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ASSESSMENT OF OPERATIONAL AUTOMATED GUIDEWAY SYSTEMS-AIRTRANS (PHASE II)

Jointly Prepared by

U.S. DEPARTMENT OF TRANSPORTATION
Research and Special Programs Administration
Transportation Systems Center
Cambridge MA 02142

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FINAL REPORT

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16. Abstract

This assessment was conducted by the Transportation Systems Center, in close collaboration with the Dallas-Fort Worth Regional Airport Board, and with active participation of the French Institut de Recherche des Transport, under a bilateral agreement between the U.S. Department of Transportation and the French government. This study, Phase II, completes the assessment of AIRTRANS, the automated guideway system located at the Dallas-Fort Worth Airport. The Phase I assessment report: "Assessment of Operational Automated Guideway Systems - AIRTRANS (Phase I)" (PB 261-339), covered concepts, history, technical evaluation, and performance through September, 1976. The work for Phase II was performed between June 1977 and June 1979, and has four main areas of coverage: 1) changes in system configuration including the addition of employee service and the modifications of the failure management and control systems; 2) the availability, reliability, and maintainability history of the system and its components; 3) the operational safety history of the system; and 4) a life cycle cost study of the system. Availability was not defined in the original AIRTRANS specification, and several definitions have been used. The official measure used today shows the system as being over 98 percent available during the 4½ years of its operation. The data analysis gives firm numbers for Mean Times Between Malfunctions (MTBM), counting all events which stopped the system. Data for the six time periods studied showed decreasing delay durations, increasing MTBMs and decreasing maintenance costs. Operational safety has been excellent. Some estimators for capital and O&M costs of new systems similar to AIRTRANS are developed, which should be useful to planners. Systems lessons learned are also addressed in this report.

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PREFACE

This assessment was conducted by the Transportation Systems Center of the U.S. Department of Transportation, in close collaboration with the Dallas-Fort Worth Regional Airport Board, and with active participation of the French Institut de Recherche des Transport (IRT), under a bilateral agreement between the U.S. Department of Transportation and the French Government.

The study is the second phase of the AIRTRANS assessment. The first phase was analyzed in TSC/UMTA Report UMTA-MA-06-0067-76-1, dated September 1976. That report covered the history, technical description and evaluation of operations from system inception through September 1976. The new report, the work for which was performed between June 1977 and June 1979, has four main areas of coverage:

1. A review of the system configuration after two years, with emphasis on the changes that have been made.
2. A detailed analysis of the Reliability, Availability, and Maintainability history of the system.
3. A review of the safety experience of the system.
4. A review of the Capital and Operating and Maintenance (O&M) costs from a life cycle cost point of view.

Extensive AIRTRANS operational data were made available to TSC for analysis, and from these were derived the charts, figures, and conclusions of Section 3.

The project leader at TSC was C.W. Watt, who is also responsible for writing most of Sections 2 and 3. Dennis Elliott, formerly director of engineering at the Dallas-Fort Worth Airport, was an invaluable source of information on the system changes. In addition, he extracted all the raw data from the system logs and maintenance records, and he wrote portions of Sections 2 and 3.

Daniel Dunoyé of the IRT was responsible for and wrote Section 4, Operational Safety, during a visit to TSC in August 1977.

Thomas Dooley, of TSC, prepared Section 5, Costs, from raw data supplied by the Airport Board.

Special thanks are due to Betty Kwok of TSC Code 231. She devised the sampling plan used in selecting reliability and maintainability data for analysis and was responsible for all the processing of the resulting data. Her reports are included as Appendices B and C. Her assistance was essential. Thanks are also due to Harry Hill, of TSC, Code 532, who contributed to Section 2, and to Ron Kangas, of TSC, Code 723, who wrote Appendices D and I.

Photographs of the AIRTRANS system that are incorporated in this report were provided through the courtesy of the Vought Aircraft Corportation, Dallas, Texas.

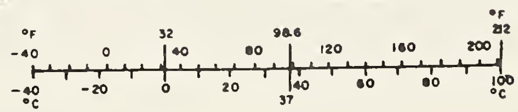
METRIC CONVERSION FACTORS

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	35	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



CONTENTS

CONTENTS (CONTINUED)

CONTENTS (CONTINUED)

CONTENTS (CONTINUED)

CONTENTS (CONTINUED)

CONTENTS (CONTINUED)

LIST OF TABLES

LIST OF TABLES

LIST OF TABLES

LIST OF TABLES (CONTINUED)

LIST OF TABLES (CONTINUED)

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (CONTINUED)

LIST OF ILLUSTRATIONS (CONTINUED)

AIRTRANS PHASE II ASSESSMENT
EXECUTIVE SUMMARY

This report continues the assessment of the AIRTRANS people mover system at the Dallas-Fort Worth Airport. It begins by describing the changes in the systems configuration that have taken place during the three years since the publication of the Phase I report in September of 1976. It then reviews the reliability, availability, maintenance, and operational safety history of the system during its entire life. The report concludes with an analysis of both Capital and Operational and Maintenance (O&M) costs.

The UMTA AGT Socio-Economic Research Program has sponsored during the past three years a series of assessments of existing domestic and foreign automated guideway transit (AGT) systems. The AIRTRANS Phase I report was the first of these to be published, and by the fall of 1978, nine others had been performed and documented. These reports included Jetrail, Cabinentaxi (in Germany), Morgantown, SeaTac, Tampa, Fairlane, Houston, Disney World, and King's Dominion systems. Several others are planned or in progress. In addition a technical description of the French VAL system has been published.

The purposes of the assessments are to provide users and designers of AGT systems with information on the operational experience of existing systems and to pass on to them some lessons learned, both on what has been successful and what has not.

AIRTRANS is the largest AGT system in the nation. The Phase I AIRTRANS assessment report covered its genesis; the technical description of its vehicles and other subsystems; the management of the program; and an assessment of reliability and safety as they were specified and realized in the design. This Phase II report, covering more than two additional years of system life, describes a mature system with increased ridership, improved availability and reliability, and diminished operating costs.

The following extract from the Executive Summary of the Phase I report gives a brief but valid statement of the AIRTRANS system.

> "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...
>
> "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."

The system has seen no major physical changes during the years since the Phase I report was published. The addition of employee service to the revenue passenger service in February and March of 1976, doubled the total passenger ridership. The system still operates 24 hours per day, seven days per week, and in September of 1978 it carried its 20 millionth passenger. The mail and baggage services, however, have not been reactivated, and it does not seem likely that they will be. The supply service utilizes four of the 17 utility vehicles for approximately seven hours per day; one utility vehicle was used by Vought as a test bed for system improvements under the AIRTRANS Urban Technology Program (AUTP); and the 12 others are in storage.

Several hardware changes have been made, yielding a more reliable system and reducing system restore times after malfunctions. These changes include:

- Computer redundancy in Central Control, which was completed just over two years ago and has worked well.
- "Speed broach" malfunctions - any violation of a commanded speed anywhere in the system - normally caused a vehicle to stop, and required a rover to go to the vehicle to restart it. With no decrease in safety, most of these malfunctions have now been made resettable from Central Control, greatly reducing system restore time.
- Some unscheduled door openings were made remotely resettable.
- Station stopping accuracy was improved.
- Merge switch blades on the guideway were removed, reducing guidewheel wear and improving ride quality.
- Guideway traction was improved.
- The uninterruptable power supply for the central computer was simplified.
- A form of obstacle detection was tested successfully and is now scheduled for addition to all vehicles.

Some changes were made in maintenance and inspection practices Preventive maintenance has benefited from improved procedures, higher frequency, and greater consistency. Total maintenance personnel has dropped from 125 in 1975 to 86 in 1978. Maintenance personnel have gradually been trained to be less narrowly specialized than before and more able to do a variety of tasks. Several experiments have been run on tires, brakes, and air conditioning in attempts to reduce maintenance time and increase the length of trouble-free periods.

The AUTP, mentioned above, which was funded by a grant from UMTA to the Airport Board, has resulted in development of an improved vehicle capable of speeds of 30 mph, with added reduncancy and presumably higher reliability. In mid-1979, tests of this vehicle began on the AIRTRANS guideway. So far few of the improvements have been incorporated into the existing AIRTRANS system. Some improvements in snow and ice removal have been accepted for operational use, and some diagnostic techniques have been improved.

Four major areas not covered in the Phase I report are covered in some detail herein. They include availability, reliability maintenance, and operational safety. The first three areas were studied by using the analysis of a large sample of data from the AIRTRANS operational logs and maintenance records. The data were organized into six time periods corresponding to six phases of the system's life that were marked by some substantial operational or hardware change. Operational safety was studied by an analysis of the accident file kept by the Airport Board since January of 1976. Some noteworthy results are summarized below:

- System availability, using the official airport method of counting only outages requiring backup bus callout, has levelled off at about 0.985.
- Single vehicle reliability, as measured by Mean Time Between Malfunctions (MTBM) and counting only those malfunctions affecting movement and control (Classes 1 and 2), has increased from about 18 hours in 1975 to about 82 hours in late 1977.
- Overall system MTBM has increased from 0.45 hours to 1.8 hours.
- Mean duration of malfunctions, excluding outages, has been cut by 50 percent and has averaged 3.9 minutes per malfunction (for Classes 1 and 2) in 1977.

A detailed study covering a two-year period of component and subsystem reliability was possible when the maintenance shop records from Vought became available. The results, included in Section 3, show, for example, a classic case of reliability growth through design improvement. The Mean Miles Between Failures (MMBF) of the traction motors appears to have increased from a low of 20,000 miles in Period 1 to a nearly constant value of about 70,000 miles after design bugs had been corrected and the motors had been rebuilt. Tables are included in the report which cover most of the major vehicle and wayside components (Tables 3-9 and 3-10).

The Maintenance Records (MRs) were sampled using the same plan selected for the availablity data. It is important to note that there is little correlation between the numbers of malfunctions, derived from the logs, and the numbers of verified failures, derived from the MRs; in general, the count of the former far exceeds the count of the latter. This is reasonable because true failures are only a subset of total malfunctions. It has proven impossible in most cases to separate the malfunction data from the logs into "failures" and "other."

In the text the number of maintenance actions is distributed by kinds, i.e., remove and repair, reset, etc. - per period, as percents of each kind. The "not verified" category shrank, from 13.5 percent of all actions in Period 1 to less than 5 percent in Period 6, suggesting better diagnosis.

The number of maintenance actions is also distributed by problem areas or causes. Wearout gradually became a major factor, increasing from 6 percent of all actions in Period 1 to 22 percent in Period 6. Mean Time To Repair (MTTR) system elements in the shops was also derived from the data. Fifty-eight percent of the actions took one hour or less of maintenance time, and only 1 percent required over 10 hours of maintenance time.

In the area of safety, this report confines itself to an analysis of the operational safety of the system since it was first operated directly by the Airport Board on January of 1976. Since that time, an accident file has been maintained, and records of 58 accidents were made between January 19, 1976 and July 1, 1977. Six of these were related to passengers, and in only one (the collision of February 22, 1977) were there any injuries. Based on these six accidents and an average AIRTRANS passenger trip time of 10 minutes, a comparison of the AIRTRANS accident rate with that of other modes of transportation shows that it has a lower passenger accident rate than subways, passenger rail, or urban bus in terms of accidents per 10^9 passenger hours (see Table 4-1).

Extensive analysis of the capital and O&M costs have been made possible by the data from the Airport Board. This analysis should be useful to new system planners, because it is a realistic display of true costs of an operational AGT system. It was stated in the Phase I report that "capital and operations costs of new developments of this complexity are not precisely predictable until a substantial portion of the development has been completed." The analysis supplied in Section 5 of this report should be helpful to new planners in making better cost projections earlier in the development process.

A review of new lessons learned from this report is included in Section 6.2 and is summarized below. (The numbers in parentheses are the paragraph numbers in Section 6.2.)

Some of the conclusions of the Phase I report are repeated in Section 6.1 because they are still valid and are well stated. One major new lesson to be applied to future systems is the importance of a comprehensive and easy to use data system at the beginning of passenger operations. The data extraction for the reliability and availability section of this report was slow and costly, even though the data set used was only a sample. In future systems, better data can mean more rapid reliability growth and less costly maintenance.

As the Phase I summary concluded: "...the step to revenue operation is a large one, and its problems must not be underestimated." The Reliability and Maintenance (R&M) history presented here gives proof of this conclusion. Several recommendations are made to ensure that problems will be anticipated, planned for, and rapidly solved:

(6a) Before the system is built, the buyer and seller of a new system must agree on the definitions of failures and malfunctions.

(3,4,6b) Expect low reliability in the early stages of the new system's operation and allocate money and time to foster reliability growth. Early troubles should surprise no one.

(5,6c) Begin operations with a pre-planned R&M data collection system in place to expedite problem detection and diagnosis.

In addition, the following conclusions are drawn:

(1) New system ridership projections must be more realistic than those prepared for AIRTRANS before it was built.

(7) Safety rules for manual operation of automated systems must be established and enforced from the start of operations.

(8,9,10,11) Certain safety measures should be considered in all new systems: passenger warnings when a vehicle is about to accelerate from a station; protection of guideway, especially at-grade guideway, from motor vehicle intrusion; performance of safety analyses of a new system during the design phase; development and inclusion of obstacle detection in an AGT system to protect automatic vehicles from collision with foreign objects in the guideway.

(12,13) In any new system a determined effort should be made to find and eliminate the causes of all malfunctions.

(14) Be very cautious about requiring that any system has multi-use capability. If it is expected to carry freight, mail, trash, or provide other usages in addition to full passenger service, it is probable that it will not do any of the functions very well.

(15,16,17) The methodology presented in Section 5.7 will enable planners to make better estimates of new system costs. These methods are derived from the extensive AIRTRANS cost data cited in Section 5 and Appendices K and L.

1. INTRODUCTION

The design and early performance of the AIRTRANS system at the Dallas-Fort Worth Airport was fully assessed in the Phase I report[1], entitled "Assessment of Operational Automated Guideway Systems - AIRTRANS (Phase I)." This report was issued by the Transportation Systems Center in September of 1976. The second assessment of the system is presented in this report. It covers system changes made during a two-year period (Section 2); the system's reliability and availability history; how configuration changes affected reliability and availability (Section 3); operational safety history (Section 4); and an analysis of system costs involving capital and operational and maintenance costs (O&M) (Section 5).

1.1 PURPOSES OF ASSESSMENTS

Assessments help establish the state-of-the-art as it is reflected in existing systems; record lessons learned from past experience; make it easier for system planners to understand realistic systems operations; and help system and equipment designers avoid repetitive mistakes. The criteria for choosing the kinds of experience that will be meaningful and helpful to the users of the assessment reports must therefore be establised at the outset of the assessment.

Experiences of one system must be "transferable" to another system to warrant discussion in an assessment report. "Transferable" experience is all experience that describes successful approaches, methods, technology, or procedures, or records any design or operational practices that have led to failures or inadequate system operation. Too much space devoted to details of harware construction, system characteristics that were peculiar to the site, etc., may obscure more important experiences of wider applicability that should be highlighted.

1.2 SCOPE OF ASSESSMENTS

Some examples of the answers an operating system assessment might provide for system planners are contained in the following list of AIRTRANS facts and descriptions.

- The Systems Development Process (Phase I report)
- Availability of System Being Assessed - Is availability clearly defined. Why is it high or low? Is it adequate? How can it be improved? (Phase II report)
- Mean Time Needed to Restore System from Unexpected Malfunctions - Is it small enough? How is it achieved? How can it be improved? (Phase II)
- Clear Definitions of Failures or Malfunctions. (Phase II)
- Reliability and Maintainability of All Components and Subsystems - What are the MTBFs and MTTRs of the parts used? Which should be avoided? Which should be reused? (Phase II)
- Descriptions and Evaluation of Non-Site Peculiar Hardware - Detail particular operational problems resulting from design defects or successes resulting from good design. (Both reports)
- Hardware and Software Problems Met and Overcome - Discuss material, environmental, and component problems. Examine problems of flammability, traction, temperature, humidity, rain, snow, and ice, and how they were overcome. (Both)
- Human Factors Questions - Effectiveness of signage, aesthetics, functionalism, maintainability, and human safety should be discussed.
- Capital Costs and Operating and Maintenance Costs - Detail methods of reducing costs or give reasons for their magnitude. (Phase II)
- System Safety Analyses Attempted - Describe effectiveness of methods used and safety standards achieved. (Phase I)
- Operational Procedures and Training (Phase I)
- Effectiveness of Maintenance (Phase II)

1.3 SYNOPSIS OF AIRTRANS - HISTORY AND DESCRIPTION

Early in the planning for the Dallas-Fort Worth Airport (D-FW) (1968), it was recognized that an efficient transportation system would be required to tie the widely separated terminals together as an integrated facility. Feasibility studies indicated that an automated system would be superior to conventional equipment such as buses and trucks. Based on these studies, the airport's Board of Directors decided to install an automated transportation system to carry passengers and cargo between the terminals and other airport facilities. The responsibility for implementing this decision rested with the board's engineering staff. Thus, in July of 1971, after completing the necessary preliminary engineering and receiving competitive bids, the Airport Board awarded a contract for the design, construction and testing of AIRTRANS to LTV Aerospace Corporation (now the Vought Corportation). The amount of this contract was $34 million. Subsequent contract additions caused the final system price to be $41 million.

A diagram of the AIRTRANS guideway network is shown in Figure 1-1. The guideway has two main lines running north and south through the passenger terminal complex, with loop guideways circling through each terminal building and the two remote parking lots. The total length of the guideway is 13 miles, and it extends over a straight-line distance of 3 miles.

The AIRTRANS vehicles travel over this guideway on dedicated routes by switching at predetermined systems locations. There are five routes for passengers; four for employees; and two for supply services.

Figure 1-2 shows an AIRTRANS train in service at D-FW. There are a total of 51 vehicles of this type in the AIRTRANS fleet. The vehicles operate either singly or as two-car trains. There are also 17 utility (or cargo) vehicles, as shown in Figure 1-3. This particular utility vehicle carries food and other supplies from a remote warehouse to the airport terminal buildings.

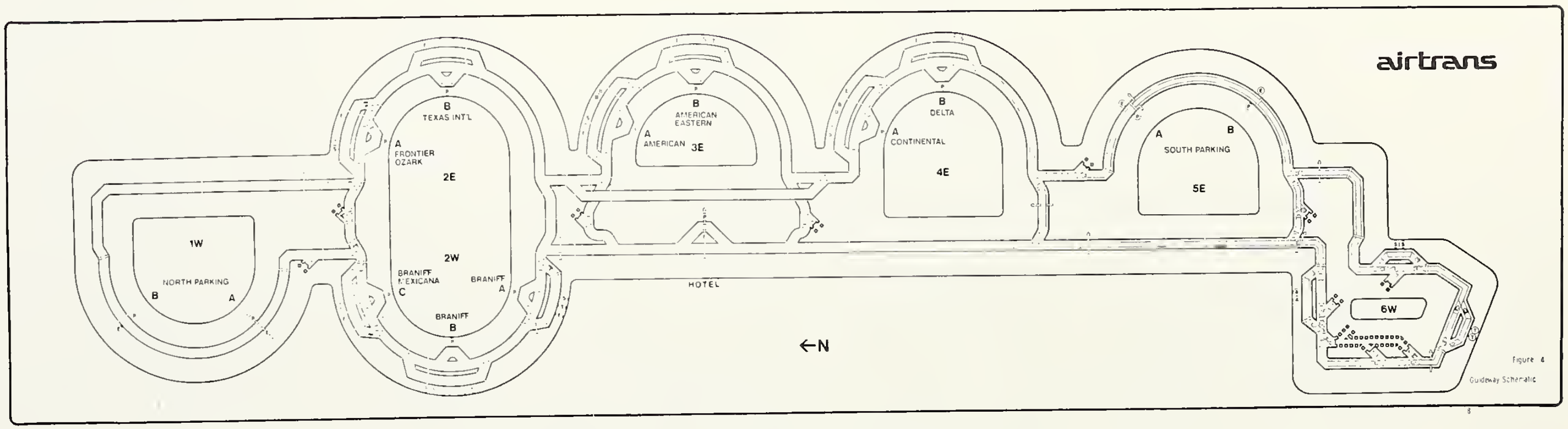


FIGURE 1-1. DIAGRAM OF THE AIRTRANS GUIDEWAY NETWORK

FIGURE 1-2. AIRTRANS TRAIN IN SERVICE AT D-FW.

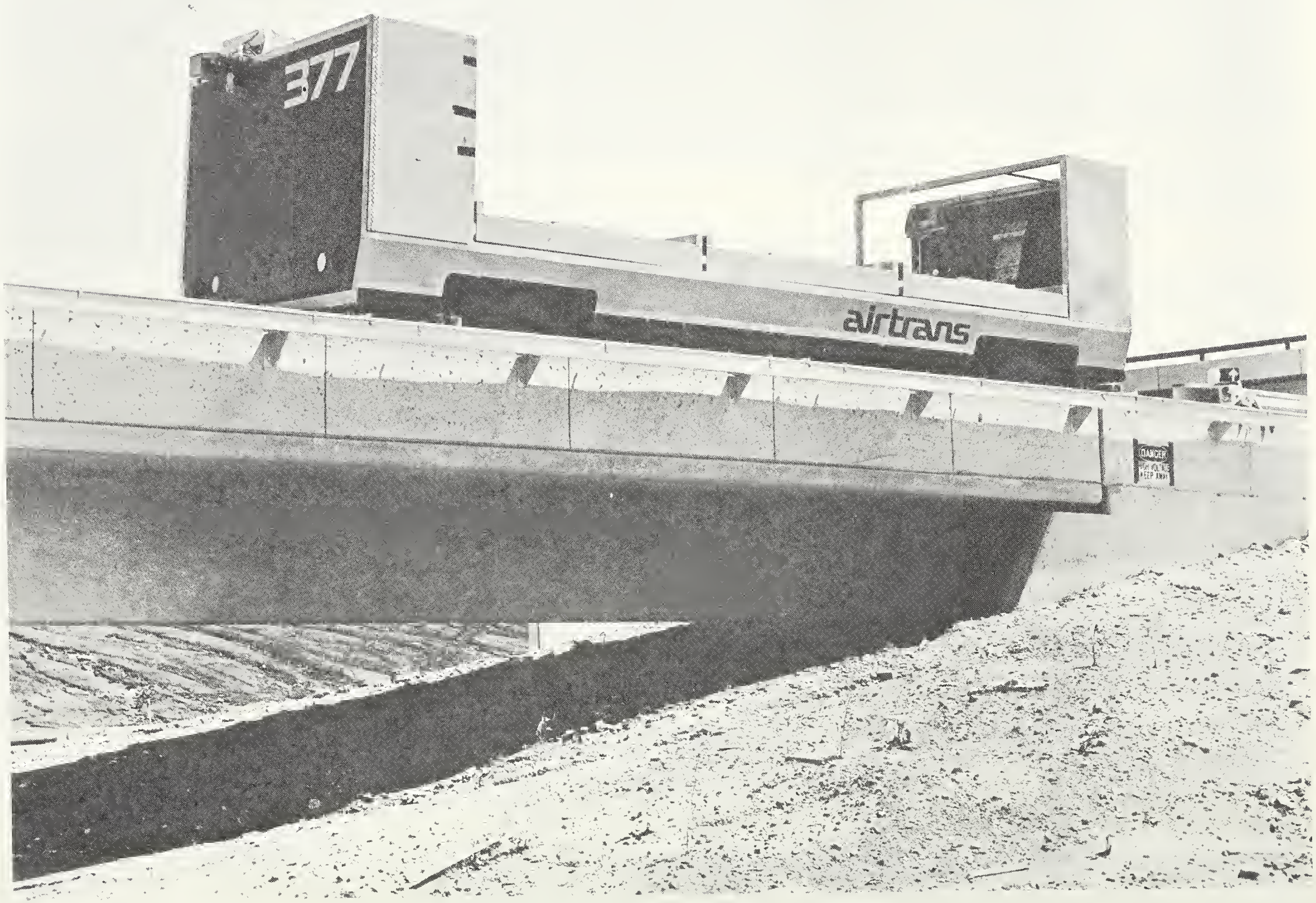


FIGURE 1-3. UTILITY OR CARGO VEHICLE.

The AIRTRANS passenger vehicles are 21 feet long, 7 feet wide, and 10 feet high. Passengers enter and leave the vehicles through side-opening, automatic doors. In addition, there are also emergency exit doors on each end of the vehicles. Inside, the passenger vehicles feature upholstered seats for 16 people and standing room for up to 24 more, for a 40-passenger capacity. On each corner of the vehicles are copper/graphite brushes which run on the wayside rails to collect power for propulsion and signals for vehicle control. The 480 Vac power is rectified on board each vehicle and fed to a 60 hp motor which drives the vehicle through a commercial truck differential. The vehicle's heating, air conditioning, and air supply systems also use AC power. In operation, the nominal maximum vehicle speed is 17 mph, and the minimum headway between vehicles is 18 seconds. The average headway is approximately 30 seconds.

The AIRTRANS guideway consists of a reinforced concrete running surface with concrete parapet walls on both sides. Ten miles of AIRTRANS guideway are at grade, and three miles are elevated on precast prestressed bridges. The horizontal running surface of the guideway supports the vehicles, while the parapet walls provide guidance, power rail support, and mounting for the switches.

The stations in the AIRTRANS system are located off-line along the guideway. The passenger stations feature a glass-enclosed waiting platform, with automatic bi-parting doors that open simultaneously with the vehicle doors. Entrance to the stations is gained by depositing a quarter (25¢) in the turnstiles. Inside the stations, a sign and map explain how to use AIRTRANS. As different vehicles arrive, their destinations are automatically displayed on lighted, color-coded signs above the boarding doors.

AIRTRANS is a fully automatic transportation system. There are no drivers or attendants on any of the vehicles. The nerve center of AIRTRANS is the Central Control facility, where the system is constantly monitored by Airport personnel. (See Figure

1-4). Here, the location and status of all vehicles is continuously displayed on a lighted schematic of the guideway. Using the console, the Central Control operators can alter the programmed operation of the system at any time. In addition, the Central Control operators have radio communications with all vehicles and can watch all of the stations on closed circuit television.

The AIRTRANS Central Control facility is also the heart of the failure management activities that are part of the regular AIRTRANS operation. Through the use of on-board sensors, the major components on all of the vehicles are constantly monitored for proper operation, and sensors also monitor wayside equipment.

In the event of any equipment malfunction, the abnormal condition is immediately displayed at Central Control by a color change (green to red) on the schematic system diagram. Simultaneously, the malfunction is displayed on a malfunction register located on the control console. This register tells the Central Control operators exactly what the malfunction is. If necessary, supplementary information is also displayed on the console's video screen.

In many locations in the AIRTRANS system, a malfunction will impede train movements until it is cleared. Accordingly, quick remedy of all malfunctions is essential to good service. Thus, the first step in clearing a reported malfunction is for the Central Control operator to attempt to "reset" the failed component to an operating mode. This is accomplished by sending a "reset" command to the affected vehicle (or wayside equipment), using the command console. If the malfunction was triggered by some temporary condition which has since cleared, the vehicle will automatically reset itself and proceed with no manual intervention. Most malfunctions in the AIRTRANS system are cleared in this way with only a minute or two delay.

Sometimes, when a malfunction cannot be reset from Central, it is necessary to dispatch by radio a roving maintenance man

FIGURE 1-4. AIRTRANS MIMIC BOARD AND CONTROL CONSOLE

to attend to the vehicle. Often, the "rover" can reset the vehicle on-board. Occasionally, in the case of a "hard failure" of some on-board equipment, it becomes necessary to manually drive the vehicle to clear the guideway. In very rare circumstances (such as a burned-out propulsion motor, motor controller, or a locked axle), it becomes necessary to tow the stalled vehicle from the guideway using aircraft-type tugs especially adapted for this purpose.

The above-described failure management system works well. The success of AIRTRANS is largely a result of this sophisticated and effective response to failure conditions as will be shown by statistics later in this report.

The AIRTRANS system has been in service at D-FW since January of 1974. Through December 1978, the system has accumulated over 17 million vehicle miles and carried over 22 million riders. AIRTRANS normally operates 24 hours per day, seven days a week. Since its opening, it has achieved an excellent system availability record.

Figure 1-5 shows an aerial view of the Dallas-Fort Worth Airport.

The recent Advanced Urban Technology Program (AUTP) included AIRTRANS vehicle improvement, and its Phase I is described in Appendix I. Phase II of the AUTP program has produced one prototype of an improved AIRTRANS vehicle, which includes the following features: on-board microprocessor control, higher speed (30 mph) redundant propulsion motors, doors on both sides of the vehicle, regenerative braking, improved signal and power collectors, on-board dynamic graphics and TV monitoring, automatic mechanical couplers, a more reliable audio announcement unit, and others, all of which should lead to a more trouble-free system and lower O&M costs. Tests of the vehicle on the AIRTRANS guideway began in July of 1979.

Plans are now (mid-1979) being developed for expansion of the airport in the next few years. It is expected that the AIRTRANS system will expand along with it, to service the new terminals to

FIGURE 1-5. AN AERIAL VIEW OF THE DALLAS-FORT WORTH AIRPORT

be built. What this will require in terms of additional guideway and vehicles has not yet been determined.

2. STATUS OF SYSTEM AT THE END OF ASSESSMENT

By July 1, 1979, the system had expanded its services beyond the level described in the Phase I report. This expansion of service has brought the system close to providing the passenger services originally planned, but the utility services are not as extensive as had been planned

2.1 SUMMARY OF CHARACTERISTICS

2.1.1 Physical Characteristics

Table 2-1 describes the current AIRTRANS system in summary form. It is similar to Table 2-1 in the Phase I report, with minor update changes. The physical characteristics of the system are almost as they were in 1975.

2.1.2 Routes and Route Loading

The revenue passenger routes as shown in Figure 2-1 remain the same as in 1975. The employee routes, however, have been added as shown in Figure 2-2. Baggage and mail routes are not yet in service, and the plans for these are incomplete. Therefore, no route diagram is included here. Figure 2-3 is a diagram of the supply route.

Routes of both revenue passenger and employee trains are identified in Table 2-2. The number of cars in each train and the nominal headway for each of the five passenger routes and the four employee routes as of July 7, 1977 are shown in this chart.

2.1.3 Ridership Characteristics

The ridership history, shown tabularly in Table 2-3 and graphically in Figure 2-4, clearly indicates the increase in employee traffic.

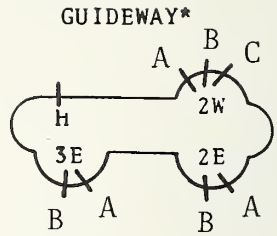
TABLE 2-1. AIRTRANS PRINCIPAL CHARACTERISTICS

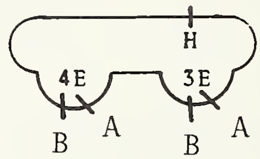
Length of concrete guideway	13 miles (single lane) 80% at grade, 20% elevated	
Passenger stations	14 (10 off-line, 4 on-line)	
Employee stations	14 (10 off-line, 4 on-line)	
Utility stations	25	
	ORIGINALLY	CURRENTLY
Lead Passenger vehicles	28	31
Trail passenger vehicles	23	20
Utility vehicles	4 operative, 12 in-storage. 1 test	
Switches	33 diverge and 38 merge	
Control blocks	708	
Operating speed (max.)	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	20 min. (inter-terminal) 30 min. to remote lots	
Vehicle seating capacity	16	
Vehicle crush capacity	40	
Vehicle diagnostic checkout time in placing vehicle into automatic mode after power removal (performed in maintenance area only)	approx. 10-20 min.	

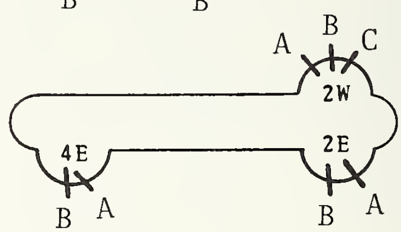
TABLE 2-1. AIRTRANS PRINCIPAL CHARACTERISTICS (Continued)

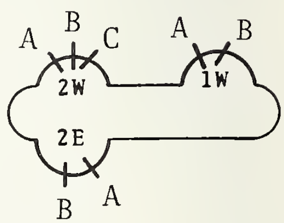
Central control computers	1 - (2 computers used one at a time - one backup)
Terminal process computers	5 - (non-redundant. 1 backup for 4)
Revenue passenger routes	5
Employee routes	4 (1 for each of 4 terminals)
Average riders per day	18,000
Average vehicle miles per day	8,400
Station stops per day	16,300
Switch calls per day	67,000
Voice communication with one or all passenger vehicles. TV surveillance in passenger and employee station areas only. Automatic wash facility for vehicles.	
Vehicle Size	H = 10 ft W = 7 ft L = 21 ft
Weight, passenger vehicle Weight, utility vehicle	14,000 pounds (empty) 10,000 pounds (empty)
Propulsion Power	480V, 3ϕ, 60 hz

Color Coded Route No.	Areas Served		
Yellow - 1	Braniff	(BN)	2W
	Texas International	(TI)	2E
	Ozark	(OZ)	2E
	American	(AA)	3E
	Eastern	(EA)	3E
	Hotel	(H)	
Orange - 2	Delta	(DA)	4E
	Continental	(CA)	4E
	American	(AA)	3E
	Eastern	(EA)	3E
	Hotel	(H)	
Green - 3	Delta	(DA)	4E
	Continental	(CA)	4E
	Texas International	(TI)	2E
	Frontier	(FA)	2E
	Ozark	(OZ)	2E
	Arkansas	(AR)	2E
	Braniff	(BN)	2W
Red-4	North Parking	(NP)	1W
	Braniff	(BN)	2W
	Texas International	(TI)	2E
	Frontier	(FA)	2E
	Ozark	(OZ)	2E
Blue-5	South Parking	(SP)	5E
	Delta	(DA)	4E
	Continental	(CA)	4E
	American	(AA)	3E
	Eastern	(EA)	3E
	Hotel	(H)	









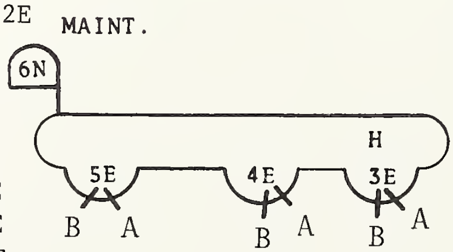
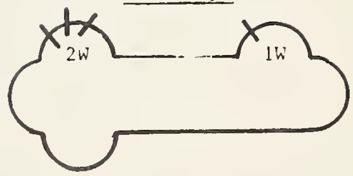
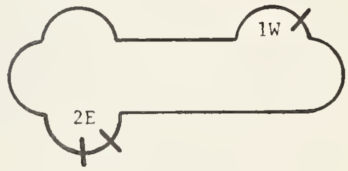
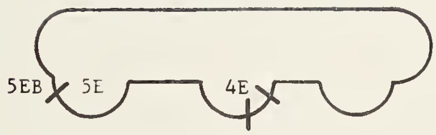
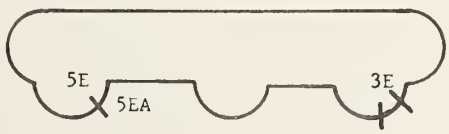
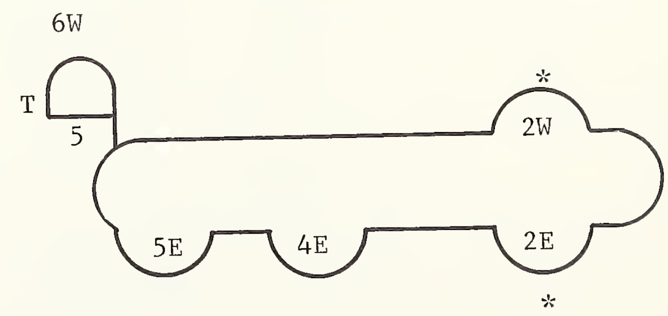
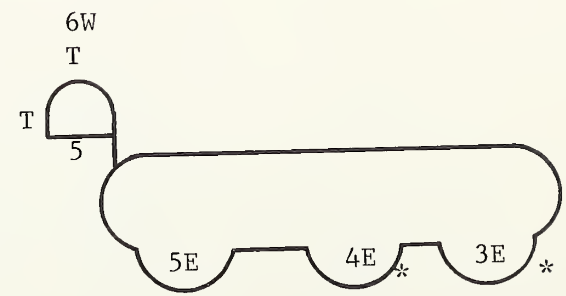


FIGURE 2-1. AIRTRANS REVENUE PASSENGER ROUTES

Route No.	Route	Guideways
26	North parking to Braniff (1W to 2W)	
27	North parking to Texas Intl., (1W to 2E)	
35	South parking to Delta and Continental (5E to 4E)	
37	South parking to American and Eastern (5E to 3E)	

Employee vehicle stations are opposite revenue passenger stations.

FIGURE 2-2. AIRTRANS EMPLOYEE PASSENGER ROUTES

No. of Routes	Type	Guideways
1	Supply	
1	Supply	

* Denotes station stop.

FIGURE 2-3. AIRTRANS UTILITY ROUTES

TABLE 2-2. PASSENGER/EMPLOYEE TRAIN ROUTES

Passenger Routes	Off-Peak Hours (0600 - 0800) Trains	Headways	Peak Hours (0800 - 2300) Trains	Headways**	Night Hours (2300 - 0600) Trains	Headways
Yellow - 1*	3	6	4	5	1	18
Orange - 2	2	7	2	7	1	14
Green - 3*	3	7	4	5	1	20
Red - 4	2	9	2	9	1	18
Blue - 6	2	10	2	10	2	20
Employee Routes	**20 Hours/Day (0400 - 2400) Trains**	**Headways**			**4 Hours/Day (2400 - 0400) Trains**	**Headways**
2W - 26*	3	5			1	16
2E - 27	2	7			1	14
4E - 35	3	6			1	18
3E - 37*	3	6			2	9

*Two-Car Trains.

**All Headways in Minutes.

TABLE 2-3. PASSENGER/EMPLOYEE RIDERSHIP

(In Thousands of Trips per Month)

Month	1974	1975	1976	1977	1978
Jan.	171	201	69	456	471.0
Feb.	225	160	158	467	434.0
March	299	134	287*	549	585.0
April	259	195	505	511	433.0
May	236	217	494	490	445.0
June	296	241	548	556	473.0
July	302	255	558	498	510.0
Aug.	320	237	535	614	513.5
Sep.	246	199	503	488	502.0
Oct.	349	Shutdown	475	458	557.0
Nov.	207	Shutdown	496	493	542.0
Dec.	220	Shutdown	538	499	492.9

*Employee service instituted March 1976.

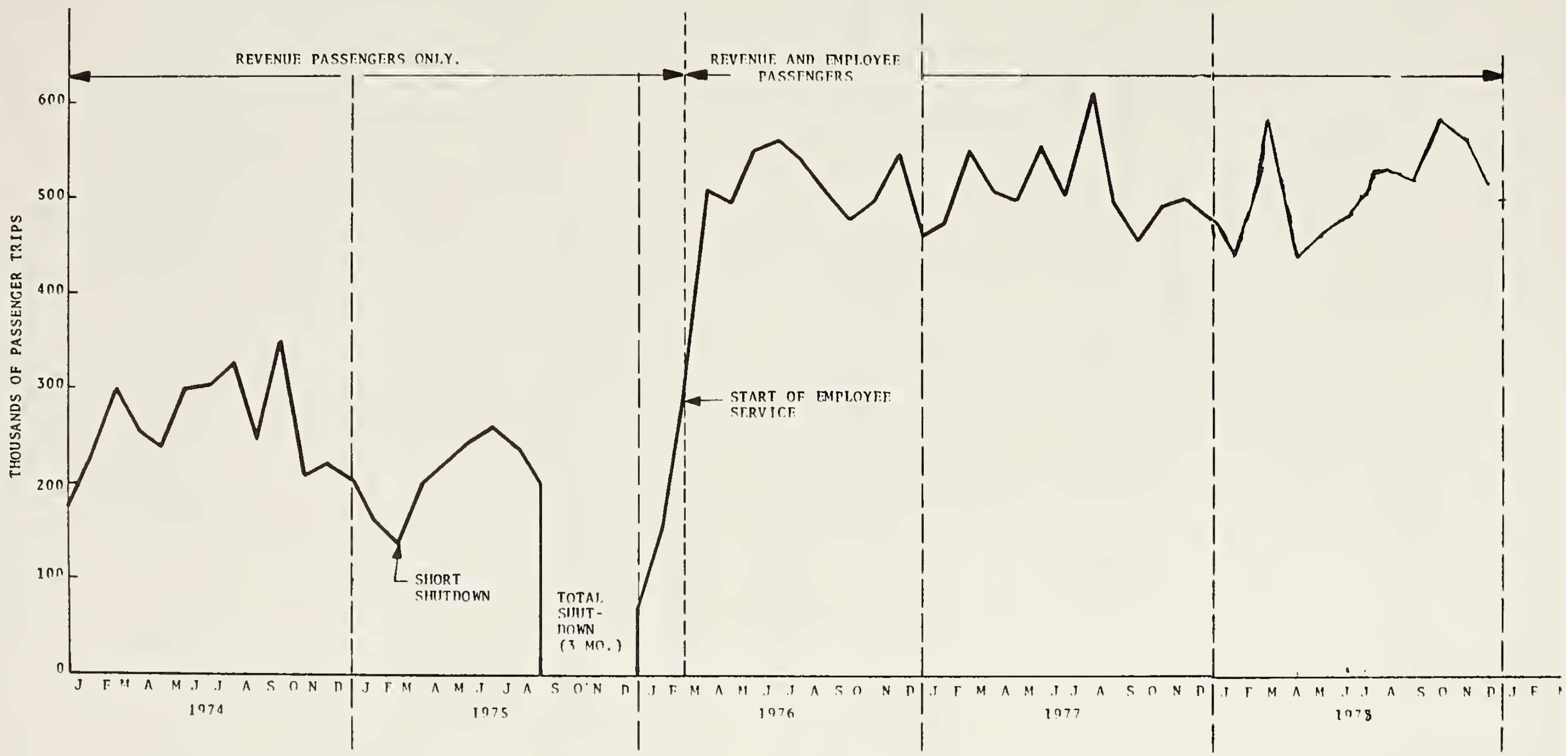


FIGURE 2-4. RIDERSHIP - 1974-1977

An interesting illustration of one of the risks inherent in planning new AGT systems becomes visible when these actual ridership figures are compared with an early prediction of ridership and costs.

A financial study was made in 1970 comparing AGT and buses as a Dallas-Fort Worth internal transportation system.[2] It predicted a daily AGT ridership of about 72,000 for 1975. The actual daily ridership for 1975 was only about 7,000, and it later reached 17,000 in 1977. The predicted income was $6.1 million for 1975, while the actual income for 1977 was only approximately $1.5 million. Predicted operating and maintenance costs were about $2.0 million in 1975; actual costs in 1977 were about $6.4 million.

It is clear that for future systems planning, cost predictions must use conservative values of ridership and include generous contingencies for startup, backup systems, early life troubles, and maintenance; they must use realistic figures for general inflation of wages, power costs, etc.

2.2 MAJOR SERVICE CHANGES

2.2.1 Addition of Employee Services - History

It was mentioned in the Phase I report that dedicated routes for employees would be put into effect in March 1976, and would significantly improve the trip times between the employee parking lots and duty stations. The methods used to accomplish this resumption of service and the results of the work are discussed in this section.

The original plan for employee service on AIRTRANS had assumed that the vehicles could be used interchangeably by revenue passengers and employees. The vehicles have doors on one side only and the employee stations are on the opposite side of the guideway from the revenue stations. Therefore when vehicles were changed from revenue passenger to employee service, they were removed from the guideway, decoupled, individually reversed, and recoupled before assigning them to employees. Each employee train made all stops, so that any employee at the parking lot could use any train to get to his duty station. This "local" service proved to be unsatisfactory because an employee's transit time to his work place was deemed too long due to long routes and many stops. As a result the employee service shut down soon after startup (June 1974).

After June 1974, employee service was provided by buses from the parking lots to the terminals and other work places. In March and April, 1976, however, a revised plan of AIRTRANS operation was put into effect that seems to be satisfactory to the workers and has eliminated the need for employee buses. A table comparing the employee transit time on buses and present transit times on AIRTRANS is shown in Table 2-4.

2.2.2 How the Employee Transport Problem Was Solved[4]

A plan, developed by the Airport Board staff early in 1976, was presented to the airlines early that year. It provided for some vehicles to be permanently assigned to employee use. In addition, each of the four terminals would be served with dedicated nonstop service from one of the two parking lots. Two things were done to accomplish this: three trail vehicles were converted to lead vehicles by modifying their on-board electronics, giving an effective net increase of three trains in the useable fleet; and the employee station stopping sequence was modified so that both two-car trains could be simultaneously loaded or unloaded.

2.2.2.1 Vehicle Conversion - This permitted the permanent assignment of a separate fleet of vehicles to the two groups of riders (the revenue passengers and the employees) while still providing a good spare vehicle backup for both services. The actual train distribution before and after this modification is as follows:

TABLE 2-4. COMPARISON OF AIRTRANS AND BUS TRANSIT TIMES

EMPLOYEES OF	BEST BUS SERVICE *		BEST AIRTRANS SERVICE **	
	TO TERMINAL	TO PKG.	TO TERMINAL	TO PKG.
BRANIFF (2W)	10	10	6.8	14.7
TI, FRONTIER OZARK (2E)	11.3	11.3	11.8	11.7
AMERICAN (3E)	13.3	13.3	10.5	18.4
DELTA	11.3	11.3	8.1	19.2

* Bus times taken from Historical Records - are approximate.

** AIRTRANS times taken from actual service.

	Train Assignments	
	Passenger/Spares	Employee/Spares
Before modification	13/2	11/2
After modification	14/2	12/3

The above distribution permits the assignment of employee trains for dedicated service to be as follows (see Table 2-2 for route headways):

Between work area 2W and parking lot 3, two-car trains
Between work area 3E and parking lot 3, two-car trains
Between work area 4E and parking lot 3, one-car trains
Between work area 2E and parking lot 2, one-car trains

2.2.2.2 Station Stopping - As originally designed, two-car trains in employee stations were stopped such that only one car at a time could open its doors, and time consuming train jogging was needed. Stopping locations were modified so that the doors of both cars can now be opened at the same time. This modification started before the proposal for revised employee trains was made, and required physical relocation of the signal rail in the employee stations. The station platforms were also enlarged.

The proposal was accepted by the Airlines, work on the stations was completed, and the three trail vehicles were converted by Vought. (GRS electronics packages were added to the trail vehicles that were converted.)

Thereafter, one terminal a week was transferred to AIRTRANS service, providing express service to the four work areas named above in the table. Only FAA and hotel employees do not use AIRTRANS because they park nearby in the hotel parking lot.

2.2.3 Other Services

As of July 1, 1978, the only utility vehicles in use were still the four dedicated to the supply system from Dobbs House to the terminals. Two active vehicles are in use, with two available spares. Twelve utility vehicles are in storage, and one has been modified by Vought Corporation for use in the Urban Technology Test Program, financed by an UMTA grant to the Airport Board.

At present the supply service begins at 7 a.m., and runs 17 trips per day, taking 4-1/2 to 5 hours. It is planned to push back the starting time to 5:30 a.m. The entire supply service is now controlled as a package from software developed by the airport during the 1975 shutdown. Operation has been refined from the earliest period, but no basic changes have been made; details of the operation have simply been tailored more closely to the requirements of Dobbs House.

2.2.4 Station Attendants and Backup Bus Drivers

The Transportation Department of the D-FW Airport has a staff of 36 station attendants/backup bus drivers including five supervisors. Thirty of these personnel work on rotating shifts as follows:

	On duty	Reserve	Stations
2300-0700	4	2	4 only in B stations
0700-1500	8/9	4/3	8 or 9 in A, B & C stations
1500-2300	8/9	4/3	8 or 9 in A, B & C stations

The 31st individual fills in as required for vacation, sick leave and high demand situations. The five supervisors also rotate, with one on duty at all times. These personnel have three functions. Their primary function is as station attendants; the secondary is as emergency bus drivers; and the tertiary is as bus drivers in the event of a failure of the AIRTRANS system.

In the first instance, the station attendants were observed to be extremely busy aiding individual passengers in finding their way about the airport on the AIRTRANS system.

The station attendants become emergency bus drivers at the request of the airlines. There are two types of primary emergencies which require the use of one or more buses. One is when a flight is arriving too late for the passengers to make their flight connections via the AIRTRANS; a bus is dedicated to drive these passengers directly to the terminal of the connecting flight. Another situation when the station attendants are used as bus drivers is when a large charter group has to be transported between terminals. A sudden stressing of the AIRTRANS system is avoided by transporting such groups by a dedicated bus

When there is a failure of the AIRTRANS system, the station attendants become full time bus drivers. They place signs at the entrances and exits of the stations and at other strategic points in the area of the station and then drive buses to carry the passengers between the airline terminals. If the stoppage of the AIRTRANS is expected to be of short duration, the employees are carried on the same buses as the airline passengers. If the stoppage is expected to be of a long duration, as is sometimes the case when the airport experiences an ice storm, contract backup buses are also brought into service, and the employee and airline passenger services are segregated again.

The backup buses driven by the station attendants are started once each hour. This startup is to maintain the air pressure for the brake system. The station attendants are also responsible for noting any deficiencies in the buses such as soft or flat tires.

Failures of the AIRTRANS system which require the services of buses occur eight or nine times a month, for a total duration of between 6 and 14 hours. If a failure is more than five minutes in duration, the station attendants are alerted, and after nine minutes the buses are called out.

AIRTRANS will probably not dispense with the use of station attendants as backup bus drivers. In addition, while the signs in the stations for directing the passengers have been improved since the AIRTRANS Phase I report was completed, some passengers still have difficulty finding their way through the system. Hence, the assistance of the station attendants at AIRTRANS is still considered vital to good passenger service.

2.3 HARDWARE CHANGES

A number of changes have occurred which make the system more flexible and have reduced the number of malfunctions that shut the system down.

2.3.1 Central Control

2.3.1.1 Central Control Computer Redundancy - Until April 1976, the central computer consisted of one Modcomp III/15 with a 64,000 word storage. The design of the ATO/ATC system does not assign the central computer an active role in the moment-to-moment operation of the system. Its function is primarily system supervision and surveillance and includes establishing equal spacing between vehicles on the guideway by means of its debunching function, operation of the failure management system and the Central Control console, and operation of the public information system. Its failure degrades system surveillance but does not stop system operation, nor does its lack impair system safety, which is ensured by an entirely separate block system involving hard wiring and vital relays.

Prior to 1976 the central computer failed quite frequently introducing confusion into the system, so it was decided to make the central computer redundant, as is mentioned in the Phase I report. Two alternate methods were proposed. The lowest cost ($50,000) method was adopted, the so-called "Proposal B." A brief description follows.

Already extant in the AIRTRANS complex was a Modcomp II/25 system in Central Control, that had been acquired from LTV as part of the Vought/Airport Board Settlement; it had been used by Vought for operational software development. Another Modcomp

III/15 system was in use in the central utilities area. A single Modcomp III/15 existed in 6W, the AIRTRANS maintenance area, and was used for departure tests and TPU functions.

It was proposed to buy a second Modcomp II/25 computer, together with appropriate bus switches and other peripheral equipment, to allow load switching between the two Modcomp II/25 machines, and to install both units together at AIRTRANS Central Control. (Small software changes would be necessary.) The existing computer in Central Control would be used redundantly with the single Modcomp III/15 machine in the central utilities plant.

This proposal was implemented, and in April 1976 it went into operation. The AIRTRANS central computer system is today composed of two machines, computer A and computer B. At any one time one computer is standby. If one computer fails, the other can be switched on and takes its place within a few seconds; it receives current operating data from the wayside computers and takes over. All operating programs are maintained in both computers.

The result of this change was not a drastic one. (Refer to Appendix G.)

2.3.1.2 Change in Malfunction Classification - Two malfunctions, that previously were classified as Class I, required a rover to go to a vehicle and manually reset it. They have been made resettable from Central Control, thus eliminating many long delays without any sacrifice of safety, and a third condition requiring rover intervention has been removed.

a. Speed Broach. Normally, if the vehicle speed exceeds the established speed limit for any block, a "speed broach" signal is sent to the Central Control, and since this is a Class I malfunction, emergency brakes are applied and can only be removed by manual intervention by a rover. (See Table 2-5 for a restatement of malfunction classifications.) This malfunction has frequently occurred, and has several causes, such as the tachometer indicating

TABLE 2-5. MALFUNCTION CLASSIFICATIONS

Class I

An infraction of certain specific safe-operation criteria, indicating a condition of imminent danger to passengers and/or equipment:

a. Vehicle overspeed
b. Vehicle intrusion in a "captured" block
c. Unscheduled door opening
d. Brake failure.

Class II

A failure or malfunction of vehicle or wayside equipment which does not endanger passenger safety, but which causes an interruption or degradation in system revenue service. These are:

a. Propulsion motor trip
b. Rollback
c. Lead car of parted train
d. Illegal speed command (same indication for short stop in station)
e. All power breakers tripped
f. Power failure
g. Propulsion
h. Contactor failure
i. Low brake pressure
j. Dragging brakes
k. Door failure

Class III

A malfunction that does not endanger passenger safety nor interrupt nor degrade service, but it does cause inconvenience to passengers.

overspeed when the wheels are spinning in wet weather. Often, when a vehicle was manually reset after a speed broach, no cause for the malfunction could be discovered[5].

Two kinds of speed broaches are possible:

1. If a vehicle is in a block receiving a positive speed signal and if the indicated speed is in excess of the maximum speed for that block, a speed broach signal is sent to Central Control.

2. If any vehicle enters a zero-speed zone, a speed broach signal is sent to Central Control.

On the strength of system experience, a proposal was made by the AIRTRANS engineering staff. It recommended that the first type of broach, excess speed, should be resettable from Central Control. The proposal was reviewed by GRS for possible effects on system safety, was judged safe, and was implemented. The second type of speed broach, vehicle in a zero-speed block, is a direct violation of the safety system and cannot be changed. Hence, this type of Class I speed broach still exists as a possibility in the system, tripping emergency brakes and requiring the brakes to be reset manually.

The change was made early in 1976. A speed broach of the first type now applies to service brakes which cannot be released until the vehicle has stopped (irrevocable), and if the reset takes and the condition doesn't repeat, the speed broach is corrected in a few seconds by Central Control. If it repeats, it is treated as a Class I malfunction, and a rover is dispatched. A speed broach of the latter type is still a Class I failure and is not remotely resettable.

In Appendix G, a comparison of the number and duration of speed broaches is made. The duration per event was reduced from an average of five minutes during the first five months of the system to two minutes during the last nine months of 1976.

This change certainly makes the speed broach failure easier to cope with, and the passengers experience only a momentary delay.

What causes the large number of speed broaches is still not known, however; the cause should be tracked down and eliminated.

b. Unscheduled Door Opening. A second Class I malfunction is an unscheduled door opening. Under certain circumstances these are now remotely resettable from Central Control. An unscheduled opening of side doors only can be remotely reset, if the unscheduled opening takes place while the vehicle is properly berthed in a station. The causes of such "unscheduled door opening" stoppages could be:

1. A passenger trying to get out of the vehicle after the doors have closed in a station.
2. A passenger arriving just as a vehicle door closes. If he succeeds in opening it, an unscheduled door opening is reported.

Before the change was made, it was reviewed by General Railway Signal Company (GRS) for possible effects on safety, and the company concurred that safety would not be degraded. Since this change has been introduced, possible causes, such as those listed above, create insignificant delays, whereas prior to this change, each event of this type required manual intervention by a rover.

The modification required revision of the electronics of the vehicle control logic assembly on the vehicle and was done on contract to GRS.

c. Modification of AVO to Reduce "Bad" Station Stops and Reduce the Requirement for Rover Intervention[6]. At the same time that the speed broach modification was installed, GRS also modified the Automatic Vehicle Operation (AVO) logic to improve the consistency of the stopping accuracy of vehicles in stations. The modification did two quite separate things:

1. An AVO modification was prototyped by Vought and tried out in 1975 on two vehicles. This reduced the incidence of "bad" - long or short - stops sufficiently, and it was finally approved as a retrofit to all vehicles. The work was done by GRS and involved

a number of changes to the AVO electronics, both in the electronic packages and in the equipment wiring or backplane. The changes were completed in early 1977 and appear to have reduced bad stops and the incidence of non-alignment. Quoted figures are:

	Before AVO Mod.	July 1977
Station stops per day	16,000	16,000
Long or short stops per month	225 per month (or 7.5 per day)	40 per month (or 1.33 per day)

Details of these changes are not discussed here because they are peculiar to the AIRTRANS AVO and thus have no general application. This is, however, a good example of reliability improvement by a design change.

2. Normally, failures to berth vehicles properly in stations or failures of doors to operate when they should are considered Class II malfunctions, resettable from Central Control. In the original AVO system, however, no Class II malfunction could be reset in any vehicle that occupied the approach zone of a station. As a result each illegitimate stop demanded rover intervention. In early 1976, this was modified to allow Class II malfunctions to be reset no matter where they occurred. As a result rover intervention in stations has been drastically reduced, which, when coupled with the lower incidence of illegitimate stops, has made for noteworthy improvement in system operation. (See Section 4, Operational Safety, for further discussion.)

2.3.2 Vehicle

Except for the conversion of three trail vehicles to lead vehicles, mentioned earlier, the vehicle configuration in the revenue fleet has remained unchanged. Seats in the employee vehicles have been recovered in Naugahyde, a plastic covering considered to be more rugged than the upholstery in the passenger vehicles.

Some changes in the air conditioning were prototyped and tested on one of the vehicles. The airflow through the system was reversed, with intake air coming from the side of the vehicle and being exhausted under it. It was hoped that this would reduce dirt pickup and also help blow small debris off the guideway. At the time of publication of this report, it was clear that this change was not going to be successful, and it has not been made on the fleet.

Doors, brakes, steering, and propulsion have remained unchanged except for modifications in maintenance practice, to be discussed below.

2.3.3 Guideway

Some changes have been made to the guideways.

2.3.3.1 Traction Improvement - On the steeper grades of the guideway, crushed carborundum mixed with epoxy has been applied to the surface of the guideway and has greatly improved traction in wet weather. Steel radial tires will be used to provide further traction advantage.

2.3.3.2 Switch Simplification - The design of the switches used for merging and demerging has required that the vehicle guidewheels be entrapped for the entire length of the switch. However, for the trailing point (merging) switches, total entrapment is not necessary, as a merging vehicle has nowhere else to go but onto the common guideway. Nevertheless, in the switches installed for AIRTRANS, positive entrapment was provided to take care of the case where reverse motion under manual control might be necessary. In this situation, the switch would become a facing point switch, and the vehicle would have to be positively guided into one of the two directions.

Reverse manual action has never been done in actual practice, and the merge switch blades have now been removed. For 6 to 8 feet, during a merge, therefore, the switchwheels on the vehicle are not positively entrapped. The rationale for this change is two-fold: 1) the blades were wearing badly due to the action of the vehicles, because they are not powered and were being pushed aside by the merging vehicle; and 2) the impact of the guidewheels on the switch blade was reflected as lateral acceleration in the vehicles, degrading ride quality. An engineering safety analysis was done showing no impairment of safety as long as the vehicle was not operated in reverse. The result was a program of switch blade removal, which was accomplished in the spring of 1977. (See Appendix A for the effect of removal on guidebar forces.)

2.3.4 Electric Power Distribution

As described in Appendix A of the Phase I report, the substations feeding AIRTRANS are connected to alternate sources of power, giving the system a measure of power source redundancy. An additional precaution was taken in the original design of the Central Control system. The Central Control computer was supplied by an uninterruptable power supply (UPS) (rectifier, battery, automatic switch, and inverter) which would theoretically keep the computer operating with no interruption in the event of primary power failure.

From an operational viewpoint there seems to have been some inconsistency in the system thinking that provided this protection to the central computer only. This can be understood by remembering that the original AIRTRANS specification did not define a dispersed control system, such as resulted from Vought's design, but rather assumed that the central computer would be all important and hence must be invulnerable to short-term power outages.

In the system as designed, the wayside computers are, of course, much more important than the central computer in keeping the system operating. They are not protected with rapidly switched backups or UPS systems because the original specifications required the latter feature only in the central computer. In practice this specification was met, and the central computer is independent of the up or down condition of its own primary power feed.

In a future design, power source redundancy for all computers should be carefully considered, and a tradeoff made between its cost and complexity, and the function it would perform in keeping the entire system going.

From an overall system safety point of view, keeping the central computer and control console operating even if their prime power fails might be reasonable insurance against chaos in case of a partial power blackout. In such a situation the Central Control operators might be able to expedite rescue activities and direct an orderly egress of passengers from the stalled system.

In any event, at the time that the computers were made redundant, it was realized that the battery system did not have enough energy capacity. A different plan was devised. The UPS was removed and sold; the central computer emergency feed was tied to the diesel-electric generator already installed in the central utilities plant; and the inevitable few seconds delay between power failure and generator startup was accepted as a computer hiatus that was not serious. (Note that the Central Control Room is located in the central utilities building.)

2.4 MAINTENANCE AND INSPECTION CHANGES

Several changes in maintenance have occurred since the reopening of the system in January 1976. Preventive maintenance has increased with improved procedures, higher frequency, and greater consistency. Three shifts of maintenance still continue, but the three have different emphasis:

- First Shift (7 a.m. to 3:30 p.m.): Emphasis on guideway and electronic equipment preventive maintenance.

- Second Shift: Primarily unscheduled maintenance support for the system.

- Third Shift: Primarily guideway switches, and vehicle preventive maintenance and cleaning.

2.4.1 Organization

The transfer of the maintenance functions from LTV to the Airport Board after the 1975 shutdown eventually resulted in total reorganization of the AIRTRANS operation. The present structure is shown in Figure 2-5.

The Vought maintenance force was organized along skill lines; the Airport Board approach has been to encourage more diversification of the maintenance staff with less specialization. About 22 of the 88 people employed in 1977 were holdovers from Vought.

2.4.2 Maintenance Force

The number of people in the maintenance force exclusive of management dropped and then rose slightly to a 1978 level much below that of 1975, as shown below:

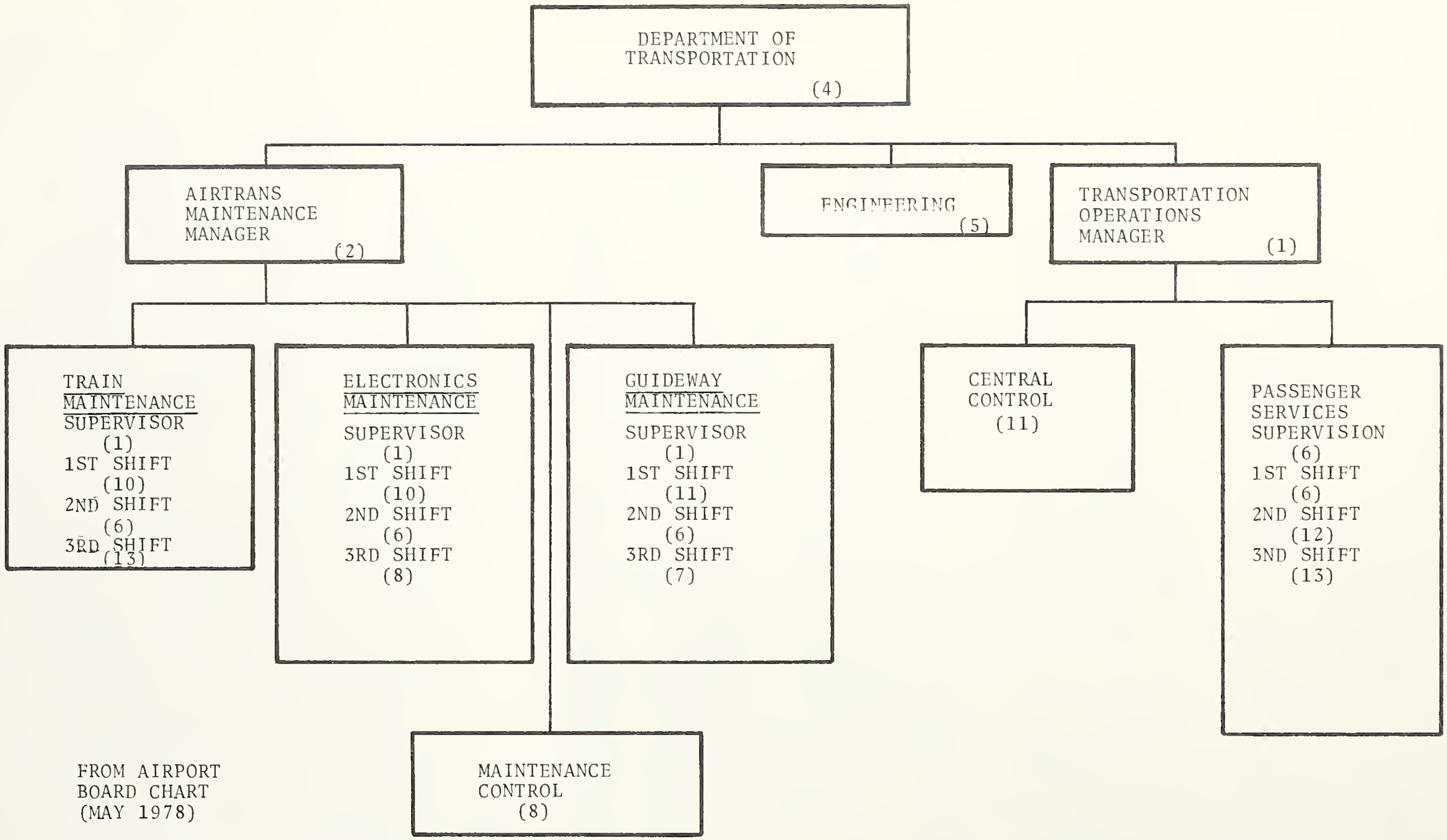
	1975	1976	1977	1977 (October)	1978 (May)
3 shifts	125	93	88	81 *	88
Central Control	3/shift	2/shift	2/shift	2/shift	2/shift

2.4.3 Rover Force

At the time of the Phase I report, there were six rover technicians on duty at all times. More recently the rover force regularly has been three persons plus a foremen.

The rovers are constantly on the alert for orders from Central Control requiring them to intervene in some situation. In addition, visual inspection of operating vehicles while in service is now done regularly from three different locations, so that all operating vehicles are observed at least twice a day. A 20-minute observation at each location gives daily visual inspection of all vehicles for obvious troubles, such as wobbly wheels, worn tires,

*Totals do not include Central Control operators.



FROM AIRPORT
BOARD CHART
(MAY 1978)

TOTAL PERSONNEL IN MAINTENANCE = 90

TOTAL PERSONNEL IN OPERATIONS = 49

AIRTRANS DEPARTMENT OF TRANSPORTATION ORGANIZATION

FIGURE 2-5. AIRTRANS ORGANIZATION AS OF MAY 1978 excess vibration, etc. In addition the rovers moving around the system constantly look for cans, bottles, etc., on the guideways, which are removed manually. The rovers normally travel around the system in pickup trucks, except when they must use a tug to remove a stalled vehicle. They also provide more maintanance services such as lubrication and touch up painting.

2.4.4 Preventive Maintenance

The performance of preventive maintenance has been put on a more regular basis than it was two years ago. In addition, the interval between maintenance actions is now based on miles travelled in most cases, rather than on hours lapsed. Only the air compressor and alternator and a few similar items are still checked on a time basis, for they operate constantly, whether the vehicle is in motion or not.

Each vehicle is given a limited inspection every 500 miles. Every 2500 miles each vehicle receives an inspection with more coverage. At 15,000 miles ("bi-monthly" inspection), 45,000 miles ("6-month" inspection), and 90,000 miles ("annual" inspection) even more complete inspections are performed.

2.4.5 Specific Maintenance Problems

2.4.5.1 Brakes - A determined effort to improve brake life has led to some interesting actions, which give promise of long-term improvement.

Normal wear rates are now being determined when matched sets of equally sized linings and drums are installed on vehicles. Temperatures of drums and linings are being monitored with an infrared probe, with the aim of making all four wheels on a vehicle operate at close to the same temperature; a condition that would exist if brake pressure of linings on drums were equal. It is expected that this will reduce corrective maintenance. The Dallas Transit System is cooperating with AIRTRANS in the preparation of matched sets of linings and drums for the vehicles.

The vehicles all have hub odometers, and the wheels are pulled every 10,000 miles to inspect for wear. During the brake equalization study, it was discovered that the non-driven axle brake wear was significantly different from the driven-axle brake wear. As a result, all brake maintenance is now being scheduled by axle instead of by wheel or by entire train. Also rivet holes in the linings were plugged with discs to reduce brake drum wear. The goal of this effort is to determine at what mileage the brakes should be routinely changed to prevent in-service failures.

2.4.5.2 Guideway

Rail Care. Communications rails in the station areas are now being burnished with an abrasive block every 30 days, and power and signal rails are periodically washed with high pressure water, which is delivered by a utility vehicle carrying a tank mounted on a removable pallet.

Guideway Cleaning. Rotary brushes mounted on a special trailer and towed by a utility vehicle are used for sweeping the guideway free of dust and light trash. As mentioned, rovers constantly scan the guideway for larger obstacles, and remove them manually when seen. There is no automatic obstacle detection in the system, although a few vehicles have been fitted with trip wires across the width of the vehicles in front. These serve as a simple but effective form of obstacle detection, in that they stop the vehicle when it hits debris on the guideways. (See Section 4 - Operational Safety for more detail.)

The test of the obstacle detection system was completed on July 5, 1978. Installation of the detection system on every operational train is planned in the near future.

2.4.5.3 Motors - Motor failure has been rare recently. At the time of sampling no failures had occurred in 2-1/2 months. Motor overhaul is now on an 18-month basis at which time the operating motor is removed and replaced with an overhauled spare. It should be more economical to replace a motor before it fails, than to let it run to failure. Costs bear out this intuition. On the average an overhaul of an unfailed motor costs $203, while repair of a failed motor costs $800.

2.4.5.4 Air Conditioning - Failures have been reduced by a program of periodic cleaning of the filters and condensor unit. They are now cleaned with steam and detergent every two months and are more thoroughly cleaned every six months.

2.4.5.5 Tires - A test program was started in 1977 with three sets of tires on three vehicles. One set was new; one set was recapped with normally used material; and a third set was recapped with material in which crushed walnut shells had been embedded.

The experiment on the latter has been completed, and it has been determined that these tires are not suitable for system use. An additional development in the tire experiments has resulted in achieving 60,000 miles of wear between retreads on a set of steel-belted radial tires, up from about 25,000 miles. These tires also have a significantly better tractive capability due to tread design. All tires used on the system in the future will be of this type.

2.4.5.6 Motor Brushes - The motor brushes are now inspected every 10,000 miles, and they usually require replacement at 30,000 miles.

2.4.5.7 Departure Testing - The full departure test, similar to that described in the Phase I report on page A-26, is performed on all vehicles every 10 days or 2500 miles. A new "mini-departure" test is performed on all vehicles that have been removed from the guideway for whatever reason, and consists only of assuring that the safety features of the vehicle are properly working.

2.4.5.8 Guideway Structure - No significant wear has occurred. Some original construction defects are being repaired by injecting epoxy into the beam and column connection of elevated guideway sections.

2.4.5.9 Power Collectors - Despite changes tested in the power collectors under the AIRTRANS Urban Technology Program (AUTP) (see Appendix I), the original power collectors are still in use. Two minor modifications have been able to extend the collector life to an acceptable level. Power type brushes are also now being used on the signal pickups.

2.4.5.10 Winterization - The experience of every winter since the airport opened has shown clearly that the present AIRTRANS system is completely vulnerable to winter ice storms. Freezing water coats the signal and power rails, and the whole system stops. Figure 3-8 (next section) shows the drastic dropoff in availability that results.

A number of attempts have been made to mitigate this problem. The latest one was developed under the above mentioned AUTP, and it consists of an advanced spray system designed by Vought. It uses hot ethylyne glycol sprayed onto the guideway under pressure, and is fan sprayed onto the power and signal rails along the sides.

In January 1979, three ice storms shut the system down for a period of eight days. The spray rig had failed mechanically in its first application, so that its usefulness still had to be tested. All doubts were resolved when a little later the sprayer worked as planned; the AIRTRANS management was pleased enough with its performance that a second rig was immediately ordered for future use. Optimism is high that these two spray rigs will substantially reduce downtime.

It must be realized that these devices, even when they work properly, are no real winterization solution; and Vought has gone on record as saying that the AIRTRANS system, as presently configured, will not be useful in severe winter weather. The spray rigs are only a palliative. Resulting side effects are untested, such as the long-term effect of elethylyne glycol on the guideway and on insulation. Use of the rigs requires follow-up washing of the power and signal rails with clean water.

At the moment, however, the promised improvement would be most welcome to the airport, and hopes remain high that it will succeed.

2.4.5.11 Other Fallout From AUTP - Diagnostic equipment designed for the AUTP test vehicle has been of use to AIRTRANS in two areas: 1) assessing loads on guideway walls; and 2) measuring signal strengths in real time.

3. RELIABILITY, AVAILABILITY, AND MAINTENANCE EXPERIENCE OF AIRTRANS

3.1 SCOPE OF RAM STUDY

In this section of the Phase II report the performance of the first three years of the AIRTRANS system's life will be analyzed and characterized in the areas of Reliability, Availability, and Maintainability (RAM). The data analyzed is only a 25 percent sample of the total data base available. This limitation was necessary because the total data base, all unanalyzed, was too massive to allow practical reduction. As will be shown in Appendix C, the statistical uncertainty introduced by the sampling is such that the performance of the system is quite accurately reflected in the performance during the sample days.

3.2 RECORDS

The investigations of AIRTRANS reliability and availability described in this report are all based on records that have been kept by the AIRTRANS operations and maintenance personnel, as a regular part of operating and maintaining the system.

3.2.1 Operational Data

It was necessary to collect general operational data about AIRTRANS. Thus, AIRTRANS management reports were researched to determine such things as scheduled hours of system operation versus actual hours of operation, types of services provided, the number of vehicles in service, system ridership, and number of maintenance personnel. This information was codified and entered on a report form devised for this purpose, and identified as "Report A-1: General Information" (see Figure 3-1).

3.2.2 Logs

Another source of information was the content of logs that have been routinely kept by the Central Control operators since the inception of revenue service. A sample of these logs is shown

AIRTRANS PHASE II ASSESSMENT

SYSTEM AVAILABILITY DATA

REPORT A-1: GENERAL INFORMATION

Date of Data 2-7-76
Sheet 1 of 1

Scheduled Hours of Operation	168
Actual Hours of Operation	165.5
System Availability (percent)	98.6
Revenue Services Provided	
Passenger	R
Employee	
Airmail	
Baggage	
Supply	R
Trash	
Vehicles in Operation	
Passenger	20
Cargo	2
Ridership	NA
Maintenance Personnel	

FIGURE 3-1. REPORT A-1: GENERAL INFORMATION

in Figure 3-2. Data from these logs were codified and entered on a second report, "Report A-2: On-System Malfunctions," shown in Figure 3-3. As is indicated by the report title, these data describe malfunctions that were observed "on the system" by the central operators in the course of their supervisory activities.

3.2.3 Maintenance Records

The source of information about maintenance and repair activities was the Maintenance Report (MR) forms that have always been used to schedule and document work by the AIRTRANS maintenance forces. A sample MR is shown in Figure 3-4. Data from the MRs were also codified and entered in a third report form, "A-3: Off-System Maintenance Actions" (see Figure 3-5).

3.2.4. Vought Records

Based on the AIRTRANS operators logs and maintenance reports, considerable raw information was gathered about system malfunctions and maintenance activities. In addition, however, it was desirable to obtain some insights into component reliability in the AIRTRANS system. To obtain this information, the manufacturer of the AIRTRANS system, the Vought Corporation, was asked to supply data from their computerized records about the performance of various components and sub-assemblies. These data were assembled by computer manipulation and printed out as the so-called "BADACTOR" report which will be discussed later.

3.2.5 Classes of Malfunctions

The original specifications of AIRTRANS seemed clear in defining system failures. This clarity turned out to be illusory when reliability testing for acceptance of the system from the contractor became important. Today, by a process of evolution, three classes of malfunctions have been agreed on, and almost all

AIRTRANS CENTRAL CONTROL LOG

DATE: 26 Dec

TEAM #

TIME	REMARKS
1400	TEAM #5 ON DUTY ASSUMING CONTROL 1418hrs
1407	SHORT 4 VEH. R/C 26 + R/C 37 ... PSS ADVISED. "SHAW/TAYLOR."
1514	PL 2·8 CLASS II "ISC" ... LTG 3 MIN DELAY
1533	EL27·19 - 3WHL01 - CLASS 1 "SB" - RESET OK.
1548	PROPER ROUTE LOADING ON R/C 37 PSS ADVISED
1600	PROPER " " " R/C 26 " "
1624	EL27·19 CLASS I SB 5ESL07 RESET OK.
1653	EL27·19 CLASS I USD' 3EBE 2TQ 4 MIN DELAY
1703	DOORS TAMPERED AT 2WCP FROM STATION PSS ADVISED FOR PSA COVERAGE ALSO R/C 37 SHORT 2 VEHICLES 1-2 CAR TRAIN.
1713	PSS REPORTS PSA PRESENT AT 2WCP, FOR TAMPERED DOORS
1722	PROPER ROUTE LOADING ON R/C 37, ALSO PSA NO LONGER REQUIRED AT 2WCP PSS ADVISED.
1729	PL5 82 CLASS I USD 4ESL06 4S POWER ZONE ISOLATED 6TQ 4 MIN. DELAY
1744	3EBP INOPERATIVE TURNSTILE REPORTED BY OPS. HERB. FISHER ROVER LEAD ADVISED.
1811	APB OPS CALLED ABOUT BLUE RT SERVICE TO 4EB PSA REPORTED NO TRAIN FOR :20 MIN. OPS WAS ADVISED THAT A 3RD TRAIN WAS ON BLUE RT AND BUNCHING WAS POOR 2 TRAINS IN 5E AND 3RD WAS ON 4WSL.
1846	PL2·8 - 2WCP - CLASS II "ISC" - ... :04 MINUTES 2 TRAIN QUEUE

ONE

FIGURE 3-2. AIRTRANS CENTRAL CONTROL LOG

AIRTRANS PHASE II ASSESSMENT

SYSTEM PERFORMANCE DATA

REPORT A-2: ON-SYSTEM MALFUNCTIONS

Date of Data 8-29-74
Sheet 1 of 8

Time	Affected System	Affected Subsystem	Nature of Malfunction	Class Malfunction	Duration	Type Action	Remarks
0630	P	11—	58	II	X	RT	
0729	C	11—	77	II	X	RP	
0927	W	32—	5	III	X	NM	
0007	P	11—	52	II	10	RS	
0009	C	11—	71	II	4	RS	
~~0035~~	P	11—	66	I	4	RS	
0037	S	31—	27	V	73	B	
0113	W	32AC∅	26	III	1	RE	
0138	P	11—	61	II	3	RS	
0203	C	11—	71	II	4	RS	
0223	W	41—	35	IV	1	RE	

FIGURE 3-3. REPORT A-2: ON-SYSTEM MALFUNCTIONS

airtrans MAINTENANCE REPORT
SYSTEM RESTORATION

PAGE 1 7 **No.** 53869 (1-6)

Col 8 — 1

DATE	ITEM NO.	VEHICLE NO.	LOCATION	WHAT FAILED
5/6/76 (9-14) **	11000 (15-19)	3/18 (20-24) **	TEST (25-31)	(L) I B C W G (32)

ORIGINAL DISC. MR NO. (33-38)

AIRTRANS MAINT. ADM.
Warranty
Vandalism
Neither (59)

OCCURRED DURING	AFFECTED MOVEMENT/ CONTROL Yes No (40)	VEH. REM.	PROB. CAUSE
Service — If Service Complete	Call Received (44) *	Reset Sw	Vandalism
Ready Track	Maint Arrived (48) *	Manual	Accident
(Test) (ATC DT)	Clear Received (52) *	Towed	Normal Op
Inspection	Sys. Restored (56) *	(57)	(58)
Maintenance			
Other (39)			

COMPLETED BY R&M
AT (60-61) HM (62-64)
DC (65-66) FT R (67) F (68) M (69)

INITIATOR NAME J Miles

A DISCREPANCY

B SERVICE BRAKES NOT RELEASING IN AUTO ON PL-3

MANHOURS (70-73)
Work Performed By
Supervisor
Date Completed

VEHICLE OR FIXED EQUIPMENT REPAIR

Complete an MR for Each Disc or Repairable Part

ITEM NO	PART NUMBER	SERIAL NO REMOVED	SERIAL NO INSTALLED
11MA7 (9-13) *	31038-326R1 (14-28) *	73162 (29-38) *	73035 (39-48) *

2

VEH HRS (49-54) * MILES (55-59) *

C D E F EQUIPMENT DISCREPANCY

SERVICE BRAKES NOT RELEASING IN AUTO ON PL-3 (MANY POTS ALSO HAD BEEN TAMPERED WITH)

G ACTION TAKEN (DISPOSITION)

H R/R AVO

J K L M N P Q

M A I N T E N A N C E

RELATED MR NO

NON-REPAIRABLE PARTS

ITEM NO REF DES	PART NO	QTY	NAME OF PART
7			
7			
7			
7			
7			
7			

R&M CODES
AT (60-61) HM (62-64)

Repaired By J Miller
Elapse Time 3.0 *
MANHOURS 3.0 *
Supervisor Tyson
Date Completed 5-6-76 *

FIGURE 3-4. SAMPLE MAINTENANCE REPORT

AIRTRANS PHASE II ASSESSMENT

SYSTEM PERFORMANCE DATA

REPORT A-3: OFF-SYSTEM MAINTENANCE ACTIONS

Data of Data 9-28-75
Sheet 2 of 3

MR Number	Affected System	Affected Subsystem	Maintenance Problem	1st Action	2nd Action	3rd Action	Man Hours	Remarks
49741	P	11CA5	3	RR	X		1	
49742	P	11CA3	3	A			1	
49743	P	11GD1	6	RR	RV		3	
49744	P	11CA4	4	RP			1	
49745	P	11EA1	3	RR			2.5	
49712	P	11ED2	1	RR			.5	
49713	P	11CA5	3	RR	X		1	
49715	P	11GA8	2	RR	X		1	
49716	P	11CA5	3	RR	X		2	
49717	P	11CA5	3	RR	X		.5	
49718	P	11AK3	4	D			.5	

FIGURE 3-5. REPORT A-3: OFF-SYSTEM MAINTENANCE ACTIONS

system or equipment malfunctions can be categorized in one of the three. Not all can be so accommodated, however, and so when the raw log data was screened, two additional classes - nuisance malfunctions and complete system outages - were added. The resultant definitions of malfunctions encompass both failures and the effects of external forces on the system - weather, guideway intrusions, noise, etc. These five classes are used in the data analysis that the Transportation Systems Center (TSC) has done, and they are shown in Table 3-1.

TABLE 3-1. CLASSES OF MALFUNCTIONS

CLASS I*	AN INFRACTION OF CERTAIN SAFE-OPERATIONAL CRITERIA ENDANGERING LIVES AND EQUIPMENT
CLASS II*	A SERVICE-DEGRADING MALFUNCTION
CLASS III*	A MALFUNCTION THAT CAUSES PASSENGER INCONVENIENCE BUT DOESN'T DEGRADE SAFETY OR SERVICE
CLASS IV	FAILURE OF A PART NOT AFFECTING SAFETY, SERVICE, OR PASSENGER CONVENIENCE
CLASS V	SYSTEM SHUTDOWN, REQUIRING PARTIAL OR COMPLETE BUS CALLOUT: AN "OUTAGE"

*Same as in Table 2-5.

3.2.6 Malfunctions versus Failures

The malfunctions considered in the reliability calculations are only those unusual incidents that cause a vehicle to stop, i.e., Class I and Class II malfunctions.

Failures are actual equipment or component breakdowns, are repeatable, and anything that has failed must be repaired.

Malfunctions, of course, include any failures that cause a vehicle to stop, but may also be due to noise, passenger action, power transients, debris on the guideway, or many other causes. Such non-failure malfunctions are often self-clearing, and a stoppage due to one can usually be reset from the AIRTRANS Central Control.

3.3 DATA EXTRACTION

3.3.1 Periods of Interest

Of particular interest was the effect on system reliability performance of the changes in equipment and operations that were made during the three years covered by this study. It appears that there were six periods that differed in some major way from one another. These periods and their differences are shown in Table 3-2.

3.3.2 Sampling Methods

It was obvious from the start, since no attempt had ever been made to analyze the log books, that the accumulation of three year's of handwritten sheets would cost a great deal to use in toto. Approximately 10,000 sheets, each with 10 to 15 entries would have to be transcribed into some standard format before the data could even be key punched for analysis.

It was decided, therefore, that the information should be sampled to allow the work to fit into the rather small budget allocated to this study. A statistical study (see Appendix B) suggested that with an approximately 25 percent random sample of days, calculated results of Mean Miles Between Malfunctions (MMBM), Mean Time Between Malfunctions (MTBM), Mean Time To Restore (MTTR), and Availability would be within 15 percent of the actual average value for the entire period with a confidence of 90 percent. This seemed an accurate enough estimate of the desired parameters, considering the obvious uncertainties in the accuracy of the raw data. This statistical uncertainty must be borne in mind in all the results to be discussed

TABLE 3-2. LIFE PERIODS OF AIRTRANS

PERIOD 1:	OPENING, JAN. 1, '74 TO MAY 31, '74	138 DAYS	PASSENGERS ONLY, 15 HRS PER DAY
PERIOD 2:	JUNE 1, '74 TO JAN. 1, '75	214 DAYS	PASSENGERS ONLY, 24 HRS PER DAY
PERIOD 3:	JAN. 1, '75 TO MARCH 31, '75	80 DAYS	PASSENGERS & SUPPLY, 24 HRS PER DAY
PERIOD 4:	APRIL 1, '75 TO SEPT. 30, '75	180 DAYS	SAME, MAINTENANCE BY VOUGHT ON 6 MONTH CONTRACT
PERIOD 5:	JAN. 1, '76 TO APRIL 1, '76	72 DAYS	PASSENGERS AND SUPPLY, AIRPORT BOARD MAINTENANCE
PERIOD 6:	APRIL 1, '76 TO JAN. 1 '77	275 DAYS	SAME PLUS EMPLOYEES

below. The original size of the data file and the size of the sample are indicated in Table 3-3. (See also Appendix B.)

3.3.3 Form of Raw Data

There were two major sources of information, as has been mentioned.

a. System operations were described in the daily logs kept by the system operators at the Central Control console. A full 24-hour day produced three sets of handwritten log sheets, on which every event of each shift was recorded.

b. Maintenance shop activities have been recorded on the MR forms already illustrated (see Figure 3-4) since the opening of the system in January 1974. These forms record the facts only about verified failures that have been repaired and do not record scheduled or preventive maintenance actions. During the first four periods described below, the manufacturer, Vought, transcribed these data into machine-readable records, and it is from them that the BADACTORS report was prepared. All the component life and maintenance time information cited in this report was extracted from four, machine-prepared reports of this type, which ranked parts by the total of verified failures attributed to each period. Each period was totalled separately. Average figures for the last three of the four periods were used to eliminate some of the infant mortality bias that caused an excess of failures in the first few months.

3.3.4 Form of Transcribed Data

The raw operational data were transcribed from the logs to a standard format. A sample page of the transcribed data was previously shown in Figure 3-3 which contains the following information for each incident.

- Time of occurrence
- Affected system (passenger, wayside, cargo)
- Affected subsystem (subsystems of vehicle, wayside)

TABLE 3-3. SAMPLING PLAN FOR AIRTRANS OPERATIONAL DATA

PERIOD	TOTAL DAYS	SAMPLE DAYS	ESTIMATED NO. OF SAMPLE ENTRIES
1	138	40	1,740
2	214	44	1,913
3	80	28	1,217
4	180	42	1,826
5	72	31	1,348
6	275	45	1,957
TOTALS	959	230	10,000

- Nature of malfunction (Approximately 80 types - See Appendix C)
- Class of malfunction (Classes I-V - See Table 3-1)
- Duration (Minutes)
- Type of system action (Approximately 10 types - See Table 3-13)
- Remarks

3.3.5 Analysis Performed

The data for the sample days were key punched and entered into the computer. They were then analyzed in various ways; the results were extrapolated from the samples to the entire periods, and standard errors and confidence intervals were determined. Appendix C contains the details of the analysis of the R&A data. The discussion in the following sections is derived from this. Appendix B contains the statistical basis for the selection of data.

3.3.6 Confidence and Error

Standard errors for all the calculations have been calculated, as have confidence intervals. Figures 3-6 and 3-7 show graphically the range of values encompassed by a confidence interval of 95 percent. In succeeding charts the statistical uncertainty will not be shown.

3.4 RESULTS: AVAILABILITY

Since "availability" was not defined in the original AIRTRANS specification, necessity required that some measure of system effectiveness be developed so that levels of system operation could be measured and reported. This systems-level measurement is derived from the operational log data, as will be demonstrated later, and several definitions of availability are reviewed.

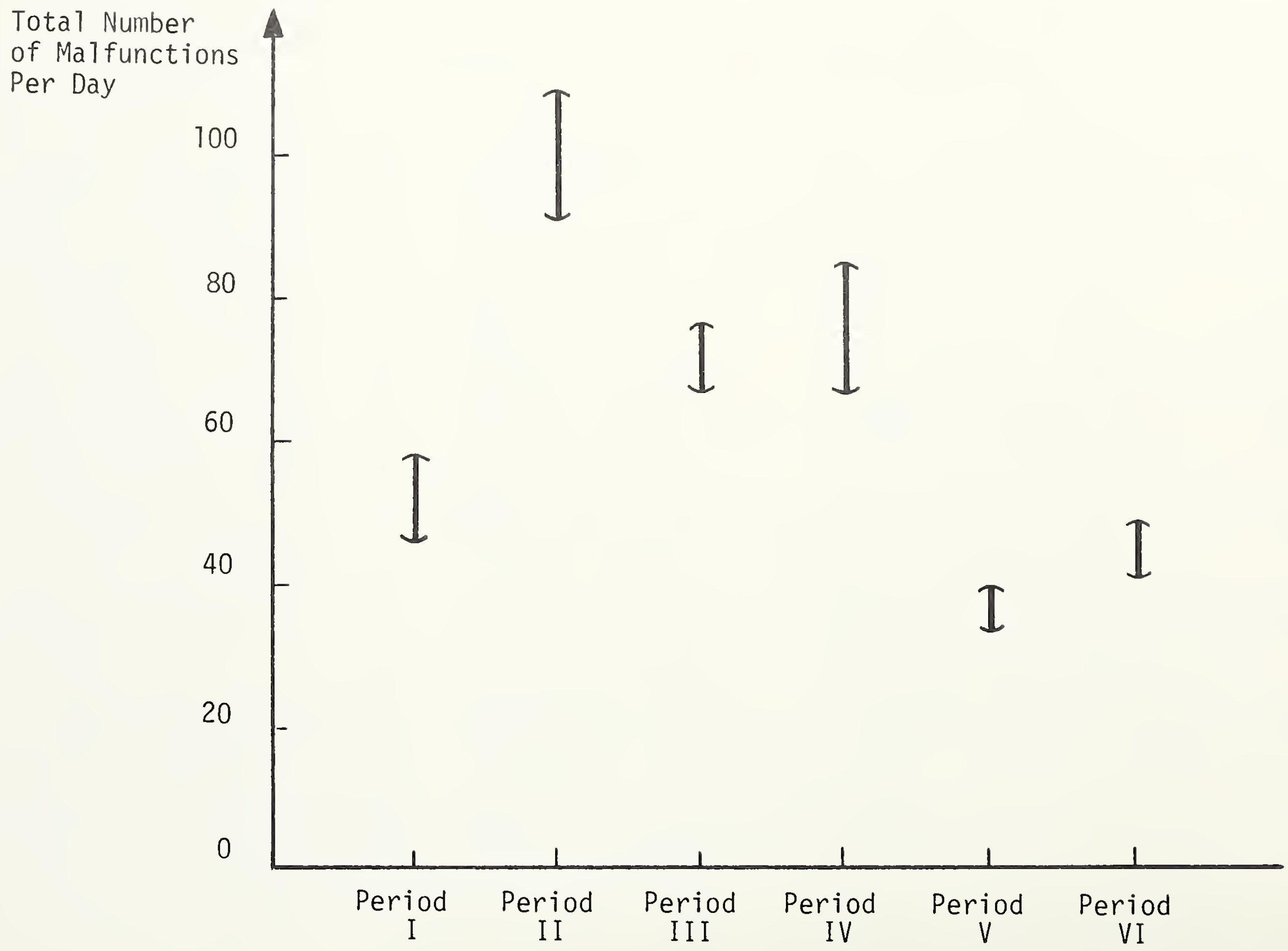


FIGURE 3-6. NINETY-FIVE PERCENT CONFIDENCE INTERVALS AROUND THE ESTIMATED NUMBER OF MALFUNCTIONS PER DAY

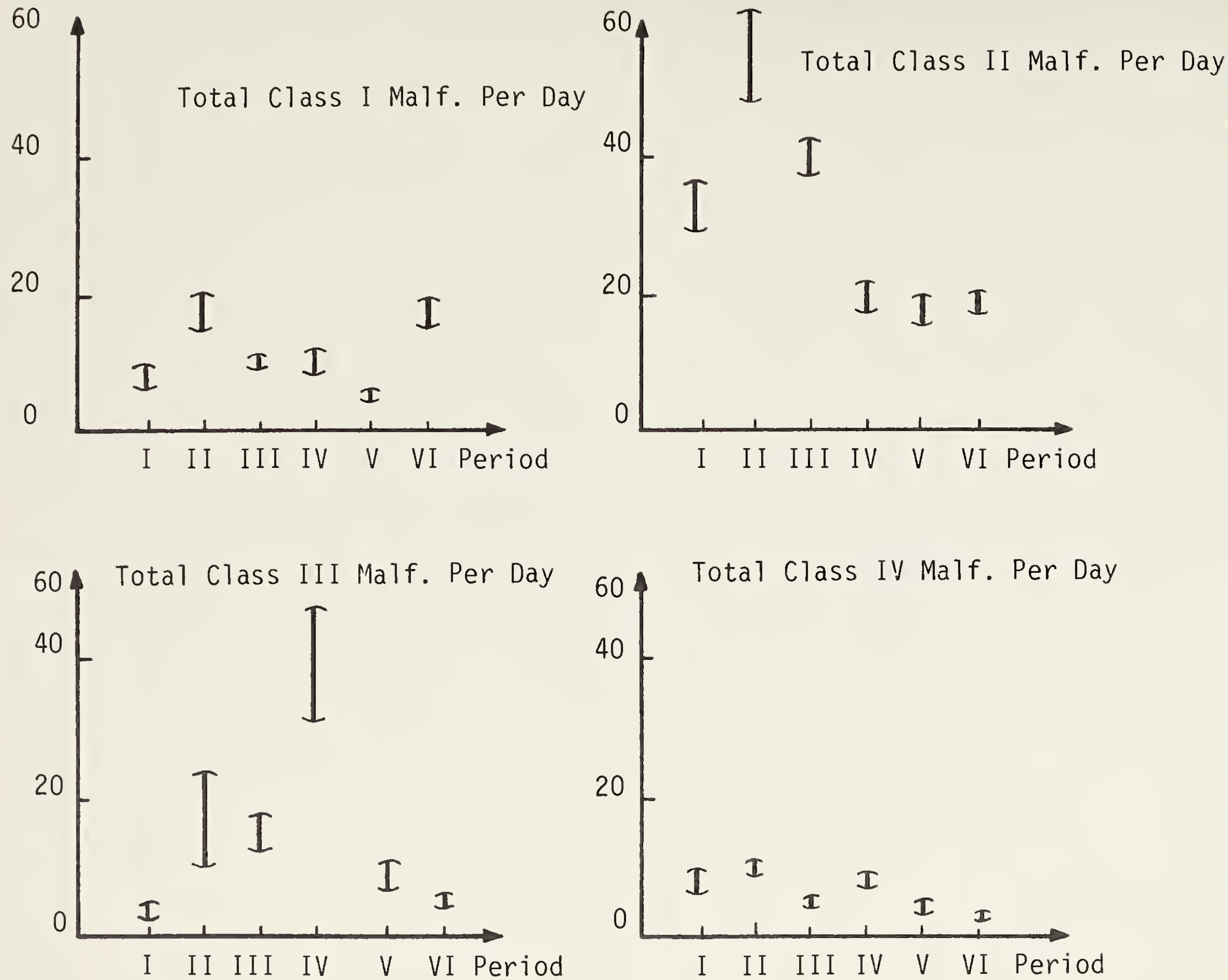


FIGURE 3-7. NINETY-FIVE PERCENT CONFIDENCE INTERVALS AROUND THE ESTIMATED NUMBER OF MALFUNCTIONS (BY CLASS) PER DAY

3.4.1 The Official AIRTRANS Measure

It was decided that availability for AIRTRANS should simply be a measure of the percent of the time that the entire system is in operation. When any portion of the system is inoperative, backup buses are called out, and the system has an "outage" by definition. Availability is then defined as

$$A_1 = \frac{\text{scheduled system time - outage time}}{\text{scheduled system time}} .$$

The criteria for declaring an outage is as follows: if a system failure lasts over five minutes, the buses are alerted. If at the end of nine minutes the system failure has not been cleared, the system, or the affected part of it, is shut down. The buses then go into service, and outage time begins to be measured. This definition simply says that the system is running or that some of it doesn't run. It says nothing about the quality of passenger service being supplied; however, customer complaints are partly prevented by the decision to provide a backup (even of lesser quality) without undue delay.

Figure 3-8 shows the availability of the system as defined this way, and recorded weekly from January 1974 through November 1977. The performance by this standard was best during Period 4, April through September 1975. It improved to almost 100 percent during the first 1 1/2 years of the system's operation, and has gone down to about 98 percent during the past two years, reflecting undoubtedly, increased system usage, hardware changes, reduced maintenance staff, and to some extent, wearout. As can be seen more clearly in the first two bars of Figure 3-9, which consists of averages of the weekly figures for each period, the system performance improved as described by this measure, levelled off, and then decreased slightly to a stable level of about 98 percent. For 1978, it averaged about 99.3 percent.

One comment is in order. Since this definition of availability was an evolving one, the criterion for allowable delay before calling out the buses - now nine minutes - was more lenient in the earlier periods. This shifting of the base of measurement partially explains the near perfection during period four, and the slight reduction during periods 5 and 6.

3.4.2 Other Measures

With the large amounts of data that have become accessible during the course of this study, it seems worthwhile to try some other definitions of a system effectiveness measure that would reflect something of the quality of service that the public was receiving from AIRTRANS. Much has been said and written about[7] "service availability" recently, a desired index that would measure the service impact of systems delays generated by both equipment failures and non-equipment causes. To see if some form of service availability measure would be derivable from the data on hand, another definition was devised as follows (see Table 3-4).

$$A_2 = \frac{\text{Total System Time} - \text{Duration of all Class I \& Class II Malfunctions}}{\text{Total System Time}}$$

The necessary sorting and simple calculations were performed on the data, and the results are presented in the last bar of Figure 3-9.

This second measure, based on the duration of all system malfunctions affecting vehicle movement and control - hence generating passenger delays - has several interesting characteristics. It is straightforward and easy to understand; it includes all factors that cause any system delays; and it shows continual improvement with time. The delays considered in this definition are vehicle delays ranging from a single vehicle stoppage to total shutdowns, and they are admittedly only loosely coupled to passenger delays. It does say that 87 percent of the time in Period 6 any passengers present received high quality service, and during 13 percent of the time the service was more or less impaired. The full length of the bar includes only Class I and Class II malfunctions. The effects of outages reduce this measure slightly and are indicated at the top of each bar.

It seems possible to conclude that measure A_2, based on Class I and II malfunctions and outages, is a more realistic picture of the system than measure A_1. A_2 is based on no speculative assumptions and accounts for all system delays caused by any sort of malfunction

TABLE 3-4. VARIOUS MEASUREMENTS OF SYSTEM EFFECTIVENESS IN AIRTRANS

*A_1	OFFICIAL AVAILABILITY:	PERCENT OF TOTAL SYSTEM TIME FREE OF OUTAGES
A_2		$\frac{\text{TOTAL SYSTEM TIME (TST) - SUM OF ALL CLASS I AND II DELAYS AND OUTAGES}}{\text{TOTAL SYSTEM TIME}}$
*A_3	SERVICE FACTOR:	WEIGHTED SUM OF NUMBERS OF CERTAIN MALFUNCTIONS PLUS OUTAGE TIMES

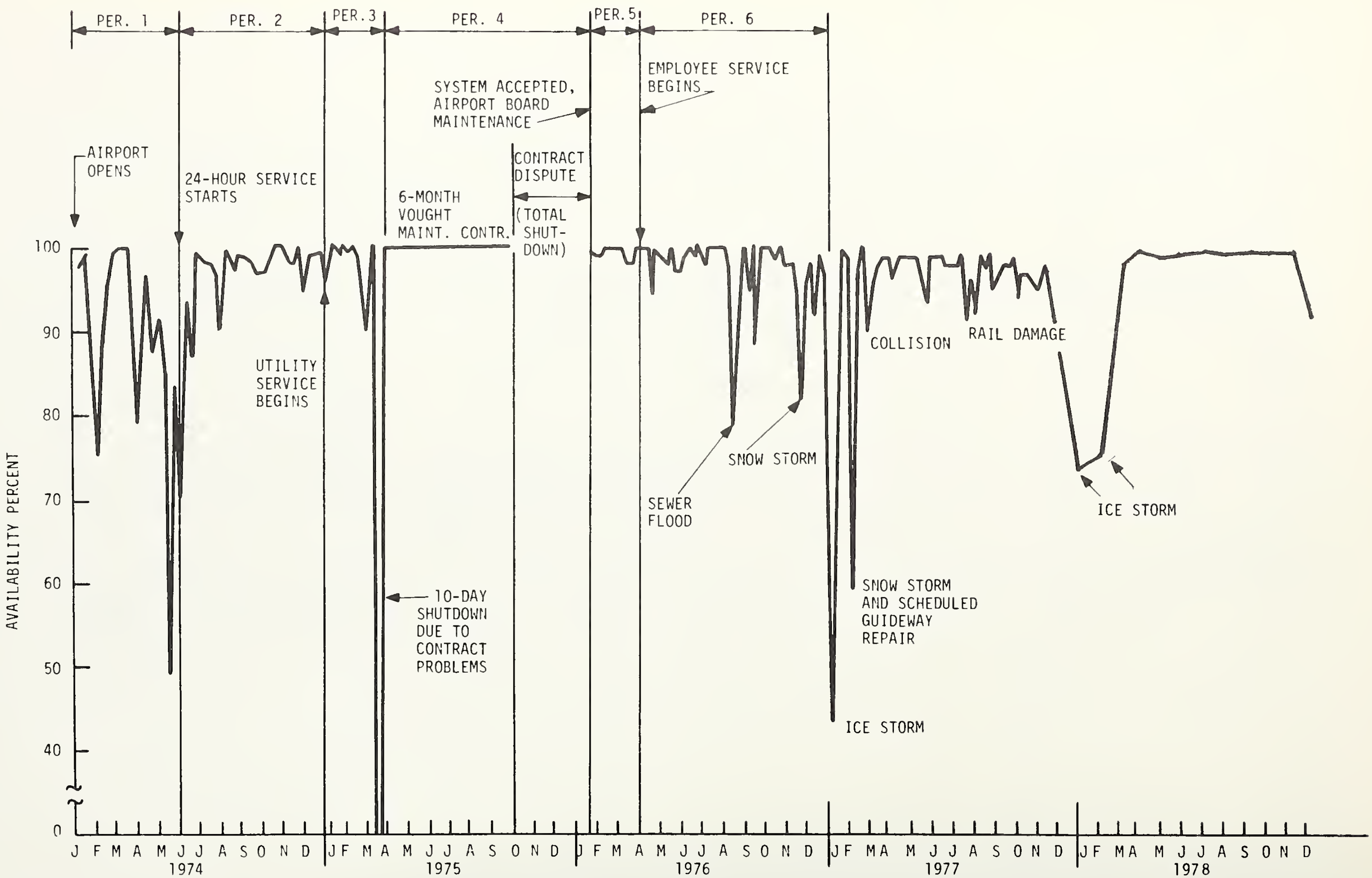
*USED BY D-FW AIRPORT BOARD

It is interesting to compare the values of availablility, as plotted in Figure 3-8, with the "service factor," a measure put into use early in 1976 at AIRTRANS. The "service factor" approach is not based on cumulative delays alone, as was definition A_2, in Figure 3-9, but on a sum of certain delays - outage delays - and weighted values of the number of malfunctions per day. This factor was developed because it was recognized that the existing availability measure A_1 used only outages and gave a distorted view of the system's operation.

This factor was not calculated for most of the system's life; however, for Period 6, records for 35 weeks were available, and were translated into a form comparable with that used in the Availability measures A_1 and A_2. Figure 3-10 shows a typical AIRTRANS "service factor" plot. "Excellent," good," satisfactory," "marginal," and "poor" can be transformed by assigning scores from 0 to 100 to each of the points. Thus, "excellent" becomes 95-100; "good" becomes 90-95; "satisfactory" becomes 85-90; "marginal" becomes 80-85; and "poor" becomes everything below 80.

This service factor measure, transformed, and identified as A_3 (see Figure 3-10) is plotted with the A_1 measure, based only on outages, in Figure 3-11. These numbers, which are a system effectiveness rather than an availability measure, reflect the incidence of malfunctions as well as outages in the system, and thus are understandably lower than A_1.

The third section in Figure 3-11 gives the A_2 availability measure for the entire Period 6, calculated as described earlier, using the duration of Class I and Class II malfunctions and the duration of all outages. Note that for this entire period A_2 = 87 percent, while the average of the service factor (or A_3) is 86.7 percent. This close correspondence suggests that perhaps a daily review of the operational logs, taking the duration of all Class I and II delays and all outages, might give a measure equally meaningful and easier to calculate and understand than the service factor approach.



Source: Data from D-FW Airport Board records.

Note: **See Appendix H, Table H-3.**

FIGURE 3-8. AVAILABILITY OF AIRTRANS

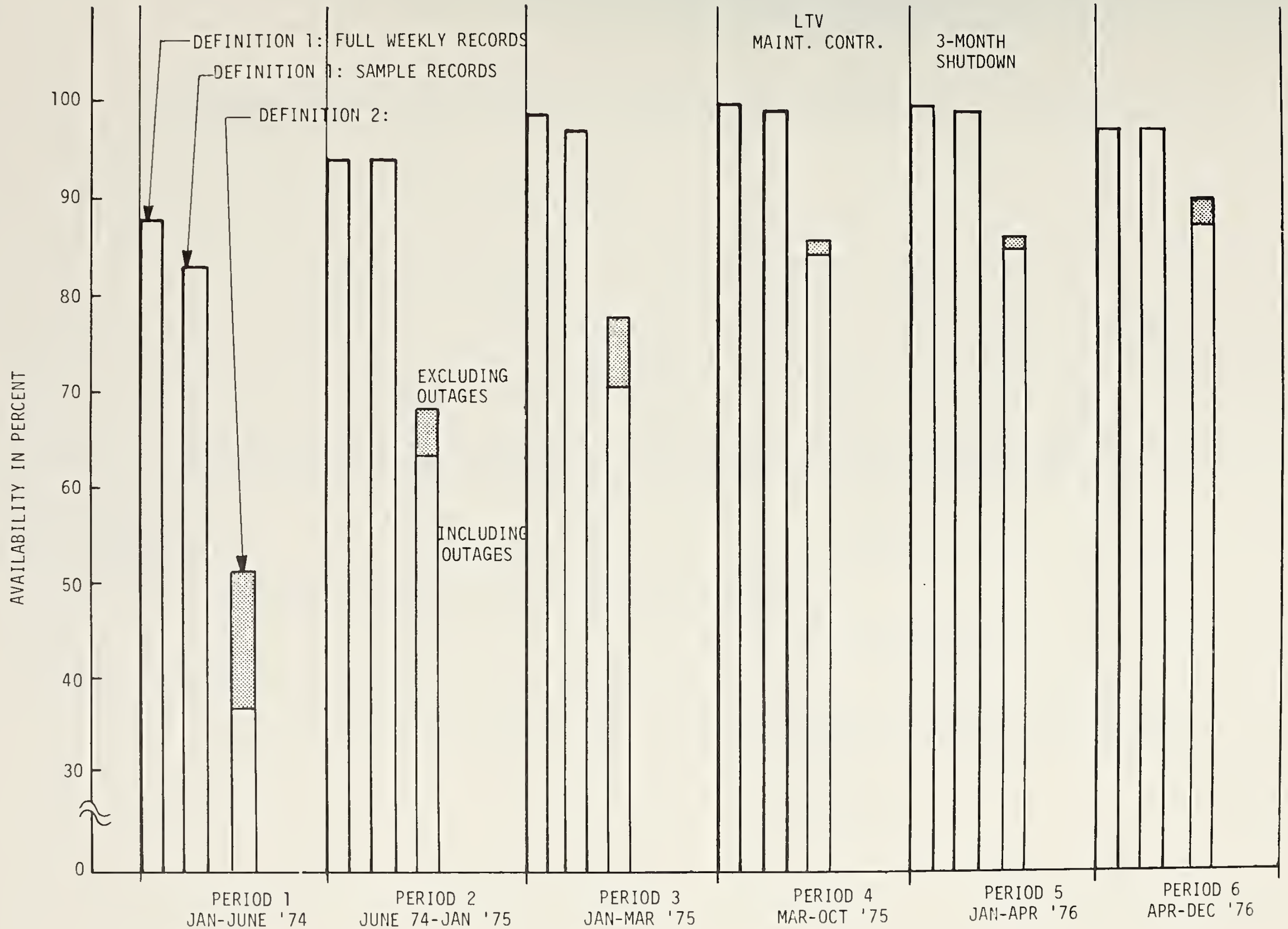


FIGURE 3-9. AVERAGE AVAILABILITY, PERIODS 1-6

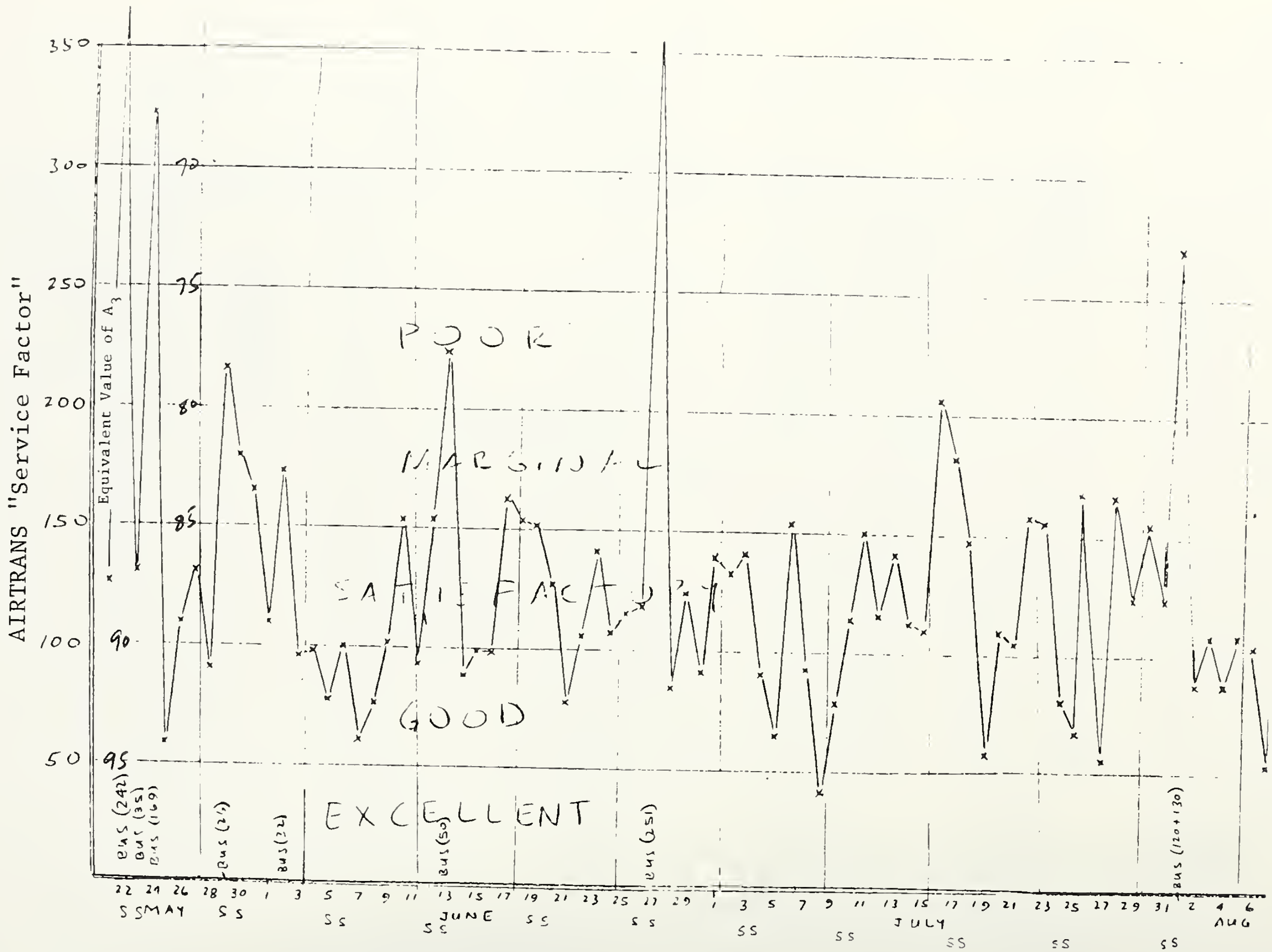


FIGURE 3-10. AIRTRANS SERVICE FACTOR

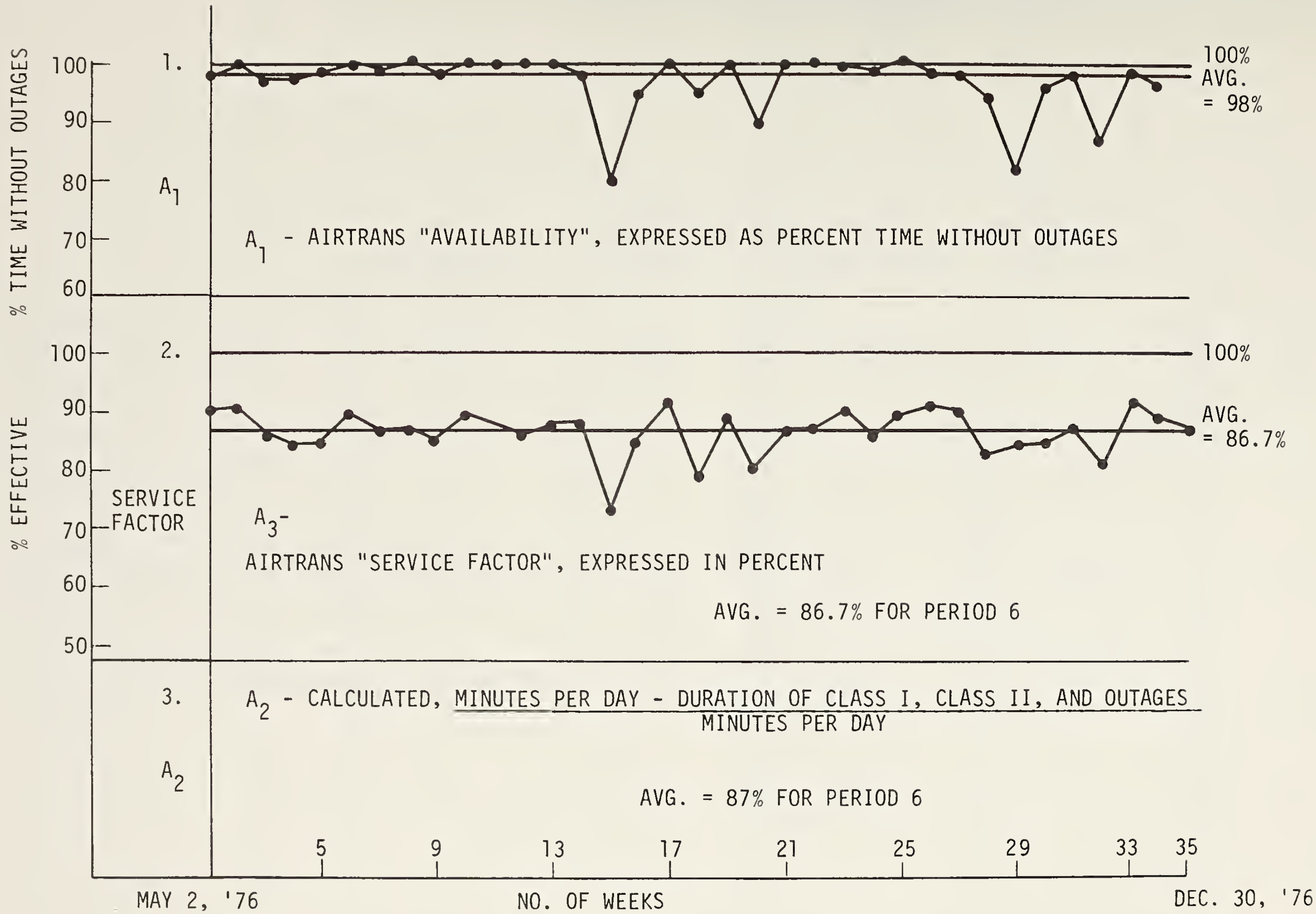


FIGURE 3-11. PERIOD 6 - COMPARISON OF THREE DIFFERENT WAYS OF CALCULATING AVAILABILITY

3.5 RESULTS: SYSTEM RELIABILITY

3.5.1 System Mean Miles Between Malfunctions

This index is a measure of reliability - or the probability that the system will not have a malfunction - rather than of availability or the usability of the system. Vehicle reliability is measured and talked about most meaningfully by using the Mean Miles Between Malfunction (MMBM) number.

In Table 3-5, this figure is presented for the system as a whole, using only Class I and Class II malfunctions or all those that affect movement and control of the vehicles. Passenger vehicles alone and the entire wayside are then segregated; for the latter Mean Time Between Malfunctions (MTBM) rather than MMBM is calculated.

Histograms of the MMBM for both kinds of vehicles are also presented in Figure 3-12. System Mean Miles Between Outages (MMBO) of the system is presented in Figure 3-13, and the data for it are displayed in Table 3-6.

Using the average number of passenger vehicles per day per period, as supplied by the Airport Board, nominal MTBMs are also calculated for the passenger vehicles. The calculation for the passenger vehicles assumes the average number of vehicles operate 24 hours per day. (See Column 5 of Table 3-5.)

A second MTBM figure is included in the vehicle MTBM column of Table 3-5, which counts only those malfunctions causing a system delay of four minutes or greater. It is based on the assumption that passengers are insensitive to short delays, and presents the MTBM for an individual vehicle, if all malfunction durations less than four minutes are ignored. All of these figures are plotted as graphs rather than histograms in Figure 3-12A. This clearly demonstrates that even as individual vehicles improve, the system reliability

TABLE 3-5. SYSTEM AND SUBSYSTEM RELIABILITY
(BASED ONLY ON CLASS I & II MALFUNCTIONS)

PERIOD		SYSTEM MMBM	SYSTEM MTBM		VEHICLE MTBM		AVG. NO. OF VEHICLES
			COUNTING ALL MALFUNCTIONS	COUNTING ONLY MALFUNCTIONS OVER 4 MIN.	COUNTING ALL MALFUNCTIONS	COUNTING ONLY MALFUNCTIONS OVER 4 MIN.	
1.	SYSTEM	159	0.375	.45	15.4 HRS	18	28
	PASS. VEHICLE	215	0.55 HRS				
	WAYSIDE	-	2.5				
2.	SYSTEM	149	0.33	.53	19	30	39
	PASS. VEHICLE	177	0.49				
	WAYSIDE						
3.	SYSTEM	188	0.49	.84	22	40.4	38
	PASS. VEHICLE	226	0.57				
	WAYSIDE	-	4				
4.	SYSTEM	283	0.62	1.72	31	70.7	28
	PASS. VEHICLE	389	1.1				
	WAYSIDE	-	1.6				
5.	SYSTEM	237	1.1	2.2	25	53	19
	PASS. VEHICLE	348	1.3				
	WAYSIDE						
6.	SYSTEM	337	0.69	1.85	27	82	35
	PASS. VEHICLE	376	0.77				
	WAYSIDE	-	8				

Source: Data from Appendix H, Table H-2.

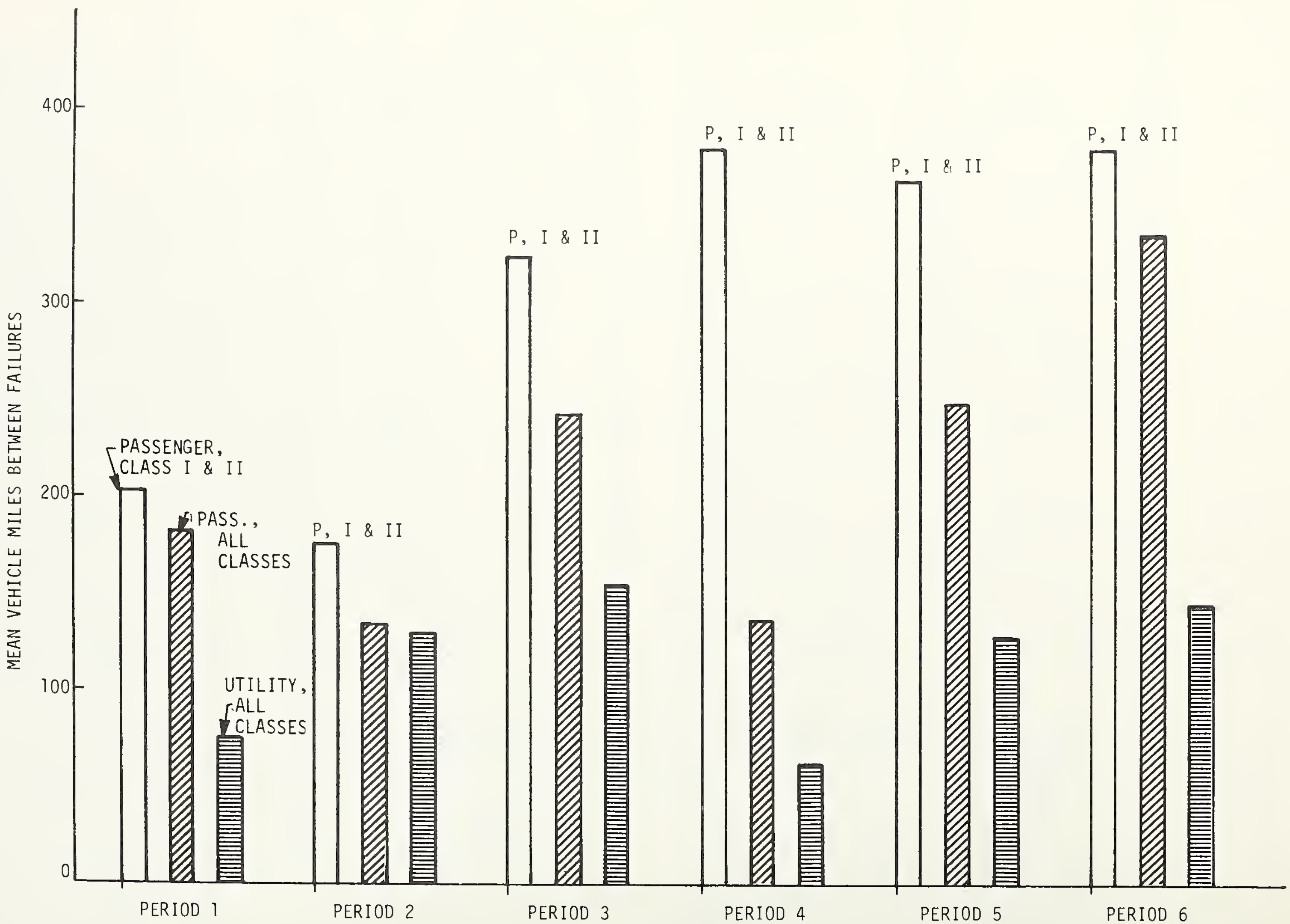
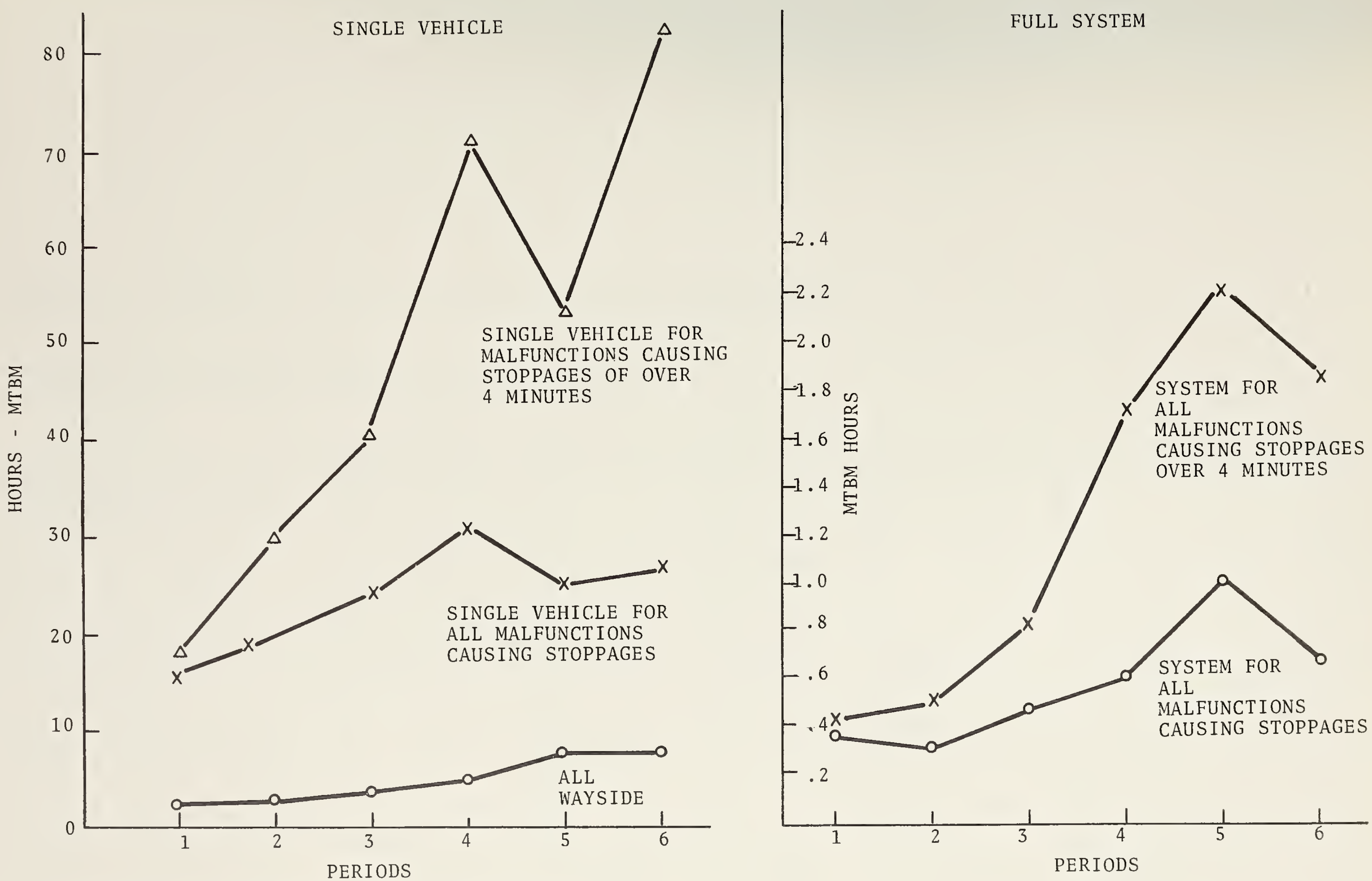


FIGURE 3-12. SYSTEM MILES BETWEEN MALFUNCTIONS



Source: Data from Appendix H, Table H-2.

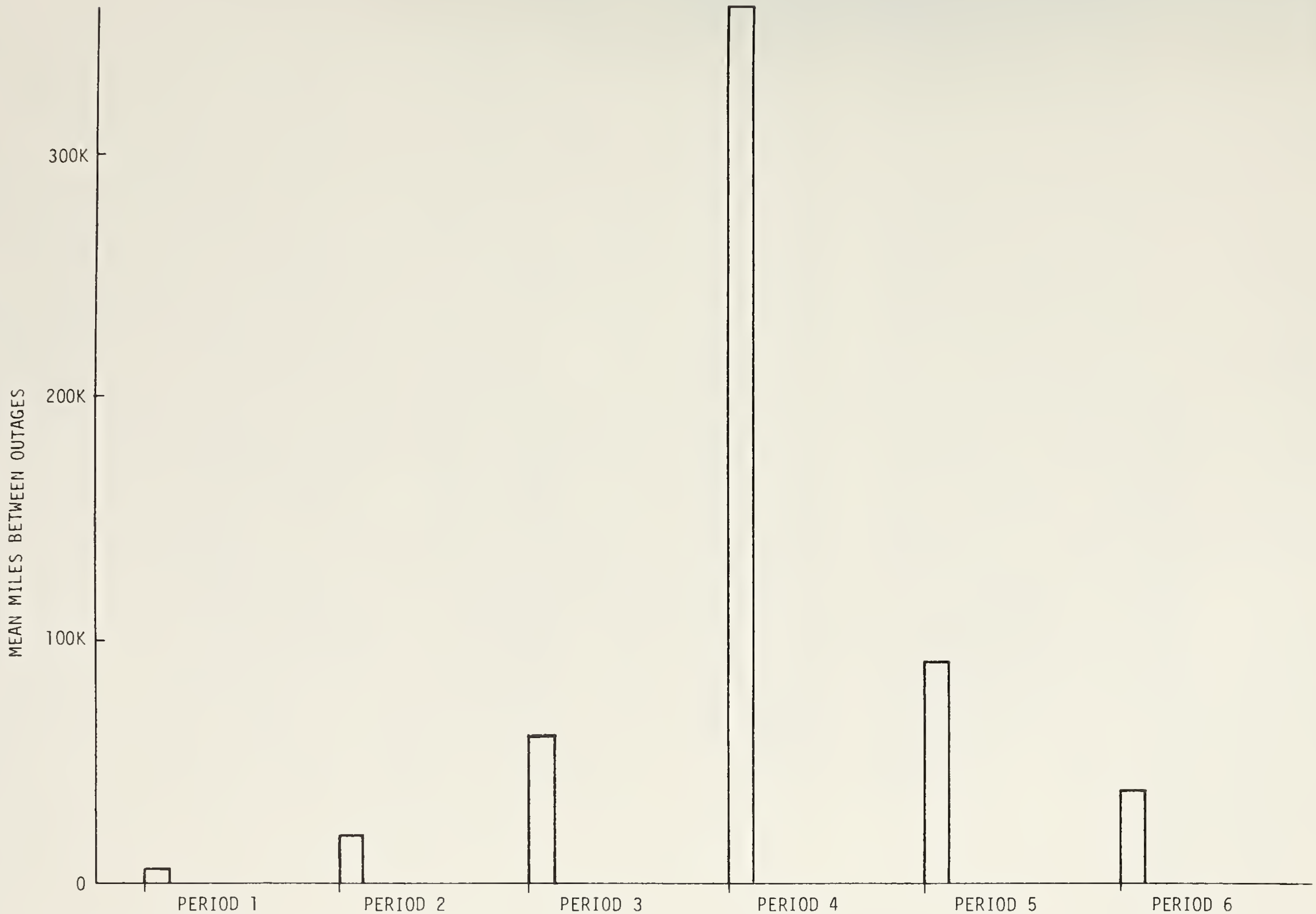
FIGURE 3-12A. MEAN TIME BETWEEN MALFUNCTIONS

TABLE 3-6. SYSTEM MEAN MILES BETWEEN OUTAGES

	PERIOD 1[Δ]	PERIOD 2	PERIOD 3	PERIOD 4	PERIOD 5	PERIOD 6
*NUMBER OF OUTAGES	127	179	14	4	5	86
*AVERAGE DURATION (MINUTES)	163	109	252	400	199	160
MEAN AVG. MILES BETWEEN (PLOTTED IN FIG. 3-13)	6,320	10,379	50,321	361,500	90,200	31,907
*TOTAL SYSTEM MILES (PASS. VEH. ONLY)	802,500	1,858,000	704,500	1,446,000	451,000	2,744,036
*AVE. PASS. VEHICLES	28	39	38	28	19	35
*TOTAL SYSTEM HOURS	2,070	5,136	1,920	4,320	1,728	6,600
AVG. PASS. VEH. VELOCITY (MILES PER HOUR)	13.8	9.3	9.7	11.9	13.7	12.0

*RAW DATA FROM TABLE C-6, APPENDIX C, AND TABLE H-1. OTHER VALUES WERE CALCULATED.

[Δ]FOR PERIOD 1 NUMBERS ARE FOR 15 HRS./DAY; FOR OTHER PERIODS NUMBERS ARE FOR 24 HOUR DAYS.



Source: Data from Table 3-6.

FIGURE 3-13. SYSTEM MILES BETWEEN OUTAGES profile will go down as the number of vehicles increases. In Period 6 the employee service had begun, and 35 vehicles on the average were running rather than 19 as in Period 5. See Appendix H for the system statistics from which these tabulations and graphs have been drawn.

3.5.2 Discussion of System Reliability

Some comments are in order regarding the vehicle MTBM (Mean Time Between Malfunction) numbers that appear in Table 3-5. Based on these data, each passenger vehicle in the AIRTRANS system experiences a malfunction on the average of once a day. This certainly appears to be significantly below the AIRTRANS specification requirement of 500 hours (average) between failures on each vehicle. But is it?

First, this report has stressed the difference between malfunctions and failures. Each of the vehicles in the AIRTRANS fleet has historically experienced a malfunction on the average of once a day. However, from a study of the data, it is apparent that many of these malfunctions are not a result of any failure, because they are resettable from Central Control. This indicates that the vehicle has, in fact, responded normally to some transient conditions, and can be easily restored to operation when that condition disappears. Thus it is quite possible that the actual vehicle MTBF is much closer to the specified 500 hours than is suggested by the 24 hour MTBM.

Secondly, it is worthwhile to put the MTBM of 24 hours per vehicle into context by explaining the large number of repetitious events (of a very complex nature) that transpire in 24 hours of vehicle operation. For example, station stops: in the current configuration, AIRTRANS vehicles stop at stations approximately 16,000 times every day. With an average loading of 40 vehicles, this means that each vehicle stops at 400 stations in the course of a day without a malfunction. This becomes even more impressive when one realizes that over 130 separate, sequential logic and/or physical actions must occur without error for <u>each</u> successful station stop. Also, in a day's time, the AIRTRANS vehicles call over 69,000 switches. This translates to over 1700 switch calls for each individual vehicle in the system.

Thus it can be seen that, although the observed MTBM of 24 hours might appear to be very low compared to the specification, in fact, it represents a considerable achievement in real hardware and also is probably not inconsistent with the specified interval between verified failures.

A third comment relates to "trip reliability." If we assume that the reliability function of the entire vehicle is exponential, i.e, failures are random, and each trip is independent of all others, we can calculate the probability that an individual passenger will complete any random trip he starts without a crippling malfunction occurring to the vehicle he is occupying.

If an average trip is 15 minutes, and the MTBM is 27 hours, as it appears to be in Period 6, then this probability is

$$R = e^{\left[- \frac{1}{27} \times .25\right]} = 0.991$$

So 99 times out of 100 he will reach his destination uneventfully. If he is a commuter, such as an employee, and takes 10 of these independent trips per week, this probability becomes $R = (0.991)^{10} = 0.912$, i.e., he has only a 9 percent chance of seeing trouble in a whole week of travel. As will be shown later in Period 6, 70 percent of the stoppage durations were four minutes or less. Thus, the probability that an average passenger might see a stoppage longer than four minutes is only 0.3 x 0.09 = 0.027 or in a week's commuting -- 1 chance in 37. Expressed differently he might expect to travel 37 weeks before he was delayed by his own vehicle more than four minutes.

3.5.3 Number of Malfunctions

Another measure that gives a relative feel for change in system performance is the number of malfunctions per vehicle per day that occur during the system's life. This is displayed in

Figure 3-14, "Class I and II Malfunctions Per Vehicle and Total Malfunction Durations Per Day." The system's incidence of Class I and Class II malfunctions and the delays - or on-system restore times - which resulted, clearly trended downward from Periods 1 through 6. (The duration total also includes outage durations.)

3.5.4 Duration of Malfunctions

Figure 3-15 portrays the average duration of all malfunctions, segregated by classes, for the six periods. Class I (safety critical) malfunction delays decreased with time; Class II (service degrading) malfunctions fluctuated in resultant delays; Class III (inconvenience) malfunctions steadily decreased; and Class IV (nuisance) malfunctions remained constant. The general picture suggests improvement in the capability to handle malfunctions, as would be expected. It may be noted that the duration of Class II malfunctions rose in Period 5, when the Airport Board took over system maintenance after the three-month shutdown. But the duration of all malfunctions was cut in half in Period 6, which speaks well for the new management, which had twice the active number of vehicles, twice the passengers, and half the number of maintenance personnel to support the system.

Table 3-7 presents the average or mean downtime durations of the six periods for the sum of Class 1 and 2 malfunctions, i.e., those that resulted in vehicle stoppages. As in Table 3-5, the average durations of downtimes for all malfunctions of greater than four minutes are also shown. This information is presented graphically in Figure 3-15A. Mean Downtimes per Malfunctions (MDTM) are also presented, which are equivalent to Mean Times to Restore (MTTR), a nomenclature often used (see Appendix G).

Another view of the time distribution of malfunctions is seen in Figure 3-16. Here the percent of total malfunctions of duration between one and four minutes increased by a factor of 3 between Periods 1 and 6. The percent of malfunctions with 10 to 14 minute

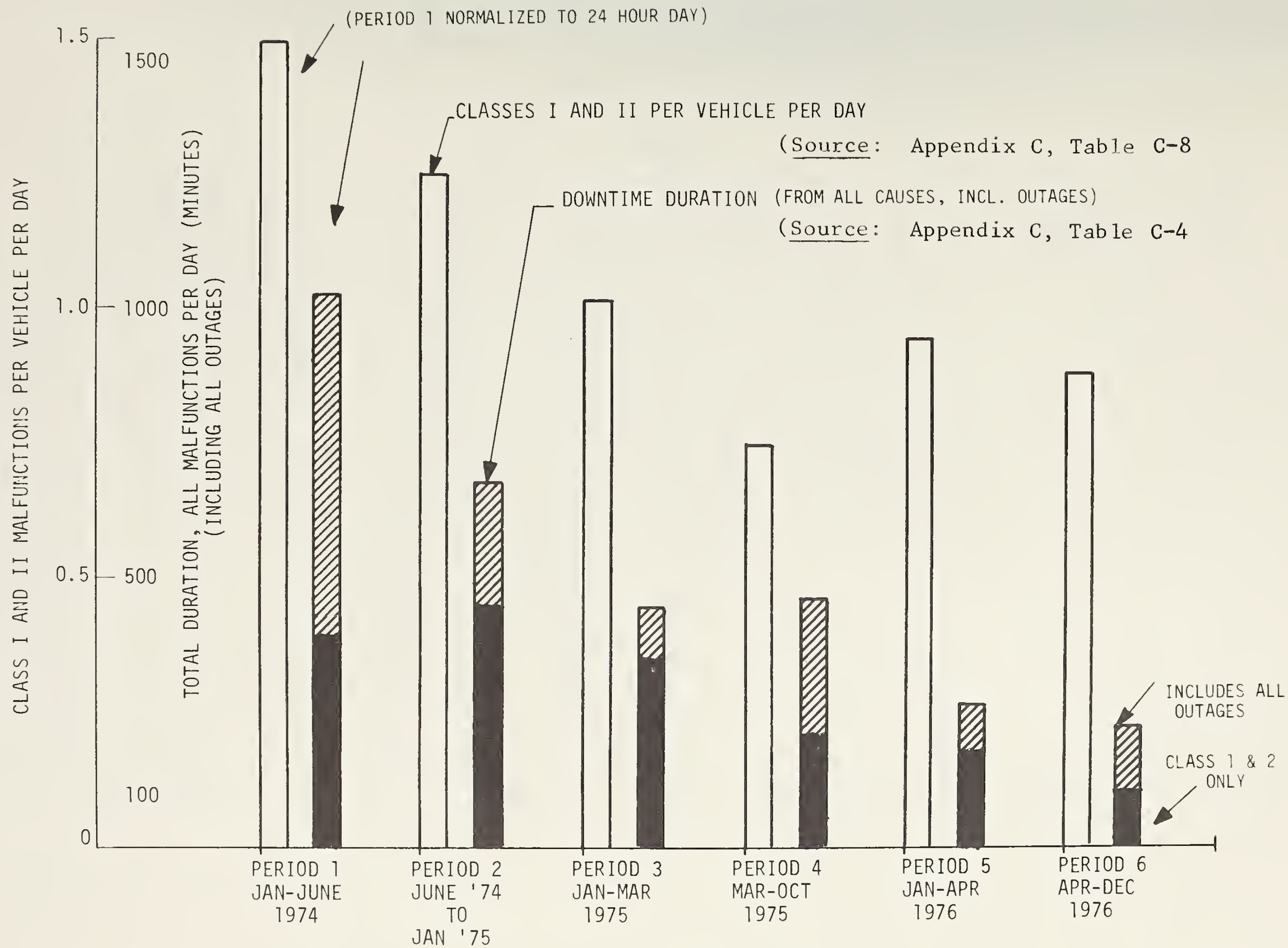


FIGURE 3-14. CLASS I & II MALFUNCTIONS PER VEHICLE AND TOTAL MALFUNCTION DURATIONS PER DAY

NOTES: - 3-MONTH SHUTDOWN OCCURRED AT END OF PERIOD 4
- APB TOOK OVER SYSTEM OPERATION AND MAINT. AT START OF PERIODS
- EMPLOYEE SERVICE BEGAN AT START OF PERIOD 6

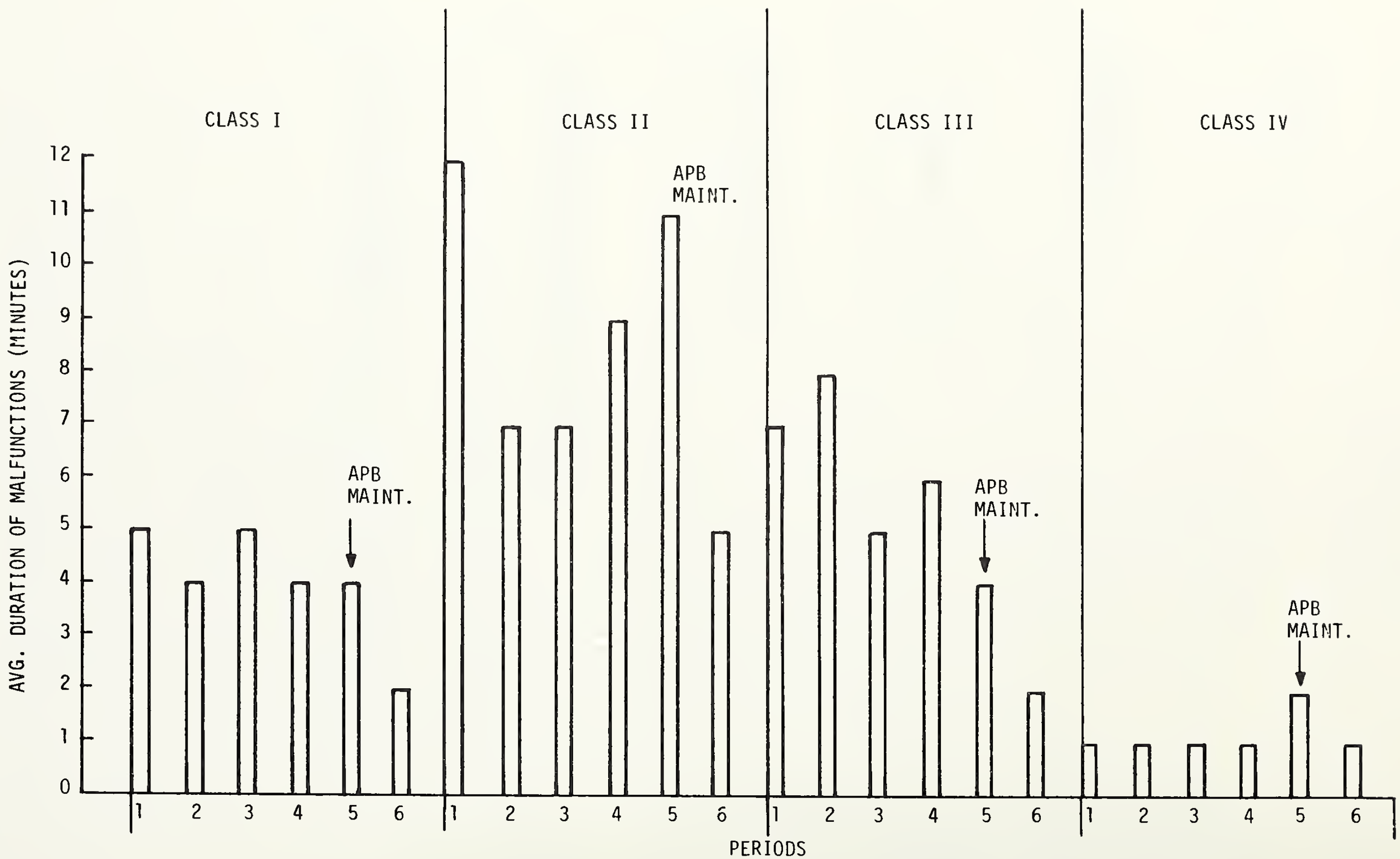
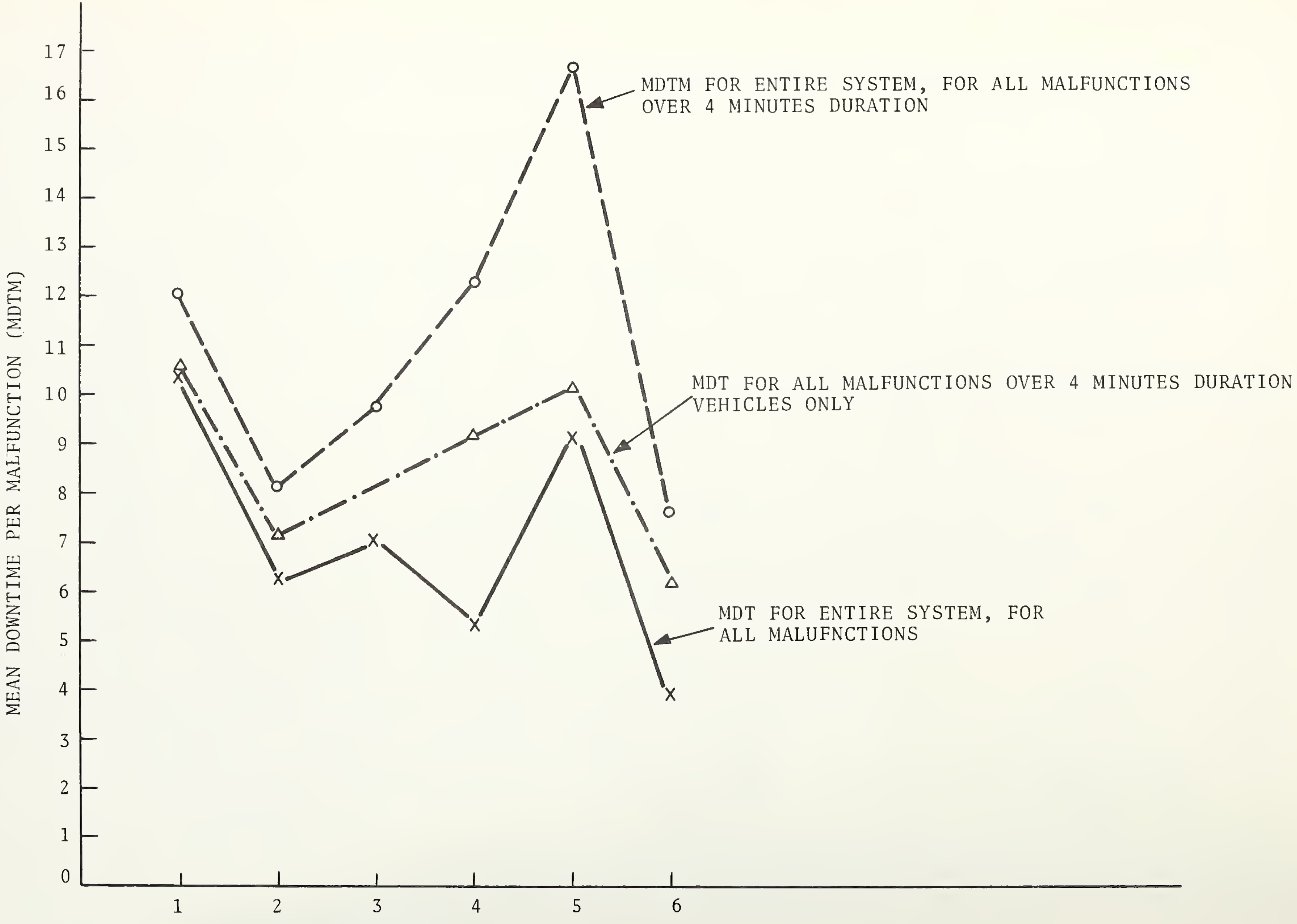


FIGURE 3-15. AVERAGE DURATION OF MALFUNCTIONS PER PERIOD
(Data from Appendix C, Table C-4

TABLE 3-7. AIRTRANS DOWNTIMES FOR CLASS I & II MANFUNCTIONS (ALL STOPPAGES EXCLUDING TOTAL SYSTEM OUTAGES)

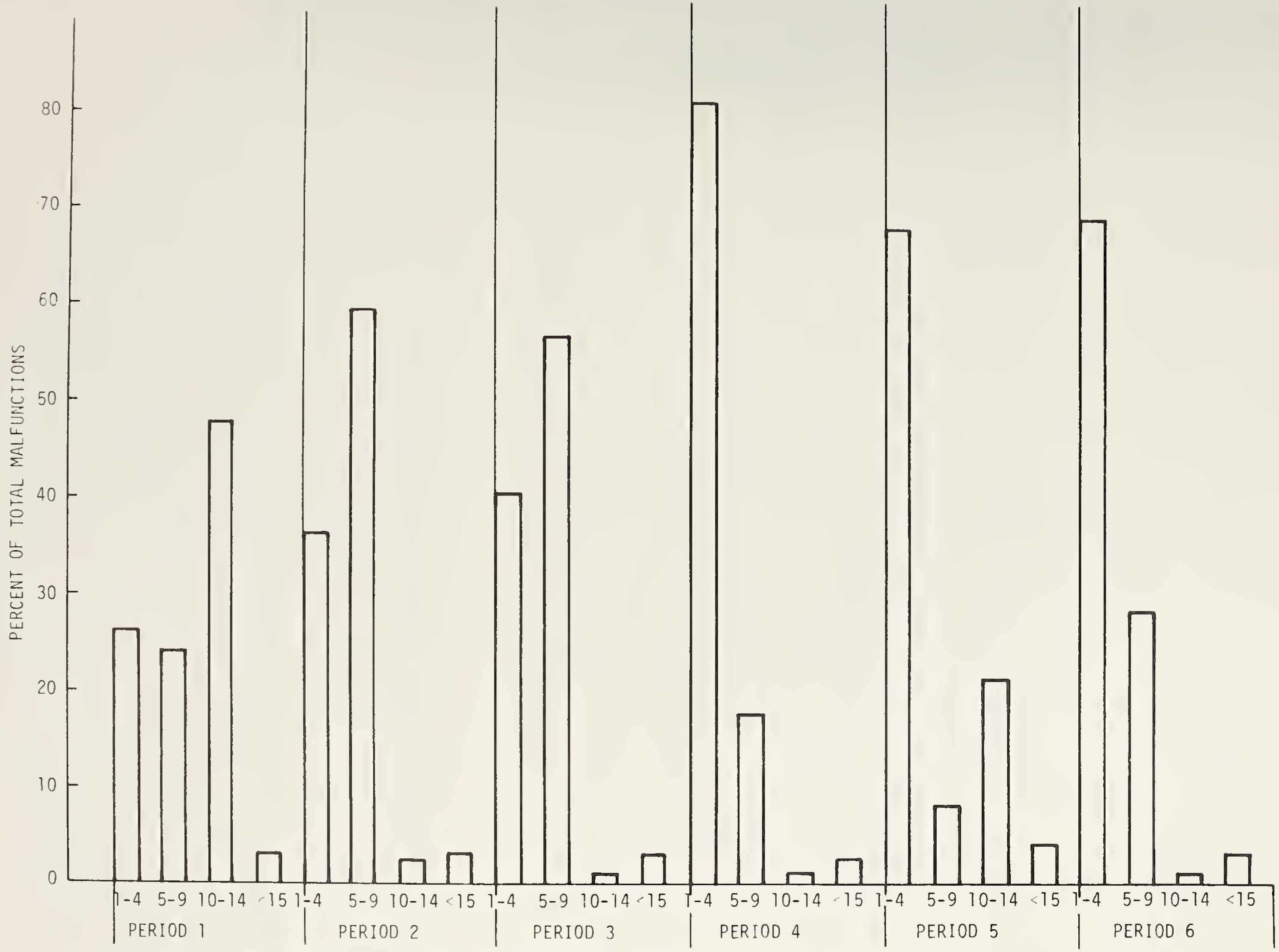
PERIOD	MEAN DOWNTIME PER MALFUNCTION (MDTM) FOR ALL CLASS 1 & 2 ENTIRE SYSTEM	MDTM FOR ALL CLASS 1 & 2 GREATER THAN FOUR MINUTES (ENTIRE SYSTEM)	MDTM ALL CLASS 1 & 2 GREATER THAN FOUR MINUTES (PASS. VEH. ONLY)
	MINUTES	MINUTES	MINUTES
1	10.4	12	10.5
2	6.2	8.1	7.1
3	6.5	9.8	6.9
4	5.3	12.3	9.2
5	9.2	16.7	10.2
6	3.9	7.6	6.2

Source: Data from Appendix H, Table H-2.



Source: Data from Appendix H, Table H-2.

FIGURE 3-15A. AIRTRANS MEAN DOWNTIMES FOR CLASS 1 & 2 MALFUNCTIONS (ALL STOPPAGES EXCLUDING TOTAL SYSTEM OUTAGES)



NOTE: TIMES ON HORIZONTAL SCALE ARE IN MINUTES OF MALFUNCTION DURATION

Source: Data from Appendix C, Table C-11.

FIGURE 3-16. PERCENT OF TOTAL MALFUNCTIONS WITHIN EACH TIME BRACKET durations decreased from 47 percent in Period 1 to 1 percent in Period 6. Again, operations are improving after the shutdown. Long delays of over 10 minutes in Period 5 made up 25 percent of the total malfunctions, but this dropped to 4 percent in Period 6. (Note that total malfunctions in Figure 3-15 are classified by 1, 2, 3, or 4, while in Figure 3-16 all classes are lumped together.)

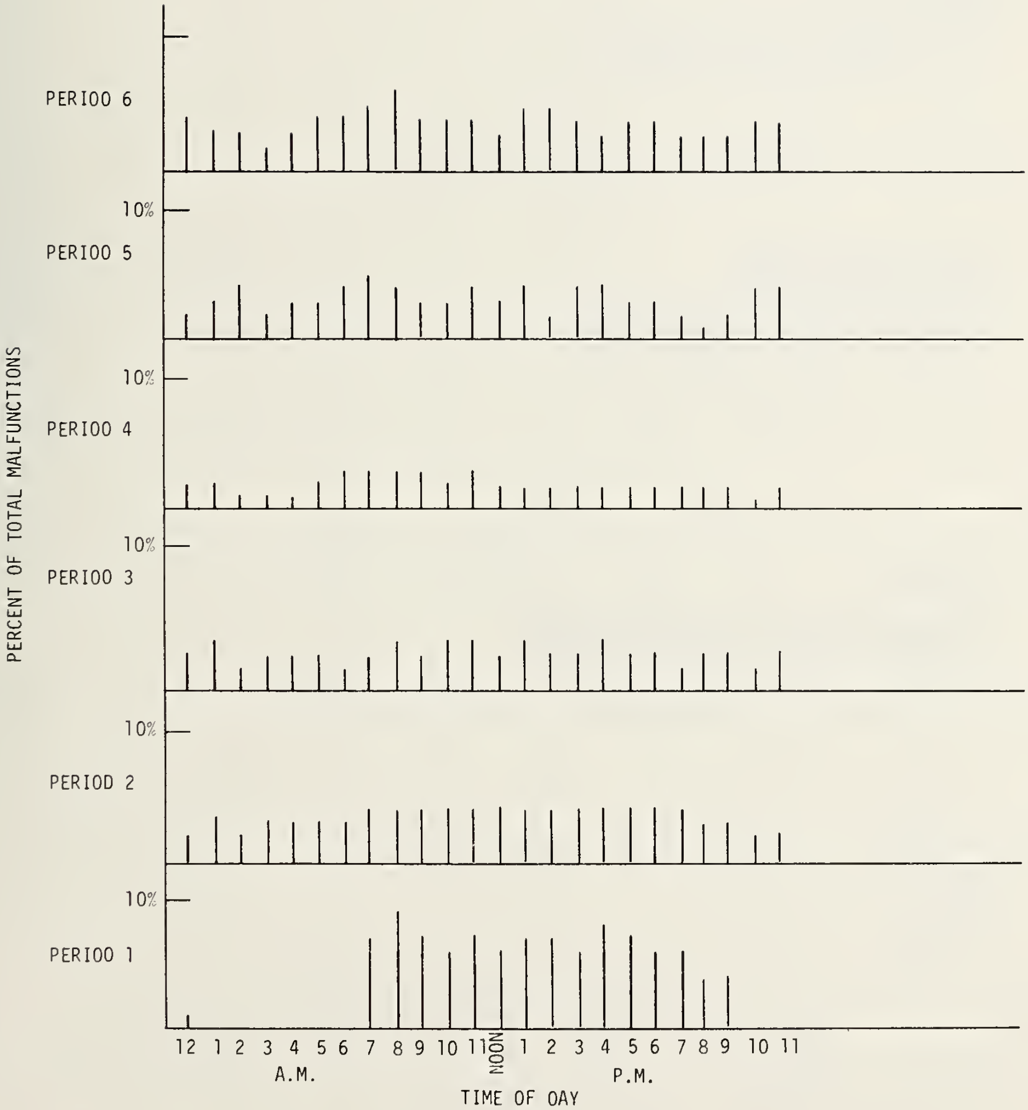
A third view of time distribution of malfunctions is depicted in Figure 3-17. Here the failures by hour of the day are plotted as percents of total failures during the day. As might be expected, the failure count is smaller during the off-peak hours when less equipment is in use than during peak hours. The variation is not a drastic one, however, and many vehicles are still in the system, going to maintenance, being tested, etc.

A look at the distribution of malfunctions by causes shows a large scattering of a few each for many causes, with about seven causes accounting for approximately two-thirds of those affecting movement and control per day. These causes and their contribution to daily malfunctions are shown in Table 3-8. A complete definition of all malfunction causes identified in the records is included in Appendix C. Several charts are also included there, showing in histogram form the frequency and average duration of each type.

3.6 RESULTS: COMPONENT AND SUBSYSTEM RELIABILITY

As mentioned earlier, the incidence of verified failures to components and subsystems was derived from the maintenance records kept by Vought, the system manufacturer, for the first two years of the system's life. In analyzing these data it became clear that the incidence of failure for most parts was much higher during the first period, (Jan. - May 1974) than during the last three periods (May 1974 - Sept. 1975); a condition that is not surprising, for the first few months saw the occurrence of a number of infant mortality failures due to design or manufacturing problems.

Figure 3-18 illustrates this point. Apparent Mean Miles Between Failures (MMBF) for traction motors and signal pickups



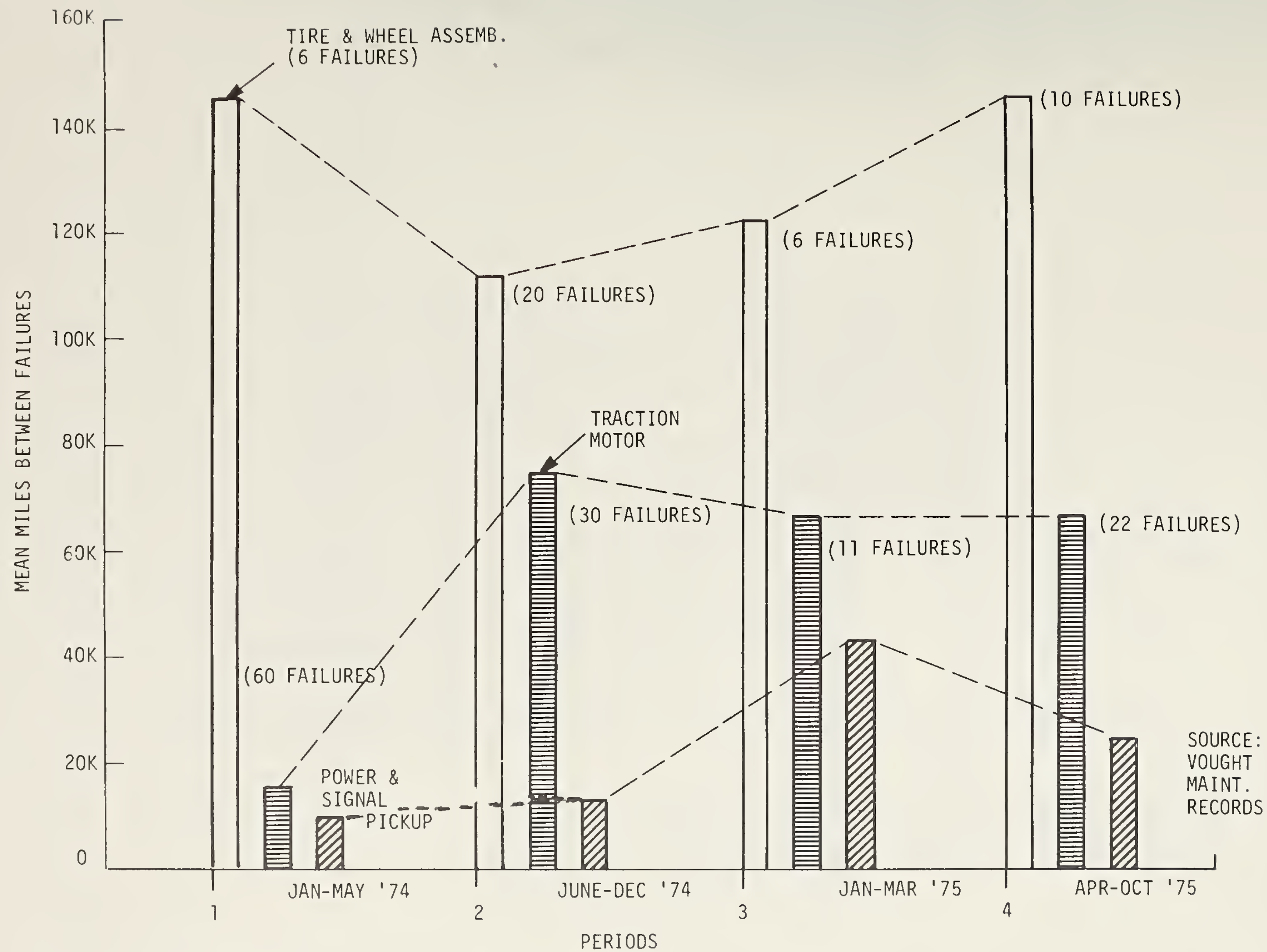
<u>Source</u>: Data from Appendix C.

FIGURE 3-17. DISTRIBUTION OF MALFUNCTIONS BY TIME OF DAY

TABLE 3-8. INCIDENCE OF ON-LINE MALFUNCTIONS

MALFUNCTION \ PERIOD	1	2	3	4	5	6
26 COMPUTER HALTED	56	165	77	77	62	84
52 INNACURRATE STA. STOP.	82	355	344	183	104	223
55 DOOR FAILURE	95	338	151	75	46	60
60 VEHICLE WON'T CALL SW.	100	155	55	44	59	110
62 UNSCHED. DOOR OPENING	69	78	36	35	42	185
66 VEHICLE SPEED BROACH	210	661	244	364	124	593
70 VEHICLE BY-PASSED STATION	245	272	83	22	43	30
TOTAL OF ABOVE	857	2,024	990	800	480	1,285
TOTAL IN SAMPLE	1,402	3,092	1,488	1,271	644	1,678
PERCENT OF CLASS I & II FAILURES	61	65	66	63	75	77

Source: Appendix C, Figures C-7 - C-12.



Source: Data from Table 3-11.

FIGURE 3-18. RELIABILITY HISTORY OF CERTAIN COMPONENTS rose drastically as initial bugs were found and removed.

3.6.1 Characteristics of the Component Data

The characteristics of Vought's data are summarized in Table 3-9. Of the four time periods covered by the data, only the last three were used to derive MMBF and MTBF. Note that what were called "malfunctions"(in the system data analysis) are here reduced to bona fide component failures, verified as such in the maintenance shops. Table 3-10 summarizes the three periods covered, giving also the average number of vehicles in use per day and their average miles per day.

3.6.2 Component and Subsystem MTBFs and MMBFs

Tables 3-11 and 3-12 summarize MMBF or MTBF values for some major system components. Table 3-11 covers vehicle-borne assemblies, and Table 3-12 covers some major wayside assemblies. (The AIRTRANS code numbers and hours of the failure types listed are shown in these tables.) In addition, total maintenance actions per part type, and total maintenance manhours expended are included, and a Mean Time to Repair (MTTR) is calculated from these figures. (Note that the MTTR is really Mean Maintenance Manhours Per Action.) More of this type of information will be presented in the next section.

In Table K-4 of Appendix K, a different view is taken of the data from Period 4 (3/75 - 9/75) as derived from the Vought maintenance records. See Section 5.6.1, f. for a discussion.

TABLE 3-9. CHARACTERISTICS OF THE COMPONENT DATA

1. TIME PERIOD: MAY, 1974 THRU SEPTEMBER, 1975

2. SYSTEM HOURS: 10,870

3. SYSTEM MILES:

L	=	LEAD VEHICLE ONLY:	2,296,000 MILES
LT	=	LEAD & TRAIL VEHICLES:	4,002,000 MILES
U	=	UTILITY VEHICLES:	456,000 MILES
LTU	=	ALL VEHICLES:	4,466,000 MILES
LU	=	LEAD & UTILITY:	2,752,000 MILES

4. ALL FAILURES COUNTED WERE VERIFIED IN THE MAINTENANCE SHOP

5. ONLY UNSCHEDULED MAINTENANCE ACTIONS ARE COVERED

6. MEAN TIME TO REPAIR IS REALLY MEAN MAN HOURS TO REPAIR

7. DATA SOURCE: SYSTEM MANUFACTURER'S "BAD ACTOR" REPORT. THE FIRST 4 MONTHS OF SYSTEM LIFE HAS BEEN REMOVED FROM THE TOTALS

TABLE 3-10. SYSTEM STATISTICS FOR COMPONENT STUDIES

	JUNE, '74-DEC., '74	JAN., '75-MAR., '75	APRIL, '75-SEPT., '75
AVG. NO. OF PASSENGER VEHICLES	39	38	28
AVG. NO OF UTILITY VEHICLES	7	2	2
AVG. PASS. VEH. SYSTEM MILES PER DAY	8,700	7,800	8,000
AVG. MILES PER DAY PER PASS. VEHICLE	220	205	282

TABLE 3-11. RELIABILITY AND MAINTAINABILITY OF AIRTRANS VEHICLE COMPONENTS EXPRESSED AS MEAN MILES BETWEEN FAILURES (MMBF) & MEAN TIME TO REPAIR (MTTR)

Mileage: L = 2.296×10^6; LT = 4.002×10^6; U = 0.456×10^6; LTU = 4.466×10^6; LU = 2.752×10^6									
Name	Code	Used On	Quan. per Unit	Total Failures	*MMBF (Veh.)	MMBF (Part)	Total Maint. Actions	Total Maint. Manhours	MTTR
Traction Motors	11EC1	LTU	1	63	70,884	70,884	318	588	1.84
Brake Ass'y	11GO0	LTU	1	6	744,279	744,279	18	20.9	1.16
Guide/Sw. Wheel Ass'y	11CA5	LTU	4	256	17,444	69,775	2425	2138	0.88
Doors	11DB0	LT	2	70	57,164	114,328	465	554	1.19
Door Operator	11DA0	LT	1	89	44,961	44,961	313	540	1.73
Power and Signal Pickups	11EA1	LTU	4	952	4,200	16,800	2965	2968	1.0
Audio Announcement Unit	11KC0	L	1	697	3,294	3,294	4363	4426	1.0
Tire and Wheel Ass'y	11BA4	LTU	4	36	124,047	500,000	587	1167	1.98
AVO Module	11MA7	LU	1	377	7,300	7,300	1083	4256	3.92
Cont. Logic Ass'y	11MA4	LU	1	266	10,346	10,346	2425	2138	0.88
AVP Receiver Module	11MA5	LU	1	137	20,087	20,087	435	1591	3.65
W-V Receiver Module	11MAF	LU	1	134	20,537	20,537	340	1241	5.17
Elec.Pwr. Dist.Panel	11EB2	LTU	1	56	178,640	178,640	101	996	0.98

*See next page.

TABLE 3-11. RELIABILITY AND MAINTAINABILITY OF AIRTRANS VEHICLE COMPONENTS EXPRESSED AS MEAN MILES BETWEEN FAILURES (MMBF) & MEAN TIME TO REPAIR (MTTR) (CONTINUED)

Mileage: L = 2.296 x 10^6; LT = 4.002 x 10^6; U = 0.456 x 10^6; LTU = 4.466 x 10^6; LU = 2.752 x 10^6									
Name	Code	Used On	Quan. per Unit	Total Failures	MMBF (Veh.)	MMBF (Part)	Total Maint. Actions	Total Maint. Manhours	MTTR
J-Relay Module	11MA8	LTU	1	86	51,930	51,930	243	843	3.47
Air Conditioners A	11JA1	LT	1	172	23,267	23,267	344	500.5	1.45
B	11JA2	LT	1	76	52,657	52,657	121	211	1.75
Coupler Ass'y	11CA1	LTU		5	893,200	893,200	20	19.9	1.0
Alternator	11EB1	LTU	1	81	55,132	55,132	255	514	2
Battery	11EB3	LTU	1	2	$2.23x10^6$	$2.23x10^6$	24	16.1	0.67
Power Sup. Module	11MAA	LTU	1	87	51,333	51,333	223	564	2.5
Propulsion Controller	11EC2	LTU	1	139	32,129	32,129	301	1038	3.45

Source: Vought-LTV printouts of maintenance records for periods Jan. 1974 thru Sept. 1975.

Period Actually Covered: June 1974 thru Sept. 1975; miles as indicated on top line; system time = 10,870 hours.

Legend: L = Lead Vechicle Only; LT = Lead and Trailing Vehicles; U = Utility Vehicle Only; LTU = All Vehicles; LU = Lead and Utility Vehicles.

Code is the AIRTRANS designation for the component or subsystem; MMBF = Mean Miles Between Failures; MTTR = Mean Time To Repair.

Note: In this table, Mean Miles Between Failures were derived by dividing total system miles by total system failures. This is proven valid by the following relationship:

For any part -- $\frac{\text{Total System Miles}}{\text{Total Vehicle Failures (Due To That Part)}} = \frac{\text{(Avg. Number of Veh. In Use) x (Avg. Veh. Miles)}}{\text{(Avg. Number of Veh. In Use) x (Avg. Veh. Failures)}} =$

vehicle miles per failure or MMBF for the vehicle. (This is true only if the MMBF (or failure rate) is constant.)

TABLE 3-12. RELIABILITY AND MAINTAINABILITY OF SELECTED WAYSIDE EQUIPMENT EXPRESSED AS MTBF AND MTTR.

Name	Code	Used On	Quan. per Unit	Total Failures	MTBF (Unit)	MTBF (Part)	Total Maint. Actions	Total Maint. Manhours	MTTR
Central Computer	32ACO	Wayside	1	2	5,439	5,439	49	131	2.7
Wayside Computer	32ABO	Wayside	5	10	1,087	5,435	43	151	3.5
Switch Machine	51AE8	Wayside	31	50	218	6,744	66	206	3.1
Power Rail	41EAO	Wayside	39 mi.	8	1,359	52,931 hrs./mi.	53	194	3.66
Signal Rail	41GAO	Wayside	26 mi.	17	639	16,644 hrs./mi.	174	287	1.65

Note: System Time - 10,870 hours

3.7 RESULTS: MAINTENANCE AND MAINTAINABILITY

3.7.1 General

The maintainability data taken from the maintenance records (MRs) for the sample days, as already described, were analyzed from several points of view.

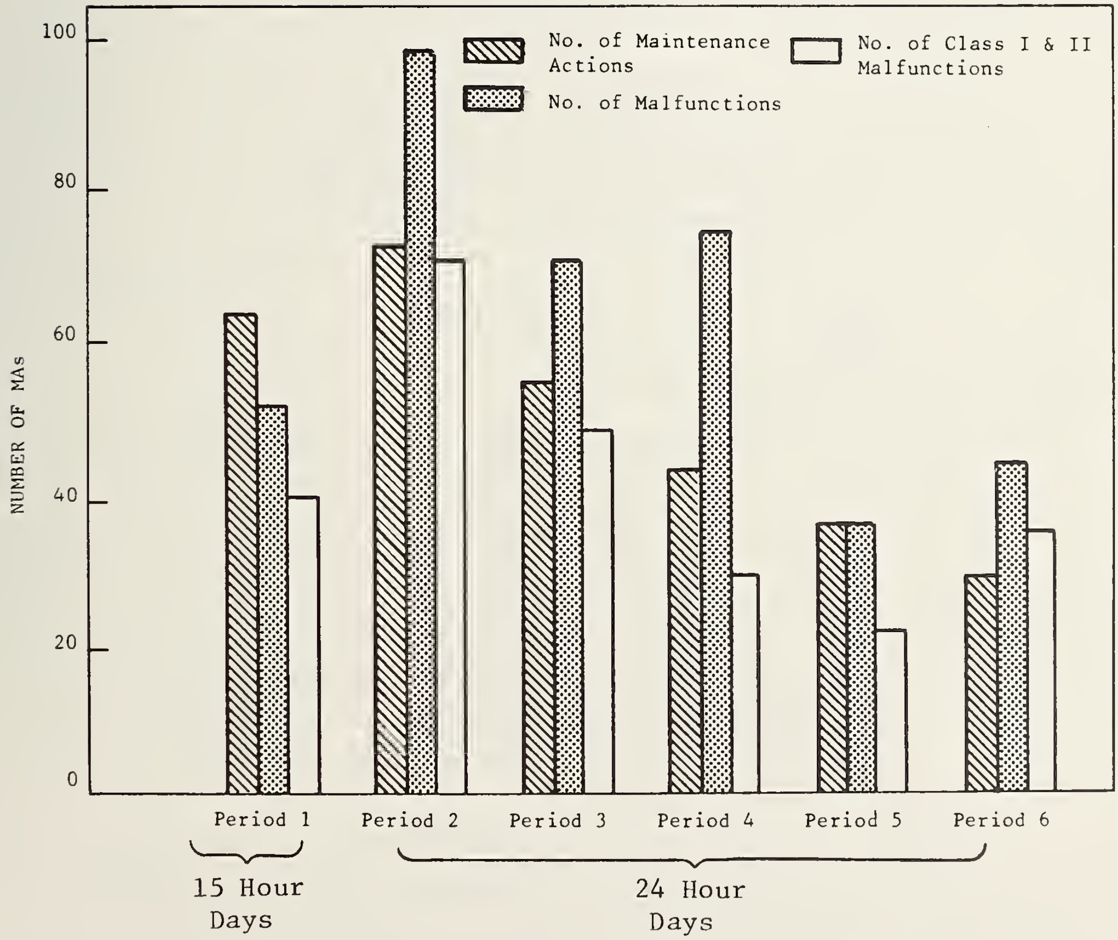
The so-called "off-system maintenance actions" include everything done to the vehicles in the maintenance shops and everything done to the wayside system in the way of diagnosis and repair, no matter where it is done. In the records transcribed from the MRs, preventive maintenance was not included for either vehicles or wayside. The analysis to follow, therefore, is entirely on maintenance actions in the diagnosis and repair of presumed equipment failures. As will be noted, in a certain percentage of maintenance actions the shop could not verify the existence of a failure.

3.7.2 Malfunctions versus Failures

As has been stated previously, the number of verified failures in general is smaller than the number of malfunctions. Figure 3-19 shows this graphically for the six periods. The data for Period 1, however, show the reverse. This situation resulted from emergency action taken to keep the system going in a period of frequent breakdown. In March and April so many malfunctions were occurring daily, that Central Control was overloaded. At that time attendants were still on the vehicles, and they successfully performed system restarts locally. Such events were, however, never entered into the logs; the logged events were therefore fewer than the maintenance actions, giving the distorted figures shown in the chart.

3.7.3 The AIRTRANS Maintenance Report

The MR was illustrated in Figure 3-4 in an earlier subsection. Table 3-13 shows a decreasing trend of the number of maintenance actions and total expenditure of manhours.



Source: Data from Table 3-13 and Appendix C, Table C-4.

FIGURE 3-19. THE NUMBER OF MAINTENANCE ACTIONS PER DAY VS. THE NUMBER OF MALFUNCTIONS PER DAY

TABLE 3-13. MAINTENANCE ACTIONS

Periods	Average Number of Maintenance Actions Per Day*	Total Manhours Per Day*	Estimated Total Number of Maintenance Action Per Period*	MTTR Or MMH Per Action
1 (n=16, d=138)	64	152.1	8,832	2.37
2 (n=43, d=214)	73	122.4	15,622	1.67
3 (n=28, d=80)	55	105.0	4,400	1.9
4 (n=41, d=180)	43	75.3	7,740	1.75
5 (n=31, d=72)	36	71.7	2,592	1.99
6 (n=46, d=275)	29	49.4	7,975	1.7

Note: n = sample days, d = actual operating days

*The standard errors of these estimates are 5 to 9% of the estimates. Also, the sample size in Period 1 drops because no maintenance records were kept before March 31, 1974.

3.7.4 Number of Maintenance Actions

The actual number of maintenance entries transcribed for the sample days was 10,104. In 27 percent of these entries, a second action was required, and 10 percent needed a third action. Some of these entries included not only "first actions" but as many as two subsequent actions. Figure 3-20 shows the percent of all maintenance reports (MRs) on which two or three maintenance actions were required. The number of third actions decreased to a negligible quantity in Periods 5 and 6.

It is important to note that in counting maintenance actions each MR counts as one, even though there may be a second and third action included; and the time recorded is for the entire series of actions. This is because, by definition, the second and third actions do not stand by themselves, but are required to complete the MR.

3.7.5 Kinds of Maintenance Actions

The maintenance actions taken are categorized as follows, and the code letters are used in the data transcription:

NV - Reported problem was not verified

NM - Notified management of further (non-maintenance) action required

RS - Reset

RR - Removed and replaced faulty subsystem or component

RP - Repaired faulty subsystem or component

RV - Returned to vendor for repair

DP - Action deferred for lack of parts

D - Action deferred

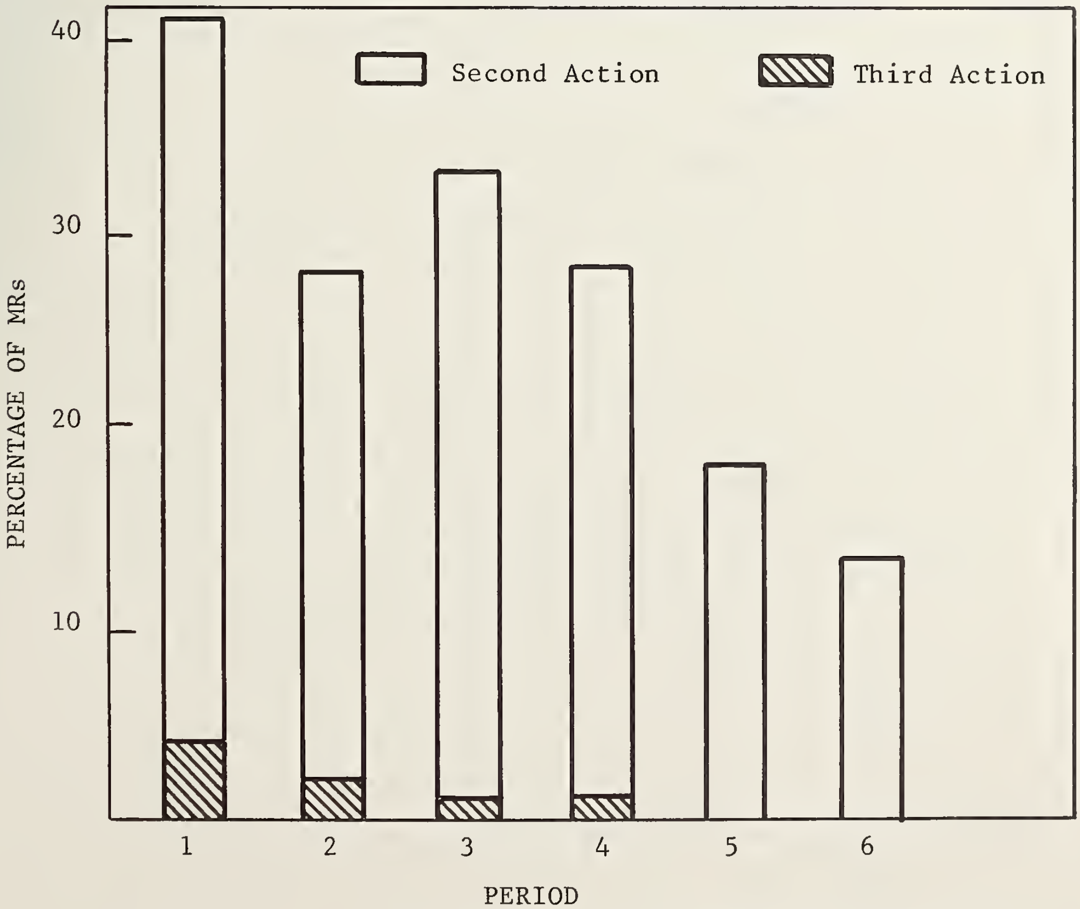


FIGURE 3-20. PERCENTAGE OF MAINTENANCE ACTIONS REQUIRING MORE THAN ONE ACTION

A - Adjusted subsystem or component

I - Inspected subsystem or component

M - Made design modifications

S - Scrapped subsystem or component

X - Indeterminate from the record.

The distribution of these kinds of actions by percentages in each period is tabulated in Table 3-14, and plotted as histograms in Figure 3-21.

It is interesting to note that the "not verified" category shrank as a percentage of all actions, from 13.5 percent in Period 4 to 4.7 percent in Period 6. The "indeterminate" category is simply a measure of the unclear or incomplete data in the record.

3.7.6 Grouping of Maintenance Actions by Types of Maintenance Problems

Maintenance problems are identified by numerical code, according to the following definitions:

1 - Subsystem or component permanently inoperative
2 - Subsystem or component operating incorrectly
3 - Excessive wear
4 - Component (or subcomponent) physically loose, broken or missing
5 - Out of adjustment
6 - Leaking oil
7 - Requires a design modification
8 - Discrepancies discovered during inspection
9 - Software problems
10 - Fire damage
11 - Dirty
12 - Problem due to external causes
13 - Time change out
14 - Vandalism.

Note also that vandalism was a very small percentage of all maintenance problems, less than 0.5 percent at its worst.

TABLE 3-14. MAINTENANCE ACTIONS, PERCENTS PER PERIOD

	PERIOD					
	1	2	3	4	5	6
RR (Removed and Replaced)	35.7	35.1	38.8	31.7	49.2	56.1
RP (Repaired)	24.6	30.1	27.9	31.3	25.9	29.1
NV (Not verified)	12.2*	11.8*	12.2	13.5	9.2	4.7
A (Adjusted)	7.1	8.0	8.8	5.6	8.5	5.9
RV (Return to vendor)	5.5	7.3	12.2	9.4	0	0.1
M (Design mods. made)	3.6	2.5	1.3	0.7	1.2	0.3
I (Inspected)	3.3	1.2	0	0	0.4	0.3
RS (Reset)	1.1	0.9	0.5	4.1	0.4	0.2
S (Scrapped)	1.0	0.5	0.58	0.6	0	0
D (Action deferred)	1.0	0.6	0.2	0.5	0.4	0.4
NM (Notified management)	0.5	0.4	0.1	0.1	0.1	0
DP (Lack of parts)	0.2	0.3	0.1	0.3	1.6	0.8
X (indeterminable)	3.9	1.1	1.0	2.0	2.9	2.1

*It is suspected that these numbers may be low for Period 1 and Period 2 due to variations in maintenance report forms and procedure and to human error.

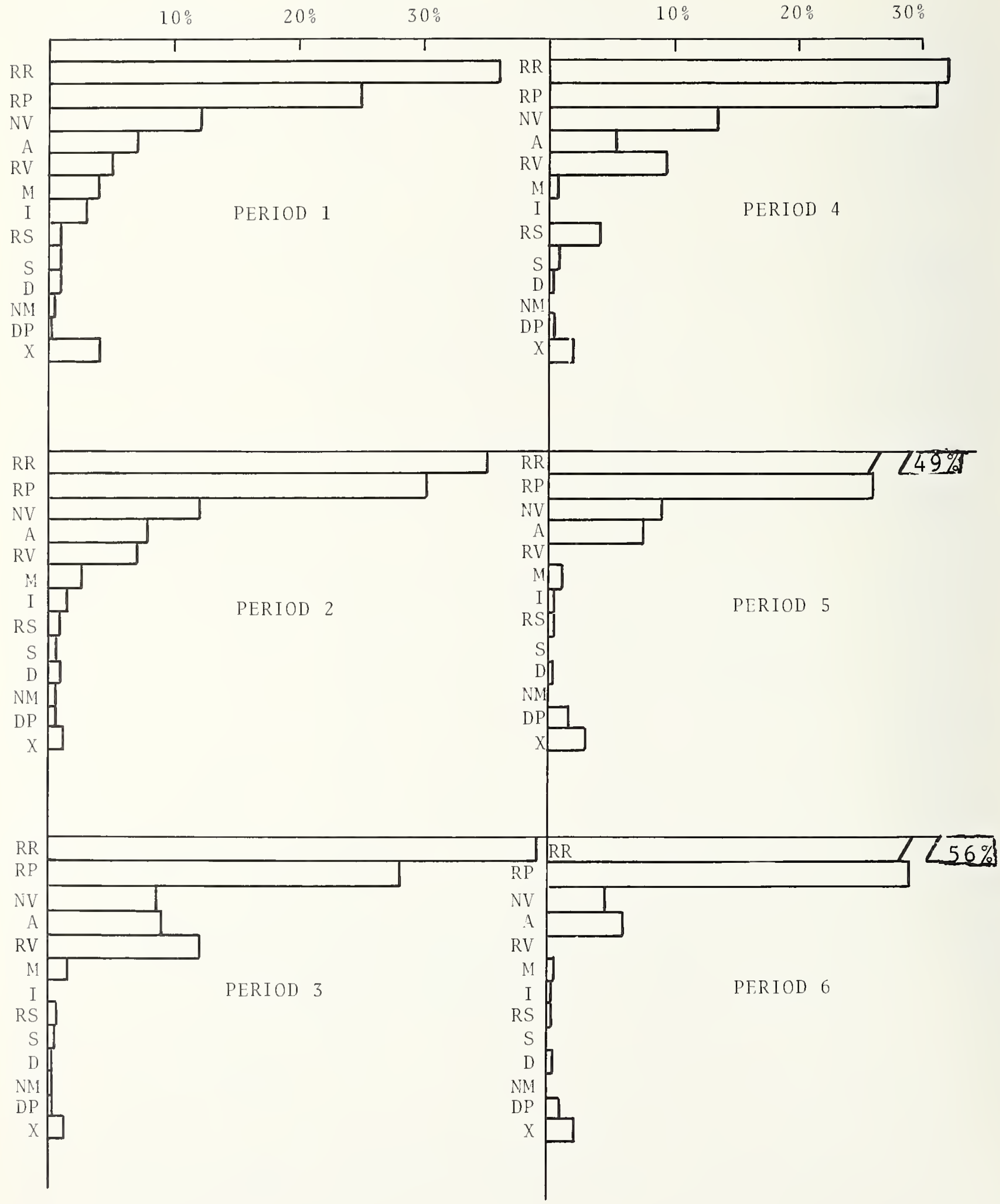


FIGURE 3-21. DISTRIBUTION OF MAINTENANCE ACTIONS BY TYPE

Table 3-15 and Figure 3-22 graphically depict the incidence of each of these causes.

TABLE 3-15. MAINTENANCE ACTIONS BY TYPE

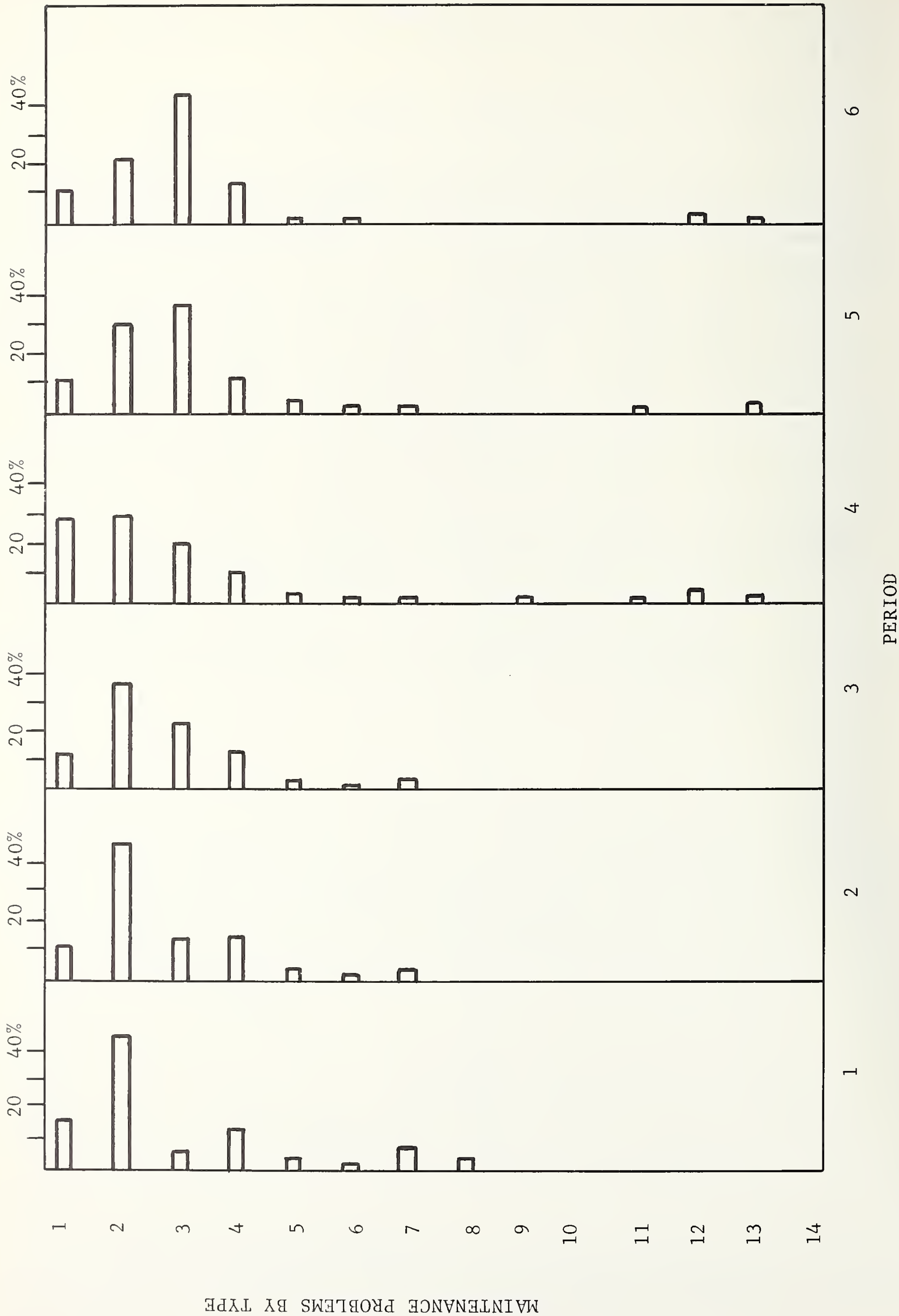
TYPE	PERIOD 1	2	3	4	5	6
0(undefined)	1	0	0	0	0	0
1	172	393	206	490	130	152
2	475	1497	559	525	338	310
3	60	486	363	367	411	611
4	140	485	205	195	124	194
5	43	114	65	58	48	43
6	12	19	15	13	8	15
7	77	129	56	22	16	7
8	45	45	3	1	1	4
9	3	14	12	10	1	0
10	6	6	3	5	2	5
11	1	8	10	14	6	1
12	0	12	9	56	4	1
13	0	3	30	41	36	40
14	0	0	6	2	1	8
	1035	3211	1542	1799	1126	1391

Figure 3-22 offers a visual comparison of the distribution of maintenance actions among the 14 types of maintenance problems. There is a significant switch from Problem 2 (subsystem or component operating incorrectly) to Problem 3 (excessive wear) as time progresses. Eighty to 85 percent of all actions fall into the first four categories.

3.7.7 Duration of Maintenance Actions

Figure 3-23 shows graphically the percent of all maintenance actions in the sample in each 1/2 hour time bracket, from 1/2 hour to eight hours.

Figure 3-24 shows a similar distribution for the six subsystems or equipment that used the most maintenance time.


MAINTENANCE PROBLEMS BY TYPE
PERIOD
1
2
3
4
5
6
7
8
9
10
11
12
13
14
20
40%

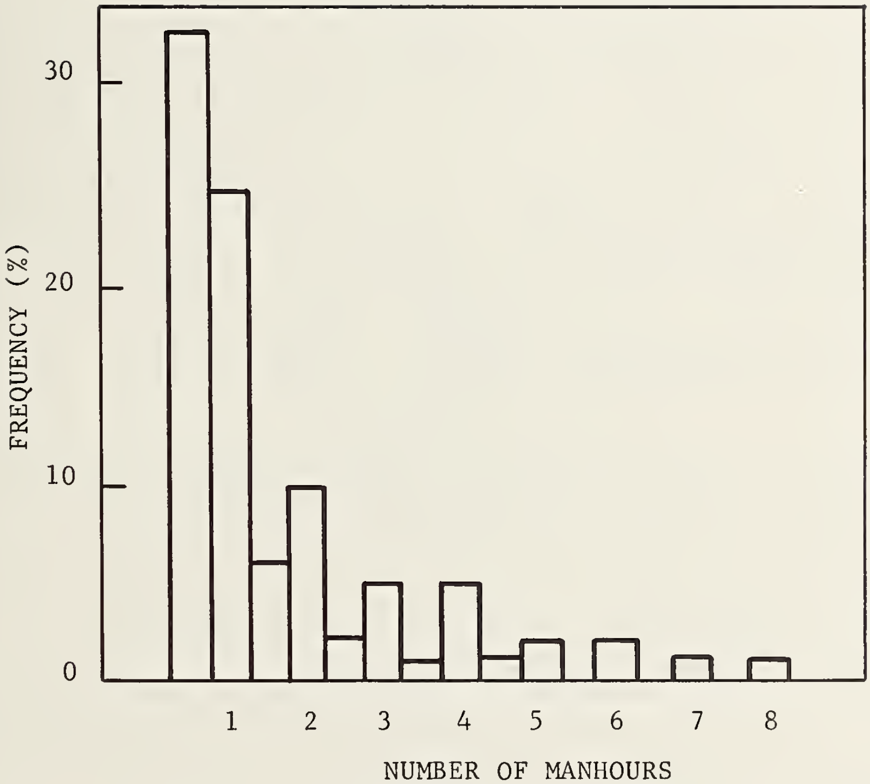


FIGURE 3-23. FREQUENCY DISTRIBUTION OF MANHOURS

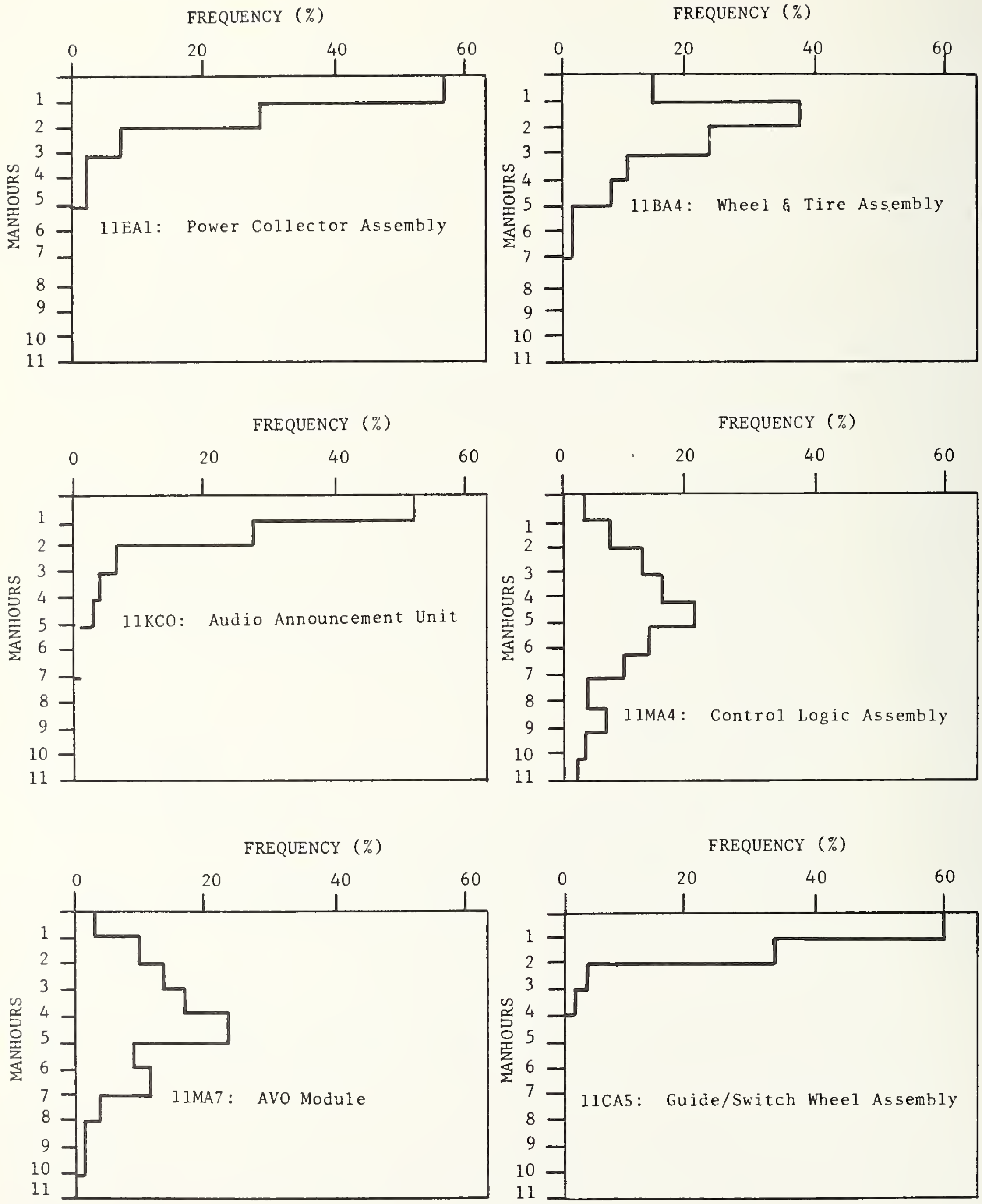


FIGURE 3-24. FREQUENCY DISTRIBUTION OF MANHOURS EXPENDED ON THE TOP SIX MOST ACTIVE SUBSYSTEMS

The mean time to repair these and other equipments, as derived from the 100 percent data from Vought's records, have already been presented in Table 3-11 of Section 3.6. A frequency distribution of manhours is shown in Table 3-16.

Only 1 percent of the maintenance actions required more than 10 manhours of work, whereas 58 percent of the problems required one hour or less.

3.8 CONCLUSIONS

The previous sections have presented AIRTRANS system availability and reliability, subsystem reliability and maintainability, and some component reliability figures.

The results have some limitations:

a. As mentioned in the text, they were derived from samples of the operating data. They therefore have a statistical uncertainty associated with them, which is elaborated in Appendix B.

b. The system records malfunctions , not failures, and there is no exact way to separate the subset of failures from the overall mass of malfunctions.

c. Maintenance data from the shops cannot be correlated, in most cases, with on-line downtime events.

d. On-line events are described by symptoms, not causes. In many of the events real causes cannot be determined. Appendix G investigates two specific malfunctions, computer stoppages and speed broaches. Certain system fixes were performed to reduce the time lost for each speed broach, thus making the malfunction easier to live with, but the cause was not determined. In the other case, the effect of the change was masked by the fact that a central computer stoppage did not immediately affect movement and control. Despite these shortcomings, the data had a wealth of information in them. The results presented a fair picture of an AGT system's overall

TABLE 3-16. NUMBER OF MAs VS. MANHOURS

Manhours Required	Number of MAs
0.1 - 0.5	349
0.6 - 1.0	3,305
1.1 - 1.5	2,569
1.6 - 2.0	558
2.1 - 2.5	1,024
2.6 - 3.0	211
3.1 - 3.5	554
3.6 - 4.0	97
4.1 - 4.5	543
4.6 - 5.0	59
5.1 - 5.5	213
5.6 - 6.0	34
6.1 - 6.5	233
6.6 - 7.0	23
7.1 - 7.5	61
7.6 - 8.0	16
8.1 - 8.5	92
8.6 - 9.0	6
9.1 - 10	21
longer than - 10	32
	104
	10,104

operations. They also serve as a case study showing that simple means of data recording (handwritten logs) complicate the analysis of the recorded data by making its use very time consuming and costly. In new systems, newer and more accessible ways of recording and processing the data should be provided to match the operators to a rapid response data system.

4. OPERATIONAL SAFETY REVIEW

AIRTRANS is the largest Automatic Guideway Transit (AGT) system with unmanned vehicles in operation in the United States. The system offers a wide range of services and caters to different kinds of patrons. It carries regular commuters (airport employees) as well as one-time users (airline passengers in transit) on dedicated routes and stations.

After several years of revenue operation it is useful to examine how the system has been performing in terms of safety and what lessons have been learned in revenue operation.

This section will not discuss the safety approach followed by LTV since it was fully described in the Phase I AIRTRANS assessment (Section 3.6). Only the safety performance of the the system will be reviewed, and only the time span from January 19, 1976 until June 30, 1977 will be covered in the assessment.

4.1 METHODOLOGY OF THE ASSESSMENT

4.1.1 Choice of an Accident Classification

At the time of the review, the system operator (the airport) had not come up with an accident classification system. (Airport management is to develop one at a later date.)

In order to present the results of assessment, it was decided to follow the classification system developed by the Paris Transit Authority (RATP) for the French PRT system Aramis. This accident classification evolved from the analysis of Paris Metro accidents. Nearly 6000 accident reports spanning 15 years of operation were analyzed[8].

Basically an accident report file will include descriptions of accidents of a wide range of seriousness: from bruises to death. Suicides* and sicknesses are also recorded in this file. However, they are analyzed separately since they are not necessarily linked to the system. Maintenance-related accidents are not part of this file, and the RATP report does not cover this aspect of safety. They are discussed, however, in Section 4.2.3.

Figure 4-1 presents a causal and geographical breakdown of the statements. The two main categories of accidents are determined by the location of occurence:

- Platform and accesses
- On board, (including egressing).

The last one is divided into three subcategories based upon the operator liability:

- System accidents (full liability of the operator)
- Passenger-system accidents (liability shared between operator and riders)
- Passenger accidents (the liability of the operator is not involved).

Other indicators related to the seriousness of the accident allow breaking down the figure in minor and fatal injuries, collective and individual accidents. For more details it is suggested that the reader consult Table 4-1.

This classification is limited to rider-related accidents. One should be aware that other kinds of accidents may occur in any transit system such as accidents to maintenance personnel and accidents involving trespassers and intrusions.

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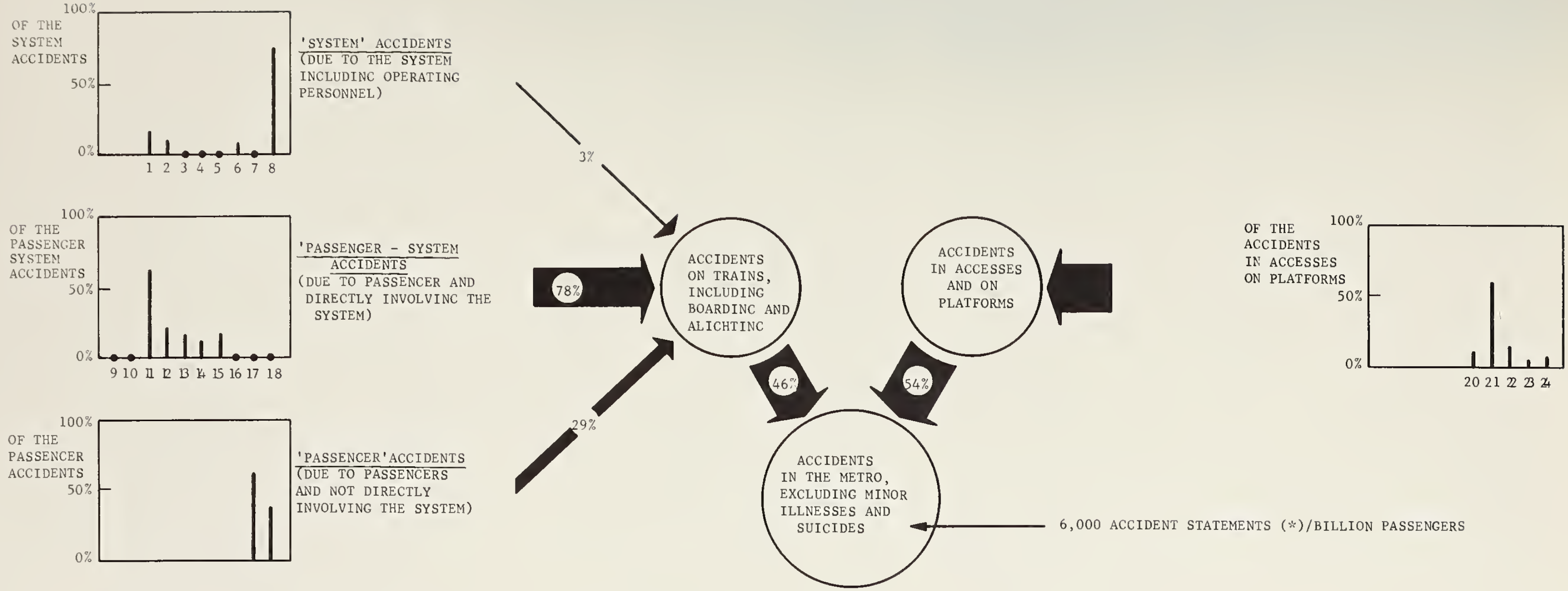
*The study has shown that the Metro suicide pattern is similar to the one in the city of Paris. The same can be said of the sickness pattern observed in the subway and Paris in general.



(1) THIS INCLUDES ALL BODILY INJURIES, EVEN THE MOST BENIGN (SCRATCHES FOR EXAMPLE). THIS FIGURE DOES NOT INCLUDE MINOR ILLNESSES - WHICH CAN BE ATTRIBUTED TO MANY DIFFERENT CAUSES - NOR SUICIDE ATTEMPTS (THERE ARE HOWEVER 3500 MINOR ILLNESSES AND 53 SUICIDE ATTEMPTS PER BILLION PASSENGERS. (SEE FIGURE 4-2)

THE NUMBERS SHOWN UNDER EACH DIAGRAM CORRESPOND TO THE 25 TYPES OF ACCIDENTS LISTED BELOW

1 COLLISION BETWEEN CARS
2 COLLISION WITH STATIONARY OBJECT
3 DERAILMENT
4 FIRE
5 EXPLOSION, LEAK
6 SHORT-CIRCUIT
7 POWER CUT
8 ABNORMAL ACCELERATION
9 VICTIM HIT BY VEHICLE
10 VICTIM DRACCED ALONC-PLATFORM
11 VICTIM TRAPPED IN DOORS
12 FALL IN VEHICLE
13 FALL BETWEEN PLATFORM AND VEHICLE
14 FALL ONTO THE TRACK
15 FALL ONTO THE PLATFORM
16 VICTIM ELECTROCUTED
17 VICTIM ASPHYXIATED
18 VICTIM BURNT
19a SCUFFLES AND ASSAULTS (TRAINS)
19b ACCIDENTAL KNOCKING OF PASSENGER
20 FALL IN ACCESSES (EXCEPT. STAIRWAYS)
21 FALL IN STAIRWAYS (INTERIOR OR EXT)
22 FALL ON THE PLATFORMS
23 INJURY IN TICKET BARRIERS OR PLATFORM DOORS
24 ASSAULT (ACCESSES)

Source: See Reference Page, entry 8.

FIGURE 4-1. CAUSAL AND GEOGRAPHICAL BREAKDOWN OF BODILY ACCIDENT STATEMENTS(1) OCCURRING AMONG PASSENGERS ON THE PARIS METRO BETWEEN 1960 AND 1975 INCLUSIVE

The AIRTRANS accident file will be examined using the following categories:

- Rider-related accidents
- Maintenance-related accidents
- Third-party related accidents.

The rider-related accidents will be examined following the RATP accident classification.

4.1.2 Data Collection

The assessment is based upon the data gathered by the airport management. The assessment team had unrestricted access to the accident file, which was initiated on January 19, 1976 when the airport took over the system.

All accidents are reported in a form similar to the one presented in Appendix F. Whenever a police or hospital report is filed, it is put with the corresponding accident sheet.

Except for a few cases, most of the accidents were well described and causes identified. Whenever possible recommendations were suggested to avoid recurrence.

The time span covered in the assessment goes from January 19, 1976 through July 1, 1977.

4.2 ASSESSMENT RESULTS

The analysis of the accident file showed that 59 accident reports were filed in this time span.

A first breakdown indicates that:

- 6 were related to AIRTRANS riders
- 42 were maintenance-related accidents
- 11 were related to third parties (such as a private automobile hitting the guideway).

4.2.1 Examination of Rider-Related Accidents

The six accidents can be broken up as follows:

- 1 system-related (two vehicles collided - see Section 4.3 and Appendix D for details)
- 5 system-passenger related
- 0 passenger-related

Nine persons were slightly injured in the first category and two in the second one, totalling 11 people injured during the time that over 8 million people were carried. A comparison can be made between AIRTRANS and various other systems. Based upon data used by the airport management (overall average trip length 1.6 km, overall average trip time 10 minutes), one can easily calculate the different values of the indexes shown in Table 4-1, which compares system sizes and safety statistics for six transit modes and AIRTRANS.

A detailed analysis of the system-passenger-related accidents shows that all but one were due to loss of balance while the train was either departing (75 percent) or berthing (25 percent). Women were involved in 75 percent of the cases. The airport management indicated that victims were usually elderly people. Insufficient data pertaining to age did not permit the figure to be broken down with respect to this parameter.

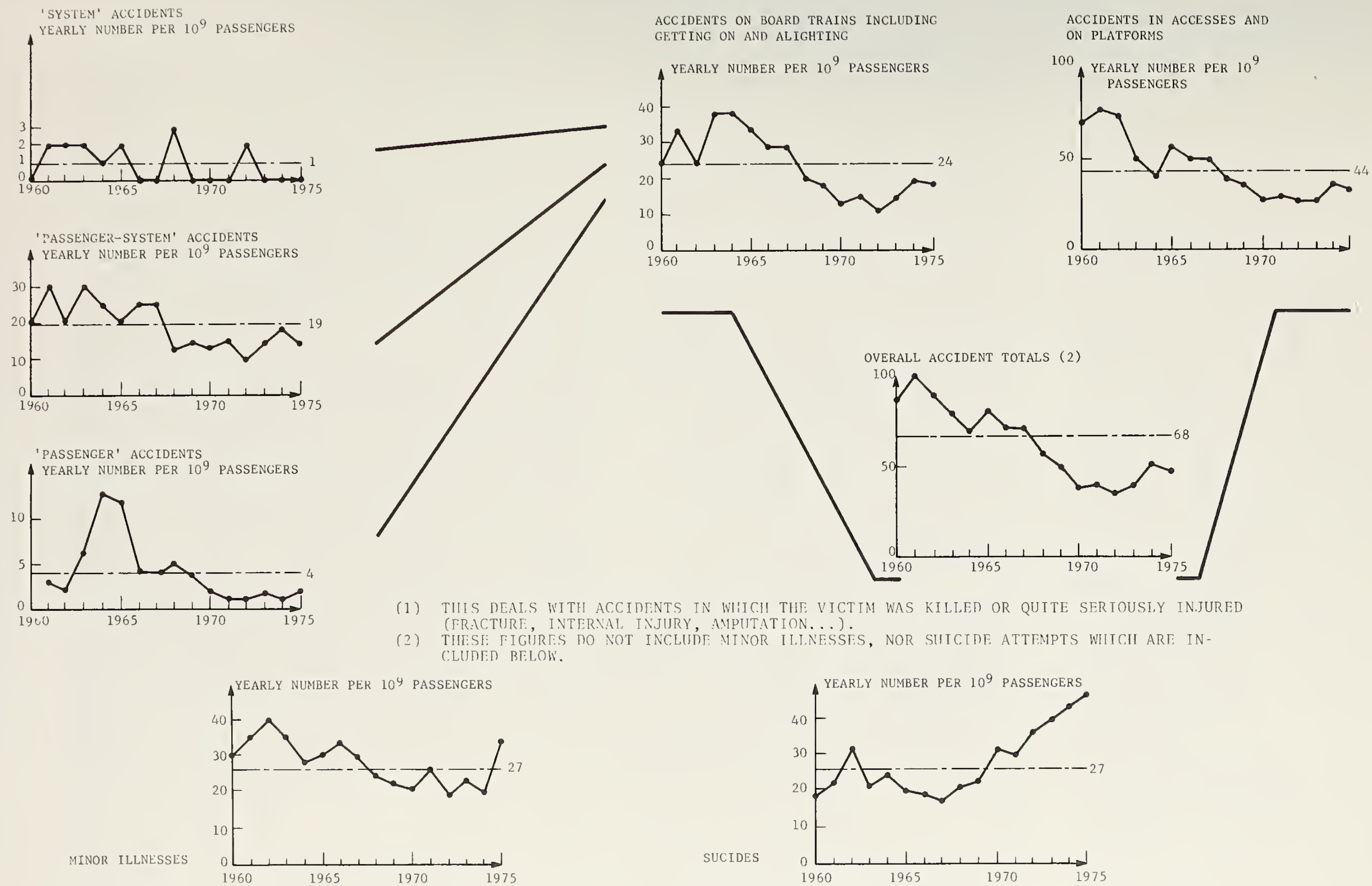
A high incidence of falls when vehicles depart can be attributed to passengers' lack of readiness. This is mainly due to the fact that there exists no paging or visual systems indicating train departure. This seems to confirm some results reported in a French study of boarding and egressing from a vehicle (see Figure 4-2). The report showed that the same levels of acceleration and deceleration were perceived differently by riders. The majority found the acceleration rates higher than the deceleration ones.

TABLE 4-1. REPRESENTATIVE SAFETY VALUES, EXCLUDING NON-PASSENGER ACCIDENTS, ILLNESSES, AND SUICIDES

MEASUREMENT BASIS	URBAN BUS	URBAN RAIL	PASSENGER RAIL	AUTOS	SCHED. AIR	ELEVATORS	AIRTRANS
Total vehicles $x10^3$	49.6	10.6	8.5	92,800	2.17	321	0.051
Vehicle km. per year $x10^9$	2.4	0.7	0.85	1526	3.1	na	0.0048
Vehicle hours per year $x10^9$	0.12	0.018	0.014	22	0.005	na	0.000273
Pass. hrs/yr. $x10^9$	1.82	0.48	0.24	50	0.3	0.308	0.000913
Accidents/year	31,597	18,062	-	23.8 $x 10^6$	34	547	6 in 1.5 years
Accidents per 10^9 pass. hrs.	20,492	42,242	-	473,255	113	1776	4380
Accidents per 10^9 pass. km	1070	1044	-	8404	0.18	-	458
Fatalities/year	15	10	25	32,200	127	13.3	0
Fatalities per 10^9 pass. hrs.	8.24	20.8	102	680	400	43.3	0

Sources: For 1st six, "Safety in Urban Mass Transportation," Battelle Columbus Laboratories, Table 2., March, 1976. (Average for 1970, 1971, 1972.) Ref. 9, Reference Page, plus detailed tabulation in Appendix B of same report.

For AIRTRANS, Dallas-Fort Worth Airport safety records. (For January 1976 - June 1977)



(1) THIS DEALS WITH ACCIDENTS IN WHICH THE VICTIM WAS KILLED OR QUITE SERIOUSLY INJURED (FRACTURE, INTERNAL INJURY, AMPUTATION...).

(2) THESE FIGURES DO NOT INCLUDE MINOR ILLNESSES, NOR SUICIDE ATTEMPTS WHICH ARE INCLUDED BELOW.

Source: See Reference Page, entry 8.

FIGURE 4-2. TRENDS IN SEVERE ACCIDENT STATEMENTS[1] AMONG PASSENGERS OF THE PARIS METRO BETWEEN 1960 AND 1975 INCLUSIVE

A survey conducted among the riders indicated that the difference was due to the fact that upon arrival into a station, passengers usually get themselves ready and grab a stanchion before the train completes its deceleration sequence. It is interesting to notice that the tests were conducted outside Paris, and most people had never used the subway in their life. However, most of them had, probably, ridden a train before and were more or less aware of the jerky stops (especially true when the brakes are cast iron shoes).

Further analysis of the data shows that no airline or airport employees* were injured during the time span of the study. These riders are similar to commuters since they ride the system at least twice a day to go to work. This is quite interesting for several reasons. One is that the volume of employee traffic is greater than the volume of passenger traffic. Another is that less protection is offered to them especially in the stations which are not as fully screened as the passenger stations. This seems to indicate that lack of attention due to familarity did not increase accident risks.

4.2.2 Accidents Involving Trespassers or Intrusions

Most of these so-called "third-party" accidents involved automobiles intruding into the guideway. About half of them have occurred on roads adjacent to the guideway. In some instances severe damage was done to the guideway (costs of repair ranging from $200 to $2,000) and the vehicles. Most of them were reported in time and did not result in injuries to passengers or employees. However, they were potentially dangerous situations which could have led to serious accidents**.

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*Except those involved in the collective accident; this also excludes the AIRTRANS maintenance task force.

**The death of a trespasser occurred shortly after this review was completed. The accident is described in Appendix D.

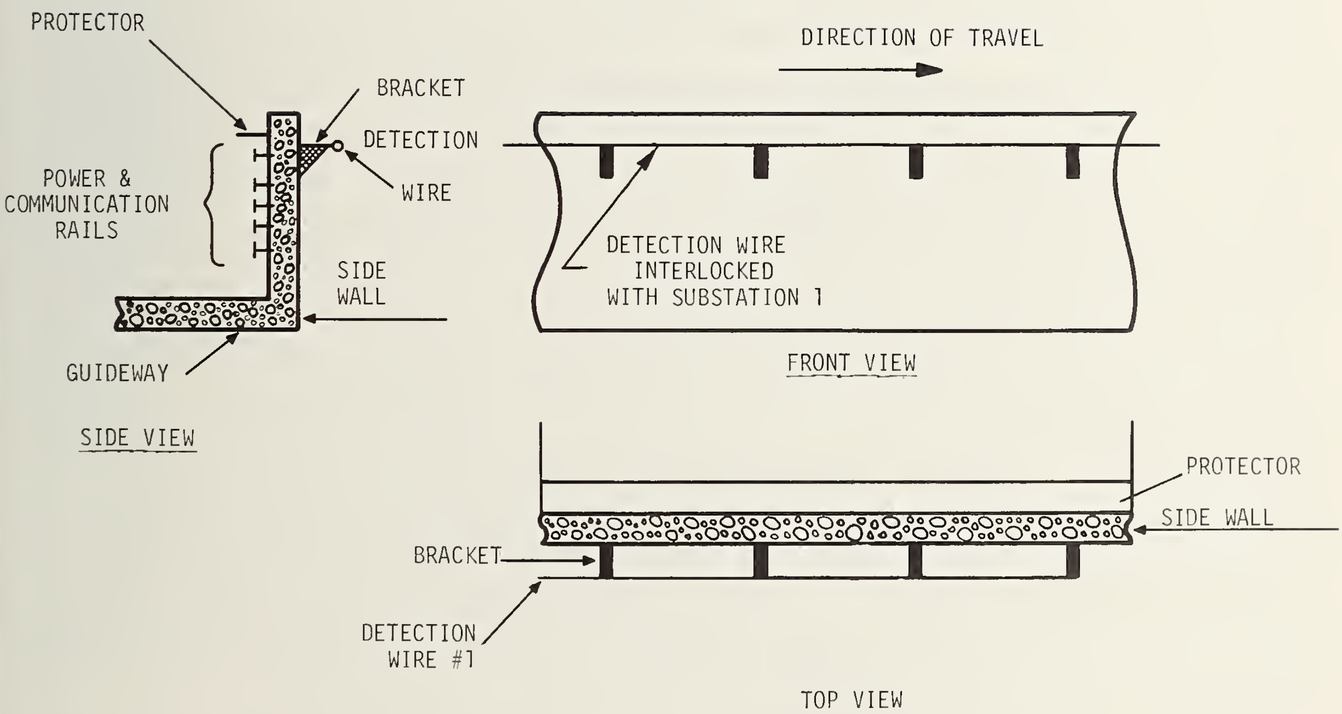
Presently, the airport management is taking some steps to prevent road vehicles from hitting the guideway. In certain areas a light type fence has been installed. However, this can only prevent pedestrians from using the guideway as a sidewalk, and does not offer enough resistance to stop a road vehicle. In most cases a highway safety fence should be required. There are a few places where even such a protection would be insufficient. Most are located close to service roads, which are mainly traveled by delivery trucks.

The airport management is testing a close range obstacle detector. It consists of a trip wire located in front of the vehicle about 4 inches above the ground. The wire is linked to a toggle switch which is mounted in parallel with the emergency exit door switch. Whenever the switch is activated by an obstacle, it brings the vehicle to an emergency stop. Recently a totally unplanned test of the system proved its effectiveness in revenue service. A trailer truck, while maneuvering, knocked down a piece of side wall on the guideway. No one was aware of it, but luckily the first vehicle to come by was the one equipped with the obstacle detector. Upon sensing the piece of concrete that had fallen onto the guideway, the vehicle went into an emergency stop alerting Central Control, which dispatched a rover.

However, it is felt that such a short-range detector will not be efficient whenever the obstacle is not lying on the guideway. There have been examples of obstacles "hanging" into the guideway which were not detectable yet were quite dangerous. Figure 4-3 shows an example of such situations.

It is reasonable to suggest that more protection should be provided in areas of the guideway where intrusions from motor vehicles are likely. A possible method for providing such protection is shown in Figure 4-4.

FIGURE 4-3. VEHICLE ON GUIDEWAY



The scheme shown here would cause power to be cut off whenever the detection wire was broken.

FIGURE 4-4. A POSSIBLE GUIDEWAY INTRUSION DETECTOR

This scheme would cause power to drop whenever the detection wire is broken as a result of an impact. This will cause any vehicle nearby to stop and eventually limit the impact speed, if a vehicle should be close to the impact point at time of the accident. An overlap of the wires should be provided in the vicinity of power section and zones. Such a system would only be needed in those areas where highway safety fences will not be sufficient.

4.2.3 Maintenance-Related Accidents

Nearly 40 percent of the maintenance-related accidents are due to falls from either the guideway or the vehicle. Part of these have occurred in the maintenance area. The airport management is considering building an adequate, elevated pathway along both sides of the track in the maintenance area, which should reduce the number of injuries.

The other falls occurred mainly on the guideway when the rovers jumped down from a vehicle that had just been reset. All those accidents have taken place on the at-grade guideway. This is due to the fact that the rovers enter the vehicle via the side doors, and that no built-in steps exist allowing them to get safely down from the vehicle. This would indicate that it might be necessary to provide the rovers with a small, portable, lightweight ladder that could be anchored to the vehicle body.

Such accidents are unlikely on elevated guideways, because the rovers have to enter the vehicle via the front door.

The remaining maintenance-related accidents are typically "on the job" ones essentially due to a lack of knowledge of the maintenance procedures or lack of attention. Most of those accidents resulted in bruises or minor cuts, while falls often resulted in sprained ankles and occasionally in broken bones. Since the airport took over the system; it is estimated that about 2084 manhours were lost due to accidents.*

*Of this total, 1400 hours were the result of a back injury which occurred in early January 1977 during a snow and ice removal operation.

No serious accidents occurred to maintenance people during the period reviewed. However, while Vought was running the system, two maintenance people were seriously injured on two different occasions. No data pertaining to those accidents are available. Vought claims that in both cases violation of maintenance procedures was the cause of the accidents.

4.3 EXAMINATION OF THE FEBRUARY 22, 1977 COLLISION

On February 22, 1977, at about 1:40 p.m., an AIRTRANS passenger vehicle collided with a stopped, two-car employee train. The accident is described in detail in Appendix D, but in brief, the accident appears to have been the result of a unique set of circumstances. Multiple failures or malfunctions seemingly occurred close together in time and in space, and the human response to them was inadequate. The failure warning system worked, but the failure clearance system, which depended on human action, did not respond rapidly enough to prevent the collision.

4.4 POTENTIALLY DANGEROUS SITUATIONS

Review of the operational logs has shown that some of the situations have been quite dangerous and could have resulted in serious accidents. However, the Airport Board has taken steps to prevent such situations from occurring again.

One of the most frequent cases was passengers or employees getting out of the vehicle through the emergency door. This was mainly happening in the vicinity of the station and was due to station undershoot. The vehicle door could not be opened because the vehicle was not properly berthed. So, quite often, by the time a rover was dispatched to the station, people would have egressed through the emergency door, gone into the guideway, opened the station door and climbed up onto the guideway or the station platform. Normal operating procedure calls for Central Control to shut off power to any section of the guideway in which a stoppage seems to require the intervention of a rover. If, for any reason, Central fails to do this, there is some risk of passengers being electrocuted if they take action on their own.

The situation has been corrected, and now trains stopping short of the station door can be berthed from the Central Control room.

In case of overshooting, the operator checks via radio communication if someone wants to egress at that specific station. If so, a rover is sent to open the doors and help the passengers out. If not, the train is dispatched to the next station.

Other kinds of potentially dangerous situations have been reported in the AIRTRANS Phase I report. Steps have been taken to eliminate them.

4.5 CONCLUSIONS

a. The AIRTRANS system has an extremely good safety record, especially when one considers that it is an innovative system.

b. Except for a single collision, which resulted from improper manual operation after multiple failures, it seems that the system has been well designed for safety.

c. On a few occasions potentially dangerous situations have evolved from a safe maneuver of the system as passengers took action on their own. This is a typical misuse of the system that can eventually lead to accidents. However, none were ever reported from such a situation, and the system has since successfully been modified to reduce their likelihood.

d. The accident report sheet is well designed. However, more detail related to riders should be collected (age, sex, was it the first time that they were using the system, etc.).

e. Highway safety fences should be considered where highways are adjacent to the guideway. A long-range guideway intrusion detector locked with the power subsystem could also be installed in those areas where fences will not be sufficient.

f. Rovers should be provided with a lightweight ladder allowing them to board and egress safely from a stalled vehicle.

5. COST ANALYSIS

LIST OF TABLES

5.1 OBJECTIVES

The objectives of this cost analysis are:

a. To develop unit costs which could be used to price a similar system in a different deployment.

b. To present the raw data relevant to the capital, operating and maintenance costs of the AIRTRANS system to reflect recent research and the experience of two additional years of system operation.

c. To show the methodology used to break down overall costs into system and site variables.

5.2 SUMMARY OF RESULTS

The capital costs to reproduce the AIRTRANS passenger system as it now exists are summarized in Table 5-1, and the methods used to derive this table are supported by extensive data in Appendix L. The figures show that a complete AIRTRANS passenger and employee system in acquisition year dollars, including the system elements that were supplied by the airport, totalled approximately $44.1 million, while to duplicate it would cost about $67 million in 1978 dollars. Table 5-1 also shows the unit costs (in 1978 dollars) for all components and the number of units in each subdivision.

The actual revenue, costs, and vehicle mileage for AIRTRANS as reported by the Airport Board are shown in Table 5-2. A description of the current Airport Board reporting categories is shown in Table 5-3. Annual totals for the most recent operating year (1978) are shown in Table 5-4. Total cost (excluding debt service and passenger service agents) in 1978 was $3,356,256 or $.96 per vehicle mile.

One of the major purposes of analyzing the AIRTRANS operating and maintenance costs was to develop equations which would enable

TABLE 5-1. CAPITAL COSTS FOR A DUPLICATE AIRTRANS SYSTEM (1978 DOLLARS)

1 XREF* TABLE	2 CATEGORY	3 UNIT	4 UNIT COST 1978	5 NUMBER OF UNITS	6 TOTAL COST 1978 DOLLARS	7 TOTAL COST IN ACQUISITION YEAR DOLLARS
L-1**	REVENUE VEHICLES(H)	VEHICLE	272,450	51	13,895,000	8,890,000
L-2***	SERVICE VEHICLES(H)	VEHICLE	24,746	13	321,700	215,000
L-3	GUIDEWAY SITE MODS	KM	97,073	20.5	1,990,000	1,281,000
L-4	GUIDEWAY AT GRADE	KM-AT GRADE	371,512	16.4	6,092,800	3,922,000
L-5	GUIDEWAY ELEVATED	KM-ELEVATED	1,296,609	4.1	5,316,100	3,422,000
L-6	GUIDEWAY SWITCHES(H)	EA SWITCH	20,991	71	1,490,390	935,000
L-7	STATION STRUCTURES	SQUARE METER	1,481	3,480	5,154,800	3,306,500
L-8	PLATFORM DOORS(H)	EA	18,012	28	504,340	316,000
L-8	STATION GRAPHICS(H)	STATION	19,265	14	269,720	169,000
L-8	FARE COLLECTION (H)	EA	3,573	46	164,390	103,000
L-9	MAINTENANCE STRUCTURES	SQUARE METER	570	1,116	636,560	436,000
L-10	MAINTENANCE EQUIPMENT(H)	TOTAL HARDWARE	5.46%	33,193,620	1,813,400	1,212,000
L-10	MAINTENANCE SPARES(H)	TOTAL HARDWARE	4.81%	33,193,620	1,596,000	1,067,000
L-11	POWER RAIL(H)	KM-LANE	215,581	20.5	4,419,420	3,027,000
L-11	POWER DISTRIBUTION(H)	SUBSTATIONS	90,617	15	1,359,260	931,000
L-12	CONTROL-WAYSIDE(H)	BLOCK	7,387	708	5,230,000	3,546,000
L-12	CONTROL-CENTRAL(H)	EA	1,624,000	1	1,624,000	1,101,000
L-12	VOICE/VIDEO(H)	STATION	36,143	14	506,000	343,000
L-13	SYSTEM ENGINEERING	TOTAL HARDWARE	24.5%	33,193,620	8,142,200	5,439,000
L-13	CONSTRUCTION ENGINEERING	TOTAL FACILITIES	12.4%	19,190,260	2,387,800	1,595.000
L-13	PROJECT MANAGEMENT	TOTAL PROJECT	4.5%	64,380,980	2,889,200	1,930,000
L-13	SYSTEM TESTING	LANE-KM	71,565	20.5	1,467,100	935,000
TOTAL					67,270,180	44,121,500

*Cross References to tables in Appendix L.
**Does not include utility vehicles.
***Two types of service vehicles are included: 7 guideway service vehicles and 6 maintenance area service vehicles.

(H) Hardware

TABLE 5-2. COSTS IN DOLLARS REPORTED BY D-FW AIRPORT (4/76-12/78)

DATE	REVENUE	CENTRAL CONTROL	TRANS CONTROL	TRANS ENG	OPERATIONS LABOR	OPERATIONS POWER	MAINT LABOR	MAINT MATERIALS	AIRPORT SERVICES	REL IMPROV. CONTR/SUPT	FACILITIES MAINT	AUTO/BUS/ BLDG. MAINT.	PASS SERVICE AGENTS	DEBT SERV	VMT (MILES)
4/76	126,960				24,495	13,399	119,844	46,423		6,442	23,726		36,894	226,248	333,210
5/76	122,425				25,609	17,893	112,923	65,797		4,261	27,173		27,937	266,248	322,281
6/76	139,822				21,314	19,221	98,081	45,092		5,980	16,671		27,427	266,248	333,858
7/76	138,511				24,698	22,090	123,046	44,545		4,035	20,013		30,862	266,248	319,384
8/76	135,276				24,648	22,798	98,755	52,125		9,508	14,975		27,058	266,248	339,141
9/76	129,820				26,294	18,728	113,551	86,825		3,864	17,880		28,844	266,248	316,868
10/76	125,263				27,278	19,038	130,086	50,767		45,044	14,159		29,343	243,554	268,492
11/76	130,648				26,108	16,056	115,730	60,858		13,599	14,648		32,303	243,554	320,034
12/76	132,068				34,711	17,714	121,687	41,734		30	14,001		28,820	243,554	254,810
1/77	117,592				35,279	19,846	121,078	65,903	5,518	1,098	16,052		36,923	243,554	310,608
2/77	123,205				37,182	18,420	120,197	63,285	4,574	1,076	19,629		32,684	243,554	269,658
3/77	137,470				36,179	21,811	111,496	49,459	5,727	740	18,134		38,969	243,554	357,085
4/77	134,440				31,732	18,372	105,598	67,523	5,792	230	19,123		31,490	262,724	298,890
5/77	125,937				33,756	19,631	97,949	55,645	5,282	2,074	18,932		29,176	262,724	264,830
6/77	138,732				34,333	19,347	99,395	59,398	5,600	297	20,581		32,470	262,724	318,046
7/77	131,572				32,040	25,932	103,496	58,775	5,791	642	16,091		33,269	262,724	308,624
8/77	149,913				32,675	31,893	103,317	60,530	5,588	1,643	22,017		30,677	262,724	308,849
9/77	125,499				31,112	25,487	97,781	124,012	6,174	1,403	17,117		30,010	262,724	299,129
10/77	121,484	15,037	15,981	5,702		22,619	110,185	58,522	5,463			17,518	32,210[1]	305,621	302,154
11/77	130,019	14,611	14,872	7,654		23,170	105,075	74,941	5,382			16,400	33,689	305,621	312,440
12/77	129,726	16,831	16,990	8,997		20,595	118,259	65,548	5,412			20,719	43,957	305,621	314,508
1/78	120,996	16,480	16,108	7,602		23,618	124,696	74,051	4,767			21,392	40,512	305,621	238,182
2/78	114,751	14,926	16,779	6,659		21,486	115,593	78,344	5,655			20,316	49,268	305,621	218,128
3/78	143,562	15,922	16,060	7,183		19,892	118,941	64,741	6,171			25,861	49,598	305,621	326,540
4/78	115,173	14,576	16,481	7,254		22,739	107,733	53,964	5,231			27,243	30,626	305,776	305,425
5/78	112,672	15,837	16,303	8,040		24,517	115,191	64,941	5,399			21,592	34,364	305,776	309,998
6/78	118,558	16,452	15,018	7,101		26,240	114,078	97,256	5,656			17,314	33,867	305,776	300,096
7/78	133,657	17,480	14,353	7,491		24,720	132,331	65,068	5,769			18,514	47,253	305,776	305,668
8/78	126,669	15,353	15,432	8,197		29,247	115,414	65,107	6,115			18,839	35,846	305,776	307,268
9/78	127,661	15,640	17,829	8,204		27,114	115,929	57,263	6,257			13,115	34,697	305,776	294,837
10/78	145,946	19,345[2]	17,842[2]	6,468[2]		24,799	118,832	66,128	6,284			24,607	37,988	352,044	319,161
11/78	138,353	18,244	17,032	6,581		21,133	119,305	68,811	6,359			27,353	37,631	352,044	311,073
12/78	132,772	22,618	17,227	8,876		22,272	134,074	62,299	6,532			23,055	60,660	352,044	271,732

1 BUS BACKUP added to this category 10/77

2 CENTRAL CONTROL; ENGINEERING SUPERVISORS begin charging sections rather than TRANS. CONTROL

TABLE 5-3. AIRTRANS REPORTED COST CATEGORIES

CATEGORY	ITEMS
1. Central Control	Salaries, fringes, overtime for ten controllers.
2. Transportation Control	Salaries, etc. for the following: Director, Maint. Manager, Operations Manager, Central Control Supervisor, Transportation Administration, Secretary, Clerk-Typist, Engineering Supervisor.
3. Transportation Engineering	Salaries, etc. of Engineering Staff.
4. Electric Power	Power rail, wayside electronics, hotel station, remote parking lot stations (terminal electricity not included)
5. Passenger Service Agents and Bus Backup	Passenger service agents, supervisors, uniforms, misc. supplies, bus rental.
6. Airport Services	Pro rata share of airport G&A.
7. Auto, Bus, Building Maint.	Facility maintenance work orders. (Janitorial not included)
8. Maintenance Labor	Includes salaries and fringes for all maintenance personnel except supervisor.
9. Maintenance Services and Parts	Includes parts and contract parts and labor for such things as motor rebuilds, etc.

Note: Items 1-3 reported labor prior to Oct. 1, 1977 at D-FW as operations.

Source: Dennis Elliott, D-FW Airport Board, Sept. 1, 1978.

TABLE 5-4. 1978 AIRTRANS REPORTED OPERATING COSTS

OPERATIONS LABOR*	
CENTRAL CONTROL	$ 202,873
TRANSPORTATION CONTROL	196,464
TRANSPORTATION ENGINEERING	89,656
TOTAL	$ 488,993
MAINTENANCE LABOR*	$1,432,117
OPERATIONS POWER*	$ 287,777
CONTRACT SERVICES*	
AIRPORT SERVICES	$ 70,195
AUTO/BUS/BLDG. MAINTENANCE	259,201
TOTAL	$ 329,396
MAINTENANCE MATERIALS*	$ 817,973
TOTAL COSTS* (EXCLUDING DEBT SERVICE AND PASSENGER AGENTS)	$3,356,256
DEBT SERVICE	$3,806,721
PASSENGER SERVICE AGENTS	$ 526,936
REVENUE	$1,530,770
VEHICLE MILES TRAVELLED	3,508,108
TOTAL COSTS*/VEHICLE MILE TRAVELED	$ .96

*These categories correspond to those reported in N.D. Lea and Associates, Supplement 1, Summary of Capital and Operations and Maintenance Cost Experience of AGT Systems, Cost Trends for the Period 1976-1978, UMTA-IT-06-0188-79-1, March 1979.

planners or other transit operators to estimate the cost of AGT system in another deployment.

Equations were developed to estimate the manpower, energy, parts and services needed to operate the AIRTRANS passenger/employee system. These equations were developed from AIRTRANS maintenance and operating records or from other information about AGT systems when data from AIRTRANS was incomplete or unavailable. These equations are summarized in Tables 5-5 and 5-6. These equations were used together with the system characteristic data furnished by the Airport Board (Table 5-7 and 5-8) to estimate the cost to operate AIRTRANS from April 1977 to March 1978. The estimated manpower and costs were compared to the actual reported figures for the same period. The comparisons in Tables 5-9 and 5-10 show that the estimated manpower and costs matched the reported values in almost all categories, thus providing a high level of confidence in the supporting data and derived estimators.

Section 5.3 describes the data sources used; Section 5.4 discusses the methodology; the capital costs are discussed in Section 5.5; and the operations and maintenance costs are discussed in Section 5.6. Section 5.7 presents a method of using these data in estimating costs for new AGT systems.

5.3 BACKGROUND

The Phase I assessment[5.1] reported the capital costs incurred under the contract with Vought to build the AIRTRANS system. Table 5-1 of the Phase I assessment reported the total capital costs by different categories. Subsequent to publication of that report, N.D. Lea and Associates[5.2] reviewed the capital costs of the AIRTRANS system for the purposes of presenting the AIRTRANS costs on a common basis with other AGT systems.

In doing this, N.D. Lea used a methodology developed by SRI International in its assessment work. This methodology attempts to define the cost of a duplicate system by 1) including costs of all system components and 2) deleting costs which can be considered non-recurring. The AIRTRANS costs have been calculated for

TABLE 5-5. AIRTRANS OPERATING AND MAINTENANCE MANPOWER REQUIREMENTS

CATEGORY	UNIT MANPOWER FUNCTION (MANHOURS)	TOTAL MANHOURS (4/77-3/78)
OPERATIONS		
CENTRAL CONTROL	2xAVL-MHRS X INTEGER (SYSHR/AVL-MHRS)	18,960
MAINTENANCE		
SUPERVISION	.186 x DIRECT MHRS	24,471
MAINTENANCE CONTROL	1.0 x SHOPHR + .4 X (VEH KM/MKMBF)	12,549
ROVER-UNSCHEDULED	.75 x VEH KM/MKMBF	7,117
HOSTELING	.66 x MAX OPERATING VEH x DAYS	9,395
REVENUE VEHICLE	.0092 x VEH KM	51,670
SERVICE VEHICLE	.01903 x SYSHR x SERV VEH	1,167
CENTRAL CONTROL	.6292 x SYSHR	5,512
WAYSIDE CONTROL	.0536 x SYSHR x LANE KM	9,630
FARE COLLECTION	.0137 x SYSHR x DEVICES	5,520
SWITCHES	.008 x SYSHR x SWITCHES	4,886
GUIDEWAY SURFACE	.0234 x SYSHR x LANE KM	4,209
STATION EQUIPMENT	.0179 x SYSHR x PAX STN	2,146
SHOP EQUIPMENT	.2302 x SYSHR	2,016
VOICE AND VIDEO	.008 x SYSHR x PAX STN	981
GUIDEWAY POWER /SIG	.0588 x SYSHR x LANE KM	10,561
NON-PASSENGER	NOT REQUIRED FOR OTHER DEPLOYMENTS	4,208
GENERAL ADMINISTRATION		
GENERAL MANAGEMENT	FIXED @ 6 PEOPLE	11,376
TRANSIT DEV. & ENGINEERING	5.6% x TOTAL O&M MANHOURS	14,072
CUSTOMER SERVICES	SMHRS/DAY x DAY x AVL-MHRS	70,080

TABLE 5-6. AIRTRANS O&M ENERGY, PARTS, AND CONTRACT SERVICES REQUIREMENTS

CATEGORY	UNIT REQUIREMENTS (ANNUAL)	TOTALS (4/77-3/78)
OPERATION		(KWH)
VEHICLE PROPULSIVE AND AUX. ENERGY	1.56 KWH/VEH KM	8761534
WAYSIDE CONTROL	9895 KWH/LANE KM/YR	202847
STATION ELECTRIC	67 KWH/M^2/YR	233026*
GARAGE ELECTRIC	343 KWH/M^2/YR	382788
STATION AIR COND	149.8 KWH/M^2/YR	521004*
GARAGE AIR COND	337.2 KWH/M^2/YR	376315
STATION HEATING	9.8 KWH/M^2/YR	34084*
TOTAL ENERGY		10511598
	ENERGY COST AT .02733 KWH	$287,281
MAINTENANCE MATERIALS		
VEHICLE	$.0932 / VEH KM	$523,000
GUIDEWAY	$8250 / LANE KM	$171,000
ELECTRONICS	.0153 x (CURRENT CONTROL + STN EQMPT) (CAPITAL COST)	$139,000
TOTAL MATERIALS		$833,000
CONTRACT SERVICES		
FACILITIES MAINTENANCE (JANITORIAL)	$9.60/SQUARE METER OF FACILITIES	$43,950*
AIRPORT SERVICES	1.92% TOTAL COST (3174213)	$60,945

*Not included in AIRTRANS reported costs but listed here.

TABLE 5-7. SITE CHARACTERISTIC INPUTS TO AIRTRANS TOTAL MANHOUR CALCULATIONS

ABBREVIATIONS	DESCRIPTION	VALUE
AVL-MHRS	Available manhours per person per year	1896
SYSHR	System operating hours per year	8760
SHOPHR	Maintenance shop operating hours	8760
DIRECT MHRS	Sum of maintenance manhours	131,567
VEH KM	Total vehicle kilometers travelled	5,616,368
MKMBF	Mean kilometers between malfunctions	590
MAX OP. VEH	Average maximum number of vehicles operating per day	39
DAYS	Number of operating days per year	365
SERV VEH	Number of service vehicles (Those with communications)	7
LANE KM	Total guideway lane kilometer	20.5
DEVICES	Number of fare collection machines	46
SWITCHES	Number of switches	71
PAX STN	Number of passenger stations with 2 doors, graphics, cameras	14
M^2(STATION)	Total station area	3478
M^2(GARAGE)	Total garage area	1116
TOTAL O&M MANHOURS	Sum of operations, maint.	251,103
SMHRS/DAY	Customer service mhrs/day based on current staffing for 10 stations	192

TABLE 5-8. SITE CHARACTERISTIC INPUTS TO AIRTRANS TOTAL ENERGY, PARTS, AND CONTRACT SERVICES REQUIREMENTS

ABBREVIATIONS	DESCRIPTIONS	VALUE
VEH KM	Total vehicle kilometers travelled	5616368
LANE KM	Total guideway lane kilometers	20.5
ELECTRONICS CAPITAL	1978 Cost=9597000/1.056 (Deflator 1978-1977) =9088068 (1977-78)	
FACILITIES	Total area = 4594 square meters	
TOTAL COST	Labor Costs = 2009982 Energy = 287281 Parts = 833000 Facilities = 43950 3174213	

TABLE 5-9. AIRTRANS COST EQUATION VERIFICATION - MANPOWER

CATEGORY	TOTAL MANHOURS (ESTIMATE)	STAFF[1] (EST)	SKILL LEVEL	1977-1978 BASE[2] SALARY	FRINGE FACTOR	ESTIMATED 1977-78 COST	ACTUAL STAFFING[4]	ACTUAL 1977-78 COST[3]
CENTRAL CONTROL	18960	10	CONTROLLER	$14580	1.20	$ 174960	10	
GENERAL MANAGEMENT	11376	6	GEN MGT	$16131	1.20	116143		
ENGINEERING	14061	7	ENGINEERING	$15242	1.20	128033		
TOTAL OPERATIONS LABOR		23				$ 419136		$ 430042
MAINTENANCE TECHNICIAN	109623	58	MAINT TECH	$12190	1.20	848424	59	
MAINTENANCE CONTROL	12549	7	MAINT CNTL	$11861	1.20	99632		
HOSTELER	9395	5	HOSTELER	$ 8169	1.20	49014		
MAINTENANCE SUPERVISION	24471	4 9	SUPERVISOR FOREMAN	$16024 $13797	1.20 1.20	76915 149007		
TOTAL MAINTENANCE LABOR		83				$1222992	81	$ 1259565
PASSENGER SERVICE AGENTS	70080	37	PAX AGENTS	$ 8285	1.20	367854	37	$ 424742
JANITORIAL	9188	5	JANITOR	$ 7375	1.20	43950	-	Not included

1 STAFF = MANHOURS/1896

2 SALARY PER TABLE K-11

3 COSTS PER TABLE 5-2

4 ACTUAL STAFFING PER FIGURE 2-5.

TABLE 5-10. AIRTRANS COST EQUATION VERIFICATION - OTHER

CATEGORY	ESTIMATE (4/77-3/78)	ACTUAL (4/77-3/78)[1,4]
ENERGY CONSUMPTION (KWH)	9976369	9953140
ENERGY FOR TERMINALS[2]	535229	
TOTAL ENERGY @ .02733/KWH	$287281	$272042
MAINTENANCE MATERIALS	$833000	$842060
CONTRACT SERVICES		
FACILITY MAINTENANCE[2]	$ 43950	-
AIRPORT SERVICES	$ 60945	$ 67077
AUTO, BUS BACKUP[3]	-	$242356

[1]ACTUAL ENERGY - TABLE K-9

[2]ESTIMATED FOR ITEMS NOT INCLUDED IN EXISTING AIRTRANS REPORTS

[3]NO ESTIMATE

[4]ACTUAL COSTS FROM TABLE 5-2

guideway site modifications, station structures and maintenance facility structure which were not reported in the Phase I assessment. Non-recurring costs include those costs associated with developing the first of a kind installation of a given technology. They include only those costs which would not occur in subsequent deployments. So $2.5 million was deleted from the "design" costs reported in the Phase I report. In addition to these items all costs associated with the non-passenger/employee system at AIRTRANS were deleted from the cost figures.

Table 5-3 of the Phase I assessment reported the operating and maintenance costs of the AIRTRANS system through April 1976. Since that time, over three additional years of operation have passed, and the cost data for this period reflects the O&M costs of a more mature system.

In addition to obtaining more recent cost data, TSC, through the cooperation of both the Vought Corporation and the Airport Board, has obtained additional supporting documentation on manhour requirements for various maintenance and operating costs, staffing levels, salaries, a clarification of reporting categories, and other information relevant to O&M costs. This supporting information was needed to ensure a full understanding of the cost of operating and maintaining an AGT System, and it is presented in this section.

5.4 METHODOLOGY

The methodology used to calculate the capital cost variables was:

$$\underset{(1978)}{\text{Unit Cost}}_{I} = \frac{(TC + ADJ)\ (ESCAL)}{\text{NUMBER OF UNITS}}$$

where: I = particular subsystem

TC = raw total cost data reported by TSC or N.D. Lea

ADJ = reductions for non-recurring investments, non-passenger services, additions for non-contract cost items

ESCAL = inflation adjustment between year of expenditure and 1978

The derivation of the above items are shown in various tables in Appendix L. The cost categories used for capital expenditures (unit $cost_1$) are shown in Table 5-11. Column 1 lists the categories. Column 2 shows the categories used in the AGT Generic Alternatives Analyses. (Ref. 5.12). The categories in Column 2 are quite compatible with the proposed UMTA Uniform System of Accounts, Records and Reporting System shown in Column 3 and the more aggregate data reported in the N.D. Lea Cost Summary of existing AGT systems. The major difference between the categories in Column 2 and Column 4 and those in Column 3 are the items associated with system implementation such as site modifications, project management, system testing and cost escalation.

The use of the set of categories in Table 5-11 will provide the basis for a set of consistent cost breakdown estimators for AGT systems in urban deployments.

The methodology used to develop the operating and maintenance cost factors is divided into three areas: labor, energy and parts. In all three areas, the basic idea is first to estimate the per unit manhour requirements, energy usage, and parts costs using available data sources; and then, apply the actual system units from a period of time for which the staffing, energy usage, and parts consumed are known, to the derived per unit data to check the accuracy of the estimates. These procedures are shown below for the three components of operating costs.

LABOR

$$\begin{pmatrix}\text{Unit Manpower}\\ \text{Requirements}\end{pmatrix} \times \begin{pmatrix}\text{Number of units}\\ \text{4/77-3/78}\end{pmatrix} = \begin{pmatrix}\text{Estimated}\\ \text{Staffing}\\ \text{4/77-3/78}\end{pmatrix} \approx \begin{pmatrix}\text{Actual}\\ \text{Staffing}\\ \text{4/77-3/78}\end{pmatrix}$$

where: Unit Manpower Requirements are derived from maintenance and operating data. The number of units is derived from the system operating data and physical characteristics during the period from April 1977 to March 1978.

TABLE 5-11. CAPITAL COST CATEGORIES

Category	AGT SER(1) Generic/Market Analysis	UMTA(2) Uniform Acct's	N.D. Lea(3) Cost Summary of AGT Systems
VEHICLES			
REVENUE	✓	M0110	✓
SERVICE	(in yards/shops)	M02	(in maint/support)
GUIDEWAY (ELEV., AT-GRADE, BELOW GRADE)			✓
SITE MODIFICATIONS	✓	not included	
BUILDING AND STRUCTURES	✓	M0331	✓
TRACKWORK/GUIDANCE	✓	included in M0331 or M0431	✓
EQUIPMENT	(included above)	M0431	(not disaggregated)
STATIONS			✓
SITE MODIFICATIONS	✓	not included	not disaggregated
BUILDING AND STRUCTURES	✓	M0332	
EQUIPMENT	(included above)	M0432	
PARKING FACILITIES	✓	M0333/0433	not included
YARDS AND SHOPS	✓		✓
OPERATING YARDS/STATIONS	not disaggregated	M0334	not disaggregated
EQUIPMENT		M0434	
VEHICLE MAINTENANCE SHOPS		M0335	
VEHICLE MAINTENANCE EQUIPMENT		M0335	
POWER GENERATION	✓		✓
BUILDING AND STRUCTURES	not disaggregated	M0336	not disaggregated
EQUIPMENT		M0436	

TABLE 5-11. CAPITAL COST CATEGORIES (CONTINUED)

Category	AGT SER[1] Generic/Market Analysis	UMTA[2] Uniform Acct's	N.D. Lea[3] Cost Summary of AGT Systems
ADMINISTRATIVE FACILITIES	✓		
BUILDING AND STRUCTURES	{not disaggregated}	M0337	(included with yards/shops)
EQUIPMENT		M0437/M05	
VEHICLE CONTROL EQUIPMENT	✓	M0438	✓
VOICE AND VIDEO EQUIPMENT	✓	M0441	(included in vehicle control)
FARE COLLECTION EQUIPMENT	✓	M0439	(included with stations)
DATA PROCESSING EQUIPMENT	(included elsewhere)	M0440	(included elsewhere)
RIGHT-OF-WAY	✓	M06	(not included)
SPARES	✓	(included with category)	(included with category)
ENGINEERING AND MANAGEMENT	✓	(not included)	✓
CONSTRUCTION ENGINEERING		(not included)	
SYSTEM ENGINEERING		(not included)	
PROJECT MANAGEMENT		(not included)	
ADMINISTRATION MANAGEMENT		(not included)	(not disaggreated)
SYSTEM TESTING	✓	(not included)	
CONTINGENCY	✓	(not included)	
ESCALATION	✓	(not included)	
LANDSCAPING, ART, ETC.	✓	(not included)	

(1) Developed by Kaiser Engineers in support of "Generic Alternatives Analysis" Contracts (see Ref. 5.12).
(2) UMTA Uniform System of Accounts, Records, and Reporting System, January 1977, UMTA-IT-06-0094-77-1.
(3) N.D. Lea, Summary of Capital, Operating, and Maintenance Costs for AGT Systems (Ref. 5.2).
✓ Indicates item is included in this category.

ENERGY

$$\begin{pmatrix}\text{Vehicle}\\ \text{Energy}\\ \text{Requirements}\\ \text{4/77-3/78}\end{pmatrix} + \begin{pmatrix}\text{Wayside}\\ \text{Energy}\\ \text{Requirements}\\ \text{4/77-3/78}\end{pmatrix} + \begin{pmatrix}\text{Housekeeping}\\ \text{Energy}\\ \text{Requirements}\\ \text{4/77-3/78}\end{pmatrix} \approx \begin{pmatrix}\text{Total}\\ \text{Actual}\\ \text{Energy}\\ \text{Usage}\\ \text{4/77-3/78}\end{pmatrix}$$

where: Vehicle wayside and housekeeping energy are derived from physical characteristics and estimated from available data sources. Total Actual Energy Usage was reported by the Airport Board.

PARTS

$$\begin{pmatrix}\text{Vehicle Parts}\\ \text{per vehicle km}\\ \text{4/77-3/78}\end{pmatrix} + \begin{pmatrix}\text{\% current year}\\ \text{capital cost for}\\ \text{control; station}\\ \text{equipment}\\ \text{4/77-3/78}\end{pmatrix} + \begin{pmatrix}\text{Wayside parts}\\ \text{per lane km}\\ \text{4/77-3/78}\end{pmatrix} \approx \begin{matrix}\text{Total}\\ \text{Actual}\\ \text{Parts Cost}\\ \text{4/77-3/78}\end{matrix}$$

where: Vehicle and wayside parts costs are derived from available data sources and percent capital cost for control and station equipment is derived from the total reported parts cost for one year. The estimated costs (left side of equation) were computed using appropriate system characteristics and inflation rates. Actual parts costs were reported by the Airport Board.

If the estimated values approximate the actual values within 5-10 percent, then the per unit requirements developed are considered reasonable. The use of unit manhour and energy requirements enables each site to estimate its costs using its own labor and energy rates. Labor costs are verified as follows:

$$\frac{\text{Estimated Manhours/year}}{\text{Available Manhours/person/year}} = \text{staff}$$

$$\text{staff} \times \underset{(10/78)}{\text{staff salary}} \times \underset{\begin{pmatrix}1978\text{-}77\\ 1978\text{-}76\end{pmatrix}}{\text{Deflator}} \times \text{fringe factor} = \begin{matrix}\text{Reported Labor}\\ \text{Costs 4/77-3/78}\end{matrix}$$

where: Estimated manhours/year are determined from the per unit and number of units data.

Available manhours/persons/year, staff salaries and fringe factors for 1978-79 have been furnished by the Airport Board.

The Deflator represents the difference between 1978-79 salaries reported by the Airport and the 1976-77 and 1977-78 salaries which were in effect during the period from April 1977 to March 1978.

If this equation is satisfied, then a dollar cost per estimated manhour can be derived from the above equations.

Table 5-12 shows the operating and maintenance cost categories used. Column 1 shows the categories of activities for which manhours, energy and parts requirements will be estimated in this report. Column 2 shows the categories as reported by N.D. Lea for AIRTRANS. Columns 3 and 4 show the corresponding category and nomenclature from the UMTA Uniform Accounts functional classification. A close correspondence has been maintained to enable comparisons to be made between AIRTRANS and conventional systems. It should be noted that while the UMTA Accounts report labor and material expenses separately within each functional category; they are treated as separate categories in this analysis. Several items are addressed in this report, which are not included in the N.D. Lea report, such as janitorial services, passenger service agents, and power for stations in terminals. Several items which are included in "operations-labor" and contract services in the N.D. Lea report are treated as separate categories in this report.

5.5 CAPITAL COSTS

In this section, the estimated cost to construct a duplicate AIRTRANS passenger system in 1978 is presented. Table 5-1 summarizes the results of the analysis to determine the unit costs of the various components of this AGT system. Column 1 lists the table in Appendix L in which the total 1978 costs and unit costs were derived. Column 2 lists the AIRTRANS subsystems. Column 3 shows the unit of measure for the unit costs shown in Column 4. Column 5 lists the number of units in the present AIRTRANS configuration.

TABLE 5-12. OPERATING AND MAINTENANCE COST CATEGORIES

AIRTRANS O&M CATEGORY	N.D. LEA[1]/KE[2] CATEGORY	UMTA[3] #	UNIFORM ACCOUNTS FUNCTIONAL CATEGORIES
OPERATIONS		010	
CENTRAL CONTROL	OPERATIONS-LABOR	012	VEHICLE MOVEMENT CONTROL
POWER	POWER	140	OPERATION OF ELECTRIC POWER
MAINTENANCE			
SUPERVISION	MAINTENANCE-LABOR	40	MAINTENANCE ADMINISTRATION
MAINTENANCE CONTROL	MAINTENANCE-LABOR	40	MAINTENANCE ADMINISTRATION
ROVER-UNSCHEDULED	MAINTENANCE-LABOR	-	(REPORTED UNDER DIFFERENT FUNCTIONS)
HOSTELING	MAINTENANCE-LABOR	50	SERVICING REVENUE VEHICLES
REVENUE VEHICLE MAINTENANCE	MAINTENANCE-LABOR	60-70	INSPECT, MAINTENANCE, REPAIR, OF REVENUE VEHICLES
SERVICE VEHICLE O&M	MAINTENANCE-LABOR	80-90	INSPECT, MAINTENANCE, SERVICE, FUEL OF SERVICE VEHICLES
CENTRAL CONTROL MAINTENANCE	MAINTENANCE-LABOR	100	MAINTENANCE OF VEHICLE MOVEMENT SYSTEMS
WAYSIDE CONTROL MAINTENANCE	MAINTENANCE-LABOR	100	MAINTENANCE OF VEHICLE MOVEMENT SYSTEMS
FARE COLLECTION MAINTENANCE	MAINTENANCE-LABOR	110	MAINTENANCE OF FARE COLLECTION EQUIPMENT
SWITCH MAINTENANCE	MAINTENANCE-LABOR	121	MAINTENANCE OF ROADWAY AND TRACK
GUIDEWAY SURFACE	MAINTENANCE-LABOR	122	MAINTENANCE OF STRUCTURES
STATION DOORS	MAINTENANCE-LABOR	123	MAINTENANCE OF PASSENGER STATIONS
STATION EQUIPMENT	MAINTENANCE-LABOR	123	MAINTENANCE OF PASSENGER STATIONS
STATION-JANITORIAL	NOT INCLUDED	23	MAINTENANCE OF PASSENGER STATIONS
SHOP EQUIPMENT MAINTENANCE	MAINTENANCE-LABOR	125	MAINTENANCE OF SHOP EQUIPMENT
SHOP-JANITORIAL	NOT INCLUDED	125	MAINTENANCE OF MAINTENANCE FACILITIES
VOICE AND VIDEO	MAINTENANCE-LABOR	126	MAINTENANCE OF COMMO. FACILITIES
BUILDING REPAIRS, IMPROVEMENTS	FACILITIES	128-131	REPAIRS OF BUILDINGS
GUIDEWAY POWER-MAINTENANCE	MAINTENANCE-LABOR	140	MAINTENANCE OF POWER FACILITIES
VEHICLE PARTS	MAINTENANCE-MATERIALS	60-70	INSPECTION, MAINTENANCE, REPAIR OF REVENUE VEHICLES.
CONTROL/STATION PARTS	MAINTENANCE-MATERIALS	100,110, 123	MAINTENANCE OF VEHICLE MOVEMENT SYSTEM
WAYSIDE PARTS	MAINTENANCE-MATERIALS	121,122, 140	MAINTENANCE OF ROADWAY, STRUCTURE
GENERAL ADMINISTRATION			
TRANSPORT CONTROL	OPERATIONS-LABOR	176	GENERAL MANAGEMENT
TRANSPORT ENGINEERING	OPERATIONS-LABOR	145,173	TRANSIT DEVELOPMENT ENGINEERING
AIRPORT SERVICES	CONTRACT SERVICES	160	GENERAL ADMINISTRATIVE
PASSENGER AGENTS	NOT INCLUDED	162	CUSTOMER SERVICES

[1] N.D. Lea cost summary of AGT systems. (Ref. 5.2).

[2] See Ref. 5.12.

[3] UMTA Uniform System of Accounts, Records, and Reporting System, UMTA-IT-06-0094-77-1.

The total costs in Column 6 were derived by multiplying Column 4 by Column 5. Column 7 shows the total costs in acquisition year dollars. This is the actual cost.

Table 5-13 shows an example of the type of subsystem calculations used to derive the total and unit costs. Tables L-1 through L-13 show these calculations for all subsystems. An explanation of Table 5-13 will provide the reader with an understanding of the process used. The raw data were derived from Table 5-1 of the AIRTRANS Phase I report, or in the case of items not reported, the estimate made by N.D. Lea in preparing its Cost Summary Report[5.2]. Adjustments to the raw data consist of reductions in manufacturing costs due to the first time application of this technology (for vehicles and control system) or additions to the costs reported in Table 5-1 of the original TSC Report[5.1] for items such as site modifications, station construction, and maintenance facility construction. These items are tabulated in Table 14 of Appendix L. The total represents the total subsystem cost in actual dollars (acquisition year cost).

Equipment engineering costs are derived from the "design" costs reported in the original TSC AIRTRANS Assessment[5.1] as adjusted for non-recurring costs by N.D. Lea and allocated by subsystem whenever possible. N.D. Lea determined that $2.5 million of the total design costs were non-recurring. This amount has been subtracted from the various subsystem design costs in proportion to the initially reported expenditures (see Table L-15 for details). The total equipment (for hardware) and construction (for facilities) engineering costs have been totalled and reported as separate categories in Table 5-1.

In reviewing the construction of the AIRTRANS system, N.D. Lea determined what percent of the total construction/manufacturing cost was expended in what year. The year and the fraction of the total vehicle costs expended in that year is shown in Table 5-13. To determine the cost in 1978 dollars of an equivalent purchase, the acquisition price in the year of expenditure is multiplied by an escalation factor.

TABLE 5-13. CAPITAL COST OF REVENUE VEHICLES

COMPONENT REVENUE VEHICLES	COSTS	SOURCE	REMARKS
RAW DATA	10,890,000	TSC Report[5.1]	
ADJUSTMENTS	(2,000,000)	N.D. Lea[5.6]	Table L-14 (non-recurring)
TOTAL	8,890,000		
EQUIPMENT ENGINEERING	1,247,000	TSC Report, value adjusted for non-recurring (Table L-15) and allocated between passenger and service vehicles by cost (Table L-16).	
YEARS OF ESCALATION* FROM N.D. LEA[5.6]	1972 - 0.5 x (8,890) x 1.60 = 7,112. 1973 - 0.4 x (8,890) x 1.56 = 5,547. 1974 - 0.1 x (8,890) x 1.39 = 1,236		Escalation using WPI Machinery and Motive Products Index (Table L-18)
TOTAL 1978 DOLLARS(X 10^3)	13,895		
NUMBER OF PASSENGER VEHICLES	51	(31 LEAD, 20 TRAIL) - Current	
UNIT COST 1978 DOLLARS	$272,450/ vehicle	(28 LEAD, 23 TRAIL) - Original	Vought Corp. estimated that lead vehicles cost 20% more than trail vehicles in original cost. In any new system only lead vehicles would be procured.
DESIGN VARIABLES AFFECTING UNIT COST			
CAPACITY	16 SEATED	24 STANDEES @ 0.225-m^2/STANDEE	
MAX. SPEED	7.5 METERS/SECOND		
MIN. HEADWAY	17 SECONDS		
POWER	45 KW		
MAX GRADE	7.8%		

*The fraction of the total system cost paid for in each year is represented by the decimal fraction.

The determination of the appropriate escalation factor requires the consideration of nationally tabulated indices, examination of the type of materials included in the national index to insure compatibility with the subsystem being considered, and review of the index and the actual prices of the subsystem over time. Notes to Table 18 in Appendix L describe the rationale and derivation of the subsystem escalation factors. These factors are similar to the ones used in other UMTA assessment reports. Table 5-14 summarizes the indices used and the five-year average inflation rate. This five-year inflation rate is recommended for determining future year prices. The use of the inflation factors is quite important. The total acquisition cost for a duplicate AIRTRANS system is estimated in actual dollars at approximately $44 million, while the 1978 dollar cost is approximately $67 million.

TABLE 5-14. SUMMARY OF INFLATION INDICES

EQUIPMENT CATEGORY	INDEX	ANNUAL INCREASE 1973-78 (%)
Revenue Vehicles Service Vehicles Guideway Switches Maintenance Equipment Station Equipment Power Generation and Distribution Vehicle Control	WPI Machinery and Motive Products	9.3
Guideway Site Modifications Guideway Structures Station Structures Maintenance Structures	Engineering News Record Construction Index	7.8
Project Management	Consumer Price Index	8.0

Referring again to Table 5-13, the unit cost of the equipment in 1978 dollars is determined from the number of units which are taken, in most cases, from the original TSC report. The tables in

Appendix L on each subsystem also list basic design variables which impact unit cost; however, no quantitative analysis has been performed with these variables.

5.6 OPERATING AND MAINTENANCE COSTS

In this section, unit manpower, energy and parts cost estimators are derived from supplementary data on the AIRTRANS system. These estimators are then used with the reported salary data from the Airport Board to predict the cost to operate the AIRTRANS system from April of 1977 to March of 1978. The estimated data are compared to the actual reported data on costs and staffing in accordance with the methodology described in Section 5.3. The estimated costs match the reported costs in almost all categories, and the total manpower estimates equal actual manpower in almost all categories. These checks provide a high level of confidence in the supporting data and the derived estimators (see Tables 5-9 and 5-10.)

Table 5-5 lists the manpower requirements estimators in accordance with the framework established in Table 5-12. For each category, the unit manpower function and the total man-hours derived from the deployment characteristics in Table 5-7 are presented. The derivation of the numbers in the unit manpower functions is documented in Appendix K, Table 1 and Table 7. A description of the process will be presented in full in Section 5.6.1.

The deployment characteristics used in Tables 5-7 and 5-8 are available from planning studies; thus, it is believed that these estimating relationships could be easily applicable to other deployments.

Table 5-9 details the derivation of the estimated costs based on the manhour requirements established in Table 5-5, the available manhours per person per year, the skill levels and their corresponding salaries at the Airport, and the local fringe package factor. The total estimated costs based on these variables is compared with the actual reported costs for operators, maintenance labor, and general and administrative personnel. The total manpower costs were estimated at $2 million versus a reported cost of $2.10 million.

The manpower estimate for maintenance technicians was 58 compared to an actual number of 59. The total number of passenger service agents is correct; however, the estimator does not account for seniority and overtime, which in this case has to result in the difference in total costs.

Table 5-6 lists the energy, parts, and facility cost estimators. Table 5-10 compares the estimates and the actual reported costs. The energy requirements are higher than the actuals because the actual figures do not include the costs to operate, to cool and to heat the nine terminal stations. The estimated costs include these stations for completeness. The most sensitive item here is the vehicle power consumption. This figure (1.56 kwh/veh-km) was derived from the Phase I report[5.1]. A more exact estimator would include both a model for the power consumed at cruise and acceleration and a model for auxiliary energy requirements which considered the climate of the site as was done for the station energy requirements.

The estimated facility maintenance cost given in Table 5-10 shows the janitorial manpower. The actual cost shown is for bus backup and facility work orders. No disaggregation of the actual cost was available, so this number is listed for completeness. For other deployments, janitorial costs should be used and the cost of replacing station components or providing a backup bus system estimated separately if required. This category could also cover improvements to the capital stock and contractor support as shown in Table 5-2 between April 1976 and September 1977.

5.6.1 Derivation of Unit Manpower Relationships

The derivation of the unit manpower estimates is described in Appendix K. Tables K-1 and K-7 give the results, and the source list accompanying these tables describes exactly how the results were derived. The accompanying tables in Appendix K list the supplementary sources. Specific categories in Table 5-5 were derived as follows:

a. The <u>Central Control</u> staffing was determined from the operation of the control room. It requires two people at all times. Since the operator must respond immediately to inputs from the console, a two-person staff is required for continuity. One person monitors the control panel, and the other monitors the closed circuit television setup. The number of shifts is governed by the system operating hours and the available manhours per person per year.

b. <u>Maintenance Supervision</u> is a function of the number of people to be supervised. The actual percentage was derived from the existing staffing at AIRTRANS which has one supervisor each for train, electronic, and guideway maintenance functions and one for maintenance control. Also, one foreman works each of three maintenance shifts. Consideration was given to deriving these requirements based on functions or the number of shifts, but it was believed that a smaller operation than AIRTRANS would be organized in a more functionally consolidated manner; thus the size of the maintenance staff would be the best parameter.

c. <u>Maintenance Control</u> requirements were derived from the existing staffing at AIRTRANS. This requirement has two components: the control of the maintenance shop and the preparation of documentation. Control of the maintenance shop is a function of shop operational hours. Documentation is a function of the number of maintenance actions. The period six data in Section 3 was used to relate documentation staffing levels to operational data, failure rates, and maintenance actions.

d. The <u>Rover Force</u> at AIRTRANS responds to unscheduled stoppages and performs scheduled maintenance on the guideway components. The time required for the rover force to perform scheduled maintenance on the guideway components is included in those categories. The unscheduled manpower requirement was derived from the time to respond, to repair, and to recover from an average stoppage and the expected number of stoppages based on the vehicle reliability.

e. The Hosteling requirement was based on Airport Board sources of the time needed to prepare a vehicle for service. The parameters influencing the total include the number of vehicles which are put into service each day and the number of days per year.

f. Subsystem Unscheduled Maintenance (except janitorial) was derived from the Vought maintenance data tabulated in Table 4 of Appendix K. In this table, the total maintenance manhours, maintenance actions, vehicle miles or system hours, and number of failures are listed for a six-month period between April and October of 1975 for each subsystem.

The number of maintenance manhours per vehicle mile or per system hour per number of units was derived from these data and is tabulated in Table K-1. Even though these data were taken during the early life of the system, they are the only data which trace maintenance manhours to operating characteristics at the subsystem level. A more recent update of this information would provide a good check on this source as well as a review of any reliability growth which may have occurred. For vehicle maintenance, the vehicle subsystems were grouped into electrical and mechanical categories to compare staffing levels, since the AIRTRANS maintenance organization is organized along functional rather than equipment lines.

g. Subsystem Scheduled Maintenance for vehicles was derived from a preventive maintenance schedule provided by the Airport Board. Vehicles are scheduled to undergo preventive maintenance at selected mileage intervals. The time and mileage for each preventive maintenance activity is listed in Appendix K, Table 5. These numbers were converted to a per mile figure using the number of vehicles (51) currently in the fleet and the number of miles (3,510,320) for the period modeled. These data have been converted to kilometers for presentation in Table 5-5.

For equipment other than vehicles, no scheduled maintenance data were available. The scheduled maintenance requirements were estimated by TSC using data available for other AGT systems. Data supplied by Boeing on the Morgantown system were used, and these data points are tabulated in Table 12 of Appendix K. Since in many cases the scheduled maintenance manhour requirements exceed the unscheduled requirements by a factor of 10, these data are subject to interpretation for the AIRTRANS system. However, in the absence of any other data, and considering that the total manpower requirements were calculated using these estimates (Table 5-4), an excellent approximation of the actual AIRTRANS maintenance staff (Section 2.4.2) resulted. Therefore, this procedure was considered appropriate.

h. Janitorial Maintenance Requirements were derived using cost estimates provided by Boeing for the Phase Two Morgantown site and manpower estimates derived by General Motors in the analysis of SLT systems[5.4].

i. Passenger Service Agents are a unique AIRTRANS function, and the unit manpower requirement was estimated using current staffing levels described in Section 2 of this report. The estimator used in Table 5-5 is unspecific, since it requires a local determination of how many customer service people will be stationed in the system per day. The AIRTRANS system uses approximately one person per terminal station. From this, it would appear that this service would be required at all stations where passenger uncertainty about routes or system usage may exist.

j. General Management and Engineering was divided into a fixed and variable component. The fixed component consisted of the AIRTRANS manager, the operations manager, the maintenance manager, and their respective secretaries. This was considered the minimum staffing level. The variable component would depend on the size of the operation and would include the special staff functions and administrative components of the AGT operation. It should be noted that the AIRTRANS operation does not have accounting, payroll, legal or other similar support functions staffed within the organization. AIRTRANS uses the central airport services, and its budget is charged accordingly. These costs are reported by the Airport Board as "Airport Services" and are listed in Table 5-6 under the category Contract Services.

5.6.2 Derivation of Labor Costs

The total labor cost estimate for the AIRTRANS operation is shown in Table 5-9. To determine these costs, the first step was to determine the total manhour requirements as discussed in Section 5.5.2. The staffing requirements were determined according to the various required skills. Most of the skill levels represent one particular functional area. The exception is the maintenance technician.

The AIRTRANS organization chart (positions and salaries are shown in Appendix K, Table 10) lists five different maintenance skills. These skills include train, electronic, and guideway technicians; train air conditioning repairmen; and train access equipment repairmen. Also included are three different skill levels within the train, electronic, and guideway technician skill areas.

Since the salary levels are consistent across functional areas, these skills were grouped together in this analysis. For a skill level staffing analysis for a different deployment, the manpower estimators in Table 5-5 could be used with the base salary levels for the location in question.

The staffing level was determined by dividing the total manpower requirement by the available manhours per person per year. The base salary levels were determined by using the salary information provided by the airport for the year beginning October 1978; weighting the salaries according to the existing AIRTRANS staffing levels; and deflating the salary data to the time frame of the system characteristics data (April 1977-March 1978). (See Appendix K, Table K-11 for details.)

The fringe factor of 1.20 was provided by the Airport Board. The fringe factor, in the case of AIRTRANS, includes the costs of employee benefits such as contributions to retirement, social security, and health plans. It does not include any indirect charges. In many urban applications an additional indirect charge is applied to each salary to cover overhead charges. This factor should be determined from an examination of local conditions.

5.6.3 Derivation of Energy, Parts, and Facility Requirements

Table 5-6 presents the unit requirements and totals of the period (April 1977-March 1978) for energy consumption, parts requirements, facility maintenance, and airport services costs for the AIRTRANS system. The energy costs were derived as follows:

a. Vehicle propulsive and auxiliary energy requirements were derived from Figure 5-3 of the Phase I report which worked out to 1.56 kwh/veh-km (2.5 kwh/veh-mile). This figure takes into account the propulsion and auxiliary energy requirements over an entire year.

b. Wayside control energy was based on the requirements derived in the GM analysis of SLT systems.[5.4]

c. The station and garage electrical requirements were based on the requirements derived in the GM analysis of SLT systems.[5.4]

d. The station and garage air conditioning and heating requirements were based on the local environmental requirements as examined in a TRW study of local heating and cooling requirements and reported in the GM analysis of SLT systems. The data for 12 U.S. cities is shown in Table 6 of Appendix K. The figures in Table K-6 were converted from btu per square meter to kwh per square meter for presentation in Table 5-6.

While the energy requirement data were derived from several sources, the total energy requirement for the system was compared to the actual reported values and found to be within 5 percent for both 1976-77 and 1977-78. The total cost shown in Table 5-6 includes additional station energy usage not currently charged to the

AIRTRANS system, but it is included in this report for completeness. (This is consistent with the "total duplicate system" concept used in capital costing.)

e. Vehicle parts costs were derived from Westinghouse data on the SeaTac and Tampa systems which are used in the GM analysis of AGT systems.[5.4]

f. Wayside parts costs were derived using the estimate for the St. Paul DPM system.[5.5]

g. Electronic parts costs were derived using the total cost figure reported from April of 1977 to March of 1978 by the Airport Board minus the vehicle and wayside parts costs. The cost per capital equipment expenditure was approximately equal to the 0.012 factor determined by GM in their analysis of SLT systems. While the estimators used here were from sources outside the AIRTRANS system, they were consistent with the trends in SLT systems, and the total cost approximates the reported total AIRTRANS costs. Again, it must be emphasized that the theory behind this approach is to use estimators which are from different sources other than the reported costs. Whenever possible, different sources within the AIRTRANS system were used, however, this was not always possible, so alternative sources were used.

The facilities maintenance category includes work orders for changes to the facilities and, when required, the AIRTRANS bus backup costs. The drivers of the backup bus are the passenger service agents, so this cost was considered negligible.

The total cost of the facilities maintenance (Table 5-10) for the period April 1977 through March 1978 was estimated using janitorial labor requirements. The actual costs are those reported by the Airport Board.

5.7 APPLICATION TO OTHER DEPLOYMENTS

The disaggregated cost estimators developed in this section can be applied to other deployments of a similar system.

5.7.1 Capital Costs

To determine the capital cost of a similar AIRTRANS system in another deployment, the unit costs of each subsystem shown in Table 5-1 can be multiplied by the number of units of the new deployment to determine the capital cost in 1978 dollars. The cost estimators for system hardware items should be good estimators. Caution should be used to insure that the specifications for the hardware are similar to those of the AIRTRANS system as described in the TSC Phase I assessment. The capital cost estimators for the guideway structure should provide reasonable estimates for elevated and at-grade sections, although the planner would be advised to check local conditions for wage and material costs and compare the local cost indexes with those of the Dallas-Fort Worth area. In addition, if the system is being planned in an urban area rather than at an airport, a contingency factor should be considered to reflect the difficulties anticipated in traffic handling and other construction delays.

The two categories which are most sensitive to local conditions are the site modification costs and the station construction costs. Site modification costs vary with the density of the location, the utility infrastructure, and soil conditions. The unit cost presented here for an airport site can be considered a lower bound. The station cost per square meter should also be used with care. The cost here is for relatively austere ground level stations, in which the total station cost is captured by the unit cost and the whole station area is on the same floor as the platform. If elevated stations are desired, and particularly if the stations have intermediate levels between the ground and the platform, the planner should not use this figure. It would be advisable to either submit the station design to a cost consultant or use the estimates from other systems planning elevated stations.

Additional station hardware, such as elevators and escalators, should also be costed.

Another important consideration is the estimation of inflation factors. The planner should determine the time frame of construction, select the midpoint of this time period, and use the inflation rates in Table 5-14 to estimate the expected cost of the project in actual dollars.

5.7.2 <u>Operating Costs, Systems with Similar Levels of Service</u>

Tables 5-5 and 5-6 can be used to estimate the operations and maintenance costs of a similar system in another deployment. The parameters needed to estimate total manhours are given in Table 5-7, and the parameters needed to estimate energy, parts, and contract service requirements are given in Table 5-8. Table K-6 provides energy requirement data for another site. Once the parameters in Table 5-7 have been determined, the planner should total the labor requirements for each skill category as shown in Table 5-9. To determine the annual labor costs, the planner should determine representative salary levels for the local site for each of these categories. This can be done by consulting the existing transit authority. In addition, the overhead rate used by the agency which will run the AGT system should be determined since this number (the Fringe Factor in Table 5-9) can vary substantially from site to site. Once the manhour requirements, salary data, and overhead or fringe factors are determined, the total labor costs can be estimated.

To determine the cost of energy two calculations are necessary. First, the local environmental factors should be matched to Table K-6 and the heating and cooling costs in Table 5-6 adjusted accordingly. After the total kilowatt hours are calculated, the local cost per kilowatt hour should be determined and multiplied by the total kilowatt hours to determine the energy cost.

Care should be taken in using the unit vehicle energy requirement. Closer station spacings and vehicles with higher speed than those used in AIRTRANS could substantially increase this unit energy requirement.

Other cost items can be calculated as shown in Table 5-6.

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5.10. Engineering News Record, 20-City Construction Index.

5.11. Consumer Price Index for Urban Wage and Clerical Workers, U.S. City Average.

5.12. "Generic Alternatives Analysis: Guidelines on Modal Applicability," Stuart, D.G., et al., W.V. Rouse & Co., under DOT Contract DOT-UT-70009, June, 1979.

Note: Due to the numerous references to this secion in Appendix K and Appendix L, Section 5 has been given a separate reference page for clarity. References for the remainder of the text are given on page R-1.

6. LESSONS LEARNED AND RECOMMENDATIONS

The AIRTRANS configuration has changed in detail from that described in the Phase I report; changes are described in Section 2 of this report. The evaluation of the system presented in Section 7 of the Phase I report, however, remains essentially unchanged, as do the assessments of the various subsystems. Certain problems cited in that report remain unsolved. For example, the system is still vulnerable to ice and snow, as the experience of every winter demonstrates.

With aid from UMTA, the Airport Board has been developing an improved version of the AIRTRANS vehicle under the "Urban Technology Program." (See Appendix I for a brief description.) Problems of speed, brush and tire wear, and others are being tackled frontally, and some proven improvements will undoubtedly be retrofitted into the operating system in the future.

AIRTRANS is still the largest operating AGT system in the United States, and it continues to be a dynamic system, capable of growing in reliability, service, and accessibility to the public. The 1979 plans for airline terminal expansion include extension of AIRTRANS into new terminals.

It is interesting to note that on September 1, 1978, the system carried its 20 millionth passenger.

In several areas the recommendations made in Section 8 of the Phase I report are still valid and well expressed. For the sake of reader convenience some key recommendations from the section will be quoted in Section 6.1 below. New recommendations, arising out of the analysis of data and more recent experience with the system, will follow in Section 6.2.

6.1 LESSONS LEARNED AND RECOMMENDATIONS FROM PHASE I REPORT

In the following section, the notes in parentheses are comments or amplification of the quotations.

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." (This Phase II Report is a beginning at this. See also Section 6.2 below.)

2. "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." (Note: The users perception of system dependability is hard to quantify and relate to hardware. The above recommendation is valid only if a useful and measurable parameter can be defined.)

3. "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."

4. "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."

5. "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."

6. "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."

7. "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." (Note: This has been partly done in AIRTRANS. See Section 2.3.1.1)

8. "The software development process must be integrated with the development process of the complete system."

9. "Use of the 'same design' for identical functional requirements is desirable to maximize reduction in life-cycle costs, while maintaining or improving operational availability."

10. "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." (See also Section 6.2, below.)

11. "Off-the-shelf, commerical 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." (See the reliability figures on the Audio Announcement Unit in Table 3-9.)

12. "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."

13. "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."

14. "Complete testing for functional operation as well as identification and redesign of early mortality failures is necessary before initiation of the production phase." (See Section 6.2 below.)

15. "The safety system must be independent of the Automatic Train Operation/Automatic Train Control (ATO/ATC) system." (It is in AIRTRANS.)

16. "New system specifications must be clear and explicit on all meanings, requirements, goals, failure definition, and acceptance terms." (AIRTRANS specification was not clear.)

17. "System design should minimize life cycle cost rather than first cost."

18. "The equipment manufacturer should be involved with both operation and maintenance for at least a year of operation following initiation of revenue service."

19. "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." (See Section 4 of this report, and Section 6.2 below.)

20. "In the AIRTRANS specification, 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."

21. "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."

22. "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."

23. "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 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."

24. "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."

25. "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." (See also Section 4.)

26. "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."

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

28. "There should be adequate maintenance training. Formal training for all maintenance people was required by GRS (General Railway Signal) for the Control System."

29. "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." (Note: From a system level point of view, MTTR must denote "mean time to restore" the system. In availability calculations the event is over when the system is cleared. Shop time to repair is not included.)

30. "There is a lack of specific noise interference limits or signal-to-noise limits on subsystem interfaces that are considered critical to movement and control. For any future application, specifications on subsystems should have such requirements."

31. "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."

6.2 LESSONS LEARNED AND RECOMMENDATIONS FROM THIS PHASE II REPORT

1. Ridership Projections (Sec. 2.1.3) - For planned systems, be sensibly conservative in projecting ridership to the time when the system is mature; startup must include generous time contingencies for early failures. These failures should come as a shock to no one.

2. Station Attendants In AIRTRANS a human interface between the system hardware and its users in the form of station attendants who provided security, system back-up, and passenger service, was found desirable. Automated and unmanned stations in AGT systems of the future will be entirely feasible if station security can be insured and if passenger confusion can be eliminated through the use of clear signs, easy-to-use instructions, and information telephones.

3. Reliability and Availability Growth (Sec. 2.3.1.2, and Appendix I) - Availability (A) and Reliability (R) will grow in any new system only when faults are identified and corrected. R will grow when the causes of failure are removed (see Figure 3-18 in Section 3 on component reliability growth). A will grow with R, and also when fault durations are reduced. New systems must expect a period of R and A growth, and since improving R means a decreasing failure rate, the exponential test methods, aimed at determining compliance with a specification value for MTBF, are wrongly used while growth is still going on, for they assume a constant failure rate.

4. Reliability Costs - It must be recognized at the start of any program that it costs extra money to provide the quality components, the design attention, the design review, and the testing needed to ensure that reliability

is built-in, and that the quality control is performed to ensure the realization of designed-in reliability.

AIRTRANS reliability has not proven to be remarkably good, but supported by effective failure management, the transportation system seems to have achieved public acceptance. Mediocre reliability in general, however, is paid for by the maintenance costs needed to keep the system going. In a new system design, the buyers must decide for themselves whether, on a life cycle basis, high operating and maintenance costs are a good trade-off for more money spent in detailed reliability assurance during design. Even with the modest growth in reliability experienced from 1975 to 1978, the maintenance work force decreased from 125 to 88.

5. Operational Data (Sec. 3.2) - System operational data must be recorded in almost real time and analyzed rapidly, or they will probably go to waste. Obtaining and analyzing the raw RAM data for this report required the time of two people for six months. If initially a method is available for taking daily logs and maintenance records directly into a computer memory, current analyses could keep the system management factually aware at all times of all aspects of system performance.

   Serious thought should be given in new systems to designing a cost effective direct link from system operators and maintainers to a data memory. Such a rapid response RAM analysis system is not just a luxury installed for the pleasure of reliability engineers. Trend spotting, i.e., identifying the components and subsystems that give the most trouble, so they can be repaired, could be rapid and very convincing to management, and hence R-growth would be more rapid. For example, in a new transit system, seven subsystems whose faults might account for two-thirds of the malfunctions, as in AIRTRANS (refer to Table 3-8), could be spotted rapidly and quantitatively.

The chances of quick fixes would be much better than if their bad performance remains only an opinion on the part of the operators. Before management commits money for a fix, proof of need is required. A data system will provide this proof.

6. New System Recommendations - Three rules for speeding up new system reliability growth can be stated as follows:

   a. In any new systems procurement, both buyer and seller must agree on clear definitions of what will and will not be considered malfunctions or failures, before the system is built.

   b. Allow the break-in period of a new transit system to be long enough for reliability growth to occur, and provide the money and people to do the failure analysis and fault elimination that is necessary to cause such growth. Do not expect a new system to meet its reliability specification during its first week or month of operation. Do expect design and manufacturing faults to show up, and be prepared to find the causes and eliminate them, one by one.

   c. Begin operation of a new system with a preplanned R&M data collection system in place, complete with definitions of failures, availability, and the various indices of reliability and maintainability that have been decided upon. Use it to monitor the new system for acceptance, to schedule and optimize preventive maintenance, to identify trends and pinpoint troubles, and to point clearly to component and subsystems that demand improvement. Such a data system would clearly be much more effective than the improvised ones that usually develop out of necessity, and would probably not be any more expensive.

7. Safety, Manual Operation - The one serious collision on the system occurred as the result of one of the vehicles being driven manually. Whenever manual operations are

needed in an automated system, operational rules must be elaborately established and enforced. Futhermore, any transfer of vehicle control from automatic to manual operation must automatically be transmitted to Central Control.

8. <u>Safety, Warning Before Station Departure</u> - All vehicles should have a warning buzzer or annunciator to alert the passengers aboard to protect themselves from being caught off balance by startup acceleration. (See p. 4-5).

9. <u>Safety, Protection Against Intrusion</u> - Guideways built parallel or in close proximity to roads or highways must be protected with fences strong enough to keep an automobile or truck from braking through and damaging the guideway. If such a hazard exists, and a strong enough fence is not feasible, the guideway should be protected with a trip wire or other warning sensor that would result in the damaged protion being shut down. Similarly, all at-grade guideway should be protected against trespassers by adequate fences or barriers. The one death that occurred on AIRTRANS in over four years of operation was presumably due to an individual trespassing on the system. (See Appendix D.)

10. <u>Safety Analysis</u> - All new systems, or changes to existing systems, should be subjected to failure mode and effects analysis or hazard analysis, and to fault tree analysis, when appropriate. The latter is especially good in detecting the effect of multiple failures on safety.

11. <u>Obstacle Detection</u> - Totally automated systems should have an automatic obstacle avoidance capability. None has today. Although none has suffered great loss as a result, large obstales that fall on the guideway remain potentially serious hazards, and a blind vehicle has no protection from them.

12. Speed Broaches - This frequent malfunction - almost the most frequent one - was rendered less of a nuisance by being made resettable from Central Control. Causes of the speed broaches have not been firmly identified but they should be tracked down and eliminated if possible in the AIRTRANS system. The defects should certainly be eliminated before the deployment of a Vought system eleswhere. (See Tables 3-8 and G-2)

13. Other Malfunctions - The emphasis of Recommendation 12 is also appropriate for the other malfunctions listed in Table 3-8.

14. Multiple Usage of an AGT System - The multiple usage of the guideway and vehicles for various services at the airport was never fully realized. Neither mail nor baggage handling has been accomplished to the satisfaction of the users of those services, the U.S. Postal Service and the airlines.

Proposals for multiple usage of future systems should be analyzed critically before being accepted, and should evaluate such things as:

- Can the mixed system guarantee the necessary performance time needed by each independent service?
- Can each service operate on the common guideway and in the common maintenance facility with no mutual interference?
- Is the operation of each service that is integrated into the system cost effective when performed in the automated system? Are there cheaper and equally effective ways of performing it?

15. Transferability of Capital Cost Information - In contrast to other AGT installations, relatively detailed infomation on capital costs was available for AIRTRANS. Disaggegated capital costs data provide the most meaningful information for future deployments.

Use of a standard set of capital costs categories such as those shown in Table 5-1 and 5-11 will greatly assist planners, operators, and suppliers in understanding and reducing the cost of AGT systems.

16. Transferability of Operation and Maintenance Cost Information - The operating and maintenance costs of AGT systems are sensitive to a variety of site-dependent characteristics as illustrated in Tables 5-5, 5-6, and 5-9. The data presented in this report can be used for other deployments because site-specific variables have been explicity identified. These include labor-related variables such as annual available hours, salaries, and fringe/overhead factors. Site characteristic variables which are important include annual system hours of operation, annual vehicle kilometers, peak fleet size, lane kilometers of guideway, and number of stations. (See Section 5.7)

17. Effects of Inflation - The cost of constructing AGT systems is extremely sensitive to inflation. Planners should carefully review recent changes in costs and use a range of inflation rates to bound actual dollar expenditures.

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Note: A separate list of references for Section 5 is provided on page 5-36.

APPENDIX A

EFFECTS OF MERGE SWITCHBLADE REMOVAL ON GUIDEBAR LOADING

Merge switches were required in the original AIRTRANS design to give the vehicle bidirectional capabilities in the guideway and to provide positive guidance of the vehicle at all times. The bidirectional requirement at D-FW was used little, and eventually steps were taken to remove the merge switches. Guidebar loads were measured at various switch locations to be certain guidebar loads were not increased by the blade removal. Table A-1 presents the results of the loads evaluation and reveals guidebar loads are less after the blade is removed.

The removal of the passenger merge switch shows the greatest reduction of load (1150 to 400). This blade is set in the mainline flow to give the passenger siding maximum comfort, which is the reason no improvement was realized when traveling through this switch from the passenger siding (400 to 400).

Considerable improvements were realized by removing this utility merge switch (1700 to 1150) as the vehicle encounters it from the utility siding. This switch is set for mainline flow, and as seen in the table, no improvement could be detected (400 to 400) as the vehicle encountered the switch mainline. The utility siding improvement is believed to be the result of two facts, one being that the vehicle impacts with a 6-inch guidewheel that has a smaller spring rate than the 4-inch switchwheel, and secondly the vehicle transitions into the mainline guideway at a smaller angle than it impacts the switchblade.

Figure A-1 depicts the AIRTRANS guideway at the Dallas-Fort Worth maintenance area and shows the power and signal rails and the switch mechanism.

TABLE A-1. MERGE BLADE REMOVAL EVALUATION RESULTS

Encounter		Guidebar Load (lbs)	
Switch	Route	With Blade	Without Blade
Passenger Merge	Mainline	1150	400
Utility Merge	Mainline	400	400
Utility Merge	Utility	1700	1150
Passenger Merge	Passenger	400	400
3SB Merge	Reverse	1120	Blade not removed
4SB Merge	Reverse	Blade already removed	860
4SB Merge	Normal*	Blade already removed	Not discernible on road trace
3SB Merge	Normal	500	Blade not removed

*Normal - Vehicle entrapped.

FIGURE A-1. AIRTRANS GUIDEWAY AT MAINTENANCE AREA SHOWING POWER AND SIGNAL RAILS AND SWITCH MECHANISM.

APPENDIX B
DESIGN OF SAMPLING SCHEME TO EXTRACT MALFUNCTION DATA FROM THE AIRTRANS SYSTEM REPORTS

PROJECT MEMORANDUM

BETTY KWOK

February 16, 1977

Transportation Information Division
Statistical Design & Analysis Branch

Revised
July 12, 1979

This document contains information subject to change. It is considered a means of communicating preliminary technical information to the project personnel. Distribution is effected by and the responsibility of the TSC Program Manager.

1. SAMPLING SCHEME

The AIRTRANS system, providing interterminal transport for passengers, employees, and supplies at the Dallas-Fort Worth Airport, has been in operation for nearly three years. To evaluate further the reliability and availability of the system, various malfunction data had to be obtained from the Dallas-Fort Worth Airport Board. This memorandum presents a sampling plan, the purpose of which was to select six sets of days of malfunction records out of the six periods of interest, so that system effectiveness parameters derived from the sample data would be representative of each period with 90 percent confidence.

The plan, as summarized in detail below, recommended a stratified random sample of 230 days which was selected from the six periods, a 25 percent sample from a total of 910 days of data from the AIRTRANS information system.

Since more than one item had to be measured by this sample, it was essential to specify which item(s) or variable(s) were most important so that the sample size could be determined, given an allowable margin of error around this variable at a 90 percent confidence level. Based on the limited information provided by the 10-month (March-December 1976) AIRTRANS Malfunction Trend Reports, it was agreed that the parameter "Service Daily Total T," represented the most important measure, where T_i was defined to the ith day in a period as:

$$T_i = \sum_j W_j M_{ij} = D_i + O_i, \text{ where:}$$

M_{ij} = Number of Malfunctions for component j

W_j = Service Factor for component j (weight or importance)

D_i = Total Delay in minutes for Day i

O_i = Total Outage for Day i in minutes.

This was an arbitrary number used by AIRTRANS as an index of excellence. It was derived as shown, and increased with increasing trouble. It was used here as an available raw statistic from which to calculate sample sizes.

A decreasing value of T was expected from Period 1 to Period 6 because of the increasing reliability of the system since the time of its inception. Hence, a systematic sampling technique, by which one out of every k days was selected after a random start, was not recommended due to the embedded time trend in the data. Rather, a simple random sample was more advisable. Shown in Figures B-1 and B-2 are calendars for the years 1974-76. The days in each period were chosen randomly according to a random number table.

1 9 7 4

JANUARY

S	M	T	W	T	F	S
		1	2	3	4	**5**
6	7	**8**	9	10	11	12
13	**14**	15	16	17	18	**19**
20	21	22	23	24	**25**	26
27	28	29	30	31		

FEBRUARY

S	M	T	W	T	F	S
					1	**2**
3	**4**	5	**6**	**7**	8	9
10	11	12	13	14	15	**16**
17	18	19	20	**21**	22	**23**
24	25	26	27	**28**		

MARCH

S	M	T	W	T	F	S
					1	2
3	4	**5**	6	**7**	8	9
10	**11**	**12**	13	14	15	16
17	18	19	**20**	**21**	**22**	23
24	25	**26**	27	**28**	29	30
31						

APRIL

S	M	T	W	T	F	S
	1	2	3	4	5	6
7	8	9	10	11	12	13
14	15	16	**17**	**18**	19	20
21	22	23	**24**	**25**	26	27
28	29	**30**				

MAY

S	M	T	W	T	F	S
			1	**2**	3	4
5	6	7	8	9	**10**	11
12	**13**	14	**15**	16	17	18
19	20	**21**	22	23	**24**	**25**
26	27	**28**	29	30	31	

JUNE

S	M	T	W	T	F	S
						1
2	**3**	4	**5**	6	7	**8**
9	10	11	12	13	14	15
16	17	18	**19**	**20**	21	22
23	24	**25**	26	**27**	28	29
30						

JULY

S	M	T	W	T	F	S
	1	2	**3**	4	5	6
7	**8**	9	10	11	12	13
14	15	16	**17**	18	19	20
21	**22**	23	**24**	25	26	27
28	29	30	31			

AUGUST

S	M	T	W	T	F	S
				1	2	**3**
4	5	6	7	8	**9**	10
11	**12**	13	14	15	16	17
18	**19**	20	21	22	23	24
25	**26**	27	28	**29**	30	31

SEPTEMBER

S	M	T	W	T	F	S
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	**19**	20	21
22	23	24	25	26	27	**28**
29	**30**					

OCTOBER

S	M	T	W	T	F	S
		1	2	3	4	5
6	7	**8**	9	10	**11**	12
13	14	15	16	17	18	19
20	21	**22**	**23**	24	25	26
27	28	29	**30**	31		

NOVEMBER

S	M	T	W	T	F	S
					1	**2**
3	4	5	6	**7**	8	9
10	11	12	13	14	15	**16**
17	18	19	20	21	22	**23**
24	25	**26**	27	28	29	30

DECEMBER

S	M	T	W	T	F	S
1	2	3	4	**5**	**6**	7
8	**9**	10	11	12	**13**	14
15	16	17	18	**19**	20	21
22	23	24	**25**	26	27	28
29	30	31				

<u>Note</u>: A "snow day" or a day in which the system is out of service due to general maintenance should be ignored when choosing the sample.

FIGURE B-1. SAMPLE DAYS SELECTED FROM 1974

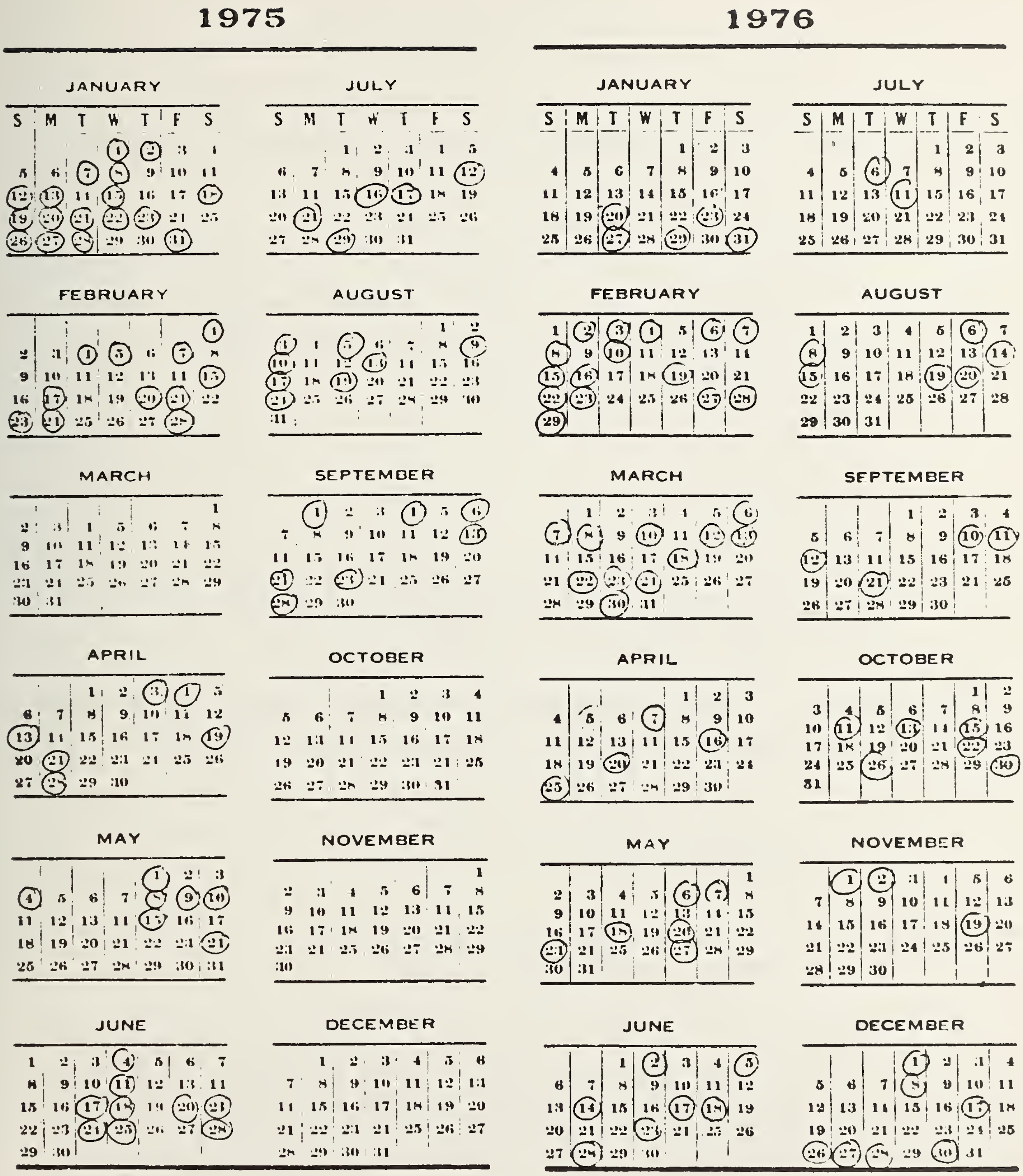


FIGURE B-2. SAMPLE DAYS SELECTED FROM 1975-76

2. ESTIMATION OF SAMPLE SIZES

Statistics were estimated from the Period 6 data. The average service daily total and its standard deviation were:

$$\hat{\bar{T}} = 124 \;\&\; \hat{S}_T = 84, \text{ respectively}$$

If $\hat{S}_T$ is taken as the estimate of the standard deviation of T_i for the entire six periods in question, then the sample size <u>for each period (or stratum)</u> is simply

$$n = \frac{t^2 \times \hat{S}_T^{\,2}}{e^2}$$

where t is the $\eta(1-\alpha/2)$ value; and e is the margin of error allowed to the estimate. At a 90 percent confidence level, or $\alpha = .10$, t is 1.65.

For example, for the estimated mean daily service time, $\bar{T}$, to be precise within 10 percent with 90 percent confidence,

$$n = \frac{(1.65)^2 \times (84)^2}{(124 \times .10)^2} \approx 125$$

Similarly, for it to be precise within 15 percent, the sample size is 55, and within 20 percent, n = 30.

It appears that a sample size which results in a precision within 15 percent or a standard error of approximately 9 percent with 90 percent of confidence is more acceptable than the others. That is, the precision criterion assures that $\bar{T}$ will be within the interval ($\hat{\bar{T}} \pm 15\%$) or, equivalently, $\hat{\bar{T}} \pm 1.65 \times 9\%$) with 90 percent confidence.

Further, since the sample was selected from a finite number of days, an adjustment of the computed sample size by a finite population factor, $(1 - n/N)$, was necessary. For Period 1, for example, the adjusted sample size, n_1, is

$$n_1 = 55/\ (1 + 55/138) \simeq 40$$

Using the same procedure results in the sample sizes for the six different periods as shown in Table B-1.

TABLE B-1. DATA SAMPLING SIZES FROM ALL SIX PERIODS

Period	Days in Sample	Total Days in Period
1	40	138
2	44	214
3	28	80
4	42	180
5	31	72
6	45	275
	230	959

Another important variable, for which some data are available at this time, is the number of malfunctions per day per period, by three classes. The average number of malfunctions per day is approximately 42, with a standard deviation of 12.63. Hence, again allowing a 15 percent margin, at a 90 percent confidence level, the unadjusted sample size for Period 6 is computed to be

$$n = \frac{(1.65)^2 \times (12.63)^2}{(42 \times .15)^2} \simeq 11 \text{ days}$$

Please notice that this sample size does not exceed 55 days which was derived earlier based on "Service Daily Total." Therefore, precision for the former implies similar precision for the latter.

APPENDIX C
AIRTRANS RELIABILITY DATA ANALYSIS, 1974-1976

PROJECT MEMORANDUM

AIRTRANS RELIABILITY
DATA ANALYSES
1974-1976

Betty Kwok

JANUARY 1978

Revised
JUNE 27, 1979

This document contains information subject to change. It is considered a means of communicating preliminary technical information to the project personnel. Distribution is effected by the responsibility fo the TSC Program Manager.

1. INTRODUCTION

This memorandum summarizes the results of the AIRTRANS system's reliability analysis based on the malfunction data supplied by the Dallas-Fort Worth Airport Board for the six periods beginning January 1, 1974 to December 31, 1976. The sampling plan is basically a stratified random sampling procedure by which 230 days of malfunction records were chosen during the three years of operation. The sample obtained is distributed as in Table C-1.

TABLE C-1. SAMPLE DISTRIBUTION

Period	No. of Days Requested	No. of Days Obtained	Total No. of Days In the Period
1. 74/1/1-74/5/31	40	37	138
2. 74/6/1-74/12/31	44	43	214
3. 75/1/1-75/2/28	28	28	80
4. 75/4/1-75/9/30	42	42	180
5. 76/1/1-76/3/31	31	31	72
6. 76/4/1-76/12/31	41	45	275
	230	226	959

The percentage of "nonresponse" was minimal and no provision was made to account for it in all subsequent estimations. There was a data problem, however, because the duration of a large number of malfunctions was indeterminable from available information. The problem is detailed in the next section.

Note: For the 230 days requested, 4 days were not available because of inoperative system due to scheduled maintenance. Hence the nonresponse rate of the sample was 4/230 = 2%.

2. A DATA PROBLEM

About 50 percent of the malfunction records over the six periods do not specify the duration of the malfunction. The problem was particularly acute for Period One and Two. Such a large percentage of "non-response" may induce bias in subsequent estimations which require the duration of malfunction as input. The following remedy was implemented whereby an arbitrary but reasonable measure of malfunction duration was inputed in each empty cell.

It is believed that the delay caused by any malfunction correlates with the seriousness of the malfunction and the capability that the system can cope with the problem. Hence the AIRTRANS data base was divided into subgroups represented by the matrix in Table C-2, in which the entry for each row and column represents the average duration in minutes obtained from those non-empty cells.

TABLE C-2. AIRTRANS DATA BASE SUBGROUPS

Class	Period 1	Period 2	Period 3	Period 4	Period 5	Period 6
1	4.75	4.21	4.53	3.91	3.38	2.47
2	12.19	6.73	6.82	9.35	11.04	5.25
3	6.30	7.52	18.16	59.80	4.28	24.28
4	1.11	1.10	1.09	10.30	7.42	13.04
5	163.42	108.52	252.2	400.00	199.00	140.79

Except for the entries within the box, the average duration for each class of malfunctions remained stable throughout the six periods. For those inside the box, a check for the variation around these averages revealed several extreme values, generally in the 400s, mixed in with the majority of low value figures. The arithmetic average thus derived, therefore, did not reflect the general behavior of the malfunctions within that row-column combination. It is proposed that for these entries, the medians, which are more resistent to the influence of extreme values, be used. A revised matrix follows in Table C-3.

TABLE C-3. REVISED MATRIX

Class	Period 1	Period 2	Period 3	Period 4	Period 5	Period 6
1	5	4	5	4	3	2
2	12	7	7	9	11	5
3	6	8	4	4	4	1
4	1	1	1	1	1	1
5	163	109	*	*	*	*

*No empty cells fell into these period-class combinations.

The empty cells in the AIRTRANS data base were then replaced with the appropriate value according to the class and period they fell into.

3. STATISTICAL RESULTS AND ANALYSES

The sample sizes were based on a requirement of a standard error of approximately 9 percent with 90 percent confidence, for most of the estimates. About two-thirds of the estimates shown in Table C-4 have standard errors ranging from 4 to 10 percent of the means. In other cases, large standard errors reflect the high variability of the malfunction behavior within some subclasses.

In general, there were more Class II malfunctions than any other class, accounting for 40 to 60 percent of the total number of malfunctions. It is encouraging to find that, in all classes of malfunctions, statistics for the six periods reflect a progression toward fewer breakdowns and shorter delays (a difference of seven hours per day between the first and sixth period). Figures C-1 and C-2 represent graphic comparisons of the estimated frequency of malfunctions across the periods. The non-overlapping confidence intervals (95 percent in Figure C-1 clearly indicate a significant downward trend.

Table C-5 is also self-explanatory. However, we can also see that the capability to cope with manfunctions (reflect in the average time spent in correcting them) is also improving slightly. Again Class 2 malfunctions interrupt the system service longer than other classes of malfunctions, except Class 5. This will be investigated in detail later in this memorandum.

Table C-4 shows only the average behavior of the system for each period. Another performance measure of the system is the element standard deviation, defined as the average variation of the individual values around the means.

Standard deviation:

$$S(T) = \left(\frac{1}{n-1} \sum_{i} \left(T_i - \bar{T}\right)^2\right)^{1/2}$$

TABLE C-4. AVERAGE TOTAL MALFUNCTIONS AND TOTAL DURATION PER DAY

	Average Per Day		Class 1		Class 2		Class 3		Class 4		□ Class 5	
	Total Malf.	Total △ Dura. (Min)	Total Malf.	Total Dura. (Min)	Total Malf.	Total Dura. (Min)	Total Malf.	Total Dura. (Min)	Total Malf.	Total Dura. (Min)	Avg. Out Per. Day	Avg. Dur. Per. Day (Min.)
Period 1 1974/1/ - 1974/5/31 (40 days requested) n = 37 N = 138	52 (3.29)	[o]640 (39.54)	8 (1.02)	37 (4.81)	32 (1.82)	380 (27.55)	4 (.53)	26 (3.19)	8 (.89)	8 (1.01)	.9	150
	*82	1024	13	59	51	608	64	42	13	13		
Period 2 1974/6/1 - 1974/12/21 (44 days requested) n = 43 N = 214	99 (4.72)	681 (36.15)	17 (1.33)	73 (5.73)	54 (3.33)	369 (23.32)	17 (3.53)	138 (29.46)	10 (.76)	10 (.89)	.8	91
Period 3 1975/1/1 - 1975/2/28 (28 days requested) n = 28 N = 80	71 (2.64)	450 (30.56)	10 (.72)	49 (3.50)	39 (1.74)	268 (23.60)	16 (1.04)	82 (9.66)	5 (.45)	5 (.48)	.2	45
Period 4 1975/4/1 - 1975/9/30 (42 days requested) n = 42 N = 180	75 (4.81)	466 (32.42)	10 (.81	38 (3.06)	19 (1.11)	171 (18.11)	39 (4.24)	223 (26.36)	8 (.70)	25[1] (8.37)	.02	9.5
Period 5 1976/1/1 - 1976/3/31 (31 days requested) n = 31 N = 72	36 (1.60)	267 (30.61)	5 (.49)	18 (1.64)	17 (.99)	185 (29.73)	9 (.90)	38 (3.78)	4 (.35)	13[2] (4.58)	.06	12.8
Period 6 1976/4/1 - 1976/12/31 (45 days requested) n = 45 N = 275	44 (2.25)	[o]224 (22.92)	17 (1.12)	42 (2.47)	18 (1.21)	95 (12.47)	5 (.62)	10 (2.34)	3 (.33)	12[3] (6.29)	.3	50

*The numbers in this row have been normalized to 24 hour days because in Period I, the days were 15 hours long.

Note: Figures in parentheses are the standard errors associated with the estimates.

(1,2,3) The large average and standard error (27 - 35%) are due to the presence of extreme values. When these extreme values are taken out of the estimation, the averages are

1. 11.23 Min. (1.49)
2. 7.33 Min. (1.96)
3. 2.49 Min. (.34)

△ Total Duration Average Per Day Includes Duration of Outages

□ Data From Table 3

o Total Duration Exceeds sum of Classes 1-5 because certain Unclassified Durations in Original Data are included in Totals.

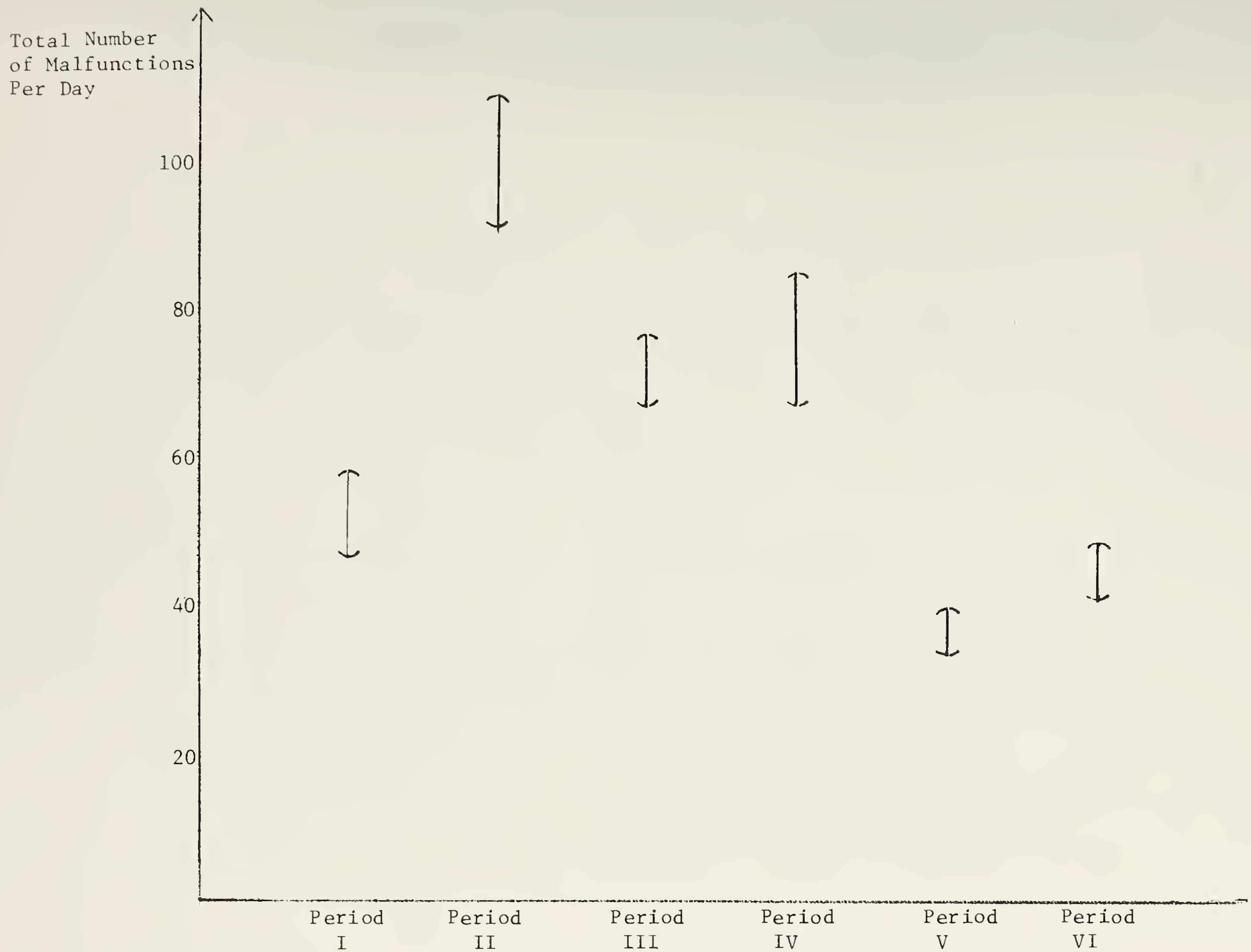


FIGURE C-1. NINETY-FIVE PERCENT CONFIDENCE INTERVALS AROUND THE ESTIMATED NUMBER OF MALFUNCTIONS PER DAY

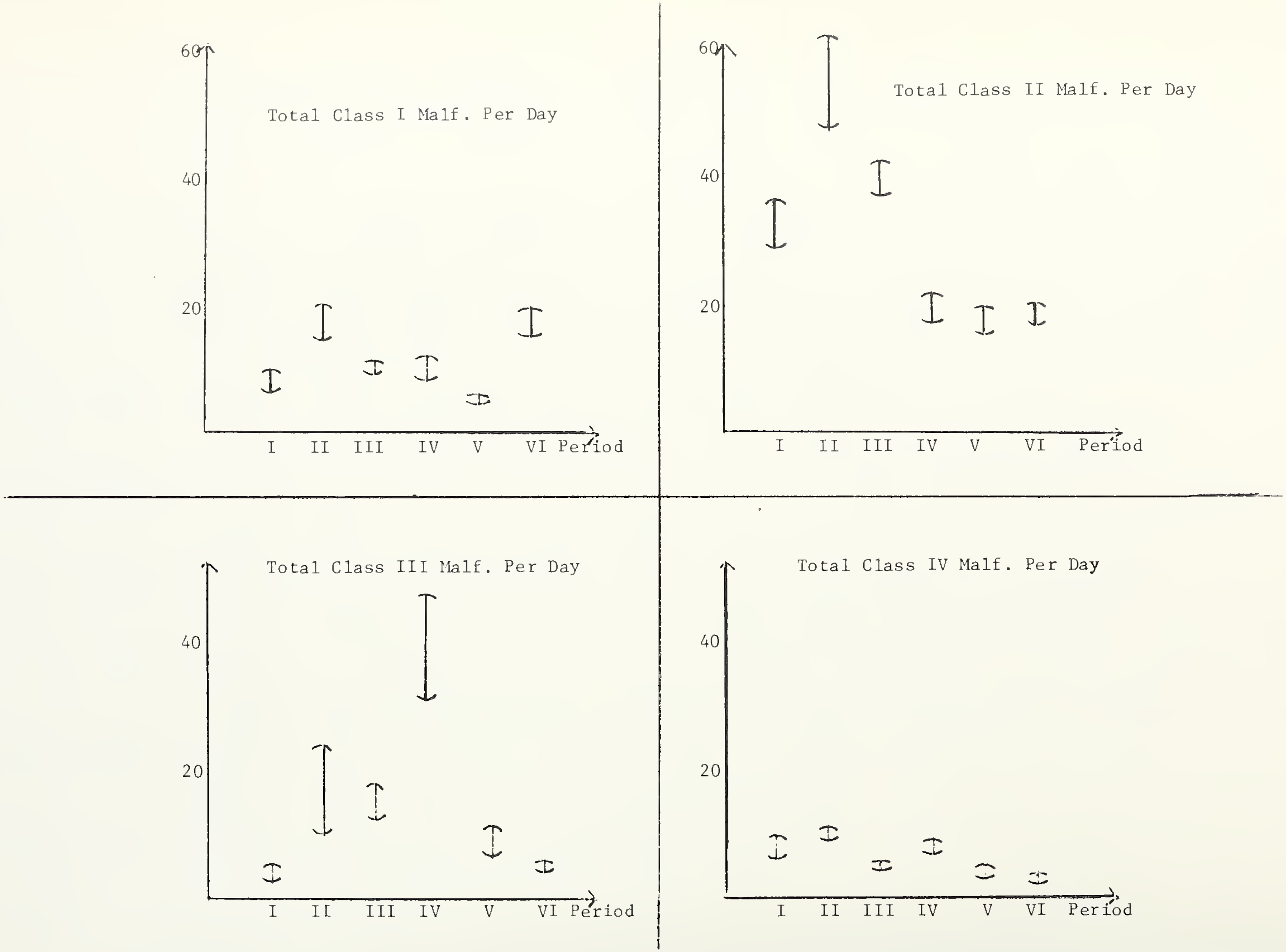


FIGURE C-2. NINETY-FIVE PERCENT CONFIDENCE INTERVALS AROUND THE ESTIMATED NUMBER OF MALFUNCTIONS BY CLASS PER DAY

TABLE C-5. ESTIMATED TOTAL NUMBER OF MALFUNCTIONS AND TOTAL DELAY FOR THE SIX PERIODS

	**Total No. of Malf.	**Total Duration (hrs.)	Avg. Dur. Per Malf. (Min)	Total No. of Class I Malf.	Total Duration (hrs.)	Avg. Dur. Per. Malf. (Min)	Total No. of Class II Malf.	Total Duration (hrs.)	Avg. Dur. Per. Malf. (Min)	Total No. of Class III Malf.	Total Duration (hrs.)	Avg. Dur. Per. Malf. (Min)	Total No. of Class IV Malf.	Total Duration (hrs)	Avg. Dur. Per. Malf. (Min)	Total Class 5 (Outages)	Total Dur. (hrs.)
Period 1 1974/1 - 1974/5/31 N = 138	7,166 *11,466	1,472 2,355	12	1,104 1,766	85.1 146	5	4,416 7,066	874 1,398	12	552 883	60 96	7	1,104 1,766	18.4 29	1	127	345
Period 2 1974/6/1 - 1974/12/31 N = 214	21,186	2,129	7	3,638	260	4	11,552	1,316	7	3,638	492	8	2,140	35.7	1	179	325
Period 3 1975/1/1 - 1975/2/28 N = 80	5,680	600	6	800	66.3	5	3,120	357	7	1,280	109	5	400	6.7	1	14	59
Period 4 1975/4/1 - 1975/9/30 N = 180	13,500	1,398	6	1,800	114	4	3,420	513	9	7,020	669	6	1,440	33	1	4	30
Period 5 1976/1/1 - 1976/3/31 N = 72	2,592	319	7	360	21.6	4	1,224	222	11	648	45.6	4	288	8	2	5	15
Period 6 1976/4/1 - 1976/12/31 N = 275	12,100	1,027	5	4,675	192	2	4,950	435	5	1,375	46	2	825	11	1	86	229

*The numbers in this row have been normalized to 24-hour days, because in Period I, the days were 15 hours long.

**Includes all outages.

Note: Numbers for Total Period derived from Table 1 by multiplying Table 1 numbers by Number of Days Per Period.

It is not to be confused with the standard error mentioned earlier, a parameter which measures how close the estimated average is to the true average rather than how close the individual values are to the estimated average.

Standard error:

$$S(\bar{T}) = S(T) / \sqrt{n}$$

The standard deviation is indicative of the stability or variability of the system's malfunction behavior. The smaller the standard deviation, the more representative the average is of the norm of the system's behavior.

Figure C-3 exhibits a downward trend of the standard deviation over the six periods. That is, the daily delay pattern is becoming less erratic as time progresses. In terms of the frequency of malfunctions per day, the trend is not as obvious or prominent. Such continuing stablizing (toward the norms of the periods) behavior is further shown in Figures C-4 and C-5. These are plots of all the daily data within the periods, revealing the range, the mean, the median and the spread of the middle 50 percent of the data (as enclosed by a rectangular box).

3.1 CONCERNING CLASS V OUTAGES

Outages are defined as malfunctions resulting in sufficient degradation of the system so that calling out of buses either partially or totally is required. Statistics concerning the average number of outages per day, etc. are difficult to interpret simply because outages do not occur very often. They only account for 2 percent or less of the total number of malfunctions and are listed in Table C-6. The major causes for the outages over the six periods were power/signal rail damage (Code 34), lack of speed code on block (Code 27), followed closely by power zone outage, inanimate object on guideway (Code 37), and switch malfunction (Code 38). All of the aforementioned malfunctions concern the wayside, although insufficiency of vehicles (Code 74) on route often was the cause for calling out the buses also.

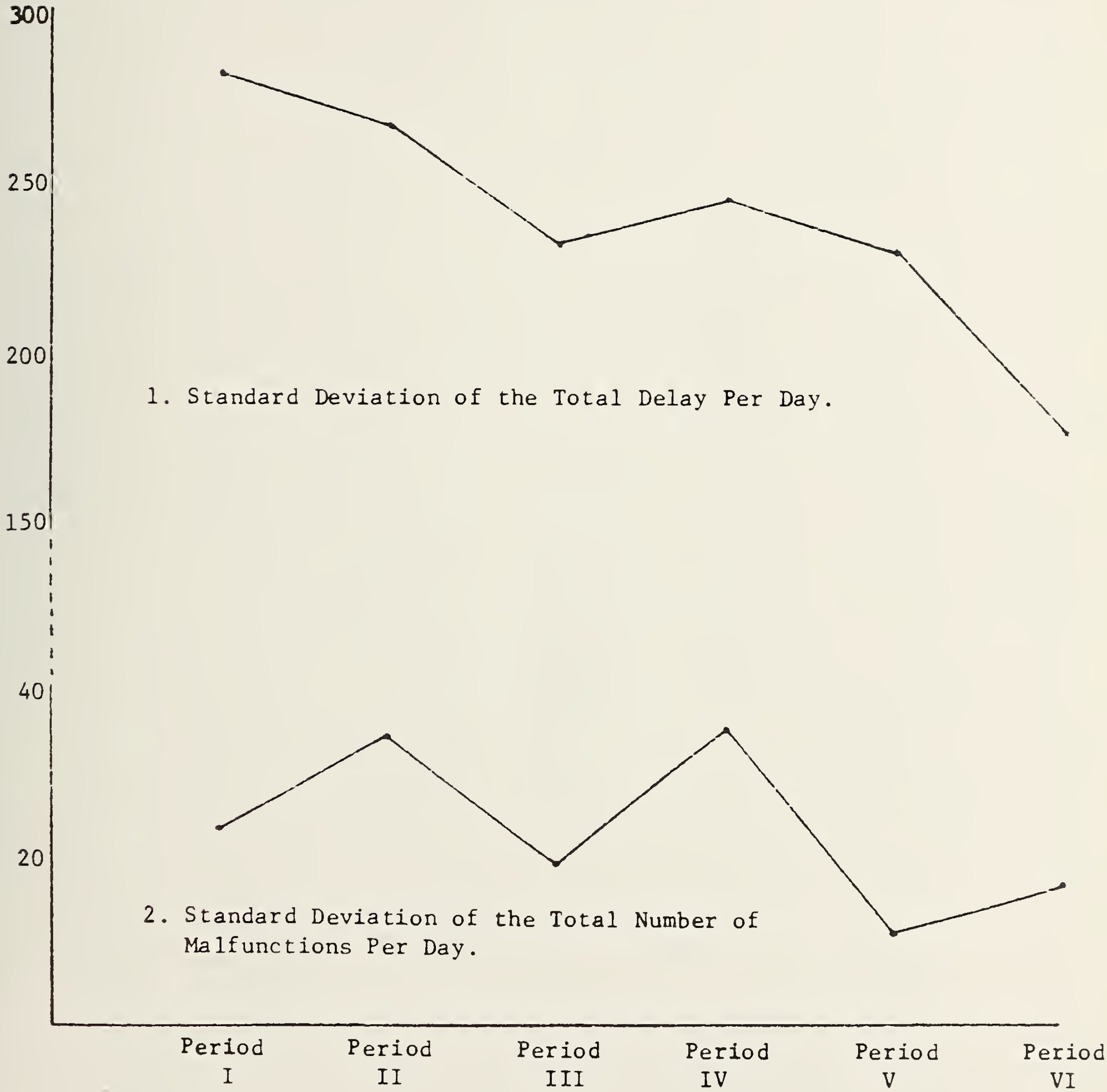


FIGURE C-3. AVERAGE VARIATION OF THE DATA AROUND THE MEANS

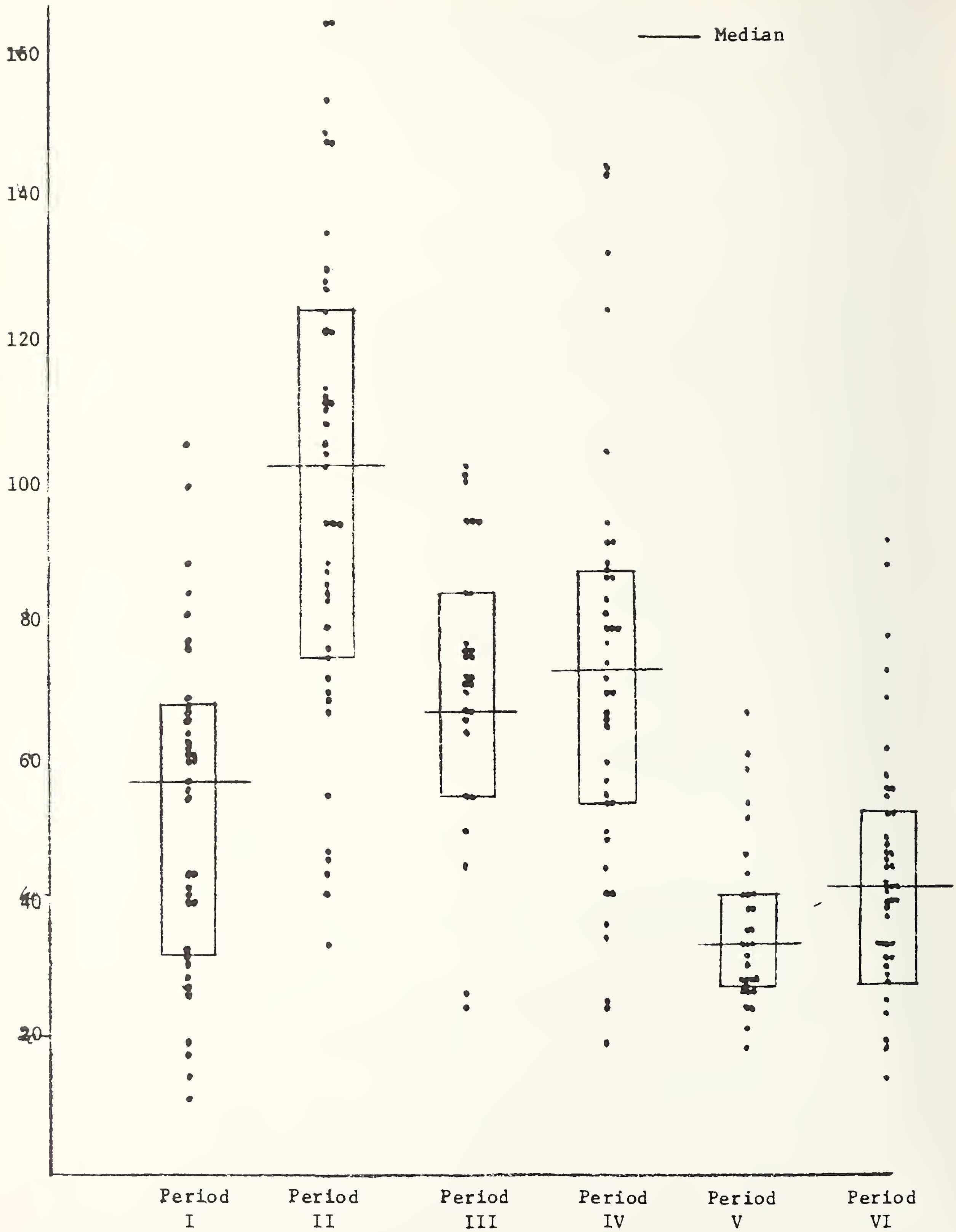


FIGURE C-4. DISTRIBUTION OF TOTAL NUMBER OF DAILY MALFUNCTIONS FOR EACH PERIOD

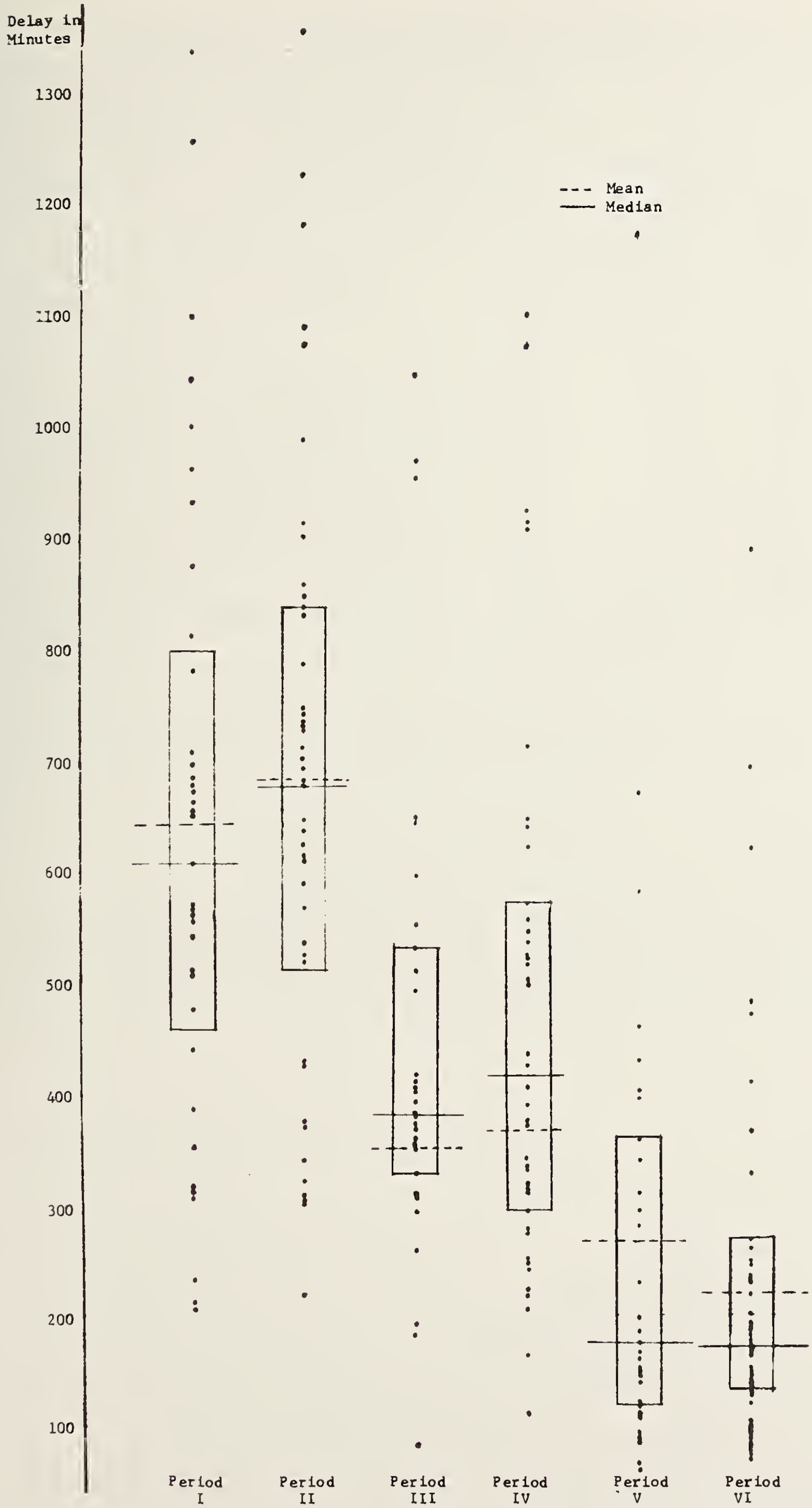


FIGURE C-5. DISTRIBUTION OF TOTAL DAILY DELAY FOR EACH PERIOD

TABLE C-6. STATISTICAL INFORMATION ON OUTAGES

Period	n	No. of Outages	Total Delay Caused by Outages (min)	Outages As % of Total Malf.	Average Duration Per Outage (min)	Estimated No. of Outages Period
		*54	8890			203
1	37	34	5556	2.0	163	127
2	43	36	3909	1.0	109	179
3	28	5	1261	0.3	252	14
4	42	1	400	0.07	400	4
5	31	2	398	0.0	199	5
6	45	14	2241	1.0	160	86

*See Note on Table C-5.

3.2 MALFUNCTIONS CAUSED BY NONEQUIPMENT PROBLEMS

Nonequipment caused malfunctions again account for a relatively small percentage of all malfunctions (only 1-3%). They are as follows and are displayed in Table C-7.

Nonequipment cause code:

6: vandalism
7: fire
8: injury to personnel
36: false malfunction report
37: inanimate object in guideway
41: freezing precipitation
73: vehicle overload
74: insufficient vehicles on route
75: vandalism on vehicle
84: passenger incapacitated
81: passenger verified leaving vehicle in guideway

TABLE C-7. NONEQUIPMENT CAUSED MALFUNCTIONS

Period	No. of Malf.	Total Duration (min)	Dur./Malf. (min)	Percent of Total No. of Malf.
1	29	1867	64	1
2	44	622	14	1
3	47	1184	25	2
4	64	500	8	2
5	35	1841	53	3
6	35	244	6	2

3.3 DISTRIBUTION OF MALFUNCTIONS VERSUS TIME

A hypothesis yet to be proven in this section is whether malfunctions occur more often in some hours of the day than the others. During a careful scrutiny of the histograms of the frequency of malfunctions versus time of the day, it was discovered that a slight peak often appeared around 7:00 a.m. and a dip occurred around 2:00-3:00 a.m. Otherwise, malfunctions occurred quite uniformly throughout the day. This data is presented in Figure C-6.

3.4 MEAN MILES BETWEEN MALFUNCTIONS

Tables C-8 and C-9 give the average number of malfunctions per passenger vehicle/service vehicle in use during the day for the six periods, and also the average miles between malfunctions. These statistics are to be used with caution, however, since the estimating procedure used was very broad-brush and the reliability of the figures which make up these estimates is in question. Although the estimates are only "ball park" figures, they do endorse the stablizing operating behavior of the ARITRANS vehicles.

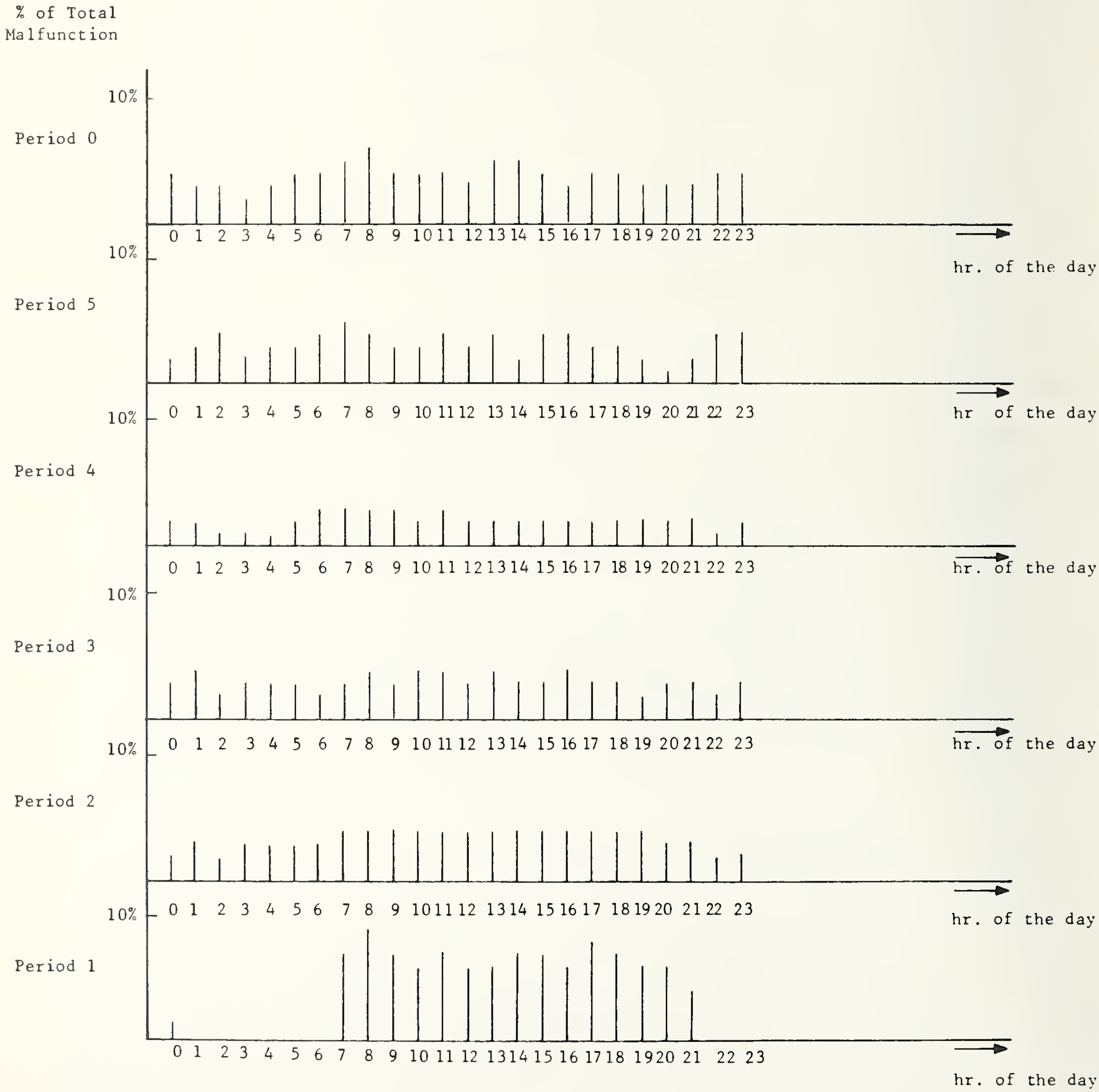


FIGURE C-6. DISTRIBUTION OF MALFUNCTIONS VERSUS TIME

TABLE C-8. MEAN MILES BETWEEN MALFUNCTIONS: PASSENGER VEHICLES

	Average Total No. of Class 1 & Class 2 Malfunctions Affecting Passenger Vehicle Per Day	Average No. of Passenger Vehicle in Use Per Day	Average No. of Class 1 & Class 2 Malfunctions per Passenger Vehicle Per Day	Total Passenger Vehicle Mileage within Period	Estimated Total No. of Class 1 & Class 2 Malfunctions Concerning Passenger Vehicles within Period	Mean Miles Between Malfunctions within Period
Period One 138 days	27 (43)*	28	1 (1.5)	802,567	3,726	215
Period Two 214 days	49	39	1	1,858,372	10,486	177
Period Three 80 days	39	38	1	705,468	3,120	226
Period Four 180 days	21	28	1	1,445,703	3,780	389
Period Five 72 days	18	19	1	451,483	1,296	348
Period Six 275 days	31	35	1	2,774,086	8,525	325

*For 24-hour day.

TABLE C-9. MEAN MILES BETWEEN MALFUNCTIONS: SERVICE VEHICLES

	Average Total No. of Class 1 & Class 2 Manfunctions Affecting Service Vehicle Per Day	Average No. of Service Vehicle in Use Per Day	Average No. of Class 1 & Class 2 Manfunctions per Service Vehicle Per day	Total Service Vehicle Mileage within Period	Estimated Total No. of Class 1 & Class 2 Malfunctions Concerning Service Vehicles within Period	Mean Miles Between Malfunctions within Period
Period One	7	3	2	77,455	966	80
Period Two	14	7	2	387,779	2,996	129
Period Three	4	2	2	34,269	320	107
Period Four	3	2	1	34,086	540	63
Period Five	1	1	1	8,801	72	122
Period Six	1	2	1	34,042	275	124

3.5 AVAILABILITY OF THE SYSTEM

Availability is defined as the percentage of total time when the system is operating. Specifically, it is:

$$\frac{\text{Total System Time - Total Downtime}}{\text{Total System Time}}$$

Availability was estimated for three definitions of downtime:

a. Downtime = Sum of all delays over 2 minutes from all causes.

b. Downtime = Sum of all delays over 4 minutes from all causes.

c. Downtime = Sum of all delays caused by outages and for the six periods:

1. Revenue service, 15 hrs. per day
2. Revenue service, 24 hrs. per day
3. Revenue and supply service, 24 hrs. per day
4. Revenue and supply service, 24 hrs. per day, with LTV maintenance
5. Revenue and supply service, 24 hrs. per day, with the Airport Board maintenance
6. Same as periods but with employees service added.

Table C-10 presents a summary of the system availability and Tables C-11 and C-12 give a distribution of malfunctions versus duration and malfunctions due to unknown factors, respectively.

3.6 DISTRIBUTION OF MALFUNCTIONS VERSUS CAUSE

Figures C-7 through C-12 are histograms of the frequency of malfunction and the average duration of delay for each indentifiable cause. Where the bars of the chart go beyond the scope of the paper, they are indicated as a dotted line with the values

TABLE C-10. SUMMARY OF AVAILABILITY OF SYSTEM

Period	Definition A	Definition B	Definition C
1	.30	.31	.83
2	.54	.59	.94
3	.70	.76	.97
4	.69	.81	.99
5	.82	.86	.99
6	.86	.88	.97

Significant improvement in the system availability is obvious.

TABLE C-11. DISTRIBUTION OF MALFUNCTIONS VERSUS THE DURATION

Duration In Minutes	Period 1	Period 2	Period 3	Period 4	Period 5	Period 6
1 - 4	26%	37%	40%	80%	67%	68%
5 - 9	24	59	56	17	8	28
10 - 14	47	2	1	1	21	1
15 and over	3	3	3	2	4	3
	100%	100%	100%	100%	100%	100%
Number of Malfunctions (having a delay of 1 hr. or more)	38 (2%)	32 (1%)	19 (1%)	24 (1%)	13 (1%)	21 (1%)
Maximum Duration (minutes)	744	551	935	815	950	480

TABLE C-12. MALFUNCTIONS CAUSED BY UNKNOWN FACTORS

Period	No. of Malf.	Average Duration per Malf. (min)	Rate of Vehicle Removal Due to All Malfunctions (veh. per day)
1	13	9	4
2	31	6	7
3	15	4	10
4	13	36	7
5	2	11	2
6	4	3	2

they represent. Consistently throughout the six periods, causes 26, 35, 52, 55, 60, 62, 66, 68, 70 and 5 were the major causes.

26 - (Wayside) computer halted or inoperative or logic error.

35 - (Wayside) breaker trip out (O/T) (Class 4)

52 - (Vehicle) inaccurate station stop (Class 2)

55 - (Vehicle) vehicle door failure (Class 2)

60 - (Vehicle) vehicle stopped; will not call switch (Class 2) (pseudo)

62 - (Vehicle) unscheduled door opening (USD) (Class 1)

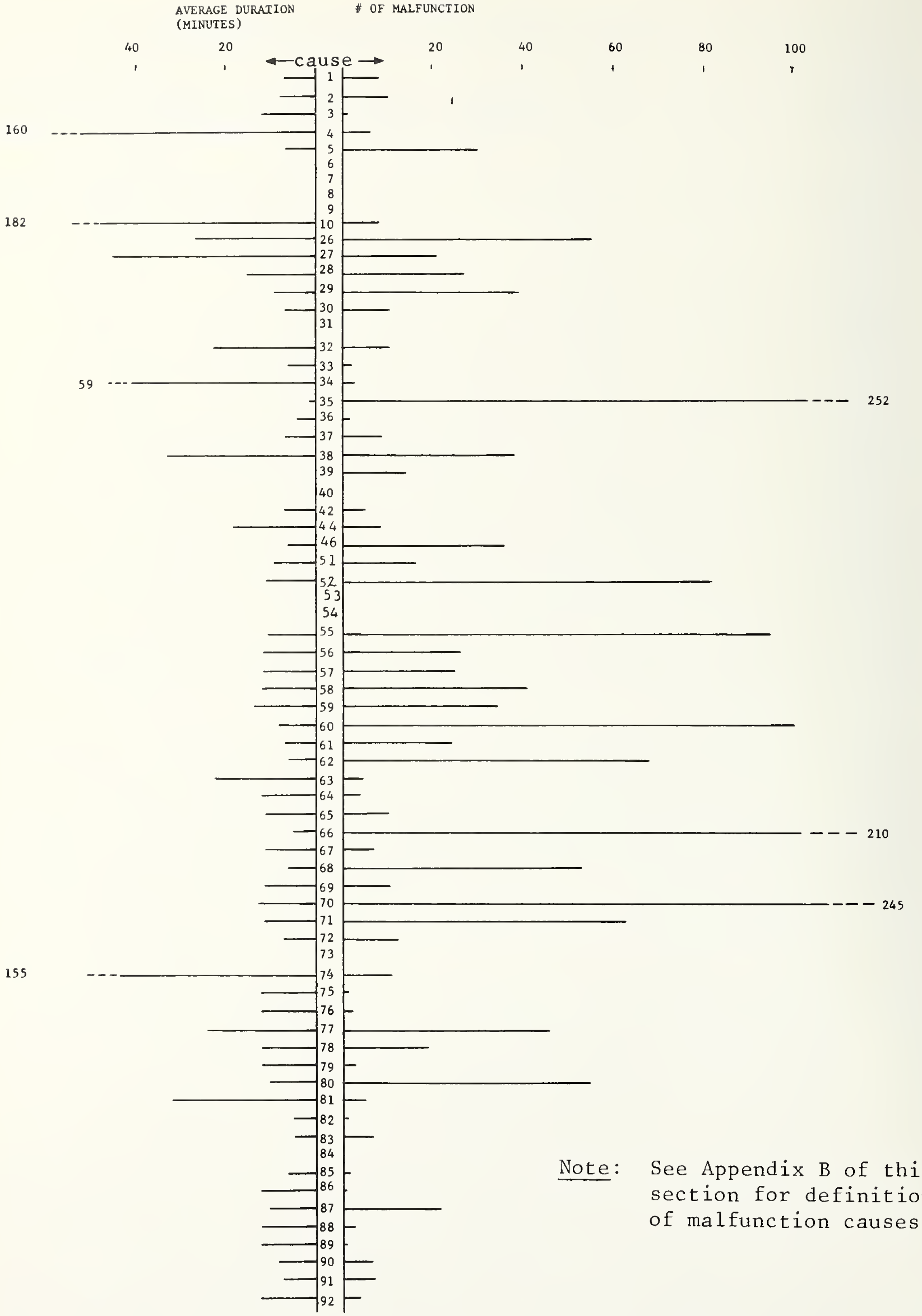
66 - (Vehicle) vehicle speed broach (SB) (Class 1)

68 - (Vehicle) AAU failure (Class 3)

70 - (Vehicle) vehicle passed through station w/o stopping (Class 2)

5 - (General) item or component functioning improperly.

There are mostly malfunctions associated with the vehicles. Those associated with the wayside, however, though occurring less often, have longer delay in general. In particular causes 27, 38, and



Note: See Appendix B of this section for definition of malfunction causes.

FIGURE C-7. FREQUENCY AND AVERAGE DURATION OF MALFUNCTION VERSUS CAUSE - PERIOD 1

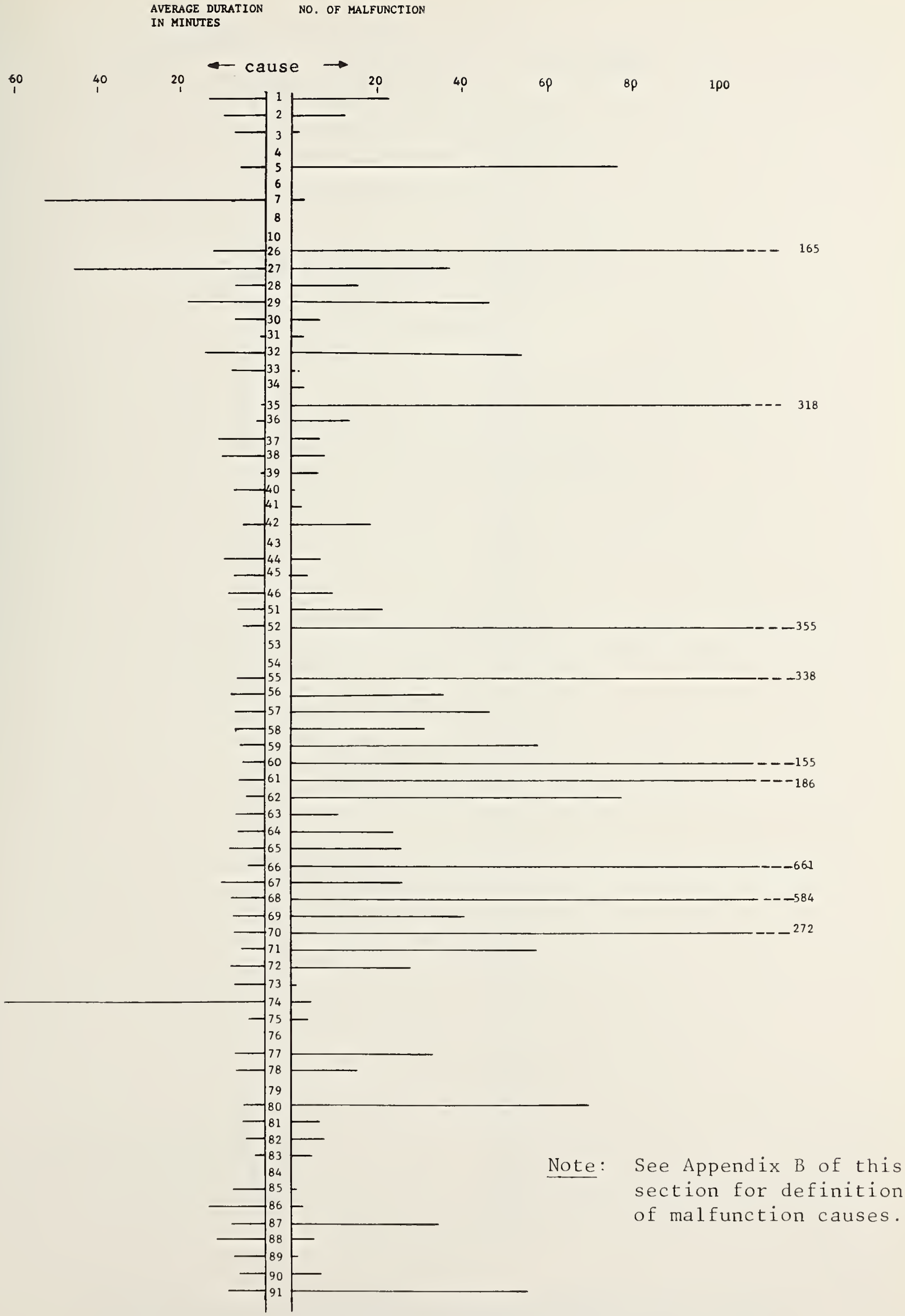
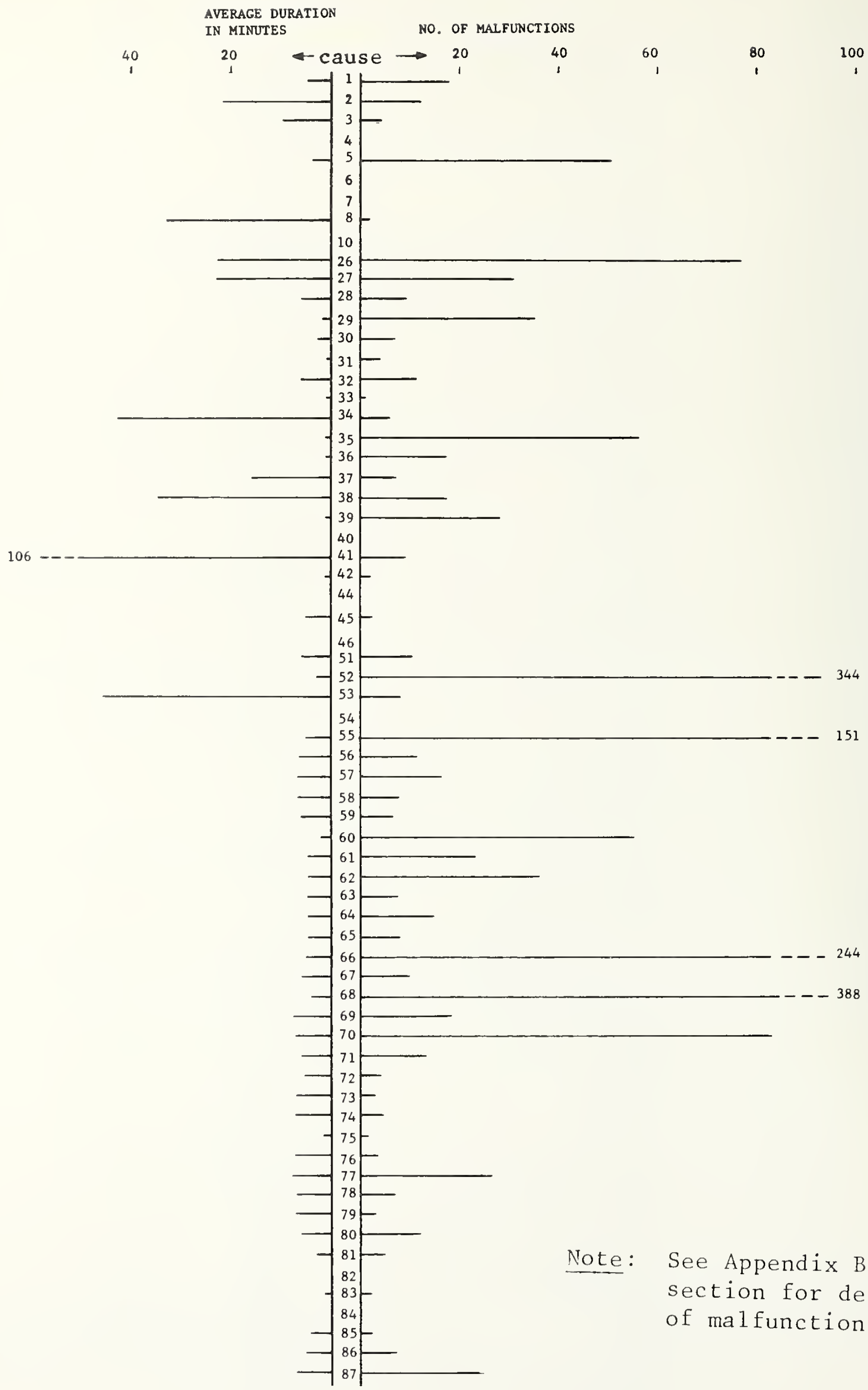
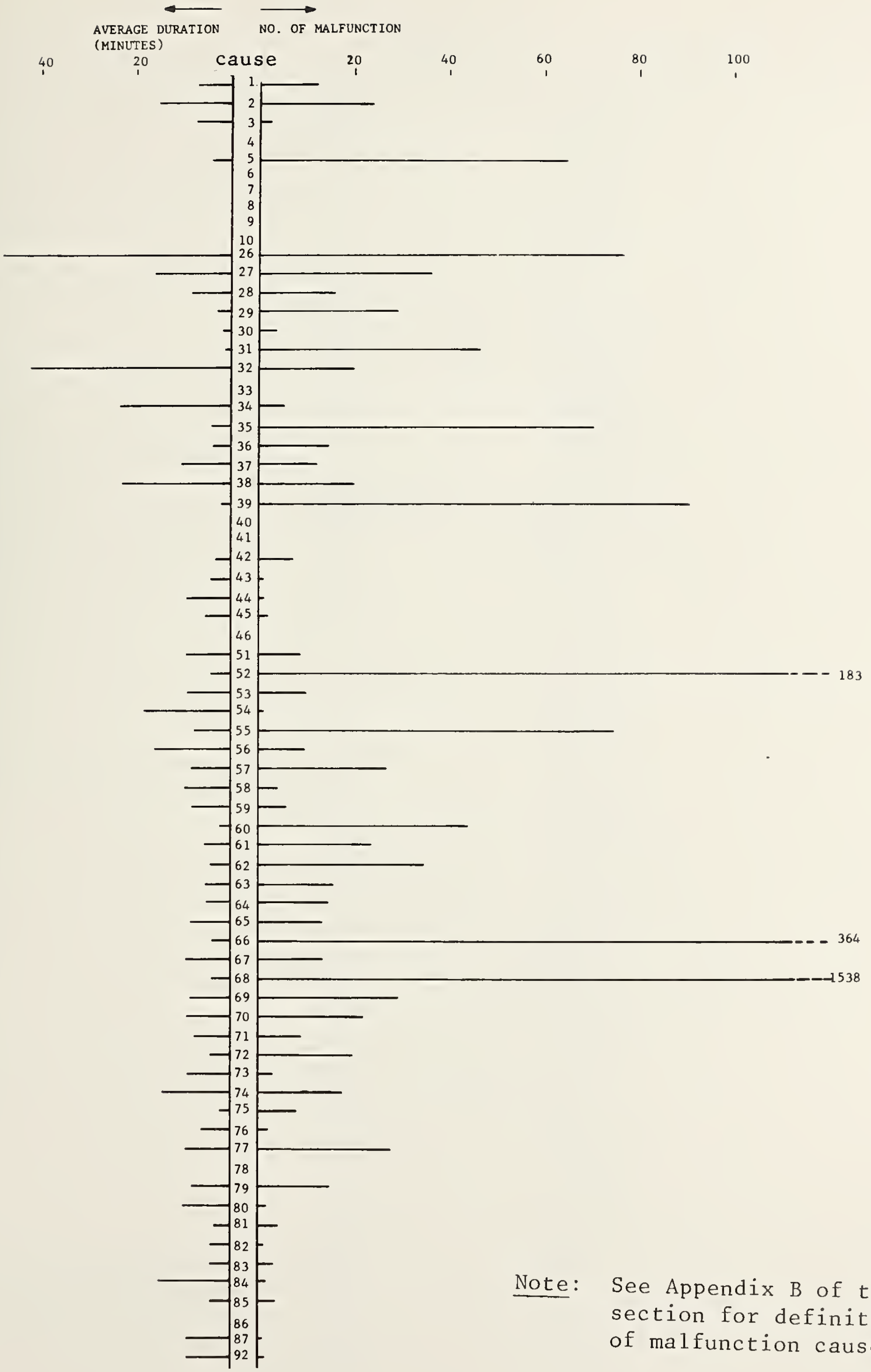


FIGURE C-8. FREQUENCY AND AVERAGE DURATION OF MALFUNCTION VERSUS CAUSE - PERIOD 2



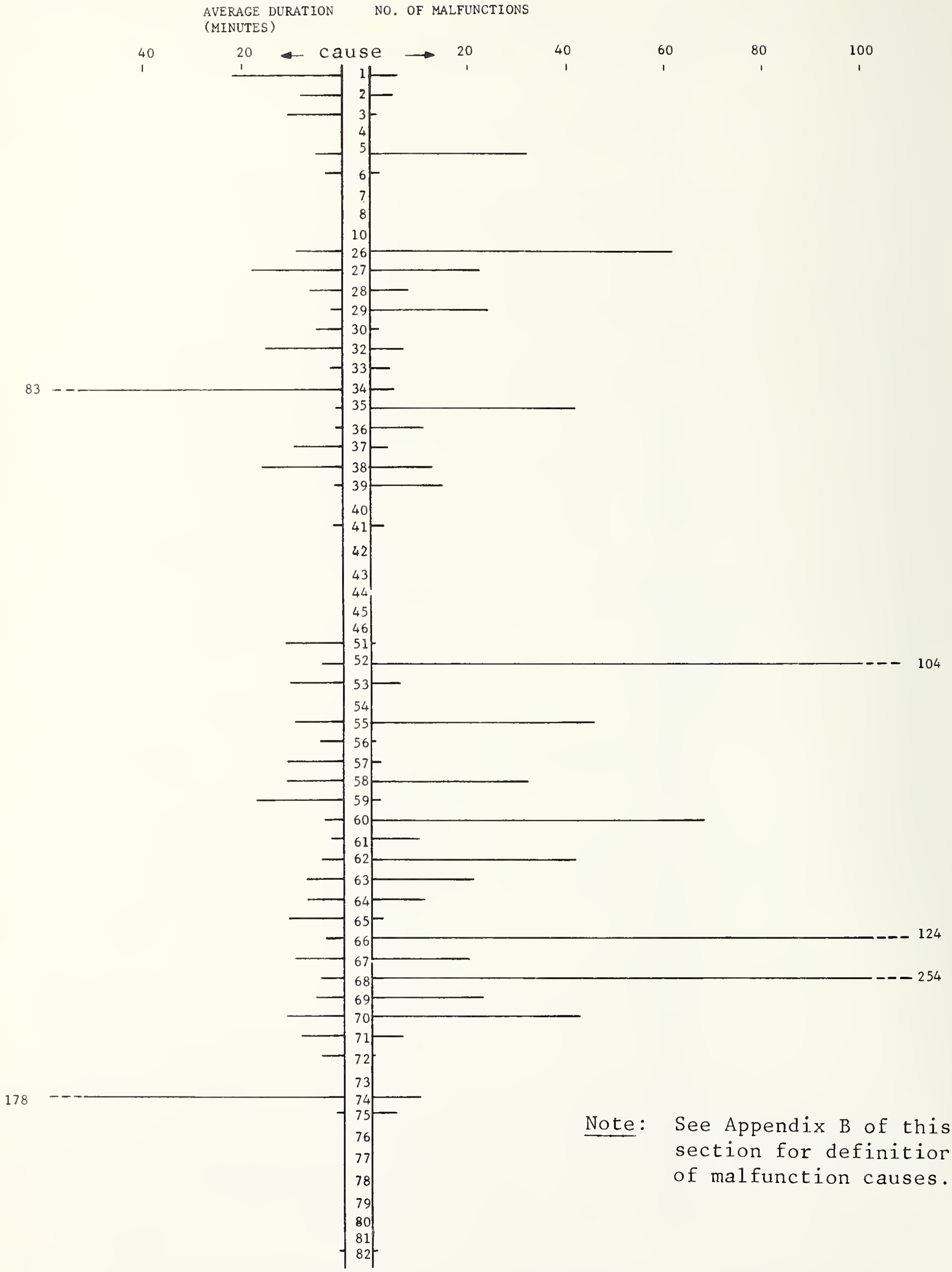
Note: See Appendix B of this section for definition of malfunction causes.

FIGURE C-9. FREQUENCY AND AVERAGE DURATION OF MALFUNCTION VERSUS CAUSE - PERIOD 3



Note: See Appendix B of this section for definition of malfunction causes.

FIGURE C-10. FREQUENCY AND AVERAGE DURATION OF MALFUNCTION VERSUS CAUSE - PERIOD 4



Note: See Appendix B of this section for definitior of malfunction causes.

FIGURE C-11. FREQUENCY AND AVERAGE DURATION OF MALFUNCTION VERSUS CAUSE - PERIOD 5

Note: See Appendix B of this section for definition of malfunction causes.

FIGURE C-12. FREQUENCY AND AVERAGE DURATION OF MALFUNCTION VERSUS CAUSE - PERIOD 6

34 usually have an average delay of more than 30 minutes. In addition, nonequipment causes such as 7, 8, 10, 41, 81 and 74 delay the system longer than mere mechanical failure.

4. SUMMARY

The malfunction sample data for these six periods clearly confirm the steady improvement in the operating performance of the AIRTRANS system. Both the frequency and duration of malfunction have declined over the years. In terms of average delay per day, the records show a 30 to 40 percent improvement every year and the malfunction behavior continues to stablize, characterized by the minor, more frequent vehicle malfunction and longer but less frequent delay caused by wayside and nonequipment hindrances. System outages took a steep drop since the third period but climbed again in the latter part of 1976. Availability of the system, however, is improving to greater than 80 percent regardless of the definition of down time. In conclusion, the results of the analyses reveal a very optimistic outlook on the AIRTRANS system.

MEMORANDUM APPENDIX

A. Class of Malfunction

The classification of the malfunction as to criticability, according to the following definitions:

Class I

An infraction of certain specific safe-operation criteria indicating a condition of imminent danger to passengers and/or equipment:

a. vehicle overspeed

b. vehicle intrusion in a "captured" block

c. unscheduled door opening

d. brake failure

Class II

A failure or malfunction of vehicle or wayside equipment which does not endanger passenger safety, but which causes an interruption or degradation in system revenue service.

Clase III

A failure or malfunction of vehicle or wayside equipment which does not endanger passenger safety, does not interrupt nor degrade system service, but which causes inconvenience or discomfort to passengers.

Class IV

A failure or malfunction of vehicle or wayside equipment which does not endanger passenger safety, does not interrupt nor degrade system service, does not cause inconvenience nor discomfort to passengers, but represents a state of degraded performance for an individual subsystem or component.

Class V

Sufficiently degraded system performance to require utilization of the backup bus system.

B. Causes and Nature of Malfunction

The nature of the malfunction is identified by numerical code, according to the following definitions:

General

1 - item inoperative

2 - component or item loose, worn, broken or missing

3 - electrical short

4 - total system collapse

5 - item or component functioning improperly

6 - vandalism

7 - fire

8 - injury to personnel

9 - system out of service to permit building maintenance

10 - initiation of revenue service delayed due to lack of vehicles and/or system problems

Wayside

26 - computer halted or inoperative or logic error

27 - no speed code on block; block is "down"

28 - station graphics failure

29 - power zone outage

30 - circuit breaker would not reset

31 - T.V. failure

32 - passenger station door failure, or cargo station equipment failure

33 - erroneous or garbled communication with trains in zone

34 - power/signal rail damage

35 - braker trip out (O/T)

36 - false malfunction report

37 - inantimate object in guideway

38 - no switch correspondence or switch malfunction

39 - turnstile inoperative

40 - all trains E.B. (emergency brake) at a station

41 - freezing precipitation

42 - no report of a verified malfunction

43 - unscheduled station door open

44 - low power in zone

45 - low station air pressure

46 - erroneous status report on guideway schematic, control console or power panel

Vehicle

51 - low vehicle air pressure

52 - inaccurate station stop

53 - incomplete cargo station cycle

54 - AAU recycling

55 - vehicle door failure

56 - vehicles bunched

57 - vehicle switched route

58 - vehicle called switch in wrong direction

59 - vehicle stopped; will not accept reset

60 - vehicle stopped; will not call switch

61 - vehicle stopped; no reported malfunction

62 - unscheduled door opening

63 - loss of presence detection

64 - rollback

65 - dragging brakes

66 - vehicle speed broach

67 - vehicle motor or motor controller failure

68 - AAU failure

69 - failed or impaired vehicle/wayside communication

70 - vehicle passed station w/o stopping

71 - vehicle will not dispatch from station

72 - air conditioner failure

73 - vehicle overload

74 - insufficient vehicles on route

75 - vandalism

76 - alternator failure

77 - vehicle power/signal collector assembly damaged or out of adjustment

78 - tripping power breakers

79 - supply operator error caused train delay

80 - vehicle will not run ATC

81 - passenger verified leaving vehicle in guideway

82 - unscheduled container unlock

83 - false vehicle malfunction

84 - passenger incapacitated

85 - vehicle losing traction

86 - vehicle changed identification

87 - vehicle guidewheel failure/damage

88 - vehicle cargo equipment failure

89 - vehicle not leveling

90 - vehicle queue caused by maintenance

91 - vehicle queue caused by cargo loading operations

92 - vehicle station bypass induced by central operator.

APPENDIX D

AIRTRANS SAFETY HISTORY

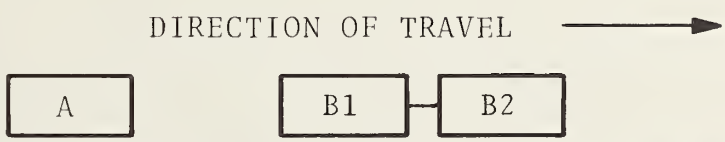
D.1 INTRODUCTION

AIRTRANS has been operational since January 1974, and in that time period has only experienced two serious accidents. The first accident occurred on February 22, 1977 in which an AIRTRANS passenger vehicle collided with a two-car employee vehicle. The second accident occurred on September 14, 1977. That accident resulted in the death of a 17 year old youth.

D.2 AIRTRANS ACCIDENT OF FEBRUARY 22, 1977

D.2.1 Background

On February 22, 1977 at about 1:40 p.m. an AIRTRANS passenger vehicle collided with a stopped two-car employee train. There was damage to all vehicles involved in the accident and nine people of the fourteen aboard the vehicles were injured. (See Figure D-1.) All were released the same day following treatment.



Car	A	B1	B2	Total
Number of Passengers	6	5	3	14
Seated	6	5	3	14
Standing	0	0	0	0
Injured				9

FIGURE D-1. PASSENGER INJURY STATISTICS

On February 28, 1977, Mr. William Rhine of UMTA and Mr. Ronald Kangas of TSC met with two of the Airport Board (Michael Brock, President of Investigation Board and Dalton Leftwich, board member), who had investigated the accident and Mr. Austin Corbin of the Vought Corporation, to obtain details regarding the accident. Separate discussions were also held during the visit with Don Oschner, of the AIRTRANS staff, and W. Hallmark, of the Vought Corporation, related to technical details of Control and Operations. Visits were also made to Central Control to view their operation and to the maintenance area to view the damaged vehicles. The following are descriptions of the events/circumstances leading to the accident as relayed by the airport staff.

D.2.2 Description of Accident

The accident occurred in the 5E area of the AIRTRANS network (Reference Figure D-2 for location). There had been a blown fuse in the communication rail in the 08 block and maintenance rovers were dispatched to check out the problem and move vehicles manually through the downed block. The 35/39 train (vehicle #35 and vehicle #39) was moved manually by a rover through the 08 block into the 01 block. The Class III and Class II failures were reset by the rover and the central controller on duty, and the train was given a speed command. The vehicle then proceeded into the 02 block, around a corner and out of sight of the rovers.

The train stopped in the front part of the 02 block, however, this was not detected by personnel at Central Control (although the mimic board and CRT display did display the problem) or any of the rover staff at the site. A second train (single vehicle #06) with another rover on board followed the 35-39 train by about 1.5 minutes. The rover manually drove the vehicle through the downed 08 block into the 01 block. Unable to get a speed command in the 01 block (since a vehicle was in the 02 block - the 01 block has a 0 speed command), the rover moved the vehicle slowly ahead until he was at the beginning of the 02 block. Once in the 02 block the rover determined that a speed command was available. The rover then climbed out of the vehicle, reset the Class III failure, and notified Central Control that the vehicle could be dispatched. Central Control reset the Class II failure, and sent a speed

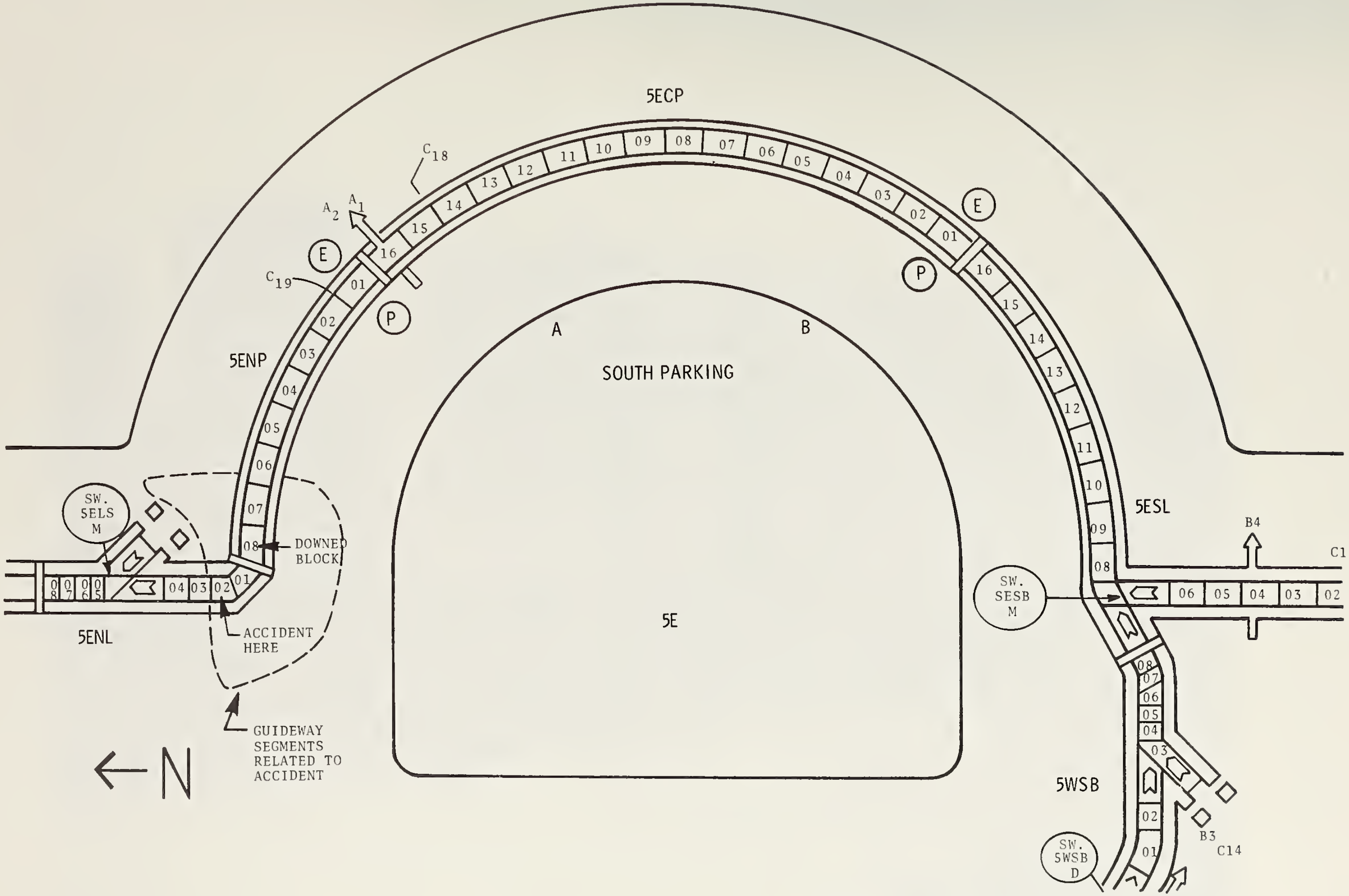


FIGURE D-2. DIAGRAM OF THE 5E ACCIDENT AREA command to the 06 vehicle. The 06 vehicle started and 13 seconds later collided with the stopped 35/39 train. The impact speed was estimated at 17 mph. (The vehicle bumper is designed to withstand a 5 mph impact.) Figure D-3 shows the extent of the damage to the 06 vehicle.

The accident has been classified as system-related since it was due to an improper operation of the system which was unable to correct the situation. The rover driving the second vehicle did not react to the fact that he drove through two blocks before getting a speed signal even though only one block has been reported malfunctioning. This was further aggravated by the fact that operators in the Central Control Room failed to notice the situation, which was reported on both the mimic board and the CRT display, and correct the rover mismaneuver. And even more important, their failure to notice the forward train that had stopped a second time in block 02 due to a Class II manfunction caused by insufficient pressure in the brake system. The latter apparently resulted from the fact that when the original Class II malfunction was reset from Central Control, insufficient time had elapsed to allow recharging of the brake pressure system.

The accident was thus caused by an unlikely combination of operator error, operator fatigue, overloading, and the almost simultaneous multiple equipment failure - the blown fuse in block 08 and the low air pressure in the first vehicle dispatched manually into block 01.

D.2.3 Seriousness of the Injuries

The collision between two AIRTRANS trains on February 22, 1977 resulted in some alleged injuries. The accident report does not show the total number of passengers on board or the seats occupied by the allegedly injured passengers. EL35 had one allegedly injured passenger; ET39 contained three allegedly injured passengers; and PL6 was transporting five of the allegedly injured. This total of nine includes one passenger examined at

FIGURE D-3. DAMAGE TO 06 VEHICLE

the request of his company. He had sustained no injuries. The report does not indicate the train in which he was riding. The alleged injuries were as follows:

a. Right shoulder strain

b. Contusion to left patella with superficial laceration

c. Left elbow strain

d. Superficial laceration to right eyebrow - contusion to right elbow

e. Contusion to right ribs

f. Contusion to extensor surface of right hand - superficial laceration and abrasion

g. Lumbo sacral strain/negative straight leg raising bilaterally

h. Contusion to left lateral leg 10 inches above knee.

D.2.4 Steps Taken by the Airport Management

As a result of the accident, the airport management took a certain number of actions.

- All the procedures involving manual operation were reviewed. However, this step was performed without a thorough analysis of multiple failures that could occur in the system. Therefore, we cannot assure that the new procedures will be totally foolproof when multiple failure situations occur, as they did in this accident.
- Clearer marking of block boundaries (done).
- Rovers must walk to visually clear at least two blocks ahead of vehicle before releasing (done).
- Probably will modify central display to indicate occupancy of two adjacent blocks via separate "flashing signal" or some other type of alarm.

D.2.5 Additional Information Related to Accident

- Weather - sunny and windy
- Time/date of collision - 1340:51 p.m. on 2/22/77
- 02 block length - approx. 180 feet
- Distance from 06 vehicle start point to impact - approx. 130 ft
- Time from 06 vehicle start to impact - 13 seconds
- Speed of 06 vehicle at impact - 17 mph (max speed)
- Visual distance from beginning of 02 block along guideway - sharp turn and bridge support limits vision to much less than entire block
- Central controller employment time - 3 1/2 years
- Central controller, hours on shift - 7 1/2 hours
- Rover driving 06 train, employment time - 4 months
- Rover driving 06 train, hours on shift - 6 1/2 hours
- All personnel had taken the training course at the time they were first employed.

D.2.6 Airport Investigation Analysis

The investigation board concluded after its examination that the rover and central controller had violated operational procedures for manual operation. The step-by-step procedure calls for continuous communication between rover and central controller for each step of the process. With position location of the driven vehicle being stated by the rover and verified by the controller through information available to him. This position verification step was not performed and because of this two trains were placed into the same block. The rover driving vehicle 06 did state that he felt he was not in the 02 block at the time the vehicle was released into automatic control. But the testimony of passengers on board that vehicle, plus a checkout of potential hardware failures, and a simulation of the accident activity (performed the following day with vehicles) convinced the investigation board that a procedure violation was the most probable cause of the accident.

Further discussion with the two members of the investigation board revealed the fact that the system had experienced a number of failures that day. These were door problems or signal outages as a result of the high wind blowing debris against the signal rails. As such, the central controller on duty had been busy during his entire shift, and it was near the end of his shift, so he was busy updating the written logs of the day's activity at the time of the accident.

D.2.7 Suggestions/Recommendations

During the discussions held with the AIRTRANS personnel (airport as well as Vought personnel) the following suggestions and recommendations were informally made by W. Rhine and R. Kangas related to steps that might be taken to further minimize the probability of another accident.

a. In order to provide additional assurance that compliance with proper operating procedures is taken seriously, the airport staff responsible for the operation of AIRTRANS should issue written disciplinary actions/procedures for future violations of said procedures.

b. The present Operations Manual for AIRTRANS personnel is on 8 1/2 x 11 paper, bound in a three-ring binder. To make it more useful and available to the rover staff, the manual should be reduced in size, so that it can be carried in a pocket. (A manual was available at the site where the accident occurred, but due to its size, it was left in the truck, and the rovers were relying on memory.)

c. The training course which is provided to all employees initially, should be continued on some regular basis as a refresher course.

d. The present Central Control staff consists of two individuals on the main console and a passenger service agent supervisor responsible for coordination of station agent and bus activity. At the time of the original AIRTRANS Assessment (Summer 1975), the Central Control staff consisted of three individuals all connected with AIRTRANS operations only. Furthermore, the two individuals now monitoring the control of the AIRTRANS system have increased duties over what three individuals previously had. Since the controllers on duty missed or did not recognize the information they had available to them (Reference Item e. below) just prior to the accident, (paperwork was being done) the functions and responsibilities of the central controllers should be reviewed to determine whether they are overloaded.

e. Since there was no failure in software or hardware, the mimic board, the alpha-numeric CRT display, and the hard copy printout provided indications that something was amiss just prior to the accident, however, the personnel on duty did not recognize the situation. The 35/39 train's Class II malfunction was detected in block 02 and indicated by a flashing red light on the mimic board, the CRT display, and hardcopy printout. Also, the 06 train movement under manual control was indicated by a yellow light on the mimic board. When both trains were placed inadvertently in the 02 block, the software responded by printing an invalid message on the CRT display and the hard copy. Furthermore, the mimic board in this area should have shown a yellow light disappearing from the 01 block as the 06 vehicle moved into the 02 block. Since the software recognized a problem, consideration should be given to a modification in the software which would either inhibit a valid start message being sent to a vehicle when two trains are in the same block or activate an audio alarm when vehicles are in adjacent or the same block. The latter approach may be better in that it provides flexibility to the staff in the event one train were to push another train. Discussions with W. Hallmark of Vought indicated this would not be difficult to implement.

D.3 AIRTRANS ACCIDENT OF SEPTEMBER 14, 1977

D.3.1 Background

On September 14, 1977, at approximately 11:00 a.m., a boy, age 17, not an employee on the airport and apparently not a passenger, was allegedly struck by an AIRTRANS train in the vicinity of the American Airlines AIRTRANS right-of-way and received serious injuries. At approximately 11:00 a.m., it was requested by one of the AIRTRANS maintenance personnel, by two-way radio, to Central Control, that the guideway power be de-energized due to the possibility of a body in the guideway. The power was immediately de-energized, however, the next train had moved approximately 18 feet over the reported body in the guideway.

Immediately after taking the power down, the AIRTRANS controller initiated the Accident Checklist, the Department of Safety responded with an ambulance and crew and began emergency operations which terminated with sending the injured person to the Hurst-Euless-Bedford Hospital.

D.3.2 Description of the Accident

It was reported by passengers riding AIRTRANS Train 23 from Gate 5 at Delta Airlines to the employee parking lot that they observed a young man walking nonchalantly through the expressways and channels of the AIRTRANS near the American Airlines building, an unauthorized area. They also observed him "... running precariously at an overpass and thought he was going to jump on the roof of our train..." It was also reported by an employee near the overpass that a boy with blue jeans hopped on the front bumper of an AIRTRANS train, at that location. The employee reported that, "... I hollered at him and whistled at him and told him to get off the car. But the boy just looked at me and the train moved away with him standing on the bumper with his hand holding on..." It was also reported by the maintenance man that, " ... Train 13 has possibly run over this man...," indicating that he possibly slipped and/or fell off the train after leaving the sight of the employee who had shouted and told him to get off.

At approximately 6:15 p.m. on September 15, the victim was pronounced in critical condition, and at 10:30 p.m. he was pronounced dead by a staff physician at Hurst-Euless-Bedford Hospital.

APPENDIX E

AIRTRANS VEHICLE SCHEDULED INSPECTION/MAINTENANCE

The following is quoted from AIRTRANS internal memos, from engineering to maintenance, dated January and February 1977. The first tabulation refers to the passenger vehicle, and the second to the utility vehicle.

"The following mileage intervals are the maximum allowable in order to retain confidence in wear life of components:

Mileage	Inspection Code	Calendar Time
500	11100	Every 2 days
2,500	11250	10 days
15,000	11400	≈60 days
30,000	11400	≈120 days
45,000	11600	Semi-annually
60,000	11400	≈240 days
75,000	11400	≈300 days
90,000	11700	Annual

"Except for the 11100 inspection, all inspection mileage criteria will not be exceeded. These are maximum mileage intervals beyond which there is no assurance of system or component failures."

"Following are the recommended intervals for utility vehicles:

Mileage	Inspection Code	Calendar Time
≈210	11100	Every 2 days
900	11250	Monthly
1,850	11400	Bi-monthly
3,700	11400	Bi-monthly
5,500	11600	Semi-annually
7,300	11400	Bi-monthly
9,200	11400	Bi-monthly
11,000	11700	Annually

"The interval, based on average mileage of 30.09/day, currently expended by vehicles in supply service, results in 12 inspections of the Monthly, Bi-monthly, Semi-annual and Annual types using the applicable utility inspection worksheets with tolerances specified by the Engineering Directives."

Examples of passenger inspection worksheets are presented in the following pages. The utility inspection worksheets are similar in format, therefore, they are not shown.

ATM-028

MANHOURS: ________

ADC REV. 8 JUNE 1977

SHEET 1 of 1

airtrans

PASSENGER VEHICLE: BI-DAILY

VEHICLE __________ HOURS __________ MILES ________ QA INSP. ________ WAIVER ________

INSPECTION/SERVICING TASK	REQUIREMENTS	DATE	SHOP STAMP
1. RIDE HEIGHT/SUSPENSION	A. VISUALLY Observe/Inspect the Train/Single for proper height within visual limits. B. INSURE Scanner Lens is clean.		
2. COMPRESSOR	**CAUTION** (Observe Safety Man.) P O W E R D O W N (C SWITCH) A. CHECK oil level and ADD as Required B. CHECK for Oil Leakage		
3. CHECK ALTERNATOR, COMPRESSOR, and UTILITY MOTOR BELTS	CHECK Belt Tension and Wear		
4. BRUSH INSPECTION/ COLLECTOR ASSEMBLY	A. INSURE Adjusting Bolt Safety Wired B. CHECK for Abnormal Wear Patterns C. DAMAGE and SECURITY D. BRUSH STRAPS (Broken or Excessive Fraying.) Fraying)		
5. GUIDEWHEEL/ENTRAPMENT WHEEL	INSURE SHORTING BAR IS REMOVED P O W E R U P A. GUIDEWHEEL: Inspect for Damage and Wear. Wear not to Exceed 5.5" Min. on DAILY. REF: ED-185. B. ENTRAPMENT WHEEL: DAMAGE and SECURITY		
6. INSPECT EXTERIOR	A. CHECK for DAMAGE and SECURITY of DOORS, RUB STRIP, and PANELS. B. CHECK GLASS for BREAKAGE		
7. CLEAN: INTERIOR	AS OUTLINED IN CLEANING CONTRACT CHECK-LIST		
8. INSPECT INTERIOR	A. CHECK for DAMAGE to INTERIOR B. INSURE CLA DOOR CLOSED and LOCKED. C. FIRE EXTINGUISHER: INSPECT to Verify Extinguisher in Proper Location and Properly Charged.		
9. TIRE INSPECTION A - ACCEPTABLE G - GUMMY S - SEPARATION W - WEAR LIMIT 3/32"Min. D - DAMAGE	LF | LR | RF | RR		

ATM-103

DATE: ________

ODD / EVEN

PASS. VEH. DAILY INSP.

MANHOURS: ________

W.O.#1770 FAC.#00600

	I.D.	MILES	RIDE HEIGHT	COMP'SOR	ALT.COMP UT. BELTS	BRUSH/COL ASSEMBLY	GUIDEW'LS	TIRES	EXTERIOR	INTERIOR	CLEANING	'P'STAMP	REPAIRS
1													
2													
3													
4													
5													
6													
7													
8													
9													
10													
11													
12													
13													
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23													
24													
25													

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ATM - 024
SHEET 1 of 3
ADC REV. 8 JUNE 1977

PASSENGER : WEEKLY

MANHOURS ___ . ______

VEHICLE __________ HOURS ____________ MILES _______ QA INSP. ______ WAIVER _______

INSPECTION/SERVICING TASK	REQUIREMENTS	DATE	SHOP STAMP
1. PERFORM A DAILY	COMPLETE		
2. CHASSIS VEHICLE INSPECTION A. TIRES and WHEELS	DAMAGE and SECURITY 3/32" Min. Tread (ED-186)		
3. STEERING SYSTEM A. GUIDEBAR ASSEMBLY B. GUIDEWHEELS C. STEERING LINKAGE	DAMAGE/SECURITY/WATER DRAIN HOLES/INSPECT and FBI PAINT CHECK excessive play in hgr. bearings. Bearings, water drain holes, wheel inspection, 3.8" & 5.6" Min. Dia., and E01726.10. OUT OF ROUND MAX. .100" DAMAGE & SECURITY (ED-021)		
4. POWER COLLECTOR A. BRUSH HOLDER ARMS B. BRUSH WEAR C. WIRE & CONNECTIONS D. BRUSH STRAPS E. BRUSH ELE. RESISTANCE CHECK	WEAR/DAMAGE/SECURITY Note any changes on proper forms. APPLY LPS-3 to oilite bushings (ck. vert. play) .25" deep to max. (to Chamfer) CHAFFING, SECURITY, WORN or DAMAGED SHRINK TUBING & CORROSION. FRAYING/BROKEN Using a DVM, ck. the resistance from the signal brush/wire to the attach point. It shall be less than 3 ohms. If it is greater than 3 ohms the assy. must be cleaned to obtain less than 1 ohm.		
5. WIRE HARNESS A. END BREAKER BOXES	CHAFFING & SECURITY Check drain holes/cycle end breaker		
6. BRAKE LININGS	0.25" Min.(ED-186)/Check for Oil.		
7. LIGHTING SYSTEM Interior & Exterior	Illuminate/extinguish		
8. END DOORS A. LATCH COVER B. MICRO-SWITCH RIGGING C. MICRO-SWITCH (ELECT)	INSPECT for DAMAGE and OPERATION 0.16±0.03" Stroke latch cover req'd CHECK out electrical function & make engry in DT Index Log.		

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PASSENGER : WEEKLY

ATM-024
SHEET 2 of 3
ADC REV. 8 JUNE 1977
MANHOURS: ____.______

VEHICLE __________ HOURS __________ MILES ______ QA INSP. ______ WAIVER______

INSPECTION/SERVICING TASK	REQUIREMENTS	DATE	SHOP STAMP
9. SIDE DOORS	CHECK for free operation/NO Drag		
10. ENTRAINMENT ATTACHMENTS A. ELECT. ATTACHMENT	INSPECT for DAMAGE and SECURITY CHECK for corrosion & cleanliness		
11. INTERNAL CONFIGURATION INSPECTION A. FIRE EXTINGUISHER B. DECAL & SIGNS C. CLA DOOR COVER D. EMERGENCY BUTTON	 CHECK GAUGE INSPECT PER PRINT CLOSED & LOCKED CHECK OF FREEDOM OF MOVEMENT		
12. AIR-COND. MOISTURE EJECTOR VALVE (flapper)	INSURE GOOD CONDITION & SECURE		
13. ALTERNATOR A. BELT ALIGNMENT B. BELT TENSION	 1/16" per ft. tolerance 2 to 2.9 lbs. per .19" deflection		
14. REFLECTOR SCANNER	CLEAN and CHECK SECURITY		
15. PNEUMATIC SYSTEM A. WILKERSON FILTER B. SYSTEM LEAKAGE C. PRESSURE LIMIT	 DRAIN WATER 3 PSI/MINUTE LEAKAGE MAX. 105 to 125 PSIG		
16. BATTERY (ER N1001.387)	BLOW & CLEAN VENT HOLES CHECK FLUID CAPACITY		
17. AIR COMPRESSOR A. OIL LEAKAGE B. OIL LEVEL	NOTE: CHECK TIME CHANGE LOG INSPECT. IF required, add SAE 30 HD, K4000, to Aux tank to fill compressor 1/16" per foot 2.2 to 3.2 lbs./.22" of deflection INSPECT and CLEAN AS REQ"D		
18. AIR CONDITIONERS A. EVAPORATOR/ CONDENSOR B. FILTER ELEMENT	INSPECT FOR DAMAGE AND SECURITY CHECK FLAPPER VALVES INSPECT FOR DAMAGE AND CLEAN REPLACE 16 x 20 x 2		
19. PROPULSION MOTOR	REPLACE 240-55014-104 filter 2 ea. CHECK Drive Shaft for Security.		
20. MOTOR CONTROLLER	REPLACE FILTER CHECK TIME CHANGE LOG FOR FAN		

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PASSENGER : WEEKLY

ATM-024
SHEET 3 of 3
ADC REV 8 JUNE 1977
MANHOURS: ____.____

VEHICLE ________ HOURS ________ MILES ________ QA INSP. ________ WAIVER ________

INSPECTION/SERVICING TASK	REQUIREMENTS	DATE	SHOP STAMP
21. RIDE QUALITY PIVOT JOINT	LUBRICATE		
22. RIDE COMFORT SHOCK STRUT	INSPECT and FBI PAINT		
23. GUIDEWHEEL SUPPORT	LUBE with Molytex 2/ERN1726.6		
24. AAU WEEKLY	REMOVE TO LAB FOR SCHEDULED MAINT. (Complete Schedule)		
25. LOG BOOK REVIEW	CHECK MR's, ED's, ETP's, AWI's, insure all removals closed and all deferrals reviewed. Ck. time changes.		
26. CONDUCT DEPARTURE TEST	PERFORM SPEC. 206-40-12 and enter compliance in the Vehicle Log Book.		
	NOTES		

ATM-002
ADC REV. 27 JUNE 77
Sheet 1 of 5

MMH: ______

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DALLAS/FORT WORTH AIRPORT AIRTRANS

PASSENGER BI-MONTHLY

VEHICLE______ HOURS______ MILES ______ QA INSP.______ WAIVER______

INSPECTION/SERVICING TASK	REQUIREMENTS	DATE	SHOP STAMP
1. PERFORM A DAILY INSPECTION	AS REQUIRED ON DATA SHEET		
2. PERFORM A WEEKLY INSPECTION	AS REQUIRED ON DATA SHEET		
3. TIRES and WHEELS	ABNORMAL Tread Wear, Damage, Cuts, and Bulges.		
4. SUSPENSION SYSTEM OPS SPEC. 206-40-002	INSPECT for cracked welds, worn bushing and loose nuts, bolts, and connections.		
5. CHASSIS STRUCTURE INSPECTION	INSPECT FOR DAMAGE AND CRACKS. Clean off corrosion/rust, prep. and prime.		
A. DRIVE SHAFT	Metal-Prep as required and check Torque on bolts per spec.		
B. C/B BOXES	INSPECT and CLEAN, (use low air pressure). INSPECT for loose connections.		
6. WIRE HARNESS INSTALLATION	INSPECT for fraying, chaffing and loose connections.		
7. OIL LEAKAGE INSPECTION			
A. DRIVE AXLE/ DIFFERENTIAL	INSPECT for Oil Leakage		
B. AIR COMPRESSOR	INSPECT for Oil Leakage		
C. AXLE HUBS	INSPECT for Oil Leakage		
8. SHOCK ABSORBERS	INSPECT for Leaks, Security and Wear.		
9. GUIDEBAR and STEERING LINKAGE	INSPECT for Wear, Damage and Security.		

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DALLAS/FORT WORTH AIRPORT
AIRTRANS

MMH: ______.______

PASSENGER BI-MONTHLY

VEHICLE__________ HOURS__________ MILES __________ QA INSP.__________ WAIVER__________

INSPECTION/SERVICING TASK	REQUIREMENTS	DATE	SHOP STAMP
10. REVERSAL SWITCH RIGGING and MECHANISM INSPECTION	A. INSURE switch actuation occurs @ 1/4 turn or 0.09" from full CW & CCW position. B. COMPLY with ED-021; Vert. Movement .08" MAX.		
11. COMPRESSOR	COMPLY with requirements of ERN1708.6		
A. INLET AIR FILTER	Clean with high detergent soap and water.		
B. CRANK CASE BREATHER	Clean with Safety Solvent and blow dry (low press.)		
C. DRAIN CRANKCASE	Drain crankcase and Aux. tank & fill with SAE 30 (K4000) Detergent Oil.		
D. AUX. VENT & FILL LINES	Flush and blow out lines.		
12. PNEUMATIC SYSTEM	COMPLY with requirements of ERN1708.6		
A. WATER EJECTORS	Operationally check. Ejectors should discharge each time compressor cuts in or out.		
B. WILKERSON FILTER ELEMENT	CLEAN with Safety Solvent or High Detergent Soap.		
C. CENTRIFUGAL FILTER	CLEAN exterior surface		
13. ALTERNATOR	COMPLY with ERN1001.459		
A. REGULATOR VOLTAGE	SHOULD Read 29.5 VDC		
14. COMMON GROUND BRUSH STRAP	COMPLY with ERN1001.208. 0.03 ohms resistance MAX. from each ground brush to common ground.		

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AIRTRANS

PASSENGER BI-MONTHLY

VEHICLE______ HOURS ______ MILES ______ QA INSP.______ WAIVER______

INSPECTION/SERVICING TASK	REQUIREMENTS		DATE	SHOP STAMP
15. PROPULSION MOTOR	COMPLY with ERN1001.319			
A. COMMUTATOR	INSPECT for wear, scoring & arching			
B. BRUSHES	WEAR MIN. is 0.75" per ED-171			
C. CLEANING	BLOW out dust and dirt from armature intake and exhaust.			
D. TIME REMOVAL	CHECK TIME REMOVAL LOG SHEET ED-226			
16. MOTOR CONTROLLER	COMPLY with ERN1696.14			
A. BLOWER MOTOR	CHECK time removal sheet in log & oil with 30 SAE.			
B. CONTACTORS	CLEAN Contacts & blow out dust and dirt and insure terminal bolt tight.			
C. AUX SWITCH INSPECTION	PERFORM ERN1001.729 & Maintenance Manual Sec. 2-1-5. (Blower Motor to be removed at 10,000 Hrs.			
17. BRAKE SYSTEM	COMPLY with OPS Spec. 206-40-007A, ERN1001.323, ERN1001.434, and ED-212.			
A. LINING	INSPECT for Temp. Crystallization, Unusual Grooving, and Wear: WEAR LIMIT 0.25" MIN.			
B. CLEARANCE	0.02" to 0.04" at toe (Actuator End)			
C. HUB	CHECK for oil leak around hub as this may indicate oil on brake linings.			
D. AUTO ADJUSTERS	CHECK condition and proper operation.			
18. LUBRICATION SERIES:	CHECK COMPLETE ITEM	✓		
A. DIFFERENTIAL OIL LEVEL	SAE 90 to 140 Gear Lube to level			
B. DRIVE AXLE HUB OIL LEVEL	SAE 90 Gear Lube to level			
C. DRIVE SHAFT U-JOINT	CHASSIS LUBE			
D. FRONT/REAR STEERING KNUCKLE	CHASSIS LUBE			

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DALLAS/FORT WORTH AIRPORT AIRTRANS

PASSENGER BI-MONTHLY

VEHICLE ________ HOURS ________ MILES ________ QA INSP. ________ WAIVER ________

INSPECTION/SERVICING TASK	REQUIREMENTS		DATE	SHOP STAMP
18. LUBRICATION SERIES (Continued):	CHECK COMPLETE ITEM			
E. FRONT/REAR TIE ROD ENDS	CHASSIS LUBE			
F. FRONT/REAR CONTROL ARMS	CHASSIS LUBE			
G. REAR & FRONT REVERSAL MECH.	CHASSIS LUBE			
H. FRONT/REAR GUIDEBAR PIVITS	CHASSIS LUBE			
I. FRONT/REAR GUIDE-BAR HANGER	CHASSIS LUBE			
J. DRIVE AXLE/U-JOINT	Purge with NLGI Grade 2 Grease			
19. BI-PARTING DOORS				
A. DOOR OPERATOR	CLEAN Door Operator			
B. CHECK DOOR OPERATION	FUNCTIONAL CHECK (ED-192) (Close and Open Ck. Switch)			
C. INSPECT DOOR OPERATOR ROD	Lube with DC#4 on Rod between coil. ERN1705.1			
D. 12 POINT DOOR CHECK	INSPECTION of doors and repair as required.			
20. SCANNER BEAM INSPECTION	CHECK ALIGNMENT PER Spec. 206-40-002			
21. COLLECTOR ASSEMBLY	INSPECT COLLECTOR RIGGING USING RIG FIXTURE. IF documentation clearly shows vehicle has been rigged in last 2,500 mi., brush wear pattern is good, guidebar secruity is good, and FBI paint is not BROKEN, this section may be omitted.			

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DALLAS/FORT WORTH AIRPORT AIRTRANS

PASSENGER BI-MONTHLY

VEHICLE ______ HOURS ______ MILES ______ QA INSP. ______ WAIVER ______

INSPECTION/SERVICING TASK	REQUIREMENTS	DATE	SHOP STAMP
22. SPECIAL INSPECTION: A. KING PINS Measure & Record (USE DIAL INDICATOR)	MEASUREMENTS 0.175" MAX. FRONT L R L R AFT		
23. A. CONTROL ARM BEARING	INSPECT for end play at each bearing and at the end of the Control Arms.		
B. SPECIAL INSPECTION: a. GUIDEBAR Measure & Record	MEASUREMENTS 0.35" MAX. FRONT L R L R AFT		
24. EMERGENCY MAGNET VALVES (4)	CHECK for proper operation, by disconnecting the Cannon Plug from each valve and insuring the brakes set. Do each valve individually with power on and pneumatic system reset.		
25. ROLLBACK SENSOR	INSPECT the cable and plug on the vehicle side for corrosion, wear or damage. RETURN the RBS to the Lab for calibration.		
	NOTE INSURE LOG BOOKS ARE CLEAR AND STAMP OFF LOG BOOK SECTION OF WEEKLY SHEET.		

ADC REV. 10 JUNE 77
SHEET 1 of 2

MMH: ______

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DALLAS/FORT WORTH AIRPORT AIRTRANS

PASSENGER: SEMI-ANNUAL

VEHICLE ______ HOURS ______ MILES ______ QA INSP. ______ WAIVER ______

INSPECTION/SERVICING TASK	REQUIREMENTS	DATE	SHOP STAMP
1. PERFORM A DAILY	COMPLETELY		
2. PERFORM A WEEKLY	COMPLETELY		
3. PERFORM A BI-MONTHLY	COMPLETELY		
4. CLEAN A. Clean Underside of Chassis B. Vehicle Exterior	CLEAN using Hot Water Cleaner and High Detergent. WASH thoroughly and wax exterior of vehicle and replace all worn decals. AVOID DIRECT SPRAY on M/C Vents, Motor Vents, and V-Belts.		
5. CLEAN ELECTRONICS BAY REMOVE B1, B2, J Module, FRG	THOROUGHLY Clean the Electronics Bay, remove all debris, and vacuum. RETURN Modules to Lab for cleaning and calibration as required.		
6. INSPECT TRANSVERSE BEAMS	INSPECT for cracked welds, rubber bushing deterioration. CLEAN corrosion around welds and prime.		
7. ALTERNATOR	CHECK the Time Removal Log.		
8. TIE ROD JAM NUTS	INSPECT Torque on the 3102-Y-3951 Tie Rod, drive and dead axle.		
9. STEERING RIGGING	WITHIN SPECT. TOLERANCE (Maintenance Manual)		
10. AXLE VENT	REMOVE, Clean and Replace as required (BI-1)		

ADC REV. 10 JUNE 77
SHEET 2 of 2

MMH: ______

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DALLAS/FORT WORTH AIRPORT AIRTRANS

PASSENGER: SEMI-ANNUAL

VEHICLE ______ HOURS ______ MILES ______ QA INSP. ______ WAIVER ______

INSPECTION/SERVICING TASK	REQUIREMENTS	DATE	SHOP STAMP
11. LUBRICATION ITEMS A. DRAIN & Refill Dr. Axle Diff. B. DRAIN & Refill Planetary Hubs C. REPACK Dead Axle Wheel Bearing	FLUSH with diesel and refill with S.A.E. 90 (ED-019) S.A.E. 90 Gear Lubrication NLGI Gr. 2 with MD (Grease)		
12. MOTOR CONTROLLER	PERFORM (ED-017)		
13. BRAKE ACTUATOR	REMOVE, REPLACE and LEAK CHECK. A. Purge the Brake Lines.		
14. SERVICE BRAKES - VARIABLE LOAD AND VALVE PRESSURE TEST	E.W.I. #7 (22 ± 2 and 42 ± 2 PSI)		
15. BRAKE ADJUSTER	REMOVE and REPLACE		
16. AIR-CONDITIONING UNITS (Basic) Not Elec. Pkg.	PERFORM FULL FUNCTION CK. OUT and CLEANING Per Sec. 2-1-11 of Maintenance Manual. (INSURE UNIT INSTALLED HAS 6 Mo. CERTIFICATION)		
17. CENTRIFUGAL FILTER Model 918 - Salem	INSURE filter is Clean and Properly functioning both inside and out.		

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AIRTRANS

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PASSENGER - ANNUAL

VEHICLE______ HOURS______ MILES ______ QA INSP.______ WAIVER______

INSPECTION/SERVICING TASK	REQUIREMENTS	DATE	SHOP STAMP
1. PERFORM A DAILY	ALL		
2. PERFORM A WEEKLY	ALL		
3. PERFORM A BI-MONTHLY	ALL		
4. PERFORM A SEMI-ANNUAL	ALL		
5. AIR COMPRESSOR GOVERNOR ASSY.	Disassemble, Clean, Reassemble. Coat Interior of Governor Housing with Chassis Lube.		
6. UTILITY MOTOR	LUBE with D6A2C5 GE Grease (Ft. & Rear Bearings).		
7. REMOVE & REPLACE AVP RECEIVER MODULE 31038-30GR 1	Vehicle MUST Pass Successfully through ATC after AVP Change or adjustment.		
8. AIR CONDITIONING	Blow out the air conditioning duct return screen.		
ATC 9. RADIO	REMOVE and REPLACE RADIO. RETURN Removed Radio to Facilities Maint. for Radiation Checks. Annual Certif-cation not required, however, radio should be sent to Facilities Maint. for radiation checks.		
10. BATTERY (PSV5) REF: ER-1001.387 Maint. Man. 2-1-5 Battery LTD Maint. Man., and ED-213	a. REMOVE and REPLACE with a P.M. dated battery that is in compliance with alkaline batteries LTD. Maint. Manual and 2-1-5 of the AIRTRANS Manual (Fully Charged) b. INSURE Battery Box is in good cond. & clean per Sec. 9, Pg. 10 of Battery LTD Maint. Manual.		

ATM-004
ADC REV. 9 JUNE 77
Page 2 of 2 Pages

MMH: ______.______

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DALLAS/FORT WORTH AIRPORT
AIRTRANS

PASSENGER - ANNUAL

VEHICLE______ HOURS______ MILES ______ QA INSP.______ WAIVER______

INSPECTION/SERVICING TASK	REQUIREMENTS	DATE	SHOP STAMP
12. EMERG. MAG. VALVE	REMOVE and REPLACE		
13. EMERG. RESET MAG. VALVE MV 633-3300	REMOVE and REPLACE		
14. EMERG. CHARGING C/O VALVE N-7238	REMOVE and REPLACE		
15. N.B. APPLICATION MAG. VALVE MV. 623-3000	REMOVE, Service and Rebuild		
16. N.B. RELEASE MAG. VALVE M.V. 621-3000	REMOVE, Service and Rebuild		

ATM-010
ADC REV. 9 JUNE 1977

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DALLAS/FORT WORTH AIRPORT
AIRTRANS

MMH: ____________

PASSENGER / UTILITY - THREE YEAR

VEHICLE__________ HOURS__________ MILES __________ QA INSP.__________ WAIVER______

INSPECTION/SERVICING TASK	REQUIREMENTS	DATE	SHOP STAMP
1. PERFORM A DAILY	COMPLETE		
2. PERFORM A WEEKLY	COMPLETE		
3. PERFORM A BI-MONTHLY	COMPLETE		
4. PERFORM A SEMI-ANNUAL	COMPLETE		
5. PERFORM AN ANNUAL	COMPLETE		
6. PERFORM A BI-ANNUAL	COMPLETE		
7. HORIZONTAL SHOCK ABSORBERS	REMOVE and REPLACE		

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DEPARTURE TEST PREPARATION INSPECTION

ADC REV. 8 JUNE 1977
MANHOURS ____.____

VEHICLE ________ HOURS ________ MILES ________ QA INSP. ________ WAIVER ________

INSPECTION/SERVICING TASK	REQUIREMENTS	DATE	SHOP STAMP
1. INSPECT ITEMS A. Inspect Chassis Structure	Inspect for DAMAGE and SECURITY		
2. GUIDEBAR and WHEELS	Inspect for DAMAGE, SECURITY, & WEAR		
3. COLLECTOR ASSEMBLY and WIRING	ERN1001.328 and MEMO 6-50800/3AVO-221		
4. BRUSH WEAR/Inspect	Min. of .25" WEAR, Position of Spring Keepers. CHECK WEAR & SECURITY.		
5. C/B & POWER PANEL, CABLE and PLUG	CLOSED and INSTALLED		
6. ACCESS PANELS	CLOSED		
7. END DOOR LATCH COVER	CHECK for FUNCTIONAL OPERATION		
8. ALL COLLECTOR BRUSHES	VEHICLE # SCRIBED on EACH BRUSH		
9. RECORD HOURS/MILES	RECORD in INDEX		
10. TIRES	INSPECT for DAMAGE, WEAR, SECURITY		
SERVICE ITEMS: 1. REFLECTOR SCANNER	CLEAN and INSPECT MOUNT SECURITY		
2. AIR-COMP. OIL LEVEL BELT TENSION ALTERNATOR SECURITY BELT TENSION	CHECK OIL LEVEL and BELT TENSION CHECK for SECURITY of MOUNT and BELT TENSION		

ATM- 033
SHEET 2 of 2

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ADC REV. 8 JUNE 1977

DEPARTURE TEST PREPARATION INSPECTION

MANHOURS: ___ . ___

VEHICLE ________ HOURS ________ MILES ________ QA INSP. ________ WAIVER ________

INSPECTION/SERVICING TASK	REQUIREMENTS	DATE	SHOP STAMP
SERVICE ITEMS Continued: 3. REVERSING MECHANISM (FWD Relay)	See maintenance manual section 2-1-8 Torque-40'pounds...Ck for FWD Relay operation by actuation & de-actuation (¼ TURN)of the microswitch to insure proper actuation and deactuation of the FWD Relay. Insure locking mech. ops. function properly and safetywire (ED-242)		
4. BRAKES (E/B) LOCKED	BRAKES-UNCAGED		
5. LOG BOOK REVIEW	CHECK MR's, AWI'S, REMOVALS CLOSED and DEFERRALS. (TIME-CHANGES) ED & ETP		
6. ATC (As Required)	206-40-12		
7. PIP-PIN INSTALLATION ON TOW BAR SAFETY	(SAFETY WIRED)		
8. DEPARTURE TEST	SPECIFICATION 206-40-12		
9. FINAL RELEASE	VEHICLE CLEAN, END DOOR LATCH COVER SECURED, REV. MECH. LOCKED, CLA DOOR ACCESS LOCKED, MAN. PLUG COVERED and LOCKED.		

APPENDIX F

AIRTRANS ACCIDENT/INCIDENT REPORT

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DALLAS/FORT WORTH AIRPORT
AIRTRANS

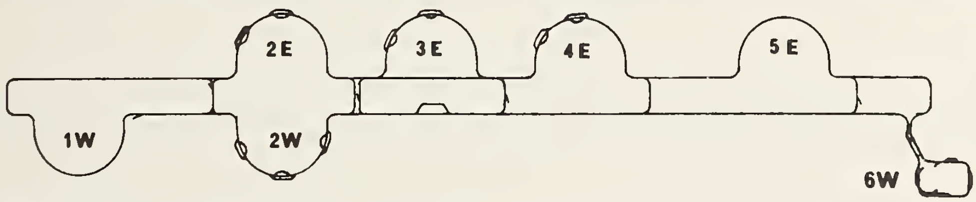
ACCIDENT / INCIDENT REPORT NUMBER ______________ (Filled in by AT Safety)

Date ______________________ Vehicle Number ______________________

Time ______________________ Vehicle Type ______________________

Central Notified By: ______________________ Vehicle Route Code ______________________

Accident Location: (Mark on the map the location of accident and then describe location in detail Below)



Location Description ____

____

____

Weather Conditions: ____

Fire: Yes ______________________ No ______________________

Witnesses to Accident (Name & Address)

PASSENGERS - ATTACH LIST OF NAMES AND ADDRESSES

Names of personnel injured

Airport Representatives:

Medical Clinic ______________________

Public Safety ______________________

Operations ______________________

Airtrans Representatives:

Maintenance Man In Charge ______________________

Leadman ______________________

Rover (If Applicable) ______________________

Description of Injury:

Accident Narrative:

Cause and/or Contributing Factors:

Other:

Recommended Corrective Action:

System Restart Authorized By:	Report Submitted By:
Form ATO - 002	

APPENDIX G

SOME SPECIFIC COMPARISONS OF THE EFFECT OF CERTAIN CHANGES ON MALFUNCTIONS

G.1 COMPUTER STOPPAGES, CAUSE 26

Figure G-1 displays histograms of the number of computer stoppages per day, their duration per day, and their average durations. The unplotted data are presented in Table G-1. The redundancy of the central computers was implemented in April 1976, at the start of Period 6. The data do not show any drastic change in the number or duration of computer stoppages between Periods 5 and 6, contrary to what might have been expected; but do show a noticible reduction in average duration per stoppage at the beginning of Period 5. It is likely that the 3-month shutdown, completed on January 1, 1976, had seen some preventive maintenance work done on the computers, and that all were working better than before. Unfortunately the data on computer outages do not separate the five wayside computers from the central computers.

Clearly, both the average numbers of malfunctions to all the computers per day and the duration of such stoppages have been reduced during Periods 5 and 6. However, the effect of the redundancy of the central computer cannot be explicitly seen in these data, and it seems impossible to demonstrate the effect of the change from the data available.

G.2 SPEED BROACHES, CAUSE 66

Paragraph 2.3.1.2 of this report discusses the changes made in the control system to allow a stop due to a speed broach - an overspeed condition - to be reset remotely from Central Control.

The sampled data from the AIRTRANS logs shows the effect of this change on the duration of stoppages caused by speed broaches. In Table G-2 the estimated average duration of stoppages from

NOTE: Date for this section was derived from information on Appendix B.

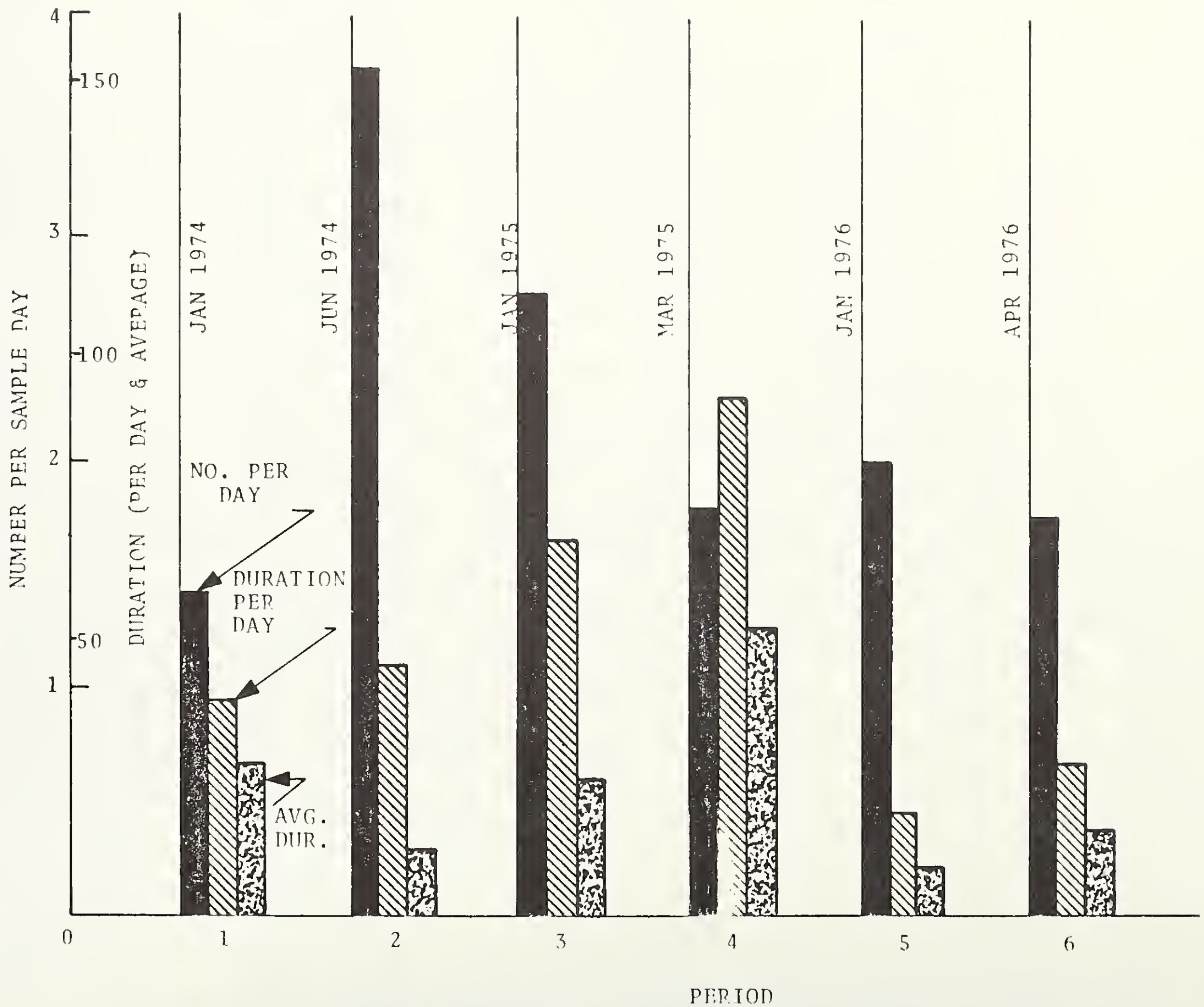


FIGURE G-1. INCIDENCE OF COMPUTER FAILURES AFFECTING SYSTEM OPERATION, CAUSE 26 speed broaches was reduced from 4.5 minutes during Periods 1-4 to 2 minutes in Period 6, after the change had been made. While the change did not affect the incidence of these malfunctions, it did seem to make them easier to cope with and less of a nuisance to the passengers.

TABLE G-1. COMPUTER CAUSE 26

Per.	No. of Events	Total Duration	No. of Sample Days	No. per Sample Day	Duration/ Day	Avg. Dur-ation	Max. Dur-ation
1	56	1512	40	1.4	37.8	27	744
2	165	1905	44	3.75	43.3	11.5	167
3	77	1779	28	2.75	63	23	393
4	77	3843	42	1.8	91.5	50	815
5	62	552	21	2	17.8	9	175
6	84	1240	45	1.8	27.5	15	475

TABLE G-2. SPEED BROACHES, CAUSE 66

Period	Sample Days	Actual Days	Events in Sample	Est. Actual Events	Est. Avg. Duration	Est. Event Per Day	Est. Duration Per Day
1	40	138	210	724	5	5	25
2	44	214	661	3214	4	15	60
3	28	80	244	697	5	8.7	43
4	42	180	364	1560	4	8.6	34
5	31	72	124	288	3	4	12
6	45	275	593	3624	2	13	26

APPENDIX H

AIRTRANS RELIABILITY AND MAINTAINABILITY TABULATION

TABLE H-1. BASIC NUMBERS FOR RELIABILITY CALCULATIONS

PERIOD	DAYS SAMPLE	DAYS TOTAL	TOTAL HOURS	TOTAL MILES		AVERAGE NUMBER OF VEHICLES
1	37	138	2070	All	880,022	28
				P. Veh.	802,567	
				U. Veh.	74,455	
2	43	214	5136	All	2,246,151	39
				P. Veh.	1,858,372	
				U. Veh.	887,779	
3	28	80	1920	All	739,737	38
				P. Veh.	705,468	
				U. Veh.	34,269	
4	42	180	4320	All	1,479,789	28
				P. Veh.	1,445,703	
				U. Veh.	34,086	
5	31	72	1728	All	460,284	19
				P. Veh.	451, 483	
				U. Veh.	8,801	
6	45	275	6600	All	2,808,078	35
				P. Veh.	2,774,036	
				U. Veh.	34,042	

Sources: Various AIRTRANS documents, compiled in CW-Table C.
See source file.

TABLE H-2. AIRTRANS RELIABILITY AND MAINTAINABILITY TABULATION

Period	All Class 1 & Class 2 Malfunctions							All Class 1 & Class 2 Malfunctions Over 4 Minutes						
	Malf per day (2)	Malf. per period (Est.) (3)	Total duration (minutes) (4)	Mean Time per Malf. (Min.) (4)	MMBM (2) (sys) (3)(5)	MTBM (sys.) hours (5)	MTBM (veh.) (5)	Malf. in sample (1)	Malf. per period (Est.) (1)	Total duration (minutes) (1,2)	Mean Time Per Malf. (Min.) (5)	MMBM (sys)	MTBM (sys) hours (5)	MTBM (veh) (5)
1. All	40	5520	57546	10.4	159	.375		1246	4647	55584	12	189	.45	
P. Veh.	27	3726			215	.55	15.4	861	3211	33675	10.5	250	.6	18
U. Veh.	7	966			80									
Way.	6	828				2.5								
2. All	71	15194	94588	6.2	148	.33		1955	9730	78971	8.1	231	.53	
P. Veh.	49	10486			177	.49	19	1328	6609	46990	7.1	281	.77	30
U. Veh.	14	2996			128	–								
Way.	8	1712			–	3.0								
3. All	49	3920	25360	6.5	189	.49		798	2240	22231	9.9	330	.84	
P. Veh.	39	3120			226	.62	24	587	1677	11622	6.9	420	1.06	40.4
U. Veh.	4	320			107									
Way.	6	480			–	4.0								
4. All	29	5220	37620	5.3	284	.83		585	2507	30900	12.3	590	1.72	
P. Veh.	21	3780			389	1.1	31	399	1710	14507	8.5	845	2.5	70.7
U. Veh.	3	540			62									
Way.	5	900			–	4.8								
5. All	22	1584	14616	9.2	291	1.1		339	787	13137	16.7	585	2.2	
P. Veh.	18	1296			348	1.3	25	266	617	6336	10.3	732	2.8	53
U. Veh.	1	72			122									
Way.	3	216			–	8								
6. All	35	9625	37675	3.9	292	.69		584	3569	27224	7.6	786	1.85	
P. Veh.	31	8525			325	.77	27	462	2823	16812	6.0	982	2.4	82
U. Veh.	1	275			124									
Way.	3	825				8								

Sources: Refer to (1) Appendix C, Table 9; (2) Appendix C, Tables 5 & 6; (3) Appendix C, Table 2; (4) Appendix C, Table 1; (5) Calculated

TABLE H-3. AIRTRANS AVAILABILITY BY THE OFFICIAL MEASURE

Week	Period 1 1/1-5/31 1974	Period 2 6/1-12/31 1974	Period 3 1/1-3/31 1975	Period 4 4/1-9/30 1975	Period 5 1/1-4/1 1976	Period 6 4/1-12/31 1976	1977	Week	1977 (cont.)
1	99	70	100	96	99.6	100	70	39	95
2	77	93	100	100	98.9	100	44	40	97
3	75	87	100	100	98.6	95	100	41	96
4	89	99	99.5	100	100	100	99	42	95
5	96	98	99	100	100	99	60	43	98
6	99	98	100	100	100	98	98	44	
7	100	96	98.8	100	100	100	100	45	
8	100	90	90	100	98	97	90	46	
9	95	98	100	99	98	97	96	47	
10	84	99	9 Wks.	100	100	99	98	48	
11	79	98	Avg.=.985	100		100	99	49	
12	96	98		100	10 Wks	100	99	50	
13	89	99		100	Avg.=.993	100	97	51	
14	88	99		100		98	98	52	
15	91	98		100		100	99		
16	84	97		100		100	99		
17	49	97		100		100	99		
18	83	98		100		100	99		
19	78	99		100		98	97		
20	19 Wks.	100		100		79	94		
21	Avg.=.87	100		100		95	99		
22		99		100		100	99		
23		98		100		95	99		
24		98		100		100	98		
25		100		100		89	98		
26		95		100		100	98		
27		98		100		100	99		
28		99		100		99.5	99		
29		99.7				99	96		
30		99.4		28 Wks.		100	99		
31		96		Avg.=.998		98	98		
32		31 Wks.				98	99		
33		Avg.=.965				94	95		
34						82	97		
35						96	98		
36						98	98		
37						87	99		
38						99	95		
39						97			
						37 Wks.			
						Avg.=.97			

Monthly 1978 Average	
Jan.	74.2
Feb.	75.0
Mar.	97.7
Apr.	99.1
May	98.8
June	99.1
July	99.5
Aug.	99.1
Sept.	99.3
Oct.	99.3
Nov.	99.3
Dec.	92.8

Source: Airport Board records.

APPENDIX I

AIRTRANS URBAN TECHNOLOGY PROGRAM, PHASE I*

I.1 BACKGROUND

The AIRTRANS Urban Technology Program was authorized by Congress in Section 148 of the Federal-Aid Highway Act of 1976 (Public Law 94-280). Partial appropriation for this authorization was included in the Department of Transportation Appropriations Act for 1977 (Public Law 94-387). The work was accomplished as a result of a grant from the Urban Mass Transportation Administration (TX-06-0020) to the Dallas-Fort Worth Regional Airport Board. The Dallas-Fort Worth Regional Airport Board in turn contracted with the Vought Corporation, an LTV company in Dallas, for the work. The work summarized herein represents work carried out between January 12, 1977 and December 23, 1977. This portion of the program is known as Phase I. A final report covering this activity is available through NTIS (Reference AIRTRANS Urban Technology Program Phase I Final Design Report (UMTA-TX-06-0020-78-1.) A second phase of the program (Phase II) was initiated on November 4, 1977 and will be fully documented, when completed, in similar reports.

I.2 OBJECTIVES

The primary objective of this program is to develop and demonstrate improvements for the AIRTRANS AGT System (now in operation at the Dallas-Fort Worth Airport) to allow the transferral of this developed technology to urban transit applications. As a result of independent assessments made by the Transportation Systems Center of DOT (See Ø1 AIRTRANS Assessment) and by the Vought Corporation, the changes or improvements recommended are as follows:

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*Parts of this section are based in whole or in part on information which appears in the "AIRTRANS Urban Technology Program Phase I Final Design Report" UMTA-TX-06-0020-78-1 June 1978.

1. Higher operating speed
2. Better passenger acceptance
3. Reduced capital and operating costs
4. Increased reliability
5. Better all-weather capability
6. Increased energy efficiency.

The first phase of the program covered the development and demonstration of subsystem improvements necessary for higher speed operations while maintaining or improving reliability, availability, cost, and performance characteristics of the overall AIRTRANS system.

I.3 CONCLUSIONS

Phase I of the AIRTRANS Urban Technology Program (AUTP) demonstrated that the existing AIRTRANS AGT system can be improved to make it a viable transit system for urban deployments. Major achievements of the program included:

1. A traction system with increased tractive capability, increased reliability, and regenerative braking capability. This system is implemented through two independent motor/controller units per vehicle.

2. An improved collector design that provides the necessary signal and power transmission efficiencies for the speeds required in an urban environment.

3. An improved mechanical steering system that lowers component and interface steering forces, and uses low-mass alloy steel construction to provide for higher speed operation with an increase in reliability and maintainability while maintaining satisfactory ride comfort.

4. An improved Vehicle Control Electronics (VCE) unit with increased flexibility, reliability, and maintainability through the use of a reduced number of parts, modular fabrication, and reduced size and weight.

5. A Wayside Signal Analyzer (WSA) unit that allows monitoring the conditions of the control signals received by the vehicle from the wayside, and provides a means to maintain the signal system through the detection and correction of faults before failures occur.

6. A radio frequency communication system with the capability for expanding the data and voice communication between the vehicle and Central Control.

The overall conclusion reached is that the basic AIRTRANS design, together with changes and design improvements developed in AUTP Phase I and the changes and design improvements expected from AUTP Phase II, will provide the technological building blocks for the deployment of an urban AIRTRANS systems.

APPENDIX J
AIRTRANS PASSENGER AND EMPLOYEE SURVEY*

MEMORANDUM

Dennis Elliott

September 19, 1978

This memorandum summarizes the results of a survey of AIRTRANS passengers and employees which was conducted on May 8-12, 1978. This survey was undertaken as part of the AIRTRANS Urban Technology Program, sponsored by the U.S.Department of Transportation.

The purpose of the survey was to obtain an accurate understanding of the current, actual usage of AIRTRANS to:

1. Analyze potential applications of a demand-responsive operating shceme
2. Develop a data base for validating simulation models
3. Evaluate the current performance of the system
4. Identify potential improvements in system operation.

Prior to this survey, the only measures of AIRTRANS usage were turnstile counts and revenues (for passengers), and airline employment records (for employees). While these data do provide estimates of overall system ridership, they do not reveal the patterns of origins and destinations; thus, the survey was the first time in the entire operating history of the system that an accurate picture of AIRTRANS ridership has been obtained.

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* Also see Appendix I.

J.1 METHODOLOGY

The basic survey was conducted over a three-day period (May 9-11). On each of these days, a different eight-hour time period was surveyed. Combined together, these data represent a composite weekday in May 1978.

The passenger survey was conducted by 32 surveyors who were hired and trained especially for this purpose. As each passenger entered an AIRTRANS station, the surveyors handed the passenger an IBM card containing the entry station identification and the time of entry. The passengers were asked to carry the card on their trip, and give it to another surveyor stationed at the exit of the destination station. There, the identification of the exit station and the time of exit were entered on the card. By this process, an accurate record of every passenger trip (except for those passengers who elected not to participate) was obtained.

The employee survey was conducted by stationing a surveyor at each remote employee station (since the destination was known in each case) and counting employees in and out of the station by five-minute time increments.

J.2 PASSENGER SURVEY RESULTS

The response (or participation) rate of passengers was exceptionally high. Approximately 97 percent of the passengers riding AIRTRANS during the survey carried a card as requested. As a result, the survey data must be regarded as a nearly 100 percent accurate representation of the ridership that actually existed during the period.

A total of 9,368 passenger trips were recorded for the composite day. A complete tabulation of these trips is contained in Table J-1 for reference purposes.

The breakdown of these trips by terminal was as follows:

Terminal	Percentage (%)
Braniff (2W)	29
American/Eastern (3E)	24
TI, Frontier, Ozark (2E)	18
Delta, Continental (4E)	17
North Parking (1W)	4
South Parking (5E)	4
Hotel (H)	4

By station, there were five major stations, each having greater than 10 percent of the total count. These were:

Stations	Percentage (%)
Braniff A	10
Braniff B	12
Texas International	12
American B	17
Delta	14

TABLE J-1. EMPLOYEE CAPACITY ANALYSIS SHOWING AVERAGE NUMBER OF PASSENGERS PER CAR

Route	Total Day	Peak Hour	Peak Half-Hour	Peak Train Trip
26	2.3	9.4	12.0	20
27	1.9	8.5	12.3	23
35	2.8	9.1	11.0	18
37	2.2	8.3	7.8	20

Of the 9,368 total trips, only 123 (1.3%) involved transferring. Also of interest, less than 2 percent of the trips (158) were "joy rides," involving starting and ending at the same station.

Also very encouraging was the fact that 95.5 percent of all logical passenger trips on the system met the original AIRTRANS specification times of 20 minutes maximum between terminals, and 30 minutes maximum to the remote parking lots (including waiting time). Of the 4.5 percent that exceeded these criteria, the worst trip took only 30 minutes (from 4EB to 2WA). This trip took 10 minutes longer than the specified maximum.

The peaking patterns for AIRTRANS passenger trips is shown in Figure J-1, and can generally be described as follows:

Time		Type Peak
8:00 a.m.	-	moderate
11:00 a.m.	-	high
3:00 p.m.	-	moderate
5:00 p.m.	-	high
9:00 p.m.	-	moderate

Four stations handled in excess of 200 passengers (in and out) in the peak half hour. Generally, the hours between midnight and 5:00 a.m. are very light. Only 273 trips were observed during this time -- approximately 55 per hour.

Conclusions and observations about the passenger survey are contained in the concluding section of this memo.

J.3 EMPLOYEE SURVEY RESULTS

A total of 6,036 employee trips were counted for the composite day. The breakdown of these trips by terminal was as follows:

Terminal	Percentage (%)
Braniff (2W)	35
American/Eastern (3E)	40
TI, Frontier, Ozark (2E)	11
Delta, Continental (4E)	14

The employee system experienced three major peaks: an early morning peak (0400-0800); a midday peak (1300-1600), and a night peak (2100-2400).

Even during these peak periods, the employee system shows a great deal of excess capacity, as shown in Figure J-2. The average number of employees per vehicle in the peak half hour was approxi-

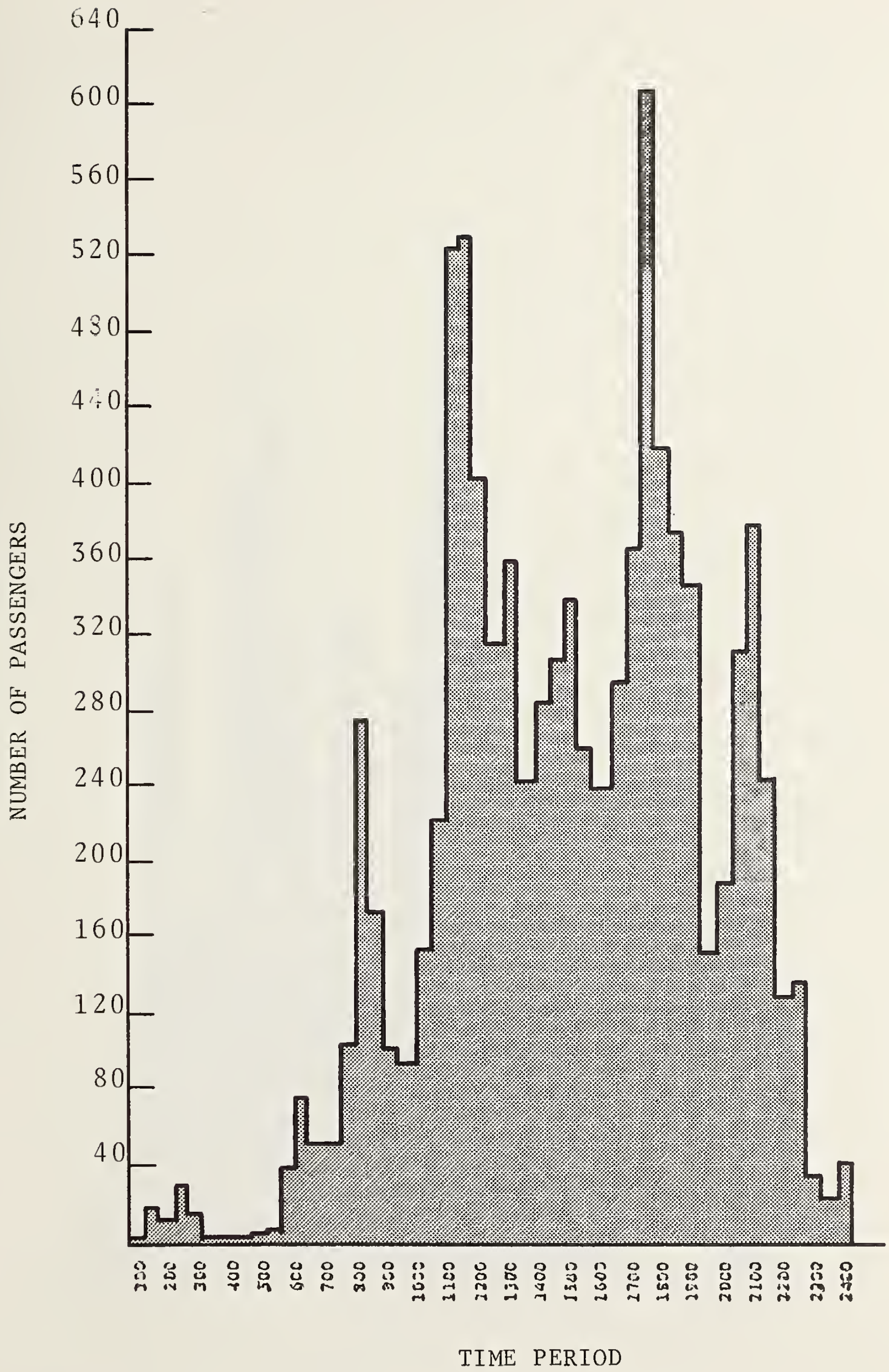

FIGURE J-1. NUMBER OF PASSENGERS STARTING AIRTRANS TRIP IN TOTAL SYSTEM BY TIME OF DAY

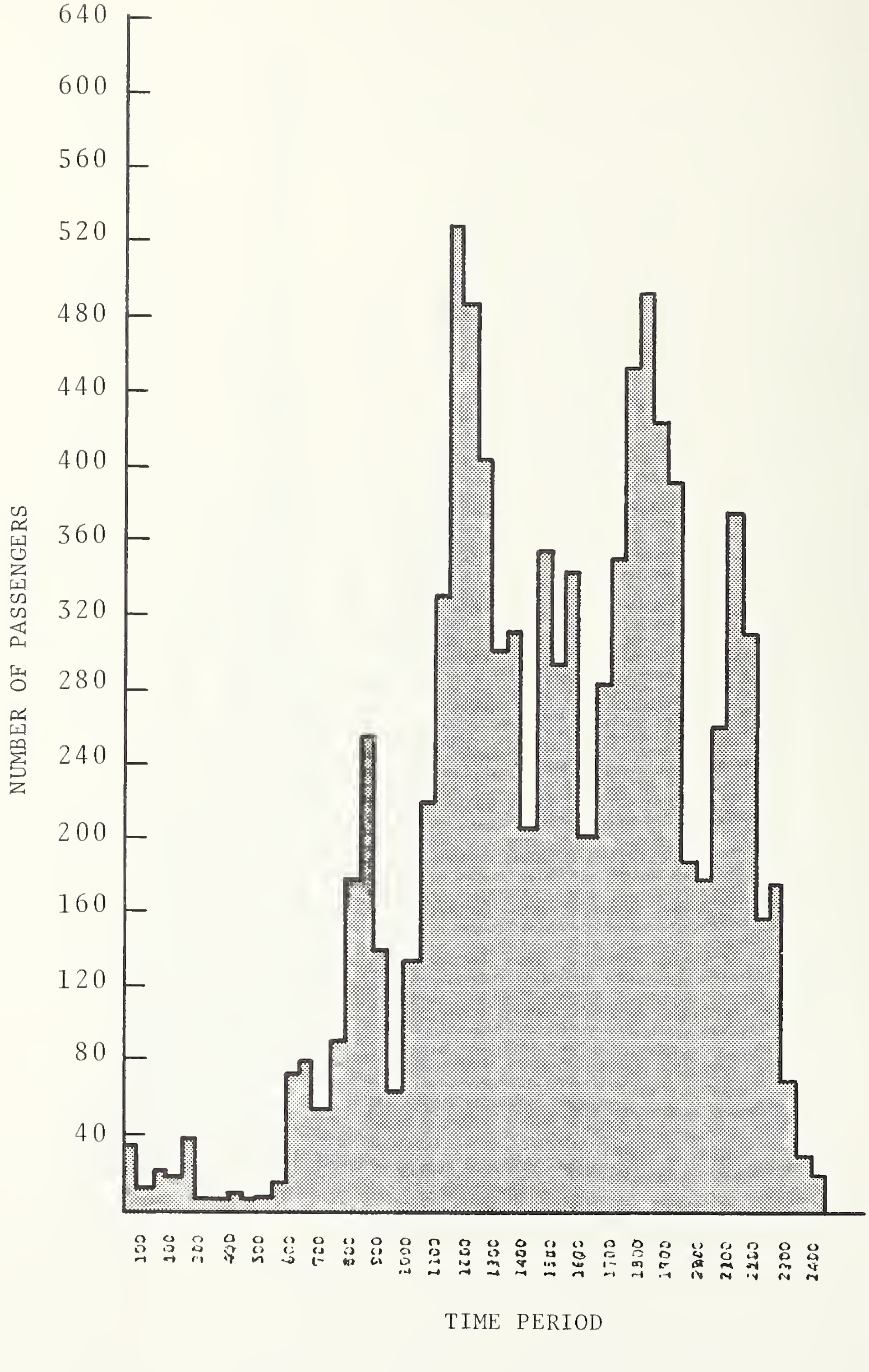

FIGURE J-2. NUMBER OF PASSENGERS ENDING AIRTRANS TRIP IN TOTAL SYSTEM BY TIME OF DAY mately 12 -- a 30 percent load factor. The most employees ever observed in a vehicle was 23 -- only a 58 percent load factor. Some suggestions regarding this matter are contained in the concluding section of this memorandum.

J.4 CONCLUSIONS

An in-depth report on the AIRTRANS passenger and employee survey, including observations and conclusions, will be published as part of the Final Report on the AIRTRANS Urban Technology Program. However, this will not occur for several more months. Accordingly, the following are some of the major conclusions which can be drawn from the survey results:

1. The survey confirmed that AIRTRANS is currently providing a high level of service to passengers and employees, consistent with that envisioned in the original AIRTRANS specifications. With only a few exceptions, passengers seem able to use the system quite successfully. The survey did reveal, however, that a major factor in passenger utilization of AIRTRANS is the Passenger Service Agents (PSAs). It was estimated by the surveyors that approximately one-third of all passengers using the system consulted a PSA.

2. The survey has provided a massive, reliable data base for use in future AIRTRANS studies. The data is available in both hard-copy and computer form, and provides an excellent method of analyzing existing usage/service, projecting future utilization, etc.

3. A significant finding of the survey is that the actual passenger ridership is much higher than estimated heretofore, while the employee ridership is much lower. Previously, passenger ridership was estimated (by counting quarters) to be approximately 7,000 per day, yet over 9,300 passenger trips were recorded in the survey. Also, previous estimates of employee ridership were roughly 9000-10,000 per day. However, only 6000 employee trips were observed during the survey. Coincidentally,

the totals are reasonably close.

4. The employee system is operating with a great deal of excess capacity. It is suggested that, if acceptable to the affected airlines, the following measures would save money by reducing AIRTRANS operating expenses by:

   1. Combining routes during off-peak periods
   2. Running fewer two-car trains
   3. Reducing the number of trains.

APPENDIX K

SOURCE DATA FOR OPERATING AND MAINTENANCE COST CALCULATIONS

LIST OF TABLES

GLOSSARY

ABBREVIATIONS	DEFINITION	TABLE USED
MHRS/VEH MI	Manhours per vehicle mile	K-1
MHRS/SYS HR	Manhours per system hour	K-1
UNITS/SYS	Number of units of this type	K-1
UNSCH, U	Unscheduled maintenance	K-1, 2
SCHED, S	Scheduled maintenance	
MECH	Vehicle mechanical components	K-1, 2
ELECT	Vehicle electrical components maintained by electronic technicians	K-1, 2
MAX FLEET	Average maximum number of vehicles in daily operation	K-1, 2
SERVICE VEH COMMO	Communication system for service vehicles	K-1, 2
OP/MAINT SPT	Operations and maintenence support equipment	K-1, 2
VEH DEP TEST FAC	Vehicle departure test facility	K-1, 2
NON-PAX	Non-passenger equipment	K-1, 2
CENTRAL CNT	Central Control	K-1, 2
WAYSIDE CNT	Wayside Control	K-1, 2
STN GRAPHICS	Station graphics	K-1, 2
VOICE/PA	Voice communciations and public address system	K-1, 2
AMHRS	Available manhours per person per year	K-1, 2, 7, 8

TABLE K-1. UNIT MANHOUR AND PARTS REQUIREMENTS FOR MAINTENANCE

MAINT FUNCTION	MHRS/ VEH MI	AIRTRANS UNITS/SYS	MHRS/ SYS HR	MHRS/SYS HR PER UNIT	OTHER	SOURCE
VEH UNSCH MECH	.00371					1
VEH UNSCH ELECT	.00590					2
VEH SCHEDULED	.00510					3
HOSTELING					.66 HR/DAY/MAX FLEET	4
SERVICE VEH COMMO		7 SERV VEH	.1332	.01903		5
OP/MAINT SPT SCHED		13 MILES	.1100	.0084		32
OP/MAINT SPT EQP		13 MILES	.0714	.0055		7
CARGO VEH MNT					.0086/CARGO VM	8
VEH DEP TEST FAC-U		29 VEH/DAY	.0192	.0007		9
VEH DEP TEST FAC-S		29 VEH/DAY	.0296	.0010		32
SUPERVISION					.186 DIRECT MANHOURS	10
GUIDEWAY SURF-UNSCHED		13 MILES	.0423	.00325		11
GUIDEWAY SURF-SCHED		13 MILES	.4441	.03420		12
POWER/SIG-UNSCHED		13 MILES	.1092	.0084		13
POWER/SIG-SCHED		13 MILES	1.146	.0857		30
SWITCHES-UNSCHED		33 DIVERGE	.0485	.0014		14
SWITCHES-SCHED		71 MERGE/01	.5093	.0071		15
STATION DOORS-UNSCHED		28 DOORS	.0671	.0024		16
STATION DOOR-SCHED		28 DOORS	.1342	.0048		17
NON PAX-UNSCHED					.535/NON PAX HOUR	6
NON PAX-SCHED					.1090/NON PAX HOUR	17
FARE COLLECT-UNSCHED		46 DEVICES	.0607	.0013		18
FARE COLLECT-SCHED		46 DEVICES	.5706	.0124		19
ROVER UNSCHED					.75 MHRS/MALFUNCTN	20
SUPERVISION					.186 DIRECT MANHOURS	10
ROVER SCHEDULED					#/SHIFT TO RESPOND TO MALFUNCTION IN LESS THAN 3 MINUTES x TOTAL SHIFTS REQUIRED x 1896 MANHOURS/PER/YR	21

TABLE K-1. UNIT MANHOUR AND PARTS REQUIREMENTS FOR MAINTENANCE (CONTINUED)

MAINT FUNCTION	MHRS/ VEH MI	AITRANS UNITS/SYS	MHRS/ SYS HR	MHRS/SYS HR PER UNIT	OTHER	SOURCE
CENTRAL CNT-U			.0742	.0742		22
CENTRAL CNT-S			.555	.555		23
WAYSIDE CNT-U		13 MILES	.1300	.0100		24
WAYSIDE CNT-S			.986	.0758		25
CCTV - U		28 CAMERAS	.0400	.00143		26
CCTV - S			.0523	.00187		27
VOICE/PA-U		14 STATIONS	.0046	.0003		28
VOICE/PA-S			.00607	.0004		27
STN GRAPHICS-U		14 STATIONS	.0185	.0013		29
STN GRAPHICS-S			.02442	.00175		27
SUPERVISION					.186 DIRECT MANHOURS	10
MAINTENANCE CNTL						
SUPERVISION					1 EACH	37
MAINTENANCE CNTL					SHOP HOUR/MHRS/P/YR	37
DOCUMENTATION					(.67 MALFUNCTIONS/4300 x 1896)	33
PARTS						
VEHICLES	$.1492					34
GUIDEWAY					$2.50/TRACK FOOT	35
ELECTRONICS					.0153 * CAPITAL COST IN CURRENT ($) (COMMAND & CONTROL + STATION EQMT)	36

SOURCES FOR TABLE K-1.

1. TABLE 4 (CODES 11A, 11B, 11C, 11D, 11F, 11G, 11H, 11J, 11N, 11O)/VEH MI
2. TABLE 4 (CODES 11E, 11K, 11M)/VEH MI
3. TABLE 5 USE TABLE 5, 51 VEH, 3510320 VEH MILES
4. TABLE 5-9 5 HOSTELERS @ 1896 HRS/YR, 365 DAYS, 39 MAX FLEET
5. TABLE 4 CODE 14/SYS HOURS
6. TABLE 4 CODE 23-28 / 1059 HRS/183 DAYS = 6 HRS/DAY
7. TABLE 4 CODE 95-99 / SYS HOUR (4368)
8. TABLE 4 115 / UTILITY VEH MI
9. TABLE 4 CODE 64 / SYS HOUR (AVERAGE OF 29 VEH/DAY 3/75-9/75)
10. $ (13 SUPERVISORS x 1896 MHRS/YR)/(SUM DIRECT HRS, TABLE K-2) or 24648/132243 = .186
11. TABLE 4 CODE 51 STRUC / SYS HOUR
12. TABLE 12 GUIDEWAY MAINTENANCE RATIOS
13. TABLE 4 CODE 41 / SYS HOUR
14. TABLE 4 CODE 51 SWITCH / SYS HOUR
15. MAJOR UNSCHED TIME ON SWITCH MACHINE, PM ON BOTH, TABLE 12 GUIDEWAY RATIO
16. TABLE 4 CODE 21C / SYS HOUR
17. TSC ESTIMATE
18. TABLE 4 CODE 21G / SYS HOUR
19. TABLE 12, FARE COLLECTION
20. APPENDIX B, TABLE 1, PERIOD 6

    $$\frac{\text{TOTAL DURATION CLASS I MALFUNCTIONS + 1/2 TOTAL CLASS II DURATION}}{\text{TOTAL CLASS I + 1/2 CLASS II}} = 3.56 \text{ MIN}$$

    = AVE MALFUNCTION DURATION REQUIRING ROVERS: ROUND TO 5 MIN
    ADD 5 MINUTES RESPONSE TIME + 5 MINUTES RECOVER = 15 MIN TOTAL
    15 MIN TOTAL x ROVERS/SHIFT (=3 FROM SECTION 2.4.1) = 45 MANMIN/MALFUNCTION
21. RESPONSE TIME PER PASSENGER SERVICE REQ HANDBOOK-(REF 5.8) page 103

22. TABLE 4 CODE 32 / SYS HOUR

23/25. TOTAL AIRTRANS ELECTRONIC TECHNICIANS = 21 (TABLE K-3). NUMBER REQUIRED FOR VEHICLE ELECTRONIC MAINTENANCE = 12; REMAINING FOR OTHER REQUIREMENTS = 9; 9 X 1896 = 17064 MHRS; OTHER NON-VEHICLE ELECTRONIC REQUIREMENTS = 3500 MHRS; TOTAL REMAINING MANHOURS = 13,500; APPORTION 13,500 IN SAME RATIO AS UNSCHEDULED REQUIREMENTS, HENCE CENTRAL SCHEDULED = .36 X 13,500 = 4860 MANHOURS/7860 = .555/SYS HR WAYSIDE SCHEDULED = .64 X 13,500 = 8640 MHRS/8760 = .986/SYS HR

24. TABLE 4 CODE 31 / SYS HOUR
26. TABLE 4 CODE 34 / SYS HOUR
27. TABLE 12, SURVEILLANCE
28. TABLE 4 CODE 83+35/SYS HOUR
29. TABLE 4 CODE 21E / SYS HOUR
30. TABLE 12 POWER MAINTENANCE RATIO
31. TABLE 4 CODE 64/SYS HOUR
32. TABLE 12 SUPPORT EQUIPMENT = 1.54
33. APPENDIX B, TABLE 2, PERIOD SIX, 8330 CLASS I; II MALFUNCTIONS X (MMBF) FROM TABLE 3-5 = 2807210 MILES/TOTAL MALFUNCTIONS (10234) = 274 MEAN MILES BETWEEN ANY MALFUNCTION. FROM APP B, TABLE 2 = 43 MALFUNCTION/DAY, FROM TABLE 3-11, 29 MAINTANCE ACTIONS; RATIO = .67; TOTAL MILE 4/77-3/78 = 3.51M DIVIDED BY 274, TIMES .67 - 8582 MAINT ACTIONS FOR 2 PEOPLE HENCE # of PEOPLE = .67 * MALFUNCTIONS/4300
34. GMSOS FROM WESTINGHOUSE: .0804/CM (1976 dollars) x 116 ESCAL 1978/1976 x 1.6 km/mi = .1492/mi POSSIBLY INCREASING WITH TIME DUE TO WEAR OUT (REF 5.4)
35. APPROXIMATION BASED ON ST. PAUL ESTIMATE OF $3.00/TRACK FOOT (REF 5.5)

SOURCES FOR TABLE K-1. (CONTINUED)

36. APPROXIMATION BASED ON AIRTRANS TOTAL COST $1978 OF STATION DOORS, FARE COLLECT, CENTRAL & WAYSIDE CONTROL, STATION GRAPHICS (TOTAL = 9597k) AND RESDUAL OF 4/77-3/78 PARTS COST LESS #34, 35 ABOVE = 147k; 147k/959k = .0153 (CLOSE TO GMSOS APPROXIMATION OF .012) REFERENCE 5.4
37. TSC ESTIMATE FROM ACTUAL AIRTRANS STAFFING.

Note: Tables refer to other tables in Appendix K.

TABLE K-2. TOTAL MANHOUR AND PARTS REQUIREMENTS FOR MAINTENANCE (APRIL 1977 - MARCH 1978)

MAINT FUNCTION	MANHOURS F(VMT)	MANHOURS F(SYSHR)	MANHOURS OTHER	AIRTRANS ORGANIZATIONAL CATEGORIES			
				TRAIN	ELECT	GUIDEWAY	SOURCE
VEH UNSCHED MECH	13023			13023			1
VEH UNSCHED MECH	20710				20710		1
VEH SCHEDULED	17903			17903			1
HOSTELING			9395	9395			2
SERVICE VEH COMMO		1167			1167		3
OP/MAINT SPT EQP-S		964		964			3
OP/MAINT SPT EQP-U		625		625			3
CARGO VEHICLES			695	695			5
VEH DEP TEST-U		239			239		6
VEH DEP TEST-S		342			342		6
SUPERVISION				7668	4042		11
TOTAL				50273	26500		
STAFF @ 1896				27	14		
GUIDEWAY SURF-UNSCHED		370				370	3
GUIDEWAY SURF-SCHED		3891				3867	3
POWER/SIG-UNSCHED		957				957	3
POWER/SIG-SCHED		9768				9768	3
SWITCHES-UNSCHED		425				425	3
SWITCHES-SCHED		4461				4461	3
STATION DOORS-ON		588				588	3
STN DOORS-SCHED		1176				1176	3
NON PAX-UNSCHED			1171			1171	4
NON PAX-SCHED			2342			2342	4
FARE COLLECT-US		531				531	3
FARE COLLECT-SCHED		4998				4998	3
ROVER UNSCHED			7117			7117	7
SUPERVISION			6817			6817	11
TOTAL						44688	
STAFF @ 1896						24	
ROVER SCHEDULED	(INCLUDES ROVER UNSCHEDULED & % GUIDEWAY, STATION SCHEDULED MAINTENANCE)						
CENTRAL CNT-U		650			650		3
CENTRAL CNT-S		4861			4861		3
WAYSIDE CNT-U		1139			1139		3
WAYSIDE CNT-S		8637			8637		3
CCTV - U		350			350		3
CCTV - S		458			458		3
VOICE/PA U		40			40		3
VOICE/PA S		53			53		3
STN GRAPHICS-U		162			162		3
STN GRAPHICS-S		214			214		3
SUPERVISION			2999		2999		11
TOTAL					19663		
STAFF @ 1896					10		

TABLE K-2. TOTAL MANHOUR AND PARTS REQUIREMENTS FOR MAINTENANCE (CONTINUED) (APRIL 1977 - MARCH 1978)

TABLE 2. TOTAL MANHOUR AND PARTS REQUIREMENTS & FOR MAINTENANCE (4/77-3/78) (CONTINUED)

MAINT FUNCTION	MANHOURS F(VMT)	MANHOURS F(SYSHR)	MANHOURS OTHER	VEHICLE	ELECT	GUIDEWAY	SOURCE
MAINTENANCE CNIL							
SUPERVISION			1,896				3
MAINT CNTL			8,759				3
DOCUMENTATION			3,786				8
TOTAL			14,541				
STAFF			8				
PARTS							
VEHICLES			$523,000				1
GUIDEWAY			$171,000				9
ELECTRONICS			$147,000				10
			$841,000				

SOURCES FOR TABLE K-2

1. TABLE 5-6 TOTAL VEH MI = 3510320 PER YEAR
2. 365 DAYS/YR, 39 MAX FLEET
3. 8760 SYSTEM HOURS/YEAR
4. TABLE 1, SOURCE 6 6 HRS/DAY x 365 = 2190 HRS/YR
5. CARGO VEH MILES 34086/1479789 (FROM TABLE 4) = .023 OF TOTAL X 3510320 = 80858
6. 39 VEH IN MAX FLEET
7. FROM APPENDIX B, TABLE 1, PERIOD 6

   # MALFUNCTIONS/DAY = CLASS I + 1/2 CLASS II = 26

   TOTAL DAYS = 365

   TOTAL TIME = .75x26x365 = 7117 (MMBF = 369)
8. MMBF (ALL CLASSES = 274)
9. LANE KM = 20.5
10. CAPITAL EQUIP = 9597K
11. .186 X TOTAL DIRECT HOURS FOR THIS FUNCTION

TABLE K-3. AIRTRANS MAINTENANCE STAFF (5/78)

FUNCTION	SUPERVISOR	SHIFT FOREMAN	MAINTENANCE	TOTAL
Maintenance Control	1	0	7	8
Vehicle Maintenance	1	3	26	30
Electronic Maintenance	1	3	21	25
Guideway Maintenance	1			
Technicians		3	9	
Rovers			12	25
Maintenance Manager and Secretary			2	2
Total				90

<u>Source</u>: D-FW Airport.

TABLE K-4. DISAGGREGATED UNSCHEDULED MAINTENANCE (MARCH 1, 1975 - September 30, 1975)

CODE	SYSTEM	MMH	M.ACT	MTBF MMBF	MMH/ACT	MI OR HRS	FAILURES
11	VEHICLES						
11A	STRUCTURE	515.	353	27920.	1.46	1479789 [1]	53
11B	LOCOMOTION/DRIVE	1077.	356	20271.	2.94	1479789	73
11C	STEERING	1672.	1075	7707.	1.55	1479789	192
11D	VEH DOORS	438.	290	21446.	1.51	1479789	69
11E	VEH ELECTRICAL	2117.	1492	3609.	1.42	1479789	410
11F	SUSPENSION	243.	223	49326.	1.09	1479789	30
11G	BRAKES	868.	303	7289.	2.86	1479789	203.
11H	PNEUMATIC P/S	235.	161	47740.	1.46	1479789	31.
11J	ENVIRONMENTAL	276.	167	15545.	1.65	1445703 [2]	93
11K	COMMUNICATIONS	2274.	2354	4034.	.96	826988 [3]	205
11M	VCCS	4344.	1026	4851.	4.23	1479789	305
11N	TRAIL VEH MOD	63.	14	61871.	4.50	618715 [4]	10
110	VEH GENERAL	104	95	67263.	1.10	1479789	22
TOTAL		14226	7909	872	1.80	1479789	1696
11T	U-VEH CARGO-HANDLE	296.3	91	1099.	3.20	34086 [5]	31
14	SERV VEH COMMO	582.	267	0.	2.18	4368	0
21	STATIONS						
21C	DOORS	285.	134	67.2	2.12	4368	65
21E	CRAPHICS	81.	98	728.	.82	4368	6
21C	FARE COLLECT	265.	484	78.	.55	4368	56
21-	MISC	8.	18	1092.	.44	4368	4
		639.	734	33.	.87	4368	131
23	BAGGAGE MAIL STN	124.	74	-	1.67	-	61
25	TRASH/SUPPLY STN	318.	87	19.6	3.65	1059	54
27	TRASH/DUMP MASH FAC	122.	7	-	17.41	-	4
28	WASH EQUIP	3.	2	-	1.5	-	0
31	WAYSIDE CONTROL	568.	198	33.3	2.86	4368	131
32	CENTRAL CONTROL	324.	163	59.8	1.98	4368	73
33	RF VOICE	3.	1	-	3.00	4368	0
34	CCTV	174.	192	106.	.90	4368	41
35	PUBLIC ADDRESS	17.	22	624.	.77	4368	7
41	GUIDEWAY POWER & SIGNAL	447	235	75.	2.02	4368	58
51	GUIDEWAY STRUC	185	43	291.	4.3	4368	15
	GUIDEWAY SWITCH	212	91	141.	2.33	4368	31
64	VEH DEP TEST FAC	84	120	-	.7	4368	0
95	MAINT SUPT EQUIP	50.	15	-	3.3	4368	0
99	OPERATIONAL SUPT EQUIP	262	158	-	1.65	4368	0
	UNIDENTIFIED ENTRIES	326	304				30
TOTALS		18992	10713				2364

MAJOR BAD ENTRIES ACCOUNTED FOR BY CODE BUT EXCLUDED FROM ABOVE	CODE	NO:
	11EA1	641
	11BA4	210
	14	231
	64	114
	99	154
	UNIDENTIFIED	260
OTHER		820
TOTAL		2430

MMH = MAINTENANCE MANHOURS
MACT = MAINT. ACTIONS
MMH/ACT = MANHOURS/ACTION
1. All Vehicles
2. Lead and Trail Vehicles
3. Lead Vehicles
4. Trail Vehicles
5. Utility Vehicles

Source: Vought Maintenance Records

TABLE K-5. VEHICLE PREVENTIVE MAINTENANCE REQUIREMENTS

CODE NUMBER	TYPE OF INSPECTION (MILES)	MANHOURS
250	2500	8.5
400	15000	29.0
600	45000	42.0
700	90000	47.0

MANHOURS = Σ(avg. mi/veh)/ (PM Interval) x hrs/PM Interval x Fleet Interval

where: Avg. mi/veh = Total veh mi/fleet size

Source: Don Hawkes, Vought Corporation.

Note: Code 400 inspection includes 250 inspection
Code 600 inspection includes 400 inspection
Code 700 inspection includes 600 inspection

TABLE K-6. HEATING AND COOLING ENERGY

City	Function	Annual Energy - BTU/m^2	
		Office (AGT bldg.)	Store (AGT gar.)
Miami	Cooling	950,356	2,054,744
	Heating	0	0
Los Angeles	Cooling	154,522	522,433
	Heating	20,322	0
Albuquerque	Cooling	280,611	653,100
	Heating	90,933	0
Denver/ Colo. Springs	Cooling	187,467	449,167
	Heating	162,044	5,178
Dallas/Ft. Worth	Cooling	511,078	1,150,422
	Heating	33,411	0
Memphis/ Nashville	Cooling	404,900	880,289
	Heating	70,944	0
Washington D.C.	Cooling	307,467	699,244
	Heating	87,633	0
Salt Lake/Odgen	Cooling	225,378	507,467
	Heating	153,922	4,322
Seattle	Cooling	70,500	227,933
	Heating	97,456	0
Boston	Cooling	152,356	408,889
	Heating	127,989	2,133
Chicago	Cooling	213,333	500,000
	Heating	150,678	5,278
New York	Cooling	243,444	573,922
	Heating	103,722	100

Source: TRW Systems Group, Solar Heating and Cooling of Buildings, Phase 0 NSF/RA/N-74-022A, Washington D.C., 1974.

TABLE K-7. AIRTRANS OPERATIONS UNIT MANHOUR AND ENERGY REQUIREMENTS

FUNCTION	MANPWR REQ	UNITS	ENERGY REQ	UNITS	SOURCES
CENTRAL CONTROL	INT $\left(\frac{\text{SYSHOURS}}{\text{AMHRS/\&F}}\right)$	SHIFTS			1
	2/SHIFT	STAFF			
PASSENGER SERVICE					2
AGENTS					
TERMINAL PEAK	.88/STN x 16 HRS	MANHRS/DY			
TERMINAL OFF PK	.5/STN x 8 HRS	MANHRS/DY			
HOTEL PEAK	.5/STN x 16 HRS	MANHRS/DY			
SUPERVISOR	1 x 24 HRS	MANHRS/DY			
JANITORIAL	2 MHRS/m^2/YR				3
GENERAL ADMIN					
REQUIRED	6	STAFF			4
FUNCTION OF SIZE	5.6%	TOTAL O&M			4
AIRPORT SERVICES	1.92%	TOTAL COST			5
ENERGY					
VEHICLE PROPULSION AND AUXILIARY			1.56	KWH/VEH KM	6
WAYSIDE C/C			9895	KWH/LN KM/YR	7
STATION ELECTRIC			67	KWH/m^2/YR	8
GARAGE ELECTRIC			343	KWH/m^2/YR	8
STATION A/C			149.8	KWH/m^2/YR	9
GARAGE A/C			337.2	KWH/m^2/YR	9
STATION HEAT			9.8	KWH/m^2/YR	9

SOURCES FOR TABLE K-7

1. INTEGER VALUE OF (SYSHOUR/AMHRS/YR) TO DETERMINE # OF SHIFTS 2 MEN PER SHIFT SINCE OPERATORS REQUIRED TO DIRECTION MALFUNCTION RESPONSE AND MONITOR CCTV AT CENTRAL CONTROL.

2. SECTION 2.2.4 OF THIS REPORT

3. BOEING ESTIMATE \$8160/YR/PERSON (INCLUDES FRINGE SINCE PURCHASED)
   AIRTRANS FRINGE 20%
   GM ESTIMATE \$7.2/m^2/YR (1978 dollars)
   ∴ \$8160/1.20/1896 MANHRS/YR = 3.58 HR
   \$7.2/m^2/YR/\$3.58/HR = 2 MANHRS/m^2/YR

4. TABLE 5-3/ITEMS REPORTED UNDER TRANSPORTATION CONTROL AND ENGINEERING
   6 PEOPLE NECESSARY + A FUNCTION OF SIZE
   6 NECESSARY ARE TOP MANAGER, OPERATIONS MANAGER, MAINTENANCE MANAGER, AND THEIR SECRETARIES
   OTHER A FUNCTION OF SIZE = (7 PEOPLE x 1896)/255144 DIRECT HRS = 5.6%
   (FROM STAFFING CHART) (FROM OTHER FUNCTIONS)

5. THIS IS CALCULATED FROM TABLE 5-2 REPORTED COST
   66312 (AIRPORT SERVICES)/3457656 = 1.92%

6. TSC REPORT (5.1) FIGURE 5-3

7. GMSOS STUDY-SLT ANALYSIS DATA SOURCES-PAGE 8-30, Section 5, Reference 4

8. GMSOS STUDY-SLT ANALYSIS DATA SOURCES-PAGE 8-30, Section 5, Reference 4

9. TABLE 6 (HEATING & COOLING ENERGY) VALUE FOR DALLAS BLDG OR GARAGE TIMES CONVERSION OF BTU/m^2/YR TO KWH/m^2/YR (.000293083)

TABLE K-8. AIRTRANS OPERATIONS TOTAL MANHOUR AND ENERGY REQUIREMENTS

	MANPOWER			ENERGY (KWH)			
FUNCTION	UNIT REQ	# UNITS	TOTAL	UNIT REQ	#UNITS	TOTAL	SOURCE
CENTRL CNTL-SHIFTS	# SHIFTS	5	5				1
-STAFF	PER SHIFT	2	10				1
PASSENGER SERVICE							
AGENTS							
MANHOURS-DAY	MANHOURS/DAY	9 TERM + 1 HOTEL	192				2
MANHOURS-YR	MHRS/DAY x OP DAYS	365	70080				2
STAFFING	(MHRS/YR)/(AMHRS/YR)	1896	37				2
JANITORIAL							
CENTRAL	m^2	0	0				
MAINT	m^2	1116	1116				3
STATIONS	m^2	3478	3478				4
MANHOURS	2 MHR/m^2/YR	4594	9188 MHRS/YR				
GENERAL ADMIN							
REQUIRED	STAFF	6	6				
	O&M	(7 people)					
FUNCTION OF SIZE	TOTAL MHRS	251103	14072 MHRS/YR				5
AIRPORT SERVICES	TOTAL O&M COST	$3,673,333	$70,528				6
ENERGY							
VEHICLE PROP & AUXILIARY				1.56 KWH/VKM	5616368	8761534	7
WAYSIDE				9895 KWH/LKM	20.5	202847	8
STATION ELEC				67 KWH/m^2	3478	233026	4
GARAGE ELECT				343 KWH/m^2	1116	382788	3
STATION A/C				149.8 KWH/m^2	3478	521004	4
GARAGE A/C				337.2 KWH/m^2	1116	376315	3
STATION HEAT				9.8 KWH/m^2	3478	34084	4

SOURCES FOR TABLE K-8

1. SYSHOUR = 8760 (24 HRS/DAY x 365 DAYS/YR) AVAILABLE MANHOURS/YR = 1896 (2080-2 WKS VAC-1 WK SICK-8 HOLIDAYS)

2. 8 TERMINAL STNS + 1 HOTEL, 365/YR, 1896 AVM/YR SEE ABOVE PLUS SYSTEM LAYOUT

3. DENNIS ELLIOT FROM AIRTRNS RECORDS

4. DERIVED FROM AIRTRANS STATION LAYOUTS
   9 PAX TERMINALS AT 180 m^2, 9 EMPLOYEE TERMINALS AT 90 m^2
   4 REMOTE PARKING TERMINALS AT 225 m^2, 1 HOTEL TERMINAL AT 148 m^2

5. TOTAL MANHOURS (TABLE K-2 AND TABLE K-8)

6. TOTAL COST (TABLE 5-7)

7. TABLE 5-2 (ANNUAL STATISTICS) MILES x 1.6

8. 20.5 KM-TABLE 5-7

TABLE K-9. AIRTRANS MONTHLY ENERGY CONSUMPTION (April 1976 March 1978)

INCLUDES VEHICLE PROPULSION, WAYSIDE CONTROL, REMOTE TERMINALS, HOTEL TERMINAL, AND MAINTENANCE BUILDING

Date	KWH	Date	KWH
4/76	618501	4/77	762450
5/76	765550	5/77	861850
6/76	827950	6/77	899600
7/76	949334	7/77	977030
8/76	981978	8/77	971830
9/76	938480	9/77	944380
10/76	872120	10/77	806160
11/76	770310	11/77	731910
12/76	825210	12/77	817050
1/77	790290	1/78	796310
2/77	744510	2/78	650110
3/77	729980	3/78	734460
TOTAL	9814213		9953140
COST	$227004		$272042
COST/KWH	.02313		.02733

Source: Dennis Elliot, D-FW Airport, Sept. 25, 1978.

TABLE K-10. POSITION AND SALARY DATA

POSITION	BASE PAY MONTH
Director of Transportation	2675
Senior Secretary	787
Clerk Typist	651
AIRTRANS Maintenance Manager	2086
Secretary	712
Transportation Administrator	1487
Transportation Operations Manager	2086
Train Maintenance Supervisor	1487
Train Technician 3	1281
Train Technician 2	1160
Train Technician 1	1104
Train Access Repairman	1160
Train Air Conditioning Repairman	1160
Hostler 2	827
Hostler 1	712
Electronics Supervisor	1487
Electronic Technician 3	1281
Electronic Technician 2	1160
Electronic Technician 1	1104
Guideway Maint Supervisor	1487
Guideway Technician 3	1281
Guideway Technician 2	1160
Guideway Technician 1	1104
Maintenance Control Supervisor	1487
Maintenance Controller	1281
Clerk-Typist	651
Engineering Supervisor	1563
Engineer	1415
Data Processing Analyst	1415
Technical Data Analyst	position abolished
Engineering Technican	1219

TABLE K-10. POSITION AND SALARY DATA (CONTINUED)

POSITION	BASE PAY MONTH
Central Control Supervisor	1643
Controller 1 (Assistant)	1219
Controller 2	1487
Passenger Service Supervisor	1347
Passenger Service Shift Supervisor	869
Passenger Service Agent	749

Note: 1. Base pay figures were effective as of September 25, 1978.
2. All position classifications have a pay range of base to base + 135%. The mean for each classification would be 1.175 x base.
3. Figures do not include fringe benefits.

Source: Dennis Elliot, D-FW Airport Board, Sept. 8, 1978.

TABLE K-11. AIRTRANS BASE SALARIES/YEAR BY SKILL LEVEL

Category	1977-78 (Est 10/78 ÷ 1.114)	10/78 Actual
Supervisors	\$16024	\$17850
Maint Tech (.5 x level 1 + .5 x level 2)	\$12190	\$13580
Hosteler (.6 x level 1 + .4 x level 2)	\$8169	\$9100
Maint Cntl (.5 x Cntl x .2 x clerk)	\$11861	\$13213
Foreman (level 3)	\$13797	\$15370
Controller (.5 x level 1 + .5 x level 2)	\$14580	\$16240
Pax Agents (.83 agent + .17 shift)	\$8285	\$9230
Janitors	\$7325	\$8160
GiA		
Fixed (3+3) (3 Secretary + 2 Mgr. + 1 Chief) / 6	\$16131	\$17970
Engineering (Engineer)	\$15242	\$16980

Source: Table K-12

TABLE K-12. SCHEDULED/UNSCHEDULED MAINTENANCE MANHOUR RATIOS

CATEGORY	BOEING ESTIMATE FOR MORGANTOWN	TSC ESTIMATE FOR AIRTRANS
GUIDEWAY		
MAINTENANCE	12.5	10.5
POWER/SIGNAL	12.5	10.5
SWITCH	-	10.5
FARE COLLECTION	9.4	9.4
SURVEILLANCE	1.3	1.3
VOICE/VIDED	-	1.3
GRAPHICS	-	1.3
SUPPORT EQUIPMENT	1.54	1.54

Note: Guideway, power, and switch ratios are lower for AIRTRANS due to size of system.

Source: Dave Osmer, Boeing.

APPENDIX L

SOURCE DATA AND DERIVATION OF CAPITAL COSTS

LIST OF TABLES

TABLE L-1. REVENUE VEHICLES

COMPONENT: REVENUE VEHICLES	COSTS	SOURCE	REMARKS
RAW DATA	10,890,000	TSC Report[5.1]	
ADJUSTMENTS	(2,000,000)	N.D. Lea[5.6]	Table L-14 (non-recurring)
TOTAL	8,890,000		
EQUIPMENT ENGINEERING	1,247,000	TSC Report, value adjusted for non-recurring (Table L-15) and allocated between passenger and service vehicles by cost (Table L-16)	
YEARS OF ESCALATION FROM N.D. LEA[5.6] 1972 -	0.5 x (8,890) x 1.60 = 7,112.		Escalation using WPI Machinery & Motive Products Index (Table L-18)
1973 -	0.4 x (8,890) x 1.56 - 5,547.		
1974 -	0.1 x (8,890) x 1.39 - 1,236.		
TOTAL 1978 DOLLARS	13,895		
NUMBER OF PASSENGER VEHICLES	51	(31 LEAD, 20 TRAIL) - Current (28 LEAD, 23 TRAIL) - Original	
UNIT COSTS 1978 DOLLARS	$272,450/vehicle		Vought Corp. estimated that lead vehicles cost 20% more than trail vehicles in original cost. In any new system only lead vehicles would be procured.
DESIGN VARIABLES AFFECTING UNIT COST			
CAPACITY	16 SEATED 24 STANDEES @ 0.225-m^2/STANDEE		
MAX. SPEED	7.5 METERS/SECOND		
MIN. HEADWAY	17 SECONDS		
POWER	45 KW		
MAX. GRADE	7.8%		

TABLE L-2. SERVICE VEHICLES

COMPONENT: SERVICE VEHICLES	COSTS	SOURCE	REMARKS
RAW DATA	215,000	TSC Report[5.1]	
ADJUSTMENTS	______		
TOTAL	215,000		
EQUIPMENT ENGINEERING	26,000	TSC Report adjusted by Tables L-15 and L-16	
YEARS OF ESCALATION FROM N.D. LEA[5.6]	1973 - 0.625 x (215) x 1.56 = 209.6 1974 - 0.375 x (215) x 1.39 = 112.1		Escalation using WPI Mach/ Motive Index (Table L-18)
TOTAL 1978 DOLLARS	321.7		
NUMBER OF SERVICE VEHICLES	13		
UNIT COST 1978 DOLLARS	$24,746/SERVICE VEHICLE		
DESIGN VARIABLES AFFECTING UNIT COST PAX VEHICLE WEIGHT			

TABLE L-3. GUIDEWAY SITE MODIFICATIONS

COMPONENT: GUIDEWAY SITE MOD GRADE AND ELEV	COSTS	SOURCE REMARKS
RAW DATA	800,000	N.D. Lea[5.6], based on costs from T.K. Dyer[5.7] grading double track for light rail in suburban area, estimate 62,500/km for 12.8 km of single lane at grade
ADJUSTMENTS	481,000	TSC adjusted additional cost for remaining 7.7 km of guideway (Table L-14)
TOTAL	1,281,000	
CONSTRUCTION ENGINEERING	N/A	

YEARS OF ESCALATION FROM N.D. LEA (5.6)	1972 -0.85 x (1,281) x 1.57 - 1,709.5 1973 -0.15 x (1,281) x 1.46 - 280.5	Escalation using ENR Construction (Table L-18)
TOTAL 1978 DOLLARS	1,990.0	
KM OF GRADE/AT GRADE GUIDEWAY	20.5 km Single-Lane Suburban At-Grade and Elevated	
UNIT COST 1978 DOLLARS	97,073/km	
DESIGN VARIABLES AFFECTING UNIT COST		
SITE LOCATION	SUBURBAN	
TRACK	SINGLE-LANE	

TABLE L-4. GUIDEWAY STRUCTURE AT-GRADE

COMPONENT: GUIDEWAY AT-GRADE	COSTS	SOURCE	REMARKS
RAW DATA	4,307,000	TSC REPORT (5.1)	
ADJUSTMENT	(385,000)	TSC reduction of 3.6 km of grading included in TSC5.1 cost (included in Table L-3) (Table L-14) and non passenger guideway Table L-17)	
TOTAL	3,922,000		
CONSTRUCTION ENGINEERING	271,000	TSC report value adjusted for non-recurring (Table L-15) and allocated at-grade and elevated by cost (Table L-16)	
YEAR OF ESCALATION 1972 FROM N.D. Lea (5.6)1973	- 0.85 x (3,922) x 1.57 = - 0.15 x (3,922) x 1.46 =	5,233.9 858.9	Escalation from ENR Construction (Table L-17)
TOTAL 1978 DOLLARS		6,092,800	
KM OF AT-GRADE GUIDEWAY	16.4 km		
UNIT COST 1978 DOLLARS	371,512/KM		
DESIGN VARIABLES LOADING WIDTH BEAM DEPTH MAX VEH SPEED SUPERELEVATION CURVE TYPES	 1,473 KG/Lin Meters 2.75 meters .9 7.5 m/sec 8% @ 45m radus curves		

TABLE L-5. GUIDEWAY STRUCTURE ELEVATED, SINGLE-LANE, SUBURBAN

COMPONENT: GUIDEWAY ELEVATED	COSTS	SOURCE REMARKS
RAW DATA	3,818,000	TSC REPORT (5.1)
ADJUSTMENT	(396,000)	TSC reduction of 4.1 km of Grading included in orig. assessment report (Table L-3) and non-passenger post per Table L-17.
TOTAL	3,422,000	
CONSTRUCTION ENGINEERING	237,000	TSC [5.1] report value adjusted for non-recurring (Table L-15) and allocated between at-grade, elevated by cost (Table L-16)
YEAR OF ESCALATION FROM N.D. Lea[5.6]	0.85 x (3,422) x 1.57 = 4,566.7 0.15 x (3,422) x 1.46 = 749.4	Escalation using ENR construction index (Table L-18)
TOTAL 1978 DOLLARS	5,316,100	
KM OF ELEVATED	4.1	
UNIT COST 1978 DOLLARS	1,296,609/KM	
DESIGN VARIABLES		
LOADING	1,473 KG/Lin M	
WIDTH	2.75 m	
BEAM DEPTH	0.9 m	
MAX VEH SPEED	7.5 m/sec	
SUPERELEVATION	8% @ 45m radius curves	
CURVE TYPES		

TABLE L-6. GUIDEWAY AND GUIDANCE

COMPONENT: SWITCHES		COSTS	SOURCE / REMARKS
RAW DATA	Merge Diverge	493,000 442,000	TSC Report[5.1] TSC Report[5.1]
ADJUSTMENT		————	
TOTAL	Merge Diverge	493,000 442,000	
EQUIPMENT ENGINEERING	Merge Diverge	49,000 40,000	TSC Report[5.1] value adjusted for non-recurring (Table L-15) and allocated between merge, diverge by number of switches
YEAR OF ESCALATION FROM N.D. LEA[5.6]	1972 - 0.85 x (*) x 1.60 1973 - 0.15 x ( ) x 1.56		Escalation using WPI Mach/Motive (Table L-18)
TOTAL 1978 DOLLARS	Merge Diverge	785,840 704,550	
NUMBER OF UNITS	Merge Diverge	38 33	
UNIT COST 1978 DOLLARS	Merge Diverge	20,680/ea 21,350/ea	
DESIGN VARIABLES SWITCH SPEED			

*Each item in TOTAL treated by escalation equations.

TABLE L-7. STATIONS, BUILDING, AND STRUCTURE

COMPONENT: STATIONS STRUCTURES		COSTS	SOURCE / REMARKS
RAW DATA	4 Station 1 Hotel	998,000	N.D. Lea[5.6] cost for 4 Remote Stations + Hotel Station with total area = 1050 m^2. Unit Cost = $950/$m^2$ in 1973 dollars
	9 PAX @ 180m^2 9 EMPLOYEE @ 90m^2	1,539,000 769,500	N.D. Lea Passenger Station Measurements[5.6] N.D. Lea Employee Station Measurements[5.6]
ADJUSTMENTS		-	
TOTAL		3,306,500	

YEAR OF ESCALATION FROM N.D. LEA (5.6)	1972 - 0.9 x (3,306) x 1.57 - 1973 - 0.1 x (3,306) x 1.46 -	4,672.1 482.7	Escalation using ENR Construction Index (Table L-18)
TOTAL 1978 DOLLARS		5,154,800	
NUMBER OF m^2	3,480		
UNIT COST 1978 DOLLARS	1,481/m^2		
DESIGN VARIABLES AFFECTING UNIT COST			
SIZE OF BUILDING - VOLUME/AREA RATIO			
ESCALATORS, ELEVATION		NO	
A/C, HEATING		YES	

TABLE L-8. STATION EQUIPMENT AND FARE COLLECTION

COMPONENT: STATION EQUIPMENT: FARE COLLECTION		COSTS	SOURCE / REMARKS
RAW DATA	Doors	316,000	TSC Report[5.1]
	Graphics	169,000	TSC Report[5.1]
	Fare Collection	103,000	TSC Report[5.1]
ADJUSTMENTS		0	
TOTAL	Doors	316,000	
	Graphics	169,000	
	Fare Collection	103,000	
EQUIPMENT ENGINEERING	Doors	53,000	TSC Report value allocated on a cost basis (Table L-16)
	Graphics	28,000	
	Fare Collection	17,000	
YEAR OF ESCALATION FROM N.D. LEA[5.6]	1972 - 0.9 x (*) x 1.60		Escalation using WPI Mach/Motive Products Index (Table L-18)
	1973 - 0.1 x ( ) x 1.56		
TOTAL 1978 DOLLARS	DOORS	504,340	
	Graphics	269,720	
	Fare C.	164,390	
NUMBER OF EACH	Doors	28	
	Graphics	14	
	Fare C.	46	
UNIT COST 1978 DOLLARS			
	Doors	18,012/ea	
	Graphics	19,265/ea	
	Fare C.	3,573/ea	

*Each item in TOTAL treated by escalation equations.

TABLE L-9. MAINTENANCE FACILITIES

CATEGORY	COSTS	SOURCE	REMARKS
RAW DATA	436,000	Vought Corporation to N.D. LEA[5.6]	
ADJUSTMENTS	N/A		
TOTAL	436,000		
YEARS OF ESCALATION FROM N.D. LEA[5.6]	1973 - (436,000) x 1.46 =	636,560	Escalation using ENR construction Index (Table L-18)
TOTAL 1978 DOLLARS		636,560	
NUMBER OF m^2	1,116	FROM D-FW AIRPORT, D. ELLIOT	
UNIT COST 1978 DOLLARS	$570/m^2		

TABLE L-10. MAINTENANCE EQUIPMENT AND SPARES

COMPONENT:	MAINTENANCE EQUIPMENT SPARES	COSTS	SOURCES	REMARKS
RAW DATA	Equipment	1,212,000	TSC Report[5.1]	
	Spares	1,067,000	TSC Report[5.1]	
ADJUSTMENTS		-		
TOTAL	Equipment	1,212,000		
	Spares	1,067,000		
EQUIPMENT ENGINEERING	Equipment	224,000	TSC Report[5.1] adjusted for non-recurring (Table L-15)	
	Spares	0		
YEAR OF ESCALATION FROM N.D. LEA[5.6]	1973 - 0.625 (*) x 1.56			Escalation using WPI Mach/Motive Products (Table L-18)
	1974 - 0.375 ( ) x 1.39			
TOTAL 1978 DOLLARS	Equipment	1,813,400		
	Spares	1,596,000		
TOTAL HARDWARE COSTS		33,193,000		
(Vehicles, Control, Station Equipment) (Switches, Power)				
	EQUIPMENT % HARDWARE		5.46%	
	SPARES % HARDWARE		4.81%	
DESIGN VARIABLES 5 HOISTS 10 BAYS				

*Each item in TOTAL treated by escalation equations.

CATEGORY		COSTS	SOURCES	REMARKS
RAW DATA	Power Rail	3,027,000	TSC reported value[5.1]	
	Power Dist. & Emergency	931,000	TSC reported value[5.1]	
ADJUSTMENTS		-		
TOTAL	Power Rail	3,027,000		
	Power Dist.	931,000		
EQUIPMENT ENGINEERING	Power Rail Power Dist.	148,000 45,000	TSC reported value adjusted for non-recurring (Table L-15) and allocated by cost (Table L-16)	
YEAR OF ESCALATION FROM N.D. LEA[5.6]	1973 - Rail 1973 - Dist.	3,027,000 x 1.46 = 4,419,420 931,000 x 1.46 = 1,359,260		Escalation using ENR Construction Index (Table L-18)
1978 DOLLARS	Rail Dist.	4,419,420 1,359,260		
KM OF POWER RAIL		20.5 km		
NUMBER OF SUBSTATIONS		15		
UNIT COST 1978 DOLLARS				
	Rail	215,581/KM		
	Substation	90,617/SUBSTATION		

TABLE L-12. VEHICLE CONTROL AND COMMUNICATION

CATEGORY		COSTS	SOURCES / REMARKS
RAW COSTS	Wayside/Guideway	4,334,000	TSC Report[5.1]
	Central	1,346,000	
	Voice/Video	410,000	
ADJUSTMENTS	Wayside	(786,000)	N.D.L. Non-Recurring and Non-Passenger Apportioned by cost (Table L-16 and L-17)
	Central	(245,000)	
	Voice	(67,000)	
TOTAL	Wayside	3,546,000	
	Central	1,101,000	
	Voice	343,000	
EQUIPMENT ENGINEERING	Wayside	708,000	TSC Reported[5.1] as adjusted by Table L-15 and allocated by Table L-16 by cost
	Central	220,000	
	Voice	66,000	
YEARS OF ESCALATION FROM N.D. LEA (5.6)	1973 - 0.5 (*) x 1.56 1974 - 0.5 ( ) x 1.39		Escalation using WPI Machinery and Motive Product Index (Table L-18)
1978 DOLLARS	Wayside	5,230,000	
	Central	1,624,000	
	Voice	506,000	
NUMBER OF UNITS	Wayside	708 Blocks	20.5 KM
	Central	-	
	Voice/Vid	14 PASSENGER STATIONS	
UNIT COST 1978	Wayside	7,387 Block	255,122/KM
	Central	1,624,000	
	Voice/Vid	36,143/Station	

*Each item in TOTAL treated by escalation equations.

TABLE L-13. PROJECT MANAGEMENT

CATEGORY		COSTS	SOURCE	REMARKS
RAW COST	Project Management	1,930,000	TSC Report[5.1]	
	System Engineering	2,568,000	TSC Report[5.1]	
	Construction Eng.	1,087,000	TSC Report[5.1]	Called Other Eng.[5.1]
	System Testing	980,000	TSC Report[5.1]	
ADJUSTMENTS	System Engineering	2,871,000		Tables L-1, L-2, L-6, L-8, L-10, L-11, L-12
	Construction Eng.	508,000		Tables L-4, L-5
TOTAL	Project Management	1,930,000		
	System Engineering	5,439,000		
	Construction Eng.	1,595,000		
	System Testing	980,000		
YEARS OF ESCALATION FROM N.D. LEA[5.6]	1971 - 0.2 x (*) x 1.61			
	1972 - 0.3 x ( ) x 1.56			
	1973 - 0.3 x ( ) x 1.47			
	1974 - 0.2 x ( ) x 1.33			
TOTAL 1978 DOLLARS				
	Project Management	= 2,889,200	% Total = (2889/64381) = 4.5%	
	System Engineering	= 8,142,200	% Hardware = (8142/33193) =24.5%	
	Construction Eng.	= 2,387,000	% Facilities= (2387/19190) =12.4%	
	System Testing	= 1,467,100	PER LANE KM (20.5) = 71,565/KM	

*Each item in TOTAL treated by escalation equations.

TABLE L-14. ADJUSTMENTS TO TSC REPORT TABLE 5-1. COSTS

X-REF TABLE	CATEGORY		REASON
L-1	REVENUE VEHICLES	(2,000,000)	Non Recurring N.D. Lea (5.6)
L-2	SERVICE VEHICLE	0	
L-3	GUIDEWAY SITE MOD	800,000	N.D. Lea Figure (5.6) - for 8 miles of Guideway not included in TSC reported costs
L-3	GUIDEWAY SITE MOD	481,000	Added to site mod for remaining guideway, subtracted from at grade/elev. covers remaining 4.81 miles
L-4	GUIDEWAY AT GRADE	(225,000)	Subtracted for site mod.
L-5	GUIDEWAY ELEVATED	(256,000)	Subtracted for site mod.
L-7	STATIONS, STRUCTURES	3,306,500	N.D. Lea figures (5.6) based on D-FW Remote/ Hotel purchase
L-9	MAINTENANCE FACILITIES	436,000	Cost to build facility N.D. Lea (5.6)
L-11	VEHICLE CONTROL	(1,000,000)	Non-Recurring N.D. Lea (5.6)

Source: See Section 5, Ref. 5.1.

CATEGORY	INITIAL[5.1]	REDUCTION[5.6]	NEW
VEHICLES (LESS UTILITY)	2,288,000	1,015,000	1,273,000
GUIDEWAY	883,000	375,000	508,000
SWITCHES	155,000	66,000	89,000
STATIONS	98,000	0	98,000
YARDS AND SHOPS	390,000	166,000	224,000
POWER GENERATION	336,000	143,000	193,000
VEHICLE CONTROL	1,729,000	735,000	994,000
TOTAL	5,879,000	2,500,000	3,379,000

Note: N.D. Lea estimated that 2,500,000 of reported design costs were non-recurring[5.6]. TSC has reduced the originally reported design costs by an amount proportional to the initially reported cost.

TABLE L-16. SUBCATEGORY DESIGN ALLOCATIONS

X-REF TABLES	PROCEDURE TO ALLOCATE DESIGN COSTS
L-1 L-2	VEHICLES % DESIGN TO PAX = COST PAX 10,890 + COST SERV 215 = 11,105 % PAX = 10,890/11,105 = .975 % SERV = 215/1,115 = .025 TOTAL DESIGN (Table 4-2) = 1,273K PAX = 1,247K,SERV = 26K
L-4 L-5	GUIDEWAY % DESIGN TO AT-GRADE = 4,082/7,644 = .534 x (508) =271K ELEVATED = 3,562/7,644 = .466 x (508) = 237K
L-6	SWITCHES % DESIGN 38 MERGE, 33 DIVERGE % DESIGN = 38/71 MERGE = .53 x (89) = 49 33/71 DIVERGE = .47 x (89) = 40
L-8	STATION EQUIPMENT % DESIGN DOORS = DOORS/SUM OF DOORS + GRAPHICS + FARE COLLECTION DOORS = 316/588 = .537 x 98 = 53K; GRAPHICS = 169/588 = .287 x 98 = 28K; FARE COLLECTION = 103/588 = .176 x 98 = 17K
L-11	POWER DISTRIBUTION % DESIGN 3,027/3,958 = .764 x 193 = 148 - RAIL 931/3,958 = .236 x 193 = 45 - DIST.
L-12	VEHICLE CONTROL % DESIGN WAYSIDE 4,334/6,090 = .712 x 994 = 708K CENTRAL 1,346/6,090 = .221 x 994 = 220K VOICE 410/6,090 = .067 x 994 = 66K

TABLE L-17. NON-PASSENGER EQUIPMENT ADJUSTMENTS

CATEGORY	COSTS	SOURCE
UTILITY VEHICLES	2,543,000	TSC Report[5.1]
CARGO/UTILITY EQUIPMENT AND CONTAINERS	3,585,000	TSC Report[5.1]
EQUIPMENT ENGINEERING NON-PASSENGER	1,500,000	N.D. LEA[5.6]
SUBSYSTEM ADJUSTMENTS		
GUIDEWAY (BY COST PER TABLE L-16)	300,000	N.D. LEA[5.6]
AT GRADE 300 x .534 = 160,000		
ELEVATED 300 x .466 = 140,000		
CONTROL (BY COST, EXCLUDING VIDEO, PER TABLE L-16)	100,000	N.D. LEA[5.6]
WAYSIDE 0.76 x 100 = 74,000		
CENTRAL 0.24 x 100 = 26,000		

TABLE L-18 COST INDICES FOR ESCALATING AGT CAPITAL COSTS*

	Equipment (Wholesale Price Index for Machinery and Motive Products) (1)		Facilities (Engineering News Record Construction Cost Index for 20 cities) (2)		Engineering & Project Management (Consumer Price Index for Urban Wage and Clerical Workers, U.S. City Average (1)	
YEAR	INDEX	Conversion Factor to 1978 Prices	Index	Conversion Factor to 1978 Prices	Index	Conversion Factor to 1978 Prices
1965	--	--	91	2.84	--	--
1966	--	--	95	2.72	97.2	2.01
1967	100.0	1.90	100	2.58	100.0	1.95
1968	103.0	1.84	108	2.39	104.2	1.88
1969	106.0	1.79	119	2.17	109.8	1.78
1970	110.6	1.71	130	1.98	116.3	1.68
1971	115.3	1.64	148	1.74	121.3	1.61
1972	118.2	1.60	164	1.57	125.3	1.56
1973	121.2	1.56	177	1.46	133.1	1.47
1974	136.3	1.39	188	1.37	147.1	1.33
1975	156.2	1.21	206	1.25	161.2	1.21
1976	165.8	1.14	223	1.16	170.3	1.15
1977	176.6	1.07	240	1.08	181.5	1.08
1978	189.5*	1.00	258	1.00	195.4	1.00

(1) Source: Bureau of Labor Statistics-U.S. Department of Labor

(2) McGraw Hill, New York

*See Attached discussion note.

NOTE TO TABLE L-18

RATIONALE AND DERIVATION OF ESCALATION FACTORS

L.1 INTRODUCTION

In comparing the costs of transit systems which have been constructed in different years it is necessary to normalize costs to a specific year. To do this requires use of an escalation factor which converts prior year expenditures to a future year price. The choice of this escalation should be based on use of a nationally tabulated index; use of an index which is derived from materials similar to those used in the equipment to which the index will be applied; and use of an index which has followed the historical price pattern of the commodity in question.

Once the index has been selected, to escalate prices from a prior year to a current year, the ratio of the prior year and current year indices can be used to normalize the cost. To determine prices in a future year, the annual percentage increase in the selected index over an appropriate time period would be used. The time period chosen for Table 5-3 was 1973-1978. This period covers the dislocations in the economy during the 1973-74 period and if projected an equivalent number of years into the future would extend to the first DPM deployments.

The indices chosen for the AIRTRANS analysis are similar to those used in other AGT assessment reports. Three indices were used:

a. <u>The Wholesale Price Index (WPI) for Machinery and Motive Products</u> - This index is a composite based on the following commodities: motor vehicles (32.34%), motor vehicle parts (4.2%), aircraft (3.78%), railroad equipment (1.68%), electrical machinery and equipment (24.36%), general purpose equipment (8.12%), tools (8.12%), heavy equipment (4.64%), and miscellaneous equipment (12.76%).

The Wholesale Price Index for Machinery and Motive Products is shown in Table L-18 together with conversion factors to 1978 prices. This index is used to escalate the price of the following AIRTRANS equipment items: revenue vehicles, service vehicles, switches, station equipment, maintenance equipment, power generation equipment and vehicle control equipment.

b. The Engineering News Record (ENR) Construction Cost Index - This index is a composite based on the following commodities: base price of structural steel shapes (38%), consumers' net price of cement exclusive of bag (7%), lumber (17%), and common labor rate (38%).

The Engineering News Record Construction Cost Index is shown in Table L-18 together with conversion factors to 1978 prices. This index is used to escalate the price of the following AIRTRANS construction items: guideways, station structures and maintenance structures.

c. The Consumer Price Index for Urban Wage Earners and Clerical Workers, U.S. City Average - This index is used to escalate the price of all professional services such as system engineering, construction engineering, project management and administration and systems testing. This index is shown in Table L-18 together with conversion factors to 1978 prices.

The values of these indices between 1970-1978 were used to determine the annual increase which might be expected for the period 1978-1986. The values were computed as follows:

$$1978 \text{ price index} = 1970 \text{ price index } (1.x)^5$$

where χ is the annual percent of change over the last five years.

$$\chi = 10^{\text{LOG}(1978 \text{ price index}/1973 \text{ price index})/5}$$

The following annual percentage rates were derived for the three indices using the 5-year period discribed above:

Index	Annual Increase (%)
WPI Machinery and Motive Products	9.3
ENR Construction Index	7.8
Consumer Price Index	8.0

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