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ENERGY STUDY OF AUTOMATED GUIDEWAY TRANSIT
(AGT) SYSTEMS

By
Clark Henderson
Robert H. Cronin
Hazel T. Ellis

MASTER

August 1979

Work Performed Under Contract No. EY-76-C-03-1176

✓ Stanford Research Institute International
Menlo Park, California

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CONVERSION

U. S. DEPARTMENT OF ENERGY

Division of Transportation Energy Conservation

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Contract No. EY-76-C-03-1176

Prepared for:
U. S. Department of Energy
Systems Efficiency Branch
Transportation Programs Office

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PREFACE

In 1976 the Energy Research and Development Administration (ERDA),* as part of its energy conservation program, initiated a study of the energy usage of railroads and rail transit systems. Work performed by SRI International resulted in eight reports in two series entitled "Energy Study of Railroad Freight Transportation" and "Energy Study of Rail Passenger Transportation." This report, which is a continuation of that work, describes the physical, operating, and economic characteristics of six automated guideway transit (AGT) systems and relates energy usage to services rendered.

An important aid to the present study was concurrent work SRI International performed for the Urban Mass Transportation Administration under Contract DOT-UT-70034. Results of that work appear in the following three reports published in December 1977:

- "Assessment of the Satellite Transit System (STS) at the Seattle-Tacoma International Airport."
- "Assessment of the Automatically Controlled Transportation System at Fairlane Town Center."
- "Assessment of the Passenger Shuttle System (PSS) at the Tampa International Airport."

The present work was performed under Contract EY-76-C-03-1176 with ERDA. The contract monitors were Ms. Estella Romo and Mr. Richard Alpaugh. Dr. Robert S. Ratner was project supervisor and Mr. Albert Moon was project leader. Mr. Clark Henderson was task leader for passenger studies. Dr. Robert H. Cronin and Ms. Hazel T. Ellis participated in the project and wrote this report with Mr. Henderson.

We gratefully acknowledge the assistance of the following individuals:

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*The functions of ERDA were transferred to the Department of Energy.

1 INTRODUCTION

Purpose and Scope

Automated guideway transit (AGT) systems provide passenger transportation on exclusive guideways in vehicles without operators. This report is an energy study of six AGT systems at the following locations:

- Seattle-Tacoma International Airport
- Tampa International Airport
- Busch Gardens, Williamsburg, Virginia
- Fairlane Town Center, Dearborne, Michigan
- Dallas-Fort Worth Regional Airport
- West Virginia University, Morgantown, West Virginia.

Selected physical, operating, and economic characteristics of the systems, services rendered, direct, indirect, and capital energy demands, and energy intensities are described. Descriptions are standardized in content and format, to the extent possible, as follows:

Overview

History

System characteristics

Service (vehicle miles, passenger trips, passenger miles, capacity miles*)

Economic data

Capital costs

Operations and maintenance costs

Total equivalent annual cost of capital, operations, and maintenance

Energy demand (kWh, gallon, Btu)

Direct

Indirect

Capital

Long-term average annual energy demands

Energy intensity (service per gallon of fuel and energy per unit of service)

* Capacity miles = vehicle miles x design capacity of the vehicle.

Definitions of Energy Demands

This report presents estimates of total energy demand including direct, indirect, and capital energy usage. These terms are defined as follows:

- Direct energy is consumed, day by day, to operate equipment and facilities.
- Indirect energy is consumed to supply labor, services, and goods (other than electrical power and fuel) for current operations.
- Capital energy is consumed to create new capital assets for construction, replacement, improvement, extension, and expansion of AGT systems and new capital assets for the public utilities and other industries that support passenger transportation.

Energy Usage Estimates and Data

Direct demands for heating, ventilating, air conditioning, and lighting of stations and maintenance areas are included as well as demands for system operations. The energy regained by regenerative braking is considered.

The method for estimating energy demands is explained in Appendix A. Estimates of energy usage for heating, ventilating, air conditioning, and illuminating buildings are based on the calculations explained in Appendix B. A method for determining the amount of energy that may be saved with regenerative braking is given in Appendix C. Long-term average annual energy demands for capital assets are computed by dividing estimates of capital energy demands by the number of years assumed for service lives--that is, 15 years for hardware, and 35 years for construction. Because many obstacles were encountered in our efforts to obtain uniform, complete, accurate, and relevant data, the descriptions and estimates cannot be offered as definitive.

2 SEATTLE-TACOMA INTERNATIONAL AIRPORT

Overview

The Seattle-Tacoma International Airport (Sea-Tac) employs an AGT system for the transportation of passengers within the main terminal complex and between the main terminal and two satellite terminals. AGT service is essential for the operation of the airport, and the AGT system is an integral part of the terminal design.

If AGT systems had not been available to facilitate expansion of Sea-Tac to its present configuration, it is possible that the airport would have been relocated to a site farther from the population center, with large impacts on gasoline consumption by automobiles used for access. Alternatively, expansion of facilities at the present site, without AGT, would have required inefficient movements of aircraft and large expenditures of jet fuel. Thus, it could be argued that the AGT system and its associated energy consumption allowed for significant energy savings in other modes when compared with available alternatives for airport development.

History

The Port of Seattle Commission is responsible for the development and operation of Sea-Tac and numerous other transportation facilities in the Puget Sound region of Washington State. The Port Commission acquired land for development of Sea-Tac in 1942. Commercial air passenger service was established in 1947. The first element of the existing passenger terminal complex was constructed in 1949. Land acquisitions increased the airport's acreage to more than 1,600 acres by 1958. Until 1970, growth in passenger traffic was accommodated by constructing a series of additions to the original terminal.

Planning studies indicated that traffic would grow to about 15 million annual passengers by 1980--up from 2.8 million in 1966. It was recognized that a long-range plan was needed to accommodate traffic growth and that major construction projects would have to be undertaken. Studies indicated that the Sea-Tac site could be developed to a capacity of 20 million passengers annually, which would accommodate growth until some time beyond 1980. A comprehensive plan for that expansion program was approved in 1966.

Many alternatives were considered before it was decided to execute the existing design. Expansion was accomplished by constructing two satellite terminals and by preserving and enlarging major parts of the existing terminal complex. The satellite design required a passenger

transportation system to avoid long walks. Thus, it appears that in 1966 the designers were confident that a passenger transportation system suitable for travel to distant satellite terminals could be obtained. That belief was an important factor in the screening of alternative terminal layouts and in the selection of the final design. AGT systems at Houston Intercontinental Airport and Tampa International Airport had been planned at that time, but no airport AGT system had been installed when this commitment was made.

Alternative Layouts Considered

Consideration was given to route layouts that could be served by pedestrian conveyors (moving walkways), AGT systems, or both. Underground, surface, and elevated routes were considered, but the surface and elevated routes were soon found impractical as links to satellites because they would have increased aircraft movement time (and fuel consumption) and sacrificed scarce land.

Use of pedestrian conveyors in underground routes was considered but not adopted for two principal reasons: their speed is low (one-third to one-half walking speed), and boarding and leaving a conveyor is difficult for persons encumbered with small children and for the elderly and handicapped.

Attention soon focused on route structures employing AGT shuttles and loops. Figure 1 illustrates five alternatives that were considered. Scheme A used two loops with stations in the garage. It was discarded because the travel patterns it would establish did not take proper account of ticketing and baggage claim functions and because the long routes and numerous stations would have been costly.

Scheme B used two loops going through the terminal complex. It was discarded because it was not possible to design a simple, efficient, and convenient interchange between loops at the two stations nearest the center of the complex. Also the two stations at the outer extremities of the main terminal were prohibitively costly in view of their limited patronage.

Scheme C was designed for eight shuttles. It would have been attractive to some travelers but involved several disadvantages. Many travelers would have to transfer between routes and were likely to be confused by the multiplicity of route choices. Stations were relatively complex. Transfers between the two central stations involved the same problems as in Scheme B. Double tunnels required on parts of the line would have been costly. Some routes would receive low patronage and were not economically justifiable.

Scheme D was designed for a single shuttle to be used beneath the main terminal and double guideway shuttles to the satellites. It made provisions for later extensions from the satellites to the ends of the finger piers. Inability to meet long-range capacity requirements and

SCHEME A

SCHEME B

SCHEME C

SCHEME D

SCHEME E

○ Indicates passenger station

Source: The Richardson Associates Report on STS (1969)

FIGURE 1 SEA-TAC ROUTE ALTERNATIVES

concern over possible low reliability of the mechanical switches required for turnbacks and crossovers caused this scheme to be ruled out.

Scheme E was finally adopted and is described in detail under System Characteristics (see Figure 2).

Alternative Hardware Systems Considered

In 1967, fourteen possible hardware systems were proposed for consideration by the Port Commission. Westinghouse and Dashaveyor received small contracts in 1968 to develop preliminary system designs, which were then used to develop specifications. The Port conducted a competition, received bids from six suppliers, and awarded the contract to Westinghouse in 1969. On-site testing with nine transit cars began in 1972, and the Satellite Transit System (STS) opened for service in mid-1973. The following year, an expansion program was initiated to add three cars and increase electrical system capacity.

System Characteristics

The AGT system network contains two loops and one shuttle--all underground (see Figure 2). The primary purpose of the loops is to transport passengers between the main terminal building and the two satellite terminals. Each loop has three stations. The north loop is 4,089 ft long and has stations at the north satellite, the northern part of the terminal, and the end of Concourse C. The south loop is 3,718 ft long and has stations at the south satellite, the southern part of the terminal, and the end of Concourse B. The shuttle route is 980 ft long and shares two station platforms with the loops. Transfers between loops and shuttle routes are made on a level surface over a short distance. There are no obstacles to elderly or handicapped travelers, wheelchair users, or small vehicles used to carry luggage or small children.

The shuttle has a one-car train that travels between the two stations in the main terminal. It is used mainly by passengers who arrive at one satellite terminal and change to a plane departing from the other satellite. Use of the shuttle is optional, as a walkway roughly parallels the shuttle route. The shuttle can be expanded to employ two-car trains, if needed.

Passengers must take the STS to and from the satellite terminals, which are located some 1,500 ft from the main terminal. The loops were designed to carry substantial loads from the outset, and provisions were made to increase capacity to accommodate all anticipated growth at Sea-Tac. Originally, four cars were used on each loop and capacity was about 4,800 passengers per hour. When fully equipped, each loop will employ up to 12 cars (three 4-car trains) and will accommodate up to 14,400 passengers per hour. Thus, provisions for 200% growth in loop capacity were made at the time of the initial installation.

FIGURE 2 SEA-TAC ROUTE STRUCTURE

The STS fleet now consists of 12 vehicles. One vehicle is always assigned to the shuttle route, and one vehicle is scheduled for maintenance. During peak seasons (Christmas, summer) each loop employs five cars in three trains. In off-peak seasons, three cars are operated on each loop.

The STS cars are based on the Westinghouse Transit Expressway AGT prototype first demonstrated at South Park, near Pittsburgh, Pennsylvania. Cars are 37 ft long by 9.33 ft wide by 11 ft high and weigh 25,500 lb. Each STS car has 12 seats and space for 90 standees at 2.5 ft² per standee. Crush loading is considered to be 125 passengers. The tare weight per passenger carried (empty car weight divided by passenger load) varies as follows:

<u>Passenger Load</u>	<u>Tare Weight per Passenger</u>
102 passengers--design capacity	250 lb
125 passengers--crush capacity	204 lb

The cars have automotive truck-type axles and rubber tires. The axles are steered by small, rubber-tired guidewheels running on a steel I-beam mounted between the concrete "tracks" that form the running surface for the load-carrying wheels. Each car is powered by a single 100-hp series wound dc traction motor that drives one axle. A thyristor controller converts the wayside 600 V three-phase ac to variable voltage dc for the propulsion motor.

Maximum speed is 26 mph on the north loop and on the shuttle and 22 mph on the south loop. Average speeds, including dwell times, are 7.8 mph on the north loop, 8.7 mph on the south loop, and 9.3 mph on the shuttle. Vehicle operation is completely automated.

Service

No fare is charged. Service is provided an average of 20 hr per day and is only shut down in the early morning hours when no flights are arriving at or departing from the satellite terminals. Under normal conditions, the round-trip times on the north loop and the south loop are 5.05 min and 4.83 min, respectively. With the usual complement of three trains, headways are 1.68 min and 1.61 min, respectively. A passenger experiences an average wait of about 50 sec to board a car and an average travel time of about 124 sec, or 2.9 min for the entire trip. The effective speed, for the 1,500 ft of straight-line travel to the satellites, is about 5.9 mph.

The shuttle is demand operated, like an elevator; that is, it sits at one station or the other until called. The round-trip time on the shuttle, including station dwell times, is 2.68 min. The average trip time experienced by riders is 1.34 min, and the effective speed is about 8 mph.

The vehicle travel distance is recorded monthly. In 1976 total travel distance for both loops and the shuttle was 410,600 vehicle miles--236,000 vehicle miles in the north loop, 133,000 in the south loop, and 41,300 for the shuttle. New vehicle testing accounted for 20,312 vehicle miles of the total.

Sea-Tac personnel estimate that annual patronage on the north and south loops was 9.3 million passengers in 1976. This estimate is based on the following assumptions: (1) 60% of all airline passengers use the north or south satellite boarding gates and ride the STS; and (2) for each airline passenger who uses the STS, 1.5 additional persons, such as friends, airport employees, and sightseers, ride the system. The STS operations staff estimates that transfers from arriving to departing aircraft at the north and south satellite comprise less than 10% of the total number of airline passengers. It is assumed that 9% of the loop passengers also use the shuttle and that the total patronage was 10.1 million.

According to Sea-Tac figures, about 56% of the STS loop passengers travel on the north loop, and 44% on the south loop. The average ride is assumed to be one-half the length of a loop plus the full length of the shuttle, when used. Using these assumptions, the annual passenger miles traveled were calculated to be 2,016,000 on the north loop, 1,440,000 on the south loop, and 155,000 on the shuttle, for a total of 3,611,000 passenger miles.

The average system load factor, based on the assumptions above, was about 9%, corresponding to an average passenger load of nine.

Economic Data

The STS system was financed by the sale of revenue bonds, as were other capital outlays. Operations and maintenance costs are paid from current revenue.

Capital Costs

No record was found of estimates made during the planning stage of the incremental costs that would be generated by the STS system nor of an economic assessment of the STS as a separate subsystem. Instead it appears that the STS was evaluated only as an integral part of the entire airport expansion program. Both practical and theoretical problems now prevent an accurate determination of all capital costs of the Sea-Tac STS system. AGT vehicles and special equipment were acquired under separate contracts, and those costs are available from accounting records. Records do not exist for some other cost elements. Major elements of the civil works--stations, maintenance and storage areas, and tunnels--were constructed as parts of large, multipurpose facilities. There is no theoretically sound method for correctly allocating parts of the joint

costs of these facilities to the STS. Such costs can only be allocated by somewhat arbitrary means or represented in some other way, as discussed below.

In 1976 a figure of \$15.43 million was published by the Port of Seattle and others as the "total estimated capital investment of the STS system." However, that figure did not include estimates for all elements of hardware and construction. It does not adequately represent the cost of the system and should not be used without adjustment.

The most notable defect of the published figure for total capital cost is the omission of an estimate of the cost for some 4,675 ft of the guideway tunnel. To develop a useful capital cost figure, SRI conducted a special cost study for UMTA.* That study postulated a hypothetical system that duplicates the Sea-Tac STS except in certain particulars and estimated the cost of producing the hypothetical system. The most important difference between the two systems is that the hypothetical system was assumed to be constructed in bare ground as an independent project with no multipurpose or joint-use facilities.

The published cost data and adjusted capital cost estimates for the hypothetical duplicate system are listed in Table 1.

Operations and Maintenance Costs

The operations and maintenance (O&M) costs of the STS in 1976 were estimated at \$751,200. Data were obtained from the STS operations and maintenance departments. Maintenance costs are based on the 1976 budget and include costs of in-house staff and support by a contractor. The operations costs of the STS are not accounted for separately but are combined with all other airport operating costs. Estimates were made by the operations staff. A breakdown of O&M costs is shown below:

Maintenance	\$585,000
Operations	
Labor	150,000
Energy	8,200
General administration	<u>8,000</u>
Subtotal	\$166,200
Total	\$751,200

* A. M. Yen et al., "Assessment of the Satellite Transit System (STS) at the Seattle-Tacoma International Airport," SRI Project 5949, SRI International, Menlo Park, California (December 1977).

Table 1

CAPITAL COST ESTIMATES: SEA-TAC SATELLITE TRANSIT SYSTEM

	<u>Published Cost</u>	<u>SRI Estimated System Cost</u>	<u>Year of Expenditure</u>
Hardware			
Engineering and administration	\$ --	\$ 1,475,500*	
First increment	5,304,000	5,902,100†	1972
Second increment	<u>1,458,500</u>	<u>1,475,400†</u>	1976
Subtotal	\$ 6,762,500	\$ 8,853,000	
Construction			
Architecture, engineering, and administration	--	2,157,000*	
Track	--	1,654,900†	1971
Loop tunnels	2,607,500‡	4,991,300†	1970
Shuttle tunnel	--	739,000	1970
Maintenance and storage areas	1,092,000	1,092,000§	1970
Stations	<u>4,968,000</u>	<u>3,217,900</u>	1970
Subtotal	\$ 8,667,500	\$13,852,100	
Total	\$15,430,000	\$22,705,100	

* SRI estimate.

† Port of Seattle accounting data.

‡ Construction cost for 4,375 ft of tunnel.

§ The Richardson Associates estimate.

The estimate of energy costs is based on reports of the amount of energy consumed to operate the STS in 1975, and an energy cost of \$0.0068/kWh. The energy cost is noticeably low when compared with other systems because energy costs for the region are relatively low. Unit energy cost may have increased between 1975 and 1976, but data are not available on any change. General administration costs include estimated insurance costs.

Estimated unit costs of O&M for 1976 are as follows:

- \$1.83 per vehicle mile
- \$0.21 per passenger mile
- \$0.07 per passenger trip
- \$0.02 per capacity mile.

Total Equivalent Annual Cost of Capital, Operations,
and Maintenance

The capital cost estimates of the duplicate system were escalated to 1976 prices and expressed as equivalent annual costs by the estimating methods explained in Appendix A. At 1976 prices, the capital cost was \$34,635,000, which includes \$22,875,000 for construction and \$11,760,000 for hardware. The equivalent annual cost of capital is \$3,918,000. The total equivalent annual cost of capital, operations, and maintenance is \$4,536,400.

The unit costs of service are computed by prorating the total equivalent annual cost of capital, operations, and maintenance over each of the four measures of service. Results are as follows:

- \$11.37 per vehicle mile
- \$1.29 per passenger mile
- \$0.46 per passenger trip
- \$0.11 per capacity mile.

Energy Demand

Direct Energy

Electrical power and natural gas are purchased for direct use by STS equipment and facilities. Electrical power is used mainly for propulsion and operation of vehicle auxiliaries; lighting, air conditioning, and ventilating of stations, tunnels, shops, and storage facilities; and operation of wayside and shop equipment. Natural gas is used for heating.

Direct demands are estimated primarily in terms of the heating value, in Btus, of the fuel oil and natural gas consumed. For convenience in presenting results, these demands are restated in terms of the total equivalent gallons of fuel oil and the total equivalent electrical power, in kWh.

Sea-Tac buys electricity from Puget Sound Power and Light Co. Formerly 100% hydroelectric, the utility now has an ownership interest in oil- and coal-burning generating plants in Washington and Montana. The average heat rate of these fuel-burning plants is 10,850 Btu/kWh. The latest available statistics indicate that the ratio of electricity generated to electricity sold in 1974 by the Puget Sound Power and Light Co. was 1,072--that is, about 7% of the power generated is lost, used by the company or given away.* Thus about 11,631 Btu are consumed for each kWh delivered to the STS transformers at Sea-Tac. This is equivalent to 0.080 gal of fuel oil per kWh delivered.

The electrical energy required for vehicle operation is metered at the output side of the stepdown transformers that supply power to the STS power rails. The metered consumption for 1976 was 1.2 million kWh. This figure includes energy for propulsion and vehicle-borne auxiliaries such as heating, air conditioning, lighting, air compressor, and electronic equipment, and losses in delivery to the vehicle. The vehicles at Sea-Tac draw about 50 kWh while in motion. Their auxiliaries are estimated by the Westinghouse staff at Sea-Tac to consume an average of 10 kWh, or about 20% of the power delivered to the vehicle. Thus, about 0.96 million kWh are used for propulsion and about 0.24 kWh are used for auxiliaries.

Energy losses in the power transformers were calculated on the basis of efficiency factors obtained from Westinghouse, total operating hours, and the metered power consumption yield. The result was a loss of about 50,000 kWh. Therefore, input to the transformers was about 1.25 kWh.

The consumption of gas and electricity for heating, ventilating, air conditioning, and lighting of stations and maintenance areas is estimated using the methods discussed in Appendix B. These calculations are based on a total station area of 32,640 ft² and a maintenance area of 28,800 ft². Seattle has an annual average of 5,145 heating degree days and 250 cooling degree days.† The calculation of ventilating load assumes an average of 20 people waiting in each station. The estimated annual electrical consumption of the stations and maintenance area is as follows:

	kWh
Air conditioning	14,400
Ventilating	23,100
Lighting	<u>863,000</u>
Total	900,500

* Federal Power Commission, "1974 Statistics of Privately Owned Electric Utilities in the U.S."

† Heating degree days are obtained from the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. Systems Handbook (1976). Cooling degree days are derived from U.S. Geological Survey, The National Atlas of the United States of America (1970).

The total consumption of electricity by the STS is summarized in Table 2. About 45% of the total electricity consumption is used for propulsion.

Table 2

DIRECT ELECTRICITY USE:
SEA-TAC SATELLITE TRANSIT SYSTEM

	<u>kWh × 10⁶</u>	<u>kWh/car mile</u>
Propulsion only	0.96	2.34
Operation of auxiliary equipment	0.24	0.58
Conversion loss	<u>0.05</u>	<u>0.12</u>
Total consumed by STS	1.25	3.04
Station and maintenance areas	0.90	
Total delivered to Sea-Tac	2.15	

The estimated gas consumption for heating the stations and maintenance areas is 4.22 billion Btu per year. This energy is equivalent to 29,000 gal of fuel oil or the purchase of 374,000 kWh. Table 3 summarizes the direct energy demands.

Indirect Energy

Indirect energy demands result from use of labor, materials, and services other than direct energy in the form of electricity and natural gas. The energy content of these resources is estimated by using a factor of 43,900 Btu/dollar of operating and maintenance (O&M) costs, excluding the cost of direct energy. (See Appendix A for a discussion of the method of estimating energy demand.)

During 1976 the O&M costs for the STS, excluding direct energy costs, were \$743,000, and indirect energy demand was 32.6 billion Btu. For comparison, the ratio of indirect energy to direct energy is 1.12 to 1.

Table 3

SUMMARY OF DIRECT ENERGY ESTIMATES:
SEA-TAC SATELLITE TRANSIT SYSTEM

	Thermal Energy (Btu $\times 10^9$)	Equivalent Fuel Oil (gal $\times 10^3$)	Equivalent Electrical Power (kWh $\times 10^6$)
Electrical power			
Propulsion of AGT cars			0.96
Operation of auxiliary equipment			<u>0.24</u>
Total consumed by STS equipment			1.20
Conversion loss by AGT transformers			0.05
Heating, ventilating, air conditioning (stations and maintenance facilities)			<u>0.90</u>
Total delivered to Sea-Tac			2.15
Lost, used by utility company, or given away			<u>0.17</u>
Total generated	25.0	172	2.32
Natural gas	<u>4.2</u>	<u>29</u>	
Total direct energy, per year	29.2	201	

Capital Energy

Capital energy demands are associated with hardware acquisition, construction, and other capital assets and have been estimated by using the factor of 43,900 Btu/dollar of cost. In a recent study for UMTA, SRI International estimated the capital cost of the system, at 1976 prices, to be \$34,635,000 (\$22,875,000 for construction; \$11,760,000 for hardware). To obtain the long-term average annual capital energy demand, the construction energy demand is divided by a service life of 35 years and the hardware energy demand by a service life of 15 years. The results are presented in Table 4.

Energy Intensity

System average energy intensities are shown in Table 6.

Long-Term Average Annual Energy Demands

Total annual energy demands are recapitulated in Table 5.

Table 4

LONG-TERM AVERAGE ANNUAL CAPITAL ENERGY DEMAND:
SEA-TAC SATELLITE TRANSIT SYSTEM

	<u>Total</u> <u>(Btu × 10⁹)</u>	<u>Service</u> <u>Life</u>	<u>Average</u> <u>Annual</u> <u>Demand</u> <u>(Btu × 10⁹)</u>
Construction energy demand	1,004	35	28.7
Hardware energy demand	<u>516</u>	15	<u>34.4</u>
Total capital energy demand	1,520		63.1

Table 5

SUMMARY OF ENERGY DEMANDS:
SEA-TAC SATELLITE TRANSIT SYSTEM

<u>Demand</u>	<u>Annual Amount</u> <u>(Btu × 10⁹)</u>
Direct	29.2
Indirect	32.6
Capital	<u>63.1</u>
Total	124.9

Table 6

ENERGY INTENSITY ESTIMATES:
SEA-TAC SATELLITE TRANSIT SYSTEM

	<u>Propulsion Only</u>	<u>Direct</u>	<u>Indirect</u>	<u>Capital</u>	<u>Total</u>
Service per gallon of fuel					
Car miles	5.17	2.05	1.84	0.95	0.479
Passenger trips	127	50.4	45.1	53.3	11.3
Passenger miles	45	18.0	16.1	8.33	4.21
Energy per car mile					
Btu	28,000	71,000	79,000	154,000	304,000
Energy per passenger trip					
Btu	1,200	2,900	3,200	6,200	12,400
Energy per passenger mile					
Btu	3,200	8,100	9,000	17,500	34,600
Energy per capacity mile					
Btu	280	700	780	1,510	2,980

3 TAMPA INTERNATIONAL AIRPORT

Overview

The Tampa International Airport (TIA) terminal complex, opened in 1971, uses a network of four AGT shuttle routes, each double tracked, to connect the central ("landside") terminal with four satellite ("airside") terminals located 800 ft to 1,000 ft away. A major design objective was to limit walking distances by air passengers to about 600 ft-700 ft. A second objective was to provide for future addition of two airside terminals to accommodate growth in traffic. These objectives are satisfied by the terminal layout and would not have been attainable without the use of the existing AGT system or some other passenger transportation system within the terminal complex. Thus, the AGT installation is an integral and essential feature of the entire design.

History

The Hillsborough County Aviation Authority which is responsible for the development and operation of TIA, was created by the Florida legislature in 1945. The TIA site, used by the Army Air Force during World War II, was placed under the Authority's control in March 1946. An existing building was adapted to serve as a passenger terminal, and scheduled airline service began in April 1946. Numerous additions to the terminal were made from time to time to accommodate growth. When annual passenger traffic passed the one million mark in 1961, the Authority concluded that further expansion of the patchwork terminal complex would not provide capacity to match expected growth.

Planning for an entirely new terminal complex was initiated in June 1962. The Authority engaged Leigh Fisher Associates, Inc. to survey, evaluate, and compare 20 key airports throughout the United States and to make recommendations regarding the design of the new TIA terminal. Two reports were issued in 1963. The first report emphasized the great walking distances (up to 7,700 ft) required for some passengers at large-capacity terminals using conventional finger piers. The second report advanced an innovative airside/landside concept and outlined a number of alternative configurations. The need for a passenger transportation system within the terminal complex was evident at that time.

The Authority publicized its interest in acquiring a "Passenger Transfer System" (PTS) in 1964 and provided suppliers with general information on both the characteristics desired and the project schedule. Responses were received from 30 firms, and 14 firms made oral presentations. Most of the schemes put forward were in the concept or partial

prototype stage and could not be "market-ready" products in time to meet the Authority's schedule. Many of the schemes would not have met the Authority's requirements even if successfully developed. For example, several depended on pedestrian conveyors, which the Authority ruled out as unsuitable for elderly and handicapped travelers.

In the end, only Westinghouse Electric Corporation (WE) was able to satisfy all of the Authority's needs. WE was then engaged in the development and demonstration of the Transit Expressway AGT prototype system at South Park, near Pittsburgh, Pennsylvania. The prototype became operational in mid-1965 and there was good reason to believe that the Transit Expressway system, with some changes, could satisfy TIA's speed and capacity requirements. The Authority entered into a contract with WE in June 1965 for technical services. A comprehensive contract for design, fabrication, installation, operation's, and maintenance was signed on March 6, 1967.

The AGT system began service when the new terminal complex opened in April 1971. Initially, system reliability was poor. An extensive debugging program made many changes and modifications to the system. By early 1972 reliability was satisfactory; since then, the performance of the system has met the requirements and expectations of the Authority.

System Characteristics

The airside/landside design concept is a scheme of specialization in which terminal functions are divided between two distinctly different buildings. A single landside building centralizes most of the passenger service functions. The AGT system links the landside terminal to four airside terminals (see Figure 3). The airside terminals and surrounding aprons contain all gate positions for loading and discharging passengers and for servicing aircraft.

The Tampa Passenger Shuttle System (PSS) consists of four separate AGT routes, each with two parallel guideways. One vehicle is dedicated to each guideway. (There are eight guideways and eight vehicles in all.) Each route connects the landside terminal with an airside terminal.

The elevated guideways between the buildings are out of doors, but the shuttle stations are located inside the terminal buildings. The guideways are straight and vary in length from 779 ft to 1,002 ft.

A pedestrian walkway is provided between the two guideways on each route and may be used when the shuttle system is not running; it is used only for emergencies and not as an alternative mode for normal travel between terminals.

The cars are 36.25 ft long by 9.33 ft wide by 11 ft high and weight 21,500 lb. They have automotive truck-type axles and rubber tires. The axles are steered by small rubber-tired guidewheels running on a steel

FIGURE 3 PLAN VIEW OF TAMPA INTERNATIONAL AIRPORT

I-beam mounted between the concrete "tracks," which form the running surface for the load-carrying wheels. Each car has two 100-hp series-wound dc traction motors, one on each axle. A thyristor controller converts the wayside 600 V three-phase ac to variable voltage dc for the propulsion motors. Maximum speed of the shuttle cars at Tampa is 30 mph. Service braking is a blend of dynamic and friction. The friction brakes are truck-type air-operated drums. Spring actuators, with air hold-off, apply the friction brakes in emergency stops. Regenerative braking, which could save some energy by feeding back energy to the power rails during deceleration, has not been provided in the Tampa design.

Vehicle operation at Tampa is completely automated. There are no onboard operators. System failures cause an alarm to register at a central console located at the airport telephone switchboard. There is no other central supervision of operations. Because each car operates on its own guideway, there is no train protection system in the sense of traditional block controls. However, there is a fail-safe overshoot protection that is entirely separate from the automatic train operation system. The overshoot protection system initiates an emergency stop if the car exceeds its programmed speed at any point on the station approach.

The PSS service is essential to the operation of the airport, and the airport management has taken steps to ensure a high availability of service. The system fails gracefully when trouble occurs. For example, failure of one vehicle will not affect the operation of the other vehicle on that route, and service continues at half-capacity. Outage of two cars on a route results in complete loss of service, but the walkway is useable. Outages are rare. A single car is available 99.9% of the time, and two cars are available 99.5% of the time.

Each PSS car has capacity for 100 standees, at 2.5 ft² per standee. Crush capacity is approximately 125 passengers. Seats could be installed, with some reduction in capacity. Lack of seats is explained by the fact that trip time is short (40 sec). The tare weight varies as follows:

<u>Passenger Load</u>	<u>Tare Weight per Passenger</u>
100 passengers--design capacity	215 lb
125 passengers--crush capacity	172 lb

Service

The PSS operates in a demand-responsive mode at all times. The cars sit at the stations with doors closed until a passenger interrupts a photosensor light beam upon entering the station area. Usually the movements of the two vehicles on each route are synchronized so that vehicles start at the same time and travel in opposite directions. Vehicle running time, calculated for an average guideway length of 900 ft, is approximately 40 sec. Normal station dwell time is 30 sec, and round-trip time is about

140 sec. The traveler spends an average of 75 sec (1.25 min) per trip including 35 sec waiting and 40 sec riding. This is equivalent to an overall speed of 8.2 mph.

The one-way lane capacity of the system, which was calculated from the above round-trip time, is 2,570 passengers per hour per direction (pphpd) under normal loading conditions (and 3,210 pphpd under crush loading conditions). Route capacity is 5,140 pphpd with normal loading.

The system operates 365 days per year. Daily hours of operation depend on the needs of the airlines occupying the different airside terminals. One airside terminal and route is shut down for about five hours every day. Some routes operate one vehicle rather than two during the early morning hours. This increases average waiting times. The most heavily traveled route operates two vehicles except for intervals when one vehicle is taken out of service for maintenance during periods of low demand.

Vehicle mileage is recorded on axle odometers, and readings are taken monthly. Approximately 405,000 vehicle miles were logged in 1976.

The patronage of the PSS is not accurately recorded. A rough estimate by the airport staff is that 14.5 million passengers rode the system in 1976. This number includes arriving and departing passengers, friends and relatives accompanying passengers, and employees. Annual passenger miles of travel in 1976 were about 2.47 million. The load factor was about 0.06. This low load factor is explained by the need to operate a 100-passenger vehicle in response to the demand of one or more riders.

Economic Data

Capital Costs

Capital costs were obtained partially from the Hillsborough County Aviation Authority and partially from estimates prepared by SRI in a study for UMTA.* Most of the construction was performed between October 1968 and April 1971. Estimates of original costs are presented in Table 7 together with construction, hardware, and total costs escalated to 1976 price levels (see Appendix A).

* A. M. Yen et al., "Assessment of the Passenger Shuttle System (PSS) at Tampa International Airport," Final Report, SRI Project 5949, SRI International, Menlo Park, California (December 1977).

Table 7

CAPITAL COST ESTIMATES:
TAMPA PASSENGER SHUTTLE SYSTEM

	<u>Original Prices</u>	<u>1976 Prices</u>
Construction cost		
Right of way	None*	
Engineering and architecture	\$ 392,000*	
Guideway substructure	451,300†	
Guideway superstructure	1,470,000†	
Eight stations	951,900*	
Maintenance facilities	<u>394,400*</u>	
Total construction	\$3,659,600	\$ 6,455,000
Hardware cost		
Engineering	785,000‡	
Hardware (Westinghouse contract)	3,827,000§	
Power supply	<u>500,000**</u>	
Total hardware	\$5,112,000	<u>7,811,000</u>
Total capital cost	\$8,771,600	\$14,266,000

* SRI estimate.

† Tampa Airport record.

‡ Westinghouse contract and SRI estimate.

§ Westinghouse contract.

** Tampa Airport estimate.

Operations and Maintenance Costs

Total O&M costs for 1976 are estimated to have been \$486,730. The cost of maintenance provided by Westinghouse Electric was \$364,980. Operations costs are not accurately known and the following estimates are rough approximations.

Maintenance	\$364,980
Operations	
Labor	20,000
Energy (\$0.025/kWh)	64,750
Janitorial	27,000
Security	NA
General and administrative	<u>10,000</u>
Subtotal	\$121,750
Total O&M	\$486,730

Estimated unit costs of O&M for 1976 are as follows:

\$1.20 per vehicle mile
0.20 per passenger mile
0.03 per passenger trip
0.01 per capacity mile.

Total Equivalent Annual Cost of Capital, Operations, and Maintenance

For escalation purposes, construction costs are assumed to have been incurred in 1969 and 1970, 50% each year. On that basis, the total capital cost, at 1976 price, is estimated to be \$14,266,000, which includes \$6,455,000 for construction and \$7,811,000 for hardware. The equivalent annual cost of capital is \$1,696,200 (see Appendix A). With the 1976 O&M cost of \$486,730, the total equivalent annual cost of capital, operations, and maintenance is \$2,182,930.

The unit cost of service is computed by prorating the total equivalent annual cost of capital, operations, and maintenance on each of the four measures of service. Results are as follows:

\$5.39 per vehicle mile
0.15 per passenger trip
0.88 per passenger mile
0.05 per capacity mile.

Energy Demand

Direct Energy

Electrical power and natural gas are purchased for direct use by the PSS. Tampa International Airport buys electricity from the Tampa Electric Company. During 1976, 80% of the fuel burned by the utility was coal and 20% was no. 6 fuel oil. The system average heat rate is 10,750 Btu/kWh.

The latest available statistics indicate that the ratio of electricity generated to electricity sold in 1974 by the Tampa Electric Company was 1.056;* that is, about 6% of the power generated is lost or used by the company. Thus, 11,352 Btu of thermal energy are used to deliver 1 kWh of electricity to the PSS.

Estimates of energy usage by vehicles were obtained from Westinghouse where a computer program is used to model train performance. It computes electricity used for propulsion as a function of speed profile, vehicle weight, motor and controller characteristics, and so forth. Westinghouse ran the program for empty vehicles, 50-passenger loads, and 100-passenger loads. The computed electricity demands, for propulsion only, are shown in Table 8.

Table 8

PROPULSION ELECTRICITY USE: TAMPA PASSENGER SHUTTLE SYSTEM

<u>Load</u>	<u>Gross Vehicle Weight (lb)</u>	<u>Propulsion Electricity Demand (kWh/vehicle mile)</u>
Empty	21,500	2.81
50 passengers	29,000	3.58
100 passengers	36,500	4.39

Linear interpolation of these results for the average load of 6 passengers produced a propulsion electricity demand of 2.90 kWh/vehicle mi. For the vehicle auxiliary equipment (heating, air conditioning, air compressor, and the like), Westinghouse suggested a figure of 1.90 kWh/vehicle mile for the Tampa vehicles. Therefore, the total estimated electricity demand for vehicle operation at Tampa is 4.8 kWh/vehicle mile, or, 1,944,000 kWh for 405,000 vehicle miles.

* Federal Power Commission, "1974 Statistics of Privately Owned Electric Utilities in the United States."

The consumption of gas and electricity for heating, ventilating, air conditioning, and lighting of the station and maintenance areas is estimated using methods discussed in Appendix B. These calculations are based on a total station area of 23,510 ft² and a maintenance area of 13,610 ft². Tampa has an average of 683 heating degree days and 3,300 cooling degree days per year.* The calculation of ventilating load assumes an average of 20 passengers waiting in each station. The estimated annual electrical consumption of the stations and maintenance area is as follows:

	<u>kWh</u>
Air conditioning	172,000
Ventilating	20,000
Lighting	<u>447,000</u>
Total	639,000

Total electricity use of the PSS is summarized in Table 9. About 45% of the total is used for propulsion.

Table 9

DIRECT ELECTRICITY USE:
TAMPA PASSENGER SHUTTLE SYSTEM

	<u>kWh x 10⁶</u>	<u>kWh/car mile</u>
Propulsion only	1.17	2.90
Operation of auxiliary equipment	<u>0.77</u>	<u>1.90</u>
Total consumed by PSS	1.94	4.80
Station and maintenance areas	<u>0.64</u>	
Total delivered to Tampa	2.58	

The estimated gas consumption for heating the stations and maintenance areas is 507 million Btu. This energy is equivalent to 3,480 gal of fuel oil or the purchase of 45,000 kWh.

* Heating degree days are obtained from the American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc. Systems Handbook (1976). Cooling degree days are derived from U.S. Geological Survey, The National Atlas of the United States of America (1970).

Table 10 summarizes the direct energy use of the PSS.

Table 10

SUMMARY OF DIRECT ENERGY ESTIMATES:
TAMPA PASSENGER SHUTTLE SYSTEM

	Thermal Energy (Btu $\times 10^9$)	Equivalent Fuel Oil (gal $\times 10^3$)	Equivalent Electrical Power (kWh $\times 10^6$)
Electrical power			
Vehicle operation			1.95
Stations and maintenance areas			<u>0.64</u>
Total delivered			2.59
Lost or used by utility company and given away			<u>0.15</u>
Total generated	29.4	201.4	2.74
Natural gas	<u>0.5</u>	<u>3.5</u>	
Total direct demand	29.9	205	

Indirect Energy

Indirect energy demand is estimated to have been 18.5 billion Btu during 1976. The estimate is based on O&M costs, excluding direct energy costs, of \$433,000 and uses methods discussed in Appendix A. For comparison, the ratio of indirect energy consumption to direct energy consumption is 0.62 to 1.

Capital Energy

Long-term average annual capital energy demand estimates are given in Table 11. These demands are estimated by methods discussed in Appendix A and employ total capital cost estimates, at 1976 prices, of 14,266,000 including \$6,455,000 for construction and \$7,811,000 for hardware.

Table 11

LONG-TERM AVERAGE ANNUAL CAPITAL ENERGY DEMAND:
TAMPA PASSENGER SHUTTLE SYSTEM

	<u>Total</u> <u>(Btu × 10⁹)</u>	<u>Service</u> <u>Life</u>	<u>Average</u> <u>Annual Demand</u> <u>(Btu × 10⁹)</u>
Construction energy demand	283	35	8.1
Hardware energy demand	<u>343</u>	15	<u>22.9</u>
Total capital energy demand	626		31.0

Long-Term Average Annual Energy Demands

12. Long-term average annual energy demands are recapitulated in Table

Table 12

SUMMARY OF ENERGY DEMANDS:
TAMPA PASSENGER SHUTTLE SYSTEM

<u>Demand</u>	<u>Annual Amount</u>
Direct	29.9
Indirect	18.5
Capital	<u>31.0</u>
Total	79.4

Energy Intensity

System average energy intensities are shown in Table 13.

Table 13

ENERGY INTENSITY ESTIMATES:
TAMPA PASSENGER SHUTTLE SYSTEM

	<u>Direct</u>	<u>Indirect</u>	<u>Capital</u>	<u>Total</u>
Service per gallon of fuel				
Car miles	1.98	3.19	1.90	0.74
Passenger trips	69	114	68	26.5
Passenger miles	12	195	12	4.5
Energy per car mile, Btu	74,000	46,000	76,000	196,000
Energy per passenger trip, Btu	2,100	1,300	2,100	5,500
Energy per passenger mile, Btu	12,100	7,500	12,600	32,200
Energy per capacity mile, Btu	740	460	760	1,960

4 BUSCH GARDENS

Overview

Busch Gardens is a "theme," or recreation, park located on the site of the Anheuser-Busch brewery near Williamsburg, Virginia. An AGT system is used to transport people from the theme park area to a "hospitality house," where food and free beer are served. The system consists of a loop, two stations, and a single two-car train. It has been in operation since May 1975.

History

Anheuser-Busch, Incorporated operates theme parks and breweries in Tampa, Florida; Los Angeles, California; and Williamsburg, Virginia. At Williamsburg, the theme is "The Old Country." In 1972, August A. Busch, chairman of the board of Anheuser-Busch, decided to install an AGT system to carry people between the theme park area and the hospitality house. An evaluation of available AGT systems was undertaken by Anheuser-Busch engineering staff in St. Louis, and Westinghouse Transit Expressway was selected. Negotiations took place in 1972 and 1973, and Westinghouse was given a contract with complete responsibility to design and construct an AGT system from the ground up. Construction was begun in April 1973, and the system was open for revenue service in May 1975.

System Characteristics

The AGT at Busch Gardens consists of a single two-car train circulating around a 1.5 mile loop having two on-line stations (see Figure 4). The guideway is 60% elevated and 40% at grade.

The vehicles at Busch Gardens are the latest version of the Westinghouse Transit Expressway design and represent a standard configuration that will also be used in other sites. Vehicles are 36.3 ft long by 9.3 ft wide by 11 ft high and weigh 26,500 lb. Each vehicle has eight seats and space for 82 standees for a rated capacity of 90 passengers. The tare weight per passenger is 294 pounds. (Crush loading capacity is not known.) The vehicles have automotive truck-type axles and rubber tires. The axles are steered by small rubber-tired guidewheels running on a steel I-beam mounted between concrete "tracks," which form the running surface for the load-carrying wheels. Each car has two 100-hp series-wound dc traction motors, one on each axle. A thyristor controller converts the wayside 590 V three-phase ac to variable voltage dc for the propulsion motors. Maximum speed is 30 mph. Service braking is a blend

FIGURE 4 AUTOMATED GUIDEWAY TRANSIT ROUTE AT BUSCH GARDENS

of dynamic and friction. The friction brakes are truck-type air-operated drums. Spring actuators with air hold-off apply the friction brakes in emergency stops. Regenerative braking is not used. Regenerative braking could save some energy by feeding back energy to the power rails during deceleration.

The Gardens Station, near the theme park, has open platforms. The AGT runs through the hospitality house when the station is fully enclosed and air conditioned. The train enters and leaves the hospitality house through double "air curtains" that reduce loss of heating or air-conditioning energy. Both stations have double platforms. Passengers are loaded and unloaded on opposite sides of the car. The unloading door opens promptly on arrival at a station. The loading door remains closed while passengers exit through the other door. It then opens to admit passengers.

Vehicle operation at Busch Gardens is completely automated.* There are no onboard operators. System operation is monitored at a central console. A block control system is provided for automatic train protection for future operation with two trains but is not needed with one train.

Service

The AGT provides service whenever the theme park is open. The hours of service vary according to the season from 12.5 hours/day seven days a week during July and August to 8 hours/day on weekends in March, April, May, and October. Total annual operating hours are approximately 1,526.

Round-trip time is 5 min including two 40 sec dwell times. Average speed, including time for stops, is 18 mph.

The annual vehicle miles are 44,000 (22,000 train miles). The AGT system has carried 7,267,000 passengers in three years of operation, for an average of 2,422,000 passengers/year. The annual passenger miles are 1,608,000. The average load factor is 0.41.

Economic Data

Capital Cost

The Busch Gardens staff estimates the cost of the two stations at \$120,000. Westinghouse was given a turnkey contract to supply all elements

* This description applies to normal conditions. At present, a section of guideway has been removed temporarily to give access to a construction site, and the AGT is operated in a shuttle mode. An onboard operator is required to operate the train in the reverse direction.

of the AGT system except the stations. The contract amount as reported by the Busch Gardens staff was \$4.2 million, and the year of expenditure was 1975. No breakdown of the contract amount was available, but a very rough breakdown was made by SRI, based on data from Westinghouse AGT systems at Sea-Tac and Tampa. Capital cost estimates are given in Table 14.

Table 14

CAPITAL COST ESTIMATES: BUSCH GARDENS AGT SYSTEM

	<u>Actual</u>	<u>At 1976 Prices</u> *
Hardware		
Vehicles	\$ 800,000	
Command and control and utilities	900,000	
Maintenance equipment	<u>100,000</u>	
Subtotal	\$1,800,000	\$1,900,000
Construction		
Guideway	2,400,000	
Stations	<u>120,000</u>	
Subtotal	\$2,520,000	2,700,000
Total	\$4,320,000	\$4,600,000

* See Appendix A for escalation method.

Operations and Maintenance Costs

The operations and maintenance (O&M) costs of the Busch Gardens AGT were obtained from the Busch Gardens staff and are based on the 1977 budget. The O&M cost for 1977, including labor, materials, and energy, is \$75,500. Of this amount, energy is estimated at \$4,500. The estimated unit costs of O&M are as follows:

- \$1.72 per vehicle mile
- 0.031 per passenger trip
- 0.047 per passenger mile
- 0.019 per capacity mile

Total Equivalent Annual Cost of Capital, Operations, and Maintenance

The equivalent annual cost of capital is \$530,000 which includes \$280,000 for construction and \$250,000 for hardware. The total equivalent annual cost of capital, operations, and maintenance is \$605,000.

The unit cost of service prorates the total equivalent annual cost of capital and operations and maintenance over four measures of service-- vehicle miles traveled, passenger miles traveled, passenger trips, and capacity miles for seated and standing passengers. The following costs were derived:

- \$13.75 per car mile
- 0.25 per passenger trip
- 0.38 per passenger mile
- 0.15 per capacity mile.

Energy Demand

Direct Energy

Only electrical power is used by the AGT system. Electricity is supplied by the Virginia Electric & Power Co. The generating capacity is 76.8% coal fired, 19.8% nuclear, and 3.4% hydro. The average heat rate of this utility is 10,868 Btu/kWh. The latest available statistics indicate that the ratio of electricity generated to electricity sold in 1974 by the Virginia Electric & Power Co. was 1.086.* That is, about 8% of the electricity generated is lost or used by the company. Thus 11,803 Btu of thermal energy are used to deliver 1 kWh of electricity to the AGT.

The electricity demand of the AGT at Busch Gardens is not separately metered. Its demand for electricity is small compared to that of the brewery. SRI has estimated the Busch Gardens AGT electricity demand by comparison with the measured demand at Sea-Tac. At Sea-Tac the unit electricity demand is 3.0 kWh/vehicle mile. Factors that affect the unit electrical consumption are maximum speed, vehicle load, and number of stops per mile. Compared with the vehicles at Sea-Tac, the vehicles at Busch Gardens are more heavily loaded (36 passengers average versus 9) and travel at greater speed (30 mph versus 26). These factors tend to increase the electricity demand. However, at Busch Gardens the train makes 1.3 stops per mile compared with almost 4 stops per mile at Sea-Tac. This factor tends to reduce the electricity demand. In the absence of more precise data, it is assumed that the electricity demand at Busch

* Federal Power Commission, "1974 Statistics of Privately Owned Electric Utilities in the United States."

Gardens is 3 kWh/vehicle mile. Therefore, the estimated electricity consumption for vehicle operation at Busch Gardens is 132,000 kWh/year.

The consumption of electricity for heating, ventilating, air conditioning, and lighting of the stations and maintenance facility is estimated using methods discussed in Appendix B. The calculations are based on the following:

1. The area of the garden, as theme park, is 2,800 ft². The station has no air conditioning or heating and is assumed to be illuminated only when the system is operated at night, or about 200 hr per year.
2. The area of the hospitality house station is 3,400 ft². It is heated by electric resistance and air conditioned, and it is assumed to be illuminated during operating hours (1,526 hr per year). The cooling degree days at Williamsburg for the months of operation are 1,500 per year, and the heating degree days are 649 per year. The calculation of ventilating load assumes an average of 70 people waiting in the station.
3. The area of the maintenance facility is 6,000 ft². It is heated by electric resistance units but not air conditioned. In the off season it is operated four days each week. During the rest of the year it is operated seven days each week. The heating degree days during the off season are reduced by a factor of 4/7.

The estimated annual electricity demand of the stations and maintenance area is summarized in Table 15.

Table 15

ELECTRICITY USE BY STATIONS AND MAINTENANCE FACILITY:
BUSCH GARDENS AGT SYSTEM

	Hospitality House Station (kWh)	Theme Park Station (kWh)	Maintenance Facility (kWh)	Total (kWh)
Heating	7,760	0	49,600	57,400
Ventilating	1,068	0	1,970	3,000
Air conditioning	7,170	0	0	7,200
Lighting	2,854	302	110,342	113,500
Total	18,900	300	161,900	181,100

Table 16 summarizes the direct energy use of the Busch Gardens AGT.

Table 16

SUMMARY OF DIRECT ENERGY ESTIMATES:
BUSCH' GARDENS AGT SYSTEM

	Thermal Energy (Btu $\times 10^9$)	Equivalent Fuel Oil* (gal)	kWh $\times 10^3$
Vehicle operation			132
Stations and maintenance facility			<u>181.1</u>
Total delivered to AGT			313.1
Lost or used by utility company			<u>26.9</u>
Total generated			340.0
Total direct energy	3.7	25,000	340.0

*The Virginia Electric & Power Co. does not have oil-fired steam plants. The equivalent quantity of fuel oil consumed was computed to aid in making comparisons among systems.

Indirect Energy

O&M costs for the AGT system, excluding direct energy costs, were budgeted at \$71,000. This is taken to be equivalent to 3.12 billion Btu or 70,800 Btu/car mile. For comparison, the ratio of indirect energy consumption to direct energy consumption is 0.84 to 1.

Capital Energy

The total capital cost of the system, at 1976 dollars, was estimated to be \$4,600,000--\$2,700,000 for construction and \$1,900,000 for hardware. These figures were multiplied by a factor of 43,000 Btu/dollar to yield the long-term average annual capital demand estimates given in Table 17.

Table 17

LONG-TERM AVERAGE ANNUAL CAPITAL ENERGY DEMAND:
BUSCH GARDENS AUTOMATED GUIDEWAY TRANSIT SYSTEM

	<u>Total</u> <u>(Btu × 10⁹)</u>	<u>Service Life</u>	<u>Average Annual</u> <u>Demand</u> <u>(Btu × 10⁹)</u>
Construction energy demand	119	35	3.39
Hardware energy demand	<u>83</u>	15	<u>5.56</u>
Total capital energy demand	202		8.95

Long-Term Average Annual Energy Demand

Estimates of annual energy demands are recapitulated in Table 18.

Table 18

SUMMARY OF ENERGY DEMANDS: BUSCH GARDENS AGT SYSTEM

<u>Demand</u>	<u>Annual Amount</u> <u>(Btu × 10⁹)</u>
Direct	3.70
Indirect	3.12
Capital	<u>8.95</u>
Total	15.77

Energy Intensity

System average energy intensities are shown in Table 19.

Table 19

ENERGY INTENSITY ESTIMATES: BUSCH GARDENS AGT SYSTEM

	<u>Direct</u>	<u>Indirect</u>	<u>Capital</u>	<u>Total</u>
Service per gallon of fuel				
Car miles	1.73	2.06	0.718	0.407
Passenger trips	95.2	113.0	39.4	22.3
Passenger miles	63.4	75.1	26.2	14.9
Energy per car mile				
Btu	84,000	71,000	203,000	358,000
Energy per passenger trip				
Btu	1,500	1,300	3,700	6,500
Energy per passenger mile				
Btu	2,300	1,900	5,600	9,800
Energy per capacity mile				
Btu	930	790	2,260	3,980

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5 FAIRLANE TOWN CENTER

Overview

The Fairlane Town Center in Dearborn, Michigan, uses a 2,600 ft elevated AGT shuttle between a large shopping mall and an 800-room hotel. The site is part of 2,360 acres owned by the Ford Land Development Company. The Ford Motor Company World Headquarters is located on another part of the property, and Ford developed, installed, and operates the AGT system.

Early plans for the development of the Center called for the construction of an extensive network of AGT routes. Total length would have been either four or nine miles according to accounts by Ford executives. The one-half mile route now in place was planned as the first stage of the larger network. However, Ford has withdrawn from the AGT business, so it is now considered unlikely that additions will be made to the existing route. The AGT system does not serve an essential function at Fairlane but would have become increasingly useful if it had been developed to a larger size.

History

The Ford Motor Company AGT system was an outgrowth of a program initiated in 1968 when a unit called the Transportation Research and Planning Staff was created. That group had a broad charter to look for important changes in the transportation of goods and people, including changes that would generate new opportunities for the Company.

In 1971, the Staff group joined forces with a Ford line organization to build an AGT vehicle chassis and a short guideway for test purposes. Later that year, the company responded to UMTA's invitation and entered competition to demonstrate an AGT system at Transpo '72. In May 1971, Ford was selected as one of four firms to demonstrate AGT systems. Market studies made by Ford in the spring of 1972 were encouraging. The Transpo '72 demonstration in mid-1972 was successful, and while the demonstration was in progress Henry Ford II announced that Ford Motor Company was in the AGT business as a supplier. Ford's name for its system is "Automatically Controlled Transit," or ACT.

The decision to install an ACT system at Fairlane Town Center was made in 1973. A new test facility was opened in February 1974. Tests were conducted first with the Transpo '72 cars equipped with advanced components, and then with four second-generation cars: two produced for use at Bradley International Airport in Hartford, Connecticut, and two for Fairlane.

Because of the close relationship between Ford Motor Company and Ford Land Development Corporation, the acquisition process for the Fairlane AGT system was unique. A joint venture (including Ford Land Development Corporation, Taubman Company, a land development enterprise, and others) was responsible for development of the mall and hotel as well as for land use planning and site development in surrounding areas. The hotel was developed and is owned by Ford Land Development Corporation under an agreement with a hotel chain. Ford Motor Company was responsible for the design, fabrication, installation, and testing of the ACT system and will operate the Fairlane system at least until 1986 under a ten-year contract.

The availability of the ACT system was emphasized in promoting the mall to tenants, was incorporated as an integral element in the design of the buildings, and was taken into consideration in the placement of the mall and hotel on the site.

System Characteristics

The ACT system at Fairlane consists of an elevated shuttle route connecting the shopping center and hotel (see Figure 5). The length of the route is 2,600 ft (0.49 mi). The guideway is "single track" except for a section midway between the stations where two paths are provided to allow two vehicles traveling in opposite directions to meet and pass each other.

There are two vehicles; single-car operation is possible, but both vehicles are used in normal operation. The vehicles are 24.7 ft long by 6.67 ft wide by 8.67 ft high and weigh 12,500 lb. There are seats for 10 passengers and standing room for 14. Crush capacity is 30. The tare weight varies as follows:

<u>Passenger Load</u>	<u>Tare Weight per Passenger</u>
10 passengers--seated capacity	1,250 lb
24 passengers--design capacity	521 lb
30 passengers--crush capacity	417 lb

The vehicles include truck axles and other automotive components. The axles are steered by small rubber-tired guidewheels running on the "curbs" of the channel-shaped concrete guideway. Rubber tires are filled with foam.

Each car is powered by two 60-hp shunt-wound dc traction motors. A thyristor controller onboard each vehicle converts 480 V three-phase ac power received from wayside conductors to dc and regulates the power delivered to the motor field and armature to control speed. Operating speed is limited to 20 mph although the vehicle is capable of higher speeds.

FIGURE 5 AUTOMATED GUIDEWAY TRANSIT ROUTE AT FAIRLANE TOWN CENTER

Friction brakes are used only for station holding and emergency stops. Normal braking is fully regenerative down to zero speed. During deceleration the motors operate as dc generators. The controller inverts dc power generated to ac power of standard characteristics. Power produced by braking vehicles is returned to the public utility via the power rails and substation. Power returned is not metered.

Guidewheels mounted onboard the vehicles control vehicle switching at the bypass section and allow two cars to meet and pass one another on the dual guideway. This feature provides double the capacity of a single-guideway shuttle at much less than double the construction cost.

Vehicle operation at Fairlane is completely automated--there is no operator on the vehicle in normal passenger service. However, operations are always monitored from a control center, and manual control can be put into effect to deal with malfunctions.

The Fairlane ACT system was placed in revenue service before the completion of development and testing. As a result it experienced a fairly low availability during the first ten months of operation while problems were diagnosed and modifications were made. By the end of that period, reliability and availability had improved to levels acceptable to the operator.

Service

The system provides service while the shopping center is open--from 9:30 a.m. to 10 p.m., Monday through Saturday, and from 12 noon to 5:30 p.m. on Sunday. No fare is charged.

The AGT services is not essential for people to reach either the hotel or the shopping mall, but the link probably has significant commercial value to both the mall and hotel. The substantial patronage experienced by the system suggests that its novelty, visual appeal, and service help to attract people to the center. Availability of the system has been featured in national advertising by the hotel chain.

The observed round-trip cycle time is 5.8 min. The cycle includes two 50-sec dwells and two 123-sec travel times. Maximum speed is limited to 20 mph. Average trip time is 210 sec (3.5 minutes) and includes 87 sec waiting plus 123 sec riding. This is equivalent to an overall speed of 8.4 mph.

The line capacity is calculated to be 496 passengers/hr per direction with normal loading, and 624 with crush loading. When one vehicle is operating, capacity is reduced 50%.

The system is designed for three modes of operation: automatic, request, and manual. In automatic, the vehicles shuttle back and forth and remain at each station with the doors open for a predetermined dwell time before moving. This mode generates the maximum demands for energy.

In the request mode (on demand), the vehicle(s) remains at the station(s) with the doors closed until service is requested by a passenger. By allowing vehicle to remain idle, the request mode can allow significant energy savings in periods of low demand. Manual control, exercised from within the vehicle via a special control panel, is used during system start-up but is not ordinarily used for passenger service.

Vehicle travel in the first 12 months of operation (February 28, 1976 to February 27, 1977) was 60,262 miles. This calculation is based on a record of the number of vehicle trips and a trip length of 2,492 ft from station to station. The annual vehicle hours of travel in the first 12 months of operation were reported to total 6,239, whereas the total system operation hours in the same time period were reported to be 3,980, indicating that the system was operated with two vehicles 56.8% of the time.

Patronage in the first 12 months of operation was estimated to be 2.4 million passengers. However, passenger-counting equipment is not employed. Estimates of patronage were based on observations by employees of the average number of passengers on vehicles and the number of vehicle trips. Passenger travel for the year was found by multiplying the estimated patronage by the known trip length. This procedure yielded an estimate of 1,150,000 passenger miles and an average load of 19.1 passengers per vehicle trip. The average ridership of 19.1 and the design capacity of 24 give an unusually favorable average load factor of 79%.

Economic Data

Capital Costs

The estimated capital cost of the AGT system was given by a former executive of the Ford Motor Company's Transportation Systems Operation to be within ± 10 percent of \$5.5 million. The total cost reportedly excludes the nonrecurring cost of developing the basic system but includes site-specific adaptations that might be incurred at any other site. Thus the costs reported are said to be the best estimates of "recurring" cost. The Ford spokesman acknowledged, however, that separation of recurring from development costs for the first installation of a system type is a difficult problem. Supporting details for estimates were not accessible.

SRI estimated the capital cost of the system to be about \$5.12 million in a special cost study conducted for UMTA.* Cost estimates were based on information from various sources. A breakdown of capital costs is shown in Table 20. This estimate is used in this report to compute the equivalent annual cost of capital, the unit cost of service, and the capital energy demand.

* A. M. Yen et al., "Assessment of the Automatically Controlled Transportation System at Fairlane Town Center," Final Report, SRI Project 5949, SRI International, Menlo Park, California (December 1977).

Table 20

CAPITAL COST ESTIMATES: FAIRLANE ACT SYSTEM
(millions of 1974 dollars)

	Estimated Cost in <u>1974</u>	Estimated Cost at <u>1976 Prices*</u>
Construction		
Right-of-way	NA	
Engineering, architecture, and administration	0.33	
Guideway	1.75	
Stations	0.35	
Maintenance shop and power substations	<u>0.10</u>	
Total construction	2.53	2.99
Hardware		
Engineering and administration	0.60	
Vehicles (2)	0.60	
Command, control, and communications	0.60	
Power and miscellaneous	<u>0.79</u>	
Total hardware	<u>2.59</u>	<u>3.12</u>
Total capital cost	5.12	6.11

* See Appendix A for discussion of method of cost escalation.

Operations and Maintenance Costs

Because the system started operation during 1976, O&M costs were not available for a full year. The cost figures used here are estimates given by Ford representatives for a full year under normal operating conditions, that is, after the shakedown was completed and modifications were made. Supporting details were not supplied.

Operations

Labor (included below)	--
Electricity @ \$0.05/kWh*	\$55,000
HVAC and lighting†	NA
General and administration	<u>NA</u>
Subtotal	\$55,000

Maintenance

Labor (10 people)	\$300,000
Material	<u>40,000</u>
Subtotal	<u>\$340,000</u>
Total	\$395,000

Estimated unit O&M costs for 1976 are:

\$6.55 per vehicle mile
\$0.34 per passenger mile
\$0.16 per passenger trip
\$0.27 per capacity mile

Total Equivalent Annual Cost of Capital, Operations, and Maintenance

The estimated construction and hardware costs, in 1976 prices, are \$6,107,000--\$3,115,000 for hardware and \$2,992,000 for construction. Equivalent annual cost of capital is \$719,800. The total equivalent annual cost of capital plus O&M is \$1,114,800.

The unit costs of service are given below:

\$18.50 per vehicle mile
\$0.97 per passenger mile
\$0.46 per passenger trip
\$0.77 per capacity mile

* Electricity covers only AGT system functions and was said to be within $\pm$ \$5,000 per year.

† Heating, ventilating, air conditioning and lighting costs for stations and stops were not available.

Energy Demand

Direct Energy

The system uses electrical power for all purposes except heating, which depends on fuel oil. The Fairlane Town Center buys electricity from Detroit Edison Company for 5¢/kWh. According to the 1975-1976 Directory of Electric Utilities, Detroit Edison's system average heat rate is 10,150 Btu/kWh. In 1974, the ratio of electricity generated to electricity sold was 1.007;* that is, about 8% of the power generated is lost or used by the company. Thus, each kWh purchased for the system requires the consumption of 10,932 Btu of thermal energy or about 0.07502 gal of fuel oil.

The electrical consumption measured for the vehicles and installations at Fairlane includes operation of vehicle, operation of the maintenance facility, and heating the guideway. It does not include energy used to heat, ventilate, air condition, and illuminate passenger areas in stations.

Metered consumption in the first year of operation was 1.1 million kWh. Energy for guideway heating is not metered separately, and estimating usage for heating presents a special problem. Based on power consumption rates during the summer months when heating is not required, about 300,000 kWh per year were used for vehicle operation and the maintenance facility. If that estimate is correct, the remaining 800,000 kWh were used for guideway heating. The direct energy demand for guideway heating is therefore a highly significant factor.

The actual consumption of electricity at Fairlane is somewhat less than reported because credit was not taken for regenerated energy returned to the utility from the vehicle braking system. Usually there is no load on the downstream side of the meter large enough to take all the regenerated energy except when guideway heating is required. Both vehicles must decelerate at the same time. Because of the need to pass at the midpoint, vehicles cannot operate out of phase. If they were out of phase, so that one vehicle accelerated as the other decelerated, then the accelerating vehicle could effectively use the energy generated by the decelerating vehicle. Therefore, most regenerated energy is returned to Detroit Edison. However, the meter does not turn backward to record the energy returned.

A rough calculation of the amount of energy recycled per stop is presented in Appendix C. With a speed of 20 mph and a loaded vehicle weight of 15,350 lb, the maximum kinetic energy of a vehicle is equivalent to 0.0778 kWh. When this number is multiplied by the number of vehicle trips per year (127,682) the total kinetic energy is 9,930 kWh.

* Federal Power Commission, "1974 Statistics of Privately Owned Electric Utilities in the United States."

This is the maximum amount of energy that could be returned to the power rails with 100% efficiency. A more likely efficiency is 30%, and the quantity returned is about 3,000 kWh per year. This amounts to 1.0% of the power consumed (except for guideway heating).

The consumption of energy for heating, ventilating, air conditioning, and lighting of the stations and maintenance areas is estimated using methods discussed in Appendix B. These calculations are based on a total station area of 4,448 ft² and a maintenance area of 2,640 ft². Detroit has an average of 6,260 heating degree days and 750 cooling degree days per year.* The calculation of ventilating load assumes an average of 20 people waiting in each station. Both ventilating and lighting calculations take into account the annual operating hours of the system, or approximately 11 hrs/day. It is assumed that the maintenance facility is operated for 15 hr/day. The estimated annual electrical consumption of the stations and maintenance area is as follows:

	<u>kWh</u>
Air conditioning	7,480
Ventilating	2,308
Lighting	<u>49,840</u>
Total	59,630

The total electricity consumption of the Fairlane ACT is summarized in Table 21. About 26% of the total electricity consumption is used for vehicle operation.

Table 21

DIRECT ELECTRICITY USE: FAIRLANE ACT SYSTEM

	<u>kWh × 10⁶</u>	<u>kWh/car mile</u>
Vehicle operation	0.3	5.0
Guideway heating	0.8	
Station and maintenance areas	<u>0.06</u>	
Total delivered to ACT	1.16	

* Heating degree days are obtained from the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. Systems Handbook (1976). Cooling degree days are derived from U.S. Geological Survey, The National Atlas of the United States of America (1976).

Table 22

SUMMARY OF DIRECT ENERGY ESTIMATES: FAIRLANE ACT SYSTEM

	Thermal Energy (Btu x 10 ⁹)	Equivalent Fuel Oil (gal x 10 ³)	Equivalent Electrical Power (kWh x 10 ⁶)
Electrical power			
Vehicle operation			0.30
Guideway heating			0.80
Lighting, ventilating, and air conditioning of stations and maintenance area			<u>0.06</u>
Total delivered			1.16
Lost, used by utility company, or given away			<u>0.09</u>
Total generated	12.63	87	1.25
Oil	<u>0.89</u>	<u>6</u>	
Total direct energy	13.57	93	

Note: Energy demands are for the period March 1976-February 1977.

The estimated consumption for heating the stations and maintenance areas is 0.89 billion Btu. Based on national averages, discussed in Appendix A, this energy is equivalent to 6,090 gallons of fuel oil. Table 22 summarizes the direct energy demands at Fairlane.

Indirect Energy

In the first 12 months of operation, the total O&M cost--excluding the cost of direct energy--was \$340,000. This is taken to be equivalent to 14.9 billion Btu (see Appendix A). For a comparison, the ratio of demand for indirect energy to direct energy is 1.10 to 1.00.

Capital Energy

The total estimated capital cost at 1976 prices is \$6,107,000 and consists of \$2,992,000 construction costs and \$3,115,000 hardware costs. Total and annual capital energy demands are presented in Table 23.

Table 23

LONG-TERM AVERAGE ANNUAL CAPITAL ENERGY DEMAND: FAIRLANE ACT SYSTEM

	<u>Total Capital Energy Demand (Btu x 10⁹)</u>	<u>Service Life</u>	<u>Average Annual Demand (Btu x 10⁹)</u>
Construction	131	35	3.74
Hardware	<u>137</u>	15	<u>9.13</u>
Total	268		12.87

Long-Term Average Annual Energy Demands

Long-term average annual energy demands are recapitulated in Table 24.

Table 24

SUMMARY OF ENERGY DEMANDS:
FAIRLANE ACT SYSTEM

<u>Demand</u>	<u>Annual Amount (Btu x 10⁹)</u>
Direct	13.6
Indirect	14.9
Capital	<u>12.9</u>
Total	41.4

Energy Intensity

System average energy intensities are shown in Table 25.

Table 25

ENERGY INTENSITY ESTIMATES: FAIRLANE ACT SYSTEM

	<u>Direct</u>	<u>Indirect</u>	<u>Capital</u>	<u>Total</u>
Service per gallon of fuel				
Car miles	0.65	0.58	0.68	0.213
Passenger trips	26.1	23.8	27.5	8.59
Passenger miles	12.3	11.2	13.02	4.06
Energy per car mile				
Btu	226,000	247,000	214,000	687,000
Energy per passenger trip				
Btu	5,600	6,100	5,300	17,000
Energy per passenger mile				
Btu	11,800	13,000	11,200	36,000
Energy per capacity mile				
Btu	9,400	10,300	8,900	28,600

6 DALLAS-FORT WORTH REGIONAL AIRPORT

Overview

The AIRTRANS System at the Dallas-Forth Worth Regional Airport was developed by the Vought Corporation. It provides passenger and goods movement service connecting four passenger terminals, two remote parking areas, a hotel, and a logistics complex. The system was designed as an integral part of the airport and has provided passenger service since the airport opened in January 1974. Walking is not an available alternative for routes served by AIRTRANS, and buses are kept on stand-by status to transport passengers when the system shuts down.

History

More than 12 years ago the decision was made to construct a regional airport in the Dallas-Fort Worth area. Included in the original concept was an intra-airport transportation system. By early 1966, the present site was approved by the Regional Airport Board. Airport plans calling for use of a fixed guideway transit system were completed by the end of 1967.

Requests for proposal were sent out in June 1968 to prospective bidders for the transit system. Twelve possible suppliers replied, and, in the fall, three firms--Varo, Dashaveyor, and Westinghouse Electric--were chosen for further participation. Varo and Dashaveyor conducted preliminary feasibility studies, which were completed in October 1969. In February 1970, the U.S. Secretary of Transportation approved a \$1.02 million grant to develop and demonstrate an AGT system for the airport.

In September 1970, Vought affiliated itself with Varo. Dashaveyor was acquired by Bendix. AIRTRANS specifications were completed the following month, and in December hardware demonstrations were conducted. Bids for ten different configurations were received in February 1971 from both Varo and Dashaveyor. In each the cost was well above the allotted \$18 million, and these bids were rejected. Revised specifications were prepared and proposal requests for five different configurations were issued in April. Four bids--from Bendix, Westinghouse Electric, Westinghouse Airbrake, and Vought--were received and evaluated. Vought won and was awarded a \$31 million contract on July 13, 1971.

At the time the contract was let, AIRTRANS was, for the most part, a design concept. Detailed engineering design, construction, and testing remained to be done. Because of the preliminary nature of the state of the art and the tight deadline for starting revenue service (January 13, 1974), reliance was placed on conservative approaches, and many existing

commercial components were adapted for the system. Because of the short time for development and lack of testing, the system experienced many difficulties in the early months of operation. Extensive redesign was necessary after the system began operations. By 1976, most of the design problems had been solved.

System Characteristics

AIRTRANS is the largest and most complex AGT system in the world. The total guideway length is 67,697 ft (12.82 mi) and extends from the remote parking lot on the north, through the airport terminal complex, to the remote parking lot and transportation center and logistics complex on the south. The straight-line distance between the remote parking lots is 3.2 miles (see Figure 6).

Unlike other AGT systems designed to carry only passengers, AIRTRANS was designed to supply six services--to carry airline passengers, airport employees, baggage, air mail, supplies, and trash or solid waste. For various reasons, including difficulties in meeting altered requirements of the users, AIRTRANS is not presently carrying baggage, air mail, or trash. The food service concessionaire uses AIRTRANS for transporting supplies.

AIRTRANS has a total of 53 stations, including 14 passenger stations, 14 employee stations, and 25 utility (freight) stations. All stations are off-line except those located at the remote parking lots. Fare collection equipment is used in passenger stations. Access to trains is through biparting doors that open with the vehicle doors when the train has stopped. Employee stations have open platforms and no fare collection equipment. The utility stations have automatic equipment for handling containers.

The AIRTRANS route system contains many overlapping loops. Rather than have each train stop at all stations, each train follows a route which serves a limited number of stations. The nine passenger and employee routes are designed to allow persons to travel to and from remote parking and between different airlines without having to transfer. Each train is directed along its proper routes by 33 active, diverging switches and 38 passive, converging switches. Employee routes carry employees nonstop between the remote parking lots and each of the four terminals. Two supply routes are currently used by Dobbs House, a caterer with installation throughout the airport terminal complex.

AIRTRANS employs 51 passenger vehicles designed and built by Vought. They are 21 ft long by 7 ft wide by 10 ft high and weigh 14,000 lb. Each vehicle has 16 seats and space for 24 standees. A single biparting door is provided on one side of the car and there are emergency exits at each end. The tare weight varies as follows:

SOURCE: Ronald Kargas, et al., "Assessment of Operational Automated Guideway Systems: AIRTRANS (Phase I)," U.S. Department of Transportation, Transportation Systems Center, Cambridge, Massachusetts (September 1976).

FIGURE 6 AIRTRANS GUIDEWAY AND STATION LAYOUT

<u>Passenger Load</u>	<u>Tare Weight per Passenger</u>
16 passengers--seated capacity	875 lb
40 passengers--design capacity	350 lb

The vehicles have two automotive truck-type axles, both with Ackerman steering, and foam-filled rubber tires. The axles are steered by 6" diameter polyurethane guidewheels rolling on the vertical surfaces of the channel-shaped guideway. Two guidewheels are needed to steer each axle. Each axle also has two so-called entrapment wheels which perform a guidance function while the vehicle is traversing a switch. Each guidewheel and entrapment wheel is backed up by a secondary wheel in case of failure. An axle on each vehicle is driven by a 60 hp compound-wound dc motor. An onboard thyristor controller converts three-phase, 480 V ac to variable-voltage dc for the propulsion motors. Maximum operating speed is 17 mph. Air-operated friction brakes are employed. There is no provision for dynamic or regenerative braking.

Seventeen utility vehicles are constructed on the same chassis as the passenger vehicles but are equipped to handle and carry containers for mail, baggage, supplies, and trash.

Normal operation of the AIRTRANS system is completely automatic, with no onboard operators. The vehicle command, control, and communications system (CC&CS) consists of the following independent fail-safe systems:

<u>System</u>	<u>Functions</u>
Automatic vehicle protection (AVP)	Train spacing, safe switching, speed limiting, all safety functions
Automatic vehicle operation (AVO)	Route control, station lineup, door and speed controls
Central control	Status monitoring, supervisory control, voice and video communication

A central control room contains a lighted display, control consoles, and communications equipment and is always staffed. Central control is not necessary for AIRTRANS to function, but the system runs somewhat more efficiently under supervisory control. Failure of AVP or AVO results in system shutdown.

Service

AIRTRANS provides service 24 hr a day, seven days a week. A fare of 25¢ is collected from passengers. Employees ride free, but employers pay for the service.

Round-trip times depend on the route and vary from 14.6 min to 24.3 min under normal conditions for passenger routes and 15.7 min to 21.7 min for the employee routes. System specifications call for a maximum of 20 min for interterminal transfer and 30 min for parking lot service. Performance of the system is said to exceed these specifications.

The vehicle miles of travel are recorded monthly for the passenger, employee, and supply routes. For the 12-month period May 1976-April 1977, the AIRTRANS vehicles accumulated mileage as follows:

	<u>Vehicle Miles</u>
Passenger routes	1,791,712
Employee routes	8,877,828
Supply routes	<u>41,579</u>
Total	3,711,119

Patronage on the passenger routes is recorded by fare collection equipment; patronage on the employee routes is estimated by the staff. Figures for the 12-month period are:

	<u>Patronage</u>
Passenger routes	2,624,865
Employee routes	<u>3,507,733</u>
Total	6,132,598

Estimates of passenger miles of service are not available from the system operator and no basis for estimates was found during the course of this research.

Economic Data

Capital Costs

Capital costs for AIRTRANS have been reported;* a breakdown of these costs, adjusted to 1976 prices is given in Table 26.

* N.D. Lea & Associates, "Summary of Capital and Operations and Maintenance Cost Experience for Automated Guideway Transit Systems" (October 1977).

Table 26

CAPITAL COST ESTIMATES: AIRTRANS

<u>Hardware</u>	
Vehicle (51 passenger + 17 utility)	\$18,806,000
Control and communication	8,343,000
Power and utilities	4,987,000
Maintenance and support facilities	<u>3,404,000</u>
Total hardware	\$35,540,000
<u>Construction</u>	
Guideways	\$13,418,000
Stations (passenger)	7,045,000
Stations (utility)	6,135,000
Engineering and project management	<u>18,751,000</u>
Total construction	\$45,349,000
Total Capital Cost	\$80,889,000

Operations and Maintenance Costs

The O&M costs of AIRTRANS are also summarized in the N.D. Lea & Associates report. The published breakdown for the 15-month period March 1976-May 1977 is as follows:

O&M costs	\$ 443,619
Labor	
Operations	1,689,406
Maintenance	
Electricity	284,354
Contract services	406,504
Materials	<u>855,379</u>
Total O&M Cost	\$3,679,262

Unit costs of O&M for the 15-month period were computed as follows:

\$0.80 per vehicle mile
 0.48 per passenger trip
 0.02 per capacity mile

Total Equivalent Annual Cost of Capital, Operations, and Maintenance

The total equivalent annual cost of capital is \$9,374,000, which includes \$4,702,000 for construction and \$4,672,000 for hardware.

The total equivalent annual cost of capital, operations, and maintenance is \$12,317,000.

The estimated unit cost of service prorates that portion of the equivalent annual cost of capital, operations, and maintenance that is devoted to passenger operations (99%) over three measures of service. (Passenger-mile estimates are not available.) The following costs were derived:

\$3.32 per vehicle mile
2.01 per passenger trip
0.08 per capacity mile

Energy Demand

Direct Energy

AIRTRANS equipment and facilities are powered entirely by electricity. The Dallas-Fort Worth Airport buys electricity from the Texas Power and Light Co. Of the total generating capacity of the utility, 88% is fueled by natural gas, 11.5% by coal, and 0.5% by diesel oil. The average heat rate of the utility is 10,369 Btu/kWh. The latest available statistics indicate that the ratio of electricity generated to electricity sold in 1974 by the Texas Power and Light Co. was 1.079; that is, about 8% of the power generated is lost or used by the company.* Thus, each kWh purchased for the AGT system requires the consumption of 11,188 Btu of thermal energy or about 0.077 gal of fuel oil.

Electrical energy used by AIRTRANS is measured in a number of locations. The sum of these meter readings is published every month as the "AIRTRANS Total Monthly kWh Consumption." The total figure includes electricity used for vehicle operation, operation of the maintenance facility, and operation of five stations located at the hotel and the remote parking lot. The published figures for the 12-month period May 1976-April 1977 add up to 9,958,162 kWh. To this figure must be added an estimate of the energy used for heating, ventilating, air conditioning, and lighting 28 stations located in the terminal buildings and maintained by the airlines. This estimate is based on methods described in Appendix B. Calculations are based on a total station area of 28,000 ft² for heating, ventilating, and air conditioning, and

* Federal Power Commission, "1974 Statistics of Privately Owned Electric Utilities in the United States."

42,000 ft² for lighting. (The employee stations are not fully heated and have no air conditioning.) Dallas has an average of 2,400 heating days and 2,500 cooling degree days per year.* The calculation of ventilating load assumes an average of 20 people waiting in each passenger station. The estimated annual electrical consumption of the 28 terminal stations area is as follows:

	<u>kWh</u>
Heating [†]	236,000
Air Conditioning	98,000
Ventilating	25,000
Lighting	<u>202,000</u>
Total	561,000

The total direct energy consumed by AIRTRANS (all electricity) is 10,520,000 kWh for the period May 1976-April 1977. This is equivalent to 117.7 billion Btu or 808,000 gal of oil.

Table 27 summarizes the direct energy demand of AIRTRANS.

Table 27

SUMMARY OF DIRECT ENERGY ESTIMATES: AIRTRANS

Electrical power	Thermal Energy (Btu x 10 ⁹)	Equivalent Fuel Oil (gal x 10 ³)	Equivalent Electrical Power (kWh x 10 ⁶)
Total delivered			10.52
Lost, used by utility company, or given away			<u>0.83</u>
Total direct energy	117.7	808	11.35

* Heating degree days are obtained from the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Systems Handbook (1976). Cooling degree days are derived from U.S. Geological Survey, The National Atlas of the United States of America (1970).

† Electrical resistance heating is used in the AIRTRANS stations.

Indirect Energy

During the 15-month period March 1976-May 1977, the O&M costs for AIRTRANS excluding direct energy costs were \$3,394,900. This is taken to be equivalent to 149 billion Btu, or 119 billion Btu for a 12-month period. For comparison, the ratio of indirect energy consumption to direct energy consumption is 1.01 to 1.

Capital Energy

The total capital cost of the system in 1976 dollars was estimated to be \$80,889,000, of which \$45,349,000 was for construction and \$35,540,000 for hardware. These figures were multiplied by a factor of 43,900 Btu/dollar to yield the long-term average annual costs given in Table 28.

Table 28

LONG-TERM AVERAGE ANNUAL CAPITAL ENERGY DEMAND: AIRTRANS

	<u>Total (Btu x 10⁹)</u>	<u>Service Life</u>	<u>Average Annual Demand (Btu x 10⁹)</u>
Construction energy cost	1991	35	56.9
Hardware Energy cost	<u>1560</u>	15	<u>104.0</u>
Total capital energy cost	3551		160.9

Long-Term Average Annual Energy Demands

Energy demands are recapitulated in Table 29.

Table 29

SUMMARY OF ENERGY DEMANDS: AIRTRANS

<u>Demand</u>	<u>Annual Amount (Btu x 10⁹)</u>
Direct	117.7
Indirect	119.0
Capital	<u>160.9</u>
Total	397.6

Energy Intensity

System average energy intensities are shown in Table 30.

Table 30

ENERGY INTENSITY ESTIMATES: AIRTRANS

	<u>Direct</u>	<u>Indirect</u>	<u>Capital</u>	<u>Total</u>
Service per gallon of fuel				
Car miles	4.60	4.54	3.36	1.36
Passenger trips	7.59	7.51	5.56	2.25
Energy per car mile				
Btu	32,000	32,000	43,000	107,000
Energy per passenger trip				
Btu	19,200	19,400	26,200	64,800
Energy per capacity mile				
Btu	790	800	1,080	2,680

Note: Estimates of passenger miles are not available; consequently, energy intensities per passenger mile cannot be computed.

7 MORGANTOWN

Overview

The AGT system at Morgantown, West Virginia, was developed by the Boeing Aerospace Company and installed under a Department of Transportation (DOT) research and development contract. It provides passenger transportation between three stations: two located at the Evansdale and downtown campuses of West Virginia University and one in the central business district. The system serves travelers formerly served by buses and autos on a parallel road.

History

The Morgantown project was originally proposed by representatives of West Virginia University to demonstrate an advanced urban transit system. In June 1969, a DOT grant was awarded for design studies. By June 1970, three design studies had been completed; one each by Varo, Dashaveyor, and Alden. The University chose the Alden concept and submitted a grant application to UMTA for a six-station, \$13.5 million system.

In September 1970, the Jet Propulsion Laboratory (JPL) was given responsibility as system manager and initiated a development plan for the Alden-type system. However, later that month, UMTA directed JPL to specify a system design having characteristics that would allow open competition among suppliers for AGT systems.

Initial performance requirements included the ability to move 1,100 people in 10 min from one station to another. This capacity was beyond that offered by any of the three proposed systems. Also, the first design used large, wide cars, which would have required costly guideways. In February 1971, performance requirements were modified to carry 1,100 persons in 20 min. Continuing iterations of system design indicated that a small nine-passenger vehicle could handle the less stringent requirements. In April 1971, JPL estimated the project cost for the revised design to be over \$37 million. UMTA requested an abbreviated and less costly version of the system, and JPL responded with four options ranging from \$23 million to \$25 million. UMTA chose the least expensive, a system that consisted of three stations, 15 vehicles, and a maintenance facility.

Boeing replaced JPL as systems manager and continued its responsibility for vehicle design. Formal construction began in October 1971. However, Boeing's estimates of system cost were higher than available funds. In search of economies, UMTA directed Boeing to prepare estimates for five alternative system configurations. On the basis of estimates

submitted in January 1972, UMTA decided on a design which, among other things, reduced the initial purchase of vehicle to five units.

System demonstration began in October of 1972. That same month, an apparent failure of an element of BART's safety system caused concern over safety of the Morgantown design and an intensive system safety review was conducted from January to May 1973. The results of the review led to some design changes.

The first part of the project (Phase I-A) was completed on September 26, 1973 when four vehicles were operated continuously all afternoon. The second part of the project (Phase I-B) began the same month. The Phase I-B contract between UMTA and Boeing called for 45 vehicles and a capability for revenue service. A number of problems caused delays. Among these were material and manpower shortages and difficulties in software development. Demonstration testing was completed in August 1975.

Phase II of the project, now under way, will add two stations and 2.94 mi of guideways, and will increase the fleet from 45 to 73 vehicles.

System Characteristics

The Morgantown Personal Rapid Transit (MPRT) system includes 2.1 mi of dual guideway, three stations, and 45 passenger vehicles. The stations are Walnut, located in the central business district; Beechurst, serving the downtown campus of West Virginia University; and Engineering, serving the Evansdale campus of the university (see Figure 7).

The line includes 0.7 mi at grade and 1.4 mi on elevated structures. Maximum grade is 10%. Vehicles operate in six revenue routes and provide nonstop service between any pair of stations. This characteristic is part of the classical PRT concept. However, the number of stations is small, and vehicles carry groups of unrelated passengers rather than single travel parties. Under the terminology now in general use, Morgantown is classed as a group rapid transit (GRT) system rather than a PRT system.

The Beechurst-to-Engineering and Engineering-to-Beechurst routes account for 60% of the vehicle trips and 85% of the passenger trips. The Beechurst station has offline platforms to allow nonstop service between Walnut and Engineering. The other stations are at the terminals of the line and platforms are online. However, Engineering station will become offline when the system is extended during Phase II.

It is reported that 22 vehicles are normally in operation and 7 are kept in ready condition. Presumably, the remainder--16 vehicles--are in maintenance. The vehicles were designed and built by the Boeing Aerospace Company. Dimensions are 15.5 ft x 6.7 ft x 8.75 ft. Empty vehicle weight is 8,600 lb. The tare weight varies as follows:

FIGURE 7 CONFIGURATION OF MORGANTOWN PERSONAL RAPID TRANSIT SYSTEM

<u>Passenger Load</u>	<u>Tare Weight per Passenger</u>
8 passengers--seated capacity	1,075 lb
21 passengers--design capacity	410 lb

Each vehicle is powered by a 70 hp dc electric motor. An onboard solid-state controller converts 575 V three-phase ac wayside power to variable voltage dc power for the motor. Brakes are hydraulically operated discs on all four wheels. Two independent hydraulic systems are each capable of giving full braking performance. An automatic-leveling air suspension maintains constant vehicle ride height, at platform level, as passenger load changes.

The vehicles have rubber tires and operate on a channel-shaped guideway. Ackerman steering geometry is employed on both axles to achieve a small turning circle. The rear axle steering is linked to the front so the rear wheels follow the path of the front wheels. A unique servo-operated steering system is controlled by guidewheels which can be commanded to follow either the right or left curb or guideway sidewall. In this way route selection at switching points is accomplished by the vehicle without active guideway switching. Only the rear axle is driven. It is an automotive-type component normally used for vehicles with front-wheel power.

The vehicles have eight seats and space for 13 standees. They are heated or air conditioned according to season. An electrically operated door is provided on each side.

The Morgantown station platforms are covered and illuminated. They are not enclosed and have no heating, air conditioning, and ventilating systems. To gain access to the station platforms, passengers must pass through turnstiles, each of which includes a fare collection unit and a destination selection unit. Two types of coded magnetic fare collection cards are used: multitrip cards issued periodically to students or sold by the university; and one-way fare cards sold to occasional patrons.

The stations use a "turnaround channel" concept illustrated in Figure 8, which shows the configuration of the Beechurst station. Each turnaround channel has three unloading berths and one loading berth. Vehicles that stop at the station must return in the direction from which they came.

Snow and ice interfere with the system operation. In the winter the guideway is heated when necessary. The heating system circulates a heated solution of ethylene glycol and water through pipes imbedded in the guideway. The liquid is heated by natural gas.

System operation is completely automated. There are no operators onboard the vehicles. Vehicles are controlled by a central computer and four wayside computers.

FIGURE 8 CONFIGURATION OF BEECHURST STATION AT MORGANTOWN

Service

The MPRT provides scheduled service from 7:15 a.m. to 5:00 p.m. on weekdays. It provides demand-responsive service from 5:00 p.m. to 8:30 p.m. on weekdays and from 9:30 a.m. to 3:00 p.m. on Saturdays and Sundays. The system does not operate during school holidays. Maximum wait time is 2 min when the system is in the demand mode and 5 min when in the scheduled mode. Average wait time is 1 min in the demand mode and 2.5 min in the scheduled mode. Maximum vehicle speed is 30 mph, and average trip speed varies as follows, depending on the route:

	<u>mph</u>
Walnut--Engineering	19.1
Beechurst--Engineering	19.9
Beechurst--Walnut	10.9

Average trip time for a passenger for the full 2.1 mi trip between the Walnut and Engineering stations is 9.1 min in the scheduled mode, which includes 2.5 min wait time and 6.6 min riding time. Effective speed for that trip is 13.8 mph.

The system has demonstrated a capacity of 5,040 passengers per direction per hour. However, as currently operated, the actual capacity is 2,520 passengers per direction per hour.

During the nine-month period, October 1976 through June 1977, the vehicle miles totaled 435,653 and 1,308,936 passengers were carried. The total passenger miles were 2,286,950. The average load factor was 0.25.

Economic Data

Capital Costs

Capital costs for the MPRT have been reported;* a breakdown of capital costs, adjusted to 1976 price, is given in Table 31.

* N. D. Lea & Associates, "Summary of Capital and Operations and Maintenance Cost Experience for Automated Guideway Transit System" (October 1977).

Table 31

CAPITAL COST ESTIMATES: MORGANTOWN PRT

Hardware	
Vehicles	\$ 8,633,000
Control and Communication	13,394,000
Power and Utilities	2,708,000
Maintenance and Support Facilities	<u>1,057,000</u>
Total Hardware	\$25,792,000
Construction	
Guideway	\$19,135,000
Stations	2,548,000
Engineering & Project Management	<u>10,241,000</u>
Total Construction	<u>\$31,924,000</u>
Total Capital Cost	\$57,716,000

Operations and Maintenance Costs

The O&M costs are also published in the N. D. Lea & Associates report. The published breakdown for the nine-month period October 1976-June 1977 is as follows:

<u>O&M Costs</u>	
Labor	
Operations	\$105,977
Maintenance	246,205
Electricity	75,820
Gas for guideway heating	100,160
Materials and services	336,724
G&A	<u>118,258</u>
Total O&M	\$983,144

Estimated unit costs of O&M for the nine-month period are as follows:

\$2.26 per vehicle mile
 0.75 per passenger trip
 0.43 per passenger mile
 0.11 per capacity mile

To estimate annual O&M cost, the costs above are multiplied by 1.33 except for the guideway heating cost. The estimate of annual O&M cost is \$1,277,000.

Total Equivalent Annual Cost of Capital, Operations, and Maintenance

The total equivalent annual cost of capital is \$6,701,200, which includes \$3,310,200 for construction and \$3,391,000 for hardware.

The total equivalent annual cost of capital, operations, and maintenance is \$7,684,000 (see Appendix A).

The unit cost of service prorates the total equivalent annual cost of capital and operations and maintenance over four measures of service. The nine-month operational statistics, vehicle miles, passenger miles, and passenger trips are multiplied by 1.33 to obtain annual figures.

\$13.23 per vehicle mile
2.52 per passenger mile
4.40 per passenger trip
0.63 per capacity mile.

Energy Demand

Direct Energy

The MPRT uses both electrical power and natural gas. Electricity is supplied by the Monongahela Power Co. The average heat rate of this utility is 10,319 Btu/kWh. The latest available statistics indicate that the ratio of electricity generated to electricity sold in 1974 by the Monongahela Power Co. was 1.125--that is, about 12.5% of the electricity generated is lost, given away, or used by the company.* Btus per kWh delivered to the AGT system total 11,609.

The total electrical consumption for the nine-month period October 1976-June 1977 is reported to have been 2,361,000 kWh. Monthly records show that electricity use drops in warmer weather. The consumption for June was 194,000 kWh. Assuming that the consumption for July, August, and September of 1977 was 200,000 kWh/month, the annual electrical consumption is estimated to be 2,900,000 kWh. Power generated was 3,260,000 kWh. This is equivalent to 33.7 billion Btu of thermal energy or 231,000 gal of fuel oil. Unit electrical consumption is 5.0 kWh/car mile.

* Federal Power Commission, "1974 Statistics of Privately Owned Electric Utilities in the United States."

Gas is used to melt snow and ice. During the unusually severe winter of 1976-77, gas containing 55.1 billion Btu was burned to heat the guideway. This is equivalent to 378,000 gal of oil.

Table 32 summarizes the direct energy use of the MPRT.

Table 32

SUMMARY OF EQUIVALENT DIRECT ENERGY DEMANDS:
MORGANTOWN PRT

	Thermal Energy (Btu $\times 10^9$)	Equivalent Fuel Oil (gal $\times 10^3$)	Electrical Power (kWh $\times 10^6$)
Electric power			
Delivered to MPRT			2.90
Lost, used by company, or given away			0.36
Total generated	33.7	231	3.26
Natural gas	55.1	378	
Total	88.8	609	

Indirect Energy

Estimated O&M costs for a 12-month period, excluding direct energy costs, were \$1,277,000. This is taken to be equivalent to 56.1 billion Btu. For comparison, the ratio of indirect energy consumption to direct energy consumption is 0.63 to 1.

Capital Energy

The total capital cost of the system, at 1976 prices, was estimated to be \$57,716,000, which includes \$31,924,000 for construction and \$25,792,000 for hardware. These figures are multiplied by a factor of 43,900 Btu/dollar to yield the long-term average annual demands given in Table 33.

Table 33

LONG-TERM AVERAGE ANNUAL CAPITAL ENERGY DEMAND:
MORGANTOWN PERSONAL RAPID TRANSIT SYSTEM

	Total (Btu $\times 10^9$)	Service Life	Average Annual Demand (Btu $\times 10^9$)
Construction energy cost	1,400	35	40.0
Hardware energy cost	<u>1,130</u>	15	<u>75.3</u>
Total capital energy cost	2,530		115.5

Long-Term Average Annual Energy Demands

Estimates of annual energy demands are recapitulated in Table 34.

Table 34

SUMMARY OF ENERGY DEMANDS: MORGANTOWN PRT

<u>Demand</u>	<u>Annual Amount (Btu $\times 10^9$)</u>
Direct	88.9
Indirect	56.1
Capital	<u>115.3</u>
Total	260.2

Energy Intensity

System average energy intensities are shown in Table 35.

Table 35

ENERGY INTENSITY ESTIMATES: MORGANTOWN PRT

	<u>Direct</u>	<u>Indirect</u>	<u>Capital</u>	<u>Total</u>
Service per gallon fuel				
Car miles	0.96	1.51	0.736	0.326
Passenger trips	2.89	4.54	2.20	0.978
Passenger miles	5.04	7.92	3.86	1.71
Energy per car mile				
Btu	152,000	97,000	198,000	447,000
Energy per passenger trip				
Btu	50,500	32,100	66,100	148,700
Energy per passenger mile				
Btu	28,900	18,400	37,800	85,100
Energy per capacity mile				
Btu	7,200	4,600	9,500	21,300

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8 RECAPITULATION OF FINDINGS AND COMMENTS

The principal quantitative findings from the energy study of six AGT systems are recapitulated in Table 36. These data provide a potentially useful perspective and point of departure for planners considering possible future uses of AGT systems, but they should be used with care.

Readers are cautioned that the requirements, site conditions, and design objectives of the six AGT systems differ greatly among sites. Evaluations based on comparisons of energy intensities among sites should take all other differences into account. The data presented do not provide an adequate basis either for overall comparisons and evaluations of merits among existing AGT installations or for comparisons of specific AGT systems with alternative modes that might have been employed. Decisions regarding exploitation of these AGT systems were made in the past and evaluations of the quality of the decisions would have little if any utility. When future-oriented comparisons are to be made regarding AGT applications, accurate definitions are needed for all of the alternatives actually available to the decision-makers. Alternatives, when properly defined, will portray all relevant local requirements and site conditions and will include careful forecasts of future energy usage and related matters. When the needed groundwork has been done, it will be possible to make comparisons and evaluations that will be useful in decision-making.

We emphasize that the definition of alternatives to the exploitation of AGT systems will often have major impacts in other areas. Alternatives are not limited in scope simply to the exploitation of different kinds of transportation. For example, use of non-AGT systems at the three airport sites would have involved major changes in the designs of other facilities at the airport and would have had major impacts in other areas. In the most extreme case, exploitations of the AGT system at Sea-Tac allowed continued exploitation and growth of commercial air traffic at a site that was well located and already in a highly developed condition, whereas the best non-AGT alternative might have required moving commercial air operations to a more remote site and the construction of an entirely new facility. At Tampa exploitation of the AGT system was the dominant factor in the design of a highly innovative air terminal complex that has proved to be convenient for travelers, efficient for carriers, and highly successful. The best non-AGT alternative might have been to design a conventional air terminal providing less convenient service, perhaps at equal or even higher costs in money and energy. At Dallas-Ft. Worth, the concept of providing a passenger transportation system (manned or automated) was adopted in the early stages of planning to allow a terminal layout that involves extreme dispersal of facilities. Other layouts involving a high degree of dispersion could have been considered, based on either alternative AGT networks or use of conventional automotive

Table 36

RECAPITULATION OF PRINCIPAL QUANTITATIVE FINDINGS

	<u>Sea-Tac</u>	<u>Tampa</u>	<u>Busch</u>	<u>Fairlane</u>	<u>Dallas- Ft. Worth</u>	<u>Morgan- Town*</u>
Physical data						
Length of route	9,007 ft	3,566 ft	1.5 mi	2,600 ft	67,697 ft	2.1 mi
Number of vehicles	12	8	2	2	68 [†]	45
Number of stations	6	8	2	2	53 [‡]	3
Design capacity of vehicles	102	100	90	24	40	21
Average load factor (%)	9	6	41	79	n.a.	25
Service data per year						
Passenger trips (10 ⁶)	10.1	14.5	2.4	2.4	6.1	1.7
Passenger miles (10 ⁶)	3.6	2.5	1.6	1.2	n.a.	3.0
Vehicle miles (10 ³)	410.6	405	44	60.3	3.7	581
Direct energy per year						
Equivalent gallons of fuel (10 ³)	201	205	25	93	808	609
Btu (10 ⁹)	29	30	3.7	14	118	89
Total energy demand per year (Btu × 10 ⁹)	125	79	16	41	398	260
Energy intensity (total demand)						
Service per gallon of fuel						
Vehicle miles	0.48	0.74	0.41	0.21	1.36	0.33
Passenger trips	11.8	26.5	22.3	8.59	2.25	0.98
Passenger miles	4.21	4.5	14.9	4.06	n.a.	1.71
Energy per vehicle mile (Btu)	304,000	196,000	358,000	687,000	107,000	447,000
Energy per passenger trip (Btu)	12,400	5,500	6,500	17,000	64,800	148,700
Energy per passenger mile (Btu)	34,600	32,200	9,800	36,000	n.a.	85,100
Economic data						
Capital cost in 1976 dollars (10 ⁶)	34.6	14.3	4.6	6.1	80.9	57.7
Total equivalent annual cost of capital and D&M (10 ⁶)	4.5	2.2	0.6	1.1	12.3	7.7
Unit cost of service per passenger mile	1.29	0.88	0.38	0.57	n.a.	2.52

* Annual data are estimated from 9 months of experience.

[†] Includes passenger and utility vehicles.

[‡] Includes 14 passenger stations, 14 employee stations, and 25 utility stations.

vehicles. Therefore, comparisons of alternatives at Dallas-Ft. Worth would have required comparison of alternative airport designs, not merely comparison of alternative AGT systems or AGT versus conventional internal transportation systems. On the other hand, alternative modes of transportation, other than AGT, could readily have been used at Busch Gardens and Morgantown, and AGT versus non-AGT comparisons might have been sufficient for project evaluation. Fairlane represents another extreme. There was no compelling need for transportation service of any kind between the shopping mall and the hotel. Consequently, the "do-nothing" alternative could have been compared with employment of AGT.

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Appendix A

METHOD OF ESTIMATING ENERGY DEMANDS

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Appendix A

METHOD OF ESTIMATING ENERGY DEMANDS

Complete and dependable data on energy demands are difficult to obtain for both practical and theoretical reasons. Available data have been obtained and data gaps have been closed by methods explained below. These methods are not entirely satisfactory. More complete energy usage reports and improvements in energy-estimating procedures are needed for decisions regarding energy conservation in AGT applications.

Direct Energy

The AGT systems use electrical power, natural gas, and fuel oil. Reports on usage are not commensurate--fuel is reported in gallons consumed, natural gas is reported in British thermal units (Btus) of heating value, and electrical power is reported in kilowatt hours purchased. Consequently, common measures of energy consumption had to be devised to compare systems and to aggregate direct energy usage. The number of Btus was used as the primary measure. Because of concern over depletion of oil, the equivalent quantity of fuel oil was adopted as a second common measure. A method was developed for computing the approximate quantity of fuel oil that must be burned to produce and deliver the electrical power consumed. While some of the electrical power consumed came from coal, natural gas, nuclear, hydroelectric, and geothermal plants, SRI assumed that transfer of power among electrical systems would allow almost all reductions in electrical power consumed by automated guideway transit (AGT) systems to be realized as reductions in consumption of fuel oil. However, we recognized that this would not always be possible as in periods of low demand when oil-fired steam-generating plants of some systems are out of service.

Two statements of energy consumption were made for each system studied: equivalent gallons of fuel oil, and equivalent Btus. The heating values of fuels vary, but detailed data were not available. Generally, the heating value of fuel oil has been assumed to be 145,719 Btus per gallon based on a national average for the public utility industry. Heat rates of steam generating plants (in Btu per kWh) and losses and miscellaneous power usages in distribution have been obtained for local utilities supplying each site, where possible, but national averages for the public utility industry were used in a few cases. The national average factors are presented below.

CONVERSION FACTORS

Electrical Power:

1 kWh purchased by an AGT system	=	11,278 Btu 0.07739 gal fuel oil 1.076 kWh generated
1 gal fuel oil consumed at a steam- generating plant	=	145,719 Btu 13.90 kWh generated 12.92 kWh purchased by an AGT system

Published reports and internal documents have been surveyed to obtain information on quantities of energy purchased and used by AGT systems. The information obtained from AGT sites usually did not include energy used for heating, ventilating, air conditioning, and lighting of stations and shops and for operation of maintenance facilities. These demands were estimated by SRI staff members (see Appendix B).

Indirect and Capital Energy Demands

Two methods can be used to estimate indirect and capital energy demands. One is based on a detailed analysis of the types and quantities of materials and services required coupled with estimates of the amounts of energy consumed to produce a unit of each type of resource. This method is burdensome as it requires a body of accurate, detailed input data and the expenditure of substantial analytical effort, but it is, in theory, more accurate than the method described below.

The second method is simple and requires little effort. It employs cost data and a factor relating Btus to dollars of cost. The factor is computed by dividing annual consumption of energy in the United States by the gross national product (GNP). In 1976, U.S. domestic consumption of energy was 74.24 quadrillion (million billions) Btus and the GNP was \$1,692 billion.* The factor used for estimating the indirect and capital energy for 1976 was 43,900 Btus/dollar.

Before the factor can be applied, capital costs for hardware and construction costs must be escalated to 1976 dollars. This is accomplished by using three cost indexes: the Engineering News Record Construction Index (average of 20 cities) is used for construction costs; the Wholesale Price Index for machinery and motive products is used for hardware costs; and the Consumer Price Index is used for consulting and administrative services.

* Total energy consumption of the U.S. economy in 1976 was obtained from the Federal Energy Administration Monthly Energy Review; U.S. GNP for 1976 was obtained from the U.S. Department of Commerce Survey of Current Business (June 1977).

In calculating equivalent annual costs, a 10% discount rate and compound interest factors are used. The straight-line depreciation convention of accounting practice is used to distribute capital energy demands over the service lives of assets. The service life of the construction is assumed to be 35 years, and the service life of the hardware, 15 years.

The total equivalent annual cost of capital, operations and maintenance is the sum of the equivalent annual cost of capital and the annual cost of operations and maintenance.

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Appendix B

CALCULATING ENERGY CONSUMED BY BUILDINGS

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Appendix B

CALCULATING ENERGY CONSUMED BY BUILDINGS

The buildings associated with AGT systems (stations and maintenance areas) use energy for lighting and for heating, ventilating, and air conditioning (HVAC). A method for estimating these energy loads is described below.

The lighting calculation is based on the formula

$$\text{Illumination [foot candles (fc)]} = \frac{\text{lamp lumens (lm)} \times \text{CU}}{\text{area (ft}^2\text{)}}$$

where CU is the coefficient of utilization. The value of CU, which is dependent on the lamp fixture and room design is assumed to be equal to 0.5. Fluorescent lamps giving 72 lm/watt are assumed. The illumination level of the station areas is assumed to be equal to 20 fc; the maintenance areas are assumed to have a higher illumination level of 100 fc, as recommended in the Handbook of the Illuminating Engineering Society. The lighting load in watts/ft² is calculated from the formula

$$\text{Lighting load (watts/ft}^2\text{)} = \frac{\text{illumination (fc)}}{(0.5) (72 \text{ lm/watt})}$$

Results are 0.56 w/ft² for stations and 2.8 w/ft² for maintenance shops.

The calculations for heating and cooling loads are based on the concept of mean annual heating and cooling degree days* and the following formula:

$$\text{Annual heating load (Btu)} = \text{heat loss factor} \times \text{heating degree days} \times \text{area (ft}^2\text{)} .$$

*The degree day is a unit based on temperature differences and time. It is used in estimating direct energy demands and for specifying nominal heating and air-conditioning loads. For example, in winter, on any one day when the mean temperature is less than 65°F, there are as many degree days as there are Fahrenheit degrees differences in temperature between the mean temperature for the day and 65°F. The average number of degree days, both for heating and air conditioning, can be estimated for an entire year for any given site.

The heat loss factor is assumed to be equal to 14 Btu/ft²/deg-day for surface buildings and 8 Btu/ft²/deg-day for underground structures. To obtain the fuel requirement, the heating load is divided by the furnace efficiency, which is assumed to be 0.06.

The cooling load is estimated using eq. 3 by substituting cooling degree days for heating degree days and by dividing by the coefficient of performance of the air conditioning equipment, which is assumed to be 2.5. Because the answer is in Btu, it is converted to kWh by multiplying by the direct conversion factor 2.93×10^{-4} kWh/Btu.

Ventilating loads in the stations are estimated using a factor of 20 cubic ft/min (cfm) of air circulated for each person in the ventilated area. It is assumed that the ventilating fans require 0.5 W/cfm.

In the maintenance area, the ventilating load is calculated using a factor of 0.1 cfm/ft² of area.

Appendix C

CALCULATION OF ENERGY SAVINGS ATTRIBUTABLE TO REGENERATIVE BRAKING

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Appendix C

CALCULATION OF ENERGY SAVINGS ATTRIBUTABLE TO REGENERATIVE BRAKING

A regenerative braking system employs the vehicle motor as a generator, converts the kinetic energy of the vehicle to electrical energy, and returns the energy to the power rails. In this way, energy that would be dissipated as heat in friction brakes or in resistor banks (in the case of dynamic braking) can be reused, provided that a load that can use the power is connected to the power system.

It is possible to estimate the maximum possible energy savings attributable to regenerative braking by a calculation based on kinetic energy and assumptions regarding efficiency. The calculations are illustrated by an example.

A vehicle weighing 15,000 lb (6,818 kg) is braked to a stop from 25 mph (11.18 m/sec.). Its kinetic energy prior to braking is given by

$$K = 1/2 mv^2 = 1/2 (6,818) (11.18)^2 = 426,100 \text{ watt-sec.}$$

The kinetic energy is converted to kWh by dividing by 3,600,000, which gives $K = 0.118 \text{ kWh}$. At 100% efficiency all the kinetic energy of the vehicle would be recovered, and 0.118 kWh of electrical energy would be returned to the power rail by a regenerative braking system each time the vehicle stopped from 25 mph. In practice, the recoverable kinetic energy probably does not exceed 30% because of numerous factors, such as vehicle drag while stopping and inefficiencies of motor and electrical circuits. Therefore, a more realistic estimate is 0.035 kWh.