facing fold-up seats at the front of the cabin designed to accommodate children. The dimensions of these seats shall not compromise the aerodynamic requirements. They shall be spring restrained into the folded-up position when not occupied. The seat material shall be durable, vandal proof, and fire resistant.

4. The Door

One possible door configuration is a single inverted U-shaped automatically powered door 36 in (914 mm) wide that would open by sliding back over the rear shell of the cabin and thus opens on both sides of the cabin as one unit. Other door configurations can be considered. The door shall open or close within 3 sec and shall be equipped with sensors that prevent closure on any object. The door-operating mechanism shall be placed under the inside floor of the cabin. To ease entry of a wheelchair, the rear edge of the door shall be in line with the front edge of the bottom of the folded-up seats. The door-operating mechanism shall be designed for a life of 160,000 operations (open and close) and with no more than one failure in 50,000 operations. The seal of the door shall be designed to prevent entry of noticeable amounts of water in a rainstorm of 2 in/hr (50 mm/hr).

5. Windows

The windows, front, back and sides, are to be of a plastic such as LEXAN and should be large enough to permit a panoramic view as the vehicle moves along the guideway, but not so large that they would compromise the structural integrity of the cabin. The material of the windows and the entire exterior shall withstand daily brushless washing and shall be coated to minimize entry of solar infrared energy.

6. Styling

Since the cabin is the one element of ITNS seen most and is the signature of the entire system, styling is critically important. The design should, as one sculptor said, ". . . bring out the kid in you" while portraying dignity to the wealthy purchaser of the system.

7. Aerodynamics

Even at speeds as low as 25 mph (11 m/s) air drag is the largest energy consumer. Also, the power to overcome air drag increases as the cube of speed. There is a substantial amount of information from wind tunnel data on shapes that minimize air drag. Since the system will operate in crosswinds up to 70 mph (31 m/s), side drag is important. As side drag increases, it increases forward drag. The corners connecting the side to the top of the vehicle should be rounded with a radius of at least 10 in (254 mm). For these reasons, air drag is an important consideration in the design.

8. Structural Design

If a U-shaped door is used, the cabin shell is composed of three parts, the front part, the back part, and the door. These parts shall be manufactured from strong, light-weight composite material with metal reinforcements as needed. When the door is open, it is possible for a strong man to push against the top of the front or back part of the cabin to see if he can break it. Therefore, as mentioned in Section 1.3, such a loading must be resisted well below the yield point of the material. The cabin contractor or his subcontractor shall have appropriate structural-analysis capability.

9. HVAC

A heating, ventilating, and air conditioning system shall be designed into the cabin, with the large components, such as the compressor and the drive motor, placed in the compartment behind the seat. The designer can assume that the vehicles will be stored in the shade and that the stations have a roof over the vehicles and waiting passengers. Moreover, in ITNS, while the vehicles will be stored power off, the HVAC designer can assume that at least three minutes will pass from the time HVAC is turned on until a passenger enters, which is a more relaxed requirement than necessary in automobile design. The HVAC designer shall work with the structural designer to specify insulation in the walls that, as close as practical, will minimize the sum of the annualize cost of the wall plus the annual cost of heating or cooling energy. The ventilation system shall provide the air exchange recommended by the Society of Heating and Ventilating Engineers. The temperature in the cabin shall be controlled to the median comfort level assuming people are clothed appropriately to the outside weather.

10. Equipment Compartment

The computers that operate all functions will be in a compartment behind the main seat and there shall be an access door at the rear of the vehicle that can be opened by qualified personnel. The major AC components shall share the same compartment. The seat back facing the equipment compartment as well as all other components of the cabin shall be non-combustible.

11. Passenger and Environmental Controls

There shall be three buttons conveniently located in the vehicle that can be actuated by the passengers: a “Go” button, a “Stop” button, and an “Emergency” button. The “Go” button causes the door to close and signals to the station computer that the vehicle is ready to leave the station. The “Stop” button causes the vehicle to stop at the next station and then the door to open after it is stopped. The “Emergency” button alerts a human operator located in a control station to inquire through a communications system as to the problem. If the rider indicates sickness, the operator can change the vehicle’s destination to that of the nearest hospital. If the rider is in danger, the operator can change the vehicle’s destination to that of the nearest police station. If the rider feels the temperature in the vehicle is too high or too low, the operator can adjust it, etc.

12. Communications

There shall be a two-way communication system in each vehicle to connect an individual vehicle or a group of vehicles to the system’s control room. This system is separate from the communication system that controls the speed and position of the vehicles, which is described separately. There will be a television screen in the front center of the vehicle near the floor. It must be possible for the passengers to turn the set on or off, and if on to switch to site-specific advertising, travel information about the passing surroundings, news, or entertainment.

13. Lighting

The cabin will be equipped with reading lights that can be switch on or off by the passengers. Exterior lighting is optional but low lumen so-called parking lights and red tail lights are recommended.

14. Attachment to the Chassis

The cabin will be built with a pair of 20” long, by 2” wide, by 2” deep inverted wells in its bottom at major structural cross members one near the front of the cabin and the other near the rear to permit bolting to corresponding members of the chassis. As specified in Task 4, these members shall be hollow so that they can accept wires to and from the chassis.

15. Wiring

Only moderate voltages, for example 24 or 48 volts DC, are to be transferred from the variable-frequency drives in the chassis to the cabin. A voltage bus in the equipment compartment shall be used to drive all the cabin components, I.e., the computer, the door motor, the heater, the air conditioner, the ventilation fan, the lights, the television set, the communications system, and the sensors. The wire insulation shall be non-combustible.

16. Fire Prevention

Fire prevention is of primary importance, which is the reason only a low voltage will be permitted in the cabin. All materials in the cabin shall be certified non-toxic and non-combustible. The cabin shall contain a smoke detector that shall cause the vehicle to stop at the next station and open the door automatically upon detecting smoke. Temperature sensors shall be placed at strategic locations in the wiring and in the electrical components to command the current to be shut off and a warning sent to central control if the temperature exceeds a preset value.

17. Lightning Protection

The cabin designer shall consult with the wayside power team to specify a suitable means for protecting the cabin from a lightning strike.

18. Environmental Specifications

The cabin shall be designed to be operable in the expected range of exterior conditions; temperatures from -45 deg C to + 50 deg C, salt spray, sand storms, and daily brushless cleaning. It is expected that the cabin will be replaced once every ten years. Minimization of the effects of vandalism must be considered in every phase of the design.

19. Cleaning

The cabin designer shall consider daily external and internal cleaning of the cabin, and shall select materials and designs of the interior and exterior of the cabin for easy cleaning. Since the cleaning means is a part of the system, methods that will minimize damage can be assumed.

20. Cabin Weight

Since the weight and therefore cost of the guideway is proportional to the gross weight of the vehicle, weight minimization of the cabin is important, if the cost of weight reduction is not more than about $30 per pound.

21. Standards

The cabin shall be designed to comply with the requirements of USO 9000 and NFSA 130.

22. Changes in the Numerical Specifications

If the design team believes that a change in one or more of the numerical specifications given above is needed, they are to bring their suggested change to the management and systems engineering team with ample justification for the change.

23. Deliverables

Three cabins and all the drawings and specifications needed to produce them.

Task #4: Final Design and Assembly of the ITNS Chassis

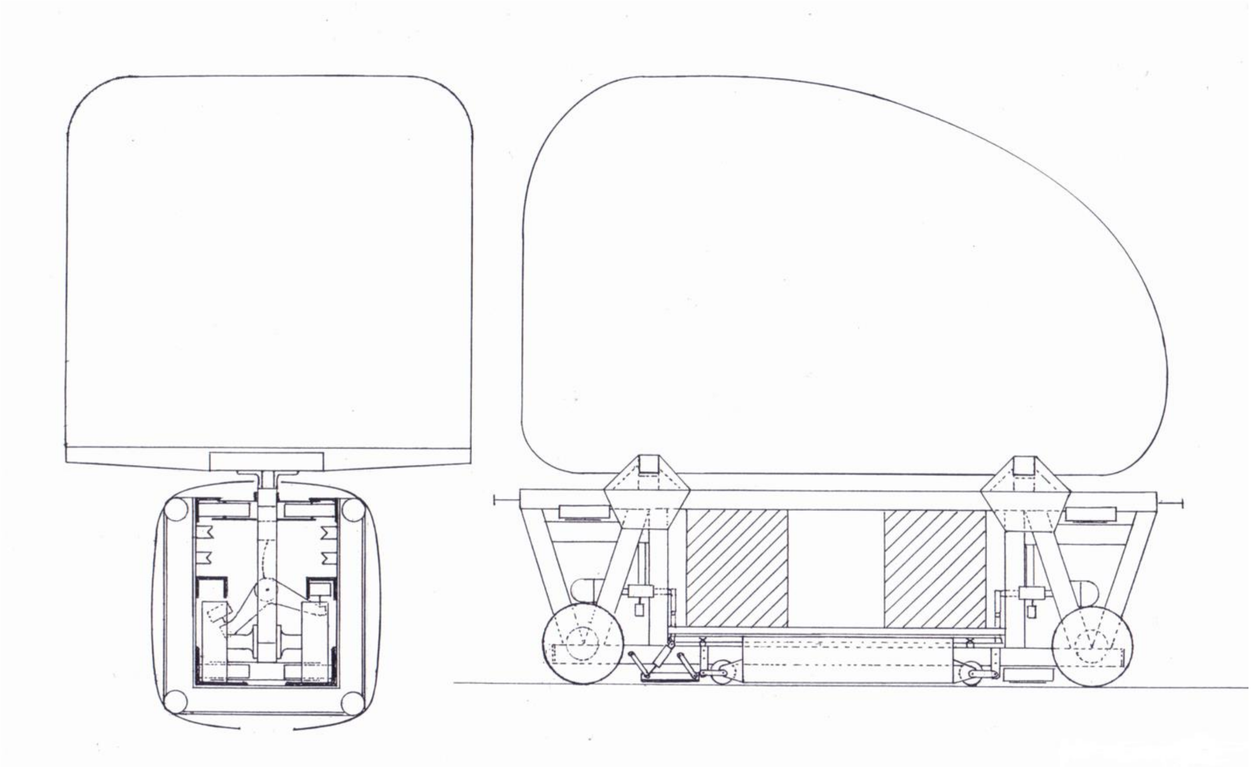


Figure 4.1. Sketch of the vehicle.

This task is for the final design, fabrication, and assembly of the vehicle's chassis. Figure 4.1 is a sketch of the side and end views of the chassis[17] with an outline of the vehicle on top, which has a length/height ratio close to the famous Fibonacci ratio, 1.618. Three vehicles will be ordered for the demonstration system. The engineers assigned to this task need to be familiar with the necessary computer tools and skills to

1. Perform an accurate quantitative verification of the design[18] with extreme wind and passenger loads to verify the maximum and steady-state wheel loads considering final dimensions, weights, and moments of inertia,
2. Produce drawings from which to fabricate the chassis frame and all brackets and linkages,
3. Select and procure the necessary components except for the Linear Induction Motors (LIMs) and their drives,
4. Assemble the chasses as finished units ready to receive the cabin.

[17] There must be a set of lower lateral wheels near the rear of the chassis like those in front. This moves the position of the parking brake to a position inside the rear main-support wheels.

[18] See "Lateral Dynamics of the ITNS Vehicle."

The chassis rides inside of a covered guideway and thus is not exposed to the sun; however, rain or snow may enter the 3” wide slot at the top of the guideway, and the chassis must perform in wet or dry conditions in temperatures from -45 deg F to +130 deg F in an atmosphere typically 20 feet above the ground that may contain salt, dust, or sand. Noncombustible material shall be used throughout. The chassis is to be designed for a life time of 20 years, during which time it can be expected to travel 1,600,000 miles. The components must be easily replaceable to minimize vehicle downtime. System cost minimization requires, *inter alia*, minimum guideway weight, which required minimum vehicle weight. Thus, weight minimization of the chassis is important until the cost of weight reduction exceeds about $30 per lb. Safety and meeting required performance at minimum life-cycle cost are the fundamental design requirements.

1. Frame

The frame of the chassis, to which all of the components are attached, is vertical and consists of eight 2x2” high-strength, square corrosion-resistant steel tubes[19], with rounded internal corners. The top horizontal tube is 104” long. Shock absorbers with a throw of 4” are secured at each end. The lower horizontal tube is 94” long. Plugs are to be welded into each end to increase torsional stiffness and to prevent debris from entering the tubes. The distance between the bottom of the top horizontal tube and the top of the bottom horizontal tube is approximately 21.13.” The exact dimension will be determined by analysis of the height needed for the 13” nominal OD main support tires, the height and clearance needed for the switch rail, and the height and clearance needed for the 600-volt DC power rails. The Task #8 & 9 engineers will participate in this analysis. The top and bottom horizontal tubes are separated by six tubes, two vertical, and four inclined as shown in Figure 4.1 to provide resistance in a collision between two vehicles at a relative speed of 10 mph. The frame is to be assembled by welding.

2. Attachment of the cabin to the chassis

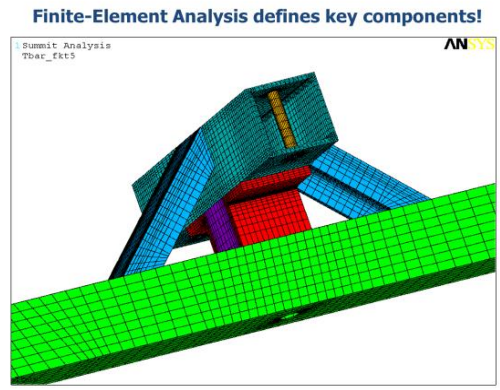
The cabin is attached to the chassis at two points.[20] The top member of each of the two attachment assemblies is a 20” long 2x2” corrosion-resistant steel tube with steel squares welded into the ends to increase torsional stiffness. When the chassis is assembled, these members are inserted into two slots in the floor of the cabin and bolted firmly to the cabin floor. The joint under the top member consists of seven pieces to be bonded together with a high-strength, 4000-psi-shear-strength, epoxy adhesive, such as provided by 3M Company, and bolted. The center piece is a block of steel 3” longitudinally, 1.5” laterally, and 2” high, hollow to

[19] Steel has the advantage that it has a fatigue limit, whereas aluminum does not. Steel is easier to weld and has a much higher yield stress. Steel has the possible disadvantage that the sections needed to keep the weight to a minimum may be so thin that their thickness would be limited by buckling, thus potential buckling must be analyzed.

[20] The reason for two-point attachment is to eliminate the need to widen the guideway covers in curves.

enable wires to be passed between the chassis and the cabin. To this block are bonded a pair of high-strength steel angles each 4” wide, 2” high, 5” long, and 1/4” thick. These angles are to be bonded and bolted to the center piece and to each of the two 20” long transverse tubes.

Next a pair of 2” wide channel sections are cut at 45 degree angles and are both bonded and bolted in place as shown in Figure 4.1. Finally, a pair of hexagonal 0.020” thick sheets of the same material, of the shape shown in Figure 4.1 are bonded to the sides with cutouts for the transverse 2x2” tubes with the above-mentioned adhesive to provide the necessary shear strength. Detailed finite element analysis is needed to verify the design. If the Task #4 engineer does not have the necessary experience to do FEA, this work can be subcontracted. In this analysis, the maximum load shall be taken as a 500-lb wind load on the side of the cabin plus a 600-lb vertical payload offset from the center line of the cabin by 15”. The empty cabin weight will be assumed for this analysis to be 500 lb, and we aim for an assembled chassis weight of no more than 600 lb.



3. Main wheels, axles and bearings

The distance between the axles of the front and rear main-support wheels is 84”. These wheels are nominally 13” OD (up to about a quarter inch more) to the outside of the tires, and are 4” wide. The width between the centerlines of the left and right wheels is 14.5”.[21] Each wheel shall be designed to carry a steady load of 550 lb with double this value for about two seconds when passing through the entrance to a superelevated turn. The tires may be high-pressure pneumatic or the designer shall investigate the new Michelin airless tire that has the same properties as a pneumatic tire. The tire stiffness shall be 2200 $\pm$ 200 lb/in. Thus, variation in deflection from a fully loaded to an empty vehicle is 900/4/2200 = 0.10”. The needed tire, wheel, bearing and axle assemblies can be purchased to order from a company such as Aerol Co., Inc. The axles will be high-strength aluminum or steel turnings, hollow to reduce weight and to permit wires to be passed from encoders, and bolted to the chassis frame as may be seen in the end view of Figure 4.1. Sealed bearings will be used. They will each contain in the hub a digital encoder with a resolution of at least 2048 pulses per revolution, such as manufactured by Timken. The output of the left and right pairs on each of the fixed axles will be averaged to obtain position and speed, and redundancy is provided by placing encoders in all four

[21] J. E. Anderson, “Deflection of the Running Surface,” under Guideway Component Analysis.

main-wheel bearings. Note that the main wheels do not steer, which is acceptable in a light-weight vehicle with a short wheelbase, the more so as the friction of the tires decrease.[22] For reference, the Cabintaxi PRT program during the 1970s found this practice to be satisfactory.

4. Upper and lower lateral wheels, axles and bearings

Four upper lateral wheels provide yaw stability and four lower wheels add roll stability and symmetrical loading. While these additional lower wheels cause the chassis to be subjected to a twisting moment when passing through the entrance to and exit from a super-elevated turn, analysis[23] shows that the offset of the second set of lower lateral wheels from the plane of the other wheels is small enough to be neglected. The centerlines of the upper lateral wheels are directly above the centerlines of the main support wheels. The diameter of the four upper lateral wheels is 8" OD and of the lower lateral wheels if possible 6", both sets with solid polyurethane tires. The maximum load on any one of these tires is 1500 lb for one second,[24] and the maximum steady load requirement for perhaps 5 or 10 minutes is 750 lb each on the pair of lateral tires. The deflection of each of these tires should be approximately 0.150" under the 1500 lb load. Each of these wheels shall be provided with sealed bearings and axles designed to fit brackets, to be designed, that attach to the chassis frame.

To provide a firm anchor for the upper lateral wheels, an additional piece of 2x2" square tube is welded below each of the upper wheels as shown in Figure 4.1. Brackets need to be designed to attach the wheels firmly to the frame.

Firm attachment of the lower lateral wheels requires a pair of arms as shown in Figure 4.1 plus a shear member between the upper and lower arms.

5. The Switch

There will be one switch arm near the front of the chassis and one near the rear as shown in Figure 4.1. The arms are slaved to each other as described below and will be thrown by rotary solenoids, such as manufactured by Johnson Electric, one to throw the switch to the right and the other to the left. A 4" OD polyurethane-tired wheel with its bearing and axle is mounted to each end of each of the two switch arms. The maximum load on one switch wheel is 1200 lb, which is applied for less than one second. The deflection under this load shall be approximately 0.100". The shape of the arm is arranged so that the line of action of the force on the wheel passes through the center of the switch axle, thus making the switch arm self-centering. To

[22] J. E. Anderson, "Effect of Non-Steerable Wheels on Road Resistance in Curves."

[23] J. E. Anderson, "The Offset of the Lower Rear Wheel on the Chassis."

[24] J. E. Anderson, "Lateral Dynamics of the ITNS Vehicle." Running this program with correct weight and inertia will verify the specified values of all wheel loads and deflections.

make the switch bi-stable, a compression spring is mounted at the top of the center of each switch arm.[25] A finite element analysis of the switch arm with its wheels and axles is needed to determine the exact shape, material properties, and moment of inertia about the axis of rotation. The required stiffness of the spring and the torque pulse required of the rotary solenoid are determined by a dynamic analysis[26] of the switch assembly, considering the inertia of the two switch arms and the inertia and friction of the mechanism that slaves one to the other. The center of gravity and strength of the spring must be selected so that a 0.20 g lateral acceleration will not throw the switch. To stop the moving switch arm at the correct position, a snubber, such as manufactured by Enidine, is mounted to a suitably designed bracket attached to the frame. A proximity sensor is suitably mounted to enable signaling to the control system that the switch has been thrown.

A problem in slaving the two switch arms results because the switch axle must be placed about 2" above the midpoint between the upper and lower lateral wheels. This determination is made by an analysis of the maximum forces to the left and to the right as the vehicle passes through a merge or diverge section of guideway.[27] But the position of the switch axles at the center of the chassis is occupied by two variable-frequency drives and a battery. The problem is solved as follows: Weld a 2" channel section, flat side up, about 2" above the lower horizontal square tube that forms the lower member of the chassis frame. To increase its stiffness, add supports as needed. Under the channel section mount a horizontal tube with bearings at two or more positions along the tube to permit the tube to rotate freely. To the top end of each switch axle mount a vertical arm forked at the bottom to receive a similar arm mounted to the lower horizontal tube with a roller at the top. With identical mechanisms at both ends, each solenoid operates both switch arms, one to the left and the other to the right. Alternative mechanisms may be considered. Zero slop is not necessary because the switch arms are made bi-stable by means of the springs.

The switch assembly must be tested separately under load for at least 300,000 cycles before being assembled into the chassis, and must be designed so that the maximum stresses are no more than 75% of the fatigue limit of the steel. Special attention must be placed on designing to reducing stress concentrations.

Inventory of switch parts:

1. Two switch arms
2. Four wheel, bearing, axle assemblies
3. Two switch-arm shafts

[25] J. E. Anderson "Analysis of a Bi-Stable Switch."
[26] The required program is available.
[27] See the paper "The Optimum Switch Position."

4. Two rotary solenoids
5. Two solenoid mounting brackets
6. Two springs
7. Four snubbers
8. Two proximity sensors
9. One long tube mounted on bearings
10. Two upper forked arms to be fixed onto and perpendicular to the switch-arm shafts.
11. Two lower arms each with a bearing on the top end to be fixed onto and perpendicular to the long lower tube.

6 LIM bogie

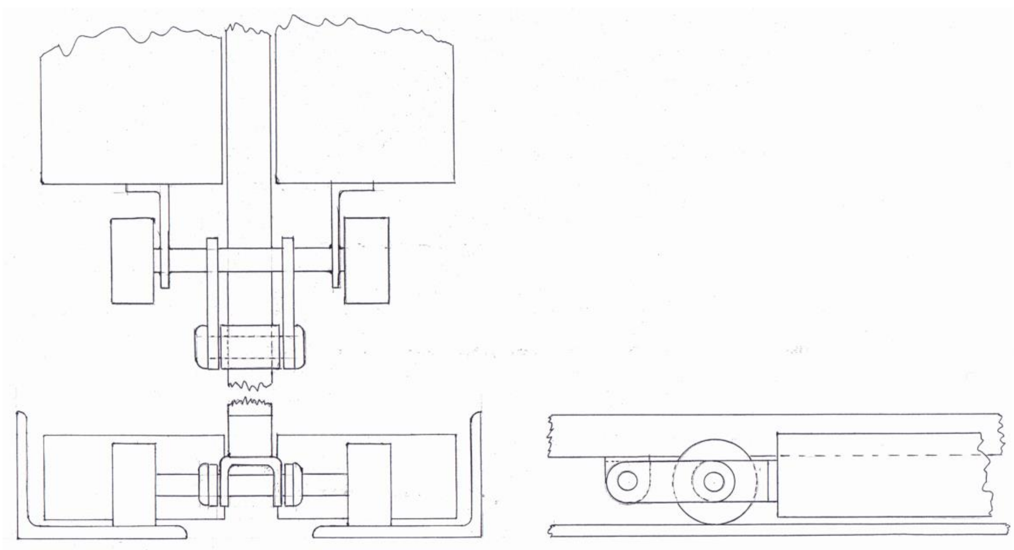


Figure 4.2. LIM-Chassis Connection.

The LIM bogie permits the LIM to maintain a steady 3-mm air gap to its reaction rail while permitting the vehicle to settle at different heights depending on the weight of the passengers. There is a pair of LIMs, one acting against the left running surface shown in the left view in Figure 4.2 and one against the right running surface. To the front and rear of each LIM is welded a bracket with a hole at the free end to receive one of a pair of fixed axles that connect the two LIMs. As shown in Figure 4.2, two 4" OD polyurethane-tired wheels with their bearings are mounted to each of these axles. These wheels must each carry a steady load of 300 lb corresponding to both the weight of the LIMs and the maximum normal force produced when the vehicle is accelerating. To each of these axles is attached a pair of horizontal links approximately 4" long. From the Pythagorean Theorem, if the link length is a and the vehicle can move up or down a total of δ then motion either up or down is $\delta/2$ and the slop the bearing at each end of the link must have is $(\delta/2)^2/2a/2 = \delta^2/16a$. If δ is say $0.2"$ and $a = 4"$ the bearing slop required is only 0.0006", which is less than can easily be achieved. The other end of each of these four links is attached with a journal bearing to a vertical bracket that is fixed to the lower frame member.

An alternative to this design is to sense the air gap and adjust it by means of servos at each of the four corners of the LIM assembly. Before investigating such a solution, data needs to be obtained from the LIM supplier on the effect of air gap on thrust and efficiency.

7. Parking & Emergency Brake

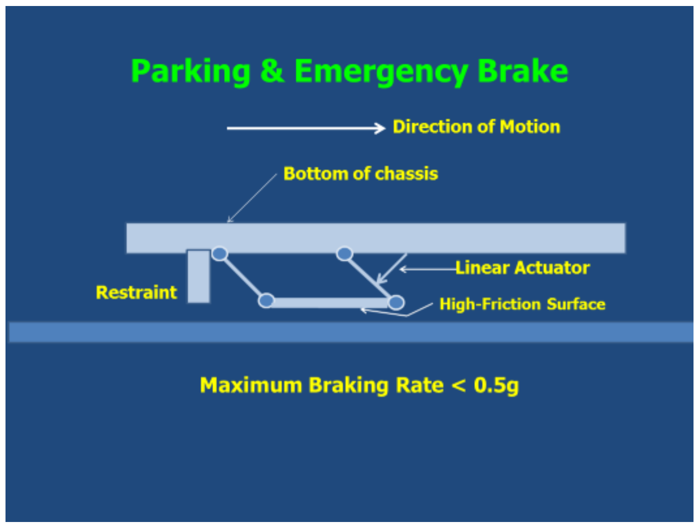


Figure 4.3. Parking & Emergency Brake.

Normal acceleration and braking is applied via the LIMs; however, when the vehicle stops in a station we must turn off the power to the LIMs, in which case it would be easy to move the vehicle either because of a wind or human force. Thus, there must be a parking brake that will hold the vehicle in position. The parking brake also serves as an emergency brake while the vehicle is moving and a rare circumstance occurs in which emergency braking is needed and the redundant LIMs, drives, or power supply has failed. Because it is possible though improbable for the dual wayside-power system to fail, the parking brake shall be powered by the on-board battery. Power must be applied to the brake only when it is operated. With the brake either fully applied or not applied the power to the brake motor must be switched off. These features are achieved with the arrangement shown in Figure 4.3 near the rear wheel. A pair of brake shoes, one acting on the left running surface and the other on the right, are horizontal members with a high-friction material bonded to the lower side. A pair of links of identical length support each brake shoe at its front and rear. In this way motion of this assembly keeps the shoe parallel to the running surface. The assembly can be actuated by a ball-screw actuator of standard design, which can be chosen so that the actuator will not back up when turned off under load. There must be a stop that prevents the assembly from moving backwards past the vertical position. Each of the two brakes must be designed to resist a maximum vertical force of 500 lb, and a maximum horizontal force of 125 lb.

8. Shock-absorbing bumpers

There shall be a 4-in-stroke shock-absorbing bumper of standard design mounted at the forward end of the upper horizontal square tube and a friction shock absorber at the rear end. The forward-end shock absorber shall be constant-force, constant-displacement, spring-return devices such as supplied by EGD Inc. The ends shall be configured to engage as the vehicle turns in a radius of 75 ft unless a special situation requires a smaller turn radius. The shock absorber shall have the highest practical in-lb rating.

9. Power pickup

For propulsive power, the vehicle will be supplied with 600-volt DC from power rails mounted inside the guideway as shown in Figure 4.1. A pair of power-pickup shoes attached to each side of the chassis carry the power to variable-frequency drives. In no situation can these power-pickup shoes rotate and short out. A special problem in a PRT application is that one of the pairs of shoes must disengage and then reengage as the vehicle passes through a merge or diverge section of guideway. Thus, there is a potential problem of chattering and hence sparking and excessive wear. Fortunately, this problem has been studied experimentally at the Insul-8 facility in Omaha, NE, and found to have a satisfactory solution.

The chassis designer shall coordinate with Systems Engineering and the power-supply engineer to design the attachment of the power pickup shoes to the chassis.

10. Transmitter/receivers

Information is carried from the vehicle's computer to the cognizant wayside zone controller and back via a leaky cable mounted inside the guideway. The information transfer device is a pair of transmitter/receivers mounted to the chassis. The chassis designer shall coordinate with System Engineering and the electronics engineer to design the required mounting means.

11. Variable-frequency drive (VFD) mounting

A pair of VFDs are mounted in the chassis. They are the green boxes shown in the picture of the chassis in the Executive Summary. The chassis designer shall coordinate with Systems Engineering and the VFD supplier to design the required mounting means.

12. Battery mounting

A battery, to be specified by the power-supply engineer, is to be mounted between the two VFDs. It is to provide uninterruptible power to the on-board computer, the HVAC system, the switch, the parking brake, and other auxiliary devices. The chassis designer shall coordinate with Systems Engineering and the power-supply engineer to design the required mounting means.

13. Wiring

The chassis designer shall coordinate with Systems Engineering to design the attachments for all the necessary wiring among chassis components and between the chassis and the cabin. Removing any chance of fire is of fundamental importance in placement and insulation of the wires.

14. Sensors

For test purposes, strain gages and possibly other sensors shall be placed at strategic points on the chassis as determined by finite-element analysis.

Task #5: Final Engineering for the ITNS Guideway and Posts

References (Included in *Contributions to the Development of Personal Rapid Transit*)

1. "An Intelligent Transportation-Network System."
2. "Guideway Criteria and how they are met."
3. "The Demonstration-System Guideway." (A computer program.)
4. "The Guideway for an Intelligent Transportation Network System."
5. "How to Design a PRT Guideway"
6. "The Guideway Cross Section"
7. "A Dynamic Analysis of the Switch Rail Entry Flare"
8. "The Equivalence between an Earthquake Load and a Wind Load on a PRT Guideway."
9. "Flexing of the Running Surface and Ride Comfort."
10. "Running Surface Stiffness and Tire Ellipticity Requirements for Adequate Ride Comfort."
11. "Vertical Acceleration of a Vehicle due to a Slope Discontinuity"
12. "Vehicle moving on a Sinusoidal Surface."
13. "The Joint between Guideway Sections."
14. "The Deflection of a Curved Guideway."

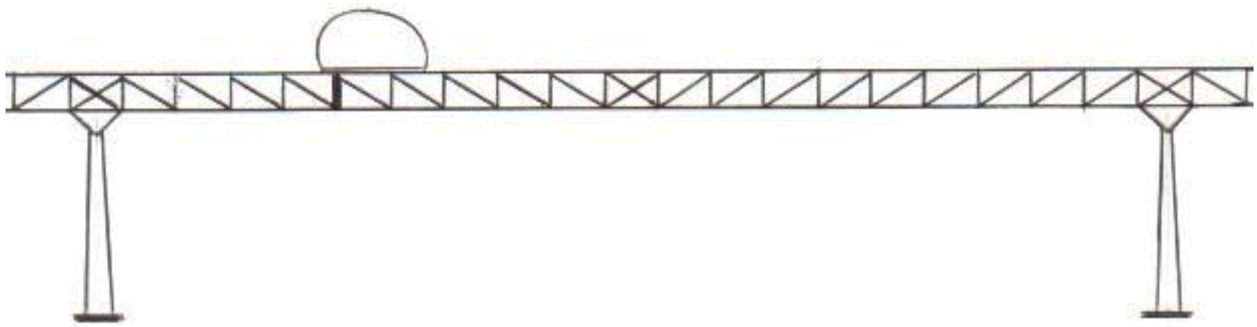


Figure 5.1. A sketch of the Guideway.

The guideway is a covered steel truss, with the elements sketched in Figure 5.1. It is clamped to posts spaced 90 feet apart, and each section has an expansion joint at the 20% point. During our Phase I PRT Design Study for Chicago, Stone & Webster engineers did extensive computer design on both straight and curved sections of an earlier but similar version of the guideway. See Figure 6.1 for the guideway cross section.

This task involves the final design verification of the guideway-post system, preparation for its fabrication, cost estimation for fabrication, and supervision of its fabrication and installation. The three-dimensional test-track layout is described in Reference 3, and the guideway that meets the maximum loading conditions is described in Reference 4. References 5 through 14 provide further information about guideway design.

To operate the Linear Induction Motors, a sheet of copper 0.080" thick and 10" wide must be attached to the horizontal 7.5"-wide surface of each of the main-wheel-support angles and overlapped underneath. Since the wheels mounted on the chassis do not steer, there will be some wear while traversing the curves in the guideway. Tests performed at Raytheon in 1993 relieved concerns about wear on the copper surface; however, using principles of tribology further analysis and testing of expected wear on the copper surface is warranted. A great deal of information about tribology can be found on the Internet including references to possible consultants. Such a consultant should be engaged to advise the project.

The Company needs the assistance of a Structural Engineer who has the computer tools and skill required to perform an accurate verification of the design, and the tools needed to produce drawings from which to fabricate the straight and curved sections of guideway. It will be expected also that the Structural Engineer will assist the Company in discussions with the fabricator. An additional firm may be needed to design and build adjustable fixtures that will lay up the guideway sections for fabrication and the fixtures needed for robotic welding.

The posts on which the guideway will be mounted are at least 90 ft apart. To ease transportation to the test site, the guideway may be fabricated in 45-ft sections and welded at the test site to form each of the required 90-ft sections.

The guideway shall be clamped to the posts using the assembly illustrated in Figure 5.2, which shall be subject to finite-element analysis before being manufactured and installed. Expansion joints (Reference 13) shall be placed at the 20% point in each span.

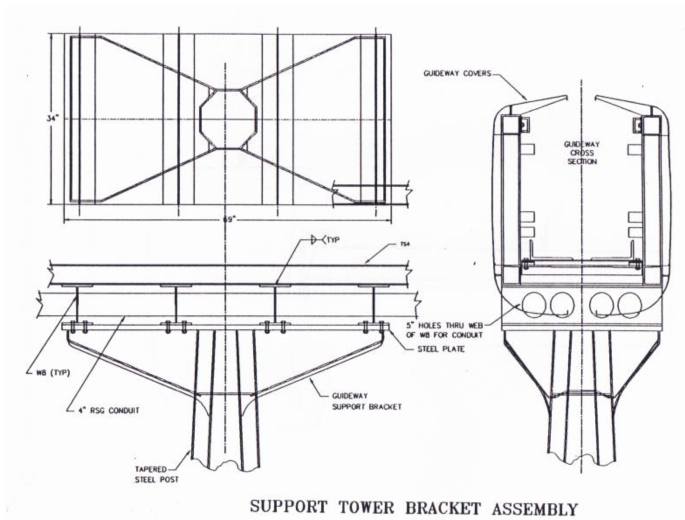


Figure 5.2. The Guideway-Post Bracket.

The guideway-support posts are planned to be bent up from 5/16” steel plate. They are to be octagonal and tapered from 10” at the top to 20” at the base, where each of them is to be welded to a 2” thick steel base plate, which is to be bolted to a reinforced concrete foundation in which four 1.5” high-strength steel studs, spaced at the four corners of a square 24” on a side, are mounted to receive the base plate. The length of each post will be given from planning analysis. Manufacture of such posts is a specialty item. One of the few manufacturers in the United States is Millerbernd Manufacturing Company of Winsted, Minnesota. They would supply the complete post with the bracket on top and the steel base on the bottom. The post-to-guideway bracket has been designed roughly and shall be verified by finite-element analysis.

Brackets are to be designed and built into the guideway to permit a hinge attachment of the covers at the bottom and a latch attachment at the stop, so that the covers can be swung down to permit access to the guideway, however remote the need to do so may be.

Deliverables: A complete set of drawings and specifications that will enable a competent fabricator to fabricate the guideway to the tolerances required for adequate ride comfort. A detailed layout of the guideway required for the demonstration will be given from Ref. 3.

Task #6: Final Design and Fabrication of the Guideway Covers

This specification relates to design and fabrication of covers for the guideway, which must be built in sections of convenient length and curved to conform to the shape of the guideway. The three-dimensional layout of the system will be given. The guideway with its maximum loading conditions is described in Task #5. Figure 6.1 includes a cross sectional view of the cover as it is hinged to the bottom of the guideway and secured at the top.

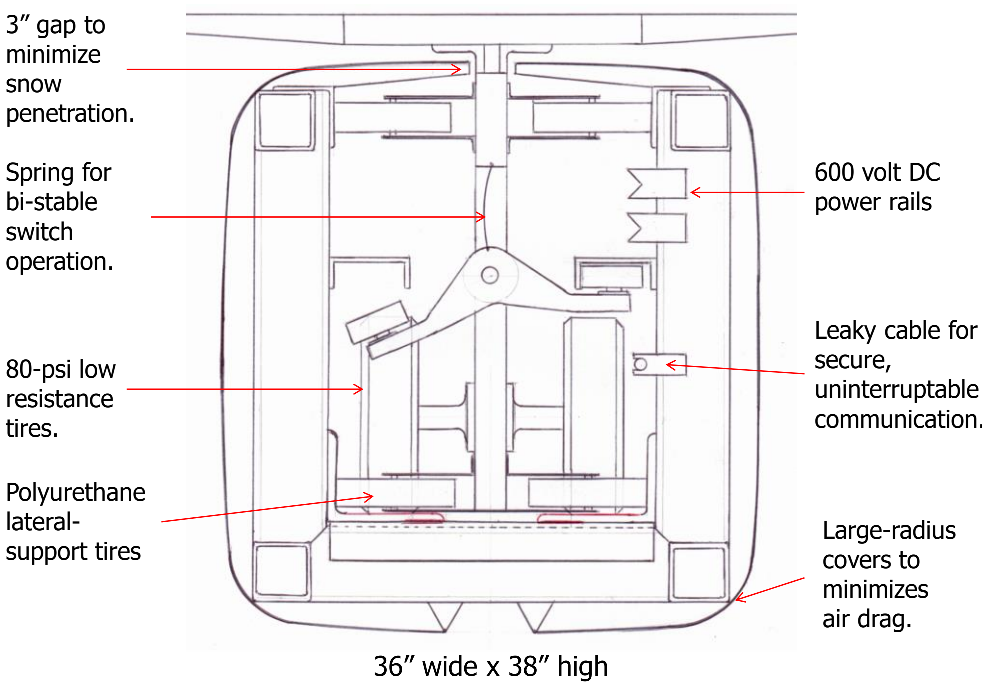


Figure 6.1. Covered Guideway Cross Section.

The radii at the top and bottom corners of each cover are 6 inches and the sides shall be slightly bowed for added stiffness. We envision the covers to be molded from fire-resistant reinforced composite material suitable for an outside environment in which temperatures may swing from 130 deg F to -45 deg F. The exterior of the cover shall be able to accept a color and texture specified by a planner, and a thin layer of aluminum is to be sprayed on the inside to act as an electromagnetic shield. Sound insulation may also be applied. The thickness of the covers shall be sufficient to ease the process of lowering the cover in the field for possible maintenance inside the guideway in winds up to 15 mph. We envision a cover thickness of about 1/8”. The covers are to be designed to be replaced no more than once every 20 years. The covers are to be fabricated with stainless steel inserts suitable for attachment at the top and bottom of the guideway to brackets fabricated into the guideway structure. The covers can be manufactured by a company such as Wilbert Plastic Services of White Bear Lake, Minnesota.

Deliverable:

A complete set of drawings of the covers in a form needed for fabrication.
Identification and negotiations with the cover manufacturer.
A complete set of covers ready to be installed to the test guideway.

Task #7. The Design and Assembly of the *ITNS* Control System

This task is for the design, assembly, and test of the control system needed to operate *ITNS* vehicles on a full-scale demonstration system.

References(Available in *Contributions to the Design of PRT)*:

1. J. E. Anderson, "The Future of High-Capacity Personal Rapid Transit," Advanced Automated Transit Conference, Bologna, Italy, November 2005.
2. J. E. Anderson, "PRT Control," *Journal of Advanced Transportation*, 32:1(1998):57-74.
3. J. E. Anderson, "Safe Design of Personal Rapid Transit Systems," *JAT*, 28:1(1994):1-15.
4. J. E. Anderson, "Synchronous or Clear-Path Control in Personal Rapid Transit," *JAT*, 30:3(1996):1-3.
5. J. E. Anderson, "Longitudinal Control of a Vehicle," *JAT*, 31:3(1997):237-247.
6. J. E. Anderson, "Simulation of the Operation of a PRT System," *Computers in Railways VI*, WIT Press, Boston, Southampton, 1998, 523-532.
7. J. E. Anderson, "Dependability as a Measure of On-Time Performance of Personal Rapid Transit Systems," *JAT*, 26:3(1992):101-212.
8. J. E. Anderson, "A Review of the State of the Art of Personal Rapid Transit." *JAT*, 34:1(2000):3-29.
9. J. E. Anderson, "Overcoming Headway Limitations in PRT Systems," PodCar Conference, Malmo, 9-10 December 2009.
10. J. E. Anderson, "Failure Modes and Effects."
11. Vehicle Control Software.
*12***.** J. E. Anderson, **"**Properties of a Linear Induction Motor."

Serious work on the design of control systems required for systems like ITNS extends back to the 1960s.
Reference 1 gives a bibliography of articles on control of HCPRT.

Reference 2 describes the *ITNS* control concept as it had advanced by 1998.
Reference 3 describes the elements of safety and why linear-induction motors are necessary.
Reference 4 shows why synchronous control is not a viable option for any but a very small system.
Reference 5 shows that only speed and position feedback are needed to control an *ITNS* vehicle and derives the gain constants needed in terms of a natural frequency, a damping ratio, a first-order thruster lag, and the mass of the vehicle.
Reference 6 describes the operation of ITNS vehicles in a network of guideways.
Reference 7 defines *Dependability* and shows why it is the most useful measure of on-time performance.
Reference 8 contains important information about control in a systems context.
Reference 9 shows how very high safety and reliability can be obtained.
Reference 10 calculates the MTBFs of many potential failure modes and in the process gives useful information on how the control system works.
Reference 11 is the vehicle-control software program.
Reference 12 derives the equations for the equivalent circuit model of a linear induction motor (LIM) and shows how they are used to optimize performance.

The details of *ITNS* control have been developed and form the basis for the current project, in which we need to consider advances in technology that may improve performance and/or lower costs. We obtained a significant amount of useful information from Boeing on their control work under the federal Advanced Group Rapid Transit program, which is described in a series of articles in IEEE publications, which are available. During the past nine years, we have developed the software programs needed to operate an *ITNS* network of any complexity. When the successful bidder is selected among those we have in mind, we will provide additional information on the details of PRT network control on an as-needed basis.

1. The Control Concept

Control is accomplished by means of three levels of computers: Computers on board each vehicle (VC), wayside zone controllers (ZC), and a central controller (CC). Each VC receives commands from the local ZC and transmits to it position and speed. The CC communicates with each ZC, but not with the VC.

There are five types of zone controllers (ZC):

1) Each station ZC, SZC, controls the movement of vehicles through and around a station.
2) Each merge ZC, MZC, controls operations through a merge section of guideway.

3) Each diverge ZC, DZC, controls a diverge section.
4) A line ZC, LZC, may be needed in a section of guideway too long to be included in one of the other types.
5) The fifth type of ZC, PZC, manages the flow of passengers in a station.

The number of vehicles that can be accommodated in each ZC depends on the data rate. The amount of data that must be transmitted is minimized as described below. The VCs and ZCs are used repeatedly without change as the network grows

2. Dual-Duplex Computers

During a study of automatic control for the federal Advanced Group Rapid Transit program, Boeing found that the best way to meet a federal safety requirement was by using two pairs of motherboards in each computer making the same computations and arranged so that the two outputs of each pair must match 10 to 20 times each second, and then the common output of each pair must match, otherwise defensive action must be taken. They called this DUAL-DUPLEX. A diagram is shown below. ITNS uses this philosophy in all computers in its system. The Boeing work is described in a series of IEEE papers, which are referenced in Reference 2 and in a series of reports in the public domain. The defensive actions required are discussed in Reference 10.

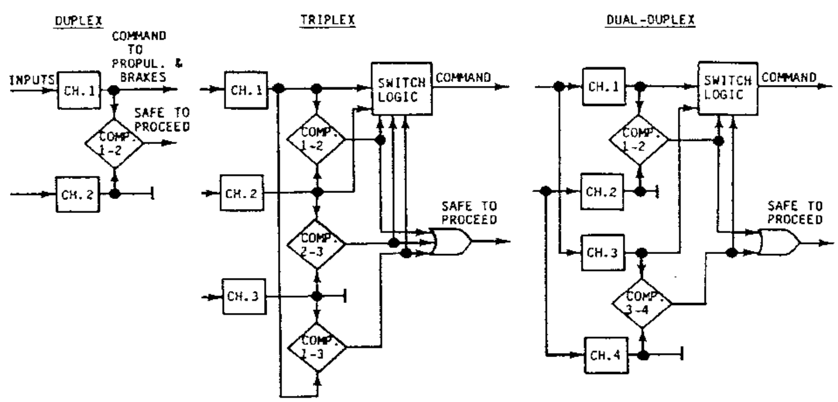


FIGURE 3: MICROPROCESSOR REDUNDANCY CONFIGURATIONS

Figure 7.1. Dual Duplex Control.

3. The Vehicle Controller

A block diagram of the vehicle controller is shown in Figure 7.2. The gain constants G_v and G_p are derived in Reference 5. The vehicle is propelled and braked by a pair of LIMs, each of which receives a variable-frequency voltage input from a Variable Frequency Drive (VFD), which receive its command voltages from a software package, which calculates the instantaneous required frequency and voltage. The frequency is a predetermined linearly increasing function of speed. Conversion of thrust commands into voltage commands is accomplished by use of an equation, derived from the equivalent-circuit model of the LIM (Reference 12) that calculates the required voltage as a function of thrust, slip, and frequency.

When operating at constant speed, the vehicle computer receives the command speed from a wayside zone controller (described below) each time-multiplexing interval. If the speed signal is not received in two successive intervals, the vehicle is commanded to a creep speed of about 1 m/s, at which a collision is of no consequence (each vehicle is equipped with shock-absorbing bumpers front and back.)

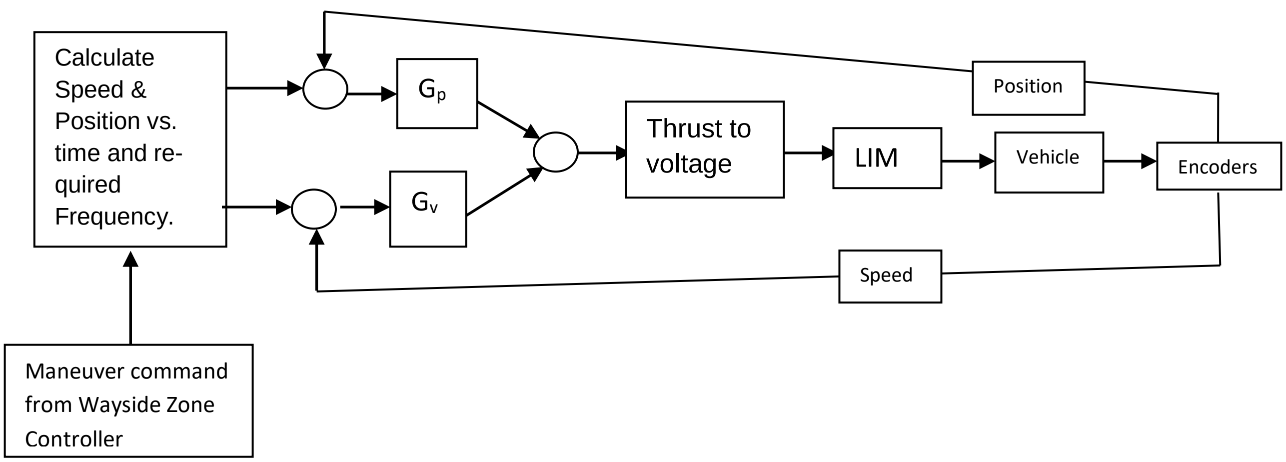


Figure 7.2. The Vehicle Controller.

A wayside ZC transmits to a specific vehicle a maneuver command with a parameter, such as "Stop in x meters." The vehicle controller has in its software the routines needed to calculate the instantaneous speed and position required of any maneuver.[28] It compares these command values with the actual speed and position every 5 milliseconds. The differences are multiplied respectively by a speed gain and a position gain, summed, and then sent as a thrust command to a thrust-to-voltage converter.

Position and speed can be obtained from digital encoders, which can be imbedded in the wheel bearings. The left and right encoder outputs are averaged to give the correct output in turns, and the fore and aft encoders provided redundancy. The accuracy of encoders has been shown to be sufficient to obtain speed by differentiating the encoder output.

[28] The maneuvers are 1) Change Speed, 2) Slip, 3) Stop in a given Distance, and 4) Emergency Stop.

In a project for the Chicago RTA in 1991 that involved Raytheon and Hughes engineers, it was determined that the most secure way to transmit data between the vehicles and the wayside zone controllers was via a leaky cable mounted inside the guideway. Leaky cables are now commercially available from multiple sources. Devices that transmit and receive data to and from the communication means need to be designed, built, installed, and tested.

4. Switch Operation

The switch consists of a pair of arms with a polyurethane tired wheel on each end as shown in Figure 4.1, Task # 4. These arms rotate about a longitudinal axis. In merge and diverge sections of the guideway, switch rails are positioned to intercept the switch wheels, thus constraining the vehicle positively as it passes through the merge or diverge section. The switch is rotated by means of a pair of rotary solenoids, one of which throws the switch to the right and the other to the left. The switch arms are held in one of two stable positions by a pair of leaf springs, and their motion is stopped by a pair of commercially available snubbers. If the switch arm is rotated so that the left wheel is horizontal, it is set to steer the vehicle to the left, and if rotated so that the right wheel is horizontal, it is set to steer the vehicle to the right.

The position of the switch is sensed by means of a pair of proximity sensors wired to the VC. When the VC receives a switch command from a cognizant wayside ZC, it determines if the switch is in the desired position or if it must be thrown. If the latter, the VC commands a pulse of current to one of the rotary solenoids, and at the same time commands the vehicle to creep speed about one second later. The action of the switch arm reaching the other position (in about 0.25 sec) is sensed by the cognizant proximity sensor, which informs the VC to cancel the signal to slow the vehicle to creep speed. This is one of the ways in which fail-safe operation is implemented.

5. Auxiliary Functions of the VC.

The VC on each vehicle

- commands opening and closing of the door,
- accepts and stores the destination command,
- changes the destination command if requested by the occupant or by a central operator,
- controls the lights,
- controls the HVAC system,
- senses and responds to overloading,

- senses and responds to smoke in the cabin by causing the vehicle to stop at the next station, alert authorities, and upon stopping causes the cabin door to open,
- keeps track of distance traveled to direct itself to maintenance on a predetermined schedule,
- senses incipient failures by means of strain gages, temperature sensors, pressure sensors or vibration sensors and, based on established criteria, dispatches the vehicle to maintenance after causing the passengers to unload, and
- Stores information on all failures for analysis of the mean time to failure.

6. Vehicle Control Program

A computer program has been written to operate the vehicle under the closed-loop control system shown in Figure 7.2 and has been tested with passengers in a vehicle, thus proving that ride comfort is excellent. Position and speed commands are derived to cause the vehicle to perform each maneuver at maximum comfort acceleration and jerk and in minimum time. A computer program has been written and tested over 40,000,000 times with random inputs to calculate each maneuver with specified input parameters.

7. Station Zone Controller (SZC)

A SZC controls vehicle operations through each station, which requires information on the position and speed of each vehicle under its jurisdiction. It keeps track of the position and speed of each vehicle from the downstream point of merge of the station-bypass guideway with the main guideway upstream to the nearest branch point, whether it is the exit of another station or a line-to-line merge or diverge. The upstream ZC informs its downstream neighbor of the arrival of each vehicle in a "hand-off" operation. The downstream neighbor informs its upstream neighbor when a vehicle in its jurisdiction must slip past the zone boundary to avoid violating the minimum allowable headway to a downstream vehicle. Slip is discussed below in the paragraph describing the merge zone controller.

At a pre-determined position upstream of each station there is a Switch Command Point (SCP). When a vehicle passes this point, its destination is transmitted to the SZC, which determines if is to be switched into the station. Normally, if the destination matches the station number the vehicle is commanded to be switched in and at the same time the forward-most, empty berth is reserved for it. But the station may be so full of vehicles that it can't accept another, in which case the SZC commands the vehicle to switch away from the station in an action called a "wave-off."

A short distance down the guideway and ahead of the station, there is a Deceleration Command Point (DCP) at which a vehicle committed to enter the station is caused to begin a deceleration maneuver to stop it at the reserved berth. But before the deceleration command, the SZC notes if there is now a free berth farther downstream, in which case it changes the berth reservation to the new forward-most, free berth. At the instant the vehicle reaches the DCP it may be moving at a speed lower than the line speed and it may be accelerating or decelerating while performing a slip maneuver. Thus, the maneuver command must consider the initial speed, initial acceleration, and the distance to stop. Such maneuvers have been programmed and thoroughly checked.

While in the station area, a vehicle may be commanded to advance to a newly freed berth, and it may be so commanded while it is engaged in a deceleration maneuver or in a station-advance maneuver. Thus, the SZC must follow the motion of all vehicles in its jurisdiction and be ready to command station-advance maneuvers when required. If the vehicle is in the unloading and loading area, the SZC determines when it can advance, not only based on availability of a free berth ahead but on the status of loading or unloading and only if the door is closed.

When the forward-most vehicle in the station area has been given a destination to a different station, it may be at rest or it may be in a deceleration maneuver or a station-advance maneuver moving to the forward-most, free berth. In either case, the SZC, which keeps track of the positions of all the vehicles bypassing the station, calculates the position in the mainline and the time of arrival at line speed if it were to accelerate to line speed at each moment of calculation. The SZC calculates the minimum distance to the vehicle ahead on line and the vehicle behind, and only if these distances are within acceptable bounds does it command the vehicle to line speed. The complete set of acceleration-to-line-speed maneuvers has been programmed and thoroughly checked with arbitrary initial speed and acceleration. An additional condition for commanding a vehicle to line speed is that the vehicles bypassing the station are not slipping. Slipping indicates that there may be too much traffic trying to enter a downstream merge, so the system manages excessive congestion by holding vehicles in stations until the congestion has cleared.

When there is an unneeded empty vehicle in the first berth in a station the SZC will give this vehicle the destination of the nearest storage station, whereupon it is released from the station exactly as any other vehicle is released. While the empty vehicle is cruising on line it can be redirected into a station where an empty vehicle is needed. This process is discussed in Reference 8.

8. Passenger-Movement Zone Control (PZC)

In each station, there is a computer that controls all functions involved with 1) passengers paying fares, 2) entering their destinations so that they can be transferred to a VC, 3) causing the vehicle door to open, and 4) determining at which berth passengers should prepare to load. The later can be indicated by a green light over the berth. By means of motion detectors, the station computer can estimate the rate of arrival of passengers from the street so that the system can be alerted to send more empty vehicles. The code for these operations has not been written.

9. Merge Zone Control (MZC)

At a predetermined distance upstream of each line-to-line merge point resides a Merge Command Point (MCP). The MZC keeps track of the positions and speeds of all vehicles within its jurisdiction. When a vehicle passes the MCP, the MZC checks the positions of the vehicles on each branch of the merge. If a conflict would occur with a vehicle too close ahead on the other branch of the merge, the MZC commands the vehicle to slip back a distance sufficient to increase the headway to the accepted value. In a slip maneuver the vehicle is commanded to follow a maneuver profile in which it first slows down then speeds up to the original speed. If in slipping, the MZC detects that the headway to the vehicle behind would be too small, the MZC simultaneously causes that vehicle to slip – usually a lesser amount. This slipping of upstream vehicles continues until the next upstream vehicle is far enough behind so that the headway criterion is not violated. Slipping may continue upstream of a line-to-line merge or diverge. If the upstream branch point is a merge, vehicles on two upstream branches may have to slip. This action is programmed into the ITNS network simulation program. A key factor in this action is that the MZC must keep track of the slip remaining for each vehicle so that it commands only the additional slip needed to avoid conflict. The slip maneuver is designed to retard each vehicle from an arbitrary speed and acceleration. All such slip maneuvers have been programmed and thoroughly checked.

10. Diverge Zone Control (DZC)

Each DZC contains a table of switch commands for every station in the network. These commands may be changed by the CC because of excessive traffic in certain parts of the network. When a vehicle reaches the Diverge Command Point (DCP), which is located at a predetermined distance upstream of the DZC, the DZC requests the vehicle's destination, looks up the corresponding switch command, and transmits it to the VC, whereupon the VC performs all the actions described above. The distance of the DCP upstream of the clearance point[29] ahead of the diverge point is the line speed multiplied by a conservative estimate of the switch throw time plus the distance required to stop if the VC can't detect that the on-board switch is in one or the other of the two stable positions.

11. Line Zone Control (LZC)

If there is a region of the guideway too remote to be served by one of the above three types of ZC, the function of the LZC is to transmit the line speed to the vehicles in its jurisdiction, to monitor the positions and speeds of the vehicles, and to remove the speed signal if one of the positions or speeds has deviated from the expected values by a predetermined amount. The result is that the VCs, lacking the speed signal, automatically slow the failed vehicle and those behind it that would be impacted to the predetermined creep speed. This monitoring function is also a function of the other three types of ZC.

12. Central Control (CC)

The CC is connected by fiber optics to each of the ZCs. Its function is to reduce traffic congestion when necessary and to gather and analyze data. Management of congestion requires that the CC keep track of all the vehicles in the network by data transfer from the ZCs and determine by established criteria when to change the switch tables for certain destinations from certain diverge points. This function has not been programmed into the network simulation program and can be delayed until the planned network becomes large enough so that it is needed.

The CC will gather data on failures in each vehicle and the difference between each actual trip time and the expected value to calculate, via the method derived in Reference 7, the system dependability, which can be used as one of the means of determining if the system meets contracted on-time performance.

13. Network Control Program

Of the above-described controllers, all but PZC and CC have been programmed and checked in a network control program, which will be made available to the Control Supplier. The program permits different speeds in different parts of the network. The simulation program is described in Reference 6.

[29] The point at which vehicles on opposite branches of the diverge would touch each other.

14. Fault-Tolerance Means

- Wayside zone controller (ZC) emits a speed signal every n[30] ms.
  With no speed signal the vehicles in its jurisdiction are programmed to creep speed.
- ZC receives position and speed from each vehicle every n ms.
  With no communication from a vehicle, ZC removes speed signal for that vehicle and those behind it.
- All commands returned and verified before action is taken.
- Temperature sensors warn the system of possible thruster failure.
- Emergency-brake command ON unless OFF received every n ms.
- Throw of switch commands creep speed in 0.5 sec unless canceled by signal from a Proximity Sensor.
- Sonar or radar back-up emergency control.

15. System Control

The demonstration system will use at least two wayside zone controllers, one of which will be used in either the mode of the SZC or both the MZC and the DZC. The other is an LZC, which will command and monitor the section of guideway from the guideway merge point out of the station approximately half way around the track, thus permitting the implementation and testing of the process of handing off information from one zone controller to the next.

16. Data to be transmitted between Vehicles and Wayside.

1. From wayside zone controllers: the speed command every Time Multiplexing Interval (TMI) and maneuver commands when needed. In case of a fault, the zone controller removes the speed command, in which case the vehicles are programmed to decelerate to creep speed.
2. From the vehicles, ID number, speed, and position every TMI. If a vehicle does not receive a speed command in two successive TMIs, it and the vehicles upstream of it are programmed to reduce speed to the creep speed.

[30] "n" may be 100 or less.

17. The Hardware Components

1. Digital encoders mounted on each vehicle to detect position and speed.
2. Transmitter/Receivers to be mounted on the vehicles and at the wayside ZCs.
3. Leaky cables − the means for communicating between vehicles and wayside computers.
4. Wayside magnetic markers to provide independent checks on the speed and position of each vehicle for the wayside zone controllers.
5. The vehicle and wayside computers to be used.

18. Information to be developed by the Control Team

1. <u>Data Rate.</u> The practical, verifiable data rate that can be used.
2. <u>Time-Multiplexing Interval.</u> From the Boeing work, available in a series of IEEE papers, the basic communication scheme was based on establishing a "time-multiplexing interval" (TMI) that would be divided into segments assigned to each individual vehicle within the domain of one zone controller. If this is still the best practice, the TMI must be selected. It must be short enough to provide adequate position and speed monitoring but long enough so that the data can be transmitted and received without error. Boeing used 40 ms and Raytheon 200 ms assuming more vehicles. The task here is to determine an acceptable TMI, if each wayside zone controller must be able to handle at least 30 vehicles.
3. <u>Frequencies.</u> The suitable frequency range for data transmission. Boeing used 100-150 kHz.
4. <u>Wayside Sensors</u>. Specifications for the independent means to be used by the wayside zone controllers to verify vehicle speeds and positions, such as magnetic markers.
5. <u>Vehicle Sensors</u>. Specifications for the means for the vehicles to obtain speed and position information. We have tested and simulated the operation of digital encoders, and know that they would be satisfactory. An alternative method must be clearly superior at lower cost.
6. <u>Communication Means</u>. Specifications for the means of communication between vehicles and wayside. If there is an acceptable alternative to a leaky cable it must be less expensive and secure.
7. <u>Common-Cause Failures</u>. Boeing recommended using dual-duplex computers, which are defined in detail in their IEEE papers. In such a system, there must be no way for the system to introduce common-cause failures. Clarification of means to ensure that common-cause faults cannot be introduced is needed.

19. The ITNS Software

The bidder shall be part of the software team to insure a seamlessly integrated, fault-tolerant control system consistent with system dependability, Reference 7, of better than 99.98%.

20. Hardware Procurement and Installation

The bidder shall procure the necessary control hardware, supervise its installation on the test track, and be available during the test program to adjust as needed.

21. Deliverables

- Complete specifications for the hardware components of the PRT control system.
- The required software.
- Procurement and installation of all control hardware.
- Supervision of installation of the control hardware and software.
- Consulting as needed during the test program.

22. Decisions Needed During the Demonstration Program

The demonstration program will involve three vehicles and one off-line station. Much of the complexity of a large system needs to be considered to prepare for commercial operation. In preparation for the demonstration program the following must be selected:

- The operating system.
- The programming language.
- The means of communication between vehicles and wayside – absolute security is a key requirement (most likely a leaky cable inside the guideway).
- The required data rate between vehicles and wayside zone controllers.
- The time-multiplexing interval if a specific time interval is needed.
- The computers to be used.
- The means of position and speed sensing (likely digital encoders).

Task 8. The Propulsion System for *ITNS* Vehicles

This Task is to specify, procure, install, and test a pair of linear induction motors (LIMs) and variable voltage, variable frequency drives (VFDs) that will propel and brake each ITNS vehicle.

1.0 Configuration

The vehicle configuration is shown in Task #4, Figure 4.1, with the LIMs mounted at the bottom of the chassis, which is inside the guideway. A photograph of the first chassis built is shown in the Executive Summary. The vehicle, see Figure 6.1, is supported by four main wheels that run on the horizontal surfaces of a pair of 8 in wide by 6 in high by 1/2-in thick steel angles. Lateral support for the vehicle is obtained by means of four side wheels near the top of the guideway and four near the bottom. The reaction surface for the LIMs is the horizontal surfaces of the angles, coated by a 0.080” thick copper sheet. The LIMs are placed between the front and rear sets of main-support wheels, and are supported as a set by four 4-in OD polyurethane-tired wheels, which are attached to the chassis via horizontal linkages, which enable us to maintain a gap of 3 mm between the undersurface of the LIMs and the top surface of 10-in wide copper sheets attached to and wrapped around the main-support angles. In a vertical curve, the gap may reduce to 1 mm or increase to 5 mm for a small fraction of a second. The VFDs are to be mounted in the cross-hatched area shown in the side view in Figure 4.1.

Figure 7.2, Task #7, shows the placement of the LIMs and VFDs in the vehicle’s control loop. On the left, the command position and speed are compared with the measured values of position and speed, with the differences multiplied by gain constants and added. The resulting signal is a command to change thrust, which in the VFD is converted into a voltage and frequency command.

2.0 Design Constraints

2.1 <u>LIM Length.</u> With the chassis as shown, the LIMs may be a maximum of 38 in long. If they need to be longer to meet the performance requirements, the chassis will be lengthened accordingly, but only after other alternatives to increase performance are considered.

2.2 <u>LIM Cross section.</u> As mentioned above, the LIMs react against the horizontal surfaces of 8x6x1/2-in steel angles. The inside vertical surfaces of the pair of angles are 21 in apart and with the 1/2-in thickness of the angles there remains a 7.5-in horizontal surface on each. Per supplier recommendation, the horizontal reaction surfaces are to be covered by 2-mm-thick (0.080") 10"-wide copper sheet with the copper sheet folded around the inner leg of the angle and underneath it. We understand that with this thickness the normal force will be roughly equal to the thrust.

2.3 LIM Air Gap. The air gap between the bottom surface of the LIM and the top surface of the copper sheet is nominally 3 mm. The LIMs will clear the inside vertical surfaces of the angle running surfaces by at least 5 mm, except in merge and diverge sections of guideway where one of the vertical angle surfaces moves away by a large amount.

2.4 LIM Side Gap. This problem is considered in a companion paper "The Required Side Gap in the ITNS Chassis," in which it is shown that the present design assumes a minimum curve radius of 75 ft, which means that the speed in curves must be 20 mph or greater.[31] In the ITNS design, tighter turns are not needed operationally. In maintenance shops, where in some systems tighter turn radii are used, in *ITNS* lateral transfer tables are used, which are much less expensive.

2.5 Input Power. Propulsive power will be obtained from power rails nominally at 600-volt DC with a variation along the guideway of no more than 10%. The LIMs shall be wound 3-phase normally Y-connected. The maximum phase voltage is 270 volts. During acceleration and deceleration, the power transmitted to the vehicle will vary as shown in the detailed specifications. Since there will be two motors in each vehicle, the power to each will be half the values given.

2.6 Drive Frequency. The motors shall be operated at the frequency at each speed that as close as practical minimizes current.

2.7 Ambient Temperature. The LIMs shall provide full performance as specified in Paragraph 3.0 over the ambient temperature range of -45^{o} C to +50^{o}C,

2.8 Temperature Protection. Each LIM shall be provided with imbedded temperature sensors to protect against damage due to overheating.

2.9 LIM Cooling. By forced air.

[31] The paper "Minimum Curve Radius" describes a case where a smaller turn radius is needed.

3.0 Thrust Performance Requirements

The performance requirements were calculated assuming that the steady grade may vary from +6% to -6%. Numerical input values are given at the beginning of the computer program included in the detailed task description. Some of these values can be expected to vary because of tests. The output performance values at three values of grade are given in Figures 4 a, b, and c of the detailed task description, which will be provided.

Task 9. Wayside Power and the Guideway Electrification

This task is for the design, procurement, and installation of components that will provide power to vehicles on the guideway and to the station, maintenance shop, and test-engineering office. The requirements are the following:

1. To provide power to the vehicles, utility power shall be converted to nominally 600-volt DC and fed to power rails, as part of this procurement, installed inside the guideway with a variation of no more than 10%. The maximum power required by a single vehicle is 40 kW so to provide a margin with three vehicles the wayside power conversion equipment shall be designed to handle 100 kW. Alternative primary power from solar cells or windmills coupled with power storage means shall be considered.

2. The house power needed for the test-facility buildings shall be determined in consultation with the designer of these facilities.

3. Standard power rails suitable for transit applications at speeds up to 40 mph (18 m/s), such as manufacture by Insul-8 or Wampfler, shall be used. They shall be rated at 300 amps. A small opening in the front face of the insulating rail covering shall allow for the insertion of the power-pickup shoes that ride against the stainless-steel face of the power rail.

4. The guideway feeder cables and the guideway power rails shall be sized to limit the voltage drop to ten percent from nominal to ensure acceptable performance on a vehicle at the end of a guideway sector under heavy load conditions.

5. Power rails shall be placed on the right side[32] of the main guideway loop and only on the left side through the station bypass guideway with sufficient overlap at the diverge and

[32] Facing the flow direction.

merge sections leading into and out of the station so that power can be transferred from one side to the other. Power pickup shoes shall be mounted on both sides of each vehicle. Electric current to the power-pick up shoes will be shut off before disengaging.

6. The power-pickup shoes are part of this procurement. They shall be designed to prevent chatter as they engage and disengage at the diverge and merge sections. Tests on disengagement and reengagement were performed at the Insul-8 Omaha facility in 1993-4 during the Raytheon PRT program with satisfactory results.

7. Lightning protection. The vehicles shall be outfitted with lightning protection terminals wired to the on-board ground. This ground shall always be in contact with the ground rail located on the inside wall of the guideway. The ground rails and all metal parts of the guideway structure shall be periodically bonded and grounded to earth. The lightning protection system shall be designed to carry lightning currents safely away from the passenger compartment of each vehicle to insure safety of the occupants.

8. Safety. The power-system design shall insure safety of passengers, operations personnel, emergency personnel, and members of the community. Emergency load-break disconnects shall be available to all personnel requiring access to the guideway. Conductor clearances, insulation, and covering of live parts shall meet National Electrical Safety Code requirements.

9. Codes. The system shall be in conformance with the following codes and standards:

    - American National Standards Institute (ANSI)
    - Electronic Industries Association (EIA)
    - Insulated Cable Engineers Association (ICEA)
    - Institute of Electrical and Electronic Engineers (IEEE)
    - National Electrical Code (NEC/NFPA 70)
    - National Electrical Safety Code (NESC)
    - National Electrical Manufacturers Association (NEMA)
    - National Fire Protection Association (NFPA)
    - Underwriters Laboratory (UL)

Task #10: Design and Construction Supervision of the Civil Works

This task involves the design and construction supervision of the buildings needed for 1) the station platform, 2) a maintenance shop with space and equipment needed to service one vehicle, and 3) office space to accommodate the chief test engineer, three associates, and 10 visitors; for the surveying, design, and construction supervision of the foundations for the posts that support the test-track guideway and the guideway itself; and for the required landscaping.

The requirements are as follows:

A station platform at least 5 ft above the ground, 12 ft deep, and 30 ft wide to accommodate three 9-ft-long vehicles. The platform shall be open to the elements on the vehicle-loading side, but provided with walls on the other three sides, a roof that covers both the station platform and the parked vehicles, and an entryway for people on the side opposite the positions of the vehicles. There shall be a wall built on the side of the vehicles away from the station platform to prevent people from exiting on the wrong side. The floor will be of durable, exterior-certified material.

A lateral-transfer table (LTT) shall be placed just upstream of the station platform to permit insertion and removal of one vehicle at a time to and from the station guideway. This device will consist of a guideway section 10-ft long secured to a platform (LTTP) that is supported by four flanged rail-type steel wheels mounted perpendicular to the guideway. These wheels ride on a pair of steel rails, with stops at the ends of the rails. In the LTTP's normal position, the guideway attached to LTTP will be in line with the station bypass guideway. In the LTT extended position, this guideway will be inside the maintenance shop, the floor of which will be at the level of the guideway running surface, which is about 40" below the station platform. When the vehicle is positioned in the LTT guideway section, the LTTP with the vehicle in place can be pushed laterally until the vehicle is in position inside the maintenance shop. Once the vehicle is serviced it can be pushed to be in alignment with the station guideway, whereupon it can move out of the station. The 10-ft section of guideway mounted to the lateral-transfer table shall be equipped with power rails so that a vehicle can be driven through it under normal wayside power.

A maintenance shop shall be placed upstream of the station platform and equipped to service one vehicle at a time. The shop will be equipped with a work bench and appropriate tools and diagnostic equipment. The shop is arranged so that a vehicle can be brought in from outside, wheeled across the shop floor and into the waiting guideway section. While on the shop floor, the vehicle shall be supported by slings from an overhead rail that shall permit the vehicle to be raised to a height suitable for easy work on either side of the chassis. The outside top of the cabin is 100 in above the running surface.

A test-engineering office shall be designed and built with room for four desks, a blackboard, the wayside computer, and an electronic board that will show the positions of the vehicles. The best position of this office is next to the maintenance shop on the side away from the guideway. In this way, the maintenance shop and the office can all be under one roof. The test-engineering office shall be sufficiently large to accommodate a group of ten visitors and equipped with projection equipment.

Provision for state-of-the-art fire safety of the buildings shall be provided.

An accurate survey to locate the precise positions of the foundations for the posts, which will be nominally 90 ft apart.

Design and construction supervision of the foundations for a loading condition of a 190,000-ft-lb bending moment at the base of each post.

Installation of the posts and guideway.

Landscaping shall be provided per local needs.

A Security System shall be provided to warn against potential vandalism while operating personnel are not present.

Requirements for PRT station and ticketing in applications

1. An ITNS station must accommodate all kind of people: regular users, occasional users, visitors who have never used it before; people who use cell phones; people who don't; blind people; deaf people; people in wheelchairs, people using walkers; and perhaps other classifications.

2. People's privacy must be protected in the sense that nothing about using PRT should reduce the limited privacy that people now retain.

3. People must be able to select the destination in the simplest possible way -- by viewing a map of all possible destinations.

4. Having selected the destination, there must be a means for paying the fare. To accommodate all types of people it must be possible to pay the fare on the spot. An alternative would be to purchase a fare card at a convenience store, but for a visitor that is an annoying additional step, and he or she may want to pay remotely for just one trip.

5. Having paid the fare, the potential rider must be able to obtain a receipt that will be used to access a specific vehicle, send the destination to the vehicle computer while standing in front of the selected berth, and cause the door to open.

6. If, upon seeing the vehicle door open, the rider notices that the vehicle has been vandalized, there must be a means of rejecting the vehicle and notifying system personnel.

7. For reasons of security, each station must be equipped with video cameras connected to screens at a control room, there must be a means of alerting control room personnel that they must pay attention to a specific station, and there must be a two-way voice communications system between the control room and either all stations or one specific station.

8. It must not be possible for a patron to walk out onto the guideway.

9. The station must be well lit and have fire-extinguishing equipment.

Task 11. Testing

To certify that ITNS is ready for people-moving applications the following series of tests shall be performed:

1. Component Tests

1.1 Switch Tests

1.1.1 One complete switch assembly will be operated for an equivalent of 10 years of operation. Since the average vehicle will travel about 80,000 miles per year, and there will be an average of about two switch operations per mile, in 10 years, there will be about 1,600,000 switch operations. Assuming one switch operation every 6 seconds (0.5 sec for the operation and 5.5 sec to cool between operations) there can be 600 operations per hour, 14,400 operations per day, or 432,000 operations per month. Hence ten years of switch operation can be accomplished in 3.7 months.

1.1.2 The switch assembly will be subjected to vibrations in the forcing-frequency range of 4 to 18 Hz to determine that there are no natural frequencies in this range.

1.1.3 One switch arm with wheels attached will undergo fatigue testing. A force cycling between zero and 1200 lb will be applied to one of the arms until either 1,600,000 cycles or failure occurs. The results of this test will be compared with the results of finite-element analysis to corroborate the properties of the switch arm, wheel assembly, and axle, and the bearing.

1.2 Door-Assembly Tests

The purpose of this test is to prove the endurance of the door-operating mechanism by operating a complete door assembly in a mock-up cabin at least 400,000 times, which is the estimated number of door cycles in 10 years. This number of cycles can be accomplished in about 33 days.

1.3 Guideway tests

1.3.1 U-Frame Strength Test. The purpose of this test is to determine the load applied at the position of the upper-lateral wheels needed to exceed the maximum yield stress at the lower corner of the U-frame and the load required to break the U-frame. This test will determine the adequacy of the finite-element analysis used to design the U-frame.

1.3.2 Guideway Bending and Twisting. Mount the first 90-ft segment of guideway manufactured on a pair of mock-up post brackets. Subject the guideway segment to a center load to determine if the ratio of deflection to load agrees with the calculated value, and subject it to a center twisting moment to determine if the ratio of twist angle to torque agrees with the calculated value.

1.4 Vehicle-to-Wayside, Wayside-to-Vehicle Communications

The objective of this test is to optimize the vehicle antenna configuration including its spacing with respect to the leaky cable, to establish link parameters, and to measure performance in a realistic electromagnetic noise environment. The test will determine how strong an electromagnetic field is needed to interfere with the zone local area network (ZLAN) and to measure its radiated field strength versus distance for comparison with FCC limits. This test will be performed in the presence of 600-volt DC traction power in the first segment of guideway fabricated. The test will be completed with and without guideway covers.

2. System Tests

2.1 The Test Facility

The general layout of the test facility is described in the document "Description of Test Track," and the planned test-facility buildings are described in Task #10. The guideway will be divided into two control zones, one extending from the merge point out of the station to the point the small curve begins in the northwest corner of the test track, and the other from that point to the merge point out of the station. With this configuration, the function of hand-off from one zone controller to the next can be tested.

The test facility will permit tests of all vehicles operating in the system to determine all-weather performance, reliability, dependability, maintainability, comfort, public reaction, environmental noise, electromagnetic noise, station capacity, wear, and operating costs. The control room will be equipped with data-collection instrumentation to support the following functions:

2.1.1 Logging of data on each vehicle for:

- Mileage
- Hours of operation, number of stops, number of door and switch operations
- Tests performed
- Speed profiles, accuracy of speed control
- Acceleration profiles related to ride comfort
- Power input
- Failures, consequences, corrective actions, time of occurrence

2.1.2 Performing tests on vehicles

2.1.3 Recording, storing and analyzing data received by the control room.

2.1.4 Overriding each vehicle-control system by the control-room operator. The operator will be able to cause a vehicle to move at a desired speed and to override automatic switching.

2.2 Single-Vehicle Tests and Demonstrations

2.2.1 Control and Communications

2.2.1.1 Speed-profile control. Determine that the vehicle acceleration, deceleration, and jerk rates in moving from rest to constant speed, from constant speed to rest, and from one speed to another are as specified. Measure stopping accuracy at a predetermined point.

2.2.1.2 Control accuracy. Measure the ability of the controller to maintain constant speed in the presence of simulated wind gusts produced by means of a drag brake, and with minimum, average, and maximum vehicle gross weight.

2.2.1.3 Vehicle handoff. Test zone-controller to zone-controller vehicle handoff.

2.2.1.4 Vehicle position and speed measurement. By means of wayside measurements, determine the accuracy of transmitted data on vehicle speed and position as determined by on-board encoders. Because of varying vehicle gross weights, accurate encoder position data requires calibration based on wayside markers as a vehicle moves out of the station. Measure the accuracy of such calibration.

2.2.1.5 Vehicle-wayside communications performance. Measure communications performance of the ZLAN.

2.2.1.6 Test the possibility of hacking into the control system.

2.2.2 <u>Chassis Operation w/o Cabin</u>

2.2.2.1 Chassis weight. Record chassis weight before other tests are performed.

2.2.2.2 Drive performance. By accelerating and braking the vehicle on a preprogrammed schedule, determine that the LIM thrust vs. speed, thrust vs. current, transport delay, and power factor are as expected.

2.2.2.3 Coasting tests. Perform coasting tests to determine the air drag and road resistance coefficients on the vehicle straight and curved sections. Formulae for determining the coefficients are derived in "Coasting Tests", *Contributions to the Development of PRT."*

2.2.2.4 Acceleration efficiency. Determine the energy efficiency in accelerating from rest to cruising speed in terms of the ratio of the energy to overcome inertia, air drag, and road resistance to the electrical energy input. Perform these tests with minimum, average, and maximum vehicle gross weight.

2.2.2.5 Cruise efficiency. Determine the motor and drive efficiencies at various constant speeds up to 16 m/s. The power output is the force required to overcome air drag and road resistance multiplied by vehicle speed. The power input is the electrical power input to the vehicle from the wayside source.

2.2.2.6 Overall efficiency. Determine the electrical power input to one vehicle required to start a vehicle from rest, circle the oval guideway once, and stop again in calm air. Compare with the value calculated using data from the previous tests.

2.2.2.7 Auxiliary brake. Observe operation of the auxiliary brake under automatic control after the vehicle comes to a stop. Determine the force required to push the vehicle with the brake applied. Observe operation of the auxiliary brake with the vehicle at line speed to simulate an emergency stop.

2.2.2.8 Tire performance. The precision of speed measurement depends on the diameter of the tire to which the encoder is mounted. The tire diameter depends on load and wear. Measure tire diameter by recording encoder output under various load conditions.

Measure the temperature of the load-bearing and lateral tires after runs to check for overheating. If overheating is excessive, modify the tire specifications and repeat the test. Measure tire wear.

2.2.2.9 LIM gap. Measure the LIM gap as each vehicle moves around the test track. Determine the closest practical gap.

2.2.2.10 Electromagnetic interference. Measure the radiated electromagnetic noise spectrum with and without guideway covers. Measure vulnerability to externally generated EM radiation.

2.2.3 Cabin

2.2.3.1 Cabin weight. Record empty-cabin weight before other tests are performed.

2.2.3.2 Interior environment. Monitor cabin temperature and humidity vs. external temperature and humidity continuously throughout the test program.

2.2.3.3 Acoustical noise. Measure the acoustical noise level in the cabin and at various distances from the guideway. Perform isolation tests to determine sources of noise.

2.2.3.4 Rain test. Subject the cabin to the maximum specified rain and determine the amount of leakage through the door seal.

2.2.3.5 Fire test. Conduct fire tests of the cabin floor in accordance with NFPA-130 specifications and requirements.

2.2.4 Single-Vehicle Tests

2.2.4.1 Acceleration efficiency. Determine the energy efficiency in accelerating from rest to cruising speed in terms of the ratio of the energy to overcome inertia, air drag, and road resistance to the electrical energy input. Perform these tests with minimum, average, and maximum vehicle gross weight.

2.2.4.2 Cruise efficiency. Determine the motor and drive efficiencies at various constant speeds up to 16 m/s. The power output is the force required to overcome air drag and road resistance multiplied by vehicle speed. The power input is the electrical power input to the vehicle from the wayside source.

2.2.4.3 Overall efficiency. Determine the electrical power input to one vehicle required to start a vehicle from rest, circle the oval guideway once, and stop again in calm air. Compare with the value calculated using data from the previous tests.

2.2.4.4 Auxiliary brake. Observe operation of the auxiliary brake under automatic control after the vehicle comes to a stop. Determine the force required to push the vehicle with the brake applied. Observe operation of the auxiliary brake with the vehicle at line speed to simulate an emergency stop.

2.2.4.5 Tire performance. The precision of speed measurement depends on the diameter of the tire to which the encoder is mounted. The tire diameter depends on load and wear. Measure tire diameter by recording encoder output under various load conditions. Measure the temperature of the load-bearing and lateral tires after runs to check for overheating. If overheating is excessive, modify the tire specifications and repeat the test. Measure tire wear.

2.2.4.6 LIM gap. Measure the LIM gap as each vehicle moves around the test track. Determine the closest practical gap.

2.2.4.7 Electromagnetic interference. Measure the radiated electromagnetic noise spectrum with and without guideway covers. Measure vulnerability to externally generated EM radiation.

2.3 Multiple Vehicle Tests and Demonstrations

2.3.1 System Tests

2.3.1.1 Normal operation. As more than one vehicle becomes certified through the Single-Vehicle Test Program, and between single-vehicle certification tests, operate multiple vehicles as in normal service, first with sand bags representing passenger weight and then with passengers aboard.

2.3.1.2 Station flow. Demonstrate vehicle flow through station and compare with simulation results. Through a station each vehicle follows the commands: Move forward if possible if in the input queue or if in the station with no destination if no passengers are approaching the vehicle. Otherwise wait in the station until a station destination is received and the door is closed. Move to line speed on command from the station zone controller (SZC). Test these operations. Determine that one vehicle stops behind another at the predetermined tolerance.

2.3.1.3 Ride comfort. Determine the acceptance of the ride comfort by obtaining the opinions of passengers of various ages and conditions who have ridden in a vehicle on the test track at various speeds up to the design maximum. Determine in this way if the values of comfort acceleration, jerk, roll rate, and bank angle to which the test track was designed need to be modified.

2.3.1.4 Inclement weather operation. Conduct tests with and without passengers during wind, snow, rain and ice storms. Determine if performance is as required and recommend changes if necessary. Particularly, determine if snow removal methods envisioned are adequate or if changes are needed. Command changes in line speed as required under high-wind conditions and observe the behavior of the vehicles as they slow down and later resume normal speed.

2.3.1.5 Vehicle merging. Demonstrate vehicle merging and compare with merge simulations. Test the operation of vehicles leaving the station and merging with vehicles on the main line at minimum headway.

2.3.1.6 Headway reliability testing. First with sandbags representing passenger weight, operate the vehicles at closer and closer headways and determine the accuracy and reliability of the inter-vehicle spacing.

2.3.1.7 Endurance tests. Run one or more vehicles continuously to determine failure rates of various components.

2.3.2 <u>Vehicle Tests</u>

2.3.2.1 Vehicle pushing. Demonstrate a vehicle soft engaging and pushing a vehicle ahead into a station, operating the auxiliary brake and switch remotely via a connection to an operator.

2.3.2.2 Rear-end collision. Cause one vehicle to run into the rear of another at speeds up to the rated speed for the shock-absorbing bumper. Measure vehicle accelerations and critical-point stresses and compare with calculated performance.

2.3.2.3 Power interruption, voltage transients and spikes. Test operation with simulated electrical disturbances including power cutoff. Observe operation of the system as it slows down and then restarts.

2.4 Station Functional Tests

2.4.1 Operational Demonstration. Demonstrate station entry and exit by passengers, passenger flow, passenger adaptability, ticket reading and destination programming, vehicle-door control, and vehicle entry and exit by passengers. Obtain data on passenger opinions of the operation.

2.4.2 Check stanchions for ease of use, environmental resistance and function.

2.4.3 Check general station arrangement for ease of use and accessibility.

2.4.4 Check station design and materials for ease of maintenance.

2.5 Central-Control Testing

Demonstrate basic connectivity between wayside zone controllers and central control. Through simulations of multi-station networks, demonstrate central-control operations of data collection, system speed, empty-vehicle movement, and traffic control.

2.6 Fail-Safe, Fault-Tolerant, Failure-Management Tests and Demonstrations

Automatic fail-safe and fault-tolerant mechanisms and failure-management procedures have been designed into the system to detect and respond to anomalies and failure conditions to minimize the risk of personal injury, personal delay, and property damage. Induce failures into the system to determine the system's response to failures in the following areas:

ONBOARD

- ZLAN communications
- Position encoding
- Auxiliary braking
- Vehicle computer
- Collision
- Marker detection and decoding

- Thruster
- Vehicle switching
- Traction power
- Battery and low-voltage power supply

WAYSIDE

- ZLAN communications
- Wayside computers
- Wayside-to-wayside communications
- Vehicle log in
- Central computer
- Wayside-to-central communications

2.7 Operations & Supportability Demonstrations

2.7.1 Reliability & Safety

Establish and maintain a daily failure log and computerized data files, and perform the following analyses:

- Compare actual reliability with system-engineering allocations and predictions.
- Determine component modifications for production models.
- Determine causes and effects of failures and prescribe corrective actions.

2.7.2 Environmental

Establish and maintain a daily weather log and computerized data files. Analyze the effects of water, ice and snow on the operation of the system during the single- and multiple-vehicle tests and demonstrations.

2.7.3 Maintenance, Maintainability, & Supportability

Establish and maintain an equipment maintenance log and computerized data files and perform the following analyses:

- Compare actual maintainability with system-engineering allocations and predictions.

- Establish design criteria for all maintenance-support equipment.

- Refine estimates of operating and maintenance costs.

Task 12. Site Planning, Network Design & System Marketing

The purpose of this task is to initiate a study of an application of ITNS in a specific setting and to initiate the marketing process. Before initiating detailed study of a specific application, a preliminary analysis must be conducted containing the basic elements of a detailed study. It is intended to obtain an initial feeling for the financial feasibility of the application before going into serious detail. The steps are the following:

- Define the expected Trip Origins and Destinations
- Layout the guideways
- Estimate the Ridership
- Estimate the Costs
- Calculate Financial Feasibility
- Develop Architectural Renderings

12.1 <u>Expected Trip Origins and Destinations</u>

The first step in a study aimed at determining whether ITNS will be feasible is to determine where people will be coming from and where they will wish to go. The characteristics of ITNS are such that the existence of the system is likely to have a strong influence on the travel patterns, so the process is iterative. The needed information is both the geographical pattern of origins and destinations and the numbers of people wishing to travel, both in the peak period and on a daily, weekly, and yearly basis.

12.2 <u>System Layout</u>

The first trial design is the first tentative plan of line and station locations based on the expected trip origins and destinations. The design of a development project is influenced by the type of transit that can be counted on as an alternative. ITNS provides great flexibility in design compared with conventional rail systems for three basic reasons:

1) The required right of way is much narrower—going from a 38-foot strip for a necessarily two-way LRT alignment to land needed only for posts two feet in diameter at the base typically 90 ft apart; and stations, the smallest of which need have a foot print of only about

28 feet along the alignment by 7 feet wide.

2) While LRT systems are virtually always deployed as a single two-way line, the in-vehicle switching system and low cost of PRT permits much greater flexibility. PRT could be in the same alignment or it can, more profitably, be deployed in networks of one-way lines, thus at least doubling accessibility for the same cost.

3) Since PRT stations are all on bypass tracks off the main line, adding a station does not reduce the average speed between stations as it necessarily does in a conventional system, where, if one car must stop, all others behind it must stop.

The analogy to ITNS is, except for width, the freeway, where one doesn't have to slow down on-line to get off. With respect to width, one ITNS line three feet wide has the same capacity as three freeway lanes 36 feet wide, a reduction of 12:1 in the land that must be set aside for transportation, yet ITNS requires land only for the posts and stations.

With on-line stations, as required in LRT, planners tend to place the stations at least a mile apart to increase the average speed to a range competitive with the automobile. With off-line stations, it is possible to have, if it makes economic sense, as many as six or eight stations per mile.[33] LRT can have speed at the sacrifice of accessibility or accessibility at the sacrifice of speed. PRT has both speed and accessibility.

Section 12.7 is required to develop a design. A preliminary design can be suggested if given the necessary information: a plan of the development indicating the expected amount of t ravel between points.

12.3 Ridership

Detailed ridership analysis requires the services of a specialist, and may be quite expensive because much data must be gathered. Preliminary estimates are, however, always necessary. The "modal split" or fraction of vehicle trips taken by transit is influenced by planning decisions such as the design of roads, the ease of parking, and the cost of parking. If the planning decisions are given, the population density, and the locations of residential areas, shopping centers, office parks, etc. a preliminary estimate of the probable amount of travel and can be developed and thus a "ballpark" feeling for economic viability.

[33]See the paper J. E. Anderson, “Optimization of Transit System Characteristics,” Appendix B.

12.4 Cost Estimate

The above information is enough to use available data to arrive at a preliminary cost estimate. Costs will come down as production quantity increases, so a cost estimate must be made in view of a probable total production quantity at the time the system would be ordered.

12.5 Financial Feasibility

A 20-story building would not be financially feasible without elevators. For some people, a stairway is an alternative to an elevator, but for most people there is no alternative to an elevator. A newly planned community may be designed completely around the automobile, as most have been. It is an alternative, but it comes at a price because of the very large fraction of land that the automobile system requires and because of unavoidable congestion resulting from slow movement because automobiles must stop at cross streets and wait for others to pass. The bus is considered an alternative, but its inherent service concept causes a typical bus trip to take about three times as much time as a typical auto trip. Moreover, to provide reasonably frequent service throughout the day, the daily average load factor of a bus system can be extremely low. In the late 1970s, the daily average number of people per Twin City bus was only 2.5. Conventional rail systems and the large-vehicle automated people movers require daytime population densities much higher than most modern developers would like, and if placed in developments of moderate density often produce shockingly high costs per passenger mile.

ITNS, on the other hand, drastically cuts land use, increases average speed and reduces energy consumption by large factors, provides much increased accessibility over on-line-station rail systems, can recover most, if not all its costs, and provides an unparalleled level of service for both people movement and goods movement. ITNS does this while virtually eliminating noise and air pollution. By powering from wayside batteries charged at night, ITNS need not add to the peak utility load.

Determination of its full financial benefit, therefore, requires a comprehensive comparison of the whole planned community with ITNS included and without. Fortunately, we find that financial feasibility quite often does not require any such elaborate study, however valuable it will be. In many developments, financial feasibility can be determined simply by offsetting its cost against the cost of parking structures that wouldn't have to be built, or in savings of the multiple of parking spaces the auto system requires. In any case, a financial feasibility study should start with a several-hour conversation between the ITNS planners and the developer to determine in some detail what is driving the cost of the development.

The internal paper “Economics of *ITNS* Networks” and its Excel companion provide a methodology for estimating the return on investment to an investor for ITNS as it would expand over a metropolitan area.

12.6 Visual Impact

Visual impact is always an important consideration. Therefore, to get a preliminary feeling for the appearance of ITNS, several architectural renderings of the system in critical locations are needed.

12.7 Principles of Network Design

All of the important parameters involved with network design depend on line speed. Kinetic energy, air drag, curve radius, and stopping distance all depend on the square of speed. The power to overcome air drag increases as the cube of speed; and, with given guideway roughness, however small it may be, the suspension required is more demanding as speed increases. The system will therefore become more expensive as line speed increases, and this must be balanced against the expected increase in ridership as the average trip speed increases. The bottom line is that the planner needs to know how line speed affects cost per passenger-mile. An iterative process, initially based on experience and judgment, is required to determine the optimum line speed.

The minimum curve radius at the desired operating speed depends on ride comfort, which is measured by the lateral acceleration felt by the passengers. The minimum right-of-way width of a pair of cross streets that can accommodate ITNS is 30% of the minimum curve radius. With all passengers seated, as is the case in ITNS, the maximum acceptable lateral acceleration is A_{max} = 0.20g, and the minimum radius of a flat curve is $R_{min} = V^2/A_{max}$, where V is the speed in the curve. If the curve is superelevated, i.e., banked, R_{min} is 65% as much.

The minimum distance between branch points is the sum of two distances: the distance the vehicle moves at line speed V during the 0.4-sec switch throw time, plus the stopping distance with a 0.5g emergency-braking rate. This distance is $V \times (0.4 + V/g)$.

The length of off-line station guideways depends on line speed and the required number of berths. Equations are available to determine these lengths.

Within these restrictions, guideways of any configuration can be deployed; however, certain configurations are better than others. Optimum design of an ITNS network is an art in itself. The following considerations need to be considered.

- *Y interchanges vs. multilevel interchanges.* Multilevel interchanges may be necessary for very high capacity, but produce greater visual impact at any one point. It is best to try to lay out a network using Y interchanges and to use multilevel interchanges only if or where necessary and acceptable. Y interchanges have the disadvantage that vehicles must merge before they diverge, thus creating bottlenecks, which can be relieved by using the higher impact multilevel interchange. Fortunately, in a great variety of applications, the network can be laid out so that the capacity is adequate with Y interchanges. Y interchanges are more of a challenge for the control system, but the problems have been solved.

- *One-way vs. two-way lines.* With one-way lines, twice as much land area can be put within walking distance of stations for the same total track length. Moreover, the interchanges are simple and visual impact at any one location is minimum. One-way lines have the disadvantage of more circuity, where circuity is defined as the ratio of the trip length on the network between a pair of stations divided by the direct-line distance. Building the network out of a series of modest-sized loops will minimize circuity. Since the trip time on ITNS is very short compared to the total trip time counting walking, the effect of increased circuity on ridership can, by careful design, be made so small that the cost per passenger-mile is lower with the one-way configuration. There is, however, no reason to constrain ITNS to one-way networks in the way that conventional transit systems, by their nature, must be deployed in two-way configurations. To eliminate vehicle-to-vehicle transfers, two-way systems require complex interchanges.

- To maximize system capacity, networks should be laid out wherever possible with merges and diverges alternating, thus relieving potential bottlenecks. The example shown in Figure 12.1 has merges and diverges alternating. In developing such a network, it is useful to think of the guideways as rubber bands of the right topology and ready to fit any street pattern.

- Because curved track costs more than straight track, curves should be kept to a minimum. ITNS is not restricted to being elevated. Positioning above ground, at ground level or underground is a planner's decision. The off-line guideways to the stations of an elevated system may be brought close to the ground so that a stairway and elevator would not be needed, but at the cost of a longer off-line guideway and the need to fence off an area on both sides of the station.

12.8 Marketing

The marketing team will develop a brochure, a virtual-reality video, a website and all other materials needed to explain the system in all detail required by consulting engineers and planners working at specific application sites, in sufficient detail to obtain orders for operating systems.

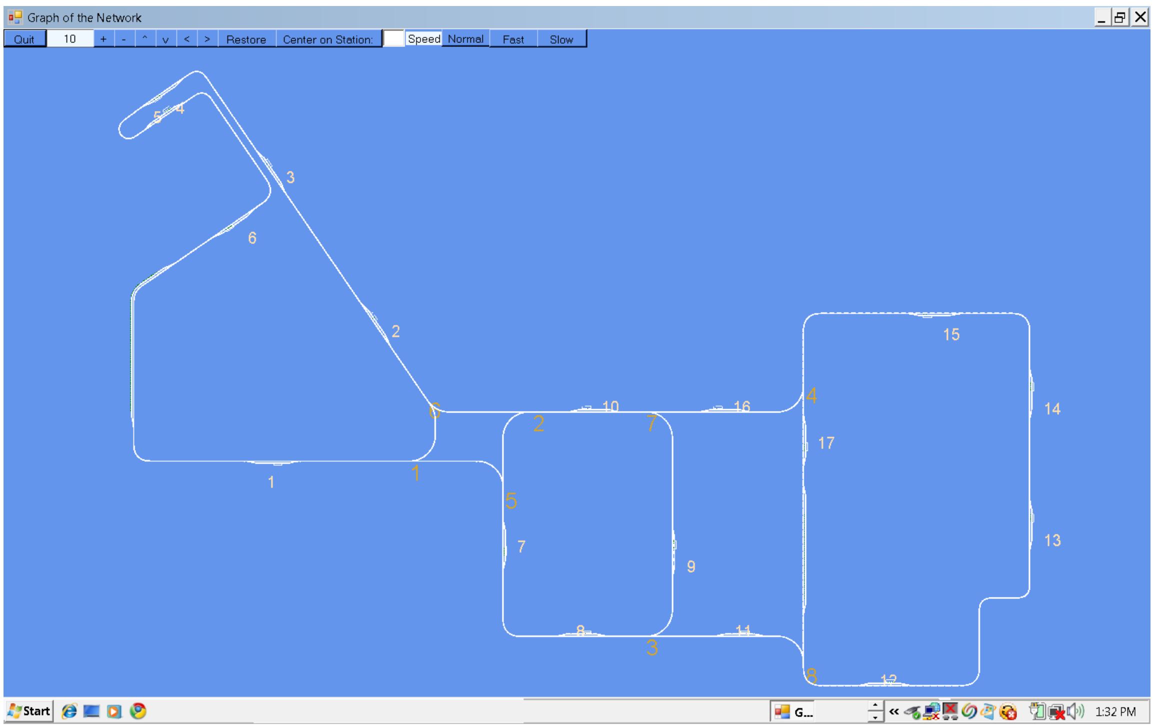


Figure 12.1. An example network.

Appendix B
Biography of the Principle Developer and Managing Director

J. Edward Anderson, BSME, Iowa State University; MSME, University of Minnesota; Ph.D. in Aeronautics and Astronautics, Massachusetts Institute of Technology.

Following his undergraduate work, he joined the Structures Research Division of NACA (now NASA), where he received the equivalent of a master's degree in the analysis of structures, developed methods of structural analysis of supersonic-aircraft wings (NACA Report No. 1131), and contributed to the design of the F-103 wing. He then moved to the Honeywell Aeronautical Division where his first assignment was to design aircraft instruments, the first of which was retrofitted into the entire Air Force fleet of over 700 B-47 bombers. The next assignment included the first transistorized amplifier used in a military aircraft and won the *Aviation Age* Product-of-the-Month Award. These projects enabled Honeywell to completely dominate the associated field. He was then assigned to the Aircraft Dynamics Group in the Research Department where he performed computer analysis of autopilots for military and space applications, and later managed a group of 15 Research Engineers in the design of the autopilots for the Air Force's two most advanced fighter aircraft. He was then assigned to the Inertial Navigation Group where he invented and led 20 Research Engineers in the development of a new type of inertial navigator now used widely on military and commercial aircraft. He was promoted to Principal Engineer at a time when only about 1% of Honeywell engineers held that title.

He received a Convair Fellowship under which, with a half-salary grant from Honeywell, he enrolled at the Massachusetts Institute of Technology to study for a Ph. D. degree. He became fascinated with magnetohydrodynamics and wrote a thesis entitled *Magnetohydrodynamic Shock Waves*, which was the only M. I. T. Ph.D. thesis that year out of 200 that was published by M. I. T. Press. It was later reprinted by the University of Tokyo Press, and translated into Russian and published by Atomizdat in Moscow. It is still receiving royalties and can be found in the bookcases of physicists who study magnetic containment of high-temperature plasma.

After returning to Honeywell he was sent to Cape Canaveral where he showed NASA engineers that erratic behavior in the gyro signals on Col. Glenn's space flight were not due to a malfunction of the Honeywell attitude control system. He later directed a team of 24 engineers in the advanced development of a solar-probe spacecraft and, following a briefing he gave with his staff to officials at NASA Ames Research Center, NASA informed Honeywell that they were equal in capability with its two funded contractors on the solar-probe effort. He had written a report justifying the solar-probe mission, which was used by NASA personnel in testimony to Congress. The Solar Probe Program led to Honeywell's first space-craft contract.

In September 1963 Dr. Anderson joined the Mechanical Engineering Department at the University of Minnesota as an Associate Professor and later as a full Professor directed its Industrial Engineering & Operations Research Division. In 1967-8 he spent 10 months in the Soviet Union, sponsored jointly by the National Academy of Sciences and the Soviet Academy of Sciences, after which his research was published in a book *Dynamic Phenomena in Thermal Plasma*, Energia, Moscow.

Upon returning home he became interested in Personal Rapid Transit (PRT) as a necessary technology for a sustainable world. Shortly thereafter he was invited to join a group of physics professors dedicated to stopping the Safeguard Anti-Ballistic Missile system; which led to chairmanship of a Symposium on the Role of Science and Technology in Society; which led to leading an Honors Seminar called "Technology, Man, and the Future;" which led to initiating, managing and lecturing in a large interdisciplinary course "Ecology, Technology, and Society," which was taught every quarter from 1970 through 1988 to over 4000 students from 100 departments in the University with support of the Deans of the Institute of Technology, Liberal Arts, and Agriculture. Simultaneously, he coordinated a 15-professor Task Force on New Concepts in Urban Transportation and chaired International Conferences on Personal Rapid Transit (PRT) in 1971, 1973, and 1975. He was the chief editor of the first two of these conferences. 156 papers were published. In 1972 he briefed NASA Headquarters on PRT in relation to a "NASA Advanced PRT Program" and in December 1972 was asked by a NASA official to chair a National Advisory Committee on the NASA Advanced PRT Program. In 1976 he was elected first president of the Advanced Transit Association.

During the 1970s, Dr. Anderson consulted on PRT planning, ridership analysis, and design for the Colorado Regional Transportation District, Raytheon Company, the German joint venture DEMAG+MBB, and the State of Indiana. For several years he was Regional Director of the American Institute of Aeronautics and Astronautics, and one of its Distinguished Lecturers. He lectured widely on new transit concepts and was sponsored on several lecture tours abroad by the United States Information Agency and the United States State Department. In 1978 he published the textbook *Transit Systems Theory* (D. C. Heath, Lexington Books), which he has used in his course "Transit Systems Analysis and Design." In addition to engineering students, enrollment in this course has included professional transportation engineers from across United States as well as from Canada, England, Sweden, Denmark, Korea, and Mexico.

In 1981 he initiated and led the development of a new High-Capacity PRT system through five stages of planning, design and costing. He developed computer programs for vehicle control, station operation, operation of many vehicles in networks, calculation of guideways curved in three dimensions to ride-comfort standards, study of the dynamics of transit vehicles, economic analysis of transit systems, and calculation of transit ridership. In 1982 he was presented with the George Williams Fellowship Award for public service sponsored by the YMCA and the MPIRG Public Citizen Award.

In 1986 he was attracted to the Department of Aerospace and Mechanical Engineering at Boston University where he taught mechanics, engineering design, and transit systems analysis and design; and where he organized, coordinated and lectured in an interdisciplinary course "Technology and Society." On his own time, he organized a team of a half-dozen engineers and managers from major Boston-Area firms to further develop High-Capacity PRT. In May 1989, the Northeastern Illinois Regional Transportation Authority (RTA) learned of his work together with Raytheon Company and initiated a program to fully develop PRT. This led to a $1.5M PRT design study led by Stone & Webster Engineering Corporation, followed by a $40M joint development program funded by Raytheon Company and the RTA. Unfortunately, Raytheon failed to follow the Systems Engineering principles given in Section 2 of this business plan, the result of which was that their design became too expensive for the RTA. While at Boston University, he developed the Maglev Performance Simulator used by the National Maglev Initiative Office, U. S. Department of Transportation, to study the performance of high-speed maglev vehicles traveling within ride-comfort standards over the curves and hills of an interstate expressway, and licensed it to Grumman and Hughes for $10,000 each.

Following the RTA program, Dr. Anderson gave courses on transit systems analysis and design to transportation professionals, and engaged in PRT planning studies for a half-dozen applications. In 1992 his PRT system (ITNS) was selected unanimously by a 17-person steering committee over bus and rail systems for deployment at the Seattle-Tacoma International Airport. In 1996 he chaired an international conference on PRT and related technologies in Minneapolis. In 1998 his work led to acceptance of his PRT system out of over 60 elevated systems as the preferred technology promoted for the Greater Cincinnati Area by a committee of Forward Quest, a Northern Kentucky business organization.

In 2001-2002 he led the design and construction supervision of a full-scale vehicle that operated automatically on a 60-ft guideway for thousands of error-free rides, many as an exhibit at the 2003 Minnesota State Fair. This system worked exactly as intended. It is shown on page 5 of this document. In 2009 he began to develop from basic principles a new and improved version of PRT now called ITNS. He continues the challenging task of determining how to fully commercialize a superior PRT system that will reduce dependence on oil, reduce carbon dioxide emissions, and reduce congestion.

For his patents on PRT, the Intellectual Property Owners Foundation named him an Outstanding American Inventor of 1989. In 1994 he was Distinguished Alumni Lecturer at North Park University in Chicago. In 2001 he was elected Fellow of the American Association for the Advancement of Science for his work on PRT. In 2008 he was named Honorary Lifetime Member of the Advanced Transit Association. In 2010 the Minnesota Federation of Engineering, Scientific, and Technical Societies granted him the Charles W. Britzius Distinguished Engineer award. In 2013 The Aerospace Corporation awarded him its "Technical Achievement Recognition for lifelong dedication to the advancement of transportation technology."

He is a registered Professional Engineer in the State of Minnesota, has authored over 100 technical papers and three books. He has been listed in 36 biographical reference works including *Who's Who in America* and *Who's Who in the World*. He is the son of missionaries with whom he spent the years 1928 - 1936 in China.