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ASSESSMENT OF OPERATIONAL AUTOMATED GUIDEWAY SYSTEMS— AIRTRANS (PHASE I)

U.S. Department of Transportation
Transportation Systems Center
Kendall Square
Cambridge MA 02142

SEPTEMBER 1976
FINAL REPORT

Prepared for

U.S. DEPARTMENT OF TRANSPORTATION
URBAN MASS TRANSPORTATION ADMINISTRATION
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15. Supplementary Notes

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16. Abstract

This report presents the results of an evaluation study of AIRTRANS, a unique, automated guideway system located at the Dallas/Fort Worth Airport. AIRTRANS was designed to move passengers, employees, baggage, mail, trash and supplies. The newest and largest system of its type in the world, it comprises 13 miles of single lane guideway and 68 vehicles, and serves 53 stations at different points in the airport complex. The system is one of the first intra-airport transit systems conceived, designed and constructed as an integral part of the airport development.

The study, conducted with the cooperation of the Dallas/Fort Worth Regional airport and the Vought Corporation, was intended to codify the information and experience gained in the planning, development, implementation and initial operation of the system into an integrated body of knowledge from which those concerned with any phase of future, similar system planning and implementation could profit.

The assessment team found AIRTRANS an impressive accomplishment. As a pioneering project, AIRTRANS did not have an extensive data base to build on, and consequently some problems arose attributable to insufficient system planning, analysis, organization and specification, as well as optimism about schedules and component reliability. Considering this, AIRTRANS is impressive and commendable but it could be more efficient and effective and is being constantly improved towards these goals. The report provides information useful to planners, designers, developers and operators of automated transit systems for intra-airport and other applications.

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PREFACE

This report describes the first phase of an assessment conducted by the Transportation Systems Center (TSC), in conjuction with the MITRE Corporation, of the Airport Transportation System (AIRTRANS) at the Dallas/Fort Worth Regional Airport. The project was funded by the Department of Transportation Urban Mass Transportation Administration (UMTA) through its Office of Research and Development, Socio-Economic and Special Projects Division, as part of UMTA's Automated Guideway Technology (AGT) Assessments Program. The work reported here was performed over the period March 1975 through March 1976. It consisted of a review of technical reports, several on-site inspections of the system, and technical interchanges with personnel from the developer, (Vought Corporation), the Airport Board (APB), and the Airlines Advisory Board (AAB). Material in this report has been reviewed by the Vought Corporation and by the Dallas/Fort Worth Airport Board Staff. A follow-up assessment is planned after additional subsystems become operational and improvements are made.

Four references were particularly valuable in the study. They were:

"AIRTRANS Revenue Operation Level Report", Engineering Department, Dallas/Fort Worth Airport, December 1974.

"AIRTRANS Performance Analysis Report", Vought Corporation, February 1975.

"AIRTRANS: Intra-Airport Transportation System", Austin Corbin, Jr., Vought Corporation SAE Paper #730384, Air Transportation Meeting, Miami, Florida, April 24-26, 1973.

"Performance Specifications for AIRTRANS at the Dallas/Fort Worth North Regional Airport", March 15, 1971.

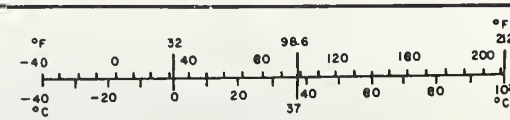
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	36	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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EXECUTIVE SUMMARY

This report presents the results of an assessment, conducted by the U.S. Department of Transportation, Transportation Systems Center, of the Airport Transportation System (AIRTRANS), developed by the Vought Corporation and designed to provide intra-airport transportation of passengers, baggage, supplies, mail and trash at the Dallas/Fort Worth Regional Airport.

The assessment was sponsored by the Urban Mass Transportation Administration for the purpose of gaining a better understanding of the capabilities and limitations of Automated Guideway Technology (AGT) systems. The more specific purposes of this assessment were to:

a) Obtain engineering, economic, system performance and public response information which can be used for planning future AGT systems.

b) Determine the feasibility of joint passenger and goods movement on transit facilities.

c) Provide information to urban planners on the applicability of AGT systems to their environment, and

d) Identify lessons learned during the design, development, and implementation of such systems.

AIRTRANS presently provides service between four passenger terminals, two remote parking areas, a hotel and the maintenance area. It was designed to move passengers, employees, baggage, mail, trash, and supplies, although only the passenger and supply services were in operation at the time of this study. It employs 68 rubber-tired vehicles and serves 53 stations on a 13-mile guideway. Electric motors provide propulsion, and a fixed-block control concept is used for train protection. The innovative four-wheel steering of AIRTRANS has been combined with a Vought-developed switch that uses wayside and on-board elements to provide positive guidance. This allows headways down to 18 seconds. Another innovative feature is the automatic train-control equipment which combines conventional train control equipment and modern digital computers for vehicle detection, communication and control functions.

AIRTRANS was conceived, designed, and constructed as an integral part of the airport development process, and opened for service concurrently with the airport, in January 1974. The overall process was accomplished in two and one-half years for a total contract price of $41 million.

In the evolution to system operation, there were problems attributable to insufficient system planning, analysis, organization and specification, as well as optimism about schedules and component reliability. Most of these problems have been solved, an especially commendable accomplishment in view of the fact that AIRTRANS, a pioneering project, did not have an extensive data base to build on.

The major findings and conclusions of this assessment are set forth below:

- Despite early start-up difficulties, AIRTRANS is now operating successfully. The system is in service 24 hours a day, seven days a week.

In its first two years of operation, AIRTRANS carried over 5.6 million passengers, and accumulated over 6.4 million vehicle miles, without any major accidents or fatalities, although two workmen have been injured by a vehicle when working in the guideway. During the period beginning mid-March of 1975, continuing to system shutdown in September, AIRTRANS logged 1.6 million operational miles over 195 days without a system failure that required using the bus backup system.

- AIRTRANS is the largest and one of the most complex AGT systems in the world. The complexity of the system is evidenced by the fact that it makes 16,212 passenger station stops per day, and calls, with the full system operating, 92,600 switches per day.

AIRTRANS passenger service and supply service have met the needs of the airport. These were the only two services in operation during the assessment period. Since March 1976, employee service has been successfully initiated. The other services have been operated and tested in a non-revenue mode, and the available data indicate that all systems are potentially operational. Since all parts of the system have not actually operated together in revenue service, no assurance of overall operational effectiveness can be given.

- Airport service requirements are more stringent than those found in typical urban areas.

At Dallas Fort Worth airport, the same level of passenger service is required over 24 hours a day with maximum allowable transit times specified on all routes. There is a continuing demand for service throughout the day requiring extensive usage of the assigned vehicle fleet, and hence, making scheduled maintenance for the fixed portions of the system very difficult. Equipment durability and scheduled maintenance have to be high to satisfy this type service demand. Schedule dependability, to insure timely airline and interairline connections, requires very close tolerances to be maintained on train intervals. In typical urban areas, more delays due to failure may be tolerable throughout the day, especially during off-peak periods, resulting in less stringent train interval tolerance requirements.

- Further technical development is necessary to make AIRTRANS suitable for urban applications.

Specific areas for development include vehicle guideway interaction, guideway construction, power control, brakes, voice communication systems, vehicle controls, high-speed switching, vehicle materials, and improved maintenance. Regenerative braking and solid-state electronics for selected components should be considered for energy conservation.

Flexibility of operational modes should also be considered to meet demand variations throughout the day. A higher maximum speed capability would be required to meet passenger flow rates of many cities. The more adverse weather conditions of many urban centers would necessitate an improved traction and de-icing capability. Finally, there is a definite need for uniform standards and guidelines in such areas as equipment reliability, safety, security, noise, ride comfort and reliability/availability acceptance standards for the effective implementation of such systems in urban applications.

- Use of a "life cycle costing" approach to system design should be implemented. Advantages of this approach over the "low capital investment approach" used in AIRTRANS can only be evaluated over a longer period of time as actual Operations and Maintenance (O&M) costs are tabulated and analyzed. Continuing operational cost and reliability monitoring would be of benefit to all concerned with new forms of transportation.

- A system like AIRTRANS, intended to be integrated into the total passenger and goods flow activity of a major activity center, must be an integral part of the total facility planning.

The assessment of AIRTRANS supports the need for complete and detailed planning (including analysis of alternative systems), during the preparation of system specifications to ensure a solid foundation for system implementation. The analysis must be continually updated during the development process to reflect changing needs and perceptions. All parties (developer, buyer, and prime users) must be continuously aware of the implications and interactions resulting from the early design effort.

- With new transportation system developments employing elements of advanced technology, problems may be expected and therefore specific contracting methods should be employed to assure performance with a minimum of disputes.

Using a single, fixed-price contract to simultaneously procure several steps of a new product development has and will continue to have shortcomings. For future implementation programs, consideration should be given to other contract methods, such as a staged performance and cost contract phased to coincide with development of the product.

- The capital and operating costs of new developments of this complexity are not precisely predictable until a substantial portion of the development has been completed.

The capital and operating costs of AIRTRANS were initially underestimated. Some portion of the actual capital costs incurred is attributable to higher-than-anticipated inflation and unpredicted development expenses. Other unexpected cost increases reflect unplanned delays resulting from other airport construction, as well as unfounded optimism about off-the-shelf hardware and construction techniques. Initial O&M costs exceeded the originally estimated costs; however, as system reliability has improved, the O&M costs have decreased, and it is anticipated that further decreases will occur.

For example, during the assessment period, the O&M work force was decreased some 15 percent. Additional engineering product improvements are being made to further increase component and system reliability, while reducing the maintenance costs. Recent data show that the system operating and maintenance cost is $0.68 per vehicle mile.

- The development, deployment and test schedule must be realistically scoped in terms of the maturity of the system being purchased.

The AIRTRANS system was, at contract initiation, largely a conceptual product requiring detailed engineering design, fabrication and test; yet the schedule was predicated on "airport opening" and not related to the time it would actually take to put the system into revenue service with high system reliability. As such, many desirable studies, developments and tests which might have reduced the number of early operational problems were eliminated. Instead, heavy reliance was placed on conservative approaches, and minimally adapting existing commercial components and approaches. In the "new environment", some of these components or approaches did not perform as planned, requiring extensive redesign after the system was placed into actual service. This procedure contributed to the developer's cost overruns and helped create some of the early user dissatisfaction.

The developer initially felt that standard, off-the-shelf hardware (from different applications) with limited or selected quality assurance and test provisions could be successfully integrated into a complete system, with minimal difficulty. Such was not the case, and many reliability problems were experienced during the early months of operation which, in turn, occasioned considerable redesign.

More extensive testing, additional quality-assurance provisions, and completion of the planned system testing at an off-line track facility prior to revenue operation might have eliminated many such failures. In an urban application in which maintenance access to the system would be more difficult, such testing is even more important.

While testing at an off-site test track is very useful in terms of establishing the proof of a concept and detecting many early reliability problems, there are many site-specific problems which simply cannot be anticipated at a test track. Hence, testing in the actual guideway configuration for a period of non-revenue-service time is also necessary. The step to revenue operation is a large one and its problems must not be underestimated.

1. INTRODUCTION

1.1 BACKGROUND

This report describes a study made by the U.S. Department of Transportation, Transportation Systems Center (TSC) of the automated guideway system, designated AIRTRANS, serving the Dallas/Fort Worth Regional Airport. The system transports airline passengers, employees, baggage, supplies, mail and trash; it was developed by the Vought Corporation.

The work was conducted under the auspices of the Urban Mass Transportation Administration (UMTA) which is sponsoring studies of existing and in-process automated guideway systems for possible application to a wide range of urban activities. The purpose of such studies is to obtain factual experience data to help planners, policy makers, technical implementers and operators associated with such future systems. It is hoped the information will help future efforts to profit by the accomplishments as well as the problems of current system endeavours.

The work is also intended to assist UMTA in decisions and actions concerned with encouraging and providing financial assistance to such programs.

1.2 SCOPE

Section 2 of this report gives a general description of the AIRTRANS Systems, and major elements such as the network, guideway, power distribution, vehicles, controls and utility systems.

Section 3 provides an assessment of the system performance, covering service requirements and how they are met by the system. Reliability, maintainability, availability, safety and security aspects of the system are described as well as passenger interfaces such as ease of access, ease of use, and comfort factors (ride quality, etc.).

Section 4 provides technical subsystem assessment, covering hardware and the control/communication subsystems.

System economics, including capital and operating costs, are covered in Section 5.

System Development management, describing the project evolution and both APB and Vought Corporation management approaches, is the subject of Section 6.

Section 7 gives the Assessment Team's overall evaluation of the AIRTRANS System, and Section 8 lists the Team's suggestions and recommendations for consideration by Government, planners, implementors and operators of future AGT systems.

2. AIRTRANS GENERAL DESCRIPTION*

2.1 GENERAL PARAMETERS

The AIRTRANS facility at the new Dallas/Fort Worth Regional Airport is designed to carry passengers and employees (in separate cars), transport all interline baggage and mail, remove all trash from the terminals to a common incinerator, and deliver commissary supplies from a common warehouse to the terminals. At the time of this study the passenger and supply services were in revenue operation. For various reasons the mail, employee, baggage and trash services were not in revenue operation, although the employee service was operating as of the spring of 1976. A typical vehicle and a typical view of the guideway are shown in Figures 2-1 and 2-2.

The prime system level design requirements of AIRTRANS were as follows:

1. 20-minute trip time for interline transfers.
2. 30-minute trip time for remote parking travel.
3. 30-minute for interline baggage movement. (Inadequate for the present desires of the airlines).
4. 30-minute mean time to restore system to operation.
5. 500-hr mean time between failure/vehicle (vehicle failures affecting movement and control).
6. 30-year design life (20 years on vehicle).
7. Expandable to meet future needs.

AIRTRANS is a fully automatic system. It has 13 miles of guideway, 53 stations, an operational maintenance facility, 68 vehicles plus 13 gasoline powered tugs, and a central control point to provide surveillance and emergency override (when the action is safe) over the automatic operation. Automatic container handling equipment is also included in the airlines operations area. Table 2-1 summarizes the AIRTRANS general characteristics.

* This section draws heavily on AIRTRANS: Intra-Airport Transportation System, Austin Corbin, Jr., Vought Corporation, SAE 730384, Air Transportation Meeting, Miami, Florida, April 1973.

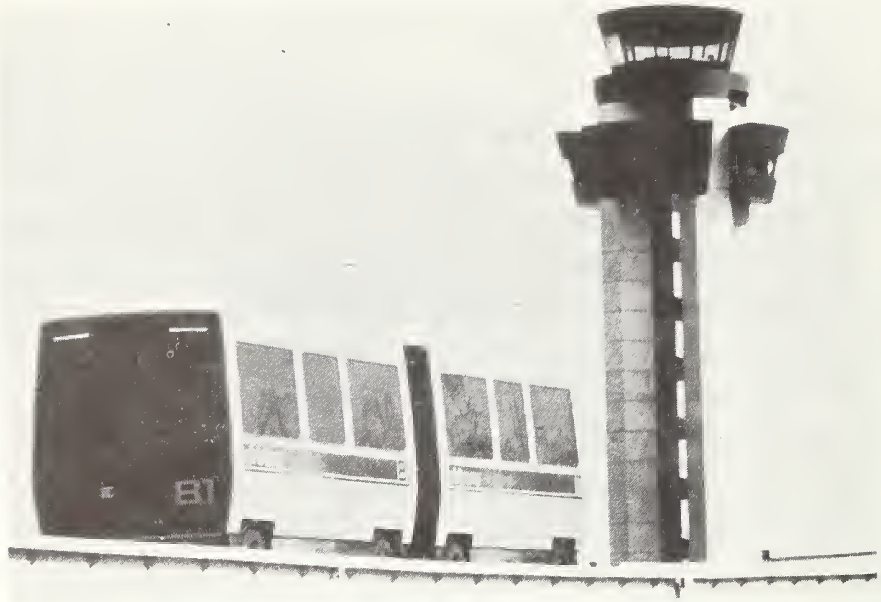


Figure 2-1 AIRTRANS Two-Vehicle Train

Figure 2-2 AIRTRANS Elevated Guideway

Table 2-1 AIRTRANS Principal Characteristics

Length of guideway	13 miles (single lane)
Passenger stations	14 (10 off-line, 4 on-line)
Employee stations	14 (10 off-line, 4 on-line)
Utility stations	25
Lead passenger vehicles	30
Trail passenger vehicles	20
Utility vehicles	17
Switches	33 diverge + 38 converge
Control blocks	708
Operating speed	17 mph
Minimum headway	18 sec @ 25 ft/sec
Min. switch time (including verification)	3 sec
Deceleration (max. emergency)	7.2 ft/sec^2 loaded 10.5 ft/sec^2 empty
Deceleration (max. service)	3.75 ft/sec^2
Jerk	2.5 ft/sec^3
Maximum passenger trip time (intra-terminal)	20 min. 30 min. to remote lots
Seating capacity of vehicles	16
Vehicle seating/ standing capacity	40
Vehicle diagnostic checkout time in placing vehicle into automatic mode after power removal (performed in maintenance area only)	approx. 10-20 min.
Number of containers for utility service	179

Voice communication ability with one or all passenger vehicles

TV surveillance in passenger and employee station areas only

Emergency stop function controlled automatically

Automatic wash facility for vehicles.

2.2 AIRTRANS NETWORK

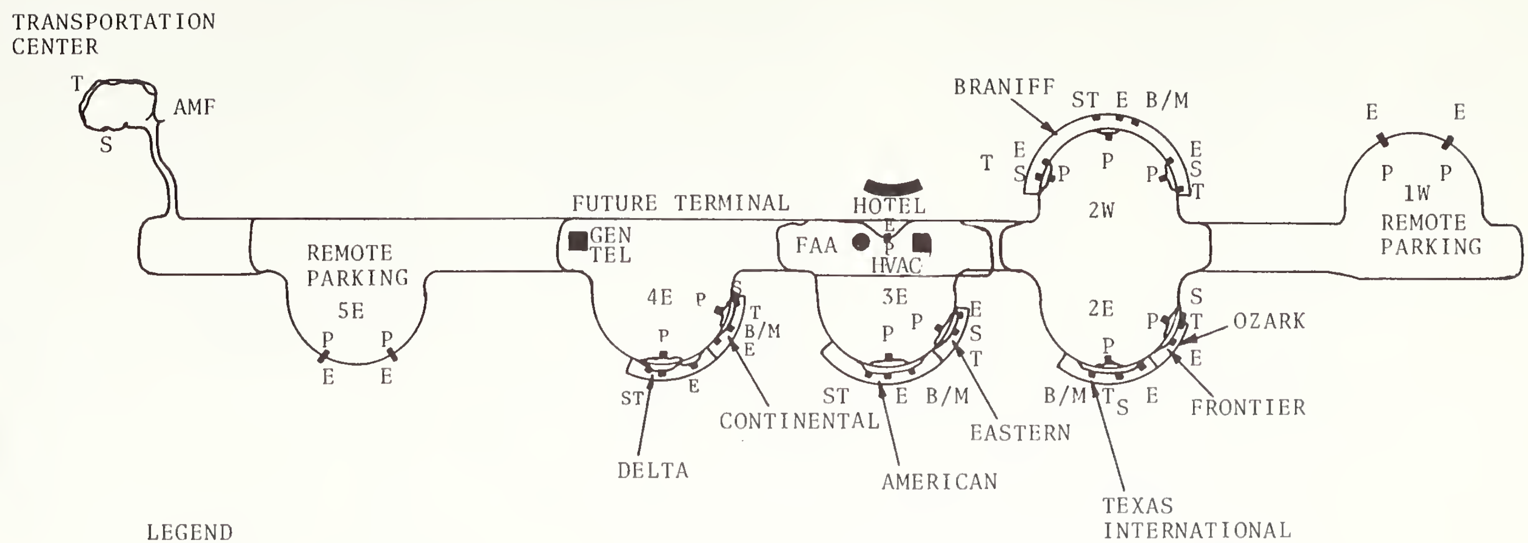
The total guideway system (See Figure 2-3), completed in 1973, is 67,697 ft. (13 miles) long. It stretches from the remote parking lot on the north to the remote parking lot and Transportation Center on the south, a straight-line distance of 3.2 miles. Vehicles travel over this guideway on a series of dedicated routes. There are five routes for passengers, four for employees, two for trash, and two for supply, (Figure 2-4), four for baggage, and two for mail (Figure 2-5). These routes overlay each other, to form the complete guideway. A vehicle will stay on its own route, taking the proper direction at the switches, unless rerouted by central control.

AIRTRANS serves a total of 53 stations at the airport, including passenger, trash, supply, baggage, and mail stations.

The passenger stations and waiting rooms, on a single siding, feature a glass-enclosed platform with bi-parting doors which open with vehicle doors when the vehicle has come to a stop, and has leveled itself to the station platform. The passenger station contains the fare collection turnstiles (25¢ fare), route map graphics above each door which automatically display the destination of the vehicle at the station, a system route map, TV surveillance cameras whose picture is displayed in Central Control, a public address system, and seats. Two doors are in the initial installation, with provisions for a third when and if three-car trains are added to the system.

The employee station is across from the passenger station on a separate siding and is screened from the passenger station. An open platform station is provided. It contains the destination graphics, TV survellance cameras and a public address system. Employees' trips are paid on a lump-sum basis.

The stations at the north and south parking lots are the only on-line stations, as the vehicle traffic there is low. Passengers enter on the left and employees on the right, in the direction of traffic. The equipment arrangement is similar to that in other



LEGEND

P PASSENGER STATION

E EMPLOYEE STATION

B/M BAGGAGE AND MAIL STATION

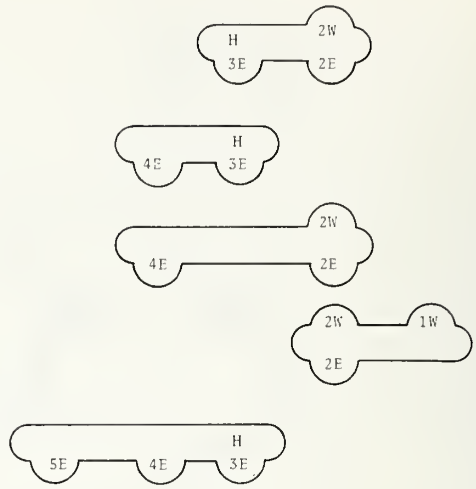
T TRASH STATION

S SUPPLIES STATION

Figure 2-3. AIRTRANS Guideway and Station Layout

ROUTES	VEHICLES AND STATIONS
1	PASSENGER
2	PASSENGER
3	PASSENGER
5a + 5b 4	EMPLOYEE PASSENGER
6 7a + 7b	PASSENGER EMPLOYEE

GUIDEWAY*

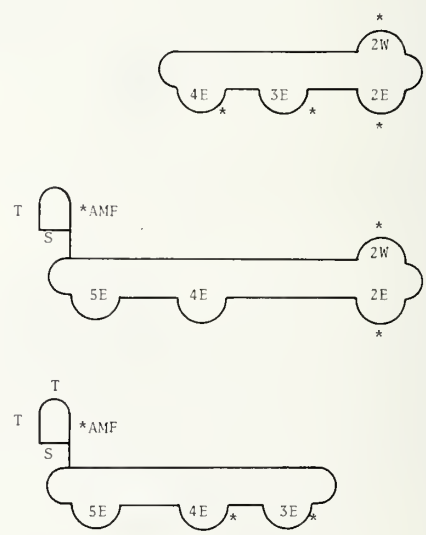


*PASSENGER VEHICLES USE THE INSIDE ROUTE THROUGH TERMINALS. ALL OTHER VEHICLES USE THE OPPOSITE (OUTSIDE) ROUTE OF THE GUIDEWAY THROUGH TERMINALS.

Figure 2-4. AIRTRANS Passenger Routes

NO. OF ROUTES	TYPE
4	INTERLINE B/M
1 1 1	AMF MAIL TRASH SUPPLY
1 1 1	AMF MAIL TRASH SUPPLY

GUIDEWAY



*DENOTES STATION STOP.

Figure 2-5. AIRTRANS Baggage and Mail Routes stations. The hotel station is an elevated station having a single siding.

2.3 GUIDEWAY

The AIRTRANS guideway is an 8 inch thick, reinforced concrete slab with 6 inch thick parapet walls, 24 inches high. The interior width of the guideway is 98 $\pm$ 1/2 inches. All surfaces are constructed to interstate highway standards of smoothness and surface tolerance. At grade, the concrete rests on 2 inches of asphalt which is on 12 inches of lime-stabilized soil. On elevated sections (20 percent of the guideway is elevated) the base is precast, prestressed beam which is fabricated off-site and placed on prepared columns at the site. The parapet wall is added after the beam is in place, to form the complete elevated guideway.

2.4 SWITCH

The switch, a Vought-developed system, is a fast-acting guideway switch which can divert the vehicles to a siding or permit them to go straight through. It consists of a movable "blade" and a fixed, entrapping rail attached to the top of the parapet wall. Depending on the position of the movable section, entrapping wheels on the vehicle cause the vehicle to be steered in the proper direction. The vehicle cannot split the switch as it is entrapped throughout the switch area. The switch actuator is a railroad mainline automated switch machine which is rugged, dependable, and fail-safe. The operation of a typical guideway switch is shown in Figure 2-6. The entrapment rail and wheels are shown in Figure 2-7.

The converge (merge) switch rails are not power operated. They are mounted on top of the parapet wall and supported at two points. The switch rail "normal" position is controlled by a strap

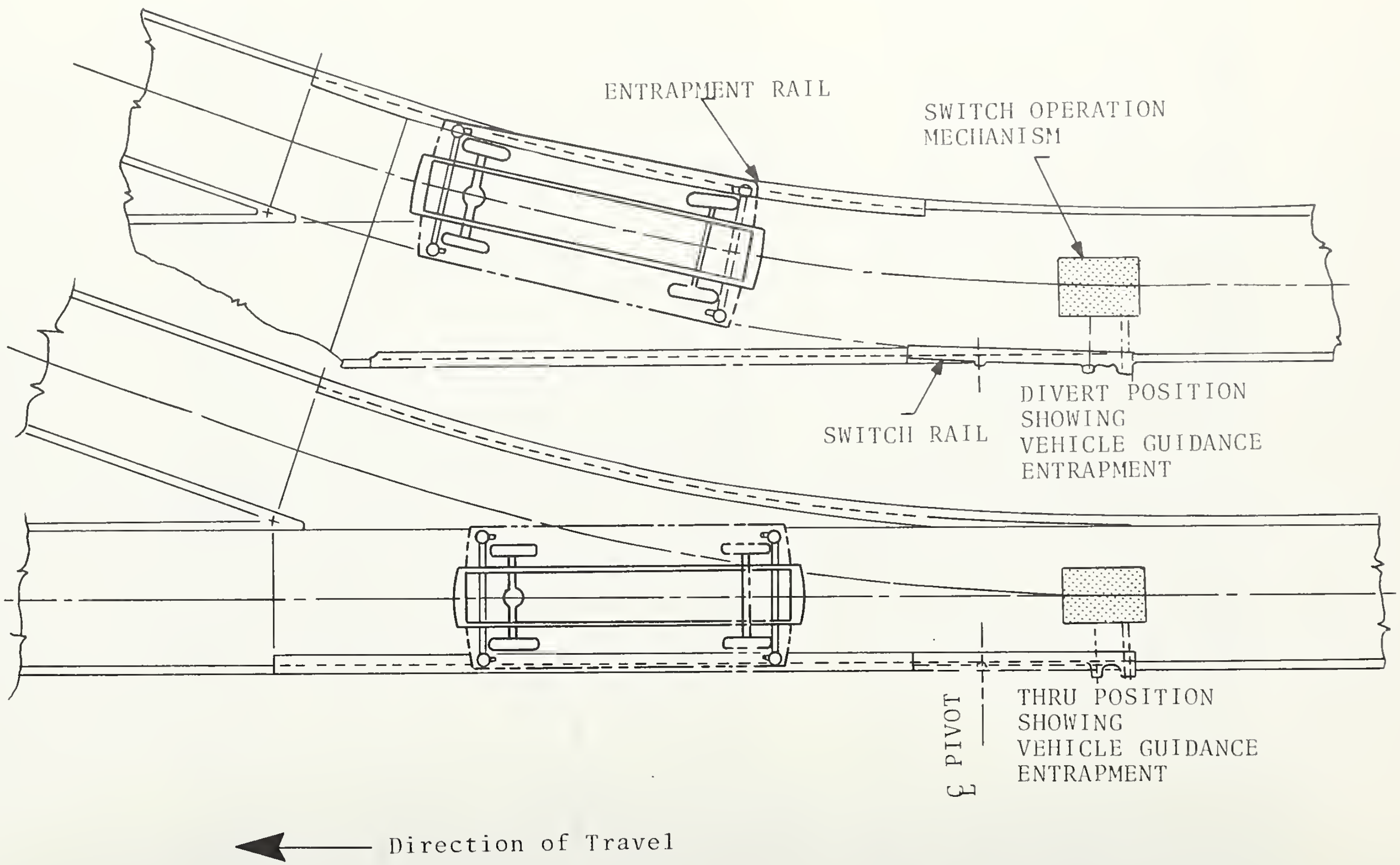


Figure 2-6 Typical Guideway Switch Operation

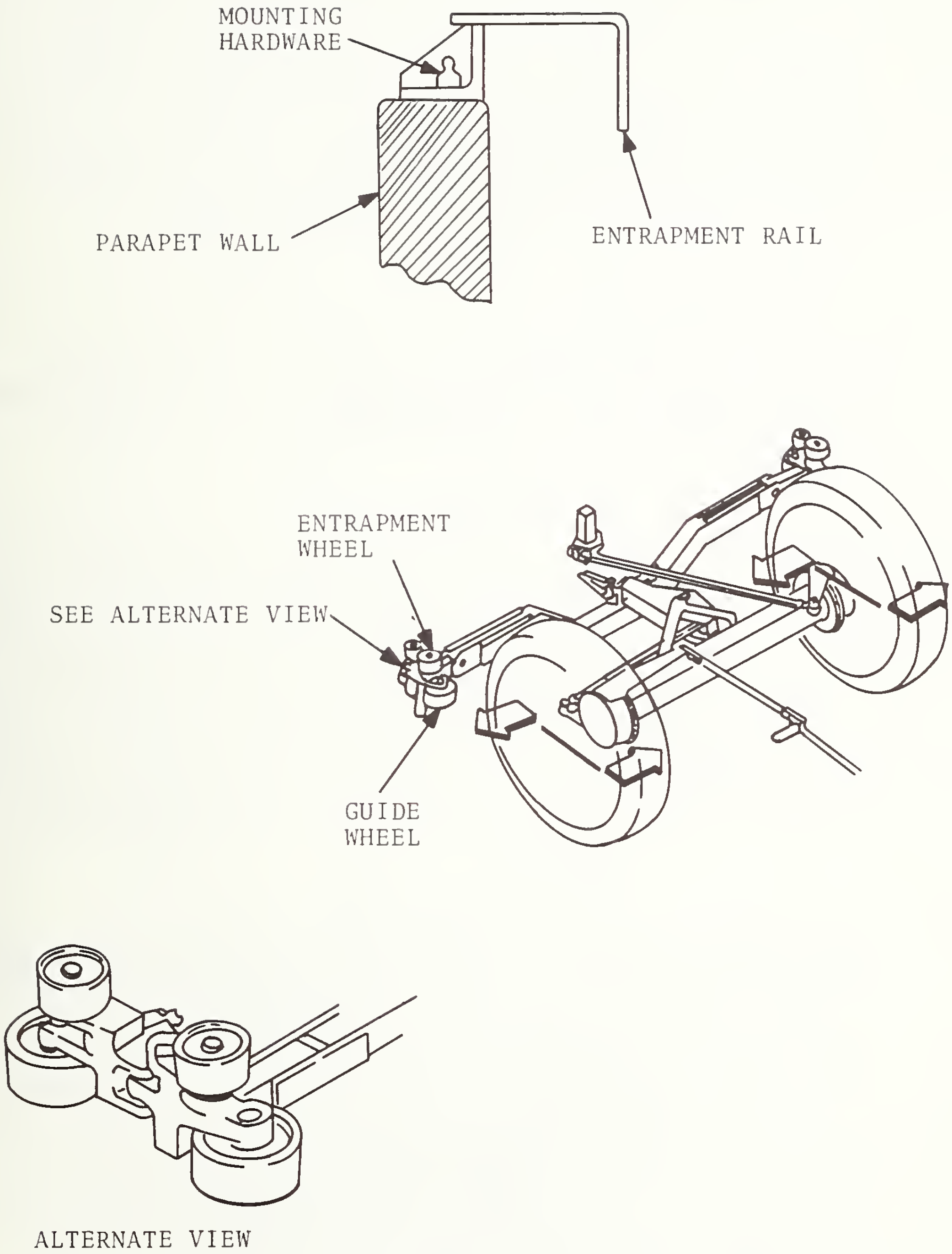


Figure 2-7 Entrapment Rail and Wheels

spring having one end attached near the pivot support and the other end resting on a roller so that the switch is spring-loaded to the "through" position. For through vehicles no switching takes place. A vehicle coming out of a siding and entering the through line will push the switch rail aside (against the force of the strap spring). After the vehicle has gone through the switch, the strap spring will bring the rail back to the through line position.

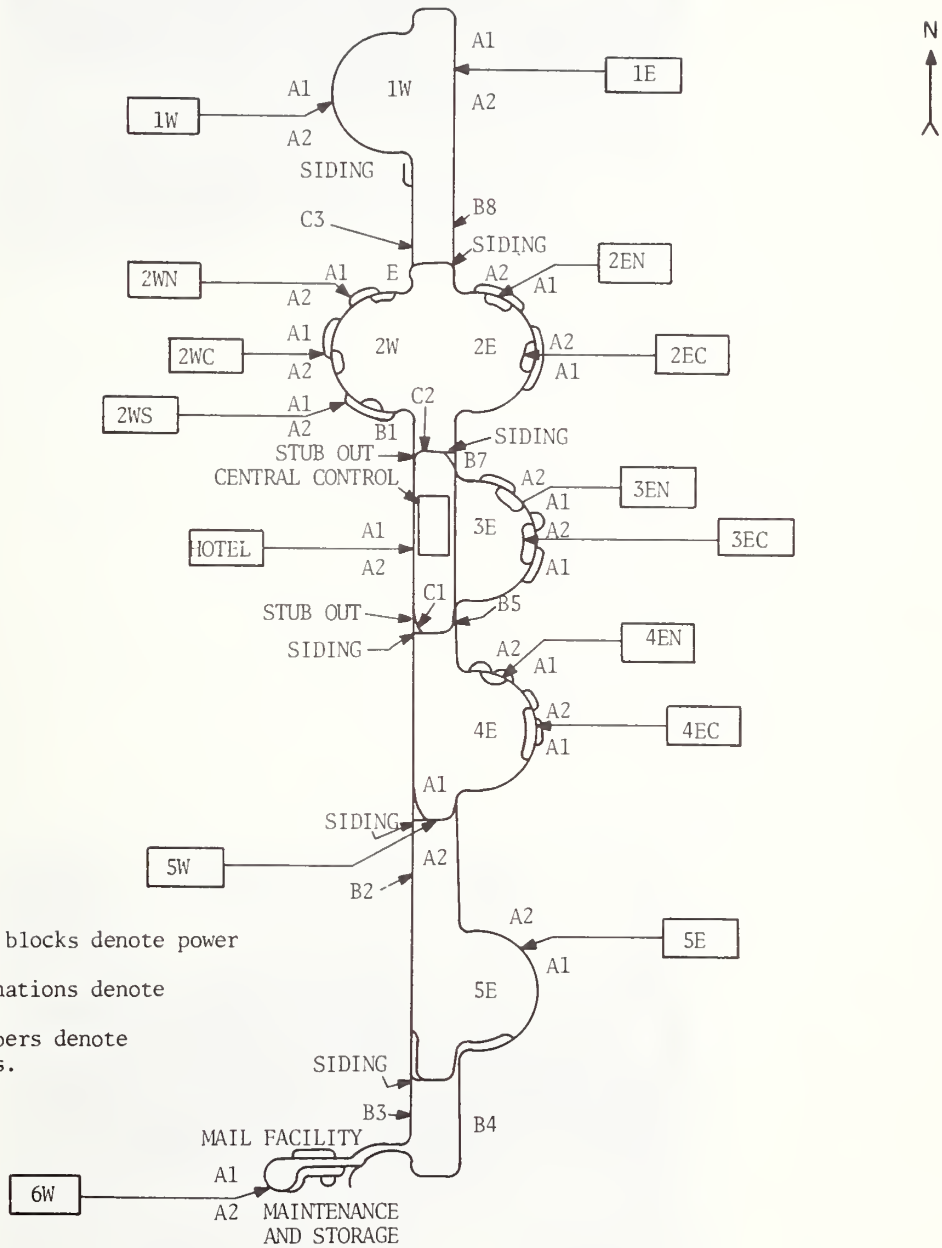
2.5 POWER DISTRIBUTION

Electric power is distributed to the vehicle from 15 substations strategically located around the airport. Each substation serves a section of the guideway. Figure 2-8 shows the power substation locations.

Three phase, 480 volt electricity is supplied to the vehicles through three copper-clad steel rails. The three power rails are recessed to prevent inadvertent contact by someone working on the guideway. Rails are mounted on one side of the concrete parapet wall on plastic insulators. They are mounted on both sides of the guideway in switch areas where the vehicle moves away from one wall. In addition, a protective cover is placed above the signal rail, covering the gap between the rail face and the concrete parapet.

2.6 VEHICLES

Typical AIRTRANS personnel, utility, and service vehicles are shown in Figures 2-9 through 2-12. The 51 personnel vehicles and 17 utility vehicles use a common chassis type and the same basic controls. The passenger and employee vehicles are identical except that they are inserted oppositely into the guideway to provide for the door on the right or left, corresponding to the location of the employee or passenger stations, which are on opposite sides of the guideway. The vehicle is 21 feet long, 7 feet wide, and 10 feet high. It has an empty weight of 14,000 lbs. In addition to the bi-parting entrance door, each end of the vehicle has an emergency exit. Exterior panels are acrylic-coated fiberglass with colors impregnated in the acrylic.



Notes:

1. Designations in blocks denote power substations.
2. Encircled designations denote guideway areas.
3. A, B, and C numbers denote circuit breakers.

Figure 2-8 Power Substation Locations

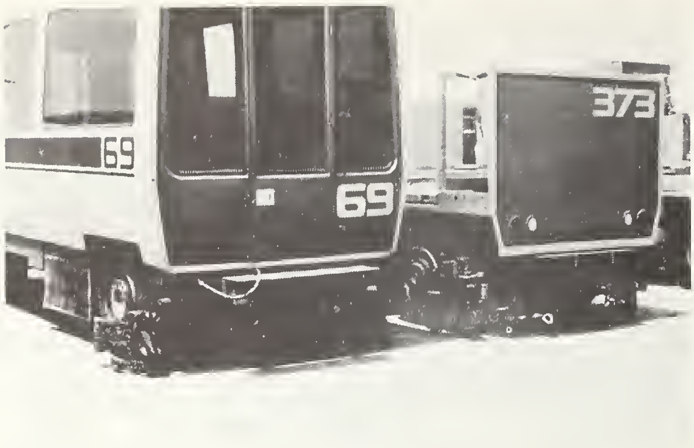


Figure 2-9 A View on a Passenger Vehicle and a Utility Vehicle

Figure 2-10 Utility Vehicles

Figure 2-11 Vehicle Undercarriage

Figure 2-12 Motorized Tug

The total passenger capacity is 40: 16 people seated and 24 standing. The floor is carpeted and the seats are upholstered. The vehicle contains a public address system, two-way voice communication equipment, and an on-board automatic station announcement system. Vehicle controls are located under the carry-on baggage rack. The vehicle chassis is a welded structural steel frame. Axles are standard automotive truck type, one of which is driven through a differential. The axles are attached to the vehicle through an air-bag suspension system. The wheels have foam-filled rubber tires, size 8.25x20.

Propulsion is by a 60-hp (continuous rating) DC motor connected to the differential by an automotive drive shaft. The 480 VAC power is rectified and controlled by the motor controller. The propulsion system is mounted on the chassis, as is the emergency storage battery. The alternator that charges the batteries and an air compressor for the suspension system, door operator, brakes, and vehicle dock leveling system are suspended below the chassis. Two heating and air-conditioning units are also suspended below the chassis, one on either side. There is a nominal 5 tons of air conditioning capacity.

Steering is accomplished with eight (4 front, 4 rear) 6-inch diameter polyurethane guidance wheels which are fixed to a guide bar connected to the steering linkage. The front tires are linked to the rear tires, so tread-over-tread tracking takes place. As the front tires steer in one direction, the rear tires steer in the opposite direction. The steering mechanism is directional so a steering reversing mechanism is provided for reverse vehicle operation.

Power collection is performed by articulated brushes, a set on each corner of the vehicle, with two sets in normal use and two for redundancy.

A vehicle bumper permits non damaging impacts at speeds up to about 5 mph. A draw bar and umbilical allows two-car trains to be operated.

The 17 utility vehicles have chassis identical to that of the passenger vehicles. The car body consists of a powered flat-top conveyor bed and framework. The utility vehicle also contains specialized controls to interface with the cargo system.

2.7 CONTROLS

The automatic control system is divided into three subsystems: (1) Automatic Vehicle Protection (AVP), (2) Automatic Vehicle Operation (AVO), and (3) Central Control (CC). These functions are summarized in Table 2-2. Components of the AVP and AVO are located both on the vehicle and in the wayside control rooms. All vehicles may be driven manually by using a plug-in unit which overrides the AVP and AVO systems.

The conventional block system is used with vital relays both on-board and on the wayside. Track circuits are 48 volts, DC. A minimum headway of 13.3-15 seconds is feasible (See Appendix, Sec. B-2), but it is normally much greater than this, because one of the main functions of the central computer bunch control system is to spread vehicles out on the route. Computer failure will allow vehicles to bunch, but not to collide, for this factor is entirely separate from the computer and software; and insulated track blocks are hardwired to vital relays. Central computer failure will eliminate the anti-bunching control, the central control graphics, and the failure management system - at least the automatic reporting part of it. Yet, the vehicles will continue to run and to protect themselves from collision.

There are two signal rails utilizing conventional block signal techniques; one mounted above and one below the three power rails. Blocks are formed by isolating sections of the upper rail, and the lower one is grounded. The vehicle bears a shunt.

Vehicle route information is stored in an on-board control logic assembly. This device responds to an interrogation from the wayside every 0.2 seconds and sends back route information as well as malfunction information. The wayside controls decode the route information and set the switches to the proper position. The proper

TABLE 2-2 AIRTRANS CONTROL AND COMMUNICATIONS SYSTEMS

1. AUTOMATIC VEHICLE PROTECTION (AVP)
   - Assures safe train spacing
   - Safe switching
   - Speed limits
   - Vehicle safety systems

2. AUTOMATIC VEHICLE OPERATION (AVO)
   - Route control
   - Position stopping
   - Door controls
   - Speed controls

3. CENTRAL CONTROL (CC)
   - System status monitoring
   - Supervisory controls
     - (a) Speed commands
     - (b) Switch positioning
     - (c) Route changes
     - (d) Bunch control
   - Station monitoring
   - Power distribution monitoring and control
   - Voice, video, data communications.

speed command for each vehicle, depending upon its location and other traffic, is transmitted to the vehicle from the wayside control units by the fixed block control system. The wayside control units are made up of standard vital fail-safe relays which bring the system to a safe-stop in the event of an emergency condition. The system is designed for a nominal operating speed of 25 ft/s (17 mph).

Vehicle operating safety relies on a nominal five block control system. The guideway is divided into 708 blocks by insulators spaced at intervals along the signal rail. The average block is 90 feet long, with blocks ranging from 45 to 240 feet. In the terminal sidings 45 foot blocks are used to allow closer vehicle spacing, permissible at the lower siding speeds. The vehicle maximum stopping distance under emergency conditions is 165 feet. In a five-block system, one block is allowed for emergency stopping. During any operation, at least one full block must separate the vehicles. At a high speed cruise, five blocks separate the vehicles. A proceed-at-full-speed signal is sent to the vehicle from the wayside whenever its separation is five full blocks or more and it is cruising at high speed. When the separation becomes less than four blocks, a signal is sent to the vehicle to slow to medium speed (14 ft/sec); for separations less than two blocks, the command is to stop. This ensures at least one clear block between queueing vehicles. In a high speed case, the vehicles have a minimum separation of 450 feet. At 25 ft/sec the minimum headway is 18 seconds.

The central control console, from which the system is supervised, is located in the central heating and air conditioning building. The console shows the status of the system and permits the operator to override the automatic operation of the system if necessary and his interference is safe.

The display route map shows the location and status of each vehicle. TV screens permit viewing of all passenger terminals. Two-way voice communication is possible with any or all vehicles. Malfunction information is also displayed. Another display route map shows the status of the power distribution system.

The supervisor does not operate the system, but he may add or subtract trains-in-operation, change the routes, and dispatch service crews. A printed copy of all operator actions and indicated malfunctions of vehicles or stations is available via the central control line printer.

The AIRTRANS Maintenance Building, the Departure Test Track, and the Ready Track are located in the extreme southern part of the airport. The Maintenance Building contains the control room for the departure test and ten stalls for servicing vehicles. Vehicles are removed from the guideway, towed to the service stalls for service and then back to the Departure Track for re-insertion into the guideway. As the vehicles have complete off-guideway mobility when towed, they may be moved over any smooth surface. There are thirteen service vehicles: six of the maintenance type and seven of the service type. The latter have an 8000-lb drawbar capability and are equipped with steering or bumper wheels and presence-detection brushes so that they may enter the guideway to retrieve stalled vehicles. The seven gasoline powered service vehicles are stationed at strategically located sidings throughout the system. Driver operated, they can tow two loaded passenger cars.

The vehicle equipment, especially the safety system, is automatically checked at the Departure Test Track before the the vehicle enters the guideway for operation under automatic control. After passing the departure test, a vehicle may be stored in the Ready Track with all power on, until it is dispatched into operation by the Central Control.

2.8 UTILITY SYSTEMS

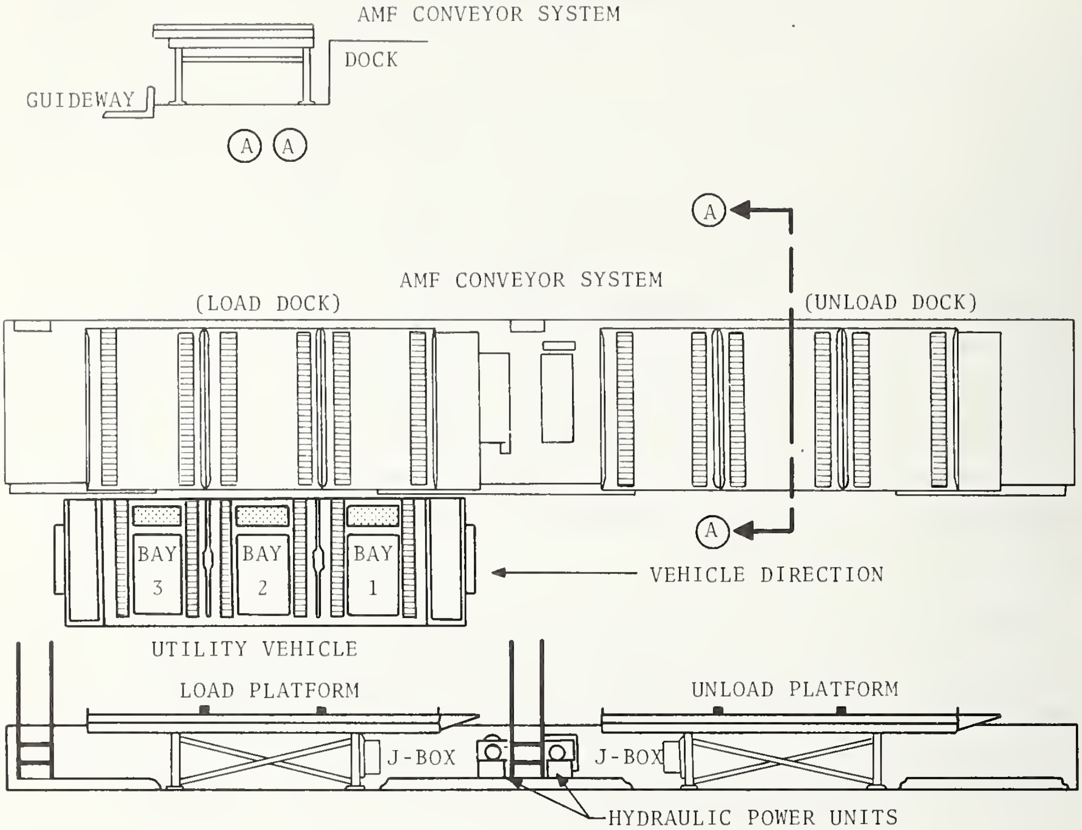
There are four freight utility services: mail, supplies, interline baggage, and trash. These four services share a common guideway with the employee passenger service within the airline terminal complex. At the 6W area (location of the Air Mail facility (AMF), trash incinerator, and the airport supplier) each service has an off-line station. However, guideways to and around the remainder of the airport into terminal areas are common to all systems. The airline passenger service within terminal areas is completely off-line, while all other services use the same off line guideway within the terminals. Aside from the passenger service, only the supply and employee services are in actual operation. The mail service operated for six months but at the time of the assessment it had been discontinued.

Utility services are provided by a fleet of 17 utility vehicles which are similar to the passenger vehicles, except for the passenger cabin and equipment provisions. A utility vehicle has the same propulsion, braking, pneumatic, suspension, bumper, guidance, and electrical systems as a passenger vehicle. However, the utility vehicles have additional equipment, such as automatic load/unload mechanisms, which interface with matching equipment at the utility vehicle stations. Cargo support and loading equipment is mounted on each of the cargo bays; mail/baggage, supplies, and trash. The conveyer transfer system and general views of the supply system are shown in Figures 2-13, 2-14 and 2-15.

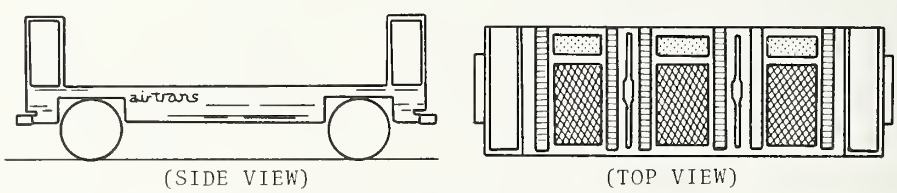
Almost all cargo is placed in containers prior to its entering the AIRTRANS system. Provision is made for handling special and unusual items, such as skis, which will not fit into the container. The containers are 78 inches long, 69 inches high and 60 inches wide. The vehicles can also handle standard LD-3 containers (DC-10, L1011 and 747 cargo containers).

Cargo consists of passenger baggage, air mail, supplies for the terminals, and solid trash from the terminals. The baggage and mail containers are transferred between the station and vehicles by fully automated systems. The supply and trash containers are semiautomatically moved and transferred to vehicles on demand. The AIRTRANS utility equipment consists of conveyorized transfer modules on the utility vehicles and the transfer platforms for all the terminal and transportation center stations. These movable platforms move containers from vehicle to platform and vice versa, in an automatic or semiautomatic mode.

At the AMF station, and each baggage and mail station there is a graphic display at the load platform that shows the destination of the vehicle, and an announcing alarm that provides notice of the impending arrival of mail vehicles.



AIRTRANS AMF EQUIPMENT INSTALLATION



AIRTRANS UTILITY VEHICLE

Figure 2-13 AIRTRANS Utility Vehicle and AMF Conveyor System

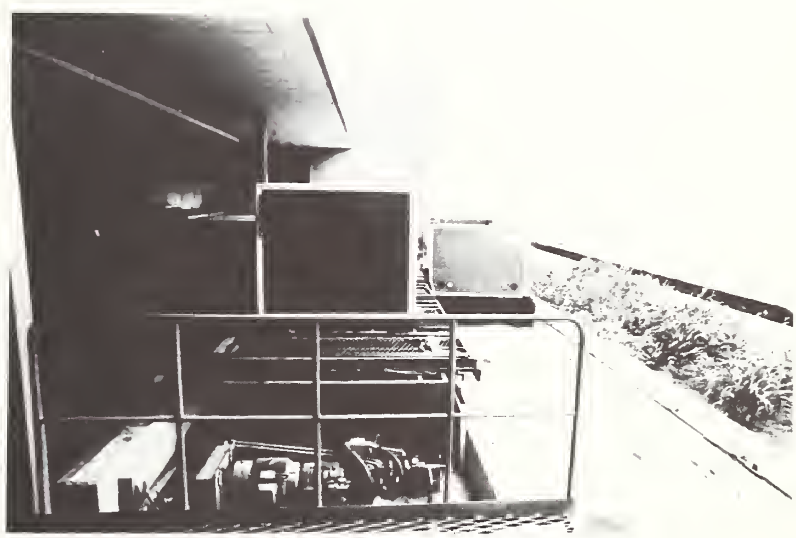


Figure 2-14 Supply System Interface - General Views

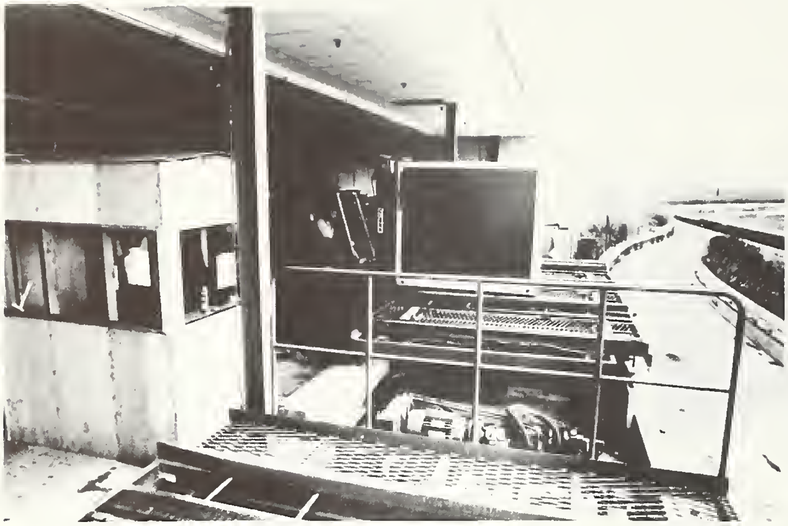


Figure 2-15 Supply System Interface Equipment

3. OPERATIONAL PERFORMANCE ASSESSMENT

3.1 GENERAL

Every transit system design attempts to integrate and reconcile the requirements of the system users, the operator, and the public. The public includes environmental factors which, in the case of AIRTRANS, are a relatively minor factor in the operational performance assessment of the system. The public benefits of AIRTRANS, including improved access, reduced highway traffic and enhanced developmental capability, are an integral part of the airport design. Most of the negative impacts, including noise as well as visual and spatial instrusion, are not very significant in the overall airport surroundings where aircraft noise is omnipresent, and the AIRTRANS guideway is adjacent and parallel to a very extensive, limited-access highway system. The ability of AIRTRANS to fit its stations into the terminal environment is a significant environmental assessment factor; this aspect of the system, a strong point of AIRTRANS, is discussed more fully later in this section.

AIRTRANS serves two basic user categories, passengers and freight service users, with overlapping interests in the baggage handling area. Assessment factors from the passenger point of view include travel time, dependability of service, security, out-of-pocket cost, comfort during the trip, and convenience of use. The differences between users of urban and intra-airport transit become highlighted, as AIRTRANS performance is assessed according to these factors. It should be noted that AIRTRANS services are provided to two types of travelers, airline passengers and employees, and each type has a different set of priorities. AIRTRANS is configured to provide completely separated services for the two types.

The assessment of freight service are not as frequently stated or analyzed as those for passenger service. Point-to-point delivery time, dependability of service, security, cost of service, damage-free delivery, and effectiveness of the loading/unloading interface are the important factors. The four users of freight service are interline baggage, air mail, supplies, and trash, and they have entirely different prioraties. AIRTRANS freight service has not been as well developed as its passenger service. Furthermore, the effectiveness of freight operations is very much dependent on the proper functioning of the interface equipment. For these reasons, the assessment of AIRTRANS freight operational performance is based on the four distinct users of freight service rather than on a discussion of performance factors applying to freight service in general.

The Regional Airport Board (APB) is the system operator. The operator's principal responsibility is to keep the system users satisfied. The system operator also has requirements of his own, such as costs, which can sometimes conflict with user requirements. From the system operator's viewpoint, the assessment factors include capital and operating costs, revenues, capacity, safety, reliability, and maintainability. Revenues and user costs are counterparts of each other, related by ridership and usage level. The system operator's costs and revenues must balance, unless a subsidy is available. The costs/revenues relationship thus constitutes an issue that relates AIRTRANS to the economic performance of the entire airport and is thus beyond the scope of this assessment effort. For this reason revenues and user costs are not included as evaluation factors in this study. The capital and operating costs of the system are discussed in terms of the capital increases and the reductions of operational and maintenance requirements as the system has matured.

3.2 OPERATING HISTORY

The AIRTRANS passenger system was put into service on January 13, 1974, the day the Dallas/Fort Worth airport opened. During the first two months of operation, the system was run with a Vought attendant aboard each vehicle to correct the many malfunctions. It was these early reliability failures which created adverse publicity and the initial dissatisfaction with the system. A major reason for these early failures was schedule constraints, which precluded performing complete system testing prior to revenue service. The airport employee service and the airmail service were also operative for a brief period in this early stage but were discontinued pending solutions to certain problems. Since March of 1976, the employee system has been satisfactorily reinitiated and plans are being made to reintroduce the cargo services. The supplies service has operated since early 1975 without difficulty.

The decision to shorten the testing period and go into revenue service was a joint decision between the Airport Board (APB) and Vought corporate management. Though resulting in the rash of early failures, this decision had some positive effects. As a result of this "trial by fire" approach, Vought had a work force of some 800 people assigned to AIRTRANS during the early months of revenue operation. This, in turn, significantly decreased the break-in period normally required to cope with infant-mortality-type failures.

Many of the people participating in this massive, short-term troubleshooting effort provided high levels of technical skill which enabled Vought to cope with failures of their own equipment, as well as that of their subcontractors. The broad technology base and large resources of Vought were significant factors in the success of this accelerated approach for putting AIRTRANS into service. The Company believed that by using major technical resources early during revenue service, they would not only provide reliable service sooner but, in addition, would also save costs in the long run. By July 1, 1974, the troubleshooting staff was reduced by 60-to-70 percent, to a total of less than 350 personnel.

Through April 1976, the system has carried 5.6 million paying passengers, while covering over 6.4 million total miles. (See Tables 3-1 and 3-2 and Figure 3-1 for detailed operating statistics). Some part of the system total miles are attributed to utility/mail vehicles and test operation of the employee-system vehicles without employees.

TABLE 3-1 AIRTRANS OPERATIONAL STATISTICS -

Total System Vehicle Miles	6,471,340
Vehicle Miles Since Restart	793,494
Average Vehicle Miles Per Day	11,107
Average Miles Per Week on a Passenger Vehicle in Service	2,065
Average Total Miles on Individual Passenger Vehicle	115,562
Greatest Total Miles on Any Vehicle (PL #06)	134,679
Total Paid Passengers	5,565,744
Paid Passengers in April (1976)	220,289
Unpaid Passengers (estimated employees since restart based on survey)	219,036 Est.
Passenger Trains in Present Service	31
Passenger Vehicles in Present Service	51
Utility Vehicles in Present Service	4

NOTE: Statistics as of April 30, 1976.

TABLE 3-2 AIRTRANS REVENUE SERVICE PASSENGERS

MONTH	NUMBERS OF PASSENGERS
1974	
January	171,000
February	225,000
March	299,000
April	259,000
May	236,000
June	286,000
July	302,000
August	320,000
September	246,000
October	249,000
November	207,000
December	221,000
1975	
January	202,000
February	161,000

3.3 PASSENGER SERVICE REQUIREMENTS

The basic function of AIRTRANS is passenger service. A system assessment must therefore be primarily based on quality service factors, i.e., how well the service is performed. The data used in the assessment was obtained through two reports prepared in late 1974 and early 1975. These reports, footnoted on page 3-7, had the following background.

The system was put in revenue service before the test phase had been completed. This made it impossible for the Airport Board to follow the planned contractual procedures for legal acceptance

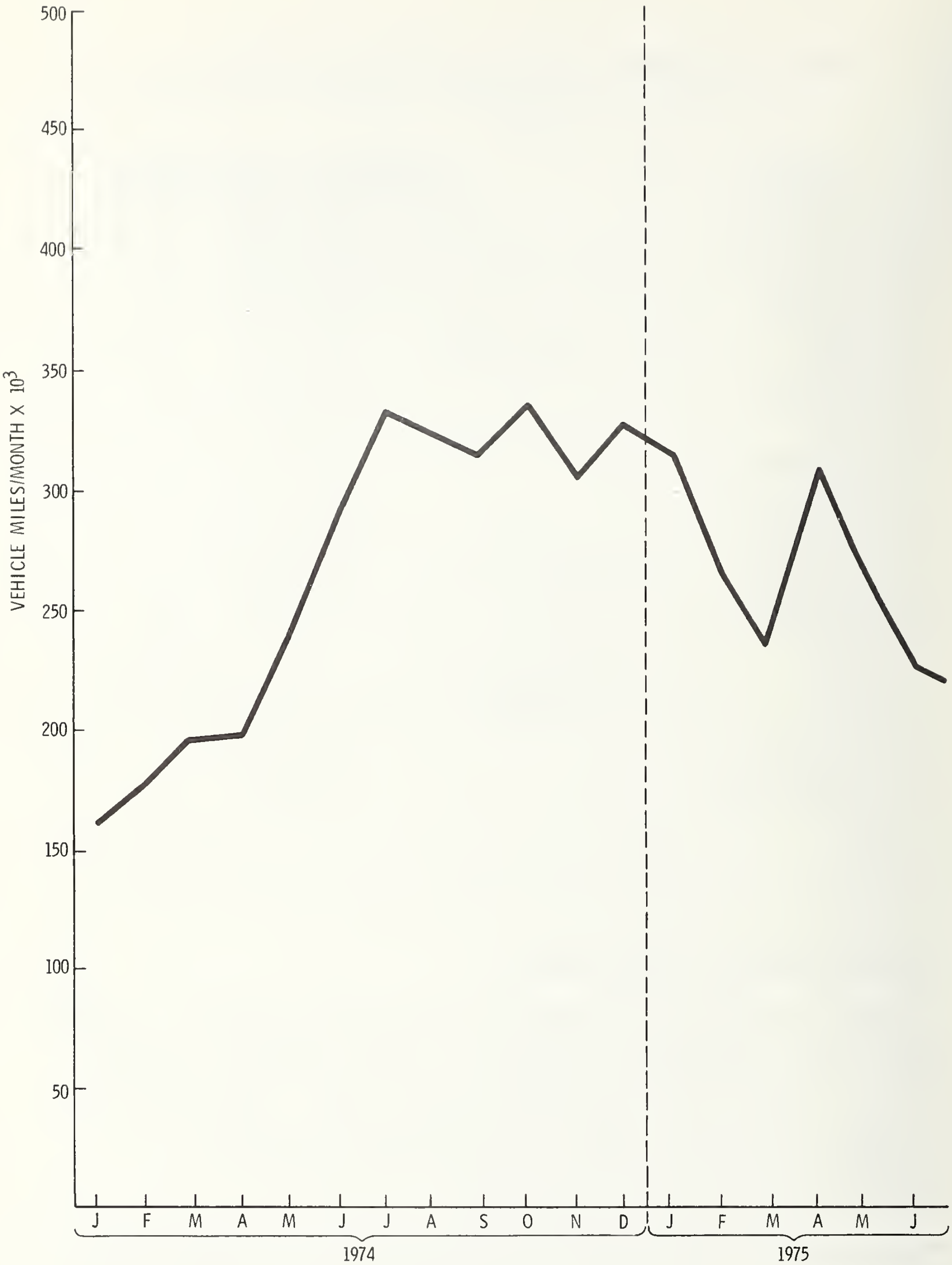


Figure 3-1 AIRTRANS Operating Mileage Record

of the system. To circumvent this difficulty, a supplemental agreement (signed on September 3, 1974) provided "revenue operation level" (ROL) criteria to demonstrate that the system and/or its subsystems were "sufficiently complete and reliably operable to the extent necessary for successful use." Parts of this supplemental agreement provided for detailed performance testing and measurement of the entire AIRTRANS system, including components not yet in service. The data collected during these tests, conducted during six four-hour periods on September 26 to 29, 1974, and repeated during October 24-26, 1974, are the principal basis for assessing AIRTRANS system performance in the areas of travel time, service dependability, and system capacity.

These ROL data are presented and discussed in considerable detail in a report issued December 9, 1974, by the Airport Board*. A subsequent report by Vought* presents further analysis of these data, based on a computer simulation of system operations. The Vought report also presents other measurements related to comfort factors, noise, and EM interference. These two reports provided some of the principal data for the U.S. DOT operational assessment of the AIRTRANS system. It is important to note that the reliability improvements in effect since October, 1974, are not accounted for in these performance data. However, estimates of reliability have been made based on data collected up through December 1974 (AIRTRANS Performance Analysis Report.) Two other factors further limit the usefulness of the data described and analyzed in these two reports. First, the data are only concerned with the specification which limited the system performance data to total travel time, train spacing, and system capacity. Also, the operating configuration used differed from the configuration necessary to satisfy the specifications. Thus, only <u>some</u> of the performance data were relevant to the specification requirements.

*"AIRTRANS Revenue Operation Level Report," Engineering Dept., Dallas/Fort Worth Airport, December 9, 1974.
"AIRTRANS Performance Analysis Report", Vought Corp., February 14 1975.

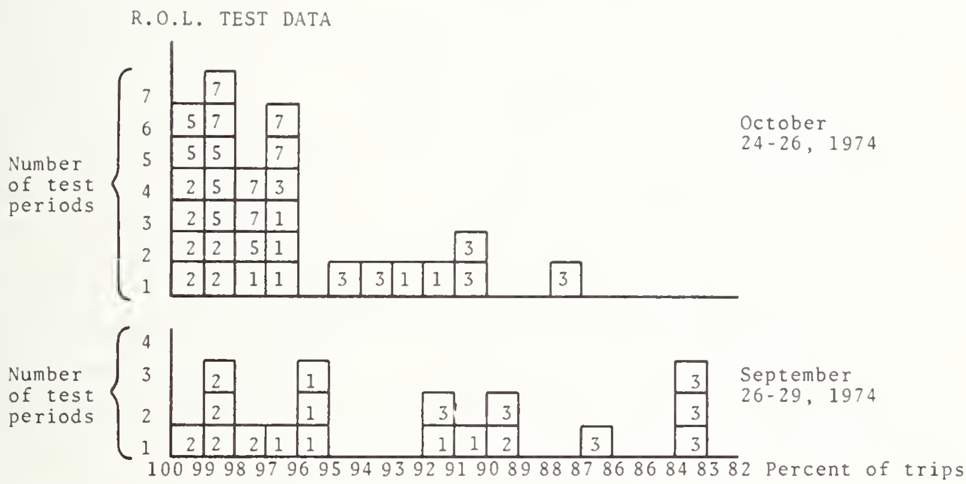
3.3.1 TRIP TIME

Trip time is generally accepted as being one of the principal performance parameters that determine urban transit service demand. For boarding or transferring airline passengers, trip time is an even more significant factor; it could very well be called the key measure of AIRTRANS performance from the passenger point of view. Trip time includes both on-board and waiting times. According to the specifications, the maximum allowable transit times for the three routes that were operated in the design configuration (interline Routes 1, 2, and 3) are twenty minutes (see Figures 2-4 and 2-5 for a definition of these routes). The ROL data indicate that in September and October 1974, the system came close to meeting this requirement but did not actually do so. For the six test periods and the three routes, an average of 92.5 percent of trips met the total trip time requirement during the September tests, and 95.6 percent during the October tests.* The histograms of Figure 3-2 represent each test period and each route as separate data points* indicating the improvement from September to October, as well as the differences in the trip time performance of the individual routes. Most of the trips on Route 2 met the travel time requirements during all the test periods, but the performance on Route 3 was unsatisfactory (ranging from a high of 96 percent to a low of 83 percent of trips satisfying the trip time requirements during the respective test periods). The average percent of trips meeting travel time requirements for the six October test periods were 95 percent for Route 1, 99 percent for Route 2, and 92 percent for Route 3.*

AIRTRANS trip time performance must be viewed in the context of the airport's and AIRTRANS' early history. The original spine type layout of the airport was rejected due to difficulties expected with manuvering the anticipated fleet of large jet aircraft on the

*Table 5, APB ROL report.

*Refer to AIRTRANS Performance Analysis Report, Table 2.1.1.3.1-1.)



NOTE:

Numbers in the histogram indicate route numbers.

Figure 3-2. Percentage of trips within Maximum Total Time Specification ground. The present layout with semicircular terminals was adopted instead as being much more suited for handling the problems of taxiing aircraft. This decision changed the functional requirements for the AIRTRANS system from one of service on a simple, all-stop, on-line-station shuttle system operating large vehicle trains to the more complex task of providing shorter headway service to loops having overlapping routes, off-line stations, and many switches.

The right of way that was available for the system was restricted; the need for keeping down installation costs was great. The resulting layout resticted the practical maximum speed of the system and increased the distances (compared to the spine type layout) that some passengers had to travel. Increases in trip time were compensated for by placing the AIRTRANS stations closer to the airline arrival and departure lounges than the spine type system would have permitted. The net result was a system that met the 20 minute trip time requirement with a minimum of walking required from passengers but with little margin left for passenger error or system delay. The 20 minute period was considered adequate for the 50 minute total interline passenger transfer time specified for the airport.

In addition to the airline passengers, the AIRTRANS system was planned and designed to transport airport employees from the employee parking lots to their employment sites. The trip time requirement for employees is also subject to pressures. Great resentment can occur when employee travel time is increased by rules that appear arbitrary and is subject to performance inadequacies, real or imaginary, of the AIRTRANS system. The requirement of reasonable trip time, and service dependability, is aggravated by the highly peaked nature of employee traffic which puts strains on system capacity and can easily result in increasing travel time.

An adequate assessment of the AIRTRANS system's employee trip time performance is not possible at this time, because during the assessment period, the AIRTRANS system was not transporting employees.

The reliability of AIRTRANS performance was, however, insufficient for daily commuters. After two days, it was decided that the service was unsatisfactory. From that time, to March, 1976 employees were not transported by AIRTRANS. In effect, the alternative bus service provided during this period was better and the airlines and the concessionaires at the airport have subsidized the transportation of their employees. The October 1974 ROL data indicate an adequate degree of compliance with the thirty minute maximum time requirement for both employee routes. These data were taken without riders; and even at that, it is questionable whether this long a travel time can provide adequate service for many of the employees. It is worth noting that in March, 1976, the employee system was placed into revenue service with additional vehicles dedicated for specific terminals with the result that the 30 minute maximum time has been reduced to 20 minutes with most trips 10 to 15 minutes.

3.3.2 ON-BOARD TIME

On-board time is affected by maximum vehicle speed, the unobstructed average speed (indicative of the number of reduced speed sections and the choice of reduced speeds), the likelihood of interference by preceding vehicles, the number of intermediate stops on the route, and the amount of time spent at intermediate stations.

Maximum vehicle speed is probably the one most important parameter that has to be selected in the design of a transit system. It impacts not only travel time but almost all other performance aspects of which cost and safety are perhaps the most important. The maximum speed is therefore basic to tradeoffs between various types of incremental benefits and costs that are incurred. AIRTRANS' maximum speed of 25 fps (17 mph) was selected by Vought, during their preliminary design studies, on the basis of RFP service requirements and right-of-way limitations. Though the vehicles are capable of higher speeds with minor changes, the control block layout is based on the selected speed and will not allow an increase in maximum speed without changes to the entire command and control system. The Vought staff indicated, however, that only minor travel time improvements would have resulted, if a higher maximum speed level had been adopted.

Acceleration, deceleration, and jerk are other design factors that have an impact on AIRTRANS on-board travel time performance. These factors are limited by comfort requirements; the AIRTRANS propulsion system is adequate to perform up to such limits ($\pm$ 3.75 fps^2 acceleration/deceleration and 2.5 fps^3 jerk) over the entire speed range on level track. The ROL data is insufficient to determine the impact of these factors, or even their combined impact, on vehicle speeds over the various routes, with or without interference by other traffic.

It was noted that during peak traffic periods the vehicle/station doors were held open longer than the nominal 15 seconds to accommodate passengers. This, obviously, has an effect on trip time.

3.3.3 WAITING TIME

Waiting time is influenced by two factors. One is the scheduled time interval between successive trains on the same route. The other is the ability of the system to keep the trains moving exactly according to the scheduled time intervals. The latter factor is often called schedule reliability or schedule dependability; this characteristic is also included in the more general category of service dependability. The following discusses waiting time performance according to the selected schedules and according to ability of the system to adhere to these schedules in the absence of failures.

3.3.3.1 Scheduled Train Intervals

When the system was configured in the early stages of design, the route structure and the assignment of trains to each route was selected in order to satisfy all travel time requirements with an adequate design margin. The anticipated time to complete a round trip for each particular route was a major factor in these considerations. This anticipated round trip time, together with the number of trains assigned to the route, determined the scheduled train interval. No data are available for these nominal waiting times or round trip times. The ROL data provide actual train intervals, which include the effects of train interference, station delays and failures, in addition to the nominal scheduled train intervals. The average measured train intervals, including both the September and October tests, are presented in Table 3-3.

TABLE 3-3 AVERAGE TRAIN INTERVALS

Route	Measured Train Interval (Seconds)
1	323
2	354
3	325
5	626
7	540

The selection of these intervals cannot be assessed apart from considering the route structure, the resulting interactions between trains, and how these factors impact on dependability and capacity, as discussed in the following paragraphs.

3.3.3.2 Schedule Dependability

Apart from failures and accidents, two conditions can interfere with the normal operation of AIRTRANS trains. A general delay can occur when capacity is overtaxed and a train takes somewhat longer than scheduled to complete its route. Both travel and waiting times are then increased in approximately the same proportion. These general problems of system or link capacity are discussed in Section 3.3.4.

The other schedule dependability problem is related to the tendency of consecutive AIRTRANS trains to bunch together when one of the trains is delayed.

Station delays and the resulting bunching of trains or vehicles is a common occurrence in operating transit systems and was recognized early in the development of the AIRTRANS system. Bunch control, based on the ability of the central processor to monitor and modify the motion of individual trains, was specified. The original bunch control specifications were modified on August 17, 1972, and are now as follows:

> "Condition 1 - at any station, the headway between trains on any given route shall not vary by more than 20 percent or 60 seconds, whichever is greater.
>
> Condition 2 - at any station and over a 30 minute period, the headway between all trains but one on any given route shall not vary by more than 10 percent or 30 seconds, whichever is greater. At any time, any train not meeting Condition 2 shall meet Condition 2 within 15 minutes."

Vehicle bunching was a major problem which has been resolved in the current operation of the system. Checkpoints are used for debunching control - blocks are chosen on the guideway where trains are checked against expected arrival time. Just 42 out of the 708 blocks in the system are used as checkpoints. Schedules are set up at these logical checkpoints (CPS). Trains can be held at stations or can be given reduced velocity performance commands to spread out bunched trains. There is no CP at the hotel station because it was decided not to hold trains at this heavy traffic point.

If a train is late, an attempt is first made to get it back on schedule by reducing its stopping times in the stations. There is no capability for increasing train speeds above the nominal speed limits on the guideway, so that lost time can be made up only by reduced times in stations. The nominal station dwell time is 18 seconds, which can be automatically adjusted by the control computer. Through bunch control, the door-open time for any one stop can range from 8 to 35 seconds.

One source of delay frequently observed in AIRTRANS was the tendency of passengers to hold vehicle doors open at stations in anticipation of other passengers boarding the train. If someone interferes with the closing of the door, the door re-opens and an attempt is made to close it 5 seconds later. This 5-second cycle can be repeated indefinitely, but after a few cycles, while the cycling continues, Central Control is notified that a problem exists.

When modification of station dwell time cannot get a train back on schedule, that train is declared to be "on schedule," and the other trains on the route are then ahead of schedule. One approach for handling "early" trains, is to extend station dwell times. The other method is to reduce the vehicle's speed; the two system possibilities being 62 percent and 83 percent of the commanded speed.

Whenever the number of trains on a route is changed, a re-initiating procedure is employed. Bunch control is not started until all the vehicles on that route have passed by what is designated as the key checkpoint for that route. Since rerouting is required when vehicles are sent to the maintenance area at night, bunch control for that time period is less effective.

The bunch control specifications* are very stringent, especially considering that they include the normal delays, as well as the effects of failures. When the ROL data were evaluated, it became clear that the system did not come close to meeting these requirements, and even apart from failures, would probably not be able to meet them under any circumstances. It was realized, in fact, that the requirements, if taken literally, were unnecessarily restrictive. Figure 3-3 reproduces "Exhibit 2" of the ROL Report, which displays a histogram of train spacing for Route 1, as well as the corresponding tabulation of the percentage of inter-train times within delta ("Del") seconds of the average inter-train time on this route (labeled "Medn"; this is the top right table). Only 41.48 percent of trains met the spacing requirement of 30 seconds, and only 65.6 percent met the 60-second requirement. To "statistically screen out the effect of malfunctions and passenger actions", the ROL Report then adopted a four point moving average of these data, as a measure of train spacing. For the data of Figure 3-3, 96.39 percent of the trains met a 60-second train spacing requirement on this basis (lower right table).

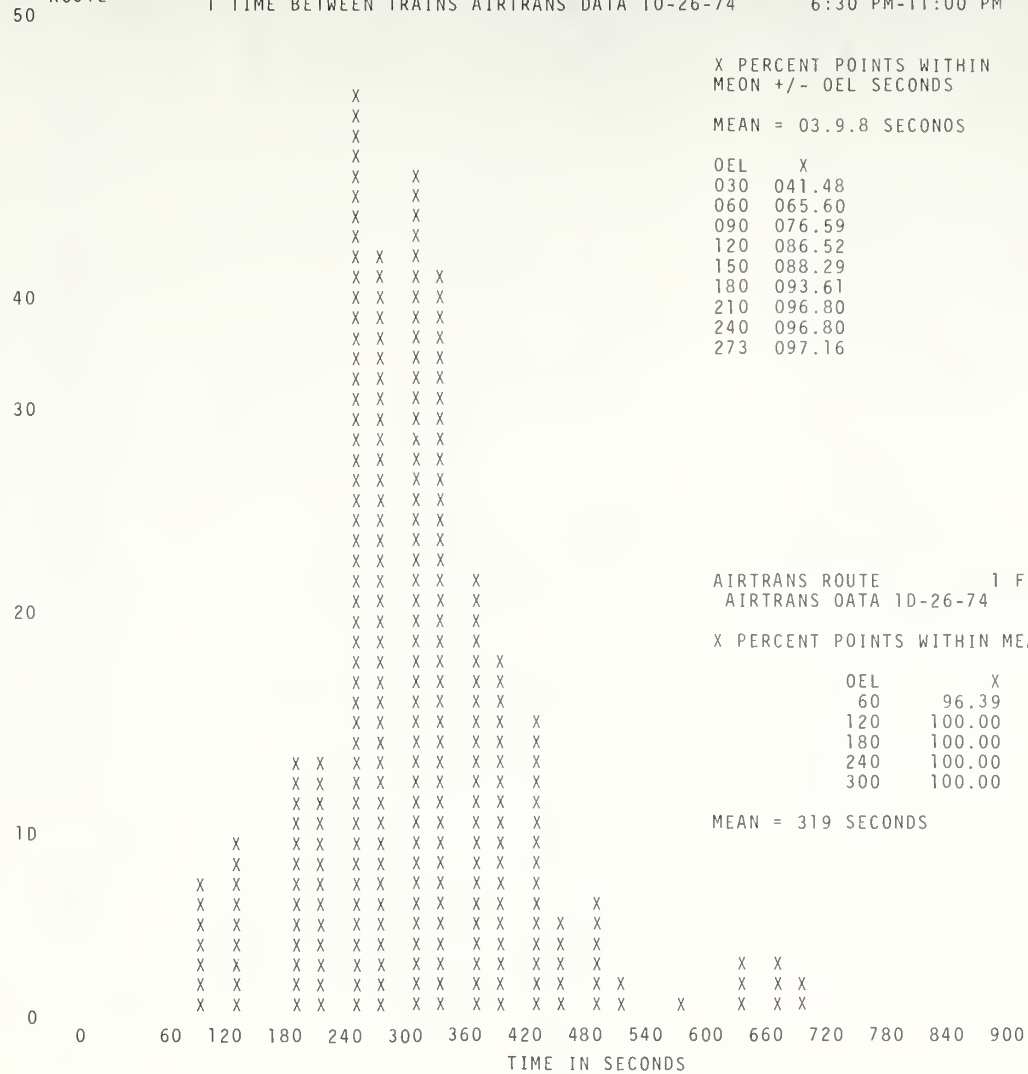
Adopting the four-point moving average method for all train spacing data, the ROL Report states that 28 percent of all trains were within plus/minus 30 seconds of the average spacing for their routes, and 95 percent were within plus/minus 2 minutes. It was then

*The third paragraph of Section 3.3.3.1 of the Performance Specifications reads as follows:

> "Means shall be provided by the Contractor for automatically maintaining spacing between trains on the same routes, such that the headway between trains does not vary by more than plus or minus 10 percent from the normal value, or by 30 seconds, whichever is greater."

According to Vought, bunch control meets the spirit, but not the letter of the specification.

HISTOGRAM
ROUTE 1 TIME BETWEEN TRAINS AIRTRANS DATA 10-26-74 6:30 PM-11:00 PM



X PERCENT POINTS WITHIN
MEON +/- OEL SECONDS

MEAN = 03.9.8 SECONOS

OEL	X
030	041.48
060	065.60
090	076.59
120	086.52
150	088.29
180	093.61
210	096.80
240	096.80
273	097.16

AIRTRANS ROUTE 1 FOUR-POINT MOVING AVERAGE
AIRTRANS OATA 1D-26-74 6:30 PM-11:00 PM

X PERCENT POINTS WITHIN MEAN +/- DEL SECONOS

OEL	X
60	96.39
120	100.00
180	100.00
240	100.00
300	100.00

MEAN = 319 SECONDS

Figure 3-3 Train Spacing Display

decided that the effectiveness of bunch control be described by using the plus/minus 2-minute criterion and the four-point moving average method. The principal results indicating the percentage of trains meeting this criterion during each of the test periods, and for the routes tested during the September and October tests, are depicted in the histograms of Figure 3-4.

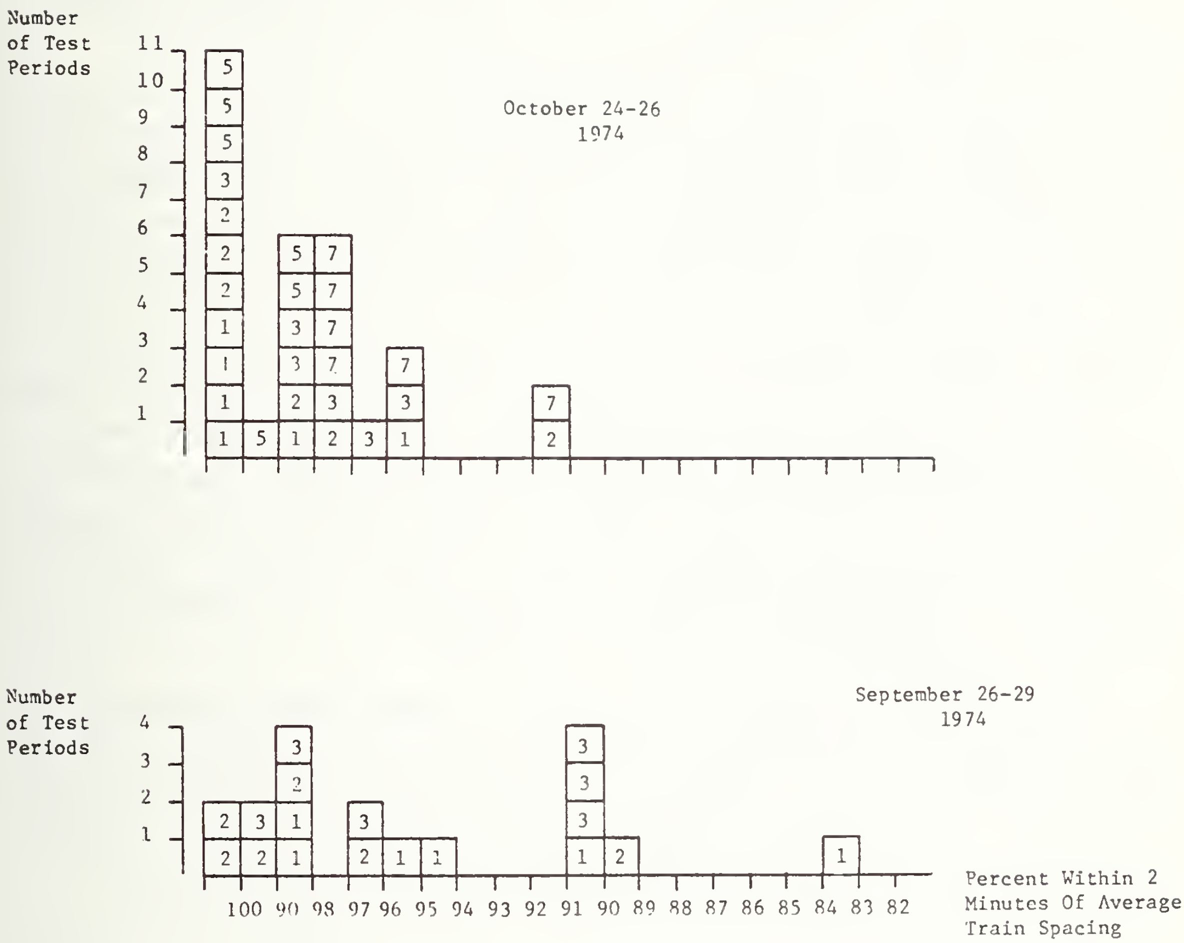
A similarity between these results and the travel time shown in Figure 3-2 can be observed, both in terms of the improvement from September to October and with regard to the differences between routes. Route 3 again appears as the poorest performer in terms of the ability of the trains to maintain constant spacing between themselves. From the traveler's point of view, these results can be re-interpreted, by using Figures 3-4 and 3-3, to conclude that a few (1 to 3) percent of the trains may require an extra five minutes of waiting when compared to the average time; and the extra five minutes could even become an extra ten minutes on some occasions.

3.3.4 System Capacity

Capacity requirements of conventional transit systems are usually easily identified on the basis of passenger (or freight) carrying requirements during peak traffic hours on the most heavily traveled links of each transit line. The overlapping route structure and diverse origin-destination pattern of AIRTRANS make it more difficult to identify the system's capacity requirements. System design studies conducted during 1971 and 1972 resolved this difficulty by incremental assignment of the predicted passenger traffic to appropriate segments of the various routes. The resulting passenger flow pattern was then translated into link-by-link capacity (i.e., trains per hour) requirements for each route.

Trains would then have to be assigned to routes to satisfy the flow requirements on all heavily traveled links. However, the actual assignment of trains to routes was performed on the basis of travel time (including waiting time) requirements, which defined the longest permissible spacing between trains for each route.

R.O.L. TEST DATA



Notes:

1. Percentages are based on four-point moving averages.
2. Numbers in histogram indicate route numbers.

Figure 3-4 Percentage of Trips Within a Two-Minute Bunch Control Specification

Some additional flexibility to meet passenger flow requirements was then available by selectively assigning one- or two-car trains to meet the travel-time based train movement requirements.

The traditional remedy of transit systems for under-capacity is longer trains. This remedy is available to AIRTRANS in the future as three-car trains can be operated.

The ROL Report compares the link-by-link train flow requirements for each route to the actual train flow observed on that route (Appendix B, ROL Report). Only the September data are reported, the October tests were not analyzed for their capacity performance, though in all other respects they gave evidence of improved service characteristics. The worst links for the three routes provided 80.4 percent (route 1), 83.2 percent (route 2) and 77.2 percent (route 3) of capacity, while the corresponding averages for the three routes were 94, 97 and 86 percent, respectively (see Table 2.1.1.2.1-1, Performance Analysis Report). The averages are based on averaging links with 100 percent allotted for links that met or exceeded the train flow requirement. The composite average for the three routes is 92 percent.

The simulation results reported in the Performance Analysis Report provide an indication of the improvement in capacity performance that could be expected if major service interruptions due to vehicle failures were removed. These failure effect were identified as 3.5 interruptions per hour, random in location and ranging randomly from 2 to 10 minutes' duration (pgs. 2-4 and 2-5, Performance Analysis Report). Without these failures, the simulations indicated that the same three routes would provide train flows that are 98.6, 99.7 and 99.8 percent of the required capacity (Table 2.1.2.2.1-1, Performance Analysis Report). These results are based on no interruptions, though the effects of "normal interference" by other moving trains are accounted for.

The assessment of these results is made difficult by the absence of more detailed data in the following areas: train performances without interference, delays incurred due to the bunch control and possible station queuing, and/or interference problems at switches. The point at which AIRTRANS could have serious capacity problems for the required trip time as additional vehicles are added has not been ascertained. The structure of the AIRTRANS system is such that capacity and trip time problems are interrelated with travel time being the governing requirement.

However, some provision has been made in the AIRTRANS design for the increased requirements of future growth. Specifically, the provision is for increasing the train length from two to three vehicles. Such features provide growth flexibility and should be considered in the design of future systems of a similar nature, particularly for urban applications.

With the present procedures, AIRTRANS does not really have much flexibility in setting its fleet size. During the day, a certain number of trains are needed to meet the expected demand. At night, a slightly lower number of trains is still required, even though demand is much lower, in order to meet the travel time constraints. For instance, during the assessment period of July-August 1975 only five fewer trains were run at night than during the day.

Neither developer or operator ever seriously considered a demand-responsive mode of operation for the present AIRTRANS configuration. Thus, no projected value of an "on-demand" system has been established, and no investigation has ever been made of the related control problems, and performance, cost, and reliability requirements.

During this assessment, TSC developed a demonstration of a demand-responsive system which was tried on two nights. It appeared that a demand-responsive system could only operate about two hours a night, when demand is lowest.

3.4 AIRTRANS RELIABILITY/MAINTAINABILITY/AVAILABILITY/DEPENDABILITY

AIRTRANS is an impressive accomplishment, and the assessment team feels that its reliability requirements will very likely be met.

The dependability of AIRTRANS service, though not in accord with the letter of the specifications, is satisfactory for all but a very few passengers. The findings indicate that the schedule dependability impact, of the additional vehicles projected for later years, could become a problem. This is all the more so because the bunch control sometimes slows down all trains on the route in order to increase the average train spacing. The control technique intended to provide schedule dependability, therefore, itself somewhat degrades the service. This has implications not only for AIRTRANS, but also for other automated systems, particularly if scheduled service, overlapping routes, and off-line stations are used.

This section discusses the effect of failures on the dependability of service. Reliability program characteristics are discussed, including specification requirements and definitions. Reliability and maintenance experience is assessed. Sections 8.1, 8.2, 8.3 and 8.4 (System Assurance) cover the problems and recommendations in more detail. The data in the AIRTRANS Performance Analysis Report indicate that system disruptions varied from 2 to 5 per hour. The time-to-restore varied from 2 to 10 minutes, but occasionally exceeded 15 minutes. These data indicate that the AIRTRANS System was generally effective in coping with most failures. Distributed control strategy, where vehicle movement and control do not depend on the central computer, has been a factor in maintaining the service. The central control computer provides the system bunch control function while the wayside and vehicle units ensure movement and safety. Hence loss of central control only effects the automatic bunch control function, not movement and safety. From March 18 through September 31, 1975, no failures occurred which required the use of the bus back-up system. Since pre-service test was never completed before revenue operation started, this is creditable.

Another factor affecting service dependability is the weather. Specifications for traction requirements call for continued service during conditions of blowing rain and blowing snow (paragraph 3.6.4.10, Specifications for AIRTRANS, March 15, 1971). Section 2.2.5 of the Performance Analysis Report describes the system's ability to comply with these specifications. The following comments briefly summarize the report's description.

Wet weather did present a traction problem, especially on grades where guideway surface wear was evident. Resurfacing has been done in several areas and seems to solve the problems.

Frosting or icing of the power and signal rails can (and did) seriously interfere with operation. Spraying the rails with anti-freeze has proven a satisfactory preventive measure, provided it is done sufficiently in advance of bad weather. This method may be combined with extending scrapers on signal brushes. Vought personnel estimated that during a typical Dallas/Fort Worth winter, frost preventive measures must be put into effect about 15 times, dictated by weather forecasts. Icing occurs very infrequently at this particular site. Icing on the power rails has resulted in one system shut down since airport opening. Snowfall, typically minor and transitory in the Dallas/Fort Worth region, presents problems generally no different than those of rain during winter weather.

3.4.1 Concept

An AIRTRANS-type system must operate dependably despite using components and subsystems on which, in general, no special effort has been expended to ensure or improve item-by-item reliability. Except for vital relays in safety-critical circuits, a transit system cannot afford the high reliability components of a military or space system.

Commercially available components were used throughout the AIRTRANS procurement. The procurement specifications for selected equipment items carried quantitative reliability requirements (MTBF and MTTR). Suppliers were required to submit analytical and/or historical reliability data. Each candidiate supplier's response was evaluated and rated for MTBF and MTTR potential. The evaluated responses were submitted to project management for the equipment selection process. A favorable prediction of the MTBF and MTTR for all equipment categories to meet AIRTRANS specification requirements was derived from data, primarily from the FARADA publication for ground support equipment, and manufacturer's data based on warranty and maintenance activity.

Good design can procure a cost-effective transit system in which modest inherent reliability and well-planned failure management can be combined to provide a highly available service to its customers. Although AIRTRANS did not define availability as such, the elements of it were actively incorporated through the reliability program, the extensive failure management system, and by a planned maintenance program.

In general terms, system availability is measured by the transit system's ability to (a) avoid failures and (b) to cope with failures when they arise. Thus, from the operator's viewpoint, this concept is a counterpart of the user's experience of service dependability, as it is influenced by failure situations. The assessments given in the later description dealing with repair and maintenance can be considered as background for the dependability-of-service descriptions given above of some of the successes and failures of the Airport Board and Vought in delivering reliable service to the customers.

3.4.2 Specifications & Experience

Table 3-4 shows the AIRTRANS reliability requirements. The adherence to these specifications by the system has not yet been measured to a statistically significant extent but initial data have been obtained from one-week samples of system operation. Table 3-5 presents a summary of these samples. Figure 3-5, in turn, shows failure data reduced from the system maintenance records for July 1975. Here, frequency of a failure accurance is plotted against failure duration.

The Vought maintenance files and the Airport Board logs contain a wealth of data which, if reduced, would be valuable in characterizing system performance, in addition to being valuable to future system design efforts. The extent of the quantitative information that was made available at the time of the assessments to the assessment team is presented herein. The mean-time-between-failures, mean-time-to-restore, reliability failure, and reliability requirement definitions given below are taken from paragraph 3.3.6.2 of AIRTRANS specifications:

TABLE 3-4 AIRTRANS RELIABILITY REQUIREMENTS

		MTBF* Hrs.	MTTR**Hrs.
1.	All on-board vehicle equipment associated with vehicle movement and control	$\frac{500}{PV^{***}}$	0.5
2.	All on-board vehicle equipment except that included in No. 1 above	$\frac{1000}{PV^{***}}$	2.0
3.	All non-vehicle equipment associated with vehicle control and movement	50	0.5
4.	All non-vehicle equipment except that included in No. 3 above	50	2.0

*This is the MTBF associated with equipment indicated at the left. These values apply to the entire Part A (people-carrying) system.

**This is the average time allowed to restore AIRTRANS to full, completely automatic operation following a failure in the equipment indicated at the left.

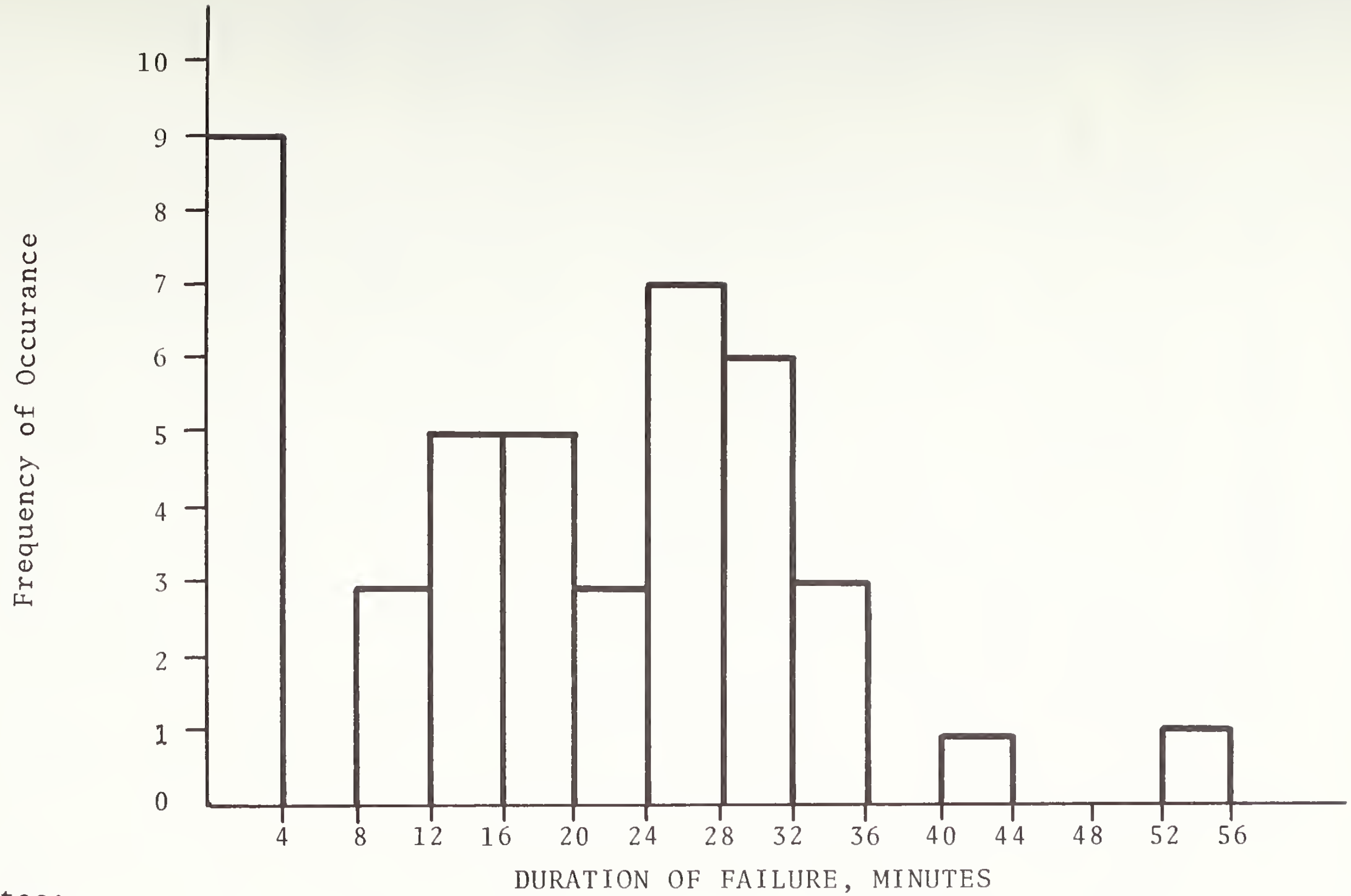
***PV is the number of people-carrying vehicles.

TABLE 3-5 MTBF REQUIREMENTS VS. OBSERVED MTBF

Equipment Category	Rqmt. (Hours)	Test Data for Period 10-30 June 1974	Test Data for Period 2-8 Dec. 1974
1. All on-board vehicle equipment associated with movement and control	500	247	422
2. All on-board vehicle equipment except that included in No. P1 above	1000	138	241
3. All non-vehicle equipment associated with vehicle control and movement	50	31	*
4. All non-vehicle equipment except that included in No. P3 above	50	18	32

*No Failures (MTBF estimated greater than 50 hours)

NOTE
Data From "Performance Analysis Report" Vought Corporation February 14, 1975 for people-carrying system in revenue service.



Notes:

1. Data are derived from LTV maintenance records.
2. Failure data represent Class I or Class II failures caused by equipment malfunction.
3. Duration does not include time to repair a vehicle, only the time needed to remove it from service.
4. Data for July, 1975

Figure 3-5 Restore-to-Operation Times after Reliability Failures

Mean Time Between Failures (MTBF) is defined as the average operating time between reliability failures: MTBF is measured in hours and, as used in this specification, is the measure of what is termed reliability. MTBF is determined by the following equation:

$$MTBF = \frac{\text{Operating Hours}}{\text{Number of Reliability Failures}}$$

Mean Time to Restore (MTTR) is the average time in hours, that is necessary to restore AIRTRANS to full operation, following detection of a reliability failure of a component or subsystem. It includes the time for location and repair or replacement of the faulty equipment. In case of vehicles, it includes the time to repair the vehicle "in place", or the time to remove it from service so that the flow of other vehicles is not interrupted or restricted, and to place another vehicle in operation as required. Detection means either notification of the maintenance man in charge by the owner's operations personnel, or discovery by the contractor's maintenance forces, whichever occurs first. However, in case of a disabled vehicle, detection means the time at which authorization is given by the owner's Operations Representative to remove the vehicle as provided in Section 3.7.3.8 of the AIRTRANS Specification.

MTTR is related to AIRTRANS as a whole, even though specific equipment failures will be involved. If the failed equipment is a part of a subsystem that requires failure correction in place, then the MTTR will be based on the amount of time required to repair or replace the item of equipment. If the piece of equipment is replaced by a properly operating one, then the MTTR does not include the time to actually repair and failed unit, but only the time necessary to replace it and to restore AIRTRANS to full operation.

Failures are defined in Par. 3.3.6.2-1.1 of the Airtrans Specification: "A failure is defined as the occurrence of any condition which renders the AIRTRANS incapable of operating within its specified performance parameter limits. It is important to distinguish between failures in general and reliability failures. In the

AIRTRANS operation, it is the reliability failures which are of interest and which will be related to the reliability requirements. For purposes of this specification, reliability failures will be all failures except those arising from the following circumstances:

"1) Induced by a prior failure. This exception applies only to those failed or damaged items which result from a general failure condition precipitated by an initial failure(s). Here, only the initial failure(s) shall be classified as reliability failure(s). Further, this exception applies only at the time of such a general failure condition and not at any later time.

"2) Caused by abusive and/or incorrect practices by operating and housekeeping personnel or passengers.

"3) Attributed to maintenance not in accord with practices and procedures set forth in the contractor-furnished maintenance manuals."

The owner and contractor jointly review each failure during the performance monitoring period (see Section 3.3.6.3.4 AIRTRANS Spec.) to determine whether it is a reliability or non-reliability type failure. In case of a disagreement, the owner's decision in this regard is final.

Two general problems are related to these definitions and specifications. The reliability level that had to be demonstrated at the beginning of the test period was not specified; neither is the level of reliability at acceptance defined. In addition, no system reliability measure can be easily derived from these specifications unless undefined assumptions are made. For this reason, any proof of the MTBF remains on a per vehicle basis and on a "total wayside" basis. The apparent growth of MTBF portrayed in Table 3-5, as excerpted from two informal reliability sampling periods, is evident.

3.4.3 Reliability Testing

The AIRTRANS test program, as planned, provided three months of complete systems tests prior to airport opening. During these tests, the AIRTRANS maintenance and Central Control procedures were to begin. Revisions and additions to these procedures were to be made (continuously) based on (a) operational experience in a "dry", non-revenue, mode and (b) operational experience in a revenue mode, carrying passengers and cargo after airport opening.

A period of three months of complete systems tests was expected to allow enough time for substantial reduction of infant mortality failures, and to establish Central Control and maintenance procedures to the point that AIRTRANS system availability would provide adequate service for passengers and cargo.
However, with the decision to initiate revenue service before testing was completed, and in order to produce this level of service availability in such a short time, it was necessary to immediately develop Central Control and maintenance procedures, utilize additional maintenance personnel, and stock additional spares. The net result of the efforts was to achieve a suitable level of availability by early identification of defective parts and replacement of these items with improved components.

Reliability performance monitoring was to begin with system acceptance.

Examples of early mortality failures included propulsion motor failures, signal loss as a result of faulty conductor connections, and failure of printed circuit boards, within the vehicle control unit, due to the environment. These problems were quickly detected and repairs made. A normal test program would have identified this type of problem before failure in service.

The reliability/maintainability improvement plan was to begin at opening. This plan was to be comprised of three goals to be reached within the thee-year AIRTRANS maintenance contract:

(a) Decrease the system maintenance costs by establishing accurate diagnostic procedures and by reducing the cost of spares through local sourcing.

(b) Isolate high failure-rate components and equipment through a failure reporting system.

(c) Replace high failure rate components and equipment, by substitution or redesign, to achieve greater MTBF's.

These goals were never attained in their entirety because, as the situation developed, the formal plan was never initiated. Nonetheless, Vought did implement their own program to work toward these goals.

The planned engineering action in reliability and maintainability improvements was to be based upon the cost effectiveness of a change. A "top ten" listing of component or equipment failure rates would be established from failure monitoring data. This list would be worked to reach the reliability and maintainability goals, while the AIRTRANS operation was maintained at an acceptable level of availability for service. The "top ten" listing of high failure rates would be kept current, replacing each item that reached the reliability/maitainability goal with the item of next highest failure rate. The "top ten" list would be retained and worked until all reliabaility/maintainability goals were reached. The progress of the improvement program was to be measured through the reliability performance monitoring program updates and corresponding reductions in maintenance actions and spares usage.

Items falling into this category included "early wear-out" devices such as motor brushes, power collector assemblies, brake shoes; "high failure components", such as the audio announcement unit (reported to have early failure of up to 50 per day, with a requirement of 16,000 activations per day); and environmentally failed items, such as the signal brush bushing which, due to materials selection, was corroding. During the entire development and early service period, although low product reliability was evident, high service availability was to be made possible through more frequent maintenance, through the replacement of parts.

The AIRTRANS system characteristics using these concepts of availability, reliability, and maintainability were planned to (a) provide, through availability, a system level of service adequate to move people and goods throughout the D/FW Airport by airport opening date; (b) to reduce the level of maintenance personnel and material required to sustain this level of availability as soon thereafter as possible; and (c) to achieve reliability goals within three years from airport opening (within the three-year AIRTRANS Maintenance Task). The reliability figure was to be determined at system maturity, the point where product improvements were no longer cost effective and further increases in reliability brought increases in life cycle costs.

3.4.4 Availability

Availability (which is not part of or even referred to in the AIRTRANS specifications) combines the foregoing definitions as follows:

$$A = \frac{\text{MTBF}}{\text{MTBF + MTTR}} \quad \text{or} \quad \frac{\text{actual operating time}}{\text{scheduled operating time}}$$

where A denotes availability.

Table 3-5 reflects a common weakness of many reliability specifications for transit systems: the achievement of the required MTBF says nothing about the system's ability to perform, unless that MTBF is derived from prior considerations of what the system availability to the passenger must be. This type of weakness should be corrected in future specifications.

Establishment of tolerable passenger delays in a system must come first, and then system availability, MTBF, and MTTR must be derived from this primary requirement. Availability and dependability of service for the passenger depends on both MTBF and MTTR.

A new, informal definition of availability has come about during the past year of AIRTRANS operation, namely, the number of days without a system shutdown. This definition, in fact is no more meaningful than the MTBF figure already discussed. It merely states that in one instance, i.e., during a stated period, no system shutdown has occurred. Thus, it was stated that there has been no system shutdown since March 1975, "that was bad enought to require the use of busses". By this definition, the system could be described as 100-percent available during that period. True enough, nothing more than a few delays of 15 minutes to 30 minutes occurred in system operation, and several 5-minute delays were inserted during slack-time operation to permit guideway maintenance; but no emergency measures were taken. See Figure 3-5 which shows the number of failures during July 1975 plotted against the time required to restore the system to full operating condition.

3.4.5 Failure Management System

The AIRTRANS Failure Management System is an essential element of the overall operational procedures, as it minimizes the time needed to restore AIRTRANS to operation after failure. A brief summary of the failure management operation is given below.

Certain critical malfunctions pertaining to safety or performance are automatically reported from the AIRTRANS vehicles to Central Control. The computer-detected signals alert the operators at the Central Control by using (a) the animated AIRTRANS map on the control room wall; (b) flashing lights and train number displays on the control console; and (c) printed trouble descriptions on a TV-type display. The operator then takes the appropriate action to clear the system in minimum time.

Extensive logs and printouts are made each day, and each message flashed to the operator at the TV tube is also printed on a line printer. All the operator-maintenance radio conversations are recorded as they occur. Malfunctions due to failures usually result in a Malfunction Report (MR). The MR is initiated by the Maintenance Controller in a response to notification by the Central Control Operator of a stoppage or need for maintenance on the operating system. Completed MR's, including time lost, time expended, man hours, failure cause, etc., are compiled daily, key-punched and entered into a computer that prepares periodic tabulations of maintenance action. Handwritten logs of the operator's daily experiences are required for all three shifts; these amount to about 60-65 pages of records per week, which are all maintained in the APB files.

3.4.6 Test Program

The original plan for the AIRTRANS Test Program called for three discrete test phases to be performed over a 16 to 17-month period. The three discrete test phases were: Phase I - Design Verification; Phase II - Preliminary Systems Tests; and Phase III - Complete System and Demonstration Tests. The Phase I tests were continuous tests which were to begin as soon as hardware became available and were to be continued on the first segment of guideway at the airport, at Vought facilities or at vendor facilities, to ensure design verification. The Phase II testing was to be eight months in length and was to be performed at the first complete loop (2W-2E). The complete system testing was to be two months in duration and was to be performed after the guideway was completed.

These test programs had a threefold objective. First, to identify areas in which further engineering might be required to meet the system performance requirements; second, to demonstrate the performance of the various subsystems; and finally, to assure that the total system performed as specified. Extensive debugging was anticipated in each phase of the test program based on the past experience of similar, but less sophisticated transportation systems. It should be emphasized that the necessity of working out minor problems during the early stages of a test program is normal and anticipated and does not represent inadequate design. However, the late availability of the guideway, as well as other disruptions, caused a significant delay and disorganization. In turn, these caused the test program to deviate from the original plans.

These problems, coupled to the late availability of the guideway caused in part by the difficulty in scheduling and interfacing with other contrators working on other construction jobs at the airport, caused delay in overall testing. AIRTRANS was thus put in service before adequate testing could be performed.

Phase I, as originally planned, was to begin with off-site tests performed, by the contractor and his subcontractors, to verify subsystem and component performances prior to production. Dynamic testing, both in-plant and on a test section of the guideway, would be used to verify the operational adequacy of these subsystems. Any initial changes required as a result of these tests would be scheduled into production. These tests were due to start before any of the production vehicles would be manufactured. Accordingly, the original plan called for a specially built test chassis for testing on the first thousand feet of guideway, which was due to be available at the airport on March 10, 1972, and on the completed 1W, 2W, and 2E halfloops, when available. These tests were due to continue for a period of approximately six months.

In Phase II, as originally planned, the first production vehicles were to be tested in the earliest available guideway installations, all of which would be modified to reflect whatever changes proved necessary from the Phase I test. These tests were due to begin about September 1, 1972, and continue until each section of the guideway had been completed and satisfactorily checked out. The most meaningful part of the Phase II tests were scheduled to begin at the end of October 1972, when the first available closed-loop section of the guideway, the 1-2 loops, should have been available. This guideway loop was really the nucleus of the complete test program. It contained all features of the complete system and would allow all subsystems to be integrated, allowing the contractor to make changes as required and to reflect these changes in the fabrication and installation of vehicles and guidance and control subsystems in remaining areas of guideway, as they were contructed. The continuous 1-2 loops would allow multi-vehicle operations of passenger, employee, trash, supply, AMF, and baggage systems. This loop test operation was planned to continue throughout the test and design process. Performance on these test routes would be upgraded, and the contractor would be able to identify improvements to be incorporated in subsequent guideway areas.

This approach would ensure that the complete system performance requirements would be met by demonstration in the latter stages of the complete system tests.

The planned system growth to completion was to use each portion of the guideway, as it became available, so that vehicle operation could progress from the 2W-2E loop. Sections 1W, 3E, 4E, 5E, and 6W would be incorporated into the operations in the order promised by the contract and by the February 4, 1972, Work Program Plan (WPP). No segmented tests were planned, because testing on discontinuous guideway would necessarily involve gross inefficiencies.

As these new and continuous guideway areas expanded from the 2W-2E loop, the checkout of operational routes would begin. Vehicles would be introduced in the production routes, as available, until a full vehicle complement for that route was achieved. In this manner, the number of operational routes would build progressively, to the point of complete system operation.

Phase III complete systems testing, as originally planned, was to start about April 16, 1973, to upgrade the system performances and permit any final adjustments on the completely operational system. The two-week final demonstration was to be conducted just prior to system completion, scheduled for July 15, 1973. During Phase III, the contractor would conduct a training program for airport, airline, U.S. Postal Service, and Dobbs House (airport supplies) personnel. Also, an AIRTRANS maintenance operational routine would be evolved during this period.

The AIRTRANS Test Program definition, as presented by the February 4, 1972, Work Program Plan, consists of (a) Phase I testing, Design Verification Tests; (b) Phase II testing, Preliminary Systems Test; and (c) Phase III, Complete Systems Tests and Demonstrations.

Discrete tests required to show AIRTRANS specifications compliance or performance capability were detailed in a formal Test Plan for each phase of testing before the beginning of the tests.

The description of each test in the plan was presented in a format which stated (1) test objective, (2) test procedure, (3) information to be obtained, and (4) test schedule. "Working" test plans were prepared by each test engineer assigned to a particular test. These test plans were normally in the form of an ATR (AIRTRANS Test Request), initiated and appropriately logged under a given test phase, along with accumulated data.

Test reports were prepared at two levels. TIR's (Test Information Releases) were issued to Engineering when a specific test was conducted that was preliminary in nature, or was one test of a series required to demonstrate subsystem or system performance. Formal test reports were issued that presented the results of each test as outlined in previously issued test plans.

The critical test program, as a result of the difficulties involved in the construction of the guideway, was about 8 months late. The 1W, 2W, and 2E half-loops were available in late 1972, as opposed to the scheduled date of March 1972. The Phase II testing, scheduled to be initiated in September of 1972, was started in early 1973. The complete system testing, scheduled for completion in July of 1973, was not begun until late 1973 and was never completed prior to initiating revenue service in January of 1974. Had there been adequate testing, many of the early "infant mortality problems" would have been corrected.

3.4.7 Acceptance

This issue constituted a major problem between the APB and Vought Corporation. Problems relating to definition of terms, test methods, test times or length, interpretation of data, etc., were never totally agreed upon to the effect that the final acceptance process could be completed within the framework of the original contract. Paragraph 3.2.11 of the original AIRTRANS specification, entitled "System Acceptance", states:

> "Final Acceptance of AIRTRANS by the Owner will be made on the basis of satisfactory accomplishment of the design,

fabrication, testing, installation, and check-out of all portions of the system, and all training of personnel and delivery of spare equipment and manuals, in accordance with the Contract Documents, and as required for a complete operating system."

In mid-1974, it became obvious that some portions of the total system were operating closer to specifications than others, while some did not represent, from the Airport Board's point of view, "satisfactory accomplishment". The Airport Board and the contractor were then left with the problems of how to define the status of the system and how the parts operating satisfactorily could be accepted on an interim basis, without removing the binding contractual agreement just quoted.

To make this first step toward acceptance, the APB issued "Supplemental Agreement No. 15" to the contract. To quote from the introduction to the APB's report of December 9, 1974, entitled AIRTRANS Revenue Operation Level Report, "Supplemental Agreement No. 15 to the AIRTRANS Contract established a level of system performance called 'Revenue Operation Level,' which although not fully in compliance with the contract requirements, is ... sufficiently complete and reliably operable to the extent necessary for successful use." Supplemental Agreement No. 15 declared that the AIRTRANS passenger and airmail subsystems had achieved Revenue Operation Level (ROL), and further provided that the Owner (Airport Board) and Contractor (Vought Corporation) would jointly establish two sets of criteria ... "(1) to establish Revenue Operation Level for subsequent AIRTRANS subsystems, and (2) for acceptance of the AIRTRANS system. The purpose of this Report is to document both the development of the Revenue Operation Level criteria called out in Supplemental Agreement No. 15, and also the subsequent tests of the AIRTRANS employee, baggage, trash, and supply subsystems, which established them as having achieved ROL."

A further quote from the referenced report stated: "The reasons for the Board's creating the intermediate perfomance level called ROL stem from the fact that the AIRTRANS system was placed in passenger service by Vought (with the Board's consent) on January 13, 1974, prior to any acceptance tests or demonstrations. The AIRTRANS contract, as originally written, contemplated that the system would be constructed and tested in a dry mode, and some form of acceptance made before revenue service was initiated. Once the system was placed in operation, it became impossible to follow the original contractual procedures for acceptance, except by withdrawing the system from revenue service. This was unacceptable to the Board and the airlines at DFW.

Accordingly, the procedure now known as Revenue Operation Level was conceived, and embodied in the Supplemental Agreement No. 15 to the AIRTRANS Contract. It is important to note that Supplemental Agreement No. 15 contains other significant provisions. One of these is an agreement by the Contractor (Vought) that the AIRTRANS system will not be withdrawn from revenue service without the Board's consent. This provision was of utmost importance to both the Board and airlines operating at DFW."

In accordance with the ROL, tests were developed in the fall of 1974, and all the AIRTRANS subsystems - passenger, airmail, baggage, employee, trash, and supply - were determined to have passed this milestone. "Acceptance", however, still eluded both parties. In February, 1975, Vought issued an "AIRTRANS Performance Analysis Report", which reviewed the status of each subsystem, including the indicated reliability (MTBF) of the subsystem. Seven months later the system had not yet been "accepted", and several of the subsystems were not being operated because they did not have the performance necessary for the current requirements of the airlines. (The current requirements were more stringent than those originally contracted for with Vought.)

Some of the trouble has resulted from changing requirements beyond the scope of the original specifications; some has resulted from inadequate detail in the original specifications; and some has been caused by inadequately defined acceptance procedures. Lack of definition, and lack of agreement on what the definitions should be when this omission was recognized, were perhaps the greatest causes of the delay. As a result, the system was operated in the pre-acceptance state, and all the measures of reliability and maintainability that were necessary to meet the specification were not implemented.

A further quote from the ROL report cited above reads as follows:

> "The AIRTRANS Specifications also include performance requirements on system reliability. Thus, it is important to note that a measure of system reliability is inherent in the above performance parameters. Obviously, trip times (for example) cannot begin to approach the specification requirements unless the system is operating with reasonable reliability. The above three performance parameters include reliability. Because of this, no direct measurement of system reliability was included in the ROL criteria, since by Specification, reliability verification monitoring commences after Acceptance, and reliability per se is not a requirement for Acceptance."

Certainly, at a minimum, some attempt should have been made to define some sort of reliability or availability figure at "acceptance", with its growth related to the overall/life cycle costs.

It cannot be emphasized enough that acceptance, its definitions, procedures, and criteria must be completely understood and appreciated by both buyer and seller at the time of contract signing.

3.5 INTERFACES

3.5.1 Convenience-of-Use

The AIRTRANS system was designed to transport airline passengers and also airport employees.

It has already been pointed out that travel time and service dependability problems had made AIRTRANS service unacceptable to airport employees. Due to these early dependability problems, busses were used to get the employees to their places of employment.

Since the assessment period, changes have been made to the employee portion of the AIRTRANS system. The changes include dedicated vehicle routes to each terminal and elimination of a "double jog" at each employee station. These changes resulted in a reduced travel time and since March 1976 employees have successfully used the AIRTRANS system with little difficulty.

3.5.2 Ease of Access

The average airline passenger familiar with AIRTRANS has to walk shorter distances at the Dallas/Fort Worth Airport than at any other major airport in the world. The airline terminal-gate areas are connected to the AIRTRANS stations by means of elevators and escalators, as well as stairs. Thus, for the airline passengers making connecting flights travel between airline terminals can be done with relative ease. In addition, the traveler who drives his automobile to the airport has access to AIRTRANS station at either of the two remote parking lots.

There are facilities for handicapped passengers at all but one of the AIRTRANS stations. The one station without special facilities is at the Airport Hotel, which provides alternate transportation for its handicapped guests to and from the airline terminals. The Hotel station access is via an escallator. At all AIRTRANS stations, for any passenger with a disability which precludes his use of the turnstiles, there are gates which are wide enough to accommodate a wheelchair. Although these gates are normally locked, airport or

AIRTRANS personnel can unlock them when necessary. Once in the AIRTRANS station, the handicapped individual should have no difficulty boarding the AIRTRANS vehicle although some difficulties and discomfort could occur during crowded conditions.

3.5.3 Signage

The signs directing the passengers to the AIRTRANS system are of the same general design as all other signs used in the airport. (See Figure 3-6.) This similarity coupled to their small size adds to the difficulty of using AIRTRANS.

In addition to this similarity and small size of the signs, many are placed close to the ceiling, further decreasing the likelihood of their being seen which further reduces their effectiveness. Many first-time users have had trouble locating the AIRTRANS stations.

Within stations the first signs used in the system describing the route structures were located above the door in the train barrier at the edge of the station platform and used a white lettering on a dark background. Many first time users of the system again had problems in locating the signs and thus knowing which vehicle to take to his or her destinction.

Such problems were recognized by the Airport Board, and a study of new signs for the stations was carried out at one of the AIRTRANS stations. In the new signs the routes serving this station have been given color names, and these colors are used in the signs for the corresponding routes. The evaluation of these signs was still in progress at the time of the team assessment. The installation of the new signs however was completed in all stations following the assessment visits.

The new signs were determined to be much better than the original ones, however, the new signs are still in the original positions above the doors, and as such are not in the direct vision of the passenger entering the station. These signs however are lighted

Figure 3-6 AIRTRANS Signage — Directing

and have a chime sounded to attract attention, as each train approaches the station. The airlines serviced by each route however, are listed in alphabetical order, and, as a result, the first-time user of an AIRTRANS train has difficulty in perception of travel time or distance to be covered to the destination (see Figure 3-7). The train, however, is equipped with an audio annunciator unit (AAU) which announces the name of each station just prior to stopping at it. The importance of good information transmission mechanizms keyed to the sensory functions in any automated system should not be underestimated.

3.5.4 Stations

The overall floor space of each AIRTRANS stations is more than adequate for the present volume of passengers. Judging from observations made during peak travel time at AIRTRANS station 3EB (the busiest), the space in the stations appears to be sufficient for triple the present demand level.

Except for the stations at the parking lots and at the hotel, each AIRTRANS station has two entrance-turnstiles and two exit-turnstiles at either end. The turnstiles are separated by a gate for traffic such as luggage trucks and wheelchairs. For the passenger carrying his own luggage, there is sufficient space beneath these gates to allow luggage to be pushed under rather than be lifted over. A sheet of metal has been attached to the floor beneath each of the gates, to facilitate sliding luggage in or out of the station area.

The depth of the stations is not really sufficient for these four turnstiles and gate. The outer turnstiles receive much less use than the inner ones because there is no space between them and the walls. The differences in the wear of the floor covering at each of the turnstiles attests to the differences in the number of passengers using each one. People tend to stay at least a half body width away from walls, as they move about a room or down a

Figure 3-7 Signs Within AIRTRANS Stations

corridor. There is not enough space between the outer turnstile and the wall for a passenger, even with the lightest bag, to use this turnstile and feel comfortable about it.

Pedestrian traffic usually follows the same "keep-right" rule as does highway traffic. Any conditions requiring pedestrian traffic to move contrary to this rule become disruptive to the traffic flow. The arrangement of the uni-directional entrance and exit turnstiles in an AIRTRANS station requires pedestrian traffic to move contrary to the "keep-right" rule. The two entrance turnstiles at either end of the station are on the side of the station that is closer to the guideway. Therefore, upon leaving the train, the passengers turning left and obeying the "keep-right" rule have no trouble; they use the exit turnstiles. The passengers turning right and obeying the "keep-right" rule, however, attempt to leave by the entrance turnstiles. In some of the stations, attempts have been made to overcome this problem for the right-turning passenger by putting large arrows of masking tape on the floor, pointing to the exit turnstiles. (See Figure 3-8).

3.5.5 Comfort Factors

Comfort factors include ride quality, noise, temperature, humidity, and illumination. Specifications were provided for all these factors, and tests were performed to verify AIRTRANS compliance with the requirements. The test results are reported in the Performance Analysis Report. A discussion of each of these comfort factors follows.

3.5.5.1 Ride Quality

Ride quality is normally defined in terms of the moving vehicle's dynamic physical attributes as they impact on the rider. These attributes include acceleration levels in all six degrees of freedom. How these attributes relate to passenger perception of ride quality in a vehicle is not yet fully determined. There is a pressing need for much systematic, basic research in this area; overdesign of a vehicle and/or guideway beyond that necessary to achieve a level of ride quality acceptable to the riders can result

Figure 3-8 Interior Views of AIRTRANS Station

in unnecessarily high costs for transit systems.*

Vibration

In order to evaluate the AIRTRANS specification for vehicle ride, vehicle ride criteria from the AIRTRANS Specifications have been converted to equal units and superimposed on the standard curves for whole-body vibration, according to ISO Standards shown in Figure 3-10.

On the basis of these comparisons the specification for vertical accelerations of the vehicle (longitudinal body axis, Figure 3-10) is more stringent than necessary, when it is considered that the duration of the ride between the most distant AIRTRANS stations on any one loop is normally under 30 minutes, including the time for stops at intervening stations. Furthermore, the unnecessarily high vibrational comfort requirement is all the more significant, because damping to reduce vibrations for frequencies below 8 Hertz is expensive.

The specifications for longitudinal and lateral vehicle vibratory accelerations (transverse body axis, Figure 3-9) are too stringent in the high frequency range, and somewhat lax for lateral vibrations in the low frequency range (sway).

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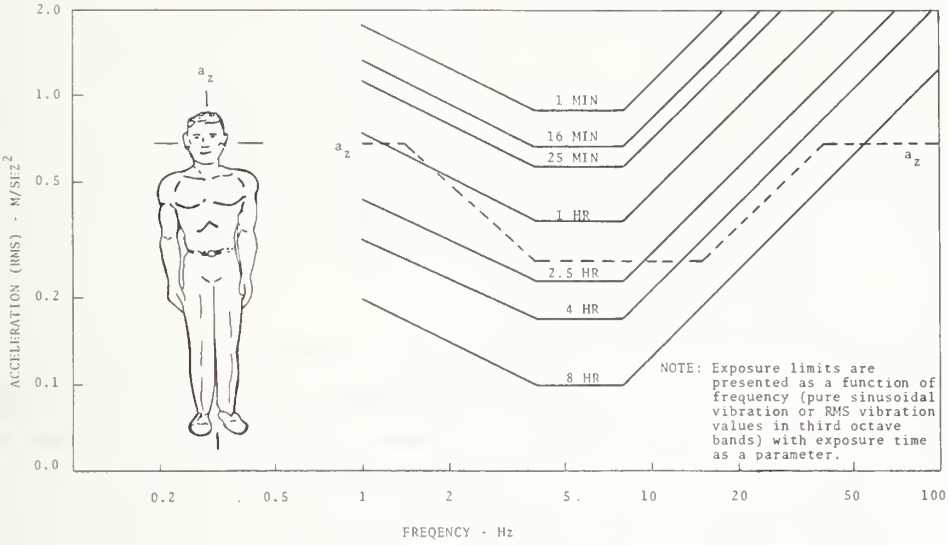
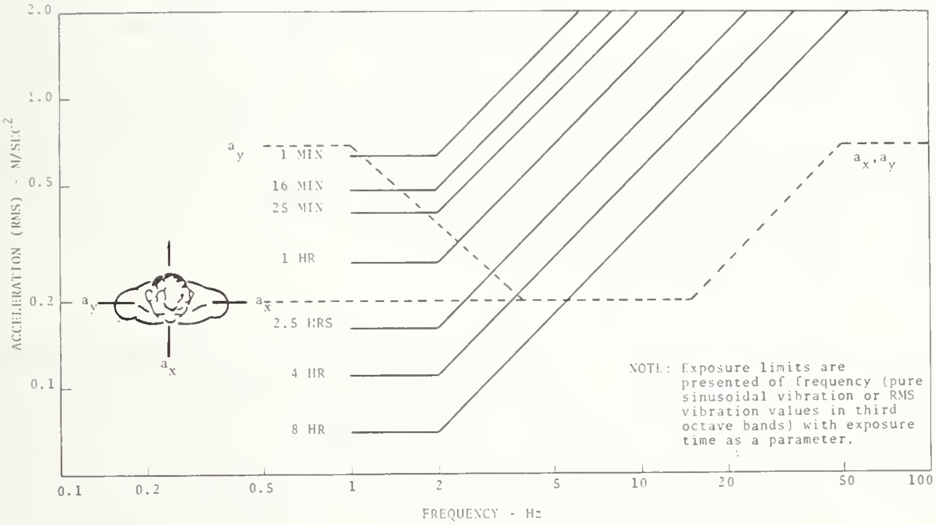
*The most comprehensive data available on which to base specifications for the dynamic physical attributes of a transit vehicle can be found in the following references:

1. ISO Standard, "Guide for the Evaluation of Human Exposure to Whole-Body Vibration", ISO 2631 (similar to MIL-STD-1472A).
2. "Acceleration and Comfort in Public Ground Transportation" by J. W. Gebhard, The John Hopkins University, Applied Physics Laboratory Report No. TPR 002, February 1970.
3. "Human Sensitivity to Whole-Body Vibration in Urban Transportation Systems" by R. M. Hanes, The John Hopkins University, Applied Physics Laboratory Report No. TPR 004, May 1970.





Notes:

1. Solid lines represent ISO vibrations criteria.
2. Dashed curves represent vibration specifications with respect to body axes.

Figure 3-9 AIRTRANS Acceleration/Vibration Ride Quality Criteria

Whether the specifications for vibratory acceleration are considered too stringent or not, the "AIRTRANS Performance Analysis Report, A5", of 14 February 1975, by Vought Corporation, reports that AIRTRANS substantially meets the specifications for vibratory accelerations. Both guideway and vehicle modifications were required to attain this level of ride quality performance.

Sustanined Acceleration and Jerk

Because of the interrelationship of sustained accelerations and jerk with the dynamics of vehicle operation, they should be discussed together. The impact of these parameters on ride quality is not yet fully understood. The AIRTRANS specifications for substained acceleration and jerk, both positive and negative, are in agreement with the criteria typically specified in the transportation industry for a rail/guideway vehicle. The Vought Corporation reported in "AIRTRANS Performance Analysis, A5," that specification requirements have been substantially met since the exception to an absolute compliance occurs only in one of these axes and then only during 1% of the time. This time pertains to the elapsed time for tranversing a selected test site. The test site when compared to a normal revenue route presents a higher number of encounters with 100 foot radius turns and switches.

Other Ride Quality Factors

Even though Vought reported in "AIRTRANS Performance Analysis, A5", that the ride quality specifications for AIRTRANS had been fulfilled, there have been reports, including one from the Office of Technology Assessment (OTA)* to the effect that the ride quality of AIRTRANS is inadequate because of sway and jerk. The OTA, without specific reference to AIRTRANS, considers guideway roughness a problem afflicting all AGT systems. The TSC assessment team found the ride acceptable, but believed it could be better. The apparent conflict between the physical measurements and subjective evaluations of the ride quality of AIRTRANS vehicles could well be due to

*U.S. Congress, Office of Technology Assessment, Automated Guideway Transit, June 1975.

the pattern of the vehicle dynamics, rather than their absolute magnitudes. The features that elicited the largest number of comments from this team, concerned the frequency with which the vehicles had to change velocity. Because of the airport layout configuration, the right-of-way of the AIRTRANS guideways has many curves, underpasses, and overpasses, and short between-station runs. These conditions create a need for frequent acceleration and deceleration.

In addition to the frequent changes in velocity required by the short inter-station distances, there are a number of other factors which might affect ride quality. These factors include the roughness of the horizontal riding-surface of the guideway, the tires and vehicle suspension system, the vertical guiding-surfaces of the guideway, and the guidance system of the vehicle. The extent to which these factors contribute to ride quality is the subject of a study being conducted by the University of Texas at Austin.* This study calls for measurement of the dynamic physical attributes of the AIRTRANS vehicles, the development of mathematical models of vehicle dynamic behavior, the examination of the nature of the vehicle inputs from both steering arms and power collectors, and the correlation of these data with passenger responses to ride quality. The final results of this investigation will be available in 1977.

3.5.5.2 Noise

Noise specifications are directed at the inside of each passenger vehicle, 5 feet above the floor, but not within 12 inches of the wall, and with all equipment functioning. Under these conditions, average noise levels are not to exceed NCA 60, based upon the preferred octave band center frequencies. Repetitive impact noises are not to exceed NCA 60 by more than 10 dB, non-repetitive impact noises by 15 dB, in any octave band.

Similar specifications are directed at enclosed station platforms at least 3 feet away from closed doors, as well as at outside

*Grant No. DOT-OS-50126, Ride Quality Studies on Ground-Based Transportation Systems.

areas at distances of 100 feet or more away from the guideway. For station platforms with no walls, the permitted noise level, five feet away from the train and five feet above the floor, is raised to NCA 70.

Noise measurements, reported in Vought Report ATRE-007 and shown here in Figures 3-10 and 3-11, indicate near compliance with these requirements. The HVAC system, door operators, and the propulsion system were reported to cause minor compliance problems at certain octave bands, inside vehicles and on station platforms.

Careful selection of key components could have improved noise performance for the AIRTRANS systems. Considering future urban applications, with its anticipated higher speeds and close proximity to residential areas, an improvement in the exterior noise performance over the present AIRTRANS level may be desired. However, some indication of vehicle presence is a necessity. At the present speed of 25 ft/sec or less, the noise level is acceptable in an urban environment.

3.5.5.3 Temperature, Humidity, Illumination

The principal performance requirements for heating and cooling the AIRTRANS passenger vehicles are as follows:

Heating: 70 ±2.5°F

Cooling: 75 ±2.5°F and 60% (or less) relative humidity applicable at the ambient conditions shown in Table 3-6.

TABLE 3-6 HEATING AND COOLING REQUIREMENTS

Parameter	Heating Conditions	Cooling Conditions
Dry Bulb Temp., °F	20	100
Wet Bulb Temp., °F	n/a	78
Wind Velocity, mph	25	n/a
Solar Radiation, B/H/ft^2	n/a	296
Passenger Load	empty	capacity

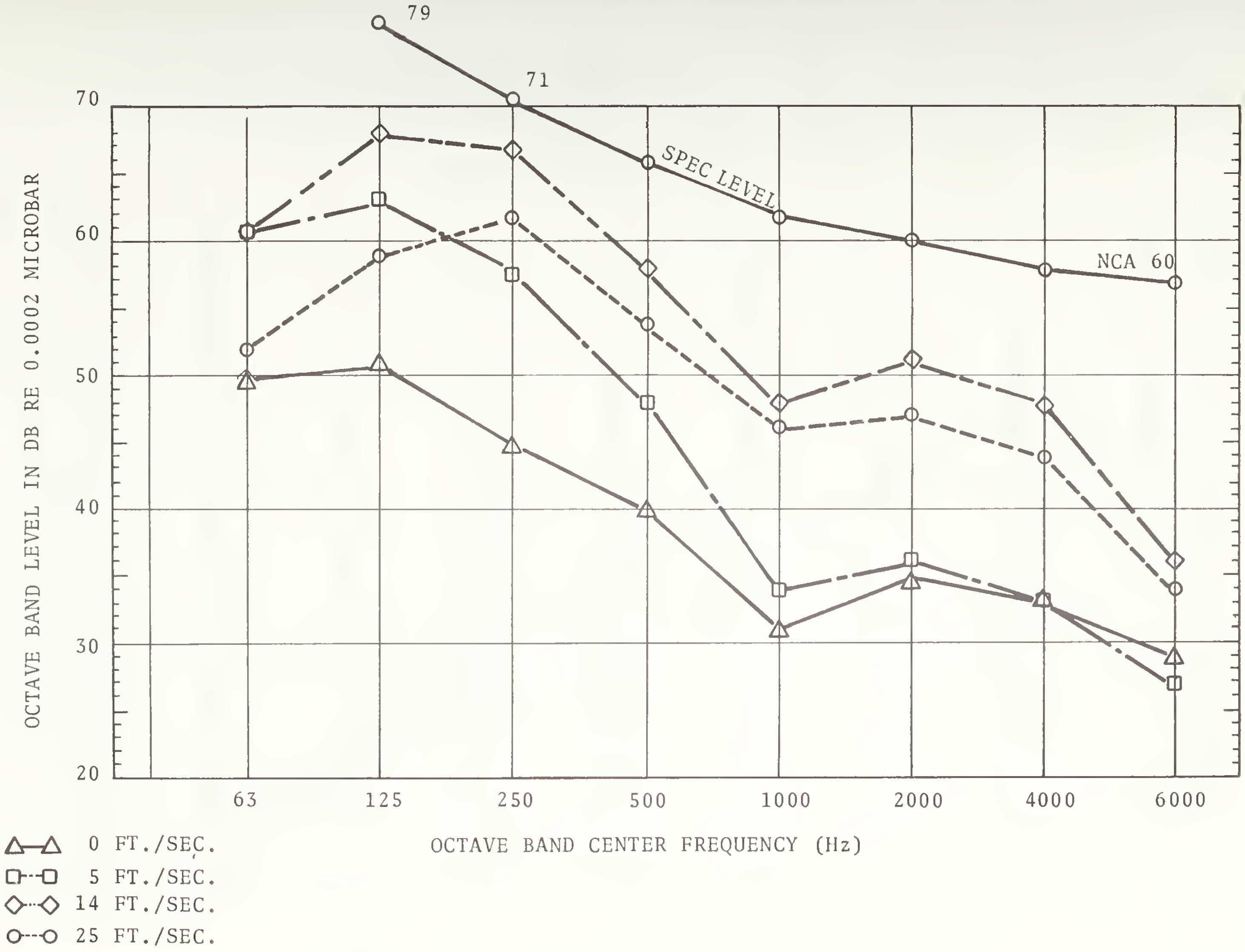


Figure 3-10 AIRTRANS External Noise

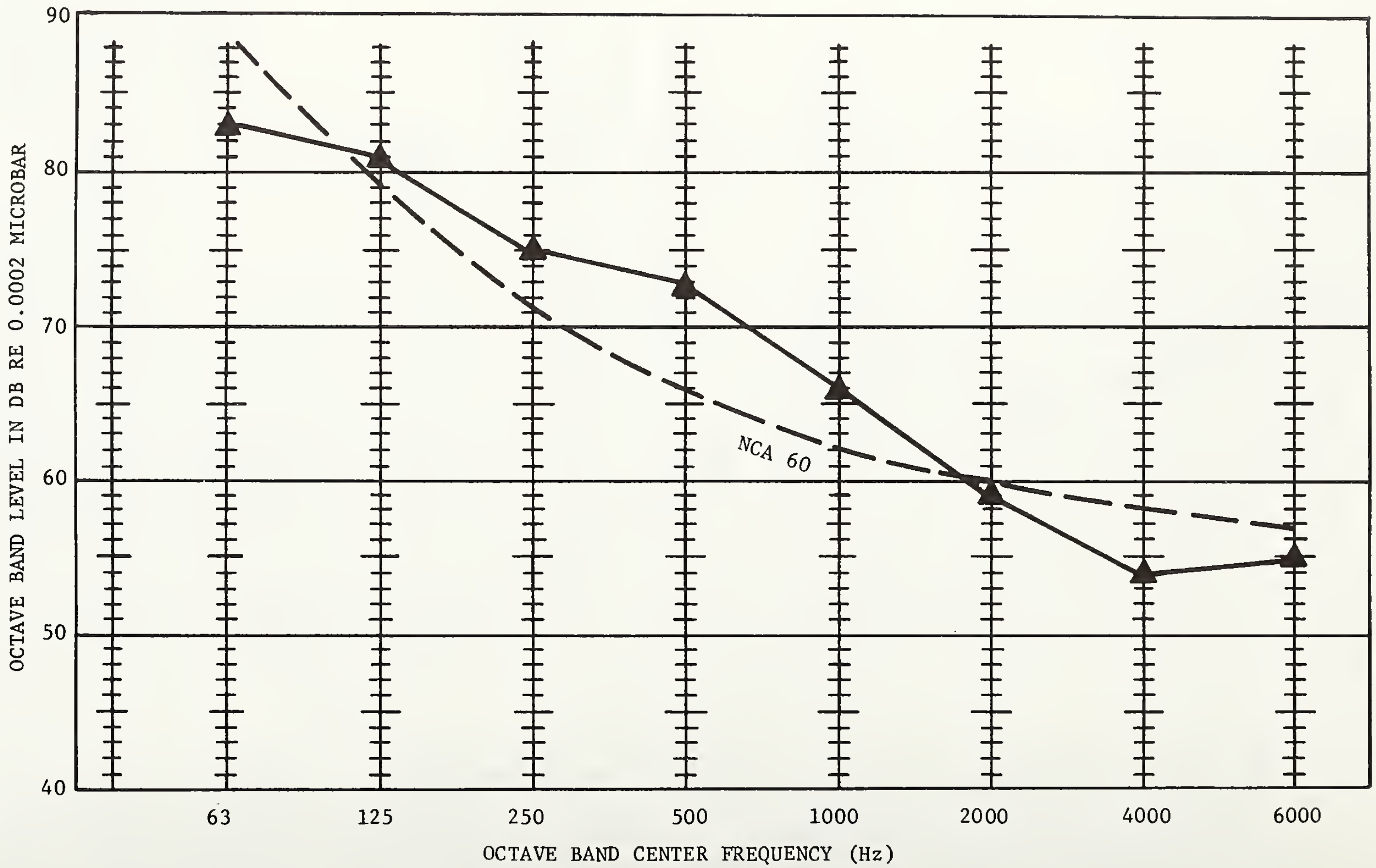


Figure 3-11 AIRTRANS Vehicle Internal Noise with Air Conditioning Operating, (Combined Runs 11 and 14)

In addition, a minimum circulation of 30 cfm of air is required for each passenger at capacity load (40 passengers). Of this flow, 7.5 cfm per passenger is to be makeup air from the outside. Verification tests, reported in Vought report #ATRE-007, Section 6.8, indicate compliance with these specifications.

The need for a reliable heating/cooling subsystem is highlighted by early AIRTRANS hot weather experience in which electrical system failures have vehicle internal temperature to rise appreciably. In such cases, passengers have occasionally forced doors to get out (perhaps unsafely on the guideway), in preference to waiting "rescue".

Specifications have been provided for both normal and emergency lighting; tests indicated substantial compliance with these specifications. In March 1974, the AIRTRANS vehicle lighting system received the Illuminating Engineering Society award for excellence.

3.5.6 Central Controllers

AIRTRANS specifications require that the vehicles normally operate automatically, without operators on board. Human operators, however, are required in the overall control of the system. The philosophy that should be used in the design of the man/system interface at Central Control was not in the specifications. The controller's role can be either active or, as in AIRTRANS, reactive. In an active role, the controller must analyze and/or integrate information displayed to him, in order to determine the status of the system and to make appropriate decisions. Since the rate and amount of information that man can receive and process is quite limited, the manning requirements for an active system are extremely sensitive to information transmission requirements for this man/system interface. This is not the case for a reactive system. In the AIRTRANS reactive role, the controller is not required to analyze or integrate any information, but responds to specific, readily identifiable stimuli, for example, a flashing light indicating that control attention is necessary. These specific stimuli need indicate only that certain conditions, emergencies, malfunctions, etc., exist. The controller acknowledges the occurence of the stimulus and follows established standard operating procedures, to determine exactly what the problem is, as weill as to take the steps necessary to rectify it in a timely fashion.

The design of the man/system interface at Central Control and the standard operating procedures that have been developed appear to be more than adequate. A review of the standard operating procedures indicated that they are primarily reactive; there are specific stimuli for each of the standard operating procedures needed to keep the system operative. The system design coupled to these well established procedures for operators have made the operator duties more routine. (see Figure 3-12). The selection of this reative type cental approach has proven to be an excellent approach in the operation of this system.

3.5.7 Maintenance

The AIRTRANS rovers are special maintenance personnel roving about the system, ready at all times to respond to calls from Central Control, when something is amiss with the system. In addition to responding to the calls, the rover performs periodic preventive maintenance on the switches, station doors, and any other operating parts of the system. The rovers are, for the AIRTRANS system, the first line of defense against failures; their primary purpose is to keep the AIRTRANS vehicles moving.

On site, in response to a trouble call from Central Control, the rover is expected to follow well-developed, standardized, troubleshooting procedures. With concurrence from the controller, he has considerable leeway to determine how the trouble should be corrected. Effectively, the rover has three possible courses of action: (a) correct the trouble on site, (b) operate the vehicle manually until it can be removed from the line without disrupting service, or, (c) (the least-desirable) use a tow vehicle to remove the incapacitated vehicle from service immediately.

The chosen course must be that which restores full system

Figure 3-12 AIRTRANS Central Control

operation in the fastest manner possible, with minimum incovenience to the passengers. A rover is expected to do everything possible to get the system back up in less than 15 minutes, i.e., the time limit at which the controllers will call out the busses to transport the passengers until the system is up again.

The dedication of the rovers to keeping the system in service is critical to the operation of AIRTRANS. As the reliability of the AIRTRANS system has increased, the number of rovers on duty at any one time has been reduced. At the times of assessment team visits, there were six rovers on duty at any one time, and, most important, there had been no need to use the busses for more than three months.

3.5.8 EMPLOYEE TRAINING

3.5.8.1 Central Controllers

The AIRTRANS specifications state that the contractor shall provide all training necessary to ensure the competence of the owner's personnel, and shall provide copies of all manuals and/or instruction material. The only documentation on training received from Vought was a syllabus for the training of central controllers for the AIRTRANS system. The syllabus appears to be an excellent program for training of such personnel and has been included in this report as an appendix.

Vought and the airport staff also developed a handbook on standard operating procedures for the operation of the AIRTRANS system. These procedures were reviewed in an attempt to identify any operating situations that had been overlooked, but none could be so identified. The controllers trained to operate on the basis of these standardized procedures appeared to be well in control of the situation, when they were observed on duty at the AIRTRANS Central Control.

3.5.8.2 Maintenance Personnel

Maintenance personnel constitute a major operating cost for AIRTRANS. In view of the AIRTRANS experience, similar high costs must be predicted for any transit system regardless of the designer and builder during the initial months of revenue operation. These costs will vary with the labor market and with local conditions, e.g., whether or not the personnel are unionized. The personnel maintaining AIRTRANS are not unionized. No documentation on the training of maintenance personnel was made available; however, Vought Corporation stated that maintenance personnel received extensive formal training in all aspects of their work. These courses varied in length from two days to two weeks. Each employee is trained in as many areas of work as possible. Thus, as the demand for maintenance decreases as the system matures, this cross-training will allow maintenance force reductions while maintaining high maintenance capability.

Because the proper operation of automatic vehicle protection and automatic vehicle operation controls is so critical to the safety of an automatic guideway transportation system, the personnel responsible for the maintenance of the AVP system received special training. This formal training was given by the manufacturer, General Railway Signal Company (GRS). GRS required such training as a prerequisite to guaranteeing the equipment.

3.6 SAFETY

The safety of passengers on AIRTRANS was considered an all important requirement, both in developing the specifications and in designing the system itself. A conservative approach was taken in providing a time-tested, highly reliable, block type train protection system.

AIRTRANS relies heavily on a fail-safe design to meet the non-quantitative and non-statistical safety requirements. Passenger safety is the paramount design requirement within the framework of overall performance goals. All control methods, circuitry, mechanical equipment, and operating procedures provided by the contractor conform with this requirement. In correcting unsafe conditions developing from equipment failure or a procedural error, fail-safe designs are employed to prevent recurrence. While it is important for the system design to minimize possible damage to equipment, the safety of people is the dominant factor governing any conflicting situation.

The above requirement resulted in the use of vital relays in the safety system, both in the vehicle and on the wayside, and the development of a safety-oriented failure mode analysis. The analysis did not, however, include fault trees or hazard analyses other than those related to failure modes. A certificate of safety was required by the contractor and the subcontractor responsible for command and control. Also, Battelle mad an independent safety analysis for the airport.

3.6.1 Methodology of System Analysis

The specification divides the failure categories into three classes according to the seriousness of the failure. These failure classes are as follows:

(1) Class I malfunctions are those that pose a threat to the safety and integrity of the train and hence, the entire system. Under such conditions, the train's emergency brakes shall be applied and maintained. The information that a Class I malfunction has occurred shall be immediately displayed on the Central Control console and shall include the identification of the train in which the malfunction occurred and the location of that train.

(2) Class II malfunctions are those malfunctions that may affect vehicle safety, but which may be self-correcting. Following a Class II malfunction, irrevocable service brakes shall be applied on the train and information that a Class II malfunction has occurred shall be immediately displayed on the Central Control console and shall include the identity and location of the train.

(3) Class III malfunctions are defined as those that do not require immediate action, but whose correction can be a matter of judgement on the part of the Central Control Operator. The information that a Class III malfunction has occurred shall be immediately displayed on the Central Control console and shall include the train

identification and location. However, the brakes shall not be applied automatically.

A considerable amount of safety analysis work was performed by the contractor. Failure mode analyses were performed for the entire system, including stations, and turnstiles. The analyses, however, were qualitative, and no fault-tree analyses were performed. As an example, there is a possible, although remote, source of trouble when a maintenance man drives a vehicle that is to be removed from operation after a Class I malfunction. In the manual mode of operation, there is automatic detection of occupied blocks ahead, but since the vehicle is under control of a human operator, there is a possibility that the vehicle could collide with an automatic train ahead, if the operator fails to note and ensure the safe speed for the upcoming blocks.

3.6.2 Safety Performance

The total AIRTRANS performance has been excellent from a safety viewpoint up to this time. No collisions have been reported for vehicles in automatic operation, and the failure management system has worked adequately in Class I malfunction cases by bringing help to the incapacitated vehicle without delay. A functional departure testing system is used to test all vehicles before committing them to the guideway from the maintenance area.

More fence protection is needed for the guideway to keep unauthorized people off the guideway. The vehicles are "implacable", and have no obstacle detection capability. Some vehicles under automatic control have hit small animals, golf balls, bowling balls, and luggage, but, so far, no passengers. Two Vought maintenance people were struck by utility vehicles on two separate occasions.

The excellent user safety record is partially a result of the setting, the use of enclosed platforms at passenger stations, the safety system, the vehicle voice communication system and the use of TV surveillance in stations. For AGT applications in urban areas, however, these issues must be reviewed to determine whether additional items such as obstacle detection are required to ensure safety.

When designing the system, Vought and the APB staff decided against providing any emergency-stop pushbuttons for passenger use on the AIRTRANS vehicles. A two-way communication system, however, has been provided for passenger use, in case Central Control must be contacted for any reason, including passenger emergency. It is doubtful if the communication response time would be fast enough to allow, Central Control to stop the vehicle in the event an obstacle were seen and reported by a passenger. Opening the emergency doors or forcing open the regular entrance/exit door, for that matter, would stop the train as a Class I malfunction. However, it is also doubtful that people not familiar with the safety interlock system would resort to such action. In terms of minimizing operational shutdowns of service, the decision against public stop switches can be accepted as reasonable. No safety-related accidents have occurred to date that would suggest a need for design change in this respect.

In passenger stations, the platform/guideway interface is protected with a glass enclosure making it almost impossible for the passengers to step onto the guideway. The employee stations do not have a forbidding separation between guideway and station, the latter having no doors, while a simple railing denotes the edge of platform along the guideway. Despite this, such a station is more enclosed than a normally encountered, conventional city-rapid-transit station.

Consideration was given to flammability characteristics of materials. Manufacturers of materials used in AIRTRANS vehicles provided flammability information on their products against AIR-TRANS specifications. However, no detailed verification testing was performed by the contractor. Fire extinguishers and emergency exit doors provided at each end of a vehicle, indicate recognition of the importance of the fire protection problem. The only fire incident on record at the time of this writing had occurred on a grade under icing conditions, when spinning traction wheels caused a rubber tire to ignite. The fire was quickly extinguished by a rover.

The fact that in a fire emergency the passengers would egress onto the guideway leads to considerations of electrical hazard cause of the power rail. Initially, electrical safety was to be ensured by interlocking the power rail with the opening the emergency doors. System analyses considering the resulting discomfort in a vehicle without air conditioning, the potential problem of passengers then leaving the vehicle on to the guideway, and the requirement for maintenance people to access a stalled vehicle without impacting other vehicles in a power zone, brought about a decision not to include the interlock. Based on the results to date, this decision has proven to be a good one. Electrical safety is obtained by grounding the vehicle structure, to prevent shock to passengers.

The breaking of a coupling between two cars of a moving train is always a potential hazard. The two-car AIRTRANS trains are protected against the hazards of such a happening by the fail-safe operation of the emergency brakes on the trailing vehicle and by the simultaneous application of the irrevocable service brakes on the lead vehicle. The difference in braking intensity between the emergency and service brakes reduces the chance of a collision between the two halves of the broken train.

A commendable design feature for train speed control has been built into the remote control arrangement, providing the vital wayside-to-vehicle speed commands with fail-safe characteristics. The vehicle-borne vital relay becomes energized only when all aspects of the command communications system function properly. A partial failure of the vital communications system can cause train speed reduction, while a total loss of signal causes the application of brakes.

AIRTRANS has an excellent safety record, having logged over six million vehicle miles without a fatality, and only two injuries listed to maintenance personnel. Some circumstantial good luck has prevailed, but it can also be said that the design philosophy and the safety review procedures undertaken by both buyer and developer have been successful.

3.7 SECURITY

The provisions for passenger security constitute one of the basic requirements of a transit system. In AIRTRANS good illumination is provided in both station areas and vehicles, TV monitoring is used for open station areas, and two-way voice communications is provided between vehicles and Central Control. In addition, guideway layout is "confined" to the airport, and passenger service agents are present within some stations. The latter were not part of the original security "design" and are considered nonessential, in this respect, by both Vought and the APB. Their presence in stations, however, provides passengers with a sense of security. Vehicles are unattended and are often lightly loaded, especially in off-peak hours. However, a sense of security is given to the passengers by the many vehicle stops at stations and the fact that airport access is controlled by toll booths. The airport also maintains a patroling security force the presence of which is generally apparent. The station TV monitoring system consists of a single, centrally located camera, which continually scans a large portion of the station. Complete coverage would require two cameras. Operators at Central Control can monitor a single TV screen which automatically sequences through each of the stations. A second monitor is also available at central to provide capability to select any station.

3.8 UTILITY SYSTEMS

There are four freight utility services: mail, supplies, interairline baggage and trash. At the present time, only the supply service is in actual operation. The Air Mail Facility (AMF) service was operated for period of six months in 1974 but was discontinued at the request of the U.S.P.S. Plans are being made to reinitiate this service in the future.

3.8.1 AMF Utility System

For the purposes of transferring mail from the airline terminals to the Airmail Facility (AMF) two separate mail routes are used. These are designated as route 16 and 17. (See Figure 2-5)

Each route consists of three mail load/unload docks, one at the AMF and one in each of two terminal complexes. Both of these routes use three vehicles each. The first route connects terminals 2E and 2W to the AMF, the second similarly serves 4E and 3E. As designed, each mail utility vehicle loaded with three containers must stop at each dock and perform at least one load/unload function on a container, before proceeding to the next station. Central Control, via a special command, can override the requirement of load/unload on containers. The end containers on the utility vehicle are designated for specific airline terminals, while the middle container is a "swing" container, being assigned as a function of demand.

It should be noted that even though the service is scheduled to keep vehicles in motion and is not responsive to a "demand", the schedules are not fixed with respect to a daily master clock. In the original design, each route was to have dedicated vehicles, i.e., route codes on each vehicle would keep the vehicle always on the same route. This allowed "bunch control" to be used on each route to keep the vehicles properly spaced. However, because the two routes were of differing length, sometimes two vehicles on the same route would arrive at the AMF facility one after another. It was more effective from a Postal Service viewpoint, then, to dispatch vehicles from the AMF facility on alternate routes. Since the AMF personnel had no way of knowing which vehicle from which route would stop at the unload dock next, (approximately 80-120 seconds of warning is provided, but this is not adequate for the AMF to efficiently load and position containers), it became easier to alternately load and position containers on the interface equipment, rather than reshuffle containers when a vehicle arrived. Thus, alternate dispatching precludes the use of the "bunch control" algorithm on AMF routes.

3.8.1.1 AMF Flow Rates

The AMF mail flow rate requirements is contained in the March 15, 1971, specification requirement. The total flow rate each way, optained by adding the individual flow rates (expept for 4W) is 440 pounds of air mail per minute, between 6 a.m. and 11 p.,. Between 11 p.m. and 6 a.m., there is no requirement for AMF traffic. The mail transit time requirement is a maximum of 30 minutes measured from the time a cargo container is properly positioned on the loading platform at the originating station to the time the container is properly positioned in the unloading platform at the destination station. The total time requirement for incoming mail is 60 minutes maximum, the interval being measured between aircraft block time (aircraft stopped at load/unload gate and "blocks" put under wheels) and arrival of mail at the AMF unload dock. For out-going mail, the 60-minute interval is between closing of the dispatch document at the AMF and aircraft departure time (measured when aircraft first moves away from the gate). Failure to met this requirement results in an financial penalty to the airline This 60-minute requirement, at present, is the <u>longest</u> of any airport in the nation. (The location of the AMF facility at the southern edge of the system in 6W areas contributes to the long trip time.)

The average volume of mail being delivered between the airlines and AMF was approximately that called out in the original specification requirement. This volume was made up of both air mail and first class mail. However, the peak volume measured in a 3-minute time frame, during the peak hour, was almost 3 times the specification requirement, Two peaks were observed during the day, the first between 11 a.m. and 1 p.m. and the second between 10 p.m. and 2 a.m. Mail was transferred 24 hours a day.

According to the Performance Analysis report, AIRTRANS can move a total of approximately 97,000 lbs. of mail per hour on the two routes, with six vehicles.

3.8.1.2 AMF Station Operating Procedure

The AIRTRANS transfer platforms are located in wells on the guideway that runs through the south end of the AMF building. The wells are slightly east of the building center and just east of the AMF container conveyor control tower. The AIRTRANS platforms consist of an unload and a load platform, each mounting three hydraulically driven conveyors spaced to mate with the vehicle conveyors. Operation of the transfer platform and vehicle conveyors, when a vehicle is stopped in the guideway opposite a platform, is controlled automatically by a console located at the AMF conveyor system control tower.

Operation of the transfer platforms and vehicle conveyors is automatic. The vehicle will stop at the unload platform and automatically off-load all containers, that are aboard, onto the transfer platform. The transfer platform will then home with the AMF equipment and await a command from the manned AMF console, to transfer the containers. After off-loading the containers, the vehicle will proceed to the load platform and load the bays programmed for mail delivery on the route the vehicle is operating. This load function is also automatic if containers are positioned on the transfer platforms. This unload, jog and load function is performed, in normal service, in about 72 seconds.

As stated, the basic operation of the AIRTRANS transfer platforms is automatic, with operation keyed by vehicle arrival at the AMF conveyor system. The arriving vehicle is announced by means of the station graphics and an audio alarm. The unload operation requires no operator attention unless containers remain on the unload platform. If containers are on the unload platform, on conveyors corresponding to loaded bays on the vehicle, the vehicle will align vertically with the platform and, after 30 seconds, a signal will be sent to AIRTRANS Central Control indicating a station delay. If the vehicle stops at the load platform, and the load platform is being loaded, yet does not have containers in proper positions for destinations, the vehicle will hold at the station, and a station delay signal will be sent to Central Control.

The primary function of the operator, in normal system operation, is to monitor and ensure that the AIRTRANS unload platform is kept clear of containers and that containers scheduled for loading are positioned in the correct conveyor positions on the load platform, prior to vehicle arrival at the platform.

3.8.2 Interline Baggage and Mail System

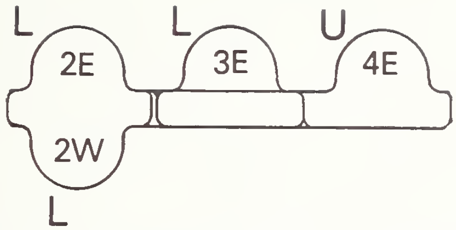
Interline baggage transfer service is provided by four routes. These routes travel over a common guideway as shown in Figure 3-13, but have different station stops. For example, the vehicles on the route #12 collect for terminal 2E; they pick up a container at 4E, 3E and 2W; return to 2E and off-load all containers.

Similarly, the other routes provide pickup service from each specific terminal, with off-load at the other terminals. In order to provide 30-minute maximum transfer, there are always two vehicles on each route during peak load periods.

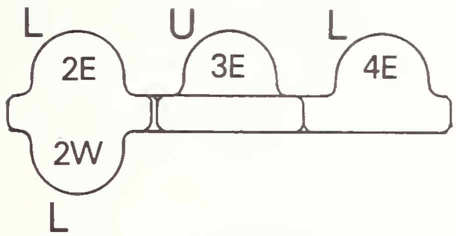
At each receiving station, the containers are automatically moved from the AIRTRANS vehicle to the interface equipment, and to the unload positions when space and a clear path are available. If space at the unload station or a clear path is not available, the container(s) is moved off the elevator and waits for clearance to the unload postion.

Approximately 80 seconds before vehicle arrival, an alarm sounds, and the arriving vehicle's route is displayed on the graphic panel between the two bays. If a second vehicle is close behind the first, the route for the second vehicle is displayed, but no alarm sounds until the first vehicle leaves the station. Following the alarm, the attendant at the container fill area has approximately 20 seconds to top off, close the door, and dispatch the proper container. After this time interval, container movement is prevented unless manual override is applied at the control console.

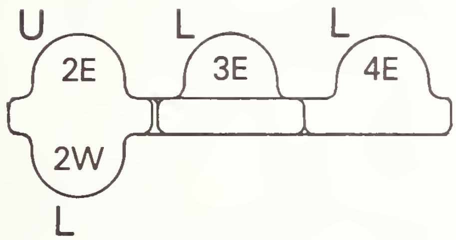
The dispatched container is automatically moved to the load elevator which lowers it to the AIRTRANS vehicle level where it awaits the arrival of a vehicle. When the vehicle arrives, the container is automatically loaded and the vehicle dispatched from the station. If no container has been dispatched, and there has been no manual intervention, the arriving vehicle dwells for approximately five seconds and departs.



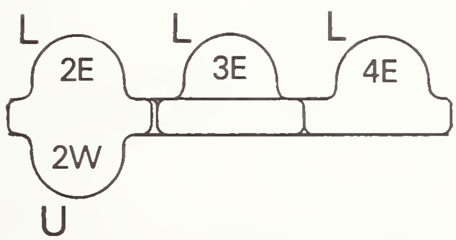
BAGGAGE INTERCHANGE TO DELTA/CONTINENTAL
ROUTE #10



BAGGAGE INTERCHANGE TO AMERICAN/EASTERN
ROUTE #11



BAGGAGE INTERCHANGE TO TEXAS INTL/FRONTIER/OZARK
ROUTE #12



BAGGAGE INTERCHANGE TO BRANNIF
ROUTE #13

Figure 3-13 AIRTRANS Interline Baggage Stations s

3.8.2.1 Interline Baggage and Mail Flow Rates and Travel Times

Interline baggage and mail use common trains and stations. Flow rate requirements for mail vary from 30 pounds/minute between some terminals to 2.5 pounds/minute for others. The original baggage flow rate requirement was 28 bags per minute from an originating station. Of the 28 bags per minute, 13 bags per minute would load onto one terminal, and 15 bags per minute would be divided among the remaining terminals. One terminal, 2E, had an inceptive flow rate of almost 2/3 that of the other terminals, or 19 bags/minute. The transit time for interline baggage and mail on AIRTRANS was not to exceed 30 minutes, the time being measured between time of departure from the loading platform at the loading station, to time of arrival at the unloading platform at the destination station.

Unfortunately, the present AIRTRANS 30 minute baggage requirement results in a total baggage transfer time greater than the 50 minute airline passenger transfer time requirement. Hence, baggage and mail are not carried by AIRTRANS at this time.

3.8.3 AIRTRANS Supplies System

The AIRTRANS supplies system carries supplies for Dobbs House, a subsidiary of E.R. Squibb which services the Dobbs House restaurants at D/FW and provides meals to some airlines. The Dobbs House complex is in the 6W area, adjacent to the AIRTRANS maintenance facility. It is off-line with respect to other services using the guideway in the 6W area. Supply stations within airline terminals are separate from the baggage and mail, trash, and employee stations. However, these stations are served by the common guideway and are on-line with respect to each other. The original requirement was for this service to operate only during off-peak hours of 12 midnight to 5 a.m.. However, in actuality, due to shutdowns of all other services using the common guideway at the airline terminals, the service is operated between 7 a.m. and 5 p.m. in a "demand mode".

Forty percent of all monthly sales of Dobbs House is moved by

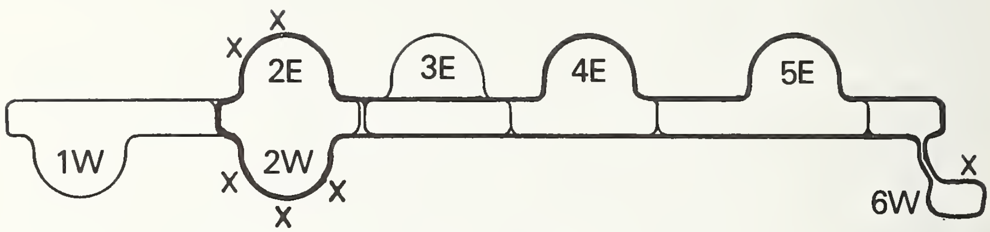
AIRTRANS. Dobbs House pays an annual fee to AIRTRANS and gets some return from Dobbs House lessees using AIRTRANS utility services. Among the lessees are companies, such as Airoplex and the Toy Shops at D/FW. Food is handled in Cres-Car Cabinets. Five cabinets are loaded into one utility vehicle supply container. Three containers can be carried by one utility vehicle. There are two utility vehicles scheduled each day, operating on two routes. These make a total of 17 trips each day.

Each route operates with an AIRTRANS cargo vehicle serving each station on the route on a rotational basis, as shown in Figure 3-14. The first vehicle to leave the supply center operates on Route 24 and delivers a full load of three containers to Supply Station 2WA. It then returns to the supply center to pick up three containers for 2WB. After delivering the containers to 2WB, it proceeds to 2WA to pick up empty containers for return to the supply center. Service on the second route, Route 25, starts with the second AIRTRANS cargo vehicle, and so forth, as shown on the chart. The distance travelled on the second route is considerably shorter than Route 24, and it is anticipated that the vehicle serving Route 25 will be back at the supply center before the vehicle serving Route 24. This means the supply center may have to hold the vehicle on Route 25 several minutes, to ensure that the station personnel in the terminals will have sufficient time to unload delivered containers and have them ready for pickup. Recent routing changes have been made to alleviate this "hold" problem for the supply system.

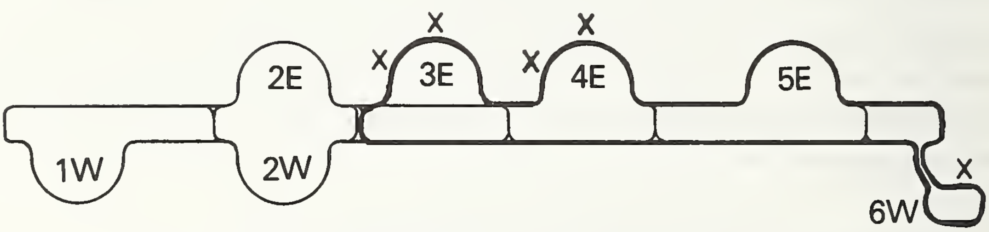
3.8.4 Assessment of the Utility Subsystems

3.8.4.1 AMF Service

The average volume of mail delivered between the airlines and AMF when the assessment was made was approximately that called for in the original specification requirement. This volume was made up of both air mail and first class mail. The peak volume measured in a 3-minute period during the peak hour was almost 3 times the specification requirement. Two peaks were observed during the day,



SUPPLY ROUTE 24



SUPPLY ROUTE 25

Figure 3-14. AIRTRANS Supply System Routes the first between 11 a.m. and 1 p.m. and the second between 10 p.m. and 2 a.m. Mail service was originally planned to operate from 6 p.m. to 11 p.m. but in actuality was transferred 24 hours a day.

According to the Performance Analysis report (using R.O.L. data), AIRTRANS can move a total of 97,000 lbs. of mail per hour on the two routes, with six vehicles. The R.O.L. data also showed that the 30-minute travel time was met 100 percent of the time. During the R.O.L. tests, no actual AMF service was provided; however, operations were simulated with actual vehicles and containers.

The original specification requirement called for all the interface equipment used in loading/unloading containers to be supplied by the AIRTRANS contractor. However, the Postal Service, on a separate competitive bid, had a different contractor design and install the unit at the AMF facility. This unit has not operated to full satisfaction and the Postal Service will retrofit the unit when a decision is made to use AIRTRANS again for mail. The major problem with the unit installed at the AMF facility was one of infant mortality failures, and an inability to satisfactorily handle LD-3 containers. (These are standard containers which fit into a 747, DC 10 or L1011 aircraft.) A brief, three-day survey performed by the Dallas/Fort Worth Air Mail Committee in September 1974 showed that this piece of equipment was responsible for about 13 percent of the delays which resulted in delivery time exceeding 60 minutes. (The same survey showed AIRTRANS responsibility for delays at 27 percent and the airline responsibility for delays at 60 percent.)

The AIRTRANS interface equipment including that at the AMF facility will operate the normal utility containers in an automatic mode between the vehicle and the AIRTRANS platform. Once a container has been unloaded to the platform from a vehicle, a postal operator is required to move the container to the proper storage or unload spot on the AMF equipment. Similarly, in loading, an operator is required to position the container on the load platform ready for automatic operation. Unloading and loading under automatic control is physically handled at two separate dock locations on the guideway, requiring the vehicle to move or jog from one location to the other. No unload/load cycle time requirement existed in the original RFP. However, 72 seconds for an unload-jog-load operation have been measured for automatic transfers. Should the unload dock be full, the utility vehicle waits until proper movement of containers is possible or until Central Control overrides and dispatches the vehicle. Notification of this comes from the console operator at the load dock by phone to Central Control. The LD-3 containers, because of mechanical difficulties in the AMF equipment installed by the USPS, require an operator for the movement of containers in the AMF station modules.

The Postal Service stated that the present containers have door operation problems when full, and also have inadequate shelving to handle fragile packages. They also stated that, due to the operational strategy and storage limitations of containers at the terminal air mail facilities, a large number of containers (65 percent), were moved empty during a given day, thus creating additional problems.

As a result of the unsatisfactory operating experience of the Postal Service, regarding the service provided by the airlines, AIRTRANS, and the associated interface equipment, the mail service was changed to trucks for 6 months in the fall of 1974. At that point, the Postal Service issued requirements for AIRTRANS service improvements to achieve satisfactory performance in carrying the mail. The Postal Service requirements are briefly as follows:

- Operate on a predetermined schedule
- Provide capacity to handle 36 fully loaded containers per hour (12 mail vehicles).
- Provide special shelves on containers to handle fragile packages.
- Modify doors in containers to permit easy operation when containers are full. (The present door arrangement has caused some minor injuries to employees.)

- Provide some method of identifying empty containers to reduce unnecessary handling of empties. (During off-peak hours, as many as 65 percent of the containers moved are empty.)
- Provide capability of identifying incoming cars and containers at AMF, at least two to three minutes prior to arrival, to allow interface equipment to position outgoing containers for the proper route.
- Provide additional security to the containers through structural modifications and increase of security force protection along the route.
- Provide an adequate back-up system to AIRTRANS (and compensate the Postal Service for any additional costs as a result of an outage of primary system).
- Provide automatic handling capability to LD-3 containers and the regular AIRTRANS containers.

At this time, no formal agreement exists between the Airport Board (APB) and the Postal Service regarding the desired changes. The airport Board and the airlines has formalated and presented a plan for resumption of airmail service which notisfies the above requirements. However, the plan has not yet been approved by the USPS.

The airlines originally indicated that they would like to go back to using the AIRTRANS system, but they expressed concern that:

1. The peak-load mail volume transfer time would probably exceed the 60 minute transfer requirement by some 15 minutes. As the 3-minute peak flows are in excess of the specification, and the 60-minute time includes unloading the aircraft, loading containers, moving containers to AIRTRANS, movement on AIRTRANS, and unloading at AMF, this could well be the case.
2. If all AIRTRANS services, i.e. passenger, employee, trash, baggage, mail, and supplies, were operational, the overall system operation would farther degrade, including the

transfer of mail; hence, additional transfer time may be required.

It is believed that the proposed plan will solve the problems.

3.8.4.2 Interline Baggage Service

The interline baggage system uses the same utility vehicles as the other services. The service is not functioning at present, because the 30 minute transfer time does not meet the needs of the airlines. The original allocation of transfer time to AIRTRANS was 30 minutes maximum, as required by the specification; it is required that this be reduced to 20 minutes, in order to meet the airlines' requirements.

The percent of trips for each route which were made in less than 30 minutes during the R.O.L. data period of October 24, 25, 26, 1974 is shown in Table 3-7.

The data and analyses showed that the specification flow rates capacity could be met 100 percent of the time. Flow rates of 4.5 to 5.4 bags per minute translated into 4.5 to 5.4 trains per hour. The R.O.L. data showed 5.6 trains per hour moved between terminals of the system.

It is claimed that, by operational procedures and minimization of routing, the 30-minute maximum transfer can be reduced. However, this has not been demonstrated operationally or by simulation.

3.8.4.3 Trash Service

The trash service is not operating since the incinerator is inoperative. It is expected, however, that operation of this service during off-peak hours would have minimal impact on the system as a whole.

3.8.4.4 Supplies Service

This service is in operation and the customer (Dobbs House) is totally satisfied. The system operates during the day (since none of the other utility systems are in operation); two vehicles

TABLE 3-7. PERCENTAGE OF LESS-THAN-30-MINUTE INTERLINE TRANSFER TRIPS

Route No.		10	11	12	13
10/24	AM	100	100	96.4	100
	PM	100	100	100	100
10/25	AM	100	96.5	100	96.6
	PM	100	100	100	100
10/26	AM	100	100	100	100
	PM	100	100	100	100

make about 17 loaded trips a day, to carry supplies in a demand responsive mode. Dobbs House is the only user which pays an annual rental fee for the AIRTRANS service.

3.8.4.5 Summary Utility Systems Assessment

The AIRTRANS utility system requirements were underestimated by both buyer and developer. Mail transfer time as well as mail security are not, in the last analysis, satisfactory to the user, the USPS. AMF interface equipment has also been unsatisfactory, at least partially due to "separate, low bidder installation. Automated baggage/mail interface equipment should be of the same design for reasons of commonality of maintenance as well as for operational standardization of required functions.

In regard to mail volume and scheduling, the brief data contained in the AIRTRANS Performance Analysis Report (February 1975) indicates that AIRTRANS can handle peak volumes in excess of the specification requirements with 6 vehicles, although this has not been demonstrated over a long period of time. The Report also indicates the system's capability to handle up to 6 loaded vehicles per hour.

The concern of the airlines over not meeting the 60-minute total delivery requirement may very well be justified in that the peak volume may tax the airline employees and interface equipment beyond the point where the 60-minute requirement can be met, even through AIRTRANS can fulfill its mission in the 30-minute time allocation. The peak 3-minute volume of three times the specification requirement could further impact the service time.

One major issue which could affect the entire operation of the baggage/mail, supply, trash, and employee interface systems is that a delay caused by one will extend into all the services, since all stations at the airline terminals are on line with respect to each other. Hence, the problems of one vehicle will affect operation of other vehicles. Given that the transfer of containers to and from vehicles for the baggage/mail system is performed automatically in 72 seconds, the supply and trash service operates in off-peak periods (midnight to 5 a.m.), and peak volumes are consistent with specification requirements, the system (through R.O.L. data) could well operate successfully, if no failure is assumed. However, from a practical viewpoint, every operation requiring human operator attention to assure proper container management at a utility system service, presents a potential problem and hence potential operational delay. Although all services did run simultaneously for two months in test, all services have not operated together in revenue service for any length of time. Consequently, overall success or failure has not been demonstrated.

Future applications of a similar system should be based on some detailed simulation of the entire system process, to ensure a complete system design, including the human interface, which can meet the requirements. Further, means must be established to test the system after installation, so that requirement compliance can be verified. The tests should also show the upper demand limits that the system (including human interface) can handle. Final there is a need for all parties to work together for the successful implementation of a new system.

4. TECHNICAL SUBSYSTEM ASSESSMENT

The AIRTRANS system is made up of various subsystems such as vehicles, switches, control and communications, guideway, and power distribution equipment. This section describes some of the more important of these, considering planning, design and implementation factors which carry lessons for future system developers.

4.1 BASIC VEHICLE

The same basic passenger vehicle serves both airline passengers and airport employees. The utility vehicles are designed for their specific tasks but use the same propulsion, braking, pneumatic, suspension, bumper, guidance and electrical system as the passenger vehicles. They do have additional equipment such as automatic load/unload mechanisms which interface with similar equipment at utility vehicle stations. An exploded view of a passenger vehicle is shown in Figure 4-1.

Passenger vehicle panels are mounted on a frame made of ASTM A-36 steel (Figure 4-2). The panels are not load bearing, but are hung on load-bearing members. The other vehicular components are mounted on the chassis.

The vehicle shell is mounted on the steel frame and chassis. This shell was fabricated by Swedlow, Inc., according to a Vought design. The shell is a reinforced, vacuum-formed acrylic sheet with a metallic luster. A rigid polyurethane foam is sprayed into the acrylic sheet, and a 0.150-0.250 inch layer of fiberglass-reinforced plastic is imposed over the foam.

Swedlow was required to give only 3-year warranty. No certification was required other than this. AIRTRANS materials were selected with consideration for fire resistance. Flammability requirements for the AIRTRANS vehicle are contained in the "Proposed Requirements Contract Document and Specifications for AIRTRANS", Section 3.6.4.14. Copies of Manufacturers statements on flamma-

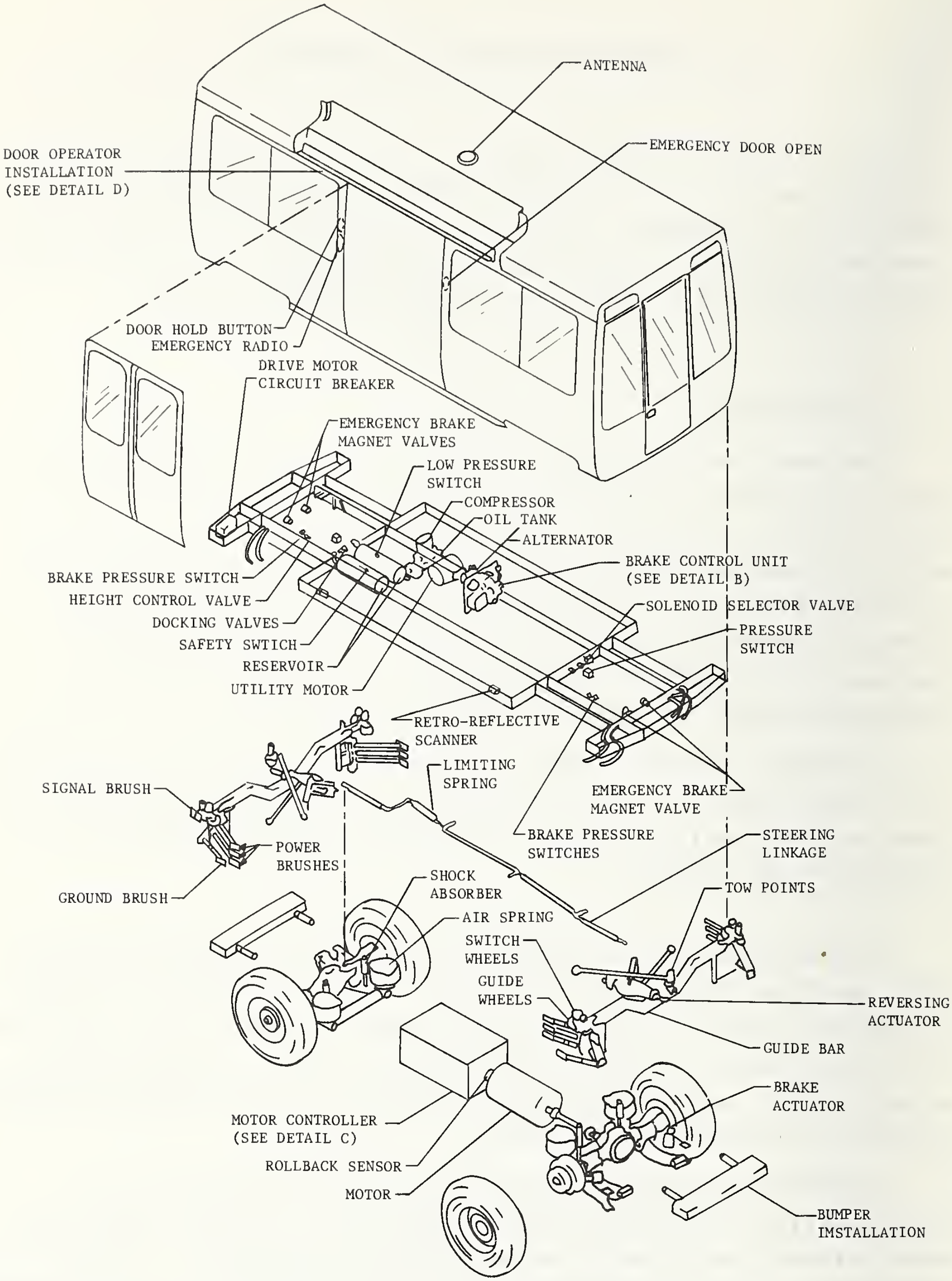


Figure 4-1 Passenger Lead-Vehicle Assembly

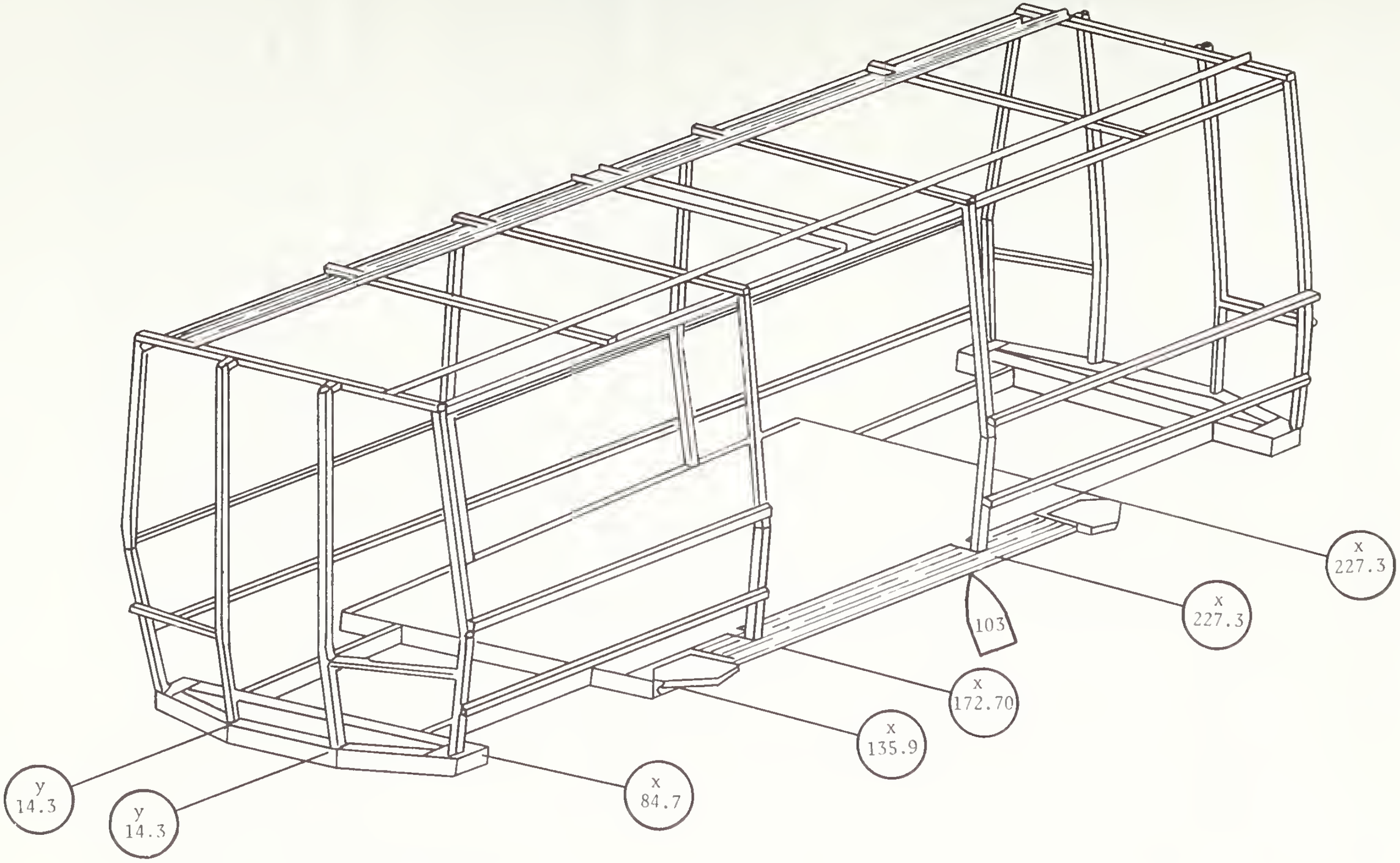


Figure 4-2. AIRTRANS Vehicle Frame Structure

bility properties of vehicle materials such as the shell, carpeting and interior panels were provided to the assessment team. The Swedlow spokesman speculated that, based on past history of the Swedcast 300, the life expectancy might be in the order of 15-20 years.

AIRTRANS tire tread life is about 25,000 miles between retreads, of which four or five are possible. This compares to a 100,000 mile life for a typical bus/truck tire tread. The difference is probably due to the "foam filling of AIRTRANS tires, which increases heating and thereby shortens life. It may also be due to the tire interaction with the airport concrete in conjunction with the many "turns". The fact has bee noted that buses operating at the airport over similar concrete pavements, and making many turns, have a much shorter tire tread life than the normal, 100,000 mile life generally expected.

4.2 VEHICLE INTERIOR

The arrangement of the interior of the transit vehicle should allow for free movement of passengers throughout the entire vehicle. It this is not the case, the passengers will bunch up in the immediate vicinities of the doors. The behavior of the passengers, usually referred to as "exit orientation", can be seen very often in building elevators during off-peak hours. The passengers already in the vehicle insist on remaining just inside the doors in preparation for leaving. As a result, other passengers cannot readily enter or leave the vehicle.

Contributing to this problem of exit orientation on AIRTRANS vehicles are the size and height of the luggage rack, the location of the stanchions, and the number and arrangement of the seats. The luggage rack, which is 65" long by 10" wide, is located in the center of the AIRTRANS vehicle opposite the doors. Its luggage capacity is somewhat limited. The rack itself is somewhat high for convenient use. The height to which a bag must be lifted to place it on the rack is increased by a bungee cord stretched between the two stanchions at the front corners of the luggage rack. The bungee cord, was required to prevent any luggage placed on the rack from slipping off and to insure that people would not sit on the rack. Some passengers were observed making no attempt to use the luggage rack even though it was empty. These passengers placed their bags on the floor and held onto one of the stanchions.

In addition to the two stanchions at either end of the luggage rack, there is another directly in front of the luggage rack. This stanchion is a cluster of four vertical rods covered with longitudinally grooved plastic to afford a better grip. The design of this stanchion is very good, since it will accommodate more standees than the usual single rod stanchion, but its location reinforces the passengers tendency to ride in the immediate vicinity of the doors. This situation is intensified by the narrowness of the aisle between the longitudinally placed seats, which restricts movement ot the more remote seats, especially when further constricted by legs and baggage of seated passengers.

The need for keeping passengers from bunching up in the immediate vicinity of the doors of a transit vehicle can not be overstressed since required station dwell time is directly related to the difficulty of passenger movement within the vehicle.

The overall interior of the AIRTRANS vehicle gave a favorable impression when inspected after the vehicles had been in service less than six months. However, when the vehicles were seen again after some eighteen months of service, and 6 million passengers some wear and tear were evident. There was however no evidence of vandalism in any of the cars inspected. Cars surveyed had stains on the floor covering near the doors, which were attributed to leading edge door leaks as the car goes through the car wash.

4.3 DOORS

Passengers holding doors open to retain a vehicle or train beyond its normal or alloted dwell period has been a constant source of system delay. The door hangers have not been reliable and have required strengthening for longer-lived operation. Present aluminum door hangers were replaced by steel units. Door units require some "fine tuning" to accommodate changes in door load friction.

Opening of vehicle doors on the guideway does not cut off power form the guideway. The reasons are (1) Removal of power cuts off vehicle air conditioning, allowing interior temperatures to rise intolerably, encouraging passengers to exit to the guideway, a dangerous area and (2) Without a source of power a maintenance man could not fix a vehicle or operate it manually and removalwould be possible only by tug. (3) Shutting off power in the one section where the vehicle is stopped does not guarentee the safety of indivuals since they could walk into a powered zone. At this time, both Vought and the APB feel the practice of maintaining power is best.

There are about 16,000 station stops per day, and 4-8 door problems per day. This includes passenger station doors, which are synchronized with vehicle doors. The testing of station and vehicle doors was very limited. There were also half a dozen "missed station" problems per day, but now this has been reduced to about two to four per week, to some extent by the extension of the target zone form ±12 inches to ±18 inches. The new, easier requirement is still adequate to align station and vehicle doors to permit the safe and easy entrance and exit of passengers.

The current standard deviation of stopping errors is ±1.5 inches. Station stops are accomplished through a profile stop command that is implemented by counting down tach pulses. A vernier update about 10 feet away from the stop point has been added for confirmation. The variance in stopping position is due to such factors as vehicle brakes, load, weather, etc. Two experimental modules to improve the station stopping accuracy are being tested. Vought has designed one which constitutes switching from the TTL logic used by GRS to CMOS logic. This provides more noise immunity. GRS has a modified module which slows down the TTL logic to get the same result. Both modules were in operation on vehicles in the system and seemed to be performing well.

4.4 PROPULSION

The APB specification required electric motor propulsion of conservative design. Acceleration, deceleration, and jerk criteria were also included in the APB specification. System requirements, such as grade, wind, acceleration, cruise conditions, and weight were analyzed by the contractor before propulsion system procurement. As a result, the vehicle torque vs. speed profile and the vehicle resistance equation were included in the propulsion system specification. The subcontractor was then able to calculate the complete requirement, not just RMS figures, and bid a system which was capable of handling the AIRTRANS load from the start.

Vought chose a DC motor drive system for propulsion. Problems which ensued were due to the application involved, not the concept. Motors had insulation and dirt problems initially. Filtered air for cooling, and reworked insulation cured most problems. Cooling air supply sources, filtering, installation, and materials are areas for motor concern in new systems.

In the case of a propulsion system failure in either the front or the rear vehicle of a two-car train, the train can be moved by either pushing or pulling with the other vehicle. A failure of this sort has been occurring about every two weeks. Trains will function satisfactorily in this way, unless the guideway is wet, when performance is degraded. One train, in the automatic mode, cannot push another, as they are kept apart by the safety system. A two car train thus has propulsion redundancy, while a single vehicle does not.

Vought specified that the propulsion system supplier use quality workmanship (Propulsion System Procurement Specification, 204-40-006, Sect. 3.2.16). A subcontractor, Randtronics, was selected who had extensive experience in producing equipment to reliability requirements comparable to those of AIRTRANS. The system, as it evolved, was not exactly the system envisioned by either Vought or the subcontractor. Although it had problems initially, most of these were quickly resolved and the performance, maintainability and as far as can be judged the reliability, are now considered satisfactory by Vought.

The propulsion system evolution at Dallas/Fort Worth was a learning process for both Vought and Randtronics. Both companies have reported that the power circuit components were adequate from the start; the changes that were made were in the controller circuit components which involved some circuit modifications, and in more quality control in the fabrication procedures. Power components were derated in voltage, current, and power levels. Transient suppression and filtering were also incorporated.

The system was tested at three load levels, including design minimum and design maximum, during design verification tests. Propulsion system parameters measured during these tests were:

1. Longitudinal acceleration.

2. Vehicle velocity.

3. Motor armature current.

4. Motor controller input voltage (speed command).

5. Vehicle input power - Phase A (measurement was not power, but phase voltage).

Performance testing of the test vehicle was done on a 1,000-foot section of the guideway. Construction problems in the area, however, prevented the accumulation of needed test mileage; after a year of testing, there were approximately 4,000 miles on the test vehicle. The test track was a level section so it was not possible to test propulsion system performance on grades. The propulsion system design, as proposed by Randtronics, was capable of meeting the vehicle torque-speed profile and the vehicle resistance equation. The testing at the Dallas/Fort Worth airport was thus correlated to the system specification and the design margin verified in that manner. Measurements were made for three speed ranges during acceleration and steady state running. The propulsion system did not exhibit any design deficiencies during these test.*

The tests did not include wind or grade conditions, and they were not performed with the specified minimum tolerance input voltage at a crush-loaded vehicle. The specification conditions represent peak loads and worst-case conditions at the vehicle and testing would have demonstrated that the system had adequate design margin. The tests did verify, however, that the system would meet jerk, acceleration and velocity control specifications, and did indicate that a sufficient margin existed, as indicated by subsequent experience in revenue service and by the verification of propulsion system component steady state and transient ratings.

The DC propulsion motor itself produced difficulties in the early stages of operation. There were two major problems:

1) Shorted windings: A suggested theory was that dirt was getting into the motor and lodging in the field windings.

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*Refer to Vought report ATRE006, Airtrans Design Verification Test Report.

Subsequent motor vibrations would cause the insulation to wear, and the winding to fail. The other theory suggested by the motor manufacturer, ASEA, was that the windings were deteriorating through the action of some contaminant. Vought incorporated two fixes. First, the insulation was upgraded in all motors. Second, dust filters were installed in the cooling air line to prevent dirt from getting into the motor. The problem was solved but since both fixes were put into all motors, it was not possible to determine the actual cause of failure.

2) Field coil mounting: The field interpole coils, in slots, are displaced by forces resulting from the motor current, and eventually short to the frame. The problem was corrected by shiming and insulation rework by Vought.

These motor problems further indicate that industrial quality component are not always suited for transit environments.

Although there were additional propulsion system problems in the early stages of AIRTRANS, many of them were one-of-a-kind failures normally expected during the break-in period of a new system. The more serious problems, two of which have been mentioned, developed after operation was initiated. They are similar to problems experienced in other transit systems (Morgantown and Metroliner). In general the causes of these problems can be summarized as follows:

1) Insufficient detail in specifications.

2) Insufficient consideration of the application and/or the operating environment.

3) Underestimation of maintenance requirements of equipment with moving parts.

4) Inadequate testing prior to revenue operation.

The portions of the specifications which dealt with electronic components were precise and complete, but there were portions dealing with environment and workmanship which were vague.

The problems of dust, dirt, water, and jet wash were acknowledged by Vought, who offered to install baffles to minimize the probability of contaminants reaching the system. However, the severity of the problem was not fully appreciated by either Vought or Randtronics until the problems accumulated in revenue service.

The propulsion motor proposed by Randtronics was an open, drip-proof, fan cooled motor, FRAME 328 AT. The motor is now self ventilated, with filters in the ventailation air ducts to avoid damage from containinants. Much of the contamination could have been avoided, if the first specification had been more precise.

4.5 POWER COLLECTOR BRUSHES

Vought specified that the collector brushes have a 5000-mile life, but initial collector shoe life was about 200 hours. The brushes were eroded after rough rails removed a protective patina which built up on the collectors, allowing brush graphite to disintegrate. The system now uses a material which operates satisfactorily under all conditions. The brush life is reported to be 35,000 miles which is equivalent to 6 or 7 months of operation.

Icy conditions cause contact problems, but these conditions do not occur often enough to warrant enclosing the guideway or installing road bed and rail heaters at the airport. Vought eliminates ice by spraying the rails with an ethylene glycol solution. Scraper brushes are also used to remove ice and snow from the rails.

4.6 BRAKING/ACCELERATION

In wet weather, slippage of the vehicle drive wheels was a problem. In some circumstances use of speed override was required to permit continued operation of the system. Investigations are underway to attempt to improve the behavior of the vehicle on the wet guideway and also to improve the track traction characteristics in wet weather. Possible solutions include variable jerk and acceleration control. Test results of braking on a wet track are given and discussed in ARTRE-007A, Section 5.2.1.3.

In the test period, the braking system suffered the highest failure rate of the vehicle systems, accounting for almost half the vehicle equipment failures which affected movement and control. The chief failures of the braking system came from leaking "apply" and "release" valves, caused by wear. A materials change corrected the problem.

The present braking system was not designed for significantly higher speed or shorter headway operations than the AIRTRANS requirements; either increased speed or shorter headway operation would make the braking requirement more severe.

The acceleration of vehicles is also more difficult under ice and snow conditions. Tire studs, de-icing, lateral grooving of the guideway, and "sand paper" applied to the running surface are some of the methods which have been tried to improve acceleration in adverse weather. Tire studs excessively accelerated the wear of the concrete guideway surface. De-icing procedures were not found to be useful in improving acceleration by preventing or removing accumulation of snow or ice. Longitudinal grooves in the running surface have been found best for permitting water to escape from under the tires surface to improve acceleration in ice or snow. "Sandpaper" bonded to the guideway in small, limited areas has also been found useful.

4.7 STEERING/SUSPENSION/SWITCHING

Ride quality is the forcing function for switching and suspension. Early testing of the vehicle to permit design changes in steering and suspension to modify ride quality is highly recommended. The interplay between steering surface of the guideway and the vehicle must be taken into account at all times for ride quality. Effects of guideway tolerances on this interface can be very significant.

Employee and airline passenger stations are on opposite sides of the guideway, so that the passenger vehicles, which have doors on one side only, must be capable of running with either end leading, depending on the particular assignment. Consequently, the wheels are set for zero toe-in because toe-in other than zero would require undesirable rerigging of the steering system each time a car is turned around. It was found during early tests that positive values of toe-in had little effect on the vehicle's ride quality characteristics. Hence, a vehicle can be thought of as steering down the guideway, first bearing on one side and then on the other.

Excessive guidewheel wear on guideway walls were early problems, both traced to improperly cured polyurethane used for steering wheels. Although not a major problem, there is also evidence that the planetary gears leak excessive grease onto the guideway.

The AIRTRANS guideway switching can be classified as a "modified" moving guideway where the only part of the guideway that moves is a "blade" on top of the parapet wall which directs the vehicle in the direction of intended travel. This type of switch has relatively few mechanical moving parts and, as such should have a high reliability rating. Vought personnel reported that for the full system about 92,600 switch calls per 24-hour day take place with very few failures. However, no MTBF allocation of reliability requirement exists for switches.

The switching mechanism is located on the wayside and not on board the vehicle, thus reducing the communications work load on the vehicle. The total activation time is about three seconds. One disadvantage associated with the switch actuator is its location under the guideway, see Figure 4-3, which makes it vulnerable to dirt and water. This specific location was selected based on esthetic considerations and right-of-way requirements.

Initial suspension design was changed to improve ride quality characteristics. Changes included the addition of springs to the lateral guide-wheel linkages and changing the volume of the air spring.

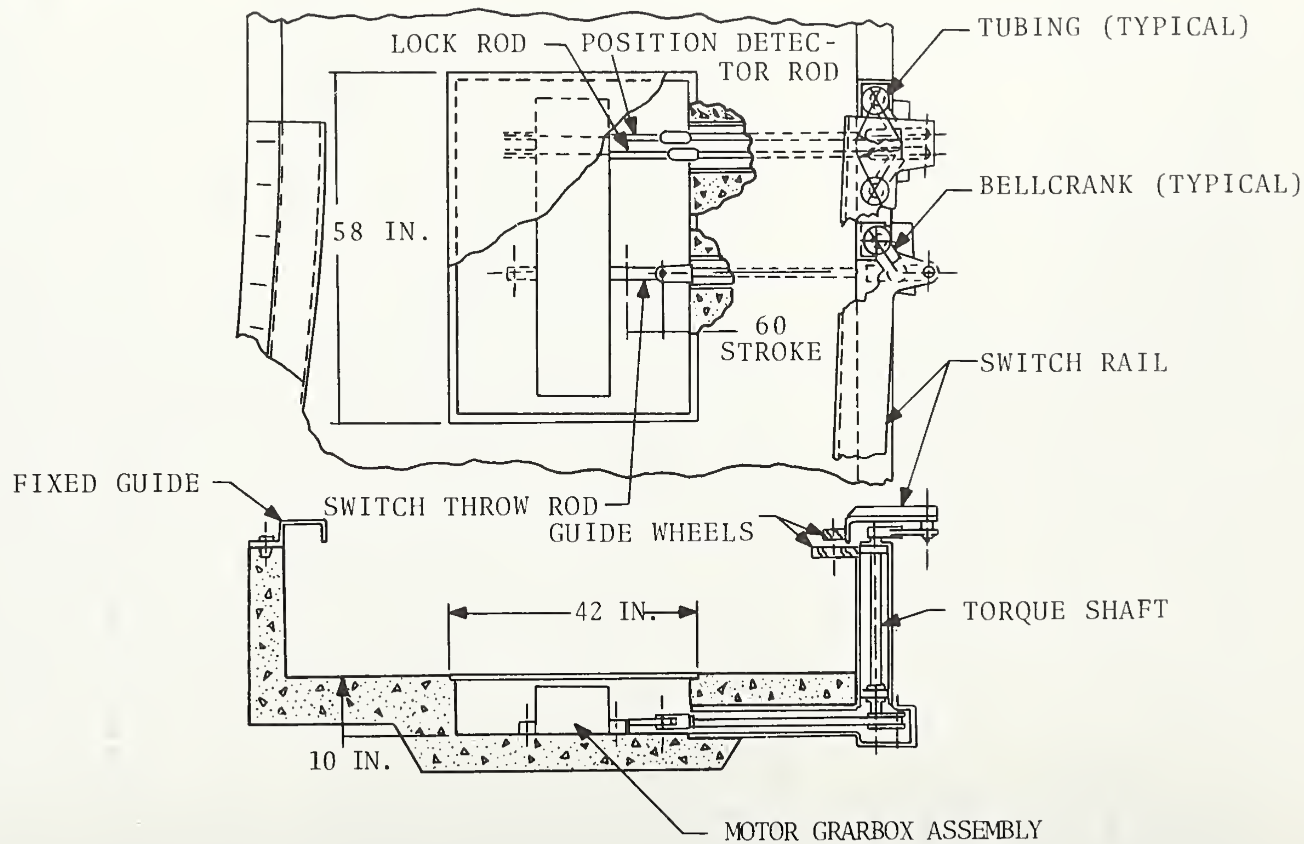

Figure 4-3. Switch Operating Mechanism Shown in Location

Again, in the development of a steering system, the interplay between guideway and vehicle is significant. The vehicle and guideway should not be designed and developed separately. The effects of tolerance of guideway running surface factors should not be underestimated in developing the vehicle suspension for a given ride quality.

4.8 CENTRAL CONTROL SYSTEM/COMMUNICATIONS/EMC

A fail-safe circuit analysis was performed by Battelle and by Vought during design and prior to revenue operation, for purposes of revenue operation certification. The analysis was not, performed in the detail required by the specification, however, as it did not include fault trees or hazard analyses other than those related to failure modes.

There were a number of decisions made in development cycle which have lead to the present success of the system.

a. The decision to make the safety system entirely independent of the operating ATO/ATC* system puts the burden of system safety on the vital relays. They are designed to be fail-safe, and have a long history of opening reliably when de-energized. Since the signal system is a conventional block system, collisions, at least, should be very infrequent. In this extremely important area, AIRTRANS adopted the traditional, and successful, rail transit systems approach.

b. The decision to decentralize the ATO/ATC system so that central computer failure would only slightly degrade the system operation appears to be working out well. The recent addition of redundancy to the central computer should further improve system opertion.

*Automatic Train Operation/Automatic Train Control

4.8.1 Communications

The speed limit and speed command communications system, as distinct from the data communications system, is highly application-specific and is based upon the fixed-block protection system implemented in the control system hardware. This portion of the communications system is controlled by the geometry of the guideway. Altering any block lengths thus requires a re-wiring of portions of the communications system.

The AIRTRANS communications system is designed for a fixed-block control concept. A major redesign is necessary should variable blocks be used for logitudinal controls -- a scheme that is envisioned for many automated systems. Although the AIRTRANS data communication system design is highly successful, this design is not easily expandable to a system with a large numbers of vehicles per loop operating in a moving block manner.

The most significant feature of the AIRTRANS communications system that is transferrable to new systems is the principle of separating vital and non-vital communications. This feature provides a fail-safe system that enables the vehicle to proceed even when the non-vital communication breaks down. The physical separation of vital and non-vital channels is accomplished in AIRTRANS at minimum cost.

4.8.2 Electromagnetic Compatability

The EMC requirements levied on the AIRTRANS system were designed (a) to prevent interference with nearby aircraft and other communications equipment, and (b) to guarantee AIRTRANS operation in the presence of electromagnetic interference generated by AIRTRANS or other airport electronic equipment.

The AIRTRANS Test Plan (ATPL 002) and subsequent test report (ATRE 007) address only the radiated and conducted interference design goals established by Vought. There were no specific limits on electromagnetic emissions defined by AIRTRANS other than non-interfering. Vought determined the probable susceptibility of candidate airport systems and defined the emission levels of AIRTRANS to be below this susceptibility. Test results plotted against these emission levels generally show operation within the allowable limits. The key consideration in this type of requirement generation is the accuracy of the original airport system susceptibility model and the relationship of multiple vehicles and abnormal events to the model. The system could pass all interference goals established in the test plan and still not meet the higher level system specification requirement for non-interference. In this case, the model must become an integral part of the system requirement.

Two types of EMI were measured: radiated emissions and conducted emissions. The conducted emissions were tested for both narrow and broadband interference.

Radiated EMI was measured throughout the spectrum of 15 kHz to 1000 MHz under ambient and various operating conditions. The results show that the radiated EMI from a powered AIRTRANS vehicle is within the allowable ambient noise signal envelope, at a range of 400 meters or nearer.

Radiated EMI was also measured at the close range of 10 meters, with the vehicle being stationary, and various on-board equipment forced to cycle through operational modes. Results show that transient radiations of magnitude greater than the ambient noise are present, but are within the design goal. These transient radiations are caused by the brake compressor, door actuating device, and the air conditioner on-board the vehicle.

Conducted emission measurements are poorer than those of AIRTRANS radiated emission. Broadband noises, due to conducted emission, on the 28-VDC bus line are in excess of design goal at all frequencies used on the testing (20 kHz to 14 MHz). The heating/air conditioning unit, brake compressor and door actuating device cause transient emission on the AC bus lines, significantly above the design goal, especially between 0.7 to 1.2 MHz, where an excess of as much as 15 db is experienced.

Vought concludes in their preliminary test report that these excess emissions do not pose a problem. The interference on DC bus lines may be adjusted by inserting transient suppression across control coils. Furthermore, the interference may be isolated on a subsystem-by-subsystem basis. Vought also predicted that excess transient emissions caused by the brake compressor and similar equipment would not interfere with the overall EMC environment due to its transient nature.

During the system design phase, it was recognized that there could be potentially EMI-susceptable communication and control logic equipment both on the vehicle and on the wayside. These critical subsystems were defined, and special tests were performed to determine if the design met the particular susceptibility levels considered necessary. Of particular interest is the lack of any requirement for specific noise interference limits or signal-to-noise ratio limits on subsystem interfaces considered critical to operation. The fact that a system will operate under a specific set of test conditions is no indication that the system has sufficient signal and noise margins to operate acceptably under degraded or normal component tolerance conditions. A system EMC requirement specification similar to the plans, quality assurance, and acceptance tests defined by MIL-E-6051D should be considered for future systems specifications. This would serve to both formalize the EMC requirements and provide a framework around which acceptance criteria could be negotiated. Also the incorporation of transient protection devices at potentially susceptible interfaces and the handling of lethal discharges in both the passenger compartment and equipment spaces was included and should be a design specification for future systems.

4.8.3 Software

The system CPU was used for intial debugging of the command and control software. Conflict with software development after the system became operational necessitated the acquisition of another CPU for software development, i.e., editing, compiling etc. The program to control the communications modems were among the hardest to debug, becuase they require two computers; these programs are not supplied because the modem is not a standard peripheral device supported by the manufacturer of the computers.

It was felt, after the fact, that it would have been very beneficial to have an environmental simulator to do the initial testing of the integrated software. From the beginning, an an effort was made to debug the control hardware and software in parallel, with the usual consequences, namely that it was hard to determine <u>which</u> was not operating properly.

The CPU reliability seemed to be getting worse, with several problems in the spring of 1975. As a result of these troubles, a preventive maintenance (PM) program was started for about 2 hours a night, once a week. During that time the CPU is shutdown, and diagnostics are run.

As is often the case, the software problems were underplayed during the first half of the project and then overplayed during the second half. It appears to be rather difficult to find the happy medium in between.

4.9 GUIDEWAY

The AIRTRANS guideway system had to fit the envelope designated for it by the Airport Board. Thus, the horizontal curves and corresponding superrelevations required to sustain the design speed were dictated to the architect/engineer by the Airport Board.

The AIRTRANS guideway uses 150 and 800-foot radius curves. Only the 150-foot radius horizontal curves are superrelevated. The maximum superelevation used on those curves is 8 percent and the design criteria for the "level" 800-foot radius curves are such that the centrifugal acceleration should not exceed 0.12 g for the cruise speed of 17 mph. In an urban environment, the radius of 150 feet would introduce a severe constraint on the guideway layout. It has been suggested that a radius of about 50 feet would be desirable in an urban scenario. The superrelevation of 8 percent reflects highway design practice. However, the issue of what the maximum superelevation of GRT systems really should be, is unresolved.

The maximum grade used in the AIRTRANS system is 7.8 percent and the dwell time on grade is about 6 seconds at 17 mph. The issue of what the maximum grade of a GRT system should be also remains unresolved.

The topography of the AIRTRANS guideway basically follows a level terrain. The substructure of the area consist of a layer of about 15 to 17 feet of "swelling clay" on top of shale. This foundation condition dictates the design criteria of the at-grade and elevated guideways.

4.9.1 Design Criteria

For determination of loads and load factors, Standard Specifications for Highway Bridges, AASHO 1969, and Strength and Serviceability Criteria, Reinforced Concrete Bridge Members, BPR 1969, were used; likewise, the strength of reinforced concrete members were determined by ultimate strength design using ACI-318-63 "Building Code Requirements for Reinforced Concrete". At the present time no special design code exists for GRT's running on dedicated guideways.

The impact factor, or fraction of live-load stress to be added for the dynamic effect of movement, was assumed to be 25 percent. Some recent work in this area indicates that for GRT systems traveling in the 30-mph domain the impact factor need not exceed 10 percent.

An analysis was performed by an APB consultant of fill settlement over a layer of swelling clay. This effort resulted in the A&E being given the design criteria that for any fills over four feet the guideway should be elevated, to avoid excessive settlement. This is a reasonable approach for the Dallas/Fort Worth site.

The guideway was designed to withstand a temperature rise of $30^{o}F$ and a temperature fall of $40^{o}F$ around the design ambient. The concrete of the prestressed beams had a strength of 5,000 psi and a density of 150 pounds per cubic foot (pcf). The modulas of rupture of the pavement slab is 575 psi.

The guideway was designed to satisfy two conditions, namely:

(a) A three-vehicle train traversing the guideway with a crush load of 12.1 kips/axle. The axle spacing is about 170 inches. Note that this allows for future expansion of the system with three car trains. The other option might be more single or two-vehicle trains.

(b) A continuous equivalent train loading of 0.982 kips per foot (no impact), assuming a capacity loading condition. This condition satisfies the case where a malfunction of the lead vehicle results in the stacking up of all the following vehicles bumper to bumper. The horizontal force on the parapet wall due to the vehicle horizontal guidance wheels assumes 3.6 kips for steering, in event of malfunction, 0.29 and 1.56 per wheel of centrifugal force respectively, for the 800 feet and 150 feet radius curves and a wind load of 1.0 kips per wheel, assuming an 80-mph wind.

4.9.2 At-Grade Guideway

The guideway consists of an 8-inch continuously reinforced concrete slab resting on 2 inches of emulsified asphalt treatment and a lime-stabilized subbase about 12 inches deep. The parapet walls represent continuous beams resting on a flexible foundation and provide substantial stiffness against differential settlement of the foundation.

The Dallas/Fort Worth site can be classified as having poor foundation conditions requiring special treatment. Thus, the 12 inch depth of lime stabilization provides the first transition layer between the natural clay soil and concrete paving. This aids in stress distribution and more importantly, it reduces tendency for the soil to swell. The 2-inch asphalt subbase provides the final transition stiffness between the soil and the slab and protects the lime stabilized layer. The 2-inch thickness represents an optimum layer for structural response for long term wear. On both sides of the concrete pavement, an asphaltic membrane is placed on top of the natural soil, for moisture control. This membrane extends outwards for about 6 feet, or to the edge of right-of-way, and forms a seal that prevents moisture from entering the soil under the guideway, thus reducing the amount of swell and eventual differential settling of the guideway structure. This type of design seems adequate, and so far the AIRTRANS experience validates it. The typical at-grade guideway configuration is shown in Figure 4-4.

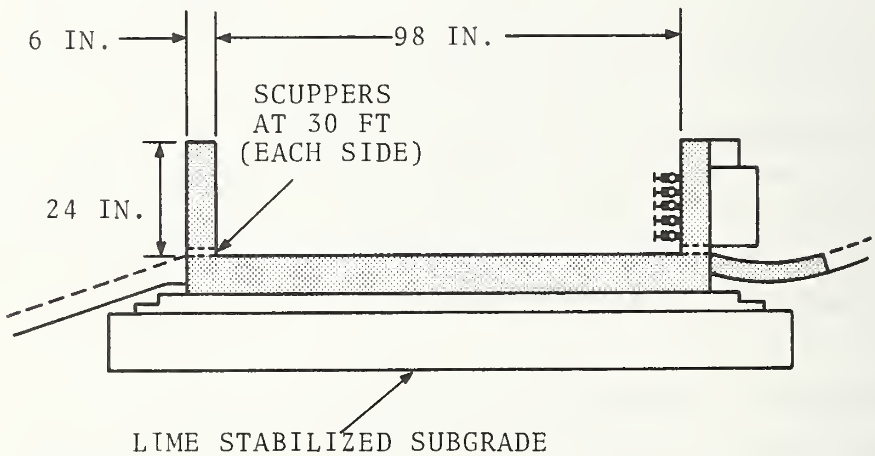

Figure 4-4. Typical At-Grade Guideway Configuration

The problem area for at-grade guideways usually occurs at the abutments, i.e., the interface of the at-grade and elevated guideways. Here, the at-grade guideway rests on fill which is susceptible to settlement. This fact has been documented by extensive field measurements by highway researchers who have identified the differential settlement at abutments as a common problem for at-grade guideways. AIRTRANS currently has a few abutments instrumented to measure the settlement as a function of time. Some settlement was noted which had introduced "some" rotation in the abutment surface. These distortions have not been considered serious enough to necessitate remedial action yet. The AIRTRANS abutments can be considered as "floating" abutments resting on clay.

4.9.3 Elevated Guideway

A typical elevated section has the following configuration:

(a) A simply supported beam from the abutment to the first interior (expansion) column (about 70 to 80 feet).

(b) A series of up to six continuous beams to a second expansion column (about 90 feet each).

(c) A final, simply-supported beam from the expansion column to the abutment (about 70 to 80 feet).

A typical elevated guideway cross section is shown in Figure 4-5.

Beam continuity is provided by reinforcing steel in the 24-inch high parapet wall. The beam/column interface is fixed by extending the column reinforcing into the beams. The beams are not post-tensioned. Thus, the assumption that the parapet wall provides beam continuity is true only for flexture caused by the vertical loading and does not cover thermal expansion. The 2-inch slot between beam ends is poured at the same time that the parapet walls are poured. The AIRTRANS elevated guideway has a typical beam depth of about 36 inches and a top flange of total width equal to about 110 inches. Thus, at noon on a sunny day, the top flange is exposed to the sun and the beam soffit is in the shade. Differential thermal strains result and the beam tries to lift up from the supports. This introduces tensile forces at the column/beam interface. Reinforcing steel was included during construction and grout injected in this area to bond the beam soffit concrete and the reinforcing steel, but it represents a potential problem area.

Full beam continuity can be obtained by post-tensioning the beams. The cost of post-tensioning is about $1,800 per 90-foot

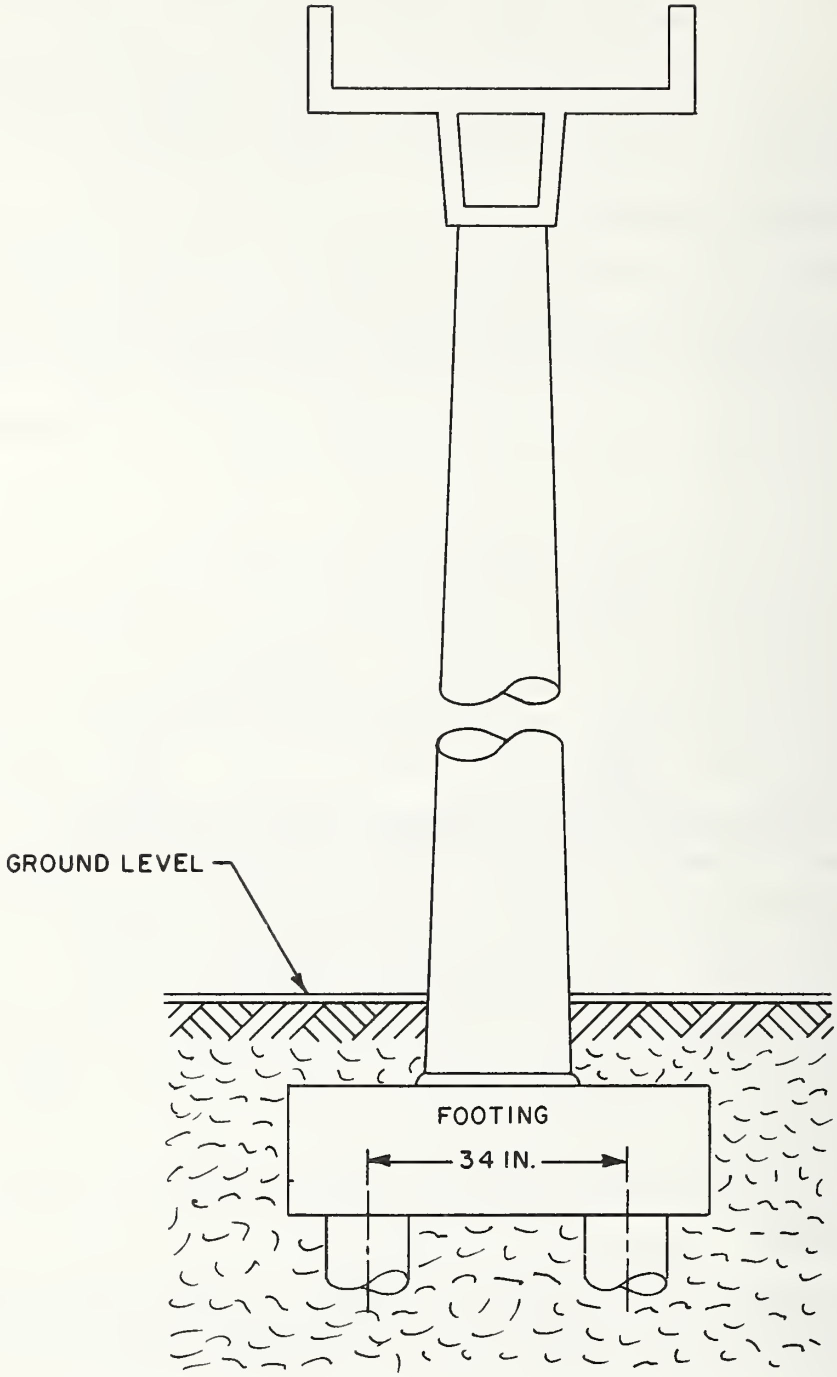

Figure 4-5. Typical Elevated Guideway Cross Section

beam, using 1973 dollars which would be about $2,200 per 90-foot beam using 1975 dollars.*

The elevated beams are precast, prestressed concrete. The cantilevered top flange supports the vehicle and the parapet wall. Beams are fabricated to a vertical curvature to match the profile geometry. Horizontal curves are obtained by holding the beam straight and curving the top flange. The parapet wall is then installed to the proper curvature as a continuous, poured-in place, reinforced concrete beam. A slight trough down the center of the beam carries water to columns to drain.

The columns are reinforced concrete and rectangular in cross section. The typical column is 24 inches square at the top and has a slight taper.

The foundation of the columns consists of 24-inch-diameter shafts penetrating 84 inches into unweathered shale. These shafts support the column footing which is fitted with bolts to provide vertical adjustments of the columns. The column foundations seem adequate for the clayey soil which overlays the unweathered shale. They provide excellent support and drastically minimize differential settlement of the columns.

4.10 SUBSTATIONS AND DISTRIBUTION SYSTEM

Vought selected three-phase, 60 Hz power for the rail system because their studies indicated it to be less expensive than a D.C. rail system. The three power rails are mounted side by side, one over another, on the guideway sidewall. There is a cover over the power rail to protect it from the weather and it does provide some protection to maintenance personnel working in the guideway. The biggest problem has been with metallic debris, foil, metallic wrappings, etc., blown against the rails and shorting them. Three routes were shut down for 5 hours in March, 1975, to repair the

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*TRW/ABAM, "Investigation of Low Cost Guideway Concepts for Tracked Air Cushion Vehicle" damage resulting from this sort of malfunction. This problem has since been fixed using fast acting supression breakers.

Power substation design and placement were based on wide ranging analyses which were verified by tests using a vehicle which could be loaded to "crush" weight. This vehicle was used during the early stages of the AIRTRANS construction and provided useful information on the power distribution system as well as the propulsion and other vehicle subsystems. The simulations indicated that the system operates at approximately 3,000 kVA; its rated capacity is 4,500 KVA. Vought reported that actual figures compare favorably with the simulation results. The simulations also show that one substation operates at 94 percent of its capacity and that six other each operate at greater than 80 percent of their respective capacities.

If the system were to be expanded, additional guideway and additional substations would be required. The analysis simulations considered the maximum number of vehicles that could be handled by the control logic and it was determined that saturated conditions would results in the heavily loaded areas.

There are 15 substations in the AIRTRANS system. In the event of a substation loss the load would be split among the remaining 14 substations. The requirement that substations be able to load-share without exceeding ratings does not appear in the APB specifications and therefore, the impact on the total distribution system is not known.

The APB specification did not require power shutdown when doors were opened on a vehicle stalled on the guideway. This was to maintain vehicle air conditioning thus encouraging people to remain in the vehicle, to avoid stopping all other vehicles in the area, and to allow powered acess to the vehicle by rovers. It was also determined that dropping power in an power zone could still present a safety problem in that people walking back along the guideway could walk into a live zone unless the enter system were shut down. The power rail design is recessed, which helps prevent accidental contract with the rail by people may be on the guideway.

The specification for the distribution system called for the sub-contractor to use "quality wormanship practices....". Vought stated that the quality of the work performed on guideway subcontract was not up to their expectations. In particular, they had to inspect each of the electrical connections and repair many since the sub-contractor had used a crimping tool improperly.

Power distribution system hardware deficiencies found during the Preliminary Systems Test consisted of poor reliability of circuit breakers, motor operators and Network Protector (NP) reverse current relays. Poor wiring practices and poor rail joints and splices also were found. These component problems have been corrected by (1) replacing unreliable circuit breaker and motor operator components, (2) reducing the number of breaker open and trip incidents (clean guideway area, vehicle unbalance corrections and elimination of false commands from the supervisory and surveillance system) and (3) initiation of periodic maintenance procedures.

The distribution system is adequate to handle the normal operating loads as shown in the simulation. It is adequately protected by automatic and manual circuit breakers in addition to the network protectors. Problems associated with connectors and rail alignment were solved in the early stages of operation.

Initial collector brush life on the AIRTRANS systems was approximately 200 hours. Reportedly a brush is now being used having a lifetime of 35,000 miles or 6 to 7 months. There is a need to either document from present transit users (data are considered proprietary by many developers) or to perform government-sponsored development in this area so that information is readily available for use by equipment designers.

4.11 TUGS

Seven radio equiped motorized tugs are kept in readiness, on 6 guideway spurs and in 6W. They are manually operated, but are equipped with guidance wheels and signal brushes and can operate freely and safely on the guideway, with their positions always known.

Tug operations have been satisfactory and extensive analyses was conducted for the specific number (7) used in the system to meet the 30 minute MTTR. The number should be great enough so that tugs are not the limiting factor in minimizing stalled-vehicle retrieval time and this criteria seems to be met.

If a vehicle fails in departure test, it must be possible to remove it easily and quickly, before it is committed to the system. A short loop for easy recycling of the vehicle exists in the 6W area.

For quick system restoration it must be possible to bypass a stalled vehicle rapidly on the guideway. The guideway was designed to be least expensive rather than most convenient and crossovers spurs, and bypasses were minimized. This has proven costly in terms of system restoration time.

Operational and maintenance functions should not be intermixed. A single guideway handles vehicles entering and leaving the Transportation Center, where airmail, trash, supply and maintenance facilities are located.

5. SYSTEM ECONOMICS

Capital and operating costs are of great importance to the system operator, ranking with safety, reliability, maintainability and service level.

Capital costs encompass the long-term design and facility expenditures as well as project management, administration, systems engineering, system test and demonstration and other similar expenditures.
Operating costs include materials, energy and personnel to operate and maintain the sytem. These elements are discussed below.

5.1 CAPITAL COSTS

Table 5.1 shows the basic contract capital cost breakdown for the AIRTRANS system in 1971 dollars. As indicated in the table, Vought Coporation incurred an overrun of about $21,400,000. The table breaks down the actual costs associated with the development of the system. As can be seen, some items represent overrun conditions, while costs for others, such as switches, were an underrun.

The information as presented was obtained through the Vought Corporation and is as accurate as possible, although in the later phases of the development cycle, such factors as the accelerated schedule, the large number of personnel assigned to insure timely development of the system, the changes instituted on a day by day basis to work around other on-going construction at the ariport, etc., made accurate expenditure accounting difficult. These activities contributed heavily to the overrun figure, and hence the cost of some $65 million is perhaps more then would have occurred had there not been these problems.

TABLE 5-1. AIRTRANS CAPITAL COST BREAKDOWN (1 of 4)

	Contract Dollars	Overrun (Underrun) Dollars	Total Dollars
A - Guideway			
AA - Elevated	3,482,000	336,000	3,818,000
AB - At Grade	3,928,000	379,000	4,307,000
AK - Design	806,000	77,000	883,000
Total	8,216,000	792,000	9,008,000
B - Switching Systems			
BA - Diverging	488,000	(46,000)	442,000
BB - Converging	545,000	(52,000)	493,000
BX - Design	155,00	-	155,000
Total	1,188,000	(98,000)	1,090,000
C - Power Distribution System			
CA - Power Distribution Equipment	578,000	181,000	759,000
CB - Power Rail System	2,306,000	721,000	3,027,000
CC - Emergency Power System	131,000	41,000	172,000
CX - Design	256,000	80,000	336,000
Total	3,271,000	1,023,000	4,294,000
D - Train Command & Control System			
DA - Automatic Train Control System			
DAA - Wayside Electronics Equipment	1,555,000	673,000	2,228,000
DAB - Guideway Electronics Equipment	1,470,000	636,000	2,106,000
DB - Central Surveillance & Supervision	939,000	407,000	1,346,000
DX - Design	1,166,000	505,000	1,671,000
Total	5,130,000	2,221,000	7,351,000
E - Vehicles			
EA - Passenger	5,946,000	4,944,000	10,890,000
EB - Utility	1,389,000	1,154,000	2,543,000
EC - Service	215,000	-	215,000
EX - Design	1,356,000	1,457,000	2,813,000
Total	8,906.000	7,555,000	16,461,000

TABLE 5-1. AIRTRANS CAPITAL COST BREAKDOWN (2 of 4)

		Contract Dollars	Overrun (Underrun) Dollars	Total dollars
F	- Voice & Video Communications			
FA	- RF Communication System	204,000	(26,000)	178,000
FB	- TV Monitoring	179,000	(23,000)	156,000
FC	- P.A. System	87,000	(11,000)	76,000
FX	- Design	67,000	(9,000)	58,000
	Total	537,000	(69,000)	468,000
G	- Maintenance Bldg. Storage Area, Spares & Equipment			
GA	- Equipment	460,000	752,000	1,212,000
GB	- Spares	405,000	662,000	1,067,000
GX	- Design	148,000	242,000	390,000
	Total	1,013,000	1,656,000	2,669,000
H	- Containers			
HA	- Baggage & Mail	221,000	52,000	273,000
HB	- Trash	68,000	16,000	84,000
HC	- Supplies	104,000	25,000	129,000
HD	- Adaptors	20,000	5,000	25,000
HX	- Design	64,000	15,000	79,000
	Total	477,000	113,000	590,000
K	- Passenger & Employee Station Equipment			
KA	- Terminal Passenger Station	187,000	(18,000)	163,000
KD	- Station Graphics & Signs	187,000	(18,000)	169,000
KF	- Passenger Station Rub Strip	22,000	(2,000)	20,000
KH	- Visual Screen Walls	147,000	(14,000)	133,000
KX	- Design	81,000	(8,000)	73,000
	Total	618,000	(60,000)	558,000

TABLE 5-1. AIRTRANS CAPITAL COST BREAKDOWN (3 of 4)

		Contract Dollars	Overrun (Underrun) Dollars	Total Dollars
L	- Cargo Station Equipment			
LA	- Terminal Baggage & Mail Equipment	391,000	71,000	462,000
LB	- Terminal Trash Station Equipment	288,000	52,000	340,000
LC	- Terminal Supplies Station Equipment	297,000	54,000	351,000
LD	- Airport Mail Facilities Station Equipment	70,000	13,000	83,000
LE	- Transportation Center Supply	73,000	13,000	86,000
LF	- Transportation Center Trash Dump/Wash	91,000	17,000	108,000
LG	- Cargo Station Fire Detection System	13,000	2,000	15,000
LH	- Cargo Station Barriers & Ladders	5,000	-	5,000
LJ	- Interface Equipment	1,374,000	250,000	1,624,000
LX	- Design	760,000	140,000	900,000
	Total	3,362,000	612,000	3,974,000
M	- Fare Collection Equipment			
MA	- Coin Turnstiles	28,000	-	28,000
MB	- Card Read Turnstiles	1,000	-	1,000
MC	- Coin & Card Read Turnstiles	19,000	-	19,000
MD	- Exit Turnstiles	28,000	-	28,000
ME	- Railings & Gates	20,000	-	20,000
MF	- Pass Cards	5,000	-	5,000
MG	- Encoders	1,000	-	1,000
MH	- Code Cards	1,000	-	1,000
MX	- Design	25,000	-	25,000
	Total	128,000	-	128,000
N	- Project Management			
NA	- Project Management & Administration	1,930,000	-	1,930,000
NB	- Systems Engineering	2,868,000	-	2,868,000

TABLE 5-1. AIRTRANS CAPITAL COST BREAKDOWN (4 of 4)

	Contract Dollars	Overrun (Underrun) Dollars	Total Dollars
NC - System Test & Demonstration Program	920,000	-	920,000
- All Other	1,087,000	-	1,087,000
Total	6,805,000	-	6,805,000
Total Capital Cost	39,651,000	13,751,000	53,402,000
Vought Cost for Maintenance & Revenue Operations	3,422,000	7,655,000	11,077,000
Grand Total Cost to Vought	43,073,000	21,406,000	64,479,000

5.2 OPERATING AND MAINTENANCE COST

In the early part of 1974, maintenance was requiring 211 personnel on a seven-day week, 10 and 12 hour-day work schedule. In December 1974, personnel had been reduced to 164 operating on a regular work week. As of May 30, 1975, AIRTRANS had a total of 125 personnel maintaining the system, on a regular work week. The total number of maintenance employees as of April 1, 1976 was 93, a level which may increase when other services become operational. Some of the man-hour reductions have been due to the implementation of an "on-line" maintenance concept, thus reducing the unscheduled maintenance man-hours.

As of September 10, 1975, the actual Vought average maintenance costs, under an interim contract were about $294,000 per month, which included some system changes and debugging tests. A tabulation of the costs paid to Vought for the period from January 25, 1975 to July 27, 1975 is shown in Table 5-2. The original estimate of maintenance costs provided in the Vought proposal was about 140,000 a month for labor and materials. As of April 1, 1976 the costs had dropped to $153.0K per month. This lower cost reflects maintenance by the Dallas-Fort Worth Airport.

Table 5-3 gives the AIRTRANS operational cost breakdown for 1975 and up April 1, 1976. The costs listed against "other" represents costs which occur as a result of some services being covered by vehicles other than AIRTRANS, or maintenance on buildings associated with AIRTRANS, and passenger service agents who are stationed in stations to assist passengers. These agents are not required but are used as an added feature.

The cost of the passenger back-up buses (11 buses were provided), as shown in Table 5-3, represents contractual expense for services not fully utilized. This was true because AIRTRANS never experienced a failure, necessitating the system to be shut down, during the period March to September 29, 1975; i.e., for a period of 195 consecutive days the back-up buses were never called. The AIRTRANS system vehicles logged a total of 1.67 million miles during this same period. The employee buses cost $102K/month in 1975 but since employees now use AIRTRANS, no costs are incurred.

TABLE 5-2. AIRTRANS MAINTENANCE COST

Period	Amount Paid	
1/25/75 - 1/26/75	$ 20,377	(2 days)
1/27/75 - 2/23/75	322,442	(4 weeks)
2/24/75 - 3/30/75	332,412	(5 weeks)
3/31/75 - 4/27/75	270,277	(4 weeks)
4/28/75 - 5/25/75	269,687	(4 weeks)
5/26/75 - 6/29/75	298,296	(5 weeks)
6/30/75 - 7/27/75	247,915	(4 weeks)
	$1,761,406	

Note: Payments to Vought under maintenance contract M-275.

Table 5-4 gives a breakdown of the power costs per month for the period January 1, 1975 to June 30, 1975. These costs when combined with the actual vehicle miles being accumulated on the AIRTRANS system results in a $.68/vehicle mile. It is expected that this will be further reduced as the system matures and improvements are made. Figures 5-1 through 5-4 show plots of AIRTRANS operation power costs, vehicle miles, power consumption per vehicle mile and power costs per vehicle mile, by month, for 1974 and the first half of 1975.

The maintenance staff, as of May 1975, consisted of 125 people spread across three shifts, 7 days a week. The general job categories and numbers of individuals assigned to each shift are shown in Table 5-5. The maintenance staff includes AIRTRANS rovers, maintenance personnel assigned to the cargo handling equipment within stations, and individuals assigned to vehicle cleaning functions. Just prior to system shutdown in September 1975, the staff was reduced to 106 people, with personnel cuts in the guideway and vehicle maintenance areas. As of April 1, 1976 the staff had been reduced to 93 (Table 5-6).

TABLE 5-3. MONTHLY OPERATING COSTS

CATEGORY	1975[1]	1976[2]
AIRTRANS OPERATIONS:		
Labor	39,000	24,500
Power	10,000	12,000
AIRTRANS MAINTENANCE:		
Labor	183,000	114,000
Materials	54,000	39,000
G&A/Profit	48,000	-
Sub-Total - Ops/Maint:	334,000	189,500
OTHER:		
Facilities Maint.	9,000	9,000
Passenger Serv. Agents	24,600	27,200
Buses:		
Employee Transport	102,000	-
AIRTRANS Backup	3,000	3,000
Trucks:		
AMF Mail	38,900	43,800
Interline Baggage	53,600	54,100
Sub-Total - Other:	231,000	137,100
Total:	565,100	326,600

Note: Costs for 1975 and up to April 1, 1976.

1. Airport operation and Vought maintenance of AIRTRANS; passenger/supply service on AIRTRANS; employees bused; mail and bags trucked.
2. Airport operation and maintenance of AIRTRANS; passenger supply and employee service on AIRTRANS; mail and baggage trucked. Costs through 4/1/76.

TABLE 5-4. AIRTRANS MONTHLY POWER COSTS

January 1975	$10,225
February 1975	8,809
March 1975	9,872
April 1975	11,347
May 1975	9,850
June 1975	11,806
Average Monthly Cost	$10,318

Note: Costs for period Jan. 1, 1975 - June 30, 1975.

Figure 5-1. AIRTRANS Operations Power Costs

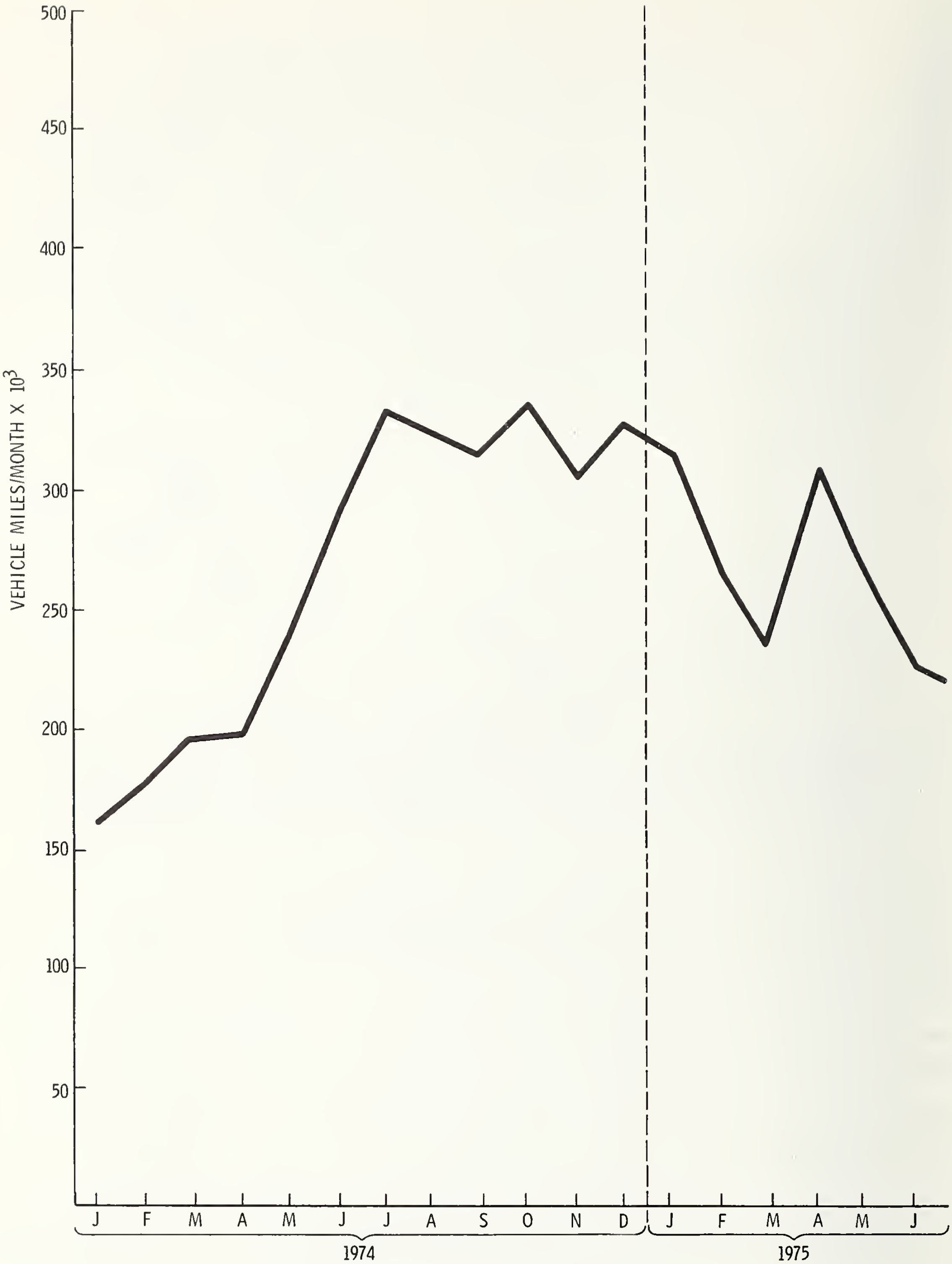

Figure 5-2. AIRTRANS Vehicle Miles per Month

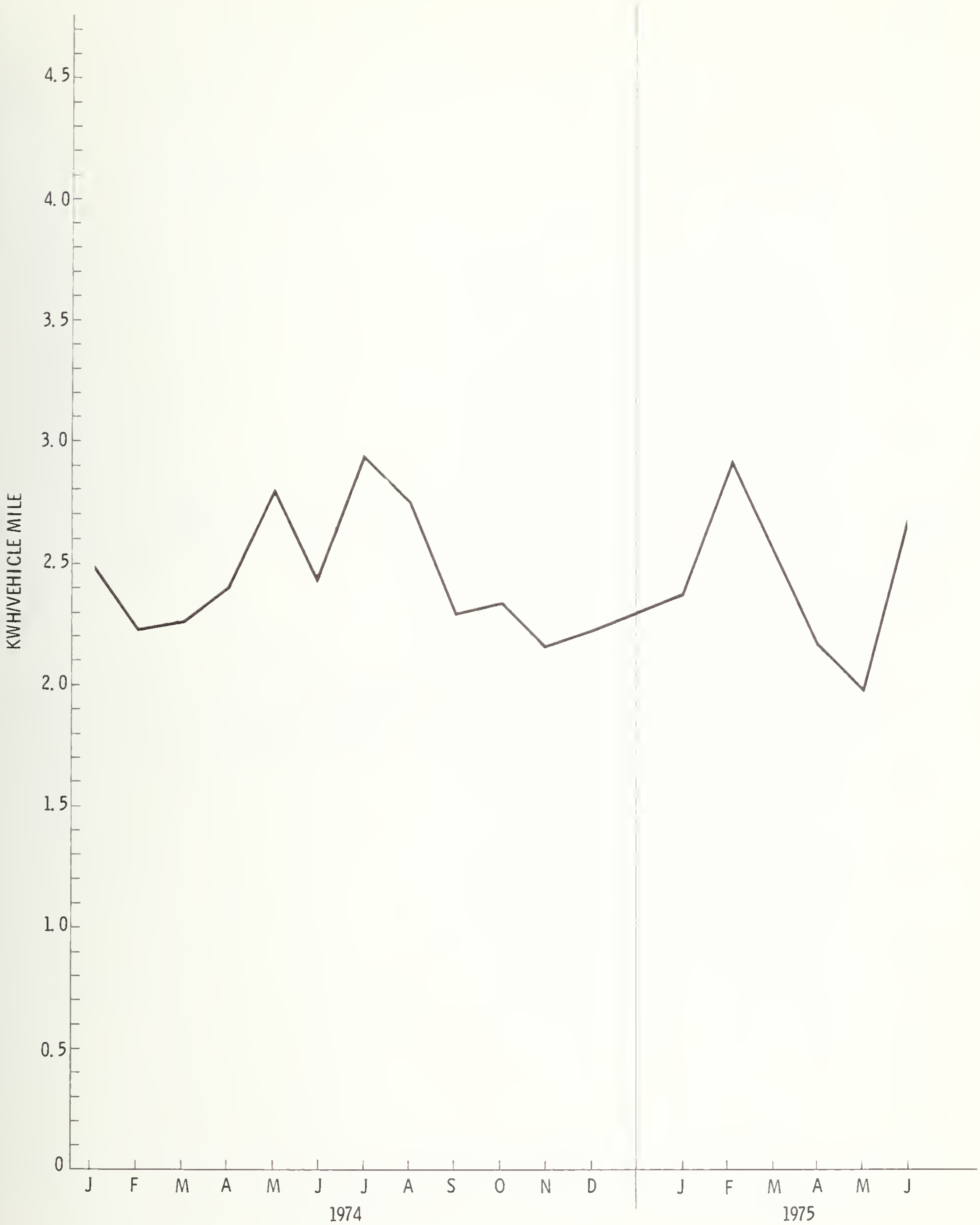

Figure 5-3. AIRTRANS Operations Power Consumption per Vehicle Mile

Figure 5-4. AIRTRANS Power Costs per Vehicle Mile

TABLE 5-5. AIRTRANS MAINTENANCE STAFF

Title/Job Category	Number of Individuals Per Shift		
	1	2	3
Chief	1	0	0
Staff and Secretary	2	0	0
Line Supervision	7	0	0
Foreman	2	2	1
Quality Assurance	1	1	1
Materials	7	1	2
Guideway Maintenance	11	10	12
Vehicle and SSE	12	8	10
Vehicle Electronic Test & Repair	9	8	8
Audio/Video	2	4	3
Shift Totals	54	34	37

Note: As of May 1975, 7-day-a-week coverage required. Reduction to 106 by September, 1975, Vought estimate is 90 at "system maturity."

TABLE 5-6. AIRTRANS MAINTENANCE STAFF

TITLE/JOB CATEGORY	NUMBER OF INDIVIDUALS PER SHIFT		
	1	2	3
Supervisor of Maintenance	1	0	0
Secretary	1	0	0
Line Supervision	4	0	0
Foreman	3	3	3
Inspection/Records	3	1	1
Materials	5	1	2
Guideway Maintenance	8	6	5
Vehicle/SSE Maintenance	7	7	6
Electronic Maintenance	9	8	9
Shift Totals	41	26	26

Note: Data as of April, 1976.

6. PROJECT DEVELOPMENT MANAGEMENT

6.1 PROJECT EVOLUTION

This section gives an historical listing of principal events and decisions leading to the present AIRTRANS system.

- Before 1965 — Decision made to construct a regional airport. Concept included an integral, intra-airport transportation system. FAA simulation studies identified the required airspace capacity for the year 2000.
- Early 1965 — Tippetts-Abbett-McCarthy-Stratton (TAMS) retained as the principal airport planning consultant. Site selection study initiated.*
- December 1965 — Site selection report completed; present site recommended.
- Early 1966 — Site selection approved by the Regional Airport Board (APB).
- End of 1967 — TAMS completed Airport Layout Plan, Financial Feasibility report and Airport Master Plan. The plans included a fixed guideway, intra-airport transit system.
- June 1968 — "Expression of Interest" RFP's for Airport Transit Systems were sent to 60 firms; 12 replies were received. TAMS prepared RFP because the Airport Board lacked a staff. (This was not a firm specification, but request for expression of interest and evidence of competence).

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*McCarthy, G.T., "Engineering Management for the Dallas/Ft. Worth Airport," pp. 165-175, Airports, Challenges of the Future, American Society of Civil Engineering, 1973.

o September 1968 — Three companies selected for further participation of RFP responses based on TAMS evaluation. Follow-up inquiry resulted in the following system decriptions:

Varo:	30 mph, 2 second headway, 6 passenger vehicles.
Dashaveyor:	30 mph, 10 second headway, 12 seated, 12 standees per vehicle.
Westinghouse Electric:	"Skybus", as demonstrated in South Park, Pittsburgh.

Due to the emphasis on a PRT solution, Westinghouse was discouraged from further participation but Varo and Dashaveyor were retained for participation in AIR-TRANS feasibility studies.

o Late 1968 — The Airport Board rejected the initial TAMS concept of a "spine" type airport with a north-south transit system and long terminal corridors at right angles to this "spine". Instead, the present configuration with semi-circular terminals was adopted.

o March 1969 — The architect-engineers developing the terminal building designs* assigned coordination responsibility for design of transit system. Six-month feasibility studies (50 K each) awarded to Dashaveyor and to Varo.

*Helmuth, Obata and Kassabaum, and Brodsky Hopf, Adler (HOK/BHA).

o	Mid-1969	Architectural studies conducted by HOK/BHA based on Varo and Dashaveyor concepts.
o	October 1969	Preliminary system feasibility studies completed by Varo and Dashaveyor. Varo's system had 232 six-passenger vehicles and 2-second headways. Dashaveyor adopted a 12 standees - 12 seat vehicle concept and 10-second headways.
o	November 1969	These studies showed that requirements had to be better specified. Alan Voorhees and Associates were commissioned by HOK/BHA to develop airport terminal user data which would be used for terminal sizing. Their inputs were CAB tapes and on-board aircraft surveys. Results were used in developing 1975 airport schedule.
o	July 1969 to January 1970	Arthur D. Little, Inc., commissioned to study problems of evaluating bus vs. automated transit service for purposes of demonstrating the merits of the automated transit option to the airlines. This study found that 245 buses would be required to provide the same level of service as the automated system. though the initial cost of an all-bus system was predicted to be less, over a 20 year period the automated transit solution would be less costly. The major conclusions and recommendations of that study are summarized as follows*:

*"Comparative Financial Analysis of a Bus System and an Automated Transit System," A.D. Little, January 1970.

"1. A bus system, if adopted must be able to offer the dependability and quality of service proposed for the automated transit system. This means that buses could not be operated on public roadways or mixed with other vehicular traffic: an exclusive right-of-way would have to be provided.

2. Even though the bus system requires a much smaller initial investment than the automated transit system, wage costs assume increasing weight with each passing year so that the long-term impact of wage inflation more than offsets the financial advantage of a relatively small initial capital investment. In other words, the threat of inflation clearly undermines the financial feasibility of a labor-intensive bus system at the Dallas/Fort Worth Regional Airport.

3. It is quite clear that the financial performance of the automated transit system is not simply better, but overwhemingly superior to that of the bus system. Unlike the bus system, automated transit is not labor intensive, hence it is not exposed to the high risks of wage inflation. At the same time, we fully recognize the high financial risks inherent in the application of new technology to an automated

> transit system is so great that substantial cost increases could be absorbed without jeopardizing the financial feasibility of the system itself.
>
> From a financial standpoint, we see no set of circumstances that could reverse the relative desirability of the automated transit system over a traditional bus system. We therefore urge the adoption of an automated transit system as the basis of future airport planning."

- Early 1970 — APB commissioned follow-up Arthur D. Little, Inc., study to evaluate conventional vs. automated transit handling of intra-airport freight.
- September 1970 — Vought, too late for independent role, affiliated with Varo in support of Varo's role in the APB transit system program.
- December 1969 to Mid-1970 — APB formulated the AIRTRANS development program. Phase I of this effort (system definition) undertaken with Battelle Columbus Laboratories. Efforts concluded by mid-1970. The methods and results of this significant effort are summarized as follows:

AIRTRANS ridership data for 1975 was developed from the Voorhees predictions of airline flight activity developed as part of their airport terminal sizing study. On the basis of this information, Battelle Columbus Laboratories and a consultant estimated the AIRTRANS traffic demand at 5-minute intervals, for the design day of the airport (average day, Wednesday, of peak month, August 1975), to provide the basis of required system capacity, Employee ridership data were obtained from airline projections and baggage transfer data.

A maximum interterminal time had not been specified but 20 minutes were alloted to AIRTRANS. This 20 minute transfer time was the key requirement in designing scheduling and routing algorithms.

At the same time, a preliminary generalized guideway right-of-way was developed by the APB staff. Subsequently TAMS and HOK/BHA performed guideway layout studies to match the airport design in conformance with the following three constraints: (a) minimum radius of curvature, (b) switch length, and (c) minimum guideway length required in approaching a switch. The switch could have been either on-board, wayside, or a combination of both. This right-of-way reserved space for future trackage, and for freight and express passenger routes. Simultaneous train safety studies, by Battelle, identified 18 seconds as the probable minimum feasible headway, using assumptions of existing train control technology. Battelle's assessment indicated that is was too risky to pursue the small vehicle systems, such as the 2-second headway systems proposed during 1968/69. To integrate these varied elements of information, a system simulation model was developed using GPSS 360 software. The results of the ensuing simulation were used to define all system parameters including vehicle size, propulsion and braking requirements, and flow rates. Block control technology and off-line stations were assumed. Service capability was the only consideration in these early studies; no trade-off against cost was considered. The location of the maintenance facility at one end of the layout was dictated by the airport design.

o February 1970 — Secretary of Transportation, J. A. Volpe approved a $1.02M DOT grant to develop and demonstrate technology for the airport.

- 1970 Fall — Vought conducted an independent design study on an AIRTRANS-size suspended vehicle. They found that the suspended vehicle could not compare with a comparable size supported vehicle from a cost standpoint if a portion of the guideway is at grade.
- October 1970 — APB staff and Battelle completed AIRTRANS specifications (during 3 week period).
- November 1970 — RFP, requesting quotes for 10 configurations, was sent to Varo and Dashaveyor. Proof of financial capabiility was also requested.
- December 1970 — Hardware demonstrations conducted of the competing systems: 1) Varo had a static display of a 30 passenger monorail vehicle (Garland, Texas) 2) Dashaveyor had two 24 passenger cars, one moving under automatic control, the other under manual control, on a short test track (Pomona, California).
- February 1971 — Bids received. The ranges were $48M to $66M for Varo and $36M to $46M for Dashaveyor, for the 10 configurations. Dashaveyor also submitted a non-conforming bid, the "Plaza System", based on four separate spurs emanating from a central terminal, at a cost of $27M. All bids were well above the $18M allotted to the project by the APB and were rejected. A new specification was generated: (a) some station doors were left optional, (b) some communication requirements were removed, (c) semi-automatic trash handling, (d) configurations to be considered for evaluation were reduced from 10 to 5.

- March 1971 — Revised specifications were prepared.
- April (15) 1971 — RFP was issued by the DFW APB, calling for five different system configurations as described below. Each configuration represented different combinations of the basic transportation requirements for AIRTRANS. Quoting from the RFP:*

  "The functional requirements of the five system configurations are described in tabular form in Table 2-1. The meanings of the five columns in this table are as follows:

  Column 1 - Configuration Designation. This column contains the numerical designation assigned to each of the configurations.

  Column 2 - People (Together). This column means that the passengers and employees will ride the same trains and use the passenger stations as described in Section 3.3.3.2. The flow rates are given in Section 3.4.1 through 3.4.1.3.

  Column 3 - People (Separate). This column means that the passengers and employees will ride separate trains and use separate passenger and employee stations as described in Section 3.3.3.2. The flow rates are give in Sections 3.4.1 through 3.4.1.3.

*Section numbers and table number refer directly to AIRTRANS RFP dated March 1971.

Column 4 - Baggage and Mail. This column means that the baggage, interline mail, and AMF mail will be handled as described in Sections 3.3.3.1 through 3.4.2.3 and Section 3.4.2.6.

Column 5 - Trash and Supplies. This column means that the trash and supplies will be handled as described in Sections 3.3.3.3.4 through 3.3.3.3.5. The flow rates for the trash and supplies are given in Sections 3.4.2.4 through 3.4.2.6."

TABLE 2-1. SYSTEM CONFIGURATION FUNCTIONS

Configuration Designation	People (Together)	People (Separate)	Baggage and Mail	Trash and Supplies
1	Yes*	No**	No	No
2	Yes	No	Yes	No
3	No	Yes	Yes	No
4	Yes	No	Yes	Yes
5	Yes	No	No	No

*A "Yes" indicates that the designated AIRTRANS configuration shall perform the function associated with that column.

**A "No" indicates that the designated AIRTRANS configuration shall not perform the function associated with that column.

Note:

The final configuration contracted for was different than any of the five. It called for passengers and employees to be separated, i.e., passengers and employees and the additional capability to carry baggage and mail, and trash and supplies.

The specific requirements of the system configurations described above are as follows:

(1) For configurations 1 through 4, the AIRTRANS Performance Specifications and the Owner Drawings shall govern the system design, fabrication, construction, testing, storage, maintenance and operation.

(2) For configuration 5, all of the AIRTRANS Performance Specifications shall apply, except that the storage area previously located in the Transportation Center shall be relocated. For Configuration 5 (only), the storage area and its associated equipment shall be located in the Remote Parking Area (5 E as shown in the owner Drawings). The Contractor shall furnish all buildings, structures and associated equipment required in this new location to properly perform all the functions associated with the storage area. The area available for these functions is approximately one acre (200' x 200'). In addition, the AIRTRANS right-of-way in the vicinity of the relocation storage area may also be used for storage provided it is not otherwise required for Configuration 5. Further, the Contractor shall provide suitable methods and equipment for transporting vehicles to and from this

storage area and the Transportation Center for vehicle maintenance; the service roads may be used for this purpose."

o June to Mid July	Four bids were evaluated:	
	Bendix-Dashaveyor	(highest)
	Westinghour-Electric	(second highest-
	Westinghouse Air Brake	(one of two low bids)
	Vought	(one of two low bids)
	The price range for the two low bidders, and for the five configurations, was $18M for passenger-only service, to $30M for all services with passengers and employees riding together. The bids were evaluated on the basis of facility visits, the estimated cost of a new configuration that separated passengers and employees, and other factors.	
o July 13, 1971	Vought was awarded a $31M contract, with GRS (wayside command and control) Ling, Oliver, O'dwyer Electric, Inc. and Trinity, Inc., (electrical, guideway construction) as their principal subcontractors on July 13.	
o Mid 1971	Parsons-McKee, Inc., was retained as a consultant for civil work and Battelle for vehicles and command and control, to assist the APB staff with monitoring Vought performance of the contract.	
o August (2), 1971	Vought received notice to proceed with work. Fixed price contract awarded.	

o	Early 1972	Vought conducted internal design review of all systems and subcontracts; vehicle design freeze occurred.
o	February 1972	First test chassis produced.
o	May 1972	Testing of chassis on track; display of first prototype vehicle at TRANSPO.
o	Mid 1972	Phase II baggage handling equipment contract awarded to Vought.
o	September 1972	Completed first production vehicle.
o	Late 1972	Completed construction of 1W, 2W, and 2W-2E loop segments.
o	Late 1972	Design verification tests of all components and subsystems.
o	Early 1973	First preliminary system testing on complete 2W-2W loop to integrate all components.
o	January (13) 1974	Airport opens; AIRTRANS revenue passenger service started with 12 trains, 7 a.m. to 10 p.m. Vehicle attendants present on every leading and trailing car. Three months of system testing completed.
o	February 1974	Passenger Service extended to remote parking lots.
o	March 1974	Initiated AMF service and service for employees, food supplies and interline baggage.
o	March (19) 1974	Employee service initiated with revised routing.
o	April 1974	Attendants removed from trains.
o	April (10) 1974	Employee Service from south parking lot initiated. Use by employees at their option.

o	May (1) 1974	Employee Service from north parking lot initiated. Use by employees at their option.
o	June (1) 1974	Around-the-clock passenger service initiated.
o	June (16) to July (19) 1974	Initiated service for employees (required)
o	June (20) 1974	Employee service discontinued. (Service was unacceptable).
o	January 1975	Initiated supply service.
o	March 1975	10 day shutdown due to contract differences related to acceptance of system.
o	April 1975	6 months system maintenance contract awarded to Vought ($1,800,000). Service resumed.
o	September 1975	AIRTRANS shut down due to inability to resolve contract differences.
o	December 1975	Contract dispute settled and system accepted.
o	January (20) 1976	AIRTRANS passenger and supply systems operational. Maintenance and operations being performed by APB.
o	April-May 1976	Required Employees Service initiated by APB

6.2 PROJECT MANAGEMENT ASSESSMENT

6.2.1 Funding and Schedule

The initial contract between the Dallas/Fort Worth Airport Board and the Vought Corporation called for the design, development, installation, and initial system operation (demonstrated through non-revenue testing) of an automated people-mover system for $32 million, fixed price, in a two-year time period. The scheduled completion date was July 15, 1973, or airport opening if later. Contract initiation was August 2, 1971. Since the initial contract, the contract value has increased to $34 million, as a result of mutally agreed upon contract changes. This does not include cost as a result of claim settlement or for interim maintenance.

Under the original contract, Vought must provide three years of maintenance at a price of approximately $5 million. The reliability requirements associated with the system (refer to AIRTRANS RFP, Section 3.3.6.2.4) must be met at the end of the three-year maintenance contract. In terms of schedule, the three year maintenance period of performance was not initiated because "system acceptance" by the owner occurred without exercising the 3-year contract. The system has, however, been in revenue service since airport opening in January 1974. The contract dispute between Vought and the DFW/APB was settled December 5, 1975. Hence, the original July 15, 1973, completion and acceptance date slipped substantially.

The contractual process also provides for progress payments to Vought upon completion of portions of the development schedule. The contract price of $34 million includes approximately $7 million from the U.S. Department of Transportations (DOT) awarded through the Capital Grant process by the DOT Urban Mass Transportation Administration and applicable to the people-mover portions of the system. The contract price of $34 million, however, does not reflect some of the normal costs associated with the development of a transit system. Some of these are:

- Cost of bringing power to the site
- Cost of the right of way
- Cost of subgrade preparation
- Cost of the station shell and some interior appointements (station doors and windows, collection turnstiles, signs are included - escalators and elevators are not).

In addition, the Vought Annual Financial Report of 1974 shows a $21.4-million investment of corporate funds in support of the development of the system. Some portion of this overrun is related to items such as accelerated schedule to complete construction following a schedule slippage created by non availability of a work area, and Vought redoing work of their own subcontractors, to improve quality rather than penalize the schedule while some action was taken against the subcontractor.

There is also an unpublished, and hence undefined, hidden cost associated with the Vought professional staff which worked many man hours of uncompensated overtime on the project. Suffice to say, the actual costs associated with the system exceed the published figure of approximately $62 million. The process has simply taken longer and cost more than originally anticipated.

Discussions with both Vought and the APB staff raised some points related to the contractual process. Vought considers the "fixed price" approach undesirable because it lacks flexibility to provide very desirable, but not contractually necessary, improvements to the system which come about during the development of a "new system". The Board staff, while agreeing in principle, is limited in funding and cannot afford the luxury of escalating the costs beyond available resources. Supplemental agreements for improvements suggested by the builder were and can be reviewed undar a separate proposal.

It is also recognized by the Airport Board staff, that, if Vought and its professional staff had not felt a commitment (Vought contributed $21.4-million internal funds) to deliver a sys-system under that fixed price contract, it might not have been completed. Hence, the contracting process, i.e., type of contract, funding limitations, and selection of contractor (resources, previous experience, as well as technical concept) must be carefully weighed in terms of such commitment. Selection of the low bidder (often a predominant selection criterion with a fixed-price contract) may not be the most desirable. It is not the intent of this report to suggest an alternative to the contractual process used, but to reflect the view that the process was not totally satisfactory and that the success of that process to date at the Dallas/Fort Worth Airport is more of a credit to the willingness of the participants to do what was needed to complete the job, than the specific contractual process.

The two-year schedule for the design, development, and testing to system acceptance was predicated on the planned opening of the Dallas/Fort Worth Airport and was not scoped in terms of what was reasonable for the development of the AIRTRANS system. Nonetheless, it was contractually agreed to by Vought. A slippage in the opening date of the airport of approximately 6 months helped to some extent, but the system had not been tested in accordance with the provisions of the contract even at the opening day. A decision had previously been reached by both the Board and Vought that in spite of the lack of testing, the passenger system would be put in service on the opening day.

In deciding to enter a contract with the Airport Board for the AIRTRANS system, Vought considered various problems which impact both schedule and funding. One item which they missed and which created difficulty was a "mutual beneficial occupancy" clause in the contract. The clause, normal in the construction business where multiple contractors are operating in the fabrication of a facility, stipulates that coordination and cooperation between separate contractors is desirable for minimum interference in construction. Vought did not anticipate the difficulties in obtaining "coordination and cooperation" from other airport construction contractors which in fact, happened. They led to serious slippage in early construction and testing which, in turn, affected the entire development process. For example, Vought was not given access for construction in some areas until 1 year after the date which was called for in the original schedule. Nonetheless, Vought did try to work around these interferences, as opposed to stopping work and awaiting availability of an area. Other items such as the environment, e.g., blowing sand and aluminum foil from workmen's sandwiches, also created failures which were not anticipated and which created additional delays. Delays also resulted early in the program, when the first communications system for the control system, requiring FCC approval, was disapproved by the FCC. Component reliability problems were another source of schedule delay.

In spite of the schedule problems, the placing of a highly complex system like AIRTRANS into revenue service in even a 30-month period must be considered remarkable. The dedication of the contractor personnel was a major factor in this accomplishment. A 2-year development cycle is unrealistically short; a time span somewhere between 30 and 48 months is usually necessary to accomplish a "similar application" program where extensive test is required for proof of acceptance.

6.2.2 Airport Board Management Approach

A management proces is as important to the success of a project as the funding process, contractual process and a reasonable schedule. The airport maintained an in-house staff of 4 individuals who had the total responsibility for ensuring the success of the project. These four people were supported by two consultants, whose primary functions are defined below.

The Airport Board staff used a "Critical Path Method" (CPM) for control. Due to the large number of schedule slippages which had occurred early in the program, this approach was dropped (Vought asked the Board to drop CPM in favor of a Master Schedule, because of the expense of maintaining an updated CPM with the "fluid schedule").

After February 4, 1972, the APB staff monitored the overall system development by using the Master Schedule prepared by Vought. They also maintained control by reviewing and responding to the "Owe List" on action items, reviewing and approving critical drawings, as well as elements that had completed construction. The "level of approval" for drawings was determined by the APB staff from a drawing list submitted by Vought early in the contract. This list was updated as time progressed, and the Board staff maintained the option to review and approve any drawings. The review process was performed in no more than 15 days, and included the use of consultants by the APB staff to perform selected reviews. The decisions rendered in the review process were "unaccepted", "accepted" or "accepted as noted". The two consultants retained by the APB staff for the review process were Parsons McKee, Inc., who reviewed civil engineering items, and Battelle for all other items, including system safety. Due to the proprietary nature of the GRS control system, drawings were not reviewed; instead, the APB staff had Battelle conduct a system safety review on the system as a whole, to ensure adequate safety. Changes did result from this review, and the process was considered satisfactory by all. The configuration control process for change requests arising after end-item approval were handled the same way, except that, depending on the nature of the change and its criticality with respect to schedule and funding, Vought did initiate the change (at own risk) prior to receiving final APB staff approval. The process from the point of view of both parties worked very well, and potential problems were avoided by close liaison between the APB staff and Vought management on all approvals. The APB staff also witnessed major tests of the system in all phases of the program and performed periodic inspections of the work in progress. Final approval of individual elements of fabrication and construction (also used as payment milestones) was made by the APB staff, or its consultants, when notified by Vought that this could be performed. Program payments were used in accordance with a percentage completion with a percentage held back at each stage until final system acceptance. A major difficulty that faced both parties was the issue of defining a measure of reliability on a system level that could be verified and on which to base buyer acceptance. This difficulty was overcome by a settlement agreement on December 5, 1975.

6.2.3 Vought Management Approach

Vought used a variety of management tools to monitoring AIRTRANS development progress. Fiscal control was exercised through a detailed Work Breakdown Structure (WBS) and monthly financial review meetings. Vought considered this very valuable and although there was a significant overrun, the process did assist in identifying key overrun areas and in keeping costs as low as possible. Schedules were originally monitored weekly. A Critical Path

Method (CPM) chart, prepared in December 1971 was quickly dropped in favor of a simpler set of 26 Master Schedules, when it became apparent that unforeseen schedule delays were causing excessive effort to maintain the CPM approach. The CPM, although discarded, did provide Vought with a good initial planning tool and, hence, was considered beneficial. CPM was also an initial contractual requirement, and APB approval was required when it was dropped in February of 1972. Supplemental to the Master Schedule and considered an excellent status/liaison tool was the "Owe List", a log which maintained the status of all action items between parties. Weekly reviews were held with project leaders, to assess status of the development process. Special problem areas were reviewed daily.

Other management tools included Design Information Request/Release (DIR) forms and Design Decision (freeze) documents, by which technical status information was relayed to all Vought team members. The purpose of the Design Decision documents was to freeze designs so that work could progress. This approach did not always satisfy all technical disciplines involved, but it was valuable for maintaining schedules.

Design reviews for the major subsystems were held at 60 and 90-percent completion points. This design review process covered both internal Vought Work and major subcontractors (Guideway, Electrification, Controls and Baggage/Mail Interface Equipment). In all management areas, the APB staff had access to or were party to all decisions in the development process. This was especially true with respect to matters affecting safety. The overall design development process, through initial operation, was handled by Vought with an average team size of about 100 people and a maximum of 180. An important factor in the skill-mix requirement was that the team had complete access to other technical specialists within the company on an as-required basis. Reliability was cited as an example where specialists were called upon, to assist in the design process. A second example was the use of simulation computer specialists from aircraft sections of Vought, who modified an existing "aircraft" program, to forecast maintenance requirements. Vought also used its design engineers during the integration test phase, in order to debug the system. While major design trade studies were performed in the design process, little was formally documented. Similarly, statistical analyses for safety (death/injury), detailed safety plans, etc., were not specifically performed. Instead, a "design philosophy of maximum safety" was used. Drawings were made to "commercial quality", and the system specificiation is only reflected through these "as-built" drawings. Operational and maintenance manuals were prepared. A brief review of that documentation shows that material presented in the documents has not kept pace with development changes of the system.

In general Vought used techniques developed in aerospace/DOD business, minimizing documentation and resisting (for cost reasons) heavy reliance on MIL specifications in the developement process. It is assumed that at the time Vought delivers all documentation to the Board it will reflect the "as-built configuration". The lag is updating documentation is to be expected in terms of the contract process which calls for "final documentation" at system acceptance. The management approach was for the most part successful with the exception of "commercial reliability" which did cause and continues to cause problems.

7. EVALUATION

7.1 PERFORMANCE SUMMARY

The Dallas/Fort Worth Airport with AIRTRANS, is the most innovative airfield developed to date. AIRTRANS is the largest operational automated guideway system in the world. It consists of 13 miles of guideway, 53 stations, 68 vehicles, and 71 switches. An integral part of the airport, the AIRTRANS system is specifically designed to carry passengers, employees, baggage, mail, trash, and supplies in the automatic mode, within an airport complex. During the assessment period, May to September 1975, only the passenger and supply systems were in "revenue operation" although the other services were operated in a "dry mode".

In the last 18 months of revenue service, the system has achieved safe operation at a reasonable level of reliability. It has logged some 6.0 million miles and carried some 5 million people without a single passenger injury or fatility, although two workmen have been injured when working on the guideway. During the period of operation from March through September 1975, it logged some 1.6 million vehicle miles without a shutdown enough to require backup buses.

A conservative philosophy was used in the design approach and selection of components. New designs, or pushing the state of the art were avoided whenever possible. Time-tested components were employed or adapted to the application. A distributed control strategy which allows safe operation despite failure of the central control computer, fail-safe relay block control logic, and a proven, on-guideway, fail-safe switch, (AIRTRANS calls 92,600 switches per day) are examples of these points. Other design features include an innovative four-wheel steering system to provide a short turning radius for the vehicle, a well designed propulsion system capable of pushing or pulling a second vehicle if necessary, and an aesthetically pleasing guideway. The guideway blends into the airport background, even though designed to meet standard highway bridge codes.

Some development difficulties were encountered. Many off-the-shelf items, while time tested in commercial applications, have not proven rugged or reliable enough for transportation application. Inadequate specification, expecially relating to reliability, led to misunderstandings and lack of proper design in some cases. Insufficient requirements, inadequate time, or inadequate trade-off studies resulted in materials and design elements which were not always cost effective. Overemphasis on initial cost savings rather than life cycle cost considerations led to less-than-the-best choices of designs and materials. An example was the choice of acrylic-finished fiberglass for vehicle exterior panels.

The construction process itself involved many difficulties. Interference from other airport construction caused schedule slippages. Subcontractor quality assurance, especially in the guideway power and signal electrification process, was less than adequate, requiring extensive rework. Even the guideway fabrication process produced problems because of difficulties in maintaining the guideway tolerances for the roadway and sidewalls in accordance with highway standards. (Surface reconstruction was required for certain portions of the guideway.)

Testing was useful in determining many changes required, yet was not completed before starting revenue service operation because of time limitations caused by schedule slippages.

The installed system is constrained by certain built-in characteristics. It would require changes to upgrade AIRTRANS to a higher speed system, or a significantly shorter headway system.

The need to improve performance for an urban application exists in most technical areas, especially those of braking, suspension, speed and guideway protection from the environment for more severe climates. Improved specifications, and increased standardization would be desirable. Parts with a quality better than commercial, but less than MIL spec. are required; a parts program would become a necessity in a new application.

Nonetheless, the present AIRTRANS design is adaptable to airport applications, shopping centers, campus applications, and with some changes to limited central business district (CBD) applications. The success of any future applications, however, cannot be guaranteed simply on the basis of a proven technology, since issues of financial viability, social, and environmental acceptance, and proper design planning and implementation must also be satisfied. Toward this end, any private or public body considering such a system should be cognizant of some of the problems and lessons learned from the AIRTRANS experience.

7.2 DETAILED TECHNICAL FINDINGS

7.2.1 Technology Assessment

AIRTRANS passenger service and utility supply service have been very effective. Since March 1976, employee service has been successfully initiated. The other services have been operated and tested in a non-revenue mode, and the interpretation and extrapolation of pertinent data indicate that all systems are potentially operational. Since all parts of the system have not actually operated together in revenue service, no assurance of this can be given.

In general, most of the reliability problems experienced in early operations have been eliminated. Some of the existing "problems" mentioned in the report, such as poor signage, poor entry/exit conditions within stations, etc., are related to the initial constraints and designs imposed by the airport architects. Additional engineering product improvements are continually being made to further increase component and system reliability, while reducing the maintenance costs.

Some of the other issues raised in the report dealing with "low initial capital investment for design selection vs. life cycle costing" can, in truth, only be evaluated in time as the actual O&M costs are tabulated and analyzed. A continuing "evaluation" of this system, in terms of operational cost and reliability monitoring, would be of benefit to all concerned with new forms of transportation.

The assessment of the technical capability of the present operational system at the Dallas/Fort Worth Regional Airport is based on a review of extensive test reports and detailed discussions with the developer, buyer, and users. Many of the issues raised as a result of the assessment process, for example, "reliability problems" and "inadequate signage in stations" either have been or are being corrected or improved. Their existence proves that there is always a learning process which, unless "planned for", can present problems in funding, schedule, and product acceptance. The assessment of the AIRTRANS design for improved performance, i.e., for significantly higher speeds, higher acceleration/deceleration capability, increased grade climbing capability, differing service policy, demand-responsive service and the use of control strategy other than fixed block, etc., has not been made. For this reason, such evaluations presented are only the judgements of the developer in combination with the assessment team. Any other application where significant changes in performance or service are required should consider such improvements as developmental and requiring an extensive test program at component, subsystem, and system level prior to production and installation.

However, the general impression of the team was that the application of this technology to a similar service function should not present serious difficulties. Technical issues that would require consideration, such as vehicle material, to satisfy life-cycle cost considerations and fire/smoke safety specifications if such standards become a requirement, would not be extensive and would not affect system performance. Other changes, required by site specific conditions, for example, redesigned software to accommodate a different control block layout, would be straightforward and the impact on implementation predictable. Reliability issues which have been a problem in the present development process could be significantly reduced through a more extensive quality assurance program. However, in spite of the assurances of "technical acceptance" based on the present application, a different application, even with identical technology requires extensive integration testing and operational demonstration testing, to verify performance in accordance with desired service requirements.

The following evaluations of subsystems, therefore, are based on (1) issues which have resulted from difficulties encountered in the present development process and thus could present problems for similar systems under development; and (2) issues which could result from any extensions of the present technology to a different environment, or which might require increased performance. The subjects treated include individual subsystems, reliability, maintainability, safety, and product assurance.

7.2.2 Vehicle Systems

Materials.

The primary selection factors for all materials used in the vehicle were based on functional requirements and minimum capital cost. The use of ASTM A36 steel for structural purposes differs from that used on modern rapid transit vehicles, where "weathering" steel is being employed. Whether the lower-cost steel will be adequate over the 20-year life span requirement for this application is not known as life testing was not performed. Future design studies and tests for other applications should evaluate the most appropriate steel for the lowest life-cycle cost. Similarly, the life of the acrylic-finished, fiberglass exterior panels is unknown since no life-cycle testing was performed to verify the 20 year life requirement.

Materials were selected with some consideration for fire safety. Tests in this area are essential an essential element of any materials selection programs and efforts in this direction are important for all future systems. The vehicles were designed with emergency exits and are equipped with fire extinguishers.

Vehicle floors are made of plywood treated for moisture resistance; again, the life span of this material has not been determined. The observed problem of water leaking through the leading edge of the bi-parting entrance/exit doors of the vehicle (reported to happen during the vehicle wash cycle) could contribute to a shortened life span.

TIRES

AIRTRANS tire tread life is about 25,000 miles between retreads, of which some 4 or 5 are possible. This compares to a 100,000 mile life for a typical bus/truck tire trend between retreads. The difference is probably due to the "foam filling of AIRTRANS tires, which increases heating thereby shortens life. It may also be due to the tire interaction with the airport concrete in conjunction with the many "turns". It has been noted that buses operating at the airport over similiar concrete pavements and making many turns have a much much shorter tire life than the normal 100,000 mile life generally expected.

Propulsion/Motor Control.

The propulsion system was well specified by Vought. However, sand and dust caused unexpected problems. The unit was adapted from an industrial application and required rework following a number of failures which occurred early in revenue service. Since similar problems have been experienced with other propulsion units in new transit systems, considerable motor development and test, early in a developmental program, is indicated for future systems.

Braking

The braking system is adequate. Although variations in service braking from stop to stop appear to be small for a given vehicle, there is less uniformity between behicles. Early use of a test chassis was found very useful in correcting some problems related to wearability (materials problem), and cleanliness (moisture and contaminants trapped in brake fluid).

Steering

The steering mechanism provides lateral control to the vehicle and is, in conjunction with the guideway switches, the means by which the vehicle switches under automated control, while operating at speed. The AIRTRANS design combines lateral guidance wheels and adjacent switching wheels with a mechanical linkage that provides the steering input to all four steerable wheels. In order to make them steerable, the driving wheels are connected to the differential through universal joints. The front and rear wheels steer in opposite directions to provide the required short turning radius for the vehicle.

Lateral stability at high speed is a potential problem for this method of steering. For speeds higher than the present 17 mph maximum, and the same ride quality comfort criteria, some redesign may be necessary.

Collector Brushes

Initial collector brush life on the AIRTRANS system was approximately 200 hours, the reported life of a new brush is 35,000 miles which represents some 6 to 7 months of operation.

Suspension

The suspension was designed and built to provide satisfactory ride quality, yet that ride quality has been questioned.* A means must be found to specify the dynamic physical attributes for a transit vehicle that will provide the needed minimum levels of ride quality. Until such specifications are available, the transit systems, in all probability, will either exhibit poor ride quality or be overdesigned. Such efforts require systems establishments of ride comfort criteria, measurements of ride quality on existing systems, and subjective ratings by users.

Improved and innovative suspension systems could also improve vehicle ride quality, and, at the same time, might reduce guideway costs.

7.2.3 Guideway Systems

The guideway system was generally designed in accordance with acceptable engineering practice. Attempts were made to form the side walls by slip forming, a technique which proved unsatisfactory because of the slumping of the concrete which caused the side walls to be slanted. Even after construction using conventional forms it was necessary to grind the side walls to obtain a smooth surface for the steering wheels. The guideway design was based on the Standard Specifications for Highway Bridges, AASHO 1969, and Strength and Serviceability Criteria, Reinforced Concrete Bridge Members, BPR 1969. The subgrade preparation for the at-grade is designed for long term wear and protection against differential settlement.

*Automated Guideway Transit, Office of Technical Assessment Washingtion D C June 1976 Pg. 11.

Guideway Environment.

Rubber-tire-to-guideway coefficient of friction is a variable with a large range of values, especially on worn or smooth guideway, and with rain, snow or ice conditions. An AIRTRANS type system, in less-mild climates than those of Dallas/Fort Worth, could be a source of difficulties unless some method were found to ensure reasonable and consistent values of tire/guideway coefficient of friction.

Rail De-Icing

The present method of deicing consists of applying liquid ethylene glycol through wipers to the signal rail prior to the onset of an icing condition. Reportedly this has been effective. Whether this would be effective in climates different from that of the Dallas/Fort Worth area is not known.

7.2.4 Command and Control

The AIRTRANS command and control system has worked well in service. The asynchronous control concept facilitates rapid system recovery after a system malfunction. Stopped vehicles, in the fixed block system, simply restart under local control after a failure has been corrected and it is safe to do so.

The communications system has very low data channel requirements since it was designed for a fixed-block control concept with a sparsely occupied guideway. The computer software works well. Bunch control is reasonably effective. The distributed computer system is good in that it allows for expansion and reduces communications needs. A backup CPU at Central Control has recently been added to improve system operational performance by providing supervisory continuity when the primary CPU is out of service.

During the assessment period some vehicle stoppages could not be traced to any specific failure. Generally, these were Class II-type failures and were quickly reset from Central. Such stoppages may have been due to the lack of specific noise interference limits or signal-to-noise limits on subsystem interfaces critical to movement and control.

7.3 RELIABILITY, MAINTAINABILITY AND SAFETY

The AIRTRANS system has achieved safe operation in the year and a half since it first opened. In the six months from March through Sept. 1975 the system has achieved very reliable operation. The fact that such a complex system is now working in revenue service with very few total breakdowns and a good safety record is a tribute to all concerned.

8. SUGGESTIONS AND RECOMMENDATIONS

8.1 GENERAL

Some of the study indicated the general need for Government action. The following recommendations seem valid and important to the study team in that context.

1. DOT should develop a methodology to ensure that reliability and maintainability data, from new systems developed under UMTA R&D money or financed by UMTA Capital Grants, are collected, processed, and made available to the transit industry and others for use in reliability analysis.
2. AIRTRANS data should be analyzed and reduced, and offered to the Government-Industry Data Exchange Program (GIDEP) for dissemination.
3. Reliability and maintainability program guidelines, now being developed by DOT, should be expedited and offered to the industry as tools for improving specifications for new vehicles and systems.
4. DOT should prepare a guideline for technically specifying the availability of a system, which would be offered as a companion to the program guidelines above. The weaknesses and strengths of the AIRTRANS definitions, as well as those of DOT-funded programs, such as Morgantown, HPPRT, and Dual Mode, should be used as inputs to such a development.
5. A technical guideline on fail-safe design for complex transit systems should be prepared for use by anyone specifying a new system.

6. Until effective and agreed-on guidelines, such as described above, are available, new specifications for systems should be subjected to critiques by disinterested third parties, to be sure that any gaps in specification are there by intent and not by accident.

7. The issue of materials selection with respect to both life-cycle costs and fire safety should be addressed by the government in terms of guidelines and/or specifications.

8.2 SYSTEM DEVELOPMENT/IMPLEMENTATION

The material in this section is organized in sequential order, starting with system planning and then considering various aspects of implementation and operation. In some cases the issues raised are a result of "hindsight" by members of the assessment team, Vought Corporation, or members of the Airport Board staff. In other cases the lessons represent reinforcement of the approach taken.

8.2.1 Analysis

Continuous system analysis from inception onward is vital to any large system program. The AIRTRANS assessment highlighted the following:

- An index of system serviceability (a trip reliability figure of merit) as perceived by the user, coupled to life cycle system costs, should be specified in quantitative terms in the RFP and used as a measure for acceptance. This approach will encourage the contractor to trade off component reliability allocations and life cycle costs.

- The requirement of service availability and life cycle costs should be staged at milestones to reflect the maturing of the system. The life cycle cost of a system or component will decrease while the "service availability" either remains constant or increases. Component or subsystem reliability will increase until reaching the lowest life cycle cost".
- Proper and adequate systems analysis early in the project (demand studies, network simulations, interface definitions, etc.) is a requirement to better understanding of interactions among system elements and to better subsystem design and definition.
- Early and continued communications with the user(s) from requirements development to acceptance is necessary so that the system reflects user needs.
- System RFP requirements should specify measures of system performance, e.g., flow rates on links, trip times, acceleration and jerk limits, etc., rather than component requirements.
- Technical requirements for a system should be specified only if they can be validated.
- Consideration should be provided to procuring spare system elements (vehicles, computers, etc.) with the aim of reducing life-cycle costs.
- There is a need for industry standardization in key areas like ride comfort, noise, and fire safety.
- Overspecification can result in increased costs and delayed schedules.
- Documentation quality and control, i.e., drawings and specifications, should be specified in some detail. "Commercial practice" is an inadequate requirement, while full Mil. Spec. is expensive.

- There is a need for better-than-commercial building code electrical standards in the guideway portion of the com-command/control circuitry and wiring.

- Experience obtained from the development and operation of existing systems (costs, problems, good solutions or approaches, etc.) must be factored into the systems analysis and development of requirements for new systems. Future procurement contracts for new systems, when funded from public funds, should consider GIDEP* or a similar program.

- The RFP should be more of a development-type contract, at least in the near future, as opposed to be "construction contract". It should include performance incentives and should be scoped for cost proposal updating following complete system design. This will better establish the cost of achieving system specifications.

8.2.2 Contract Process

The types of contracts selected, and their administration, have an important bearing on the outcome of the overall system program. In addition, effective and acceptable performance depends on mutual understanding and agreement, by program and contractor, about program goals, requirements, schedules and costs.

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*Government Industry Data Exchange Program, GIDEP MNL 5200.7, Nov. 1974, Policies and Procedures Manual, Failure Data Interchange. Published by Government-Industry Data Exchange Program.

Some of the AIRTRANS study team's conclusions were as follows:

Contract Process, Schedules and Program Management

- Unless specifically provided for, a fixed price contract, limits the role of the buyer in the design decision process and requires system and subsystem specifications which are complete and non-ambiguous. Unless otherwise specified, a fixed-price contract will cause the contractor to minimize the initial capital cost and not necessarily minimize the life-cycle cost (capital plus operating and maintenance).
- Full responsibility for system management should fall on one organization. Subcontractors and professional specialists must be properly organized to reflect proper management in terms of design responsibility and quality assurance monitoring. Example: the guideway architect-engineering should not report to the construction contractor.
- Performance penalties should be passed from prime contractor to major subcontractors.
- Construction phases of "other projects" should be scheduled for non-interference with the construction and testing of a transit system. Priorities must be established in the RFP for possible conflicts.
- Local agencies wishing to install automated transit systems should assemble capable teams of professional specialists to monitor and review the process from design to initial operation and acceptance.
- Selection of the "low bid" from an initial capital cost viewpoint should not be the overriding criteria for contractor selection. Instead, technological maturity and life-cycle costs should be used to replace "capital costs".

- The buyer should require the developer to institute a "configuration management" process to ensure that drawings and specifications are current and reflect the product delivered and installed. This should include complete software, as well as hardware items. The quality of drawings and specifications must be specified.
- The development and installation process should also require a complete set of training and maintenance manuals, and a training program that makes operation by locals possible.
- Developer and buyer should establish and maintain formal and informal communication channels regarding project status and problem areas so that speedy approvals/disapprovals/decisions can be made.
- The development installation test schedule must be realistic. The test program should not be short-changed. It must be (1) adequately structured with component and subsystem tests to ensure that design problems are resolved early in the design process, and (2) the program must be long enough and properly phased to ensure that early infant mortality problems have been eliminated by product improvements in the production phase.
- The buyer must recognize that even with a high degree of system maturity, significant additional development costs may be required in order to satisfy local ordinances and requirements for safety, operational reliability, maintainability, and operational service availability.
- Some benefits might be gained through local/federal sharing of development costs and through development of a common set of requirements for AGT systems, such that the initial cost of product development, can be partially shared.

- Full product development and attendant testing for a new AGT system requires 5 to 7-years. AIRTRANS has completed 3 years of this process at the time of this writing.

8.2.3 Design/Development/Construction/Test

- Specifying top-level requirements on system availability and life-cycle costs allows the contractor to apportion reliability requirements at system and component levels consistent with minimizing total costs, while maintaining the required level of system availability.
- When estimating computer processing and core storage requirements, sufficient margins (50-100%) should be allowed for estimation errors.
- A major portion of the cost of any group rapid transit (GRT) operational system is the initial guideway investment and the subsequent cost for guideway maintenance. Because of the importance of minimizing these costs, research and development on the design of low-capital and minimum-maintenance GRT guideway is needed. The lessons learned from the AIRTRANS assessment should be incorporated into this effort, e.g., (a) the experience gained in solving the problem encountered at the column/beam interface due to differential thermal expansion of the beam cross section; (b) knowledge on concrete mixtures amenable to slip forming, and (c) knowledge useful for the development of guidelines and tentative standards leading to a design manual for at-grade and elevated guideway structures, especially in the area of determing the loads and load factors applicable to GRT systems.
- The development of surface tolerances for guideways must reflect a realistic trade-off among speed, suspension, and cost. Imposing FHWA surface tolerances to sidewall construction (1/8-inch deviation in 10 feet) is costly to achieve. The present state-of-the-art for sidewalls cannot consistently produce tolerances approaching the FHWA standard for surface tolerances.

- Redundant computers should be considered at all levels, with final redundancy decisions based upon such factors as cost effectiveness and the impact of computer failure.
- A separate computer, distinct from the CPU, should be used for software development and modification, if at all possible.
- An environmental simulator (computer program which simulates interfaces with operational hardware) should be used if possible to facilitate software testing and debugging.
- Trade-off between direct, hard-wiring control power circuit breakers to Central Control as opposed to software control must consider reliability and safety as well as costs.
- The software development process must be integrated with the development process of the complete system.
- Use of the "same design" for identical functional requirements is desirable to maximize reduction in life-cycle costs, while maintaining or improving operational availability.
- The design process must consider the "human interface" for the entire system, including maintainability issues, interaction of the employee with the automated system at all levels, and the needs of users in terms of comfort, convenience, and safety.
- The funding requirements for test equipment and other support equipment for the development/test phase of the program should not be underestimated and must be continually reappraised during the design cycle, to ensure adequate funding.

- Off-the-shelf, commercial quality hardware, when integrated into a transit application, requires extensive development and testing to ensure proper system operation. The contractor should plan and allow funding for some design improvements to such hardware.

- The establishment of interfaces for failure recovery, i.e., the use and placement of special recovery vehicles, restarting from failures, movement of failed vehicles along "standard" road network, etc, should be heavily considered in system design.

- A separate test track should be considered to avoid having to integrate and schedule a "test program" in the midst of ongoing construction interference, a process which is likely to result in unanticipated schedule delays. A test track is very important for preliminary performance recognition but it is essential to recognize that the development of an operational system presents many problems which cannot be solved on a test track.

- Complete testing for functional operation as well as identification and redesign of early mortality failures is necessary before initiation of the production phase.

- Trade-off studies for guideway length requirements should consider functional flexibility, as well as reductions in capital cost. Minimizing the guideway length based on costs alone can result in compromising the system's operational performance.

- The safety system must be independent of the automatic train operation/automatic train control (ATO/ATC) system.

- New system specifications must be clear and explicit on all meanings, requirements, goals, failure definition, and acceptance terms.

- Reliability should give way to availability as the system level parameter; and availability should be based on passenger delays.

- System design should minimize life cycle cost rather than first cost.

- Operational and maintenance guideways and areas should be separate.
- Parts and materials program are vital in any complex system development and should be implemented.
- Subcontractor control is necessary to ensure reliability of purchased equipment.
- Maintenance reliability and failure management are closely related and must be considered together.

8.2.4 Acceptance

- Progress payments based on percent-construction-completion and/or satisfaction of specific functional specification requirements should be part of any contract process.
- Functional specification requirements must be accompanied by non-ambiguous definitive measures of test and acceptance.
- The specification requirement for system availability should contain precise provisions for acceptance at initiation of revenue service, as well as provisions for decreasing the O&M costs with time, while maintaining or improving system availability.
- The definition and measurement of availability must include consideration of unidentified causes as well as actual hard component failures.

8.3 OPERATIONS

- Maintenance and operations personnel must have complete training. The training process must be supported by detailed operation and maintenance manuals.
- The equipment manufacturer should be involved with both operation and maintenance for at least a year of operation following initiation of revenue service.
- For automated systems where the guideway is at grade, the need for adequate safety and security from intrusion must be considered and treated in the initial design.

- Operations studies, such as failure modes and effects, recovery strategies, etc., should be part of the design studies, to ensure high operational availability. (A reliability analyses alone is not adequate to predict service availability problems.)
- A complete separation of services in station areas is recommended for a multiple service system.
- The maintenance area and guideway sidings should be located to minimize the time to restore the system after a failure requiring vehicle removal from the guideway.

8.4 SYSTEM ASSURANCE

8.4.1 General

System assurance includes all efforts expended during design to ensure that system safety, reliability, maintainability, availability, human engineering, and life cycle costs are carefully considered and optimally built into the design; and that during production and construction, the hardware and software are fabricated in accord with the design.

During the entire course of planning, designing, and construction of a transportation system, the owners and the systems builder must each have a staff of professional managers/specialists representing the key disciplines required in the development process. This staff should be individually responsive only to the highest levels of management. Whether the specialists are hired directly or as consultants is of little consequence; however, that the group of specialists should be independent and have direct access to top management is most important. In addition, the need for independence of the various disciplines must be taken into account, and no one discipline should dominate.

For example, when an engineering consulting firm is hired to do the initial planning, the fact that this firm claims to have a large staff with all disciplines represented should not preclude the transit system owner hiring directly, or as consultants, his own small, but independent staff of specialists such as architects, human factors specialists, and safety engineers, to review the output of the engineering consulting firm. This precaution should continue throughout the course of the entire project since without this capacity for adequate review and evaluation, system assurance may be compromised.

Similarly, the general contractor, who builds the transit system, must protect his own interests in the same fashion when employing subcontractors. The fact that a structural firm has its own architects should not preclude the general contractor hiring his own architect. An architect responsible to the general contractor, may be the latter's only protection against inadequate performance by the subcontractor for structures.

Such assurance programs generally require a large staff of individuals for both buyer and developer and is the general approach taken by many organizations in a major construction program such as a transit system. The AIRTRANS development required review and evaluation related to contractual compliance. However, these were done with small staffs. The Airport Board, for example, retained a direct staff of four individuals, and two consultant firms. One firm concentrated on safety while the other reviewed the "civil engineering items. Vought relied on the direct staff assigned to the project for review of its major subcontractors. The small staff did allow for "quick turnaround" for reviews (15 days) and was considered by both parties a successful approach in terms of minimizing costs and maintaining progress. Vought did have some difficulties in the subcontracting area with respect to quality assurance. However, they did not feel that more reviews with larger staffs would have significantly reduced problems or costs.

Management, whether owner or contractor, must maintain some effort to review system assurance. Furthermore, the costs of system assurance must be balanced against the overall cost of the development and deployment to ensure a minimum life cycle cost.

8.4.2 Reliability and Maintainability

The reliability, maintainability and safety activities required during the design of AIRTRANS are defined in the AIRTRANS specification of March 15, 1971, under Par. 3.3.6, "General Features and Characteristics".

In specification paragraph 3.3.6.1, failsafe design is required, defined and related to all failure modes and procedural errors.

In specification paragraph 3.3.6.2, MTBF and MTTR for equipment are defined and specified; reliability testing is called out in detail, including accept-reject criteria; and MTTR demonstration is required. It would thus appear, at first reading, that the Airport Board's consultant had done an excellent job in preparing the requirements for a comprehensive system assurance program.

However, there were enough ambiguities and omissions in the specification to effectively blunt it.

With this as background, the AIRTRANS assessment team arrived at the following conclusions:

- Performance specifications for reliability and maintainability must be clear and explicit, and all parties involved in the system procurement and design must fully agree on what is meant by each requirement or goal.

- Acceptance of a system must be defined in the contract as clearly as possible. The reliability and maintainability criteria to be met for acceptance must be carefully spelled out and mutually understood by all concerned.

- System requirements for availability should be established at the outset. AIRTRANS had no system-wide requirement or goal for this factor, nor was the term identified. Reliability, alone, however, is not enough. Time to restore a failed system element for a given malfunction must also be explicitly defined. This involves time for fault detection, location, and clearance, and would require a specification for the mean time to restore (MTTR) the system to operation for the given malfunction. All parties seem to agree now that an availability requirement based on acceptable passenger delays in a system is most meaningful. This creates a direct relationship between service dependability and system availability.

  The AIRTRANS specification included requirements for MTBF and MTTR for several categories of equipment. (See Section 5.2.2.1, Item 7, AIRTRANS Spec.) The meaning of the terms and how they were to be measured in operation, however, were subject to various interpretations, despite the fact that a consultant was used to establish the requirements in the specifications. One area subject to these different interpretations contained the distinction between on-board and wayside equipment used for "movement and control". Localizing a control system failure at times may be difficult, for some control is on-board, and some is wayside. A disagreement between the Airport Board and Vought centered on the interpretation of what was a failure and what was not.

- The system simulation used in the initial design assumed 100 percent reliability of the hardware. More recently some malfunction rates and mean times to restore have been included. In the future, a measure of the effect of there factors on passenger trip time and schedules should be included in any system simulation.

- It is not known how long a malfunction can last without creating intolerable passenger dissatisfaction. The system design should consider how to discourage passengers leaving stopped vehicles. Occasional stoppages of 15 minutes have occurred and passengers, as a result of being in communication with Central Control, have not left the vehicle. However, vehicles have been stopped for so long that some passengers have climbed out and tried to walk to adjacent stations, thus placing themselves in jeopardy.
- For a system that must be cleared of malfunctions in minimum time, minimum first cost should not be the major guideway design criterion. AIRTRANS guideway length was minimized to keep costs down. As a result, access guideways for removing failed vehicles, for substituting new vehicles for failed ones, and for providing alternate paths around blockages were also minimized. This has cost a great deal of system time in clearing a failure from the system. It is now recognized that future AGT installations should make trade-off studies of the costs of additional bypass trackage against prolonged downtime, to determine the most economical track configuration over the life of the system.
- The maintenance facility should be located, to the extent possible, to provide maximum accessibility to the operating guideway.
- The importance of maintenance can scarcely be overstressed, for good and rapid maintenance leads to high availability. It must, however, be planned realistically. In AIRTRANS, initial estimates were for 67 people in maintenance and this was revised upward to 90. The system started in January, 1974, with 200 maintenance-related people. The force is now down to about 90 people on three shifts,

seven days a week, for only a partial system. This is also believed to be the minimum for a fully operating system. Two or three people are continuously in Central Control; and several rovers are constantly available for dispatching to assist stalled vehicles.

- Freight handling functions, such as mail services or supply services, should not be performed in areas adjacent to, or using the same guideway as, the maintenance facility. Both Vought and APB found that the proximity of these areas creates mutual interference.

8.5 HARDWARE

General Hardware Aspects

- Failure Mode Analysis. The AIRTRANS Specification states that "an overall design objective is that fail-safe system operation be attained in all known failure modes - in all the failure modes - considered singly or in combination". This procedure proved to be so complicated and so expensive that it was not implemented. A safety oriented Fail Mode Analysis (FMA) was performed on the assumption of single-point failures.

  This again demonstrates that specifications must be realistic as to what is practicable. The AIRTRANS FMA, as it was done, is a large effect, but despite this work, early system operation showed problems that had not been anticipated.

- A number of parts problems showed up in early operation because no special parts effort had been mounted. Some of the examples are as follows:

(a) Connectors for assembling modules into the vehicle control logic assembly were initially very poor. They were all retrofitted with better ones. This emphasized the need for good component selection, a prime reliability technique.

(b) An undefined number of printed circuit boards failed early, because of high humidity, and had to be removed and coated.

(c) The 60-hp motors developed loose coils, a serious mechanical defect. A manufacturing defect was suspected. All motors were rewound by local repair shops for Vought, although the motor was of Swedish manufacture, having been purchased as a package with the power controller. In addition, more air filtering was added for the motor cooling air; and brush material was changed to improve life.

(d) The power and signal pickups and the rails were purchased as a package from one supplier in the hope that interface problems between pickup and rail could somehow be minimized. Despite this, so much difficulty arose, that Vought considered it expedient to redesign the pickup themselves and to retrofit the vehicles with the new design.

(e) A standard GRS railway switch, Model 55G was selected. For aesthetic reasons and right of way requirements, the switch actuator was mounted under the guideway. However, in this location the hardware is vulnerable to dirt and water. There has been some failure of correspondence indication (feedback of the switch having operated as commanded) but this was mostly a matter of adjustment. Once-a-week routine maintenance keeps failures very low at present. The switch is considered good, and GRS has fulfilled on the warranty when needed.

(f) Vought concludes that so-called "commercial" grade parts are not adequate in a system of this sort. Better specifications are needed, not as severe, perhaps, as MIL specs, but including reliability requirements.

- Subcontractor Control. Performance penalties should be indicated in the contract with any subcontractors. This was not done by Vought due to the refusal of the subcontractors to accept risk.

  Some equipment was purchased to specification with reliability requirements included, and some was not. In the latter case the criteria seemed to be that the equipment had a long proven record of reliable performance behind it, or that it was not very important in the system operation. The latter case is illustrated by the Audio Announcement Unit (AAU), which was not thought of as being vital. It is not a major system element, but it has proven to have a great nuisance value, both as a maintenance problem and as a public relations embarrassment. These units, one of which is in every vehicle, uses prerecorded tapes announcing the identity of the next station stop. The AAU's were off-the-shelf only in the respect that all pieces were extant; and unit itself was new. It had no reliability requirements put on it, and it has had the highest incidence of failure in the system.

- Quality. Not much attention was paid to quality in the specification. Vought recommends that much more attention should be devoted to it, expecially the quality of workmanship in the electronics and wiring. In guideway installations, the power and signal wiring alway must be carefully inspected for conformance with already established workmanship specifications. Poor wiring practices and poor rail joints and splices contributed to early troubles.

- There should be adequate maintenance training. Formal training for all maintenance people was required by GRS before GRS would agree to back up their safety guanantees. Vought people were certified as knowing how ATC works and is maintained. The Vought training department prepared a training syllabus that was approved by GRS. Switchmen were required to pass AAR switchman tests.

- Maintainability. Deriving a meaningful operational figure for MTTR becomes difficult if the figures required are not clearly defined ahead of time. MTBF and MTTR should be defined in such a way that they reflect the effect of malfunctions and failures on the service dependability of the system, and should not be simply a measure of hardware performance. These definitions should be made at the time of system specification, and should be used to help design the test program that will measure them.
- There is a lack of specific noise interference limits or signal-to-noise limits on subsystem interfaces that are considered critical to movements and control. For any future application, specifications on subsystems should have such requirements.
- A system EMC requirement, similar to the plans, quality assurance, and acceptance tests defined by MIL-E-6051D should be considered for future system specifications. This would serve to both formalize EMC requirements and to provide a framework around which acceptance criteria could be negotiated.

APPENDIX A
THE AIRTRANS VEHICLE AND ANCILLARY SUBSYSTEMS

A-1 VEHICLE DESCRIPTION

The AIRTRANS System is serviced by a fleet of 68 vehicles: 51 passenger vehicles, each with a maximum capacity of 16 seated passengers and 24 standees (crush capacity is 16 seated passengers and 44 standees); and 17 utility vehicles each capable of carrying three utility cargo containers.

The utility vehicles are identical to the passenger vehicles, except for the passenger cabin and a few minor details. The utility vehicle utilizes the same propulsion, braking, pneumatic, suspension, bumper, guidance, and electrical systems as the passenger vehicle. To perform cargo handling functions, the utility vehicles have additional equipment, such as automatic load/unload mechanisms which interface with utility vehicle stations where cargo support and loading equipment is mounted on each of three cargo bays.

The vehicle dimensions are 21 feet (6.4 m) long, 7 feet (2.13 m) wide, and 10 feet (3.05 m) high. The empty weight of the passenger vehicle is 14 kilopounds (6,363 kg); the gross weight is 20.8 kilopounds (9,455 kg) full, or 24.2 kilopounds (11,000 kg) crush load. The passenger vehicle is designed to provide 2.5 ft^2 per standee, and 3.9 ft^2 per seated passenger.

The passenger-vehicle body is composed of a metallic-finish, acrylic-over-fiberglass shell (Swedlow Corp.) (with foam insulation) mounted over a welded steel truss and chassis. A bi-parting automatic side door on one side of the vehicle provides for passenger entry and exit. Emergency doors are located at each end of the vehicle. Tinted safety glass windows are on all four sides. Bumpers capable of withstanding 5-mph collisions are located at each end of the vehicle; they are fixed to the vehicle chassis and transmit shock loads into the body structure through shock-absorber units. Running lights are located on each end of the vehicle.

Vehicle width was essentially predetermined by the space envelope allocated to the system in the airport design. The largest-width vehicle permitted by these requirements was chosen. Headway was not specified. A major design factor was the number of vehicles and the passengers-per-vehicle capacity required to meet maximum passenger flow requirements. Vehicle speed was basically limited by (1) the space envelope allocation which required curves and grades and (2) by station distances. The need to minimize the height of the guideway side wall caused the space under the vehicle floor to be restricted.

The vehicles have brake and door controls, station stopping control, speed regulator, governor, VWC transmitter, AVP receiver, VWC receiver and brushes for communicating with the wayside. The vehicles are equipped with a station announcement system and an RF voice communication system.

There is no on-board stop button, per se. Manual parting of the side doors, or opening of an end door will stop the vehicle, in an emergency mode, i.e., the vehicle cannot be restarted remotely from Central Control, but must be restarted manually on-board the vehicle.

Vehicles are designated (and dedicated) lead and trail vehicles, the former being "smarter" than the latter. There are 31 lead vehicles and 20 trail vehicles. Train consists are either (a) single lead-vehicle or, (b) two-vehicle trains that are composed of a lead and a trail vehicle. The present station configurations and system controls do not permit trains longer than two vehicles. The vehicle design however, is adaptable to longer trains with only minor modifications of structure and on-board equipment.

The mechanical coupling maintains a fixed distance between the lead and trail vehicles and provides the flexibility needed for negotiating the guideway. The electrical coupling is accomplished by cabling which joins the control systems and the signal systems of the two vehicles and enables the lead vehicle to provide train control to the trail vehicle. The braking function is normally initiated and controlled by the lead vehicle. There is no motion detector on the trail vehicle. The brake controller of the trail vehicle has no feedback transducer since it is slaved to the lead vehicle commands.

Vehicles are multidirectional to accommodate both employee and passenger service, but lead vehicles must remain lead vehicles and trail vehicles, trail vehicles; uncoupling of vehicles is required to reverse a train. To transfer steering from fore to aft, a mechanic must also reset the steering control system. Since vehicles must be removed from the power system in order to be reversed, they must be tested on the departure test equipment before being returned to service.

A-2 BRAKING

The performance requirements for vehicle traction are specified in Section 3.6.4 of the AIRTRANS Specification and are in part, as follows:

"PROPULSION AND BRAKING TRACTION REQUIREMENTS - The Contractor shall verify the ability of the vehicles to provide the tractive and braking forces between the guideway and the vehicle necessary for safe operation of AIRTRANS and shall validate his proposed method for achieving the required force levels under worst-case loading and environmental conditions. Worst-case environmental conditions shall, at a minimum, include blowing rain and blowing snow. The Contractor shall devise and conduct, for Owner's approval, a test capable of demonstrating the method chosen for achieving the required tractive force level. Also, this test shall demonstrate that there is a reasonable degree of conservatism in the tractive force level chosen."

There are three modes of braking available: Normal service braking, irrevocable service braking, and emergency braking. Braking rates called for are: normal rates for service deceleration, irrevocable service braking for Class II failures, and emergency braking for Class I failures.

Further from the AIRTRANS specifications:

"(1) Normal service braking shall be the braking used in routine operation and shall provide controlled deceleration and jerk. It may consist of dynamic, regenerative, and friction braking modes. If more than one mode is used a smooth transition from one to the other shall be provided in accordance with the acceleration and jerk specifications. Loss of power to a vehicle shall cause normal service braking to be applied.

"(2) Irrevocable service braking shall be the same as normal service braking except that once applied, it shall bring the vehicle or train to a complete stop and remain applied until released. Irrevocable braking caused by Class I malfunction, "unscheduled door opening including emergency opening" shall be releaseable only by manual resetting on the vehicles by authorized personnel. All other Class I malfunction irrevocable braking shall be releaseable either by manual resetting on the vehicles by authorized personnel; or by a control signal to that vehicle from the central operator. This control actuation shall be of a temporary nature so that the irrevocability of the brakes is removed for only a short period of time. If conditions are not safe for the vehicle or train to move, the brakes shall remain applied. If safe conditions exist after irrevocability has been removed the vehicle or train may be allowed to move, but if a subsequent Class I malfunction occurs, the irrevocable service braking shall occur under any condition designated as a Class I malfunction.

"(3) Emergency braking shall consist entirely of friction braking. A mechanical spring-actuated system, or an equivalent approved by the Owner, shall be provided for this brake to assure a positive means for stopping the vehicle. Application of the emergency brake shall be irrevocable once initiated and shall be releaseable in the same manner as described in (2) above. Application of the emergency brake shall occur, when there is a failure of the service brake, to limit the speed below the safe speed envelope. The brake controls shall be interlocked with the propulsion controls so that braking commands dominate. Application of emergency braking will cause redundant drop-out of power contactors.

"Under normal operating conditions, on level sections of guideway, longitudinal acceleration from sources such as starting, stopping, and speed changing shall not exceed 3.75 ft/sec^2 (0.116 g) in either direction. On grades, the magnitude of the maximum allowable acceleration shall be determined from the following formula:

$A = M \pm 0.322\ S$

A = the maximum allowable magnitude of acceleration on grades (in ft/sec^2)

M = the allowed maximum magnitude of logitudinal acceleration of level guideway (in ft/sec^2)

S = the magnitude of the slope of the grade (in percent). Use the plus sign (+) when slowing down while going uphill or when speeding up while going downhill. Use the minus sign (-) when speeding up while going uphill or when slowing down while going downhill.

"Under emergency braking conditions, the longitudinal deceleration shall not exceed 10.5 ft/sec^2, except on uphill sections of guideway where it shall not exceed 10.5 ft/sec^2 plus 0.322 $ft.sec^2$ times the magnitude of the slope in percent. The minimum value of longitudinal deceleration shall be consistent with safe operation of AIRTRANS, and shall include considerations such as vehicle speed, headway, train control system design and fail-safe requirements. In no event shall the minimum value of longitudinal deceleration compromise AIRTRANS safety."

Jerk limitations are specified in part, as follows: "Under normal operating conditions, the allowed magnitude of the longitudinal jerk from starting, stopping and speed changing shall be 2.5 $ft/sec^3 \pm 15\%$. In the interval beginning 0.3 seconds before the completion of a stop and ending at the completion of the stop, the jerk requirements shall be considered to have been met if the net change in acceleration yields a net jerk of not more than the allowed magnitude of jerk. The vehicle propulsion controls shall be adjustable so that the magnitude of the jerk shall be readily adjustable at any future time from 2.0 ft/sec^3 to 6.0 ft/sec^3."

A load weight feature feeds into the braking system to give more uniform service braking, by means of a pressure regulation based upon an input from the air spring pressure. The tachometer output is differentiated to yield $\frac{dv}{dt}$, an average deceleration. Actual values of emergency braking rates are measured in the range of 6 to 7.2 f/s^2 for an empty car; and for a crush load car, 4.5 to 5.5 f/s^2. The maximum jerk rate is 2.5 f/s^3. Test values of 2.2 f/s^3 have been observed. Other figures are shown in Table A-1.

The braking system is basically composed of pneumatically actuated, automotive type mechanical brakes. Each wheel is equipped with a foundation brake using wedge actuation on 17.25 by 4 inch leading-trailing brake shoes. The brake lining is of asbestos composition. Mechanical force is transmitted to the brake at each wheel by a dual chamber brake actuator. Service braking is accomplished by air pressure in an application chamber, while air pressure is simultaneously applied to a spring release chamber holding the emergency brake in ready position. The application pressure for service braking is regulated by the brake controller to achieve the deceleration commanded by the velocity control system and vehicle load. On-board accelerometers furnish the input to control the deceleration rates of the vehicle. Because regenerative braking had not been sufficiently explored and ad vanced at the time of design of the AIRTRANS system, no provision is made for any type of regenerative brakes.

The emergency braking is obtained by venting a spring release chamber to atmosphere. A break-in-two (the accidental parting of a train in two sections) thus activates the emergency braking system on the trail vehicle. In a parted train condition, the lead vehicle experiences an ISB (Irrevocable Service Brake). Brake pressure is regulated from the drive axle end of the vehicle, by sensing pressure in the suspension air springs. Since the drive axle for an employee vehicle is at the front end, vehicle pitch would tend to increase brake pressure and result in a shorter stop than that

TABLE A-1. TEST VEHICLE IRREVOCABLE SERVICE BRAKE AND EMERGENCY BRAKE PERFORMANCE

VEHICLE CONFIGURATION	SPEED COMMAND	IRREVOCABLE SERVICE BRAKE PERFORMANCE		EMERGENCY BRAKE PERFORMANCE	
		ENTRANCE VELOCITY fps	DECELERATION dv/dt fps^2	ENTRANCE VELOCITY FPS	DECELERATION dv/dt fps^2
Empty 14950 lbs. Final Brakes	Low	4.58	4.11	4.48 4.38	5.02 5.55
	Medium	13.69	4.71	15.6 15.8	6.06 6.89
	High	25.1	4.56	26.8 26.8	6.62 7.20
Crush 24625 lbs. Final Brakes	Low	4.43	3.75	4.52 4.30	3.79 4.18
	Medium	13.55	4.38	15.3 15.1	4.51 5.04
	High	24.9	4.56	27.9 27.1	5.43 5.11

for a passenger lead vehicle. The trail vehicle in a parted-train condition, experiences an EB (emergency brake) stop, and is unaffected by vehicle orientation. The braking rate differential assures that the parted trail vehicle will be braked to a stop without overtaking the braking lead vehicle.

The braking system of the lead vehicle consists of a brake control unit, emergency charging cut-off valve, reset magnet valve, release magnet valve, apply magnet valve, variable load transducer, application feedback transducer, relay-valve, two brake cylinder cutout cocks, four emergency magnet valves, test gauge coupling, choke fitting, test cutout cock, four brake actuators, service brake pressure switch, emergency pressure switch, two couplings, and a pneumatic supply pressure switch. (Refer to Section 3.6 of the AIRTRANS Specification for pertinent details.)

Changes have been made in some of the components of the braking system. The brake lining material was changed. Changes were also made in the axles and planetary hubs to reduce leakage of oil and grease which was leading to deterioration of braking surfaces.

Four foam-filled rubber tires, at truck-tire (80 psi) pressure, are the ultimate braking mechanism (to the running surface). The coefficient of friction between rubber and the guideway concrete has been measured (wet) using a British pendulum tester. Values of 0.75 for new guideway and of 0.30 for "ground" guideway were found. ("Ground" guideway refers to the smoothened condition of a concrete surface which has been "ground" or sandblasted to achieve a specified guideway dimensional tolerance).

With ice and snow conditions, the braking of vehicles is more difficult. Tire studs, de-icing, lateral grooving of the guideway, and "sand paper" applied to the guideway surface are some of the methods which have been tried to improve braking in adverse weather. Tire studs excessively accelerated the wear of the guideway concrete surface. De-icing procedures were not found to be useful in improving braking, by preventing or removing accumulation of snow or ice. Longitudinal grooves in the running surface have been found best for permitting water to escape from under the tires of the vehicles, but do not seem to afford sufficient extra braking surface to reduce braking distance in ice or snow. "Sandpaper" bonded to the guideway has been found useful. in small portions of the guideway. This last approach has been very effective on grades.

Antislip systems were tested, but have not been used because improvements were not sufficient to justify the costs. The cost factor for retrofitting antislip systems into the existing fleet of 68 vehicles would be high.

Slippage of the vehicle drive wheels is a problem in wet weather. In some circumstances use of the speed override of the sections has been required to permit continued operation of the system. Several alternative solutions are available, and investigations are underway to attempt to further improve the behavior of the vehicle on the wet guideway and also to improve the track traction characteristics in wet weather at lower cost. (Test results of braking on a wet track are given and discussed in ARTRE-007A, section 5.2.1.3).

In a test period, the braking system suffered the highest failure rate of the vehicle systems, accounting for almost half the vehicle equipment failures which affected movement and control. The chief failures of the braking system came from leaking 'apply and release' valves.

The present braking system was not designed for significantly higher speed or shorter headway operations than those of AIRTRANS, and would be inadequate for such conditions. Installation of a similar system in a colder climate would require additional provisions to assure sufficient traction for braking. Guideway heating or guideway covering are two possible directions such effort could take.

A-3 VEHICLE STRUCTURE

The vehicle has a welded steel frame and chassis. Bumpers are mounted on each end of the chassis. These transmit shock loads into the body structure through shock absorber units.

Some draft force data are presented in ATRE-007A, Section 5.2.1.3. Buff forces between vehicles in a moving two-car train have not been measured. Buff load was not considered, since automatic coupling is not used.

The major constraints of the vehicle design loads are wind loads on the upper structure and skin panels, and a three-mile-per-hour collision rate on the bumpers, based on live-load passengers and equipment.

Wind load specifications, in part, read as follows: "For stationary trains, the design wind velocity shall be 80 mph, when designing to the AASHO specification. In determining worst-case loading for this condition, design investigations shall include various combinations of train spacing and train weights. The condition of zero spacing between trains, and train weights ranging from that of an empty car to that of a train carrying a capacity load shall be included in this investigation.

"Trains shall operate at wind velocities up to 65 mph. In determining worst-case loading with operating trains, design investigations shall include various combinations of train spacing and train weights.

"As a minimum, a fully equipped car shall be capable of sustaining each of the following loading conditions:

"(1) A static vertical floor load of 1.5 times the capacity passenger load, distributed in a manner consistent with the way such loads are distributed in service. This load shall produce no stress in excess of 50 percent of the yield strength of the materials used, and no member loads in excess of 50 percent of buckling loads.

"(2) None of the four possible combinations of the following vertical and horizontal static loads shall produce stress in excess of the yield strength of the materials used:

a. Horizontal Loads: An end load, applied separately in both buff and draft of 2.0 times the fully equipped weight of the empty vehicle, and occupants under capacity loading conditions, whichever is highest, applied through the vehicle couplings.

b. Vertical Loads: Floor loads of zero, and 1.5 times the capacity passenger load, distributed in a manner consistent with the way loads will be distributed in service.

"(3) If a vehicle or train can strike an over travel bumper, vehicles shall not sustain damage at speeds up to 3 mph."

A-4 HVAC

The performance requirements for heating, cooling, and dehumidifying the passenger vehicles are specified in section 3.6.4. 3. 1 of the AIRTRANS Specification and are in part as follows:

"Passenger vehicles shall be equipped with a thermostatically-controlled air conditioning system whose set point shall be continuously adjustable over the range 65 to 80 degrees F. Design and/or location of the control shall be such that it can be adjusted by authorized personnel only. The system shall be capable of automatically maintaining the temperature inside the vehicle within $\pm$ 2.5 degrees F of 70 degrees F, when the ambient design conditions listed below exist. The system shall also maintain the relative humidity at a level below 60 percent, under all conditions. No moisture addition is required under heating conditions."

The ambient design conditions under which the environmental control system must operate are shown in Table A-2.

"A minimum circulation of 30 cfm of air shall be provided for each passenger under the capacity load condition; of this a minimum of 7.5 cfm shall be makeup air from outside the vehicle. Makeup air intake shall be located in such a manner as to minimize the intake of rain and dust. Uniform draft-free circulation of air throughout the vehicle is a design requirement."

The HVAC system consists of two independent ventilating and air conditioning units, each providing a 2.5-ton refrigeration capacity and 5.8-KW of electrical heating. They operate off the 480-volt, 3 phase power. Ducting from a plenum chamber returns
480-volt, 3 phase power. Ducting from a plenum chamber returns

compartment air to the units. Galvanized sheet metal, with formed plastic insulation, is used for the ducting. Air from the units is ducted to provide cross feed in the passenger cabin.

TABLE A-2. ENVIRONMENTAL CONTROL REQUIREMENTS

Parameter	Heating Conditions	Cooling Conditions
Dry Bulb Temp., ^oF	20	100
Wet Bulb Temp., ^oF	N.A.	78
Wind Velocity, mph	25	N.A.
Solar Radiation, $B/H/ft^2$	N.A.	296
Passenger Load	Empty	Capacity

The air conditioning units are standard units manufactured by Thermo King. Initially, problems of reliability, chiefly with compressors and thermostatic controls, were encountered. Thermo King aided in the modification of the units to improve the reliability.

The air conditioning system noise exceeded the specification requirement. In general, increased acoustic insulation or increased effective length of ducting reduces noise observed within the cabin. Attention to such provisions would be required in future urban applications.

With power off in summer heat, the vehicle heats up quite rapidly and on occasion, passengers have left a stalled vehicle. Provisions to avoid such changes in the passenger compartment should be made in future applications.

A-5 VEHICLE AND STATION DOORS

Specifications for doors are quite detailed. Vehicle doors are specified in part as follows:

"The number and size of vehicle doors shall be sufficient to facilitate the required flow of passengers into and out of the vehicles. For vehicles with only one set of doors on a side, the door openings shall be at least 4'-0" wide X 6'-4" high. For vehicles with more than one set of doors on a side, the door openings shall be at least 3'-0" wide X 6' 4" high. Automatic doors shall be provided, and the doors and door mechanisms shall conform to the following:

(1) Kinetic energy of each door leaf and all parts rigidly connected thereto, computed for the average closing speed (see item (2) below), shall not exceed 7 foot-pounds.

(2) The average closing speed shall be computed using the time required for the leading edge of the door to travel from a point one inch away from the open jamb to a point one inch from the closing point of the doors.

(3) The door closing mechanism shall be adjusted to produce not greater than 30 pounds closing force should any intruding object come between the doors, and the touch-stop edge fail to operate. Closing force shall be measured at the door-open-rest position with nominal voltage and stall current applied to the closing mechanism power source.

(4) Each door leaf shall be equipped with a door touch-stop edge which will function automatically, to stop the door from closing further, but not reverse its direction, in the event the door is obstructed while closing. Door edges are to be sufficiently flexible to permit passengers to extract themselves if caught by the door during door closing.

"A manual emergency method of opening vehicle doors shall be provided in the vehicle. This method must be capable of overriding all interlocks including that related to zero speed detection. The manual operating mechanism shall be conspicuously marked and simple conspicuous operation instructions shall be placed adjacent to the mechanism. These instructions shall be clearly visible under normal and emergency lighting conditions. Safety latching interlocking of the vehicle doors shall be accomplished. Also, a means shall be provided for authorized maintenance or operations personnel to open the doors from outside the vehicle under all conditions."

Watertightness of the vehicle, especially of the doors is called for, in part, as follows:
"The complete vehicle body and doors shall be watertight. After completion of the body and installation of the doors and windows, but prior to the installation of interior finish materials, each vehicle shall be subjected to a full-coverage spray test for leaks.

Spray nozzles shall be located approximately two feet from the surface of the roof and five feet from the car surface on both sides and both ends. Nozzles shall be arranged to have an overlapping pattern. Each nozzle shall have a minimum flow of 5 gpm and shall be supplied with water at a pressure not less than 40 psi measured at the nozzle.

The vehicle shall be sprayed continuously for ten minutes. An inspection shall then be conducted and all leaks located and repaired. The vehicle shall then be retested and the procedure repeated until no leaks are found. A small amount of seepage will be permitted at door seals under these test conditions. However, no water shall spray into the vehicles at the door seals."

"Provisions (e.g., rain gutters) shall be made over doors such that water will not run off the top of the vehicle in the area of the door openings when the doors are opened."

In the AIRTRANS System, each passenger vehicle is equipped with a set of bi-parting doors located on one side of the vehicle for passenger entrance and egress. The doors are automatically operated. No documented trade-off studies were made concerning methods of door operation on the passenger vehicles. The door operating mechanism concealed above the doors, is automatically controlled and door position is sensed by on-board logic. Compressed air is used for the motive power to operate a piston rod which is connected directly to the door, which is top hung and bottom guided. The air flow for opening and closing the door is controlled by electrically operated solenoid valves. One door is driven directly by the door operator mechanism; the second door is slaved to the first by a cable operating over pulleys. Each door is equipped with sensitive edges which can stop door motion. A maximum of thirty pounds force can be exerted by the doors closing. The edge mechanism is a pneumatic, sensitive edge manufactured by Horton Company of Corpus Christi, Texas.

The door opening is a total of 54 inches, equally divided between the two doors (27 inches each). The door sill gap (to the platform) varies from 1/2 to 1-1/2 inches. Load levelling compensates very well, to minimize the vertical difference between platform level and door sill level. The door sealing is not always tight, with gaps appearing. Water appears to gain entrance, during washing, by way of the leading edge of the forward bi-parting doors.

Escape doors located at each end of the vehicle are approximately 2 feet wide, and are each posted with a sign warning of guideway hazards, moving vehicles, etc. Opening of an escape door puts a vehicle into emergency braking. Guidway power is not shut off by the opening door.

For station doors, both electric and pneumatic door operators were considered. The pneumatic door operators for station doors were chosen on the basis of reliability and reduced space requirement.

A-6 STEERING SYSTEM

In addition to more general requirements for steering, AIR-TRANS specifications require vehicle entrapment by the guideway. Pertinent portions of the specification follow:

"The vehicle and guideway interface shall be designed so that a vehicle shall not leave the guideway under any combination of worst-case operating and/or stationary conditions. Such conditions shall include, but not be limited to, stopping on a maximum super-elevated section of guideway, rounding curves at maximum speed, crush or empty passenger loads, winds as specified, and maximum deflections of the guideway or vehicle."

"In addition, if calculations show that a horizontal lateral force of less than 0.70 times the crush loaded weight of the vehicle (applied to the center of gravity of the crush loaded vehicle, on a level section of guideway) would overturn the vehicle, then the previously described method for entrapment is not adequate. In this event, the vehicle must be entrapped (using positive mechanical methods) by the guideway in both lateral and both vertical directions. The calculations used to determine whether or not the vehicle would so overturn should consider the effects of such factors as lateral movement of the vehicle body with respect to the tires, unsymmetrical tire loading and deflection and vehicle roll."

The steering system drives each axle set of wheels as required to maintain the vehicle position in the guideway. The steering system consists of automotive components for both driven and undriven axles, steering linkages and guideway follower bars with guide wheels and switching wheels.

A standard Rockwell International powered steering axle, weighing about 1 kp, complete with tie rod and steering arms, supports one end of the vehicle. The axle is a single reduction hypoid gear, with planetary gears in each hub. The planetary gear reduction is 3.3:1.

The guidewheels are equipped with ball bearings. All eight wheels (main and switching) have molded-on urethane tires. The design loads for the steering wheels are as follows: for the guidewheels, 1600 pounds, and for the switch wheel, 600 pounds.

Supporting the four guide wheels and four switching wheels are two horizontal follower bars running laterally. Either can furnish guidance force to its steering (front or rear) arm through input levers. The vehicles are prepared for opposite-end running (for employees or passengers) by use of a reversing mechanism.

A limiting spring is used in the linkage to permit independent steering of each axle during guideway operation, while permitting interconnected steering for off guideway. All four wheels steer: universal joints are used to provide steerability of the tractive wheels.

The vehicle is guided by contact with the two guideway parapets, between which it operates. When switching is required, an additional vertical surface is added to the single parapet which entraps the switch wheels. The moving vehicle contacts the guideway or switch guiding surfaces through wheels that turn on a vertical axis. There are four primary guidewheels and four primary switching wheels. Adjacent to each of these wheels is a secondary wheel which will function in place of the primary wheel.

The lateral motion of the guide bar is translated into steering inputs through the steering reversal actuator and rods to the vehicle steering mechanism. A series of rods, bell cranks, and a link-assembly limiting spring connect the front and rear axles, providing four-wheel steering.

A-7 VEHICLE SUSPENSION

The suspension system is specified in terms of the desired ride quality in part as follows:

"The suspension system shall provide for a quality ride in accordance with the ride specifications. A further requirement of this Section is that a positive mechanical connection be provided between the vehicle body and the truck(s)."

The suspension system is composed of the necessary pneumatic, mechanical, electrical, and electronic equipment to control the ride, vertical docking alignment, and overload of the vehicle.

In general, the suspension components are automotive-type equipment. Two air springs are provided for each axle, so positioned that one is functioning on each of the two trailing arms to which the axle is hung. Transverse beams and control arms position the axles with respect to the vehicle chassis. Damping is accomplished by automotive shock absorbers.

The pneumatic springs are inflated and deflated by valves that sense and control the height of the chassis from the axle, during guideway operation. At stations, air to the springs is controlled in response to an optical light-reflective system which senses the light from a reflective tape at the station and determines the necessary vehicle vertical positioning required for level docking. The capability to sense overloading of the vehicle is an integral part of the vehicle control equipment.

A-8 PROPULSION

The AIRTRANS Specifications forced some system design parameters. Curve radii, guideway widths, routes, elevations, and schedules established limits on civil speed, car length, car width, capacity, and headway. They specified performance characteristics, such as acceleration rates, deceleration rates, emergency stop deceleration rates, and jerk rates. The specifications served as inputs from which the propulsion system design criteria were established.

The propulsion system was specified* to meet the following performance criteria:

a) Vehicle empty weight - 14,000 lbs.
b) Vehicle crush weight - 24,000 lbs.
c) Maximum velocity - 25 fps.
d) Acceleration and deceleration rates - 3.75 fps^2.
e) Maximum emergency deceleration rate - 10.5 fps^2.
f) Grade 7.8%.
g) Headwind - 35 mph.
h) Operation shutdown with 60-mph winds.
i) Gear ratio - 17.44.
j) Rolling radius - 1.51 ft.

The original airport plan included an electrified transit system, and the APB specification called for an electric motor propulsion system of demonstrated conservative design. The criteria to be used to demonstrate that the design was conservative, however, were not specified.

The propulsion system was subcontracted by Randtronics of Menlo Park, California, the same company that designed Phase I B propulsion system for the Morgantown vehicle.

The motor is a 60-hp compound-wound DC motor with a rated speed of 2736 rpm and a maximum speed of 3200 rpm. This motor supplies 4800 lbs of thrust at limit torque. It is overload-rated for 330 amperes and 520 volts for 10 seconds; cruise current drain is approximately 45 amperes. The ASEA corporation of Sweden manufactured the motors, but maintenance is performed by a local vendor. Motor brush life was originally 2000 hours, but recent data show 4,000 to 5,000 hours.

Motor speed, and therewith the vehicle speed, are both directly proportional to the motor armature voltage. This voltage

*Procurement Specification for Vehicle Propulsion System No. 204-40-006. (Vought Corporation) is controlled by a six-thyristor, phase-controlled bridge. The bridge output voltage can be controlled from zero to full output voltage by controlling the conduction intervals of the six thyristors (SCRs). An SCR is turned on when a current pulse is injected into its gate lead. By delaying the point in the cycle at which the gate trigger signal is applied, the conducting time is controlled. The speed control signal is transmitted to the vehicle from the wayside and used to regulate the SCR gate trigger signal timing which, in turn, controls armature voltage and current. Acceleration is controlled by comparing the output of an on-board accelerometer to a reference and by adjusting the gate signal timing to hold the parameter in limits. Jerk is limited by comparing the output of a circuit which differentiates the accelerometer signal, to a reference, and using that output to control the SCR gate timing signal. The phase-controlled rectifier circuit used in the motor controller cannot be operated as an inverter; thus, braking is not regenerative.

The motor controller incorporates protection circuitry which shuts down the propulsion system in the event of abnormal conditions. Such conditions include:

a. Loss of one of the input line voltages (phase loss).
b. Imbalance between input voltage lines.
c. Vehicle overspeed.
d. Overloading as evidenced by a sustained overcurrent.
e. Momentary overloading evidenced by a high, instantaneous overcurrent.
f. Over-temperature.

In keeping with their policy of minimizing computer control, Vought made the interface between vehicle and guideway independent of the Central Processing Unit (CPU). Vehicle control signals are set by relays in the Wayard Electronic Units (WEU). Speed signals are generated on the wayside, but acceleration and velocity are controlled by on-board sensors. Acceleration is controlled by an output of an accelerometer and tachometer. Velocity settings are controlled by the output of an on-board tachometer. The speed control signals can be changed to lower levels by the Central

Processing Unit, but they can not be raised over preset guideway limits. Vehicles can traverse the guideway safely even if the CPU fails.

The motor and controller are sized to propel two vehicles. If one system fails, the other vehicle in a two-car train can push or pull the pair at reduced performance. There have been instances where a failed propulsion system did not impact performance until a wet guideway condition existed when wheels spun.

A-9 SWITCHING

A-9.1 General Description

The AIRTRANS guideway system incorporates 33 diverge and 38 converge automatic switches. The switches provide the means of routing vehicles through the system and the means to introduce and remove vehicles from the system. In normal operation, vehicles are introduced into the system exclusively in the 6W loop through Departure Test.

The power to operate and control the diverge switch rails is provided by conventional railroad switch machines. The switch machines are housed in 4- by 6-foot pits in the center of the guideway and covered with a four-piece steel cover plate consisting of a rim and three square inspection plates. Switch machine locations are confined to the areas of switch-rail entry points. Each machine is connected to the switch-rail by push rod, bell crank and torque tube. The main power rod, called the throw rod, runs through a tunnel from the pit to a cutout under the parapet wall where it is attached to the input bell crank of the main torque tube. The main switch torque tube is supported top and bottom by flange mounted ball bearings. The torque tube runs through a vertical conduit in the parapet wall. The top of the torque tube mounts to the switch throw output bell crank which, in turn, is connected to the actuating arm. Immediately toward the entry end of the switch-rail, from the actuating arm attaching point, is a pointer-indicator that shows switch position. This visual indicator consists of a tab, captive to a parapet wall, that remains stationary when the switch arm moves. Behind the moves. Behind the captive tab is a vertical plate attached to the switch arm on which are painted switch-position arrows. When the switch-rail moves from one switch throw position to the other, the tab uncovers one arrow and covers the other.

There are two additional push rods attached to the switch machine. They are the lock rod and the detector rod. These rods run through a common tunnel to respective bell cranks and torque tubes. The detector rod is slaved to the switch-rail and is the meachnical follow-up to the switch throw rod output. The movement of the detector rod is representative of the movement of the switch rail. The movement of the detector rod inside the switch machine is monitored by electric switches. These switches provide signals to indicate whether the switch is, or is not, in the fully actuated position or in a position other than the throw position ordered by the signal control system. The lock rod controls the locking bar in the switch machine and locks the switch machine throw rod actuating gear train in the extreme throw positions. The minimum curve used for switches is 150 feet, which is superelevated. The design specification calls for lateral acceleration not to exceed 0.1 g at the cruise speed of 17 mph.

A-9.2 <u>Switch Machines</u>

The AIRTRANS switch machines are a standard General Railway Signal Company lightweight railroad switch (Model 55 G). In a railroad application the switch machine is normally located alongside an outside rail and moves a pivoted double section of track. In the AIRTRANS application, the switch machine is in the guideway and is used to position a pivoted entrapment rail on the guideway parapet wall. The switch uses a 110VDC reversing-drive motor which gives the switch a nominal actuating time of three seconds. Control signals originating from the wayside electronic unit (WEU) trackside relays are 24 VDC, and the position indication, provided by the switch machine, is zero or 24 VDC. The operation of the switch is normally controlled through the AIRTRANS block and signal control system. The control computer system automatically tracks each vehicle through the system and then switches each vehicle in accordance with an established route program, or in accordance with override commands from AIRTRANS Central Control. Each switch may be manually pinned or locked in either position. The machines also incorporate a manual cranking capability which, in this system, requires the removal of the switch cover plate. Then, by inserting a special crank, the switch may be unlocked and cranked to the desired position.

The converge (merge) switch rails are not power operated. They are mounted on top of the parapet wall and supported at two points, at the pivot point and at the switch stop/support. The switch rail normal position is controlled by a 0.90 inch thick by 2.0 inches wide strap spring, having one end attached near the pivot support and the other end resting on a roller so that the switch is spring-loaded to the "through" position. To a vehicle traveling on the through line, the switch rail in this position is equivalent to an extension of the entrapment rail. No switching action takes place. A vehicle coming out of a siding and entering the through line will push the switch rail aside (against the force of the strap spring). After the vehicle has gone through the switch, the strap spring will bring the rail back to the through line position. The impact resulting from the switch rail being pushed aside by the vehicle is damped by a shock strut and rubber bumpers.

A-9.3 Entrapment Rails and Switches

The AIRTRANS vehicles are steered by steering bars. A steering bar is provided on each end of the vehicle. The ends of the steering bars are equipped with two sets of polyurethane-tired caster wheels mounted parallel to the running surface, on the top and bottom faces of a casting. The lower wheels are the largest and are the primary steering wheels, while the upper wheels are designed to provide vehicle switching capability. The walls are designed for the following wheel loading conditions with respect to the parapet wall:

Steering = 0.1 kips (normal operation)
= 3.6 kips (in event of malfunction)

Centrifugal force = 0.29 kips/wheel (800' radius)

= 1.56 kips/wheel (150' radius)

Wind = 1.0 kips/wheel

The configuration of the AIRTRANS guideway is similar to a conventional railroad in that it incorporates "turn-out" diverge switches and "turn-in" converge switches. Rather than swinging a section of rail to accomplish switching, AIRTRANS pivots a section of the entrapment rail, using a railroad type switch machine to perform the function for diverge switches. The converge switch is a passive element and is simply deflected by a vehicle merging with the mainline.

The entrapment rail is a heavy steel angle curved to match the contour of the guideway parapet wall and bolted to the top of the wall. The L-shaped cross-section of the entrapment rail is 6 x 8 inches. Entrapment rails are used only in the switch areas. Their function is to trap the vehicle steering bar switch wheels. The entrapment rails are mounted on either parapet wall, but never directly opposite each other. The entrapment rail is designed for a 600 lb concentrated lateral load.

Switch rails are actually pivoted sections of the entrapment rails. Some switches are in curved areas of the guideway, and the switch rails are curved to follow the guideway contour. In a switching operation, the switch rail is used to entrap the vehicle guidebar switch wheel or divert it.

A-10 POWER DISTRIBUTION

The power distribution system includes the three power rails distributed along the guideway, the interconnection wiring and the individual circuit breakers and network protectors. Vought responsibility for the distribution system begins at the output of the distribution transformers, which are the responsibility of the Airport Board. Vought specified the output voltage and rating of the transformer to the Airport Board, and the APB was then responsible for procuring the transformer and installing primary regulation and protection. Vought selected a voltage of 480-VAC, 3-phase, center-grounded, as their distribution voltage.

Substations were standardized at 300 KVA. Vought originally specified 14 substations distributed about the guideway. An additional substation was later added near the north parking lot. Except for the last, substation spacing was determined on a basis of load patterns, not by separation distance. There are sixteen power zones served by substations at either end. Zone boundaries are either at the substation where there is a network protector and two "A" breakers, or between substations where there is a "B" breaker. Vought selected the distribution voltage, the location of the substations, and the substation rating. The APB was responsible for selecting the feed voltage, the transformer, and any primary side network protection and regulation. The AIRTRANS specification stated that the output voltage available to Vought would be three-phase AC. Vought then selected 3-phase AC power for the rail system, as a result of a trade-off study which indicated that a DC rail system would be more expensive.

Power is distributed along the guideway through a set of three power rails which are vertically aligned and spaced 3.25 inches apart. The rail hangers are Valox, a material made by General Electric. Two other rails, a signal rail and a ground rail, complete the rail system. The signal and ground rails extend two inches beyond the power rails. The top rail is the signal rail, the bottom rail is the ground rail, and the power rails are between the two. They are made of copper-clad steel, come in 45-foot standard lengths and have an impedance of $(60 + j80) \times 10^{-6}$ ohms per foot. Rated fault current is 16,000 amperes for 20 cycles at 60 Hz. The ground rail is grounded at 60-foot intervals and is capable of carrying a fault current of 20,000 amperes with a voltage rise of less than 50 volts.

The substation output is 3-phase, 480-volt AC, center grounded, wye connected. The substation outputs are coupled through network protectors to a pair of "A" breakers. These "A" breakers divide each output into two zones, and they are controlled from the CPU. There are additional "B" breakers, also controlled by the CPU, which isolate sections of the guideway. The guideway is divided into zones with either an "A" or "B" breaker at the end points of each zone. Since both the "A" and

"B" breakers are controlled by the CPU, a CPU failure results in loss of reset capability and requires the deployment of 5 men about the guideway to reset breakers. Vought engineers indicated that in a redesign, the breakers would be hard-wired so that manual reset would not be required. The system also includes manual "C" breakers which can further isolate the guideway sections and zones. There are a total of 43 separate circuit breakers which protect the distribution system. The breakers, GE style J-600, also serve as arc-suppressors because they are fast-acting breakers. In the event of substation failure, that substation can be isolated and its load assumed by the other substations in the system.

The airport is served from two distribution feed stations, one to the north of the airport and the other to the south. The feeder line voltage is 25 kV, and there are four feeders from the south and a pair of feeders from the north. The AIRTRANS system has 2 substations connected to the northern feeder lines, and the remaining 13 to the south feeders. The substation transformers are connected to the feed lines alternately so that the effect of a 25-kV feeder failure is minimized.

A-11 MAINTENANCE FACILITY

The 6W section of the guideway layout is dedicated to maintenance. However, the utility and cargo vehicles must enter and leave their areas over the same guideway, for the airmail, freight, supply and trash facilities are in the same area.

"Down" vehicles are removed from the guideway and towed to the maintenance building which contains 10 maintenance stalls, arranged in two wings of 5 stalls each. One of the wings has no hoists, and is used for electrical work. The stalls in the other wing have hydraulic hoists. There are doors at each end of a stall.

Each vehicle is put through a sequence of tests before it is committed to the guideway. The original specification requirement called for a 5-minute departure test cycle; however, the actual term approaches a minimum of 8-9 minutes. Although this presents no problems to the AIRTRANS operation, future systems should consider problems which could occur as a result of a long departure test sequence. The following description of departure test routine is excerpted from the AIRTRANS Operation Manual.

1) GENERAL INFORMATION The Departure Test Station contains all equipment required to automatically test one- and two-car passenger trains and utility vehicles. Certain operator actions are required as a part of the test. The teletype prints instructions for completing these operations and resuming the sequence. One station operator and a train operator are required to perform the test.

2) TEST PREPARATION. The train is installed on the test track and towed to the starting position. Vehicle steering and mode are configured properly for manual operation in the normal direction of travel. All vehicle circuit breakers are closed. Prior to start of test, voice communications are established between the test operator and maintenance personnel at the vehicle. Maintenance personnel use a walkie-talkie and the test operator uses an interphone link. The station operator then closes the circuit breakers to apply power to the test guideway power contactors.

3) TEST INITIATION. When test and maintenance personnel are both ready to begin, the test operator types START on the teletype and hits CR (carriage return). Departure Test starts and the teletype prints date and time of day.

4. TEST STATION/VEHICLE INTERFACE. The basic test station components consist of a test track with four blocks of wayside control, electronics for a combination passenger/employee/utility station and means of remotely applying

control and power signals to the test track. The maintenance terminal processor controls test station operation independently from AIRTRANS system operation.

(a) Block 1 is the point at which trains are entered onto the test track. Here, the train is checked for: (a) reaction to loss of power, (b) reaction to loss of speed-signal input, (c) the presence of vehicle-generated signals (such as identification, route, block occupancy, and malfunctions alarms), (d) control-system interpretation of input speed commands, including zero-speed, and (e) proper application of emergency brake signal. The train proceeds from this block with a high-speed/high-limit velocity command.

(b) Block 2 contains a medium velocity profile stop mode command (M/P) and is only long enough for the train to decelerate to approximately 5 feet per second.

(c) Block 3 has a low speed velocity command and is used for measuring train velocity at 5 feet per second.

(d) Block 4 contains the station electronics. The train enters block 4 and proceeds to stop in the low speed profile mode. Station electronics verify train alignment at the station, and proper door operation. Baggage handling control is verified for utility vehicles.

5) COMMUNICATIONS AND CONTROL INTERFACE. Control for the four active test blocks is designed to operate in a fail-safe manner, exactly as in the AIRTRANS operational system. Block 1 is the first block and operates independently of preceding blocks since no preceding blocks exist. A section of control rail extending from the entry ramp to block 1 is installed to keep the train shunt relays energized. The Automatic Vehicle Protection (AVP) system provides speed commands to each of the four active test blocks. Test track AVP is connected to simulate non-occupancy of a non-existent block 5. This phantom

block has the control capability of responding to pseudo-block-occupancy override command from the Terminal Processor (TPU). Test wayside electronics also contain circuits for each active test block.

Vehicle identification and route are transmitted over both the Vehicle-to-Wayside-Communications (VWC) and Wayside-to-Vehicle-Communications (WVC). The WVC enables the route of the vehicle to be changed remotely.

6) TYPICAL TESTS. The following sample of departure test stimuli and reactions will illustrate the methodology: The list is not complete. Both passenger and service vehicle are checked.

   a) REACTION TO LOSS OF POWER. Three phase power is momentarily removed and reapplied causing propulsion trip. The WVC verifies report of motor trip Class II malfunction, and service brake application. The terminal processor applies remote reset to the train and checks that the malfunction condition is corrected.

   b) CONTROL SYSTEM INTERPRETATION OF INPUT SPEED COMMANDS. The vehicle logic system provides for transmission to departure test equipment, a 4 bit digital signal representing the analog output of the speed command to the velocity control system. An emergency brake test then verifies reaction to loss of speed signal inputs by momentarily applying a high speed command and then removing all speed signals. The train should start to move under control of the high speed command and then apply emergency brakes and generate a Class I malfunction when the speed command is removed. Emergency braking action allows the train to move approximately 10 feet. If it moves more than 10 feet, the boundary to block 2 will be crossed indicating improper braking. Report of Class I malfunction and emergency brake application is determined by WVC interrogation. Speed commands are restored to the test track and the malfunction alarms and emergency brakes are reset by maintenance personnel. The train is now ready to move from test block 1 under automatic control.

c) POWER COLLECTOR AND SIGNAL COLLECTOR BRUSHES. The train proceeds under automatic control to the test station alignment link. Signal and power rails on the test track are segmented so that as the train moves along the guideway each collector is in independent and separate contact with its respective buss rail for at least 10 feet. Should a collector failure exist, power is removed from the test track and test terminated.

d) VEHICLE VERTICAL ALIGNMENT. Vertical alignment is activated when the train is positioned at a station stop. Optical sensors on the train cause it to be raised or lowered as required by a station vertical reference. Retro-reflective tape is installed on the guideway to provide the vertical reference.

e) LOW BATTERY VOLTAGE. Malfunction detection provides a voltage level detector that indicates a failure should the battery voltage drop below approximately 20 volts. Departure Test checks battery voltage by operating the vehicle control, communications and lighting systems on vehicle emergency power and verifying that low battery voltage is not reported.

f) ALTERNATOR FAILURE. An alternator failure is indicated when power is removed from the test track. Departure test verifies that an alternator failure is reported when power is removed, and not reported when power is applied to the track.

g) VEHICLE GROUNDING. Loss of vehicle grounding results in shunt relay drop-out and report of Class III malfunction.

Departure test verifies presence of ground implicit in the velocity command response test performed in block 1. DC power is removed from the signal rail to simulate loss of ground shortly after the train is positioned at the station stop.

h) BRAKES EQUIPMENT. The brake system can report the following signals to departure test via data communications:

1. Low air pressure.
2. Dragging brakes.
3. Service brake applied signal.
4. Emergency brake signal.

APPENDIX B
COMMAND, CONTROL, AND COMMUNICATIONS

B-1 MAIN CONSTITUENTS

The following division of the AIRTRANS command, control, and communications system has been selected as appropriate for the purpose of this discussion: (a) control system hardware; (b) communications; (c) computers and software; and (d) system management.

The functional breakdown of the AIRTRANS control system is as follows:

1. Automatic Vehicle Protection (AVP)
   - Safe train spacing
   - Safe switching
   - Speed limits
   - Vehicle safety
2. Automatic Vehicle Operation (AVO)
   - Route control
   - Position stopping
   - Door controls
   - Speed controls
3. Central Control
   - System status monitoring
   - Supervisory controls:

     Speed overrides
     Switch positioning
     Route changes
     Bunch control
     Dispatching and recall
   - Station monitoring
   - Power distribution monitoring and control

The AVP and AVO systems together comprise the Automatic Train Control (ATC) system. Central Control is overlaid on top of this system, to provide more flexibility and efficiency of operation, consistent with safety constraints.

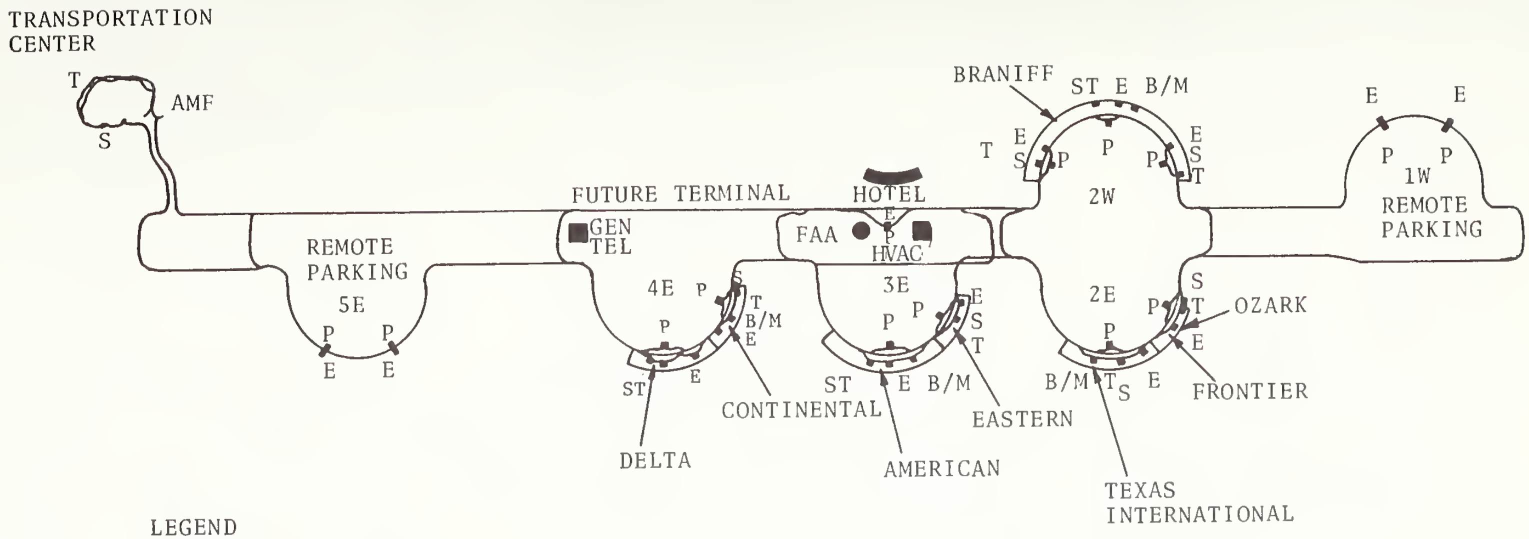
B-2 CONTROL SYSTEM HARDWARE

The ATC system provides automatic train and wayside control, as well as basic system safety control. The ATC functions are performed by five distributed wayside electronics units (WEU) which interface with stations, wayside equipment, and the supervisory system, and also with vehicles, through the wayside equipment. The WEU's are physically located in equipment rooms of terminals 2W, 2E, 3E, 4E and in the maintenance area (6W) as shown in the Guideway Layout, Figure B-1. The computers are not included in this discussion of control system hardware, since AIRTRANS could operate (in a degraded fashion) without its computers, as they are not part of the safety system.

A fail-safe circuit analysis was performed by Battelle and Vought during design and prior to revenue operation, for purposes of revenue operation certification. A full analysis was not performed in the detail required by the specification by mutual agreement between APB and Vought.

The basic AIRTRANS control philosophy is based on asynchronous, fixed block controls. The average block length is 90 feet, with blocks ranging in length from 45 to 240 feet on the main guideway. The nominal separation between trains is 5 blocks, which at the maximum speed of 25 ft/sec. gives a headway of 18 seconds. There is a 13.3-15-second minimum headway in the lower speed regions with 45-foot blocks (13.3 seconds when there is a single car in front and 15 seconds when following a 2-car train).

The following sections review various aspects of the control system hardware. Consideration is first given to the speed and stopping control, then to block control, next to control of trains in the region of a station, and finally, to switching. Other control aspects are also discussed — the headway separation assurance system, vehicle malfunctions, and manual control.



LEGEND

P PASSENGER STATION

E EMPLOYEE STATION

B/M BAGGAGE AND MAIL STATION

T TRASH STATION

S SUPPLIES STATION

Figure B-1. Guideway Layout

B-3 SPEED AND STOPPING CONTROL

Relative spacing of AIRTRANS vehicles is controlled in the block system by controlling the vehicle speed. There is no position control incorporating calculated position error, except for station stops. The speed is controlled to $\pm$ 1 foot/second, with speed being controlled most of the time to $\pm$ 0.5 ft/sec (excluding errors in absolute velocity due to tire wear). Tire differences in extreme cases could cause a variation of up to 4% in actual velocities. The maximum acceleration is 3.75 feet/second^2 and the maximum jerk is 2.5 feet/second^3.

The speed control on a vehicle is determined by the WEU on the basis of downstream occupancies, switch positions, and station stops. In general, the AVP allows a safe emergency stop in 180 feet from high speed, 90 feet from medium speed, and 45 feet from low speed. High-to medium speed changes usually require 135 feet, medium to low speed changes require 45 feet, medium-profile stops need 43 feet, and low profile stops need 25 feet. The AVP stopping distances are calculated to guarantee that the vehicle can stop under emergency braking, short of an existing occupied block, taking into account grade and worst-case situations (crush-loaded vehicle, partial brake failure, wind loads, etc.). The geometry of the guideway block layout dictates the maximum allowable safe speed limit by using available block headway between trains.

All vehicles have three braking modes: (1) Emergency, (2) Irrevocable Service, and (3) Normal Service. The Emergency mode is resettable, once applied, by local manual operation only. The Irrevocable Service Braking mode can also be reset by a qualified local operator, but in addition, it may be reset by the remote central operator via the communications data link. Both of the preceding modes can be reset only if the malfunctions causing the brake action have been cleared. Normal Service braking is used for automatic control in station stops, speed control, queueing stops and routine data-link, central-operator-commanded stops. Normal Service braking is released by routine restarts under automatic control.

B-4 BLOCK CONTROL

In the fixed block-control scheme, the speed limit and speed command are transmitted to each block. The communications system for transmitting these signals is described in B 15. There are four different speeds - 25, 15, 5, and 0 ft/sec, which are referred to as the high (H), medium (M), low (L), and zero (0) speed limits. There are six different speed commands - High (H), Medium (M), Low (L), Long Profile Stops (P), Short Profile Stops (S), and 0. The long-profile stop is given only in conjunction with a medium speed limit, and it causes a vehicle to stop within 25 feet. The commanded speeds are based upon normal braking system response and are selected to achieve maximum control speed that remains at or under the speed limit.

There are six valid combinations of speed limits/speed commands: H/H, H/M, M/L, L/S, M/P, and 0/0. The standard configuration, for 90-foot blocks on a straight portion of guideway with no switches, is a five-block, with the speed limits/commands being a function of the number of blocks behind a vehicle as shown in Table B-1.

TABLE B-1. SPEED COMMANDS IN A FIVE-BLOCK SCHEME

BLOCKS BEHIND	SPEED LIMIT	SPEED COMMAND
1	0	0
2	MEDIUM	LONG PROFILE STOP
3	HIGH	MEDIUM
4	HIGH	MEDIUM
5	HIGH	HIGH

At stations and switches there is a six-block region used with three 90-foot blocks and three 45-foot blocks. The combinations in this case are as follows:

Blocks Behind	1	2	3	4	5	6
Speed Limit/Speed Command	0/0	L/S	M/L	H/M	H/M	H/H
Block Length	45	45	45	90	90	90

Other situations arise which are not discussed here. Each of the speed limits is prescheduled in the Wayside Electronic Units (WEU) speed signal selector logic for each block in the system. The speed limits are continuously checked against the separate vehicle tachometer for safety, to determine if speed-limits are exceeded with a consequent need for braking. This check is performed by the AVP (Automatic Vehicle Protection) module of the Automatic Train Control System ATCS. The speed command and subsequent vehicle propulsion and service braking closed loop speed control are accomplished by the AVO (Automatic Vehicle Operation) module of the ATCS equipment.

The computer supervisory system can reduce speeds through overrides, but can not increase them above ATCS commands.

B-5 STATION CONTROL

The basic station for a two-vehicle train employs four 3-foot align rails located opposite the station platform. The align rails are used for automatic door control. Passenger and employee stations are the same, except that doors and align rails are oppositely situated. Originally, the system required two-car employee trains to "jog" in the employee stations; the train had to move up to allow second car exit/entry. Making the stations alike eliminated the need for jogging and also allowed eliminating the second vehicle door control.

As a vehicle arrives at a station-approach vehicle wayside communication (VWC) block, the vehicle route code instructs the WEU to award the diverge switch (station loop entry) and merge switch (station loop exit) to the vehicle. Unsafe conditions at a station, such as doors open, are monitored by the ATCS, by direct WEU-to-station interface, for action to prevent vehicle entry into such a station.

A vehicle senses the "Position Mode Command (PMC)" when it arrives on the station block (also a VWC block). The PMC is placed on this block before vehicle arrival and held until a vehicle has been stopped at the station and berthed. This function, when sensed by the vehicle, trips the nominal 522.5-inch profile stop; incidently fixing the block boundary and align-rail separation distances. There is also a short, 302.5 inch, profile stop command which is used in the baggage and mail stations and supply/trash stations, which was formerly used for the jog-stop in employee stations.

At the vehicle stop, the on-board motion detector (sensing no motion), combined with the subsequent setting of the service brakes and the presence of PMC detection and certain other safety permit functions, allows the "vehicle berthed" message to be transmitted.

WEU receipt of berthing from the vehicle transmitter starts the dwell timer and issues the "door open" command. The WEU also drops the exit merge route assignment to this vehicle. The doors of both the vehicle and the station are then commanded open by the door control relays in the vehicle and WEU if the vehicle is aligned within ± 18" of the 2 align-rail centers. If it is not aligned, the vehicle is held in place until supervisory control takes positive action.

The terminal processor unit (TPU) command function of "extend dwell" or "terminate dwell" will override the normal WEU timer functions on door open/close commands, with "extend dwell" taking precedence.

At the end of the dwell period, the WEU timer will time out, and, if the vehicle berthing signal is not present, the doors will close. The vehicle "route request" function in the WEU re-assigns the "exit merge" switch to the vehicle if the route is clear (not assigned to another through-vehicle), and if so done, speed commands are issued to the vehicle after the doors are closed.

"Berthing hold-in" is initiated and sustained by vehicle overload, a door obstruction, actuation of the door hold switch, passenger emergency, or an external "door reopen" command. Presence of "berthing hold in" will normally cause the "door open" command to be re-issued. Normal operation is restored by removal of "berthing hold-in." In case of a door obstruction, the "HELD" door stops in place. In the case of passenger-emergency-switch tripping, positive supervisory-system or manual reset is required to remove "berthing hold-in."

Station stop accuracy specification was relaxed from ±12 to ±18 inches due to some early stopping problems which have since been corrected. Vought seems to feel that, even though the current standard deviation of stopping errors is +1.5 inches, there still may be four stops per day, out of the 9000 daily stops, that exceed the 12-inch accuracy, thus justifying the requirement relaxation. Actually, the 4 to 8 stopping problems per day encountered consist of short and long stops or door-control failures. There is a profiled stop command that is implemented by counting down tach pulses. A modification was to add a vernier update about 10 feet away from the stop point, for confirmation. The variance in stopping position is due to such factors as vehicle brakes, load, weather, etc. Two experimental modules to improve the station stopping accuracy are being tested. Vought has designed one which constitutes switching from the TTL logic used by GRS, to CMOS logic, to attain more noise immunity. GRS has a modified module which slows down the TTL logic to get the same result. Both modules were in operation on vehicles in the system and seemed to be performing well.

B-6 SWITCHING CONTROLS

Switching is controlled at the wayside, with Central Control having a software override capability. Every wayside control switch has hard-wired settings for each of the 32 possible routes. The vehicle's route is interrogated about five or six blocks before the switch (in the switch approach block). The physical world time to move the switch is less than three seconds, so there is not much impact on the scheduled flow of traffic.

Switches are controlled by the WEU logic on the basis of the vehicle Vehicle-to-Wayside-Communication (VWC) route code. Diverge switches (1 entry, 2 selectable exits) must be positioned and locked to the correct route, before a vehicle is given a proceeding speed command in the approach blocks preceding a switch.

These switch decisions require a switch-approach VWC receiver in a block upstream of that switch, to provide route information to the WEU. These VWC's may control the logic on subsequent switches, dependent upon clearance distance between switches. Failure to receive a definable VWC message at one of these switch approaches will cause the WEU to stop a vehicle short of the switch, to await external override action.

Merge switches (2 entry, 1 exit) are non-driven, spring-loaded automatic switches which require only right-of-way assignment by the WEU. This assignment is determined by occupancy of a specified approach block in each line coming into that switch. The WEU handles the two approaches to these switches by switch-approach, queuing logic. Vehicle occupancy of one approach sets up speed commands into the switch and stop commands on the other approach. The switch queue logic will award the switch to trains in either approach on a first in, first out basis. The WEU has detection of the unpinned (free-to-move) state of these switches which must be unpinned before the switch may be awarded.

Diverge switch route control logic is predetermined for all 32 (5-bit binary route code in VWC message) possible routes. Should a vehicle show up at a switch (diverge) not normally on its route, the logic is preset to select the switch position which returns the vehicle to its correct route.

Queueing logic in the WEU uses vehicle occupancies and VWC data, to accomplish alternate switch routing and commands for a multiple number of vehicles in the switch approach area. The queueing logic memory functions on the first-in, first-out basis, generally accommodates as many as six trains in the queue. Switch logic queues, and subsequent switch and vehicle proceed commands, are safety interlocked to require switch occupancy before stepping the queue logic and then switch-cleared before repositioning commands can be issued to the switch.

At each switch, the settings for each of the routes is diode-board changeable, so that routes can be easily modified in the hardware, as well as in the software.

The ATCS provides switch control and detection which allows stopping of any train that approaches an improperly positioned or unlocked diverge switch or a pinned merge switch, before an unsafe condition can occur.

The switch position is interlocked into the speed command, so that a vehicle can continue on the main line past an off-line station that is occupied.

If a train is in the block before a merge, the switch cannot be awarded to a train coming on the other entry leg. If the train is not in the block before a merge switch, the switching assignment can be overridden after the time interlocking has expired (to assure that the train has halted).

Central control can override a switch command, but a zero speed command is given for 20-30 seconds in the block preceding the switch to be sure that the vehicle is stopped if it is that close, in case the route the vehicle is to be switched to is not clear.

B-7 HEADWAY SEPARATION ASSURANCE

The vehicle separation assurance system operates on a check-in/check-out, continuous-detection principle. The vehicle first has to check into the block which it is entering, before it is allowed to check out of the block which it is leaving. Additionally, the vehicle's presence in the designated block is continuously detected since the vehicle shunts (short-circuits) the signal in the signal rail in a manner analagous to that employed in standard railroad detection systems. The vehicle communicates occupancy to the wayside by low-impendance relay loading of the track-side 48-VDC power. This loading is accomplished by the vehicle shunt relay which must be continously energized to prevent a Class II malfunction (and subsequent stopping). The relay, by

DC-shunt loading of the occupied block, bleeds current from the vital occupancy relay in the WEU, which is connected to this block by an ATCS block coupling unit. The vehicle AVP receiver (detecting frequency-encoded speed limits and commands from wayside) also acts as a DC-shunt relay with respect to the wayside block.

Both the front signal collector brushes (in parallel) and the rear signal collector brushes (also in parallel) individually convey occupancy to the local WEU.

B-8 VEHICLE MALFUNCTION

On board the vehicle, malfunction conditions are monitored and problems reported to the central operator, and depending on importance, may be used to stop the vehicle.

Malfunctions causing emergency braking are Class I malfunctions of:

(a) Unscheduled door opening (or container unlocked).

(b) Exceeding speed limit (includes motion with zero-speed limit)

(c) Trail car of parted train.

Malfunctions which could lead to safety problems causing irrevocable service braking are Class II malfunctions of:

(a) Propulsion Motor Trip

(b) Rollback

(c) Lead Car of Parted Train

(d) Illegal Speed Command

(e) All Power Breakers Tripped

(f) Power Failure

(g) Propulsion

(h) Contactor Fail

(i) Low Brake Pressure

(j) Dragging Brakes

(k) Door Failure

Another general group of lesser malfunctions exists (Class III) which are warnings to maintenance. These include the AAU, temperatures, and light bulbs. They do not cause automatic braking, but are reported to the central operator, for his decision, via the supervisory system and Data Link Communication. Obviously, the Class I and Class II malfunctions also are reported by the same mechanism to Central Control.

In two-car trains, both cars apply emergency brakes for Class I failures. Class I failures require a manual on-board reset, except that an overspeed malfunction in a block with a non-zero speed limit may be reset by a remote command from Central Control. Class II failures call for an irrevocable service brake which can be reset by a remote command if the failure is corrected.

In the case of a propulsion system failure, either in the front or the rear vehicle of a two-car train, the train can be moved by either pushing or pulling with the other vehicle. A failure of this type occurs about once every two weeks.

B-9 MANUAL OPERATION

Each vehicle in the system has manual operation capabilities which are independent of the ATCS (dependent only on guideway power). This mode uses ATCS speed commands only for display to the operating hostler. Vehicles may be operated against the guideway traffic flow, with safety being a responsibility of the hostler, and operation must be limited to low speeds (up to 5 mph). Manual operation is accomplished by a portable "carry-on" control panel in conjunction with a fixed maintenance control panel. The maintenance control panel contains switching which provides for "automatic", "manual", or "tow" mode selection. Switching is also provided for "forward" (passenger) or "reverse" (employee) mode selection for all vehicles, with the passenger and employee nomenclature applicable only to people-carrying vehicles. The forward and reverse changes also require an external steering (turnscrew operation) change to complete the mode change. This change places steering on the forward wheels in the direction of travel. A vehicle which is placed in the automatic mode, but reverse-directioned to guideway traffic flow, will be "emergency braked" as soon as it proceeds across the first block boundary, since automatic reverse operation is inherently unsafe.

B-10 VEHICLE CONTROL ASSESSMENT

In compliance with section 3.6.4.2.1. of the Specification, Vought asserts that it is possible to increase the accelerations to 4.5 ft/sec^2.

In compliance with Sec. 3.6.4.7.3.2 of the Specification, the positions of the switching equipment are displayed on the guideway schematic wall display in Central Control.

The greatest problem with the separation assurance system had consisted of a number of failures to check out of a block because of the loss of signal brushes on a vehicle. Failure to check out of a block causes a block-occupied signal to remain in effect, thus stopping any trains that approach the "occupied" block. This brush loss is now rare.

B-11 COMMUNICATIONS

Initially, Vought saw data communication as a matter of RF mobile communications. The company was unable, however, to secure the FCC band permission and so used sliding contacts on a signal rail to convey data communications.

The AIRTRANS communication system may be divided into a command data system and an RF voice system. The voice system does not have direct data communication with vehicles. It communicates with vehicles through an RF voice link for passenger security and announcement purposes.

The command data system has the entire data communication responsibility of AIRTRANS. The wayside electronic units (WEU) form the pivot points of the data link between the central control and the operating vehicles. Each WEU consists of one wayside-to-vehicle-communications (WVC) control logic module, two types of WVC/VWC (vehicle-to-wayside communications) receiver modules and a block control receiver. (One type of WVC/VWC receiver module is hardwired to the same fixed VWC block all the time, while the other type (transceiver) is for data communications to any block.) Central Control transmits its command data in a format of 16 bits of parallel information. The WEU converts the parallel format into a serial one; it then inserts parity bits and transmits these to the vehicles using frequency-shift keying (FSK), with a 4 percent frequency deviation. All vehicle/wayside data communications are in digital form. There are individual communications wires to each wayside block. There are no analog communications signals.

The vehicle receiver decodes the signals and forms mark and space pulses. The message content enters a shift register and is stored in the vehicle control logic module.

An initial problem was the high signal level loss between the wayside control room and the signal rail.

The vehicles transmit in a similar manner, except a non-return-to-zero format is used in FSK, while wayside transmitting uses return-to-zero format. The distinction is made in order to separate the origin of messages. Each signal block in the wayside guideway has a block coupling unit for transmitting data between the WEU and a vehicle.

The critical path of communication between the vehicle and wayside is accomplished by two pairs of brushes contacting the signal rail. These brushes are located at the front and rear ends of the vehicle, on both sides. Other data links, such as between WEUs, stations, and Central Control are through medium-grade cables.

B-12 WVC/VWC TRANSMISSIONS

FSK is used throughout the WVC/VWC transmissions. In WVC transmission, the serial bit stream is transmitted on two lines (the mark keying line and the space keying line) in a return-to-zero (RTZ) bit format. A zero-level on a bit line appears on the space keying line. A one-level on a bit line appears on the mark keying line. The carrier frequency for WVC is centered at 13.8 kHz, with a data rate of 1200 bits per second.

Vehicle to wayside (VWC) transmission is non-return-to-zero (NRZ) FSK with a center frequency of 20.9 kHz, at the same data rate. The wayside receiver receives the FSK signal from the signal rail, converts it to pulses, performs a series of security checks, and, if passed, places the decoded information into permanent storage.

Either the vehicle or the wayside (computer) can initiate communications. A vehicle can only initiate communications in a dedicated VWC block. About 10% of the blocks are VWC blocks, and are located at entrances to switches or stations, TPU zone transitions, and other special spots. Vehicles can respond to wayside polling, however, in any block. In wayside to vehicle transmissions, a command or request is sent to a specific vehicle in a zone. This message consists of a single word. The vehicle responds to each wayside message, that is addressed to the vehicle and transmits a single word response. Additional messages may be transmitted, with just one word being sent at a time.

Messages are transmitted using 25-bit words, 16 bits of which contain data and 9 bits of which contain parity and bookkeeping information. For example, when the vehicle initiates transmission, the first word sent from the vehicle has the 16 bits split into three fields:

3 bits	start message
7 bits	vehicle ID
1 bit	parity
4 bits	status and berth
1 bit	parity
5 bits	route code
1 bit	parity
3 bits	end message

The vehicle ID portion of the message is the same, for wayside initiated messages but the other two fields vary according to the nature of the message.

After receiving a message from the wayside, the vehicle to which the message was addressed must respond. Examples of these messages are: a Speed Modification Command (where a vehicle is told to go at either 83-percent or 62-percent of whatever the civil speed command is), a Route Change Command, a command to use the Audio Announcement Unit (AAU), or any status request. The vehicle-to-wayside message may contain a train malfunction report.

B-13 FUNCTIONS OF VWC

The Vehicle to Wayside Communication (VWC) system consists of vehicle-mounted transmitters for the transmission of information from the lead vehicle of each train to the wayside, and receivers at selected locations along the guideway, as well as one common receiver in each WEU.

Since each vehicle carries its own route information, the proper alignment of "diverge" switches depends upon the route information transmitted to the wayside via the VWC subsystem, as approaching trains pass the wayside receiving location. In addition, the identity of the first vehicle of each train (which identifies the train) is received by the wayside at these locations, for transmissions to the terminal processor, as a part of the train progress report.

For stations, the equipment receives a VWC message from a train a few blocks prior to the station stop. The route identity message is displayed in the station, in accordance with the route information communicated from the train to the station via VWC. When the train has completed its positioning stop, as described in Section B-5, each vehicle initiates an independent request to the platform for permission to open its doors. These independent requests are transmitted to the platform via the station alignment and door control circuits. Concurrently, a message is transmitted via the VWC, indicating that the train has completed its positioning stop and requests permission to open the doors. If the train has stopped at the wrong position, the independent requests for each vehicle are not received at the platform. At this time, if the train is improperly positioned, it will be apparent in the station because of the presence of the berthed signal received from the VWC system and because of the absence of any independent door open requests from the vehicles. The vehicle sets irrevocable service brakes after 5 seconds and awaits Central Control action.

B-14 FUNCTIONS OF WVC

The Wayside-Vehicle-Communications (WVC) system transceiver module contains 11 channels of 13.8-kHz transmit modem equipment, and 11 channels of 20.9 kHz receive modem equipment. The receive section of this module functions the same as that of the communication block module, except that the receive channels respond to vehicles which transmit a second time from other than communication blocks. The transmit section of this module transmits simultaneously to all vehicles in blocks within its zone of control.

The communications block receiver contains 19 channels of receiving modem equipment, each channel tuned to the frequency of 20.9 kHz. Each channel contains a coupling unit, receiver input unit, receiver amplifier, and squelch and carrier detector.

The outputs of these squelch and carrier detectors are fed into the WVC/VWC transceiver. The WVC/VWC transceiver combines the output from all 11 detectors, passes the signals through a common mark-space detector and feeds them into the receiver logic module.

The WVC receiver decodes the carrier signal and forms mark and space pulses. The message content enters a shift register when a clock pulse is present. At the same time, a bit counter is driven which, through decoding, allows parity memories to be toggled by the incoming marks. The number of marks in each word is always odd. At the end of a properly received word, all parity memories reflect an odd parity.

At the end of the message transmission, the information contained in the shift register is strobed into permanent storage, providing the parity flip-flops are all proper; the 25 bits are counted, and the start and end of the message bit format is proper. Following the strobe pulse, a reset pulse appears which resets the shift register, the parity flip-flop, the bit counter, and the word counter. Permanent storage is updated with each new valid message transmission.

These WVC/VWC channels are referred to as non-vital channels to differentiate them from the speed command communications described in the next section.

There is one "common" VWC receiver which is coupled to all blocks in the control zone of the WEU. Data transferred over this channel include vehicle route and ID number, vehicle malfunction status, berthed status, detailed malfunction reports, supervisory system override commands, and various detail data words. Typical operation is as follows:

Upon receipt of an "Okay to Update" signal from the WEU, the Terminal Processor Unit (TPU) transmits to the WEU a vehicle poll message (16-bit parallel data transfer). This is the WVC message. The WVC transmits this word to each vehicle in its zone (serial data transfer, 1,200 bits/second).

The TPU cycles through all vehicles in its zone in sequence, and all the vehicles in the zone respond with a standard status message including vehicle ID number, route, passenger or employee mode, and malfunction status.

The polled vehicle transmits a response containing the data required by the pool word. During this time period only the common VWC receiver is enabled; all other receivers are disabled. Cycle time is approximately 200 milliseconds (5 train/sec polling rate), but only 60 milliseconds are actually used. Messages within a zone are synchronized, but not between zones.

A reversion to asynchronous reporting occurs in the event that a vehicle does not receive a wayside carrier within approximately 3 seconds of the last poll message. All responded data are available to the interfacing TPU by a parallel data transfer. An asynchronous vehicle propagates its status word at a 450 millisecond rate. This word is only interpreted at a VWC block.

B-15 COMMUNICATION OF SPECIFIC COMMANDS

The main function of the Automatic Vehicle Operation system is to regulate vehicle speed. All speed regulation functions are accomplished via the same wiring as the WVC/VWC data link, through the "vital communication" channels which are described below. The speed commands are given in the form of both speed levels and speed limits as described in Section B-4. The selected speed level is "vitally" communicated from the wayside to the train.

Each vital channel uses a code signal which requires that its transmitter sends pulses alternately at the upper and lower sidebands of its channel. The fail-safe decoding circuit in the receiver picks up a vital relay only if the input signal constantly alternates between these conditions: high shift and no low shift: low shift and no high shift. The presence of any one frequency within the channel bandwidth cannot pick up the relay continuously. A continuous signal can cause a safe failure only by violating the code condition that requires one shift and the absence of the other shift.

The speed command transmission uses two vital tones sent via FSK, which can be referred to as F_1 and F_2. By itself, F_1 denotes the low speed limit, and F_2 denotes the medium speed limit. The combination of F_1 and F_2 denotes the high speed limit. Note that with the absence or failure of either tone in this combination case, the speed limit received by the train represents a more restrictive limit. If neither tone is present, the vehicle applies its emergency brakes.

Two non-vital frequency channels, F_3 and F_4, are used to assist the vital frequencies F_1 and F_2, to accomplish the command transmission. These frequencies form the command codes as follows:

	H/H	H/M	M/L	M/P	L/S	0/0
Speed limit (ft.sec)	26.5	26.5	16.5	16.5	6.5	0
Speed command (ft/sec)	25	15	5	0	0	0
Command signals	$F_1F_2F_3$	F_1F_2	F_2F_3	F_2F_4	F_1F_4	

Onboard the vehicle the speed limit information generated by the F_1- and F_2-receiving relays is sent to the speed governors on the control system in a digital form. Similar digital speed signals are sent to the speed regulators.

The decoded speed commands are converted to an analog reference voltage, to serve as the speed command profile.

B-16 PASSENGER COMMUNICATION SYSTEM

TV monitoring, public announcement (PA), and station graphics are subsystems of passenger communications. The first two of these subsystems are controlled from Central Control panels. Station graphics are controlled by the terminal processor unit.

There are two CRT displays for TV monitoring, which are controlled by the central computer. One of the CRTs, at fixed intervals (either 3 seconds or 10 seconds), is automatically advanced, showing stations in sequence. It will automatically focus on a station whenever that station sends out a fault message, such as a vehicle door held open, to the controlling computer. The scanning sequence can be resumed whenever the fault signal is removed from the control computer. The other CRT display is selected by the controller, who focuses on a desired station. There are 28 TV cameras in the station.

Public announcements may be made to the passengers on-board a vehicle via a two-way mobile radio. Passengers may request voice communications with the contral controller by pressing down the red button on the passenger service panel. When not used for special announcements, the speaker on-board announces station arrivals through a tape recorder (Audio Announcement Unit, AAU).

In stations, announcement of incoming vehicles is visual on the overhead graphics. Destination stations are all pre-printed on the graphic board; the route code of the incoming vehicle will automatically illuminate those stations the vehicle was programmed to visit. Central Control cannot interrupt this automatic illumination; however, the controller may override this information by public announcement in station areas.

The passenger communication system is, in general, similar to those used on other automatically controlled transit systems such as BART and Seattle-Tacoma Airport.

B-17 COMMUNICATION SYSTEM ASSESSMENT

Vought's employment of the fixed-block control has drastically reduced the channel requirement for data communications. For example, vehicle locations in the system are automatically reported to the resolution within the control block units because of the fixed block control scheme. These vehicle location reports would otherwise require special data band allocation. The fixed-block control also separates local safety control and operational control, further reducing the collective communications requirements.

The 17-mph top speed of AIRTRANS gives a smaller upper limit to the number of vehicles to be communicated to in one communications loop. This arrangement reduces the stringent channel capacity requirement which most small-vehicle automated systems must have.

The AIRTRANS communications system is designed for a fixed-block control, with a sparsely occupied guideway. A major redesign would be necessary should variable blocks be used, a scheme that is envisioned for many automated systems. Although the AIRTRANS data communication system design is highly successful, it is not easily expandable to a system with large numbers of vehicles per loop, operating in a moving block manner.

The most significant feature that is transferable to new systems is the principle of separating vital and non-vital communications. This feature provides a fail-safe system that enables the vehicle to proceed even when the non-vital communication breaks down. The physical separation of vital and non-vital channels is accomplished at minimum cost.

The bit error rate is reportedly very low, perhaps on the order of 1×10^{-5}. This is not used as a measure of performance, however, which is, rather, the success of a roundtrip message. A communications error is only reported if there are seven consecutive polling errors. The communications workload is helped by having no on-board switching. The communication error rate requirement is only that 66 percent of the messages be transmitted correctly. The actual performance is 95 percent correct messages; the error rate has no effect on command and control system reliability.

There is no written report of a communications noise analysis. The communications system was designed by GRS, and there was a specification for non-interference with airport systems.

B-18 SYSTEM MANAGEMENT

B-18.1 General

Simulation studies were conducted to determine operational strategies to be employed in system management. Efficient vehicle flows are important for achieving the desired level of service. Route structure and travel times along the routes must be considered. Scheduling of vehicles is closely linked to the bunch control algorithms.

B-18.2 Simulation

The vehicle management simulation is considered proprietary and, thus, no general report is available. It was first written in Simscript for the IBM 360 and then coverted to GASP for the CDC 6600. The guideway is broken up into blocks which correspond to the 708 hardware blocks. The average block length is about 90 feet, with blocks up to 180 feet at the remote parking areas. There are 45-foot blocks at the stations and at some switch approaches. Some downgrades have 240-foot long physical blocks, which are treated as 45-foot long logical blocks, for safety purposes. One other simplication is the use of linear acceleration without any jerk limitations.

The original simulation runs assumed 100-percent reliability of the hardware. More recently, stoppages were put in, as well as MTTR's comparable to actual experience. The only function not simulated is a passenger's holding a door open, after it has started to close. No passenger flow is considered in the simulation - the flow rates given by the Airport Board define arrivals at the stations, but no other action is taken. No simulation is done to analyze response to abnormal conditions. The simulation was validated by running it against a known set of data gathered after the airport opened, and it pretty much conformed to the observations.

B-18.3 Vehicle Flow

Vehicle flow as a whole is controlled by means of the debunching algorithms.

AIRTRANS vehicles operate over fixed routes. The routes were chosen early in the program. Initially, a simulation of an ideal moving block spacing system was developed with trains of zero length which went between all terminal pairs. This approach had large queues, and, when finite lengths were given to the train, the system stopped. Vought then began to use routes instead of pairing every set of terminals. The intent was to choose routes to minimize the guideway needed, especially costly crossovers, and still remain within the right of way given by the Airport Board. Counterclockwise travel was chosen so that the vehicles would be going in the same direction as the cars traveling on the spine highway through the airport. For a selected route, the number of trains needed to satisfy the trip time was determined. and then the number of cars needed to meet the given demand level. Where three-car trains would have been needed, the number of trains of the route was increased, to keep to a maximum of two cars per train. The simulation was used to get distributions of stopping times. Basically, a trial-and-error approach was employed. If the work on route selection were being done now, serious consideration would be given to adding guideway and reducing the number of cars.

Using the simulation, Vought considered changing the routes. However, changing the routes might have required more vehicles, revised graphics, and changes in the easily-modifiable hardwired wayside logic for the switches and stations (refer to Section B-6).

With the present procedures, AIRTRANS does have some flexibility in managing its fleet size. During the day, a certain number of trains are needed to meet the expected demand. At night, only a lower number of trains is required. At present, only ten fewer trains run at night than during the day.

B-18.4 Schedules

AIRTRANS service does not work on schedules in the classical sense of the term, but rather works on schedules based on headway separation between trains on a given route. This approach, in conjunction with the control hardware and safety separation system, determines the spacing of the trains. Nominally, the trains on a given route are equispaced by use of the bunch control algorithm. Whenever the number of trains on a route is altered, or whenever trains are detained elsewhere by failed trains on another route, the debunching procedure goes to work to get a uniform time spacing between the trains. A slow train may at first be speeded up by reducing the door-open times at the stations. If this most desirable approach does not do the job, it is then necessary to delay the following trains on the route and, effectively, slip the schedules for that route. This change in schedules is not difficult to accomplish.

Since schedules are not computed in terms of absolute times, but rather in terms of spacing between trains, the automatic change of schedules is handled by the bunch control system. A change of the number of trains in operation is handled by the central operator.

B-18.5 Bunch Control

Vehicular traffic control is accomplished by the supervisory system. This control consists of exercising, through software bunching algorithms, vehicle speed and dwell overrides on all the variously routed vehicles, to prevent vehicle stack-ups on the guideway and to maintain equal headways between trains on any route.

Vehicle bunching was a major problem which has been resolved in the current operation of the system. Checkpoints are used for debunching control - blocks are chosen on the guideway where trains are checked against expected arrival time. Just 42 out of the 708 blocks in the system are used as checkpoints. Schedules are set up at these logical checkpoints (CPs). Trains can be held at CPs or can be given reduced velocity performance commands to spread out bunched trains. There is no CP at the hotel station because it was decided not to hold trains at this heavy traffic point.

If a train is late, an attempt is first made to get it back on schedule by reducing its dwell times in the stations. There is no capability for increasing train speeds above the nominal speed limits on the guideway, so that only in stations can lost time be made up.

One of the implementations of the bunch control algorithm is through the modification of door-open time in the stations. The nominal dwell time is 18 seconds, which can be adjusted at the control console. In conjunction with bunch control, the door-open time for any one stop can range from 8 to 35 seconds. If someone interferes with the closing of the door, the door re-opens and an attempt is made to close it 5 seconds later. This 5-second cycle can be repeated indefinitely, but after a few cycles central control is notified that a problem exists, while the cycling continues.

When modification of station dwell time cannot get a train back on schedule, that train is declared to be "on schedule," and the other trains on the route are then ahead of schedule. One approach for handling trains which are early, described above, is to extend station dwell times. The other approach is to use one of the two reduced performance levels which apply to guideway speed commands, 62 percent and 83 percent.

Whenever the number of trains on a route is changed, a re-initiating procedure is employed. Bunch control is not started until all the vehicles on that route have passed by what is designated as the key checkpoint for that route. Thus, when vehicles are sent to the maintenance area at night, bunch control for that time period is ineffectual.

B-18.6 Future Operations

No larger vehicles are contemplated in future AIRTRANS operation. Higher speed may be needed in the future, to establish high-speed spine links between different sections of the airport. The 150-foot radius curves limit the speed of the current system to about 25 ft/sec. The 4W terminal was dropped from the plans late in the project. When it is added, additional guideway to the system may be proposed for additional turnarounds and/or by-passes.

In the future the switching locking arrangements might be changed to allow either higher speed and/or shorter headways. The goal is to have two main line tracks and two separate sidings in each station. It is not planned to combine passengers and employees.

Some modifications to increase capacity by 25 percent have been considered. There is already the capability to run three-car trains and space for expansion in the stations to install a third door. The top speed could be uniformly raised from 25 ft/sec to 28 ft/sec with a change to the on-board controller.

The expense of modifying the present maximum civil speed has not been examined. A higher speed would require an increase head way, all other things being equal, due to the greater stopping distances.

If a moving block system replaced the fixed block system, the headway could go down from 15 seconds to 12 seconds.

During this assessment, TSC developed a demonstration of a demand-responsive system which was tried on two nights. It appeared that a demand-responsive system could only operate about two hours a night, when demand is lowest.

Vought has not seriously considered a demand-responsive mode of operation for AIRTRANS. Thus, there is no projected value of an "on-demand" system. No investigation was ever made of the control problems, performance, cost, and reliability. The implementation of a demand-responsive system would be made more difficult because the TPU's have no extra core storage.

B-18.7 Abnormal Operations

The basic system control philosophy results in good system recovery after a failure. As soon as a failed train is fixed, it starts up. The following trains simply wait until the proper spacing exists and then automatically start themselves, without any action on the part of the central operator. The procedures for abnormal operation are in Volume III of the Systems Operation Manual (see List of References). The software reports the problems, and the operator generally responds. Some of the responses are handled automatically by the software.

There is no automatic guideway power shutdown if a vehicle emergency door is opened. It is felt that, if the air conditioner works and the car makes noise, people will stay in the car longer.

B-18.8 Bunch Control Assessment

The third paragraph of Section 3.3.3.1 of the Performance Specifications reads as follows:

> "Means shall be provided by the Contractor for automatically maintaining spacing between trains on the same routes, such that the headway between trains does not vary by more than plus or minus 10 percent from the normal value, or by 30 seconds, whichever is greater."

According to Vought, bunch control meets the spirit, but not the letter of the specification.

B-19 SUPERVISORY SYSTEM

The supervisory system (Central Control) oversees, monitors, and provides certain system override functions by computer and central operator (at the central console), as permitted by ATCS safety inhibits. As a part of normal operations, the supervisory system aids the ATCS in efficient vehicle dispatching, bunching control, routing, station handling, and the other system management functions. The supervisory system has: a speed reduction capability by a data link to the vehicles and by block rail sections through ATCS interface; switch position override capability and false block occupancy (pseudo) through ATCS interface; vehicle station dwell time overrides through ATCS; station notification, monitoring, public address and closed circuit television control capability through direct station interface; status monitoring of vehicles through the data link; and two-way voice communications (vehicles and maintenance personnel) by direct RF communications. The supervisory system consits of a central computer (CPU) and five (5) satellite computers (terminal processors - TPU) which interface one-on-one with the WEU in that zone. There are also three additional smaller satellite computers (remote location multiplexers - RLM) located at the two remote parking areas and at the hotel. Central operator control is exercised through the central console which interfaces through the computers, public address, closed circuit television, and radio frequency transceiver (to vehicles), to form the total supervisory system.

The computer can override ATC functions only when it is safe to do so, and then only in a more conservative fashion. For example, the computer can command lower speeds, but not higher speeds. The computer controls car functions, such as route changes, station dwell (bypass) and train separation for debunching.

B-20 COMPUTER SYSTEM FUNCTIONS

The functions described in this paragraph are the responsibility of the computer system.

1. Console Display indicates real time system status, performance, malfunctions, and discrepancies within the AIRTRANS equipment, by lamp indications and alarms, of the following functions:

Guideway Vehicle Occupancy;
Guideway Switch Status;
Guideway Override in Existence;
Guideway Power Status;
Stations Operative Status;
Stations Occupancy;
Stations Malfunctions or Discrepancies;
Stations Overrides in Existence;
Vehicle Malfunctions or Discrepancies;
Vehicle Override in Existance;

2. Console CRT Display

Detailed Malfunction/Discrepancy Reporting;
Detailed Data as called by operator through CRT keyboard;
Additional commands to system;
Command keyboard repeats/disallow illegals.

3. Effect Specific Console System Command of over-ride functions initiated by operator, such as:

Station Dwell Overrides;
Vehicle Speed Overrides;
Switch Overrides;
Station and Siding Overrides, such as stop inhibits, bypasses,
Discrepancy Recovery Overrides;
Vehicle Entries (add vehicles to system)
Vehicle Data Requests;
Vehicle Route Changes;
Vehicle Voice Mode/Annunicator Commands;
Vehicle Malfunction/Brake Reset.

4. Line Printer - Permanent record-keeping functions of system operations, malfunctions, discrepancies, statistical performance of data and background task operations.

5. Off Line Background or Special Task Operations via available peripherals, such as Disk Memory, Teletype, Tape Punch, Tape Reader.

6. Television Monitoring and Control: automatic and operator-initiated, of people and stations in the system.

7. RF System Control from operator-initiated commands for maintenance and passenger/employee vehicles of the AIRTRANS systems.

8. PA System Control by operator initiated commands for passenger/employee stations of the AIRTRANS systems.

9. CPU autonomous operations, including bunching control; certain malfunction responses, sensor data monitoring, TPU communication for obtaining wayside data, issuing wayside override commands, obtaining vehicle data, issuing vehicle override commands, issuing television camera switching commands, issuing Public Address switching commands, and continuous updating of the console displays listed previously.

During standard operations, performance data is not generally collected on the disk. Events of interest are recorded on the line printer.

Circuit breakers are monitored and controlled by the CPU, circuit breakers open automatically without the CPU, but with a CPU failure, attendants in the WEU rooms must reset the breakers, when tripped.

10. TPU Functions: direct monitoring of vehicle and wayside operation and status through direct ATCS and station interface; vehicle communication through ATCS for status and issuing of vehicle override commands and data request; autononmous operation of CPU bunching commands; changing station graphics, baggage handling, and mail bay handling via route decoding; continuous data transmission to CPU of its zone's wayside station status; implementing ATCS override functions as commands by Central Control (and some by autonomous responses) such as graphics and bay

control overrides, station overrides, speed overrides (vehicle and wayside), and switch overrides.

Loop 6W-Maintenance (in addition to above): vehicle system entry and exit by local or central command, through local ATCS interfacing; departure testing using a special interface and teletype peripheral; bench testing of Control Logic Assemblies (vehicle on-board control units), through special interface and software.

11. Abnormal Operations. A number of abnormal situations are handled automatically by the software, including the following:

a. If a vehicle is below speed in a restricted control zone, lower speeds are commanded in the trailing zone.

b. The television automatically switches to a station where there is a trouble report and stays locked until released by the operator.

c. An overloaded train will not depart from a station.

d. There are special switching routines for area 6W.

e. The passenger emergency talk button causes a train to stop at the next station on the route and stay there with its doors open until given a reset command by Central Control.

12. Overrides. In conjunction with the basic ATCS, certain supervisory system overrides exist. There are speed reduction overrides, applied by the TPU to the WEU by sections of the guideway. There are approximately 10 to 15 such sections per WEU zone.

These overrides change the resultant speed limit/command tone combination placed on a signal rail. There are also data-link-superimposed speed overrides placed on a single train, which will alter the train's interpretation of its command speed (downward) but not its speed limit. It is to be noted that receipt of a speed command that does not cause a speed limit violation, but is not one of the valid combinations (see Section B-4), will cause an Irrevocable Service Brake stop.

In general, for all of the ATCS control functions, there are corresponding monitoring and, in certain functions, override command functions available to the central operator through the supervisory system. The vehicle to supervisory system interface is accomplished by the ATCS data link and the vehicle logic control box.

Wayside and supervisory system interface through the WEU and TPU provides for monitoring of individual block occupancies, VWC receiver data, switch positions (diverge), switch routing assignments (merge), station operate commands, and "free-to-move" status of merge switches. Supervisory system override capabilities existing are: simulated occupancy of certain selected blocks, three steps of speed reductions (including all stop) for groups of blocks called "sections", diverge switch position overrides, merge-switch route overrides, and station dwell (and stop inhibits) overrides. Each of these override functions are buffered by the ATCS where necessary, to prevent unsafe conditions which might otherwise be caused by an inappropriately exercised override. All overrides may be either "temporary" (one train) or "permanent" (until removed).

There are various overrides and status monitoring functions on board the vehicle, through the supervisory system data link and the vehicle logic box. These consist of speed (command and tachometer) monitoring, as well as interpreted wayside signal rail limit and command speeds, vehicle malfunction status, and a number of vehicle discrepancy functions primarily associated with station stops and servicing. The on-board annunciator for passengers is controlled through this link.

B-21 COMPUTERS

All the computers have 16-bit words. The Central Computer (CPU) is a modular computer (Modcomp II) with 64K core memory. It has the following inputs and outputs:

a. CRT keyboard the CRT display, including a standard keyboard input to the CPU and CRT display output for conversational information exchange between the operator and CPU.

b. Line Printer, which is driven by the CPU.

c. A Teletype consisting of a standard teletype keyboard, printer, tape punch, and tape reader peripheral for background usage (not for general system operation). This unit is housed in Central Control.

d. A Dual Disk (used to store memory snapshorts, special background use routines, data for later output, etc.) is housed at the central console area also. This device is capable of storing 2.5 million, 16 bit words to data.

e. A tape reader used for initial and subsequent program or data read-in for system changes and background operations.

f. Tape Punch used for producing program or data tapes as required.

An identical modcomp II is installed as an offline backup unit. About 25 percent of the available CPU time is devoted to communications tasks. The total CPU utilization is about 40 to 47 percent. The CPU has five 1800-baud, full-duplex data modems, two channels for each TPU. As an indication of the average instruction execution time, and add time is 2.4 microseconds.

The Terminal Processing Units (TPU) in the four terminal areas are Modcomp I computers and have 16K of core, while the fifth one, located in 6W and used for departure tests is a Modcomp III and has 32.5K of core. The three RLMs each have 2K of core (they are Modcomp I computers). The RLM at the hotel is a satellite of the TPU at 3E. The RLM at North Parking is a satellite of the TPU at 2E and the RLM at South Parking is a satellite of the TPU at 6W. Full duplex 1800-baud modems link the RLMs to the TPUs. A backup Modcomp III is being added to 6W.

The TPU handles the following inputs and outputs:

<u>INPUTS</u>

a. CPU Modem - Central Commands, train zone forecasts communication containing:

Pseudo Occupancy Commands;

Bunching (dwells and vehicle speeds, headway parameters);

Switch Route or position overrides;

Station-associated overrides, special dwells, inhibit stops, graphic overrides.

Vehicle communication link commands, data requests (WVC), Power System Breaker Commands-open (open-road), close breaker, TV. PA, and RF control commands (RF becomes vehicle communication command).

Request for routine wayside, station, and vehicle data.

b. Loop 6W Special Functions:

Dump wash facility control;

Departure Test interfacing WEU and teletype.

c. Remote Modem Data:

Parking lot station data of same nature listed below on direct station interface.

d. Stations:

Door status, (operating status of utility);

Emergency power status.

e. WEU - All wayside and vehicle status data:

Block occupancy status;

Switch routing and position status;

Vehicle VWC data and WVC response data;

f. Power System status inputs:

Network protector breaker tripped, open.

g. Local emergency power status inputs.

OUTPUTS

a. To CPU.
b. TPU Status.
c. Switch, position or route overrides.
d. Station dwell terminate or extend, stop inhibits.
e. Zone initialize.
f. Section speed reducer overrides.
g. Pseudo occupancies.
h. WVC vehicle messages.
i. Circuit breaker commands, TV camera selection, pasedean graphics, RLM data reports.

The TPU's are not redundant, but there is a backup unit stored at Central Control to reduce down-time. This unit is plugged in to replace a failed TPU, which is then fixed off-line.

On-board the vehicle are special-purpose digital computers.

B-22 SOFTWARE

B-22.1 General

The software functions are divided between the CPU and the TPU's so that the TPU's are as autonomous as possible. There is 113.6K of code for the CPU, of which 43.6K is core resident in the 64K memory. This, resident portion consists primarily of common data (8K), computer/computer communications (16K), and executive and control programs (24K). The rest of the code is swapped in and out from the disk as needed. There is more than enough CPU time available to handle all the necessary swapping. In contrast, all of the code for the TPU's (and RLMs) is core resident, eliminating the need for peripheral storage such as a disk.

No formally documented software requirements specifications were used. A small group of people defined the software interface based on the system specifications.

The software was written in assembly language for the Modcomp computers. No formal control procedures were employed, since the software was developed by a very tightly knit, eight-man group. The Modcomp Executive, was the starting point. but it had to be overhauled, because it was not real-time oriented. About 10 percent of the Executive was changed to make it more responsive to the specific application, and also to correct errors that were uncovered. A separate communications package had to be written for the equipment. These major efforts may be considered to be proprietary in nature. System engineers and computer specialists were combined in their software group, to develop the programs. An overview of the system flows was established, and then the Supervisory Data System (SDS) for the CPU and for TPU's was defined. The functional I/O was defined, data bases set up, and output displays and peripheral functions defined. The modular software organization is shown in Figure B-2.

There are six main sections in the CPU software as indicated by the six boxes across the second row of the organization chart. Roman numerals in blocks denote the section program functions. Section I handles power system control and monitor. II covers the closed circuit television system control. III deals with the public address system control. IV handles train voice radio communications control. V, the major section, encompasses train and guideway control and monitor. VI covers console power monitor and test control, including emergency power, phantom monitor, and lamp test.

The TPU software contains an Executive, some peripheral control programs, code for interfacing with the ATC hardware, and programs corresponding to I-V in the CPU, with similar titles," as well as the modem control routines.

The CPU software is outlined in Table B-2 which gives the functions and words of program for each area. This breakdown excludes the other utility programs that are required.

Each TPU and RLM uses all its core. The TPU at 6W has 9504 words of program, to handle the departure tests, in addition to the 16K words used in each of the other four TPU's. Each of the three RLMs utilizes all 4K words of core.

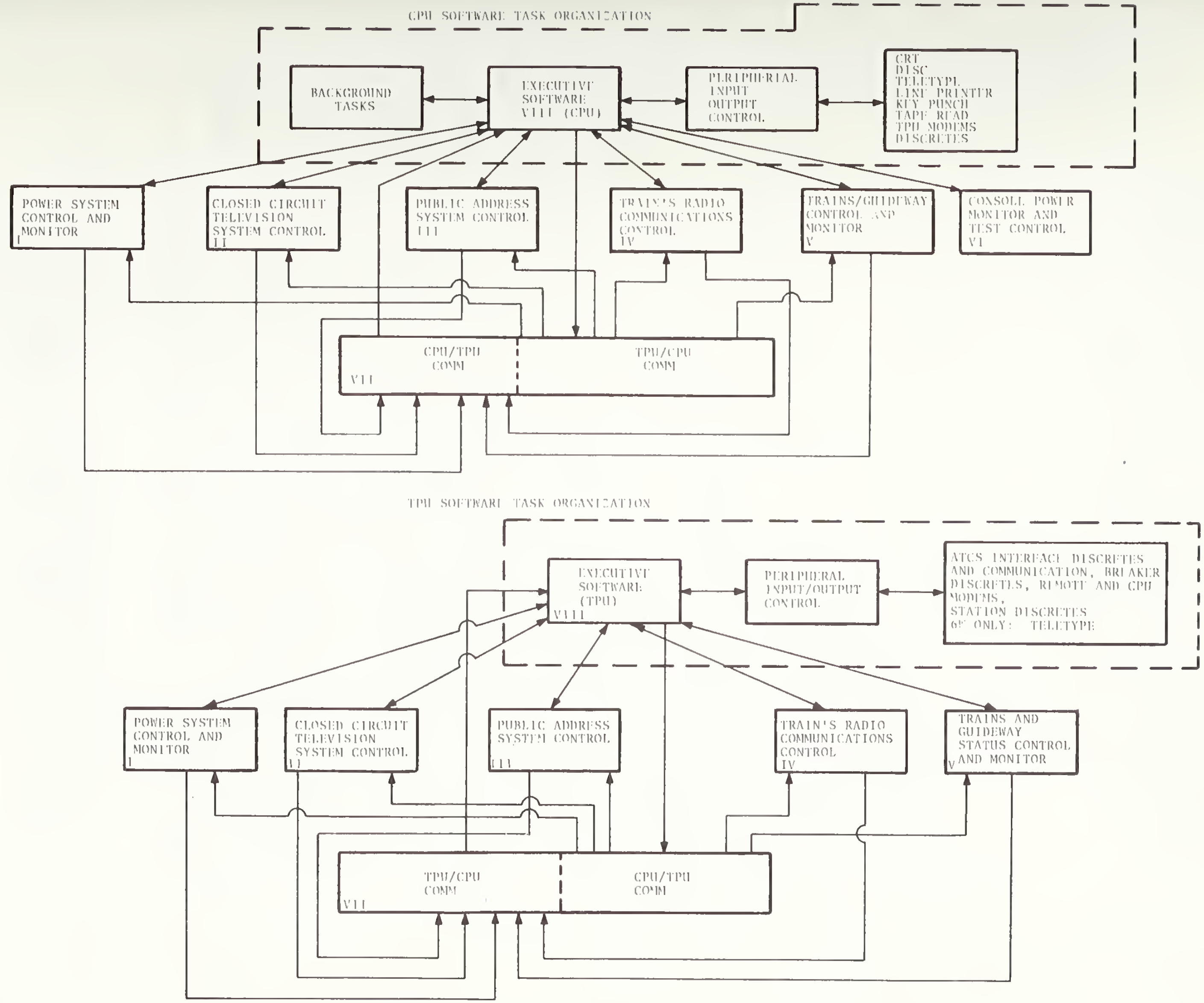


Figure B-2. Modular Software Task Organizations

The CPU software system can be reloaded fairly quickly — in about one and a half minutes. To modify the software, the capability exists to make a hand-load at the CPU directly.

TABLE B-2. CPU SOFTWARE DIVISION

Area	Size
Power system	2,688
Public address	768
Voice control - radio	1,664
Closed circuit television	768
Malfunction acknowldge + console + guideway lamp display group	7,424
CRT/lineprinter/disk write management group	14,976
Bunch control	4,096
TPU communications - control-load-status monitor group	11,571
Subroutine executive + executive	25,869
Data - common	8,000
Operational/control & monitors	35,776
	113,600

The TPU software can be reloaded either from Central Control thru the modems (which takes about 15 minutes), or from a paper tape reader in the TPU room (which takes about 2 minutes). The proper paper tape is kept in the room with the TPU at all times.

As is often the case, enough core memory was not purchased initially. There were no reported major design changes in the software during the project. One small change was the elimination of the automatic shutdown of power on the guideway, if a door on a vehicle were opened. However, this capability exists in a passive program in the CPU.

No final software documentation exists. The software specifications are treated as an as-built item by Vought.

B-22.2 Failure Impact

A computer, monitor, or software failure does not have an effect on safety, since the safety system is independent of the computers. The impact on system performance is given in the System Operation Manual, broken down into the impacts from a failure of the CPU or TPU. If the CPU fails, the impacts are as follows:

a. Total console failure.

b. No TV monitoring control (frozen at last station).

c. No PA.

d. No RF to vehicles - exception, tone addressing for emergency use.

e. No system status knowledge.

f. Absolutely no system control - cannot shut down system or stop trains.

g. Total loss of operator contact or knowledge of the system except via telephone and radio.

h. No bunching updates to TPU's (no bunch control).

i. No TPU to CPU information exchange.

Thus, when the CPU is off, the central operators have almost no visibility of what is happening in the system, and just coordinate the radio communications. An extra load is placed on the rovers, because about 6-8 extra operational people are needed at this time (the rovers perform these functions instead of their normal tasks). Some rovers have to go to the TPU rooms to watch for indications of any system malfunctions which would normally be reported to the CPU.

The results of the TPU failure are:

a. Loss of any existing train control overrides (e.g., switching, velocity performance level, etc.) in a zone.

b. Loss of any station graphics in that zone.

c. No PA, TV switch control, or RF voice system control with that zone's stations and vehicles (the RF Voice System will have emergency call capability by non-computer coupled means).

d. Loss of bunching control in that zone - with detrimental effects on rest of system.

e. Loss of power system status and control in that zone.

f. Reversion to semi-automatic baggage and mail handling in that zone.

g. No malfunction detection in that zone of wayside, stations, and vehicles. No subsequent status knowledge.

h. No Audio Announcement Unit (AAU).

i. In 6W (in addition to above): reversion to manual entry of vehicles to system; no departure test; loss of automatic vehicle dump and wash control.

When a TPU fails, special action has to be taken for a period of about 15 minutes, while a backup TPU is being carried from Central Control and plugged in to replace the failed unit. Passenger service agents are assigned to all the affected stations, to assist the passengers. The agents know which train numbers are serving which routes, so they can make announcements in the station, to control passenger flow. (The same procedure is used whenever the station graphics are inoperative for any other reason.) In addition, for safety relative to the power system, one person is sent to the WEU room, to monitor the system status.

B-22.3 Assessment

Initially, the system CPU was used for software debugging. However, it soon became apparent that there was a conflict in developing and debugging software at the same time, so another CPU was obtained for software development use (editing and compiling programs, etc.), and the initial CPU used for program testing. The programs to control the communications modems were among the hardest to debug, because they require two computers; these programs are not a standard peripheral device supported by the manufacturer of the computers.

It was felt, after the fact, that it would have been very beneficial to have an environmental simulator to do the initial testing of the integrated software. An effort was made right from the beginning to debug the control hardware and software in parallel, with the usual consequences, namely that it was hard to determine <u>which</u> was not operating properly.

The CPU reliability seemed to be getting worse in the spring of 1975. As a result of these troubles, a preventive maintenance (PM) program was started for about 2 hours a night, once a week. During that time, the CPU is shut down, and diagnostics are run.

As is often the case the software problems were underplayed during the first half of the project, and then overplayed during the second half. It appears to be rather difficult to find the happy medium in between.

APPENDIX C

AIRTRANS SYSTEM TRAINING SYLLABUS

AIRTRANS CENTRAL CONTROL
OPERATOR ORIENTATION/TRAINING SYLLABUS

1st Day	
0830-1030	Introduction to AIRTRANS Department. Organization policies, facilities, work schedules, etc.
1030-1200	AIRTRANS Film plus discussion of Airport Layout and relationship of AIRTRANS to DFW Operations.
1300-1400	Distribution/Introduction of Operations Manual, Section I, II, & III. A brief review of the manual and the point of development of procedures.
1400-1530	Overview of AIRTRANS systems. Guideway & Switches, Stations, power distribution, control sections. Plus AIRTRANS acronyms.
1530-1730	Manual study: AIRTRANS System operation and switch system. Pages 1-26.
2nd Day	
0830-1030	Introduction to AIRTRANS Nomenclature: Control sections, Stations, Switches, TPU's, sidings, breakers, trains.
1030-1200	Classroom review of pages 1-26.
1300-1400	Tour of Central. Noting Console, Schematic, CPU, Line Printer, and standby power system located at East end of HVAC.
1400-1530	Description of different routes serving passengers, employees, baggage & mail, trash, supply, 31/36 to 6W and mention various test routes.
1530-1730	Manual Study: Power distribution system, station doors and walls, fare collection system, graphics, public address and CCTV systems. Pages 28-67.
3rd Day	
0830-0930	Organization structure of maintenance. MCP, Rovers, Wayside, Computer Maintenance. Brief description of facilities available in 6W, Departure Test, etc.
0930-1200	Review of pages 28-40, Guideway Power Distribution.
1300-1400	Visit hotel area and observe network protector, A Breakers, RLM, Station Doors, Turnstiles, Graphics, PA, and CCTV.
1400-1530	Review of pages 42-67.
1530-1730	Manual Study: Passenger Vehicles, Utility Vehicles, propulsion systems, power systems, steering, hearing, air conditioning, AAU, etc. Pages 68-108.

4th Day	
0830-0930	Review of AIRTRANS nomenclature.
0930-1200	Classroom review of Pages 68-108.
1300-1530	ATCS System, elements (CPU, TPU, WEU, VWC Blocks), GRS Equipment, Speed limits/Commands, AVP, AVO, AVS, Checkin-checkout feature.
1530-1630	Manual Study: Automatic Train Control and Surveillance System description. Pages 109-126.

5th Day	
0830-1030	Tour of 6W. Noting switches, vehicles, departure test, receiving tracks, ready tracks, and wayside equipment.
1030-1200	Review of pages 109-126.
1300-1530	Question/answer period on 1st weeks material.
1530-1730	Manual Study: Cargo handling system. Pages 132-149 PLUS Appendix A.

6th Day	
0830-1030	Tour of B/M Station noting Phase I and Phase II equipment. (While in utility siding point out trash, supply and employee stations).
1030-1200	Review of pages 132-149 and appendix A.
1300-1530	Classroom identification of AIRTRANS nomenclature. (Using mockup).
1530-1730	Manual Study: Departure Test, hostlers, service vehicles, and radio equipment. Pages 151-170 and 258-295.

7th Day	
0830-1030	Review of pages 151-198 with emphasis on radios.
1030-1200	Introduction to Section II, Console and Guideway Schematic Description.
1300-1530	Guideway Schematic . . . light logic for blocks, switches, stations and sections (use mockup).
1530-1730	Manual Study: Section II, Pages 1-81.

<u>8th Day</u>	
0830-1030	Classroom review of Section II, Pages 1-81.
1030-1200	Console Control Panel and Command Keyboard Panel Training using operator worksheets and/or mockup.
1300-1400	Introduction to Central PA Announcements. Where they are needed and where they are critical.
1400-1730	Review for Test.
<u>9th Day</u>	
0830-1200	Test
1300-1400	Procedures (Sample of procedures being used in Central Control).
1400-1730	Monitor Central Control from behind glass wall.

APPENDIX D - REFERENCES

1. AIRTRANS System Operation Manual, Vol. I, Section 1,2, & 3. Vought Corporation, Change 2, 15 January 1975.

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