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ASSESSMENT OF THE PHASE I MORGANTOWN PEOPLE MOVER SYSTEM

N.D. LEA & ASSOCIATES, INC.
Washington, D.C. U.S.A.

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16. Abstract

This assessment describes the installation and operation of Phase I of the Morgantown People Mover System at West Virginia University in Morgantown, West Virginia. A detailed description of the technical subsystems is included as well as a review of performance, reliability, maintainability, and cost. A system implementation history is also provided. Where important, the review of technical subsystems includes applicability, modifications and/or improvements for application in an urban environment.

Information and data presented were collected through surveys of the literature, site visits, a visit to the manufacturer, interviews with site and manufacturer's personnel, site measurements, reviews of operating and maintenance logs, and compilations generated by the manufacturer, the operator, and the U.S. Department of Transportation.

A draft of this report has been reviewed by the operator, the manufacturer, and the Urban Mass Transportation Administration. Their comments have been incorporated where it has been possible to do so without compromising the objectivity of the assessment.

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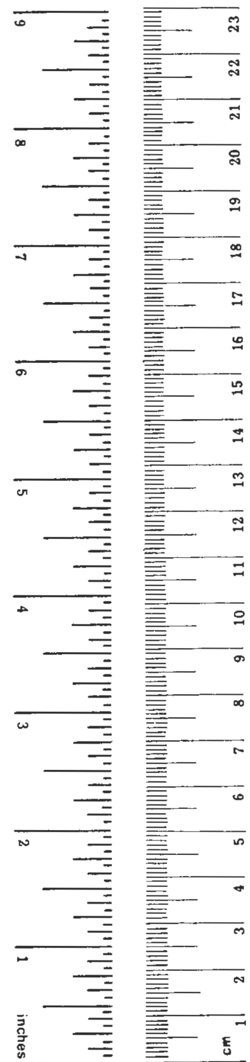
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

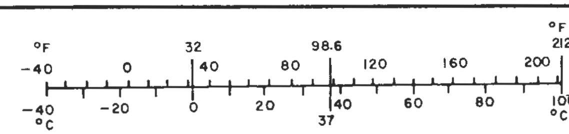
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	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

*1 in ≡ 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



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	
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	
l	liters	2.1	pints	
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



PREFACE

This report presents results of an initial assessment of the Morgantown People Mover System. The assessment covers the period from the start of the prototype system through operation of the system in public service through July 3, 1978, just before it was shut down for Phase II expansion. Only after the system is completed under Phase II, and a sufficient period of time has been allowed for maturation, can a final assessment be made.

The assessment was funded by the U. S. Department of Transportation, Urban Mass Transportation Administration (UMTA) through its Office of Technology Development and Deployment. The project was managed by the Office of Socio-Economic Research and Special Projects as part of its AGT Assessments Program. The study was carried out by N. D. Lea & Associates, Inc. in collaboration with SNV Studiengesellschaft Nahverkehr mbH of Hamburg, Germany. SNV's participation was funded by the Bundesministerium für Forschung and Technologie (Federal Ministry of Research and Technology), Federal Republic of Germany under a bilateral agreement with the U. S. Department of Transportation.

The cooperation received from the UMTA Office of AGT Applications, the Boeing Aerospace Company, West Virginia University, the West Virginia Board of Regents, and the Transportation Systems Center has been commendable throughout the study. This report has been reviewed by them and their comments have been incorporated where it has been possible to do so without compromising the objectivity of the assessment.

The study Project Manager wishes to acknowledge the special efforts of the assessment team members. Mr. F. A. F. Cooke carried out the assessments of costs, guideways and stations. Mr. H. W. Merritt researched the system development process, contributed to the assessment of system effectiveness and edited the report. Mr. T. J. McGean was responsible for assessments of the vehicle, the collision avoidance system, brakes, steering and switching. Messers. Frank Smith and Herbert Theumer were responsible for the analysis of system reliability and maintainability, propulsion and power. Dr. John Fruin carried out an independent human factors evaluation. Century Research Corporation performed the public attitude survey. Mr. Wolfgang Bamberg assisted the team on many of the aspects of the assessment making specific contributions to the analysis of reliability, noise and ride comfort data. Dr. William Garrard and Mr. Hans Hosenthien contributed to the assessments of command and control. Messers. Hans Ludwig and Karl Scharpf of SNV participated in the assessments of system operations, maintenance, safety and security and ride quality.

Mr. Howard D. Evoy, Program Manager, Office of Socio-Economic Research and Special Projects is especially acknowledged for his guidance and support throughout the assessment.

N. D. LEA & ASSOCIATES, INC.

Charles P. Elms
Project Manager

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont.)

TABLE OF CONTENTS (Cont.)

TABLE OF CONTENTS (Cont.)

LIST OF TABLES

LIST OF TABLES (Cont.)

LIST OF TABLES (Cont.)

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Cont.)

LIST OF ILLUSTRATIONS (Cont.)

LIST OF ILLUSTRATIONS (Cont.)

LIST OF ILLUSTRATIONS (Cont.)

LIST OF ILLUSTRATIONS (Cont.)

1.0 INTRODUCTION

This assessment of the Morgantown People Mover System has been accomplished as part of the Urban Mass Transportation Administration's Socio-Economic Research Program. This program was established in response to recommendations of the U.S. Senate. The purpose is to relate the characteristics of Automated Guideway Transit (AGT) technology to the needs for improved forms of urban transportation and to determine the social, economic, environmental and performance factors which affect the usefulness of AGT systems.

The objectives of this assessment of the Morgantown People Mover (MPM) system are threefold:

- To provide information on the system installation, including engineering and operating data; descriptive information on system performance, economics and public response; experience with system design, development and implementation.
- To evaluate the information in order to assess system and subsystem technical performance, system economics and overall system performance in meeting transportation requirements.
- To report results of the assessment in ways useful for guiding R & D on key problem areas, for planning AGT installations and for making product improvements in AGT systems.

The assessment was accomplished in four steps. Organization of the project team involved the assignment of responsibilities for tasks, reporting and coordination. Available data from extensive documentation in UMTA, with the supplier and at Morgantown was assembled and analyzed. Field visits were made to interview key project personnel and to make on-site measurements of certain performance characteristics. Reports documented the evaluation of the system and assessment findings.

This assessment is expected to be useful to local planners and decision makers in their consideration of AGT installations. It will also be useful in suggesting areas in which government policies and procedures may need revision to foster the adoption of AGT systems.

Only the operating experience with the Phase I system has been assessed. This experience covers almost three operational years, from September 15, 1975, through June 30, 1978. A complete and final assessment cannot be made at this time. System operations have not yet reached a state of constant performance. As with any new system development, including new conventional rail transit systems, a shakedown period is required during which both personnel and equipment undergo a series of adjustments. This period was nearly completed for the Phase I system at the time it was shut down for Phase II expansion. Another such period for adjustment will be required at the end of Phase II, before a final assessment can be completed. Nevertheless, sufficient experience and data have been collected from the past three years of operations to make a meaningful assessment possible. The results derived from this study should provide an initial insight into the planning and performance of an AGT system which is implemented in stages.

2.0 EXECUTIVE SUMMARY

2.1 PROJECT HISTORY

2.1.1 The Morgantown Transportation Problem

Morgantown, West Virginia, is a small coal-mining and manufacturing town nestled in the valley of the Monongahela River. It has also been the home of West Virginia University (WVU) since 1867. The University expanded from 10,000 students in 1964 to over 15,000 in 1970 with an additional staff of 6,200. To meet this expansion, facilities were established on property already owned by the University, with the result that three campuses were formed: the Downtown Campus, the Evansdale Campus and the Medical Center.

Transportation between these locations became a difficult problem. The hilly terrain discourages walking or bicycling. As many as 10,000 students and staff used automobiles between campuses, making congestion on the only two street routes almost intolerable. The University employed 15 to 18 buses to make as many as 400 trips a day between campuses. The slow service over steep, two-lane, congested roads, coupled with five distinct peak periods during the times classes change, made bus service inadequate. A study of the traffic situation by the Traffic Engineering Division of the State Road Commission of West Virginia in September 1969 concluded: "The best solution for the pedestrian-vehicle conflicts in the Main Campus Area is not readily discernable."

2.1.2 The AGT Role

A study of new systems of urban transportation in 1967-1968, undertaken by the U.S. Department of Housing and Urban Development at the direction of Congress, provided the impetus for a possible solution to Morgantown's transportation problems. Early statements by Secretary of Transportation John A. Volpe on the role of new technologies in meeting transportation needs encouraged WVU officials to apply for a demonstration grant.

UMTA approved funds on June 20, 1969, for a feasibility study of a new transit technology for WVU and the Morgantown area. The study found that an AGT system would be attractive and economically competitive with other modes, and that the University offered an excellent potential for a demonstration site. A grant application was submitted by the West Virginia Board of Regents on behalf of the University on August 15, 1970 for a system installation expected to cost about $18.0 million.

2.1.3 System Development

UMTA approved the concept of a system demonstration at Morgantown, but decided that the national significance of the project required UMTA management. It was also determined that procurement of the system would be through competitive contracts. In deciding to proceed with the project, an operational demonstration of the system was set for October 1972.

In September 1970 the Jet Propulsion Laboratory (JPL) of the California Institute of Technology was retained as system manager. JPL in turn retained Frederic R. Harris, Inc. to provide A & E services. Competitive contracts were awarded in May 1971 to the Boeing Aerospace Company for vehicles and to the Bendix Aerospace Corporation for the control and communication system. Difficulties in negotiating a direct, follow-on contract with JPL led to the selection of Boeing as the system manager to replace JPL in August 1971.

During this period more refined project analyses resulted in better estimates of project costs. UMTA took several actions to reduce the scope of the project and to stage the installation in ways that would meet the demonstration objectives, while reducing the effects on limited research appropriations. This action resulted in accomplishing the project in the following phases:

Phase I, December 1970 - July 1978

The goal of this phase was to demonstrate the feasibility of a fully automatic, demand-responsive, advanced technology transit system in daily public service. Phase I was undertaken in three parts and was financed with UMTA RD & D funds and with capital grant funds for A & E services to design the Phase II extension.

Phase IA, December 1970 - September 1973

This phase encompassed construction of three stations, a maintenance facility, 2.1 miles of double-lane guideway, five vehicles and limited control system software. A dedication and public demonstration of the system was held on October 24, 1972. Phase IA system tests were completed on September 26, 1973, with the operation of four vehicles. Experience with this prototype system resulted in extensive changes to be made during the next phase.

Phase IB, September 1973 - September 1975

This phase provided 45 improved vehicles, completion of a guideway heating system, development of hardware and software for a fully operational automatic control and communication system; expanded the maintenance facility and made provisions for demonstration operation of the system in public revenue service. On August 29, 1975, the system completed a test demonstration by accumulating 60 hours of operation with 25 vehicles. Satisfactory test performance indicated contractual compliance. UMTA accepted the system on September 12, 1975, and operations in public service began the next month.

Phase I O&M, October 1975-July 1978

Acceptance of the MPM system by the University was conditional upon meeting mutually acceptable performance criteria during a one-year operating period. Capital funds issued during this period initiated engineering design to establish the cost and scope of extensions to be made in Phase II. Acceptance of the system by the University on September 30, 1976, signalled the start of Phase II with a $63.6-million capital grant from UMTA. Operations under Phase I O&M continued until the system was shut down on July 3, 1978, for Phase II integration.

Phase II, October 1975 - March 1980 (Planned)

Phase II, financed with UMTA capital assistance funds, calls for engineering design, construction, fabrication and the modifications necessary to complete a revenue system, as follows:

- Two additional stations (Towers Dormitory and Medical Center)
- Expansion of the Maintenance Facility
- Addition of a Mini-Maintenance Facility
- Completion of the Engineering station
- Extension of the guideway to 3.4 miles of double-lane track
- Addition of 28 vehicles and retrofit of 45 vehicles for a total fleet of 73 vehicles
- Modifications to existing facilities, vehicles and controls to improve winter operation, dependability and maintainability.

The objectives of Phase II are to complete the system in accordance with WVU's basic needs, to refine the system technology and to verify operation and maintenance costs. This expanded system began operations with the fall academic term in 1979.

2.1.4 Summary

The total reservations of UMTA RD & D funds for Phase I, including early substantive research and planning studies, amounted to $65.8 million. The following summarizes the distribution of these funds, in millions of dollars.

Boeing Aerospace Company	$ 60.2
West Virginia University	2.1
Transportation Systems Center	1.2
Jet Propulsion Laboratory	2.0
Others	0.3
Total RD & D Reservations	$ 65.8

In addition Phase I included $4.3 million in capital funds, bringing the total reservations for this phase to $70.1 million.

Phase II, including engineering, start-up operating costs, construction, fabrication, procurement and monitoring is currently budgeted at $63.6 million. The total expected Federal expenditures for the Morgantown People Mover System from its inception through Phase II, are currently established at $133.7 million.

2.2 SYSTEM DESCRIPTION

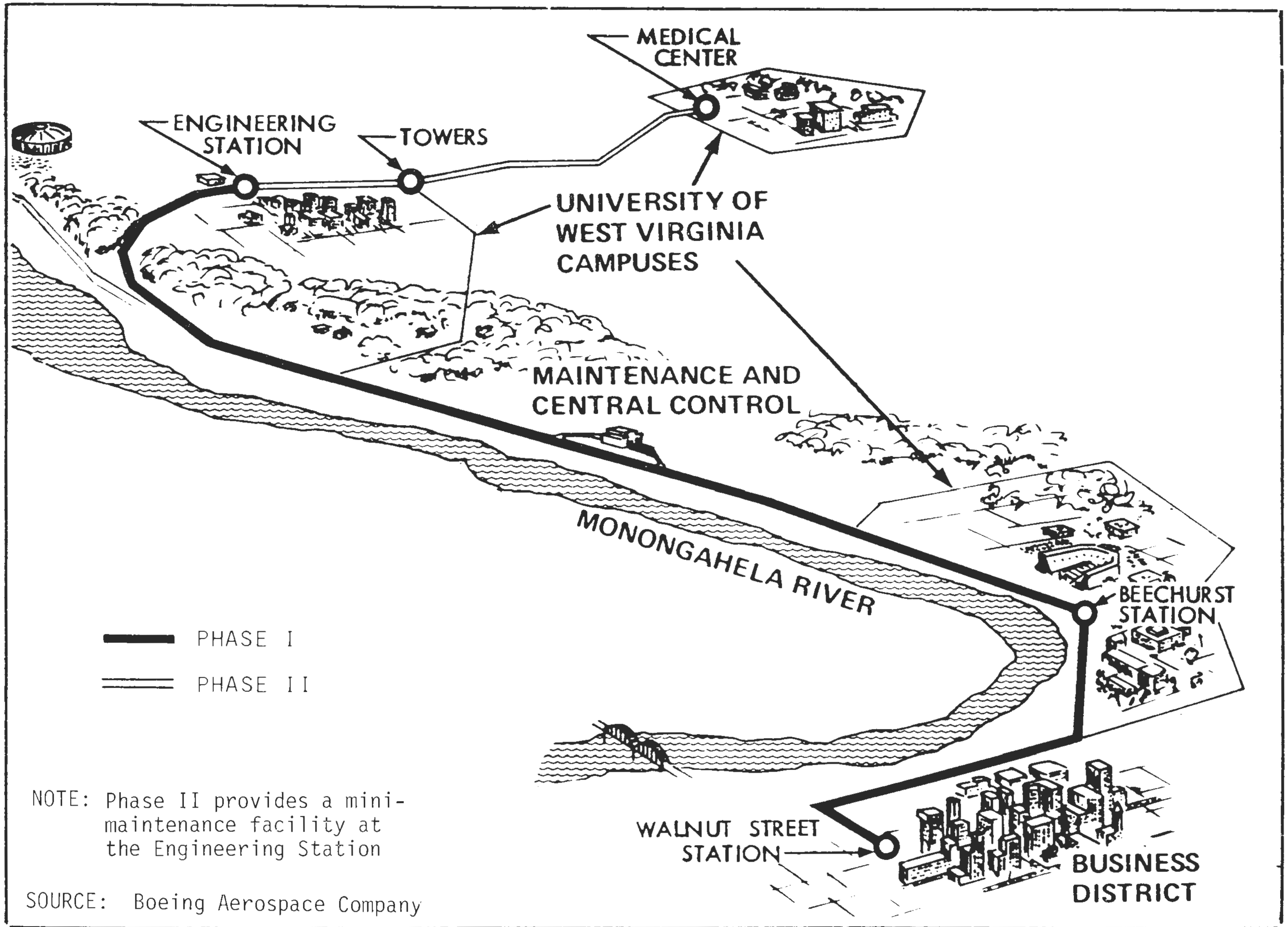
The Morgantown People Mover System (MPM) is the world's most sophisticated automated guideway transit system in regular passenger service. This section summarizes its essential features. More comprehensive technical information concerning system design and function are contained in following sections of the report.

2.2.1 System Layout and Operational Concept

The Morgantown System connects the Main (Downtown) Campus of West Virginia University with both the Morgantown central business district and the newer Evansdale Campus on the northern edge of the city. As shown in Figure 2.1, there were three stations In Phase I connected by a double-lane guideway system somewhat over two miles in length. The route from downtown Morgantown northward parallels the railroad tracks along the Monongahela River. The maintenance shop, vehicle test facility and the control center are located about halfway between the Beechurst station at the Main Campus and the Engineering station at the Evansdale Campus.

Also shown in Figure 2.1 is an extension to the system, construction of which has now been completed. This extension, built under Phase II of the project, added new stations at the Towers Dormitory complex and the Medical Center, together with a new car-wash and minor maintenance facility. The Engineering station has also been expanded and all three Phase I stations upgraded, including installation of elevators for the handicapped.

A total of 45 operational vehicles was delivered in Phase I. An active fleet of 29 vehicles, each capable of carrying 21 passengers, was maintained. Passenger demand during Phase I could be satisfied with 22 vehicles in service, leaving seven vehicles in reserve. Under Phase II, 28 new vehicles have been supplied. The 45 original vehicles have been retrofitted, bringing the total fleet to 73.



NOTE: Phase II provides a mini-maintenance facility at the Engineering Station

SOURCE: Boeing Aerospace Company

FIGURE 2.1: SYSTEM ROUTE

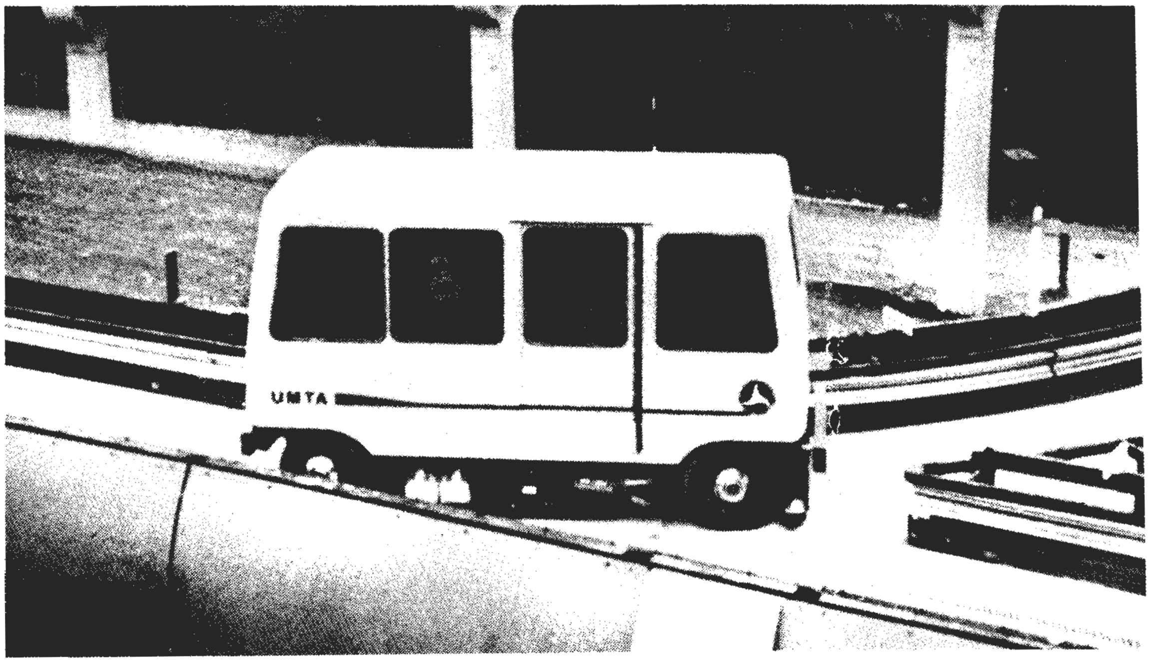
An essential feature of the Morgantown design is its ability to automatically operate driverless vehicles along the main-line guideway at 15-second intervals. During acceptance testing in August 1975, a total of 21 vehicles was launched consecutively from the Beechurst station toward Engineering at 15-second intervals. Due to the size limitation of the Phase I Engineering station, all vehicles could not complete the trip and some had to be stopped on the guideway. However, this test demonstrated the effectiveness of the control system in achieving the specified operational headways.

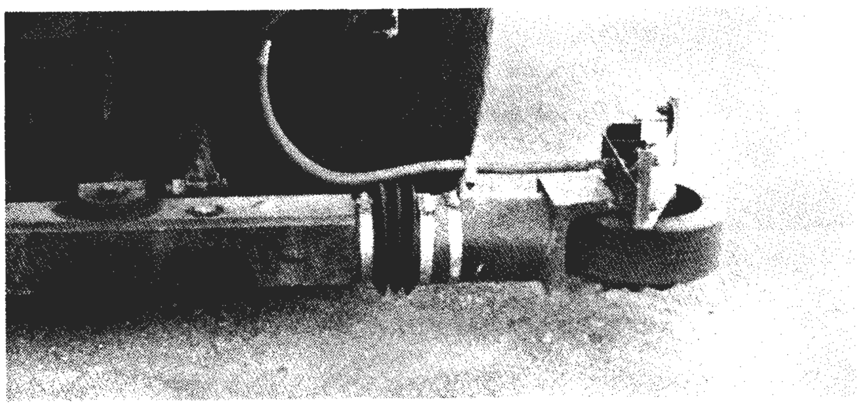
Unlike all other AGT systems in service in the U. S., MPM provides nonstop service from origin to destination on either a scheduled or on-demand mode. During Phase I, scheduled service was generally used during periods of heavy travel, with on-demand service available at other times.

2.2.2 Vehicles

The MPM vehicles are completely automated and travel from origin to destination under computer surveillance. They are relatively small, 15.5 feet long and 6.7 feet wide. Each has seats for eight passengers and space for 13 standees. They travel along the guideway system at speeds up to 30 miles per hour.

The vehicles (Figure 2.2) have doors on both sides. They draw electric power for propulsion, heating and air conditioning, lighting and other purposes from power rails along the edges of the guideway. Lateral guidance is accomplished through a sensing wheel which keeps in contact with a steel guiderail by controlling an automotive-type steering mechanism. Since tight turns must be negotiated in station areas, both front and rear wheels are steered. Steel guiderails are located on both sides of the guideway in those locations where the route branches. Vehicles are switched by a simple command from the control system, instructing the steering system to maintain sensing wheel contact with the guidance rail on the side of the track which corresponds to the direction the vehicle is to turn. The cars run on rubber tires which provide traction to negotiate grades up to 10 percent required by the rugged Morgantown terrain.





STEERING ARM

INTERIOR

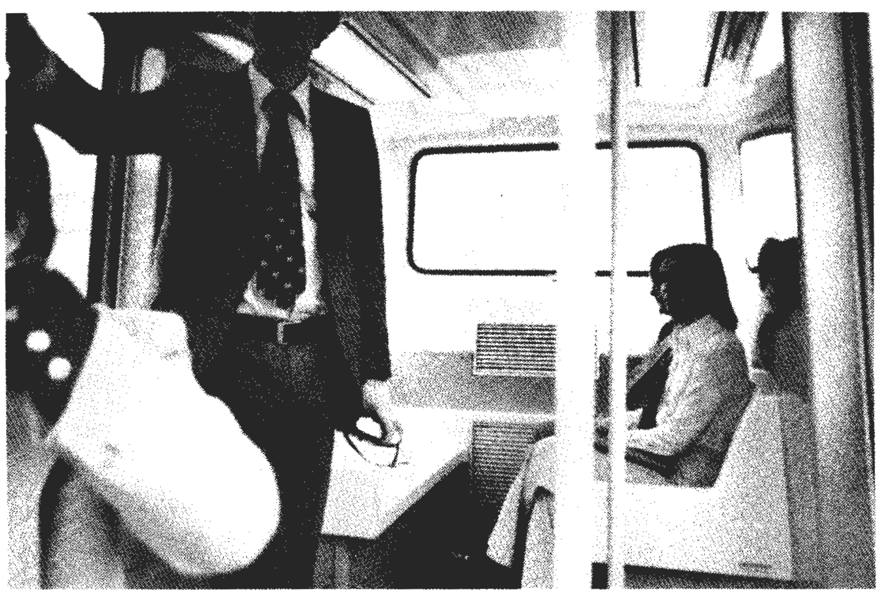


FIGURE 2.2 : VEHICLE

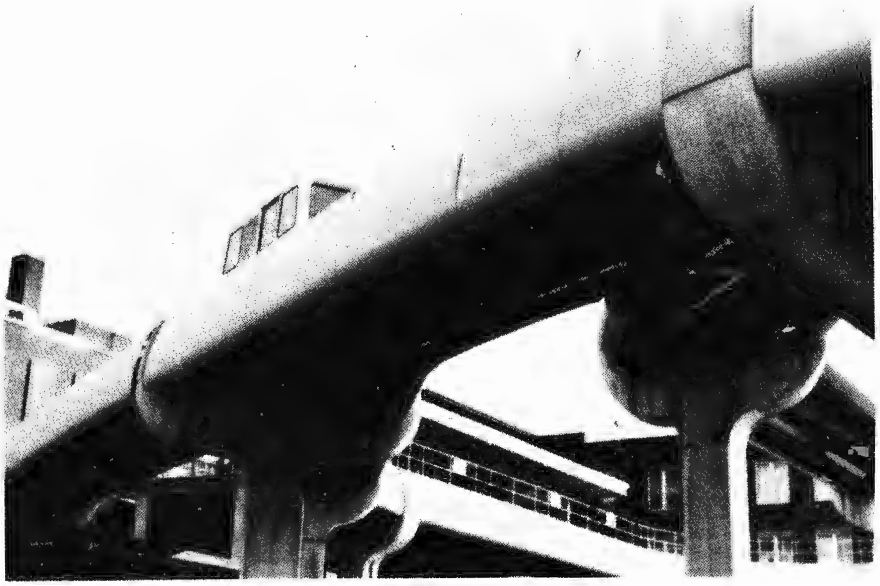
2.2.3 Guideways

The Phase I main-line guideway system was 2.1 miles in length. About two-thirds of it was elevated well above street level and the rest built at grade. Including station ramps and the vehicle testing and storage loops in the maintenance area, a total of 5.3 miles of single-lane guideway existed at Morgantown during Phase I.

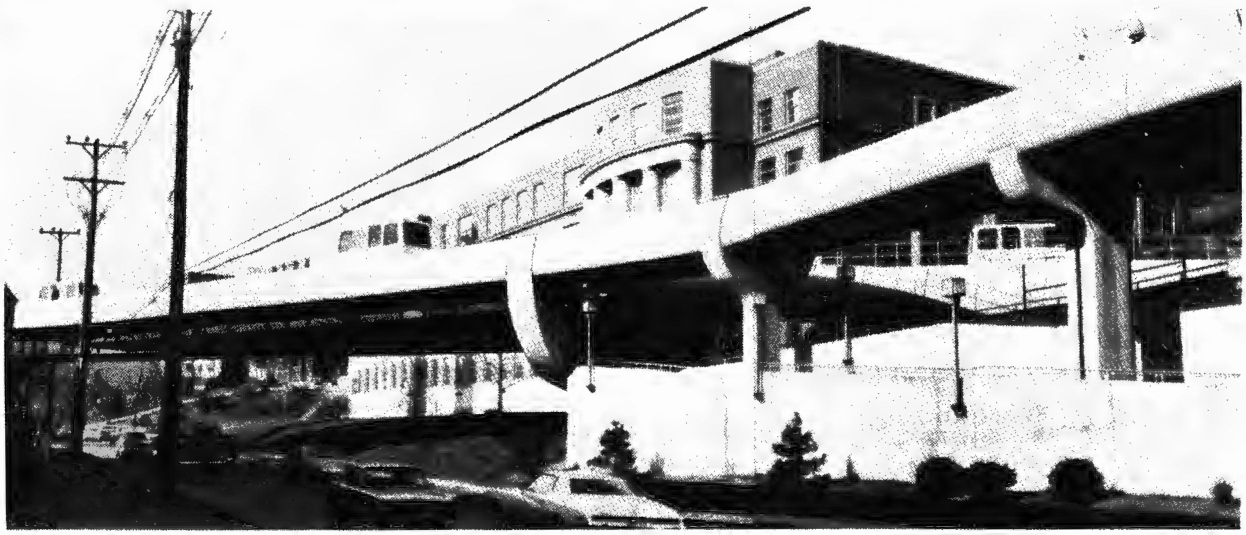
The general arrangement and type of construction used for the guideways is shown in Figure 2.3. The running surface is reinforced concrete. It is supported in elevated sections by a steel superstructure mounted on sturdy concrete piers. The at-grade guideways blend in well with the existing terrain and are relatively unobtrusive. This is not the case with the elevated structures, which tend to be rather massive. However, most elevated sections are located in an industrial area along a railroad right-of-way, so that the visual impact is not objectionable.

Operations during severe winter weather require that the guideway be heated by circulating a hot water and glycol solution through pipes imbedded in the concrete running surface. Natural gas fired boilers provide the heat required to keep the guideway free of ice and snow. The entire heating system is remotely operated from the control center and may be activated by the system supervisor whenever weather conditions so dictate.

The MPM system was severely tested during the second two winters of Phase I operations. The 1976-1977 season was recorded as a "100-Year" winter where the temperature fell to -15^{o}F. Figure 2.4 shows the kind of icing conditions which prevailed during this winter weather. Though there were operational problems, the system was only down on January 17, 1977, through mid-afternoon of January 18, 1977, due to severe weather. WVU subscribed to a special weather service in order to fire up the boilers four hours in advance of guideway heating requirements. In addition, the power distribution system was sprayed to prevent the accumulation of ice on power rails and collectors. Keeping the system operable was as much due to dedicated operating personnel who performed various maintenance functions at the height of storms, as it was to the existence of a guideway heating system. Seven



UNDERSIDE OF ELEVATED GUIDEWAY



AT-GRADE GUIDEWAY

FIGURE 2.3 : GUIDEWAYS

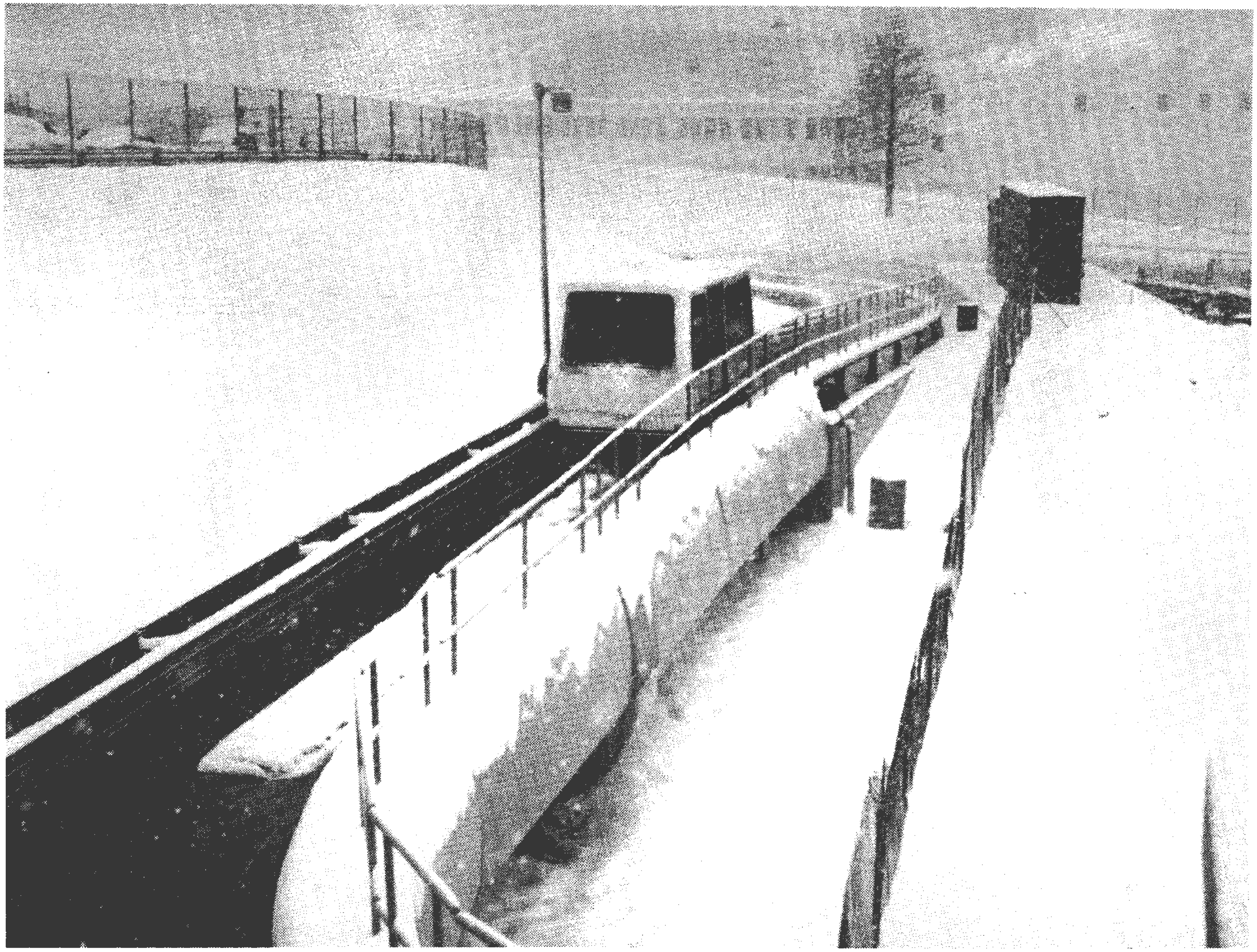


FIGURE 2.4: WINTER OPERATION

boilers have been added in Phase II. More details are provided on adverse weather operations in subsection 4.1.5 and the guideway heating system in subsection 3.7.1.1.

2.2.4 Stations

Of the three Phase I stations at Morgantown, Beechurst, which serves the downtown campus, was the largest and the most complex. As shown in Figure 2.5, this station has the following unique features.

- There are two separate island platforms, one of which serves trips only to and from the Engineering station and points north. The other platform serves trips to and from points in either direction (i.e., Walnut or Engineering stations during Phase I).
- There are six channels where vehicles stop to discharge and pick up passengers. Four channels are turnbacks, one in the direction of the Walnut station and three in the direction of the Engineering station. The other two channels are through channels.
- The turn-back channels have four berths each, three for discharging passengers and one for loading passengers. The through channels have only three berths, two for discharging passengers and one for loading passengers.
- The mainline guideway passes under the station platforms, permitting through traffic to bypass Beechurst without stopping.

The Walnut station, which serves the Morgantown Central Business District, has one island platform served by two turn-around channels. The Engineering station had the same configuration but has been expanded during Phase II to include a second island platform which makes it equivalent to Beechurst in passenger-handling capability.

All of the platforms are island structures, which could be reached only by stairways in Phase I. However, Phase II improvements include elevators for use by the elderly and handicapped. Upon reaching the platform level by stairway, passengers pass through fare-card turnstiles and are then directed to the proper loading gate by lighted signs. Passengers using the elevators are delivered directly to the paid platform area.

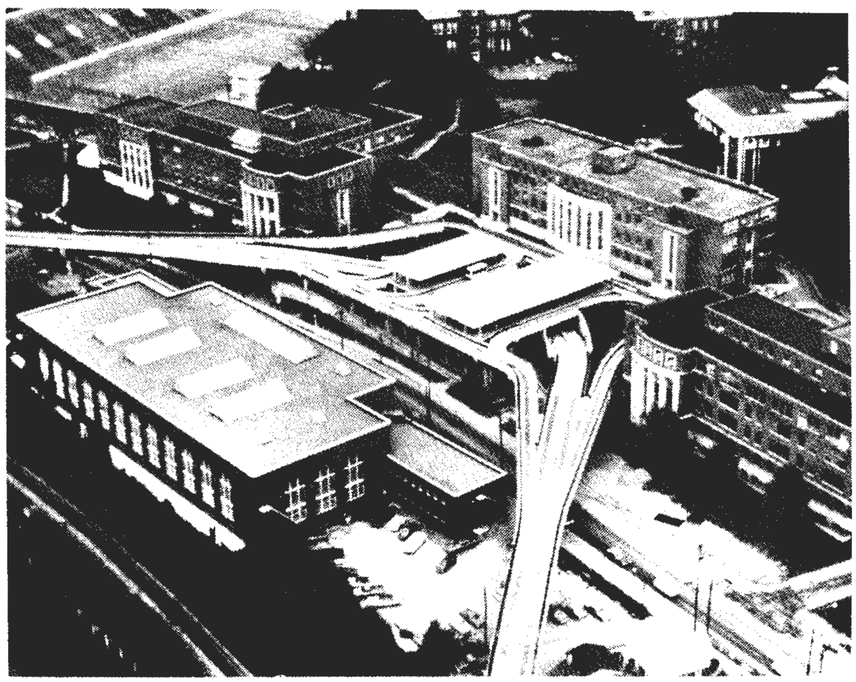


FIGURE 2.5 : BEECHURST STATION

2.2.5 Control and Communication

There are four principal components of the Control and Communication System; their functions are summarized briefly as follows:

Central Control and Communication.
Dual computers and peripheral equipment monitor and control all system operations. In the control room there are display consoles, a closed circuit television system and voice and data communications circuits. The central computer is programmed to manage the movements of all vehicles in the system for either scheduled service or on-demand operation.

Station and Guideway Control and Communications Subsystem.
Station computers control local vehicle operations such as switching, stopping, door operations, vehicle dispatch and station graphics. This subsystem includes the special-purpose electronics between the computer and the vehicle. These electronics provide inductive communications for collision avoidance and digital data interfaces. Information is transmitted between vehicle-borne antennae and wire loops embedded in the guideway.

Vehicle Control and Communication Subsystem.
This control equipment is carried on board the vehicles. It receives and executes commands received from the guideway wire loops. In addition it operates propulsion and braking controls in order to regulate speed and guideway position. Once a vehicle is dispatched, control of vehicle speed and position is the sole responsibility of vehicle-borne equipment. Station and central computers monitor its performance but are unable to issue any commands to correct vehicle trajectory other than to stop an offending vehicle.

Collision Avoidance System.
A redundant, failsafe technique assures that safe spacing of vehicles is maintained along the main guideway, in switch areas, and at ramps leading into stations. The guideway is divided into segments or blocks. Vehicle-borne magnets actuate reed detector switches in the guideway segment, and through logic circuits, automatically turn off a "safetone" signal for the segment of the guideway behind the vehicle. If a vehicle intrudes into this segment, the lack of a "safetone" signal will automatically apply emergency brakes.

Vehicle management is based upon the concept of a series of imaginary moving points, separated by 15-second time intervals, circulating through the system continuously along the guideway. Vehicles are dispatched to merge with one of these moving points. The position of each of these points as it circulates through the system is stored in the station computers and is compared with actual vehicle progress through the system. Should the vehicle drift too far out of synchronism with its assigned moving point, the appropriate portion of the system will automatically shut down.

2.2.6 Power Supply and Electrification

In Phase I, electric power for the vehicles was supplied to the guideway power rail system at three propulsion substations spaced about evenly along the route. Three-phase, 575-volt, 60-Hz power is fed into the power rails and picked up by the vehicles through specially designed power collectors. The AC power is rectified on board the vehicle to supply a 70 HP, DC traction motor. Housekeeping power for the stations and support facilities was supplied in Phase I by separate substations located at the maintenance facility and at each of the three stations. In Phase II, one new propulsion substation and two new housekeeping substations have been added and the housekeeping substation at Engineering has been relocated.

2.3 OPERATIONAL EVALUATION

2.3.1 Public Acceptance

An attitude survey of both riders and non-riders was conducted during April and May 1977, the results of which are summarized as follows:

- o Both riders and non-riders consider the system to be generally satisfactory. The most frequently cited reason for not riding the system was that it does not take them where they want to go.
- o Neither safety nor personal security appeared to be of concern to passengers.
- o Most of the riders considered the appearance of the guideways and stations to be acceptable, but a sizeable minority did not.
- o There were no serious objections to vehicle comfort, but many respondents objected to the wet and cold station platforms.
- o The most frequent criticism related to system reliability. Many of the riders had been inconvenienced by frequent system failure, but much of the criticism related to problems encountered during the first operational year (Sept. 1975 - Aug. 1976).
- o Most respondents considered the 25¢ fare and the $15.00 charge for a semester pass acceptable, but there were some objections to the University's policy of requiring all students to purchase a semester pass.

2.3.2 Cost

The capital cost of the Morgantown System has been the subject of detailed investigations by the General Accounting Office and other government agencies. Rather than duplicate these efforts, the assessment team has reviewed the record of expenditures to determine what it would cost in 1978 dollars to duplicate the Morgantown facilities and equipment under normal conditions and a realistic implementation schedule. Since much of the money spent on this project was for non-recurring research and development, adjustments were made to eliminate the estimated cost of this R & D effort. Similarly, estimates were made of amounts spent to meet the exceptionally short time schedule established for the project, as well as amounts needlessly spent as a result of the undue haste which characterized the project. These adjustments, together with the application of separate escalation rates for construction, hardware and personal services, resulted in an equivalent 1978 estimated cost of $66.5 million for the Phase I system. This amount omits the R & D and other costs attributed to the unique circumstances under which the system was built and thus more accurately reflects costs to duplicate a similar system.

A more detailed analysis of the MPM system costs is contained in Chapter 5. For a comparison of costs of the MPM system with other AGT systems, refer to:

> "Summary of Capital and Operations and Maintenance Cost Experience of Automated Guideway Transit Systems", prepared by N. D. Lea and Associates, Inc., June 1978 (Report No. UMTA-IT-06-0157-78-2) and Supplement I, October, 1979 (Report No. UMTA-IT-06-0188-79-1).

Boeing was responsible for operating and maintaining the system during its first year of operation and for training WVU personnel. This initial period of operation required much developmental and problem-solving work, as might be expected with the start-up of a very sophisticated first-of-a-kind system. As a result, O&M costs for the first year's operation were high, reported by Boeing as more than $3.00 per vehicle-mile traveled (unescalated 1975-1976 costs). As the system matured, O&M costs decreased significantly, and during the last operational year, July 1977-June 1978, the cost per vehicle-mile was $2.35 at 1978 price levels. This resulted in a 1978 cost per passenger carried of $0.65.

2.3.3 Energy Consumption

Excluding the energy consumed for guideway heating, the entire system used somewhat less than 5 kilowatt hours per vehicle-mile traveled during the 21-month period, October 1976 - June 1978. This consumption includes the power supplied to the vehicles for propulsion, lighting, climate control and the housekeeping power used at the stations and maintenance facility. This is roughly the energy equivalent of a third of a gallon of petroleum fuel per vehicle-mile, about the same as the fuel consumption of a typical city bus. It is important to note that since the system runs on electrical energy, it need not depend on petroleum-based fuels.

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The hilly terrain of Morgantown, including one long hill with a ten percent grade, contributes to higher propulsion energy use than would be typical for many U.S. cities. According to Boeing, a system based on the MPM technology which was installed at Okinawa on less hilly terrain used 3.2 kilowatt hours of propulsion energy per vehicle mile during the 1975 International Oceanographic Exposition.

In contrast to the vehicle fleet, the guideway heating system is quite energy intensive. During the first year of operation, the consumption of natural gas by the guideway heating system was about equivalent in energy useage to the electrical energy required by the rest of the system. In the second year, which included the unusually severe winter of 1976-1977, guideway heating accounted for almost twice as much energy as did the vehicles and housekeeping demands. This situation prompted the examination of various techniques for conserving energy, which appear to be reflected in lower usage for the third operational year.

2.3.4 System Performance

As of the end of June 1978, after three years of operation, the system had carried about 4.5 million passengers and had accumulated in excess of 1.6 million vehicle-miles in passenger service.

Since the vast majority of the system users are students, travel demands closely parallel activities at the University. Thus, the pattern of travel differs significantly from a typical urban application, in that there are several peaks of relatively short duration during the average day. Another interesting feature of the Phase I operation was the transfer of numerous students to and from the University's campus bus system at the Engineering station.

The operational procedure used at Morgantown involves discharging passengers from a vehicle at the first available of three unloading berths in a station channel. The vehicle then moves forward to the loading berth, takes on passengers, and waits there until it receives a dispatch command which will launch it onto the mainline guideway at the precise time necessary to match up with the moving point assigned to it by the central computer. During periods of light travel, empty vehicles are customarily stored in the station channels, where they are available for dispatch in response to passenger demand or a scheduled rate of dispatch determined by the central control.

During peak periods of operation, vehicles are dispatched sequentially from different channels. Beechurst, which has three channels "facing" the Engineering station, could launch vehicles continuously at 15-second intervals, filling all of the available main guideway "slots". Walnut and Engineering, however, had only two station channels and were limited to dispatch rates of 2.67 vehicles per minute, filling two out of three available "slots." With the expansion of the Engineering station in Phase II, the system should be able to utilize the full capability designed into the Beechurst station.

Due to the limited capacity of the Engineering station, which was only half completed for Phase I, the system was unable to sustain its maximum line capacity of 5,040 passengers per hour (four vehicles per minute, each with 21 passengers). In actual practice, much lower dispatch rates were used. For example, during peak periods Engineering dispatched one vehicle to Beechurst every minute and one to Walnut every five minutes. This would have permitted a single-direction passenger flow rate of 1,512 per hour, assuming each vehicle were loaded to its design capacity. However, after a football game in October 1976, the system moved about 3,500 people in one hour; approximately 3,200 of these boarded in the first 45 minutes. This passenger flow rate compares favorably with the design objective of 1,100 passengers in 20 minutes from Beechurst to Engineering.

Operating Statistics

Overall system performance, and the improvements which occurred during the 33 months of Phase I operations, can be gauged from the statistics developed in the course of this assessment. Some of the significant results are summarized below.

Vehicle/Fleet Operation

- o The average number of vehicles operated was steadily improved, from 17.6 vehicles in the first year to 21.2 during the third year. This implies a higher state of readiness through reductions in failures and better maintenance.

- o The average number of miles traveled by a single vehicle ranged from 18,700 to 20,200 in the first two years and declined to about 16,500 vehicle-miles in the third year. This is low compared with buses at 40,000 to 50,000 miles per year and other AGT systems at 40,000 miles per year. This low mileage can be attributed to the high number of vehicles available for an incomplete guideway system, and to the operating strategy of increasing the dwell time to match passenger demands.

Ridership Demand

- o Ridership in the third year was more than twice that of the first year of Phase I.

- o System productivity in the third year was almost 700 passengers per hour, which was 2.5 times better than in the first year.

- o October is a month without holidays and occurs during the first semester, when ridership should be higher. The average weekday ridership in October 1977 (third year of operation) was 12,800 passengers.

- o The greatest number of passengers carried on a single day was 18,228 during registration in the system's third academic year of operation.

- o An average load factor of 29.2 percent during the third year is high compared with conventional bus and rail transit, where the average is 16.2 to 18.6 percent (based on statistics from the APTA Transit Fact Book, 1977-78 edition).

Labor Requirements

- o Slightly more than two employees per active vehicle were required for operation and maintenance in Phase I. Since the system operates 13 hours per weekday (two shifts), this can be viewed as less than one employee per active vehicle. This labor ratio is less than the requirement for a bus system, where total employees are greater than one per vehicle. In Phase II, the MPM labor ratio is expected to decrease to one employee per active vehicle, which is slightly less then one-half that experienced in Phase I.

2.3.5 System Assurance

Assessment of system assurance considered dependability, downtime, reliability and maintainability. Results of the assessment of these factors are summarized below.

Availability and Dependability

As might be expected, the MPM System improved steadily since passenger service was initiated in October 1975. Very large improvements were made to increase system availability during winter conditions. Annual averages calculated from the detailed records maintained by Boeing during the first operational year, as well as the University's operating logs for the second and third years, indicate the following pattern:

SYSTEM AVAILABILITY AND DEPENDABILITY

	1975-76		1976-77		1977-78	
	A	D	A	D	A	D
Winter (1)	72.0	67.6	90.0	88.4	95.9	95.2
Non-Winter (2)	93.7	91.7	96.7	96.1	97.5	97.2
Annual Average	89.2	86.5	95.2	94.2	97.1	96.6

D-Dependability, A-Availability

Notes: (1) Dec; Jan; Feb.
(2) All other months.

The system dependability pecentages cited above are a composite of:

a) The overall system availability, that is, the percentage of time the system was actually operating as contrasted with periods when it was shut down due to vehicle or other malfunction; and

b) The probability that a vehicle dispatched on a trip would complete it within certain prescribed limits.

During the last year of Phase I operations the system achieved a dependability of 96.6 percent, which was very close to the specified 96.7 percent. During May through August 1977 and May through June 1978 the system approached or exceeded the original dependability design requirement of 98.1 percent for maturity.

Downtime

Improvements can also be seen as an increase in the average time between downtime events: first year -- 3.3 hours, second year -- 6.8 hours, and third year -- 8.1 hours. The third year is a 245 percent improvement over the first year.

Similar improvements were made in the times required to restore service after a failure occurs. Initially it took an average of about 27 minutes to get the system operating again. In the second year this average was reduced to about 22 minutes and to 13 minutes in the third year.

Winter conditions had the effect of doubling the number of downtime events, but this situation improved with experience. The Mean Time to Restore (MTTR) system operation during winter months of the first two years was almost three times greater than for the non-winter months. This was reduced to a value nearly equal to the non-winter MTTR during the last year.

Throughout the nearly three years of Phase I operations, the distribution of downtime event statistics normalized -- indicating greater system stability and confirming the trend toward higher system reliability.

Reliability and Maintainability

The reliability and maintainability of the MPM system successively improved during each of the three Phase I operating years. This is evidenced by the achievement of a 98.1 percent conveyance dependability at the time Phase I operations were concluded. Other factors are reflected below:

- The Phase IB program schedule had a high degree of concurrency which precluded "feedback" into the design from a planned endurance test program. Phase II has benefitted from almost three years of operations during Phase I.

- Reliability testing or "hard" test data for some specific components were not required for Phase IB system verification. Generic data were used in the analyses, which may have contributed to early reliability and maintainability problems.

- The components and subsystems that produced the highest frequency of downtime events or unscheduled maintenance actions were generally ordinary hardware (e.g., fare gates, power collectors, hydraulics, brakes). The higher technology items did not surface as significant problems until after the mundane hardware problems were corrected -- and then the high technology cases were relatively less severe. A stronger quality assurance program at the component level may circumvent recurrence of such problems in future AGT applications.

- There were many engineering design changes incorporated during the first year and planned for Phase II. These changes might have been avoided had there been an opportunity to place more emphasis on subsystem tests under simulated operational and environmental conditions prior to system integration. A reasonable development, test and demonstration phase would have permitted this increased emphasis.

Experience shows that a system of the complexity of the MPM, operating under severe environmental conditions, requires an extended period of time to mature, especially since it is one of the first such systems. The experience gained will be of significant assistance for the implementation of future urban applications of AGT.

2.3.6 Safety and Security

There were no fatalities during operation of the Phase I system and no accidents which caused major damage. There was one serious system-related accident; however, it did not involve passengers or occur while operations were under automatic control. Similarly, no serious security problems or instances of criminal behavior occurred. There were a few incidents with pranksters. Most of these were successfully handled through the use of the closed-circuit TV, reports by passengers over the emergency telephone and the rerouting of vehicles to stations or to the maintenance area, where campus police were able to apprehend the offenders.

On some occasions vehicles bumped together while moving at slow speeds in station channels; otherwise there were no collisions between vehicles. There were a few incidents where vehicles lost steering control and made contact with the protective guard rails along the edge of the guideway, but without any serious damage and only when the vehicles were entering or leaving channels at speeds of four to eight feet per second. In a number of these cases, snow and/or ice were present.

Positive traction for both front and rear wheels is essential to insure safe operation. The guideway heating system is used to prevent icing or snow accumulation and will melt any accumulation of ice and snow, given enough time. There was no evidence of any operating problems attributed to lack of traction or skidding, due to moisture.

The maintenance facility available during Phase I was overcrowded. This circumstance contributed to the possibility of accidents involving maintenance personnel and several accidents were reported which could be attributed to the crowded conditions. Maintenance services which must be carried out while the vehicles are electrically powered are of particular concern.

There have been incidents where passengers -- generally students -- have hopped down onto the guideway from station platforms. In doing so, they were exposed to high voltages and oncoming vehicles, but fortunately no one was hurt.

The Morgantown safety record for the first three years of operation was excellent. Comments contained in the assessment findings are intended to insure that concern for safety is sustained as system operations become more routine.

2.3.7 Technical Assessment

This section summarizes some of the results of the technical assessment which contributed to the operational evaluation.

Collision Avoidance System

- The Morgantown system is provided with a checked redundant hard-wired and software collision avoidance system (CAS) which protects against vehicle and merge conflicts. This CAS is implemented along all sections of mainline guideway and the acceleration and deceleration ramps, but not in the station channels. In these channels, vehicle/vehicle impacts at speeds of around 4 fps are possible and occurred on the average about once a month. There were no passenger injuries from these low-speed impacts.

- The CAS is entirely solid state, using no relays, and should be of interest to those concerned with the use of solid-state logic for railroad signalling systems.

- Although the present CAS layout limits vehicle headways to around 15 seconds, it would be possible, using a multiple block system, to reduce headways to as short as 7.5 seconds.

- It is possible for maintenance personnel to defeat the hardwired portion of the redundant CAS by manually inserting CAS override plugs. Some form of alarm or lockout system seems desirable to assure that regular operation cannot occur with these plugs in place.

Steering/Switching

- Steering is based upon a curb-follower concept where guidewheels mounted at the front end of the vehicle follow either the left- or right-hand wall of the "U" shaped guideway. Such a steering system relies upon tire friction for control, in the same manner as automobile or bus steering. Guideway heating, double-wall tires, impact drums placed at high-speed switch frogs, and safety guard rails are among the steps taken at Morgantown to protect against loss of traction.

- Switching is accomplished by commanding the steering system to guide against either the left- or right-hand guiderails along walls of the guideway. Verification of proper switch-linkage position and of proper contact with the guiderail is required; otherwise, an emergency stop is commanded.

- Numerous problems with the steering system during Phase IB resulted in a redesign for Phase II which is expected to improve switching system reliability.

- The Phase I steering system, while stable above 30 mph, did not provide acceptable lateral ride comfort above that speed. Stricter guiderail tolerances or improvements in steering and suspension system design would be necessary for higher speeds.

- The steering system limits vehicles to travel in only one direction.

- Training of vehicles using the present steering system may be feasible, but would require further analysis and development.

Braking

- The braking system consists of disc brakes on all four wheels equipped with completely redundant hydraulic actuation systems.

- Service braking is closed-loop to achieve a specified deceleration rate. In Phase IB, emergency braking applied a fixed force and thus the rate varied with vehicle load and other conditions. For Phase II, a closed-loop emergency brake has been implemented to control the deceleration rate.

- Emergency braking rates for Phase IB could be as high as 0.5g, roughly twice the levels normally used within the fixed guideway transit industry. The apparent lack of passenger complaints or injuries is encouraging, but further experience with elderly and handicapped passengers is necessary before these rates are used in an urban application. In Phase II, emergency braking is controlled at a nominal rate of 0.34 g and limited to a maximum level of 0.45 g.

- There were numerous problems with the Phase IB brake system, including excessive pad wear, caliper and disc failures, hydraulic leaks and valve and pump failures. As a result, the brake system has been redesigned for Phase II.

Suspension

- The Morgantown vehicle runs on four rubber tires, mounted on axles suspended from the vehicle by four air-bag springs.

- Tire wear was initially quite rapid, but careful attention to wheel alignment and the use of recapped tires have solved the problem. Present tire life is up to 50,000 miles.

2.4 ASSESSMENT FINDINGS

The significant findings which resulted from this assessment are summarized below. More detailed conclusions and recommendations are contained in the main sections of the report.

2.4.1 The System As Installed At Morgantown

The following findings are made with respect to the nearly three years of operation of the Phase I system and the expansion under Phase II.

System Operations and Performance

- The MPM System is expected to satisfactorily meet the University's requirements at the conclusion of Phase II.

- The off-line type of vehicle management used for the MPM stations, while necessary for on-demand service, increases the in-station dwell time when the system is in the scheduled mode. At Morgantown, peak demand occurs in a series of short spurts which coincide with the changing of classes. It was therefore necessary to provide for a queue of vehicles which would be ready to service these intermittent demands; otherwise a larger fleet would have been required.

- For Phase I, the MPM System was designed to provide on-demand service for off-peak periods (evenings) and scheduled service during peak travel hours. The algorithms for on-demand service were not efficient. Consequently, a new demand algorithim incorporating an improved vehicle management system has been implemented for Phase II. To assess the full capability of the MPM System, tests will be conducted during Phase II to measure its ability to meet peak loads in the demand mode. Results should be thoroughly documented for their potential usefulness in providing on-demand services in urban areas.

System Assurance

- System reliability steadily improved during the Phase I operating years. System downtime was aggravated by two factors: the severest winter weather experienced in recent history and the failure of ordinary production hardware items such as hydraulic fittings, valves, electrical power pick-up brushes and switches.

  -- Many of the winter weather problems resulted from a program decision to delay installation of a power rail and power collector heating system.

-- Difference in an acceptable quality of parts from the same supplier has been a continuing problem. Boeing has established a qualification and screening program for certain items. Purchasing certain components and parts through a testing laboratory is another way Boeing has recommended for maintaining system reliability. Boeing estimates the additional cost would range from $.30 to $1.00 per part for moderate quantities and believes the higher parts cost would be more than offset by fewer maintenance hours.

- Maintenance records for the first year of operations were excellent. While records were also kept for subsequent operating periods, reporting was not kept current and data were not processed. This situation was corrected and the results are reflected in this assessment.

Human Factors

- The Phase I fare-gate and fare-card equipment caused more than twice as many maintenance repairs as the next highest problem area. An improved fare gate has been designed for Phase II. The fare card will not be released by the user, thus precluding the loss of the card into the machine.

- All stations require vertical access to platforms. Phase II has added elevators to make the system accessible to patrons who use wheelchairs, or have other ambulatory disabilities.

Public Acceptance

- Overall impressions of the MPM System were favorable; fear for safety and security was not a major concern of the passengers.

- Negative attitudes appeared to reflect early experiences with low system reliability during the first operating periods.

Safety and Security

- An independent safety review should be made of the Phase II installation. This review should particularly address the specification and design changes made in the brakes, steering system, and collision avoidance system, as well as the use of hard-rubber recapped tires.

- Safety for maintenance personnel should also be reviewed. This review should include the adequacy of training regarding maintenance practices and operations in emergency situations. It should also address the maintenance facility layout and procedures.

- Occasional vehicle bumping in the station berthing areas appears to be acceptable to the University and to UMTA.

Costs

- The escalating costs of the MPM project are a matter of record. The original estimates, prepared by the University and potential system suppliers with no experience in actual installations, were low. Inflation, a difficult construction site, severe winter weather, a politically motivated time schedule, as well as concurrent R & D, testing, design and construction efforts all contributed to increased costs. Sufficient information has been obtained from the project that inadequate estimates and serious cost escalations need not occur in similar future installations.

System Development Process

- Once initial difficulties with system management were resolved, the project became a tightly run and thoroughly documented endeavor.

- The UMTA decision to retain management responsibility for the project left the University with an uncertain role. This action presaged the later difficulties in reaching agreement on the conditions under which the University would accept ownership and responsibility for operating the system.

- The project experienced several design, test and operating iterations. The Phase IA R & D prototype testing led to extensive changes during Phase IB. Experience with the Phase IB system and continued operation during Phase I O&M discovered additional changes and improvements which are being accomplished during Phase II under the system management of the West Virginia Board of Regents. These iterations are normal for the development and implementation of new technologies. Rarely are they made while attempting to introduce a new public service and with so much public attention.

2.4.2 Urban Applications

Future urban applications of AGT systems should consider the following findings:

System Operations and Performance

- The maximum line capacity of the MPM System, as presently installed, may be too low for many urban applications. This capacity could be increased for urban installations through such changes as the following:

  -- Revising the vehicle passenger compartment to accommodate more riders

  -- Entraining vehicles

  -- Redesigning the collision avoidance system to permit operation at 7.5-second headways.

- o An early decision is necessary on whether to use scheduled or on-demand operations or a combination of these operating strategies.

  -- Where only scheduled service is necessary, off-line stations may not be required.

  -- Where on-demand service is to be provided, consideration must be given to the design of off-line stations and the management of vehicle queues.

  -- A combination of these two strategies requires an optimization of station design and vehicle management.

- o Although an AGT system is fully automated, successful operation and performance depend upon a nucleus of competently trained and highly motivated personnel. Reliance on such a group becomes especially important during emergencies and adverse weather conditions. Early association of operating and maintenance personnel during installation and acceptance testing of the system will help achieve the necessary dedication.

System Assurance

- o Allowances should be made for adequate feedback from system and subsystem tests of new AGT developments so that results can be incorporated in product improvements and engineering designs.

- o A quality assurance program should be established to insure that "off-the-shelf" hardware items meet established reliability requirements.

- o Adequate funding and timing should be provided for reliability testing at the subsystem and component levels to avoid reliability failures during initial operations, and to monitor performance during in-service use.

- o Sufficient "shake-down" operations should take place before commitments are made to public revenue service. Alternative public transit service (buses) should not be prematurely abandoned before the new system has stabilized.

Human Factors

- o Unless multiple station channels are needed, center island stations of the type built at Morgantown should be avoided, if possible, in urban installations. This design requires stairs or escalators and elevators for handicapped patrons. The short turning radius and steep grade capability of the MPM vehicles could be utilized to reduce, or eliminate, vertical access and egress by patrons.

- o Other improvements in station design for urban applications should consider:

  -- Stair widths based not on standard building codes, but on more appropriate transit criteria

- -- Better graphics to guide patrons in use of the system
- -- Facilities and communication techniques to aid elderly and handicapped riders
- -- Windscreens or climate-controlled platform areas.

Public Acceptance

- o Although a minority of respondents to the attitude survey criticized system aesthetics, the negative response was sufficiently large to suggest that improvements in overall system appearance should be made in urban installations.

Safety and Security

- o There have been enough incidents where MPM System passengers stepped onto the guideway to suggest that attention needs to be given to this matter in urban areas.
- o Consideration should be given to lowering the emergency braking rates and to implementing collision avoidance in station areas of urban installations to prevent unnecessary jostling of patrons who are less hardy than university students.

Technology

- o Alternative methods for sustaining all-weather operations should be considered. The efficiency of the MPM guideway heating system could be improved by adding automatic surface temperature controls and by insulating elevated running surfaces.
- o There may be situations where technological solutions are inappropriate. Consideration should be given to the intensities of winter weather where operations should cease, rather than to invest in the protective devices and back-up equipment necessary to sustain operations under all conditions.

System Development Process

- o On future projects of this kind, there should be an early and clear understanding among all participants as to precisely what their roles, responsibilities and relationships throughout the project will be.
- o Preparation of a comprehensive project development plan should be the first order of business early in the project. While the plan may become quickly outdated, the process will uncover issues to be clarified and will pinpoint responsibilities that may otherwise be overlooked. The project development plan will also provide an insight into the consequences of changes that are inevitable as a project progresses.

- In undertaking a major project of this kind, particularly one involving the application of new developments, UMTA should find ways to limit its financial exposure. Sponsors should endeavor to avoid premature commitments to operational success and should resist the spiral of rising expectations as to what the final project will accomplish.

3.0 TECHNICAL SUBSYSTEM ASSESSMENT

This section presents results of the assessment of technical subsystems. System operating performance, reliability and maintainability are included in Chapter 4. It is important to note that these technical assessments are made for the Phase I subsystems only. Improvements have been made during Phase II which should correct many of the problems cited.

3.1 VEHICLES

The rubber-tired Morgantown vehicle (Figures 3.1 and 3.2) is relatively small compared with conventional transit vehicles. Passenger capacity is 21, with eight seated and thirteen standing. The vehicles are relatively complex and consist of the following subsystems:

a. Passenger Module - the enclosure which houses the passengers

b. Environmental Control Unit (ECU) - provides a controlled temperature and humidity environment for the passengers

c. Chassis - the structural framework and running gear

d. Hydraulic - provides energy for braking and steering

e. Pneumatic - provides automatic vehicle leveling and power collector extension/retraction

f. Steering - an active control system which allows the vehicle to follow a guiderail mounted on either side of the guideway

g. Braking - provides redundant service and emergency-rate stopping and a mechanical parking brake

h. Propulsion - the motive power to turn the rear wheels at the command rate

i. Electrical - receives and converts electrical power from the guideway power rails for vehicle functions

j. Vehicle Control and Communications System (VCCS) - receives guideway and on-board commands and controls the motor, brakes and doors in the prescribed manner.

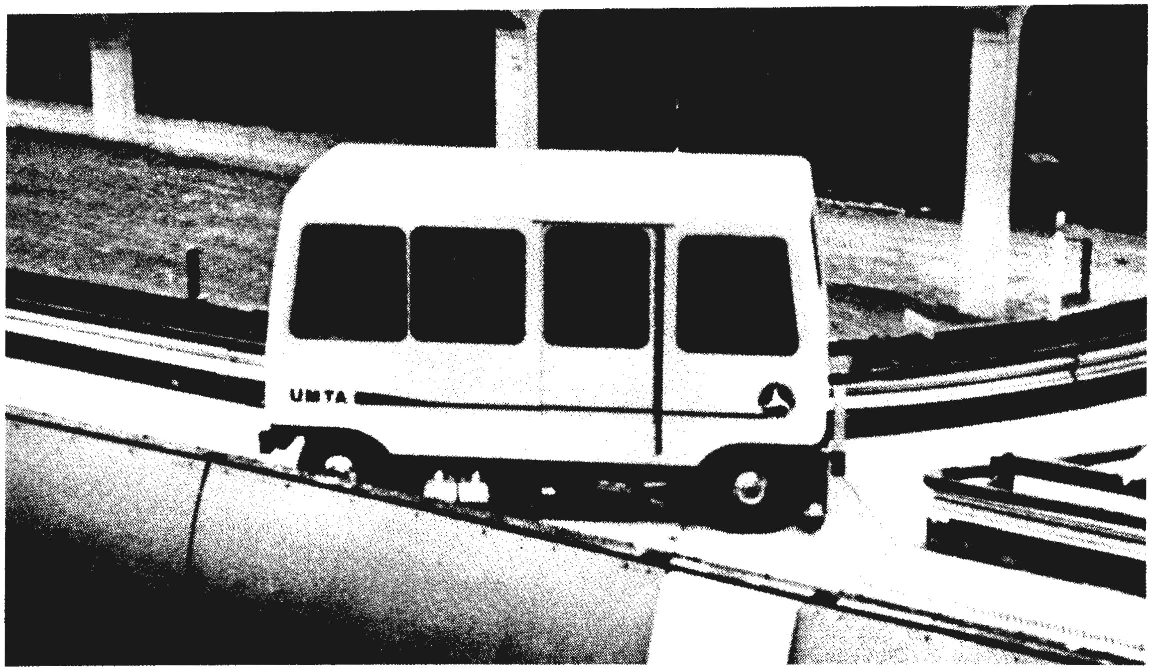
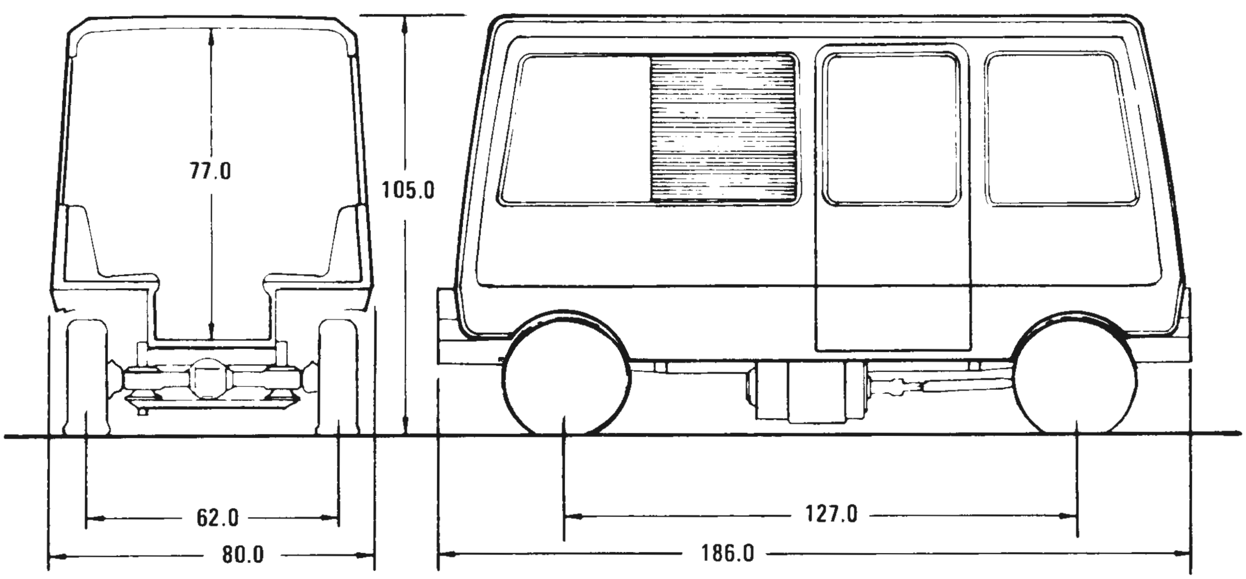


FIGURE 3.1 : MORGANTOWN VEHICLE



ALL DIMENSIONS IN INCHES

FIGURE 3.2 : GENERAL DIMENSIONS OF VEHICLE

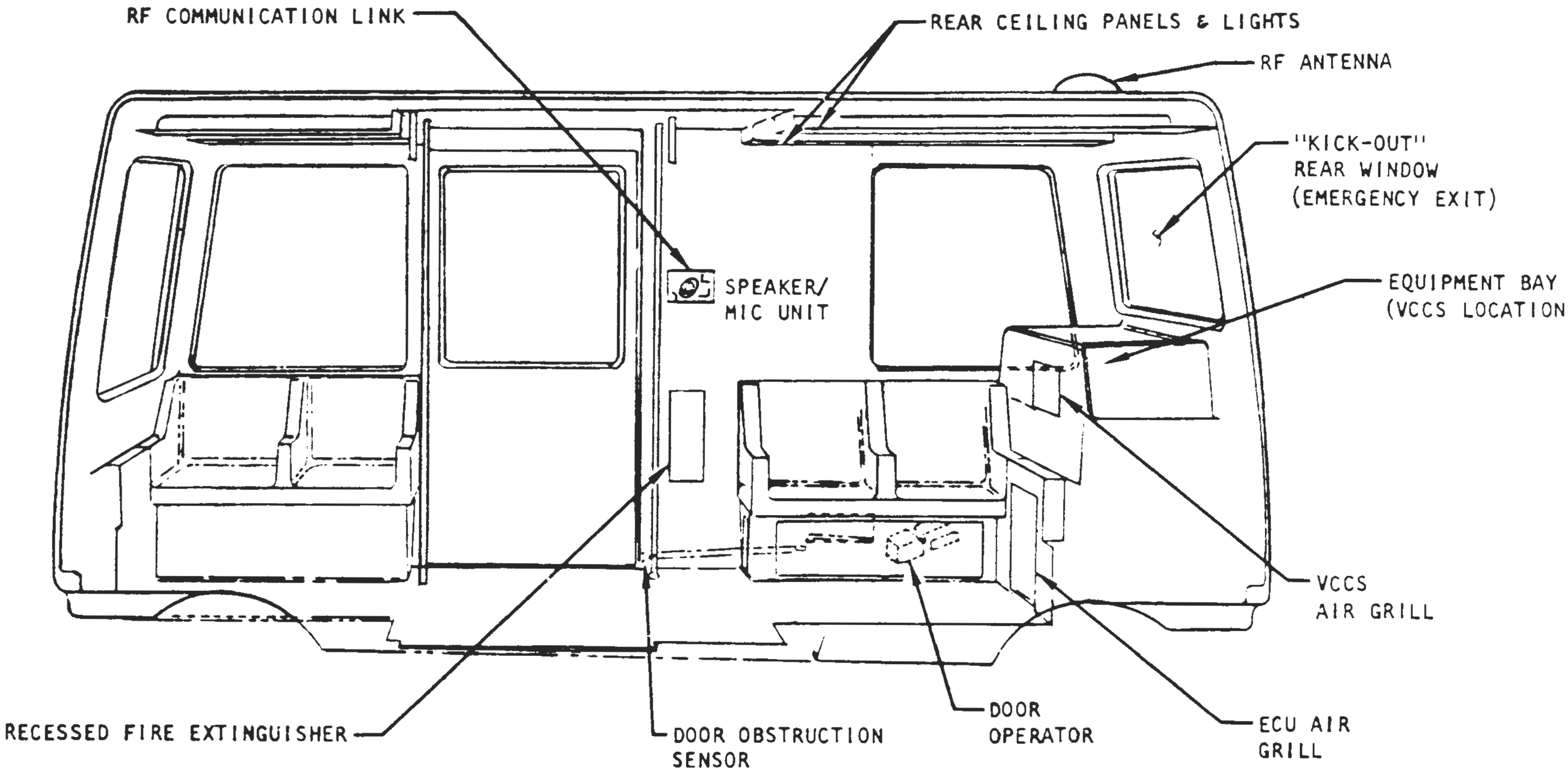
SOURCE: Boeing Aerospace Company

3.1.1 Passenger Module and Chassis

The passenger module (Figures 3.3 and 3.4) is fabricated of molded fiberglass-reinforced plastic. Both the interior and exterior have a clean, functional design and aesthetic appeal. The use of hard, smooth surfaces inside (walls, ceiling and seats) reduces vulnerability to vandalism and facilitates cleaning. However, these surfaces reflect noises generated by on-board equipment. The floor is covered by a fabric carpet which offers a non-skid surface important to the safety of standing passengers and reduces interior noise level. The carpet does collect dirt and becomes encrusted with mud which is hard to clean. Future applications might consider covering the floor with rubber matting of a type used in conventional rail equipment.

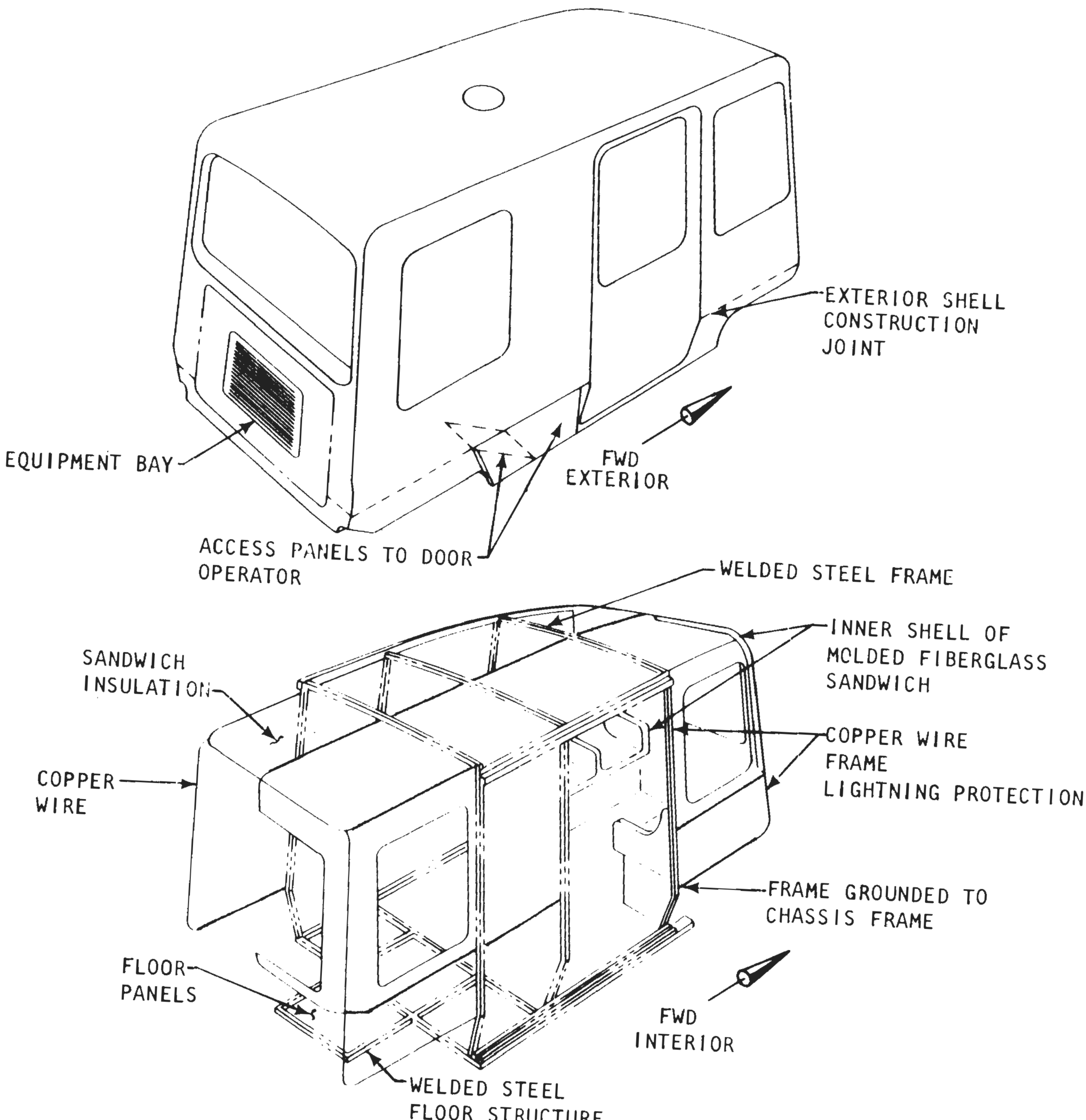
The chassis (Figure 3.5) consists of a welded framework, axles, wheels and suspension. The front bumper is mounted through a shock absorber which is sized to take impacts of up to four feet per second without any damage to equipment. The axles were specifically designed from basic truck-type commercial units. All four wheels are steered; however, propulsion is provided only through the rear wheels. Steering, propulsion, braking and vehicle control are discussed separately in later sections of this chapter.

Figure 3.6 is the floor plan of the Morgantown vehicle, giving essential dimensions. This figure shows a standing well of 26 square feet, indicating an average of 2.16 square feet per standee. Design was based upon 2.13 square feet per standee. An 18-inch by 24-inch body ellipse, which is equal to 2.36 square feet of standing area, is commonly used by transit properties to determine standee positions and car capacity for relatively "comfortable" conditions. Even at this spacing, inadvertent contact will occur between passengers. Figure 3.7 shows the Morgantown vehicle floor plan with slightly smaller ellipse diagrams (1.80 square feet) to illustrate the maximum capacity resulting from probable positioning of standees. The figures show that the aisle area between the seats does not allow for standees and that capacity is one person less than the quoted capacity. At Morgantown, since the majority of riders are younger university students of lighter



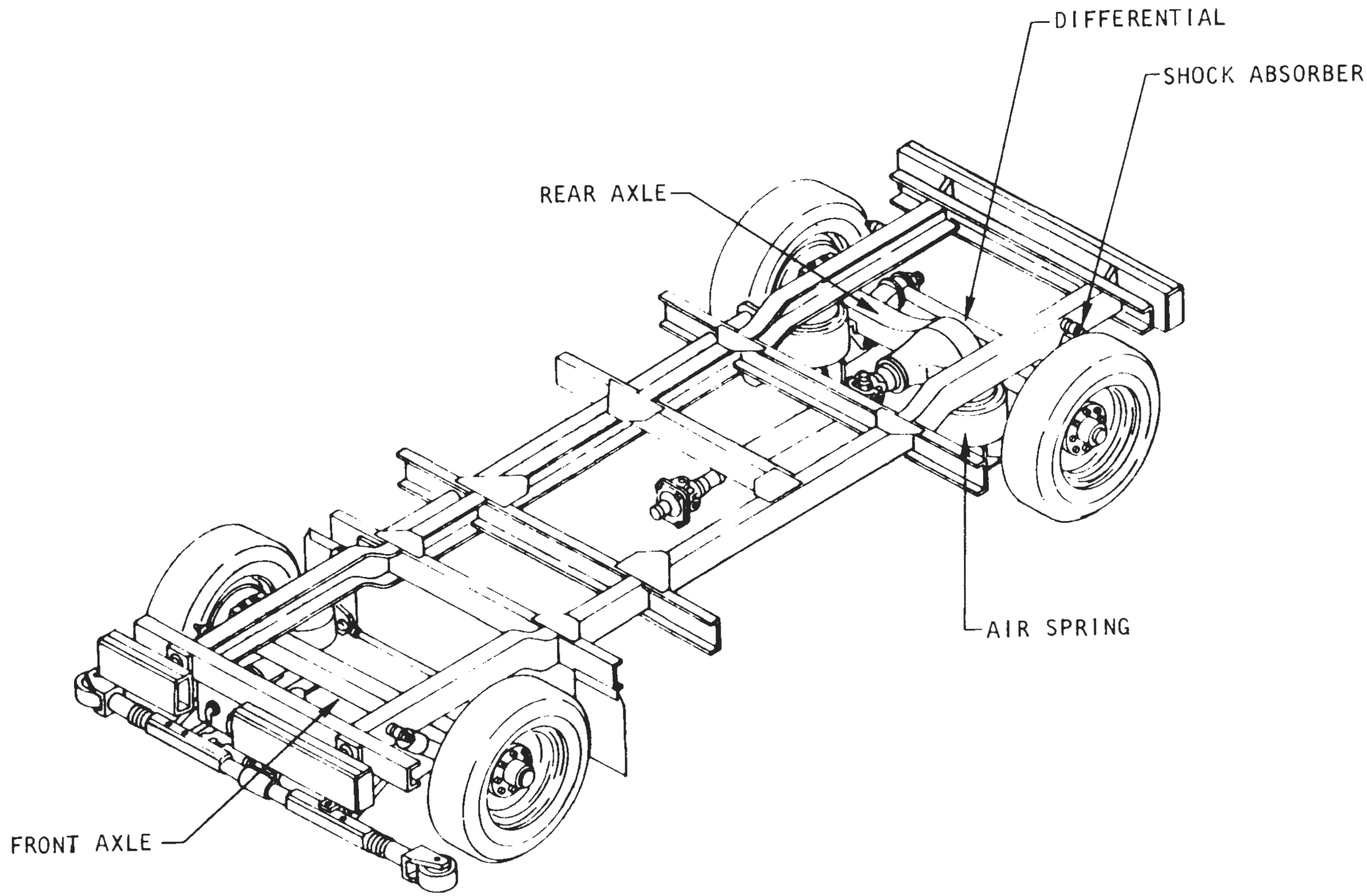
SOURCE: Boeing Aerospace Company

FIGURE 3.3 : PASSENGER MODULE INTERIOR



SOURCE: Boeing Aerospace Company

FIGURE 3.4 : PASSENGER MODULE CONSTRUCTION



SOURCE: Boeing Aerospace Company

FIGURE 3.5 : VEHICLE CHASSIS

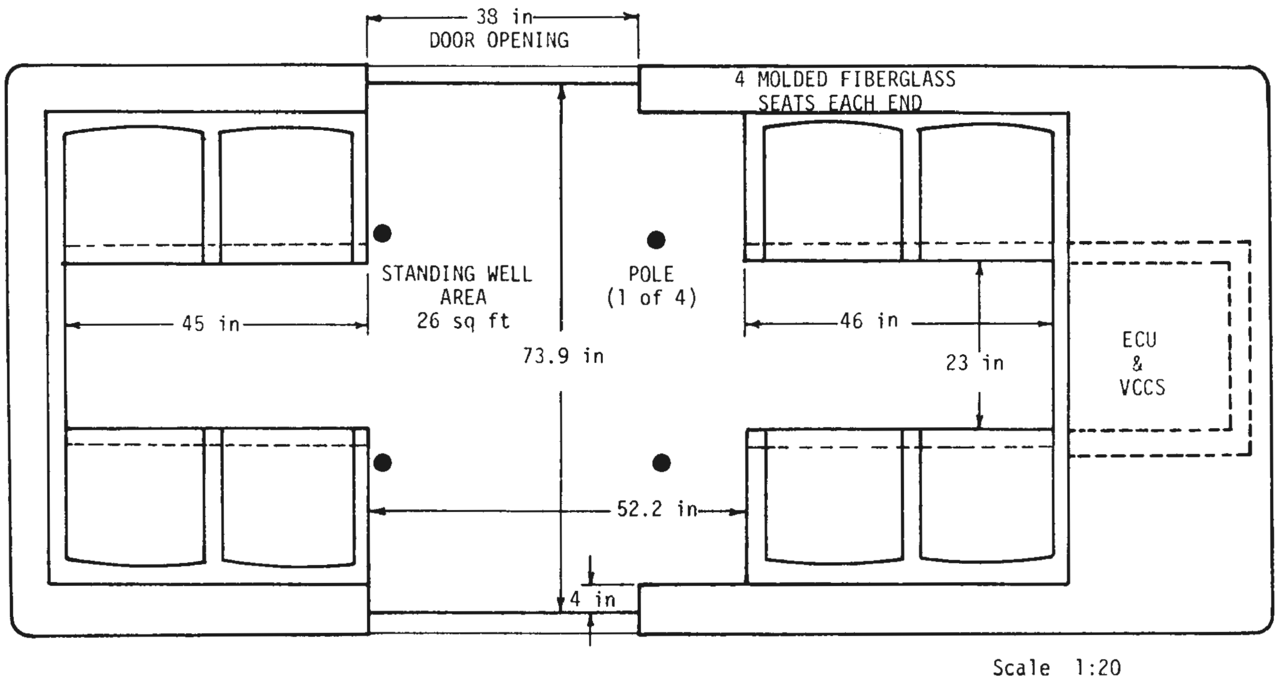


FIGURE 3.6 : VEHICLE FLOOR PLAN

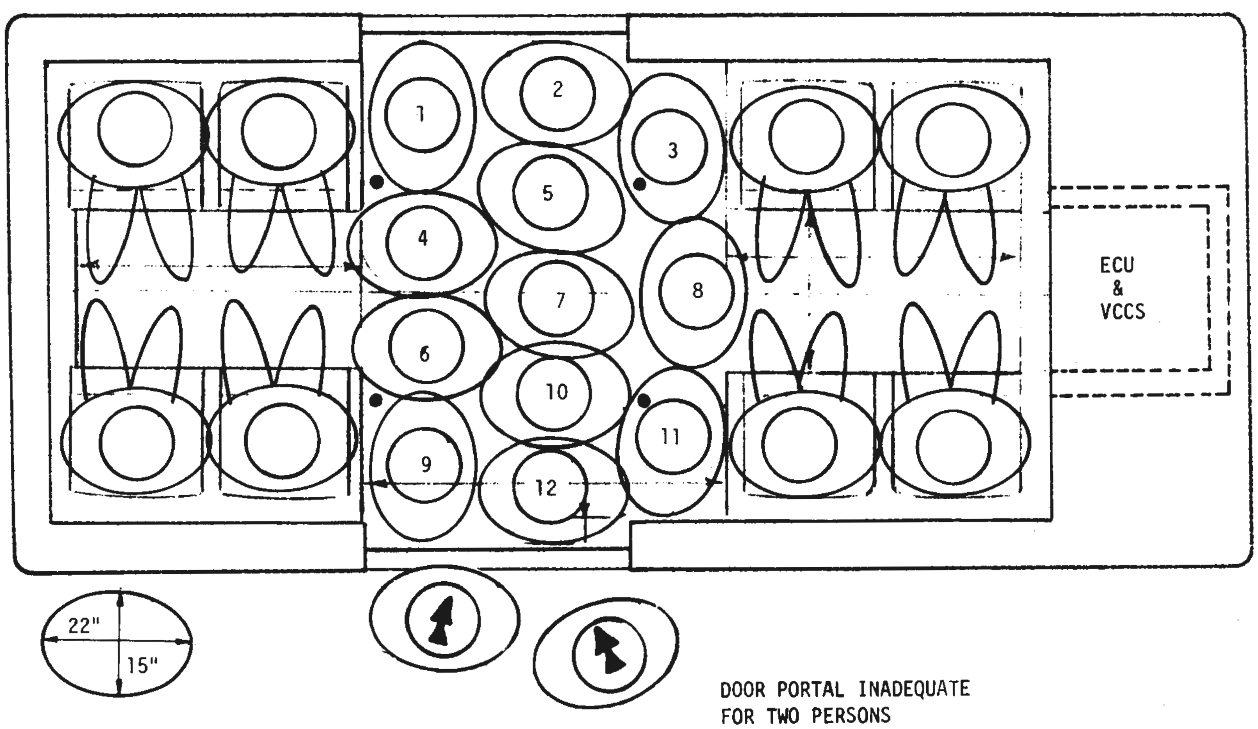


FIGURE 3.7 : VEHICLE OCCUPANCY DIAGRAM

build, loadings higher than 21 passengers per vehicle have been observed.

For many future urban applications the capacity of the present MPM system will be inadequate, and it may be desirable to consider ways to increase vehicle capacity. Figure 3.8 shows one possibility which does not increase the overall vehicle dimensions. It should be noted that increased payload will affect performance of brake, propulsion, and control systems. Seats could be placed either as bench or bucket seats (options shown) facing each other at the vehicle ends. Such an arrangement enlarges the standing well and permits faster loading of the seated passengers. The existing arrangement requires passengers to enter seated sections one at a time. Figure 3.9 shows this suggested vehicle interior superimposed with body ellipse diagrams, with the resulting capacity increased to 25 passengers. Further increases in capacity, up to four more passengers, might be gained by removing the ECU and VCCS from the interior of the vehicle. Placing the ECU on the roof, as an alternative, could also reduce interior noise levels. These alternative arrangements suggest that the present-sized MPM vehicle could be increased to a capacity of 29 passengers, which would increase overall system capacity by 38 percent. Studies carried out by UMTA (1975 and 1977) showed that the increased capacity is feasible, except that it would not be cost effective at Morgantown.

The present vehicle doorway is 38 inches wide, which is considered to be too narrow for urban transit use. Observations of boarding rates for 110 passengers showed an average boarding time of 1.08 seconds per passenger, which is consistent with boarding in a single file. In a later section, the station berth capacity shows that a boarding time of 1.0 seconds is assumed, reinforcing the conclusion that the doorway width permits only single-file passenger entry. A larger width door, 50 inches wide as shown in Figure 3.8, would permit loading of passengers two abreast, allowing a revised vehicle to be loaded in 14.5 seconds as contrasted with 21 seconds for the existing vehicle. This change in door width would effect a 31 percent savings in the present loading time for a larger capacity vehicle.

No significant problems have been reported in the vehicle passenger modules or chassis. The only structural problems have been with the power train. Redesigns were required for the steering knuckles and axle shafts between Phases IA and IB. Axles, tracta axle joints and differentials showed wear problems in

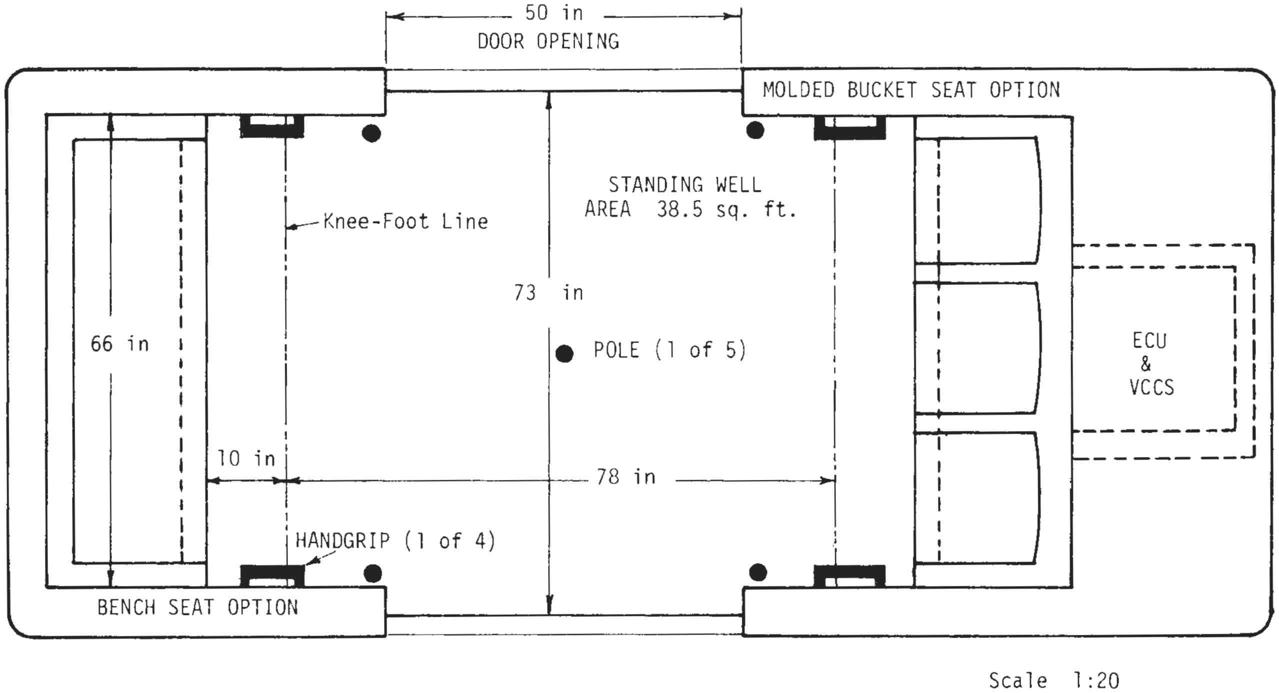


FIGURE 3.8 : EXAMPLE OF A REVISED FLOOR PLAN FOR POTENTIAL URBAN USE

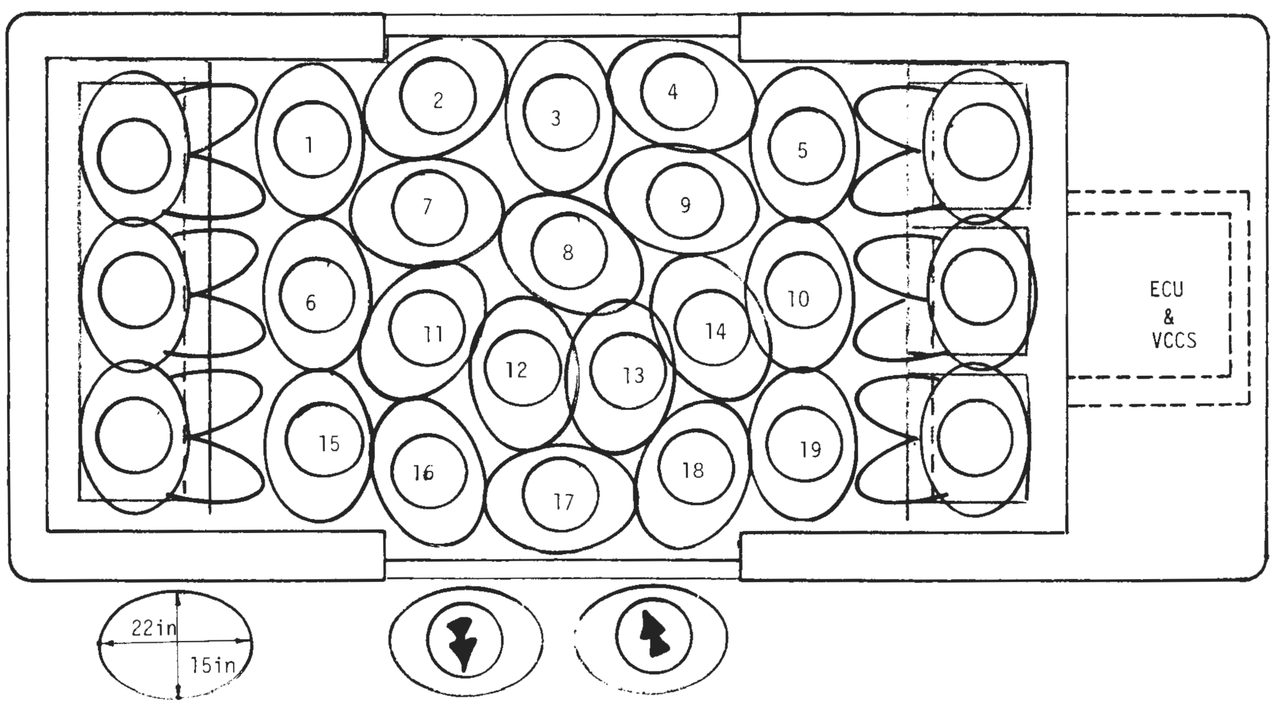


FIGURE 3.9 : OCCUPANCY DIAGRAM FOR EXAMPLE REVISED FLOOR PLAN

Phase I. The problem with the differentials was found to be contamination which occurred at the supplier's manufacturing plant. The tracta joints (which are no longer in production) have been replaced with cardan joints for Phase II.

3.1.2 Vehicle Doors

The vehicle doors are opened and closed by a geared electrical drive and linkages. In the Phase I design, the maximum force level was constrained by a current limit on the electric motor. In addition, a spring-actuated recycle switch was active during the last six inches of door travel. It is estimated that the doors of a typical vehicle in operation experience about 200 open/close cycles per day.

No major operational problems were reported by the operator and no serious icing problems were experienced with the doors. During the first year's operation, 132 "door mechanism inoperative" incidents were reported in eight months, making this the sixth most frequent problem. There were some problems where doors had a tendency to slide open one or two inches while the vehicle was climbing a hill. When door closure was not tight, it was possible to pull or force the door to a maximum opening on the order of four to six inches, where it was prevented from opening any further by a mechanical lock.

For Phase II, the door system has been revised. Pressure-wave touch edges, such as are used on elevators, have been installed on the doors. This modification should permit higher door closing forces and prevent the problem mentioned above.

Coordinated vehicle/station-platform doors were not employed for a variety of reasons. These include their high cost (estimated at $1 million); the idea that their installation at Morgantown was not necessary and could establish a precedent that might be interpreted as a Federal requirement; and the additional maintenance problems caused by malfunctioning or unreliable equipment.

3.1.3 Environmental Control Unit

The vehicle Environmental Control Unit (ECU) is, according to the operator, adequately sized to heat and cool the passenger compartment (15,000 BTU/hr of heat, 24,000 BTU/hr cooling, and 500 cfm circulation). Problems of low reliability have been reported -- primarily attributed to the control system -- and major problems have involved the humidity controls. Since air conditioning units for many other conventional transit vehicles do not incorporate humidity control, consideration should be given to dropping this requirement. Phase II vehicle modifications include changes to the thermostat and compressor mounts. Since the air circulation fan for the ECU is located inside the vehicle shell, it is the major contributor to interior vehicle noise. Noise reduction considerations for future small-vehicle AGT systems might include alternative locations of the ECU, such as on the roof. However, relocation may pose other maintenance problems; in its present location it is readily reached and maintained.

3.1.4 Electrical System

A simplified schematic of the vehicle's electrical system is shown in Figure 3.10. Three-phase, corner-grounded delta AC power is collected from a wayside power rail consisting of three electrical bus bars in a specially shaped insulator. Power collectors are located immediately below the doorways on both sides of the vehicle. Only one collector, either one side or the other, is engaged to the power rail at any one time. The unengaged collector is electrically switched off so that the collector shoes are not energized. There were three major problems with the Phase I design, sufficiently serious that it has been replaced with an entirely different collector and power rail for Phase II:

a. Collector Shoe Wear - Phase I collector shoes had to be replaced at 2,000 to 3,000-mile intervals. During the first operational year they required replacement at 1,000-mile intervals.

b. Improper Contact with Power Rail - There were instances where the collector became misaligned with the power rail and power to the vehicle was lost. It should be noted that the collector was mounted on the sprung mass of vehicle, thereby aggravating this problem. Axle-mounted collectors have been incorporated in Phase II.

c. Frost on the Power Rails - The high humidity and freezing winter climate caused major problems. The new power rail for Phase II incorporates

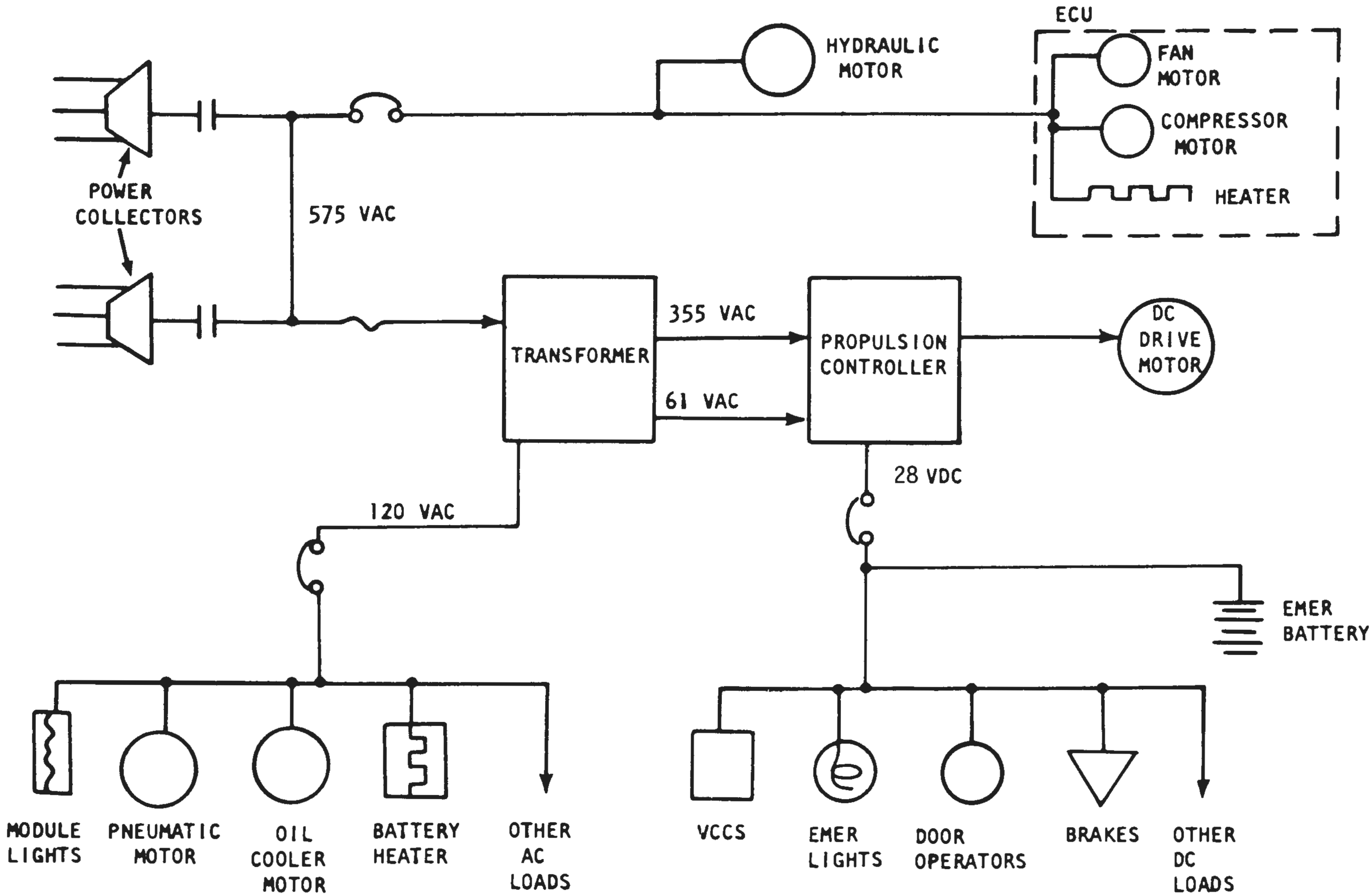


FIGURE 3.10 : VEHICLE ELECTRICAL SYSTEM

SOURCE: Boeing Aerospace Company

electrical resistance heating with 15 watts per linear foot for each of the three rails. Heaters may also be added to the redesigned power collectors if found to be necessary in Phase II.

3.1.5 Hydraulic and Pneumatic Systems

The Morgantown vehicle has both hydraulic and pneumatic power on board. The hydraulic system provides pressure to operate the braking, switching and steering systems. Pneumatic pressure is used for air spring suspension and to maintain a uniform force between the power collector and the power rail.

There are two distinct hydraulic systems (Figure 3.11) on the MPM Phase IB vehicle. Both systems are powered by the same three-phase AC motor and share the same fluid reservoir.

One system is driven by a variable flow pump which provides a constant 1,050 psig pressure to operate the braking system and the switch actuation mechanism. The other system provides a constant flow rate of 4.5 gpm which is metered by the power steering valve to control the steering force.

Accumulators are installed in the brake and bias switch actuation lines. These devices regulate pressure to the desired 1,050 psig level and have enough capacity to safely bring the vehicle to a stop if the pump fails. The vehicle is automatically emergency braked if hydraulic pressure drops below 800 psig.

The hydraulic system is a critical element of the steering, switching and braking systems and its performance is discussed further in sections 3.3 and 3.4. In general the performance of the hydraulic system was not satisfactory and a complete redesign was undertaken in Phase II.

The pneumatic system (Figure 3.12) on the Morgantown vehicle supplies 90-100 psig air for suspension. In addition, it pressurizes air cylinders which maintain a uniform force between the power collector and power rails.

The compressor, powered by a 110-volt AC motor, is provided with an air reservoir and check valve to maintain pressure if the compressor or motor fails. The vehicle is automatically stopped if pressure falls below 25 psig.

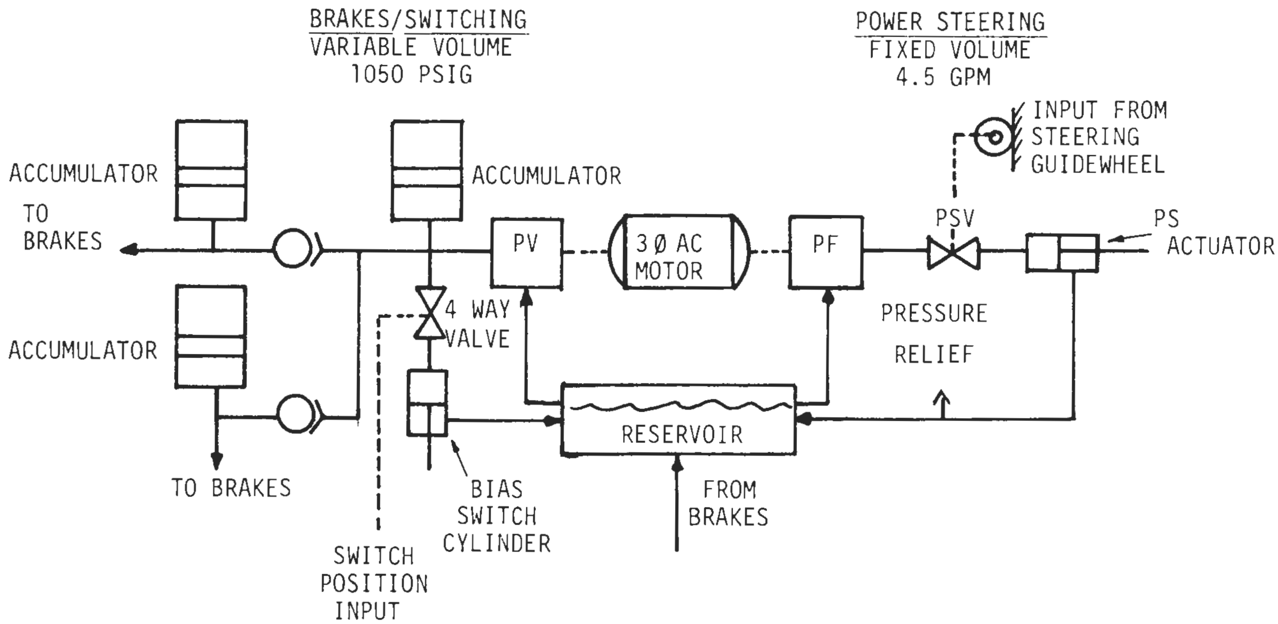


FIGURE 3.11 : SIMPLIFIED HYDRAULIC SYSTEM SCHEMATIC

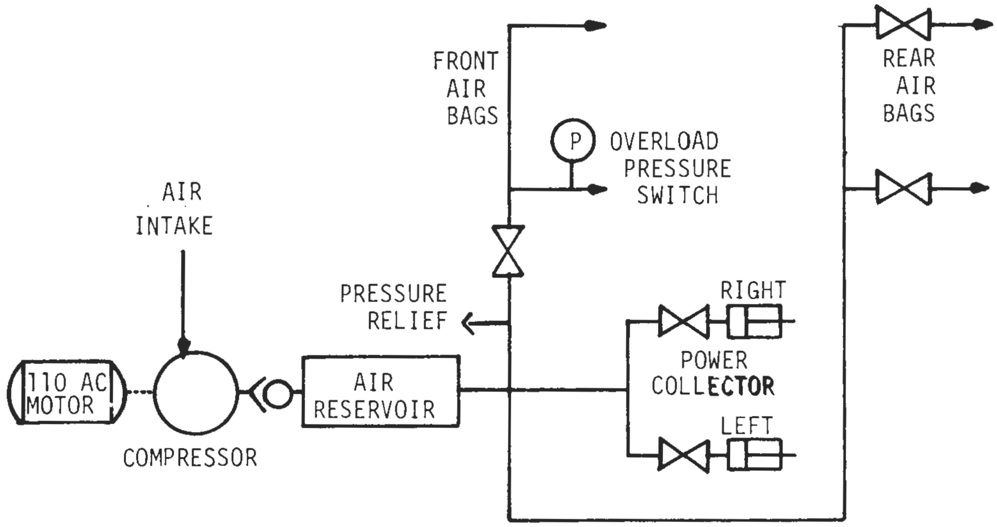


FIGURE 3.12 : SIMPLIFIED PNEUMATIC SYSTEM SCHEMATIC

Load-leveling valves are provided to maintain a constant floor height by varying air bag pressure in response to vehicle load. An overload pressure switch located in the line to the left front air bag prevents the vehicle from leaving the station if the passenger load exceeds 3,150 pounds.

Further details of the pneumatic system as it relates to the suspension and power collection systems are given in sections 3.5 and 3.6.

3.1.6 Overall Vehicle Performance

By the present standards of AGT performance, the MPM system should be considered as having high-performance vehicles. In the forward direction only (the steering system limits the vehicle to single direction operation) the fully loaded vehicle (21 passengers) is capable of the following:

a. Acceleration to 30 mph up a 1 percent grade with headwinds of 30 mph

b. Acceleration to 22.5 mph up a 6 percent grade with headwinds of 30 mph

c. Sustained velocity operation of 22.5 mph up a 10 percent grade for periods of 2 minutes with headwinds of 30 mph

d. Longitudinal acceleration from 0 to 0.0625 g with longitudinal jerk limited to 0.125 g/sec.

During interviews with Boeing engineers, it was reported that speeds up to 45 mph have been attained powering downhill during tests without any significant lateral instabilities. However, the propulsion and braking systems, longitudinal control system, collision avoidance system, lateral guidance system and possibly the suspension system would require redesign to accommodate the higher speeds. Also, higher speeds would probably require a tighter tolerance on guiderail alignment.

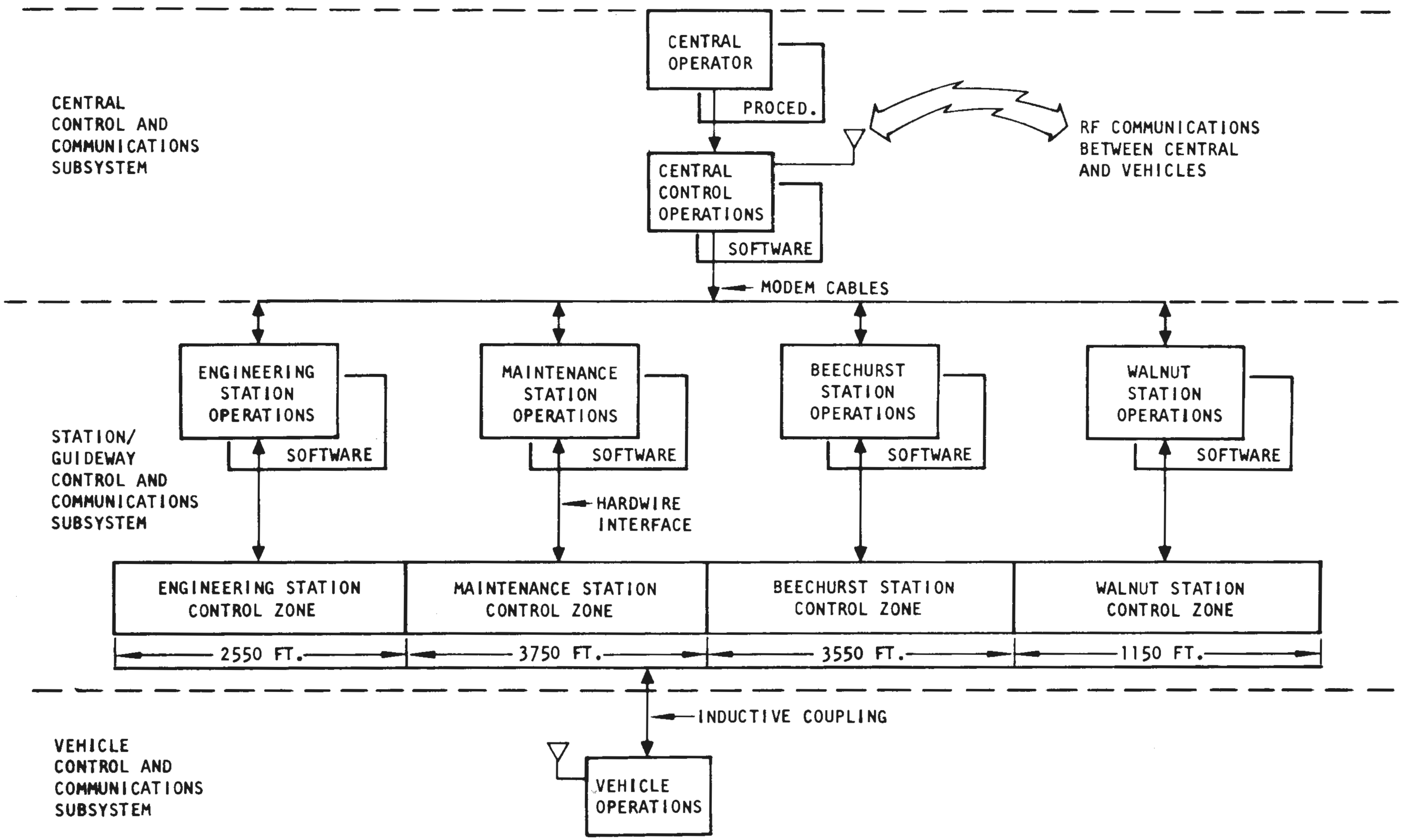
The vehicle is also capable of a short turning radius (30 feet). This characteristic, coupled with its ability to negotiate 10 percent grades, could allow a wide range of urban situations to be accommodated. The resultant flexibility in routing can reduce costs by minimizing the requirements for surface land use and by facilitating system installation into an existing environment. These performance capabilities could also contribute to improved station design. However, inability of the present vehicle design to permit bi-directional motion prevents operation with switchbacks and in shuttle or pinched loop configurations, which could be a limitation in an urban application.

3.2 CONTROL AND COMMUNICATIONS

The Control and Communications System (C & CS) controls all system operations under the supervision of the central operator. Figure 3.13 depicts its hierarchal configuration. The C & CS is responsible for operational vehicle management, longitudinal control, independent collision avoidance and other aspects of station and system management. The C & CS is separated into the following functional/hardware subsystems:

a. Central Control and Communications Subsystem (CCCS) - is responsible for overall monitoring and control of all system operations. It consists of dual central computers, computer peripheral equipment, central-to-station communication lines and modems, operator control and display consoles, a closed circuit television system, digital and voice communications equipment and the position mimic display. The original PDP 11/40 computers in Central Control have been replaced with PDP 11/55's in Phase II. The heart of the CCCS is the Central Applications Program (CAP), a software package which defines all vehicle management procedures. The CAP governs vehicle dispatch either in the scheduled or on-demand modes, prescribes reduced service modes, allows central operator intervention in the remote mode, and allows manual operation of a vehicle by an on-board operator. The CAP also collects, evaluates, and displays system status to the operator and governs system anomalies and abnormal operations.

b. Station and Guideway Control and Communications Subsystem (S/GCCS) - has both operational and safety-related functions. Operationally it performs the control and monitoring functions for local transit operations at the passenger stations and the maintenance facility under the direction of Central Control. Dual station computers control local vehicle operations such as switching, stopping, door operations, vehicle dispatch (according to dispatch timing set by the CAP), and station graphics. The S/GCCS also includes the fare gates and all guideway-mounted equipment related to monitoring and control (i.e., frequency shift key and signal tone wires, vehicle presence detectors, and cabling). In addition, the S/GCCS includes active electronic elements which drive guideway-mounted components. The station computers generate commands which are communicated to the vehicles inductively via loops buried in the guideway running surface. They also receive vehicle status information over inductive loop communications transmitted by the vehicle. Each station computer has a real-time software program, the Passenger Station Application Program (PSAP), similar to the CAP, for control of all passenger destination requests, vehicle berthing and movement through station channels, passenger loading and unloading, and vehicle dispatching. The PSAP also monitors all



SOURCE: Boeing Aerospace Company

FIGURE 3.13: CONTROL AND COMMUNICATIONS SYSTEM CONFIGURATION

vehicle operations in the station, acceleration and deceleration ramps, and guideway under its jurisdiction. When a vehicle arrives at the boundary where a different station computer has jurisdiction, control is handed over to the station computer ahead of the vehicle, via the central computer. There is no direct communication between station computers.

The safety function of the S/GCCS is performed by the Collision Avoidance System (CAS). The CAS is provided to ensure safe movement of vehicles along the main guideway, switch areas, and station ramps. There is no CAS in the station channels. The CAS is a fixed-block system which detects a vehicle as it enters the block by means of magnetically sensitive presence detectors. Upon detection, the "safetone" is removed from the immediately preceeding block. Vehicles must receive a safetone, otherwise emergency brakes are actuated. The CAS implementation is redundant (fail safe) in that it contains separate hardware and software logic, both of which must operate and agree before a safetone can be transmitted.

c. Vehicle Control and Communications Subsystem (VCCS) - is the portion of the C & CS on board the vehicle. It receives commands from the S/GCCS and processes them to generate motor and brake commands for regulation of vehicle speed and guideway position, door open/close signals, and switching functions. The VCCS also transmits vehicle status to the S/GCCS via the inductive loop system. The Longitudinal Control System, basically implemented in the VCCS with the central computer monitoring vehicle position along the guideway, is discussed further below.

3.2.1 Vehicle Management

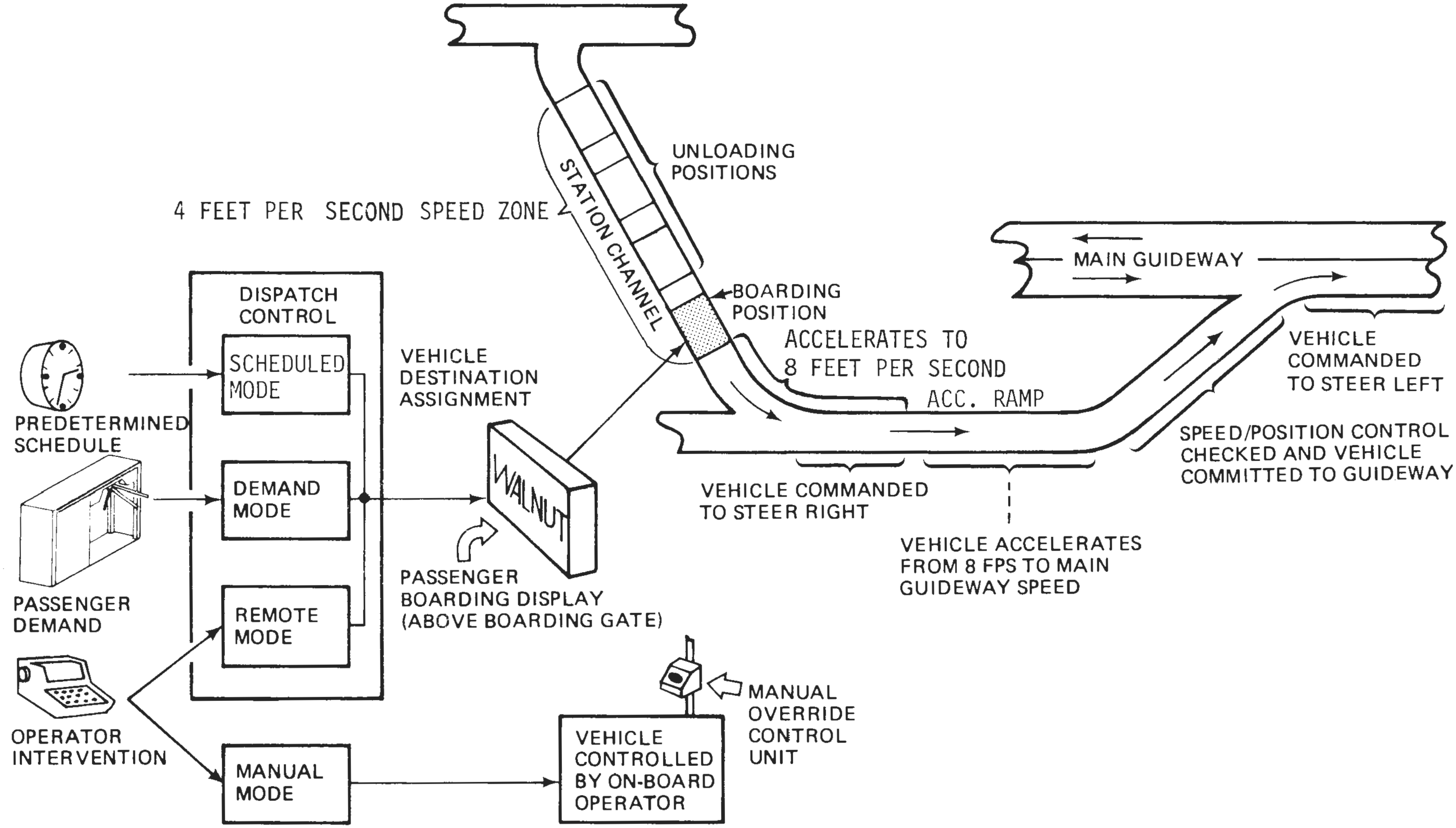
Vehicle management is provided by the CCCS and S/GCCS. System operational strategies are classified under either the normal state or the non-normal state. In the normal state there are two basic modes, scheduled and on-demand, with a transition mode for changing from one to the other. In the non-normal state there is a remote mode and a manual mode. In Phase I the non-normal state also included a reduced-service mode which has been deleted in Phase II.

During Phase I, the scheduled mode was used primarily during the hours of maximum passenger demand, from 7:15 a.m. to 5:30 p.m. The on-demand mode was used only in the evenings, from 5:30 p.m. to 8:30 p.m. The new Phase II demand mode algorithm may be more efficient during both peak and low-demand periods and it will be tested at peak demand during Phase II.

Figure 3.14 shows the process by which a vehicle is dispatched, accelerated and merged onto the main guideway. As discussed later in subsection 3.2.2, virtual points (or slots) separated at 15-second intervals move along all guideway sections except station channels in a synchronous fashion. A vehicle can be dispatched only to an empty slot moving on the main guideway. One station channel is capable of dispatching a vehicle to one out of three empty slots (i.e., one vehicle every 45 seconds.) Therefore, a three-channel station is capable of dispatching vehicles to every guideway slot at a rate of four vehicles per minute.

Scheduled Mode

The scheduled mode consists of a pre-programmed set of dispatch rates, calculated to correspond with a prescribed WVU demand. The schedules are not rigidly fixed--vehicles do not arrive at and depart stations at precise times. Table 3.1 gives the Phase I scheduled dispatch rates for Tuesdays and Thursdays. The schedule for Mondays, Wednesdays, and Fridays was similar, except that it was tailored to the expected demand occurrence on those days.



SOURCE: Boeing Aerospace Company

FIGURE 3.14 : DISPATCH CONTROL

TABLE 3.1: SCHEDULED DISPATCH RATES FOR PHASE I
(Tues. & Thurs.)

Schedule Number	Schedule Start Time	Dispatch Rate E-B or B-E*	Vehicles/5 min B-W or W-B*	E-W or W-E*
151	0715	5	1	1
152	0800	2	1	1
153	0840	4	1	2
154	0905	5	1	1
155	0940	2	1	1
156	1020	5	1	1
157	1100	2	1	1
158	1135	3	1	1
159	1200	5	2	1
160	1235	3	1	1
161	1330	4	2	1
162	1420	2	1	1
163	1505	5	1	1
164	1540	2	2	2

* E - Engineering, B - Beechurst, W - Walnut stations

In the Phase I system there were two types of scheduled mode operations for the Beechurst station, "normal" and "dedicated platform". The Beechurst station has two platforms, designated as Platforms "A" and "B". Platform "A" is served by two channels which always turn vehicles back in the direction of the Engineering station. From Platform "A" passengers can board vehicles only to Engineering. Platform "B" can dispatch vehicles in either direction, but will do so only in the "normal platform" mode. In the "dedicated" mode, Platform "B" dispatches vehicles only in the direction of Walnut. Every schedule was based on one or the other of these two types of operations. The type of operation was required to correspond with the schedule and vice-versa or traffic between stations would not remain in balance. Other than the schedule itself, there was no automated procedure for balancing station vehicle inventories, such as existed in the demand mode. For each station, however, there was a table of channel inventory goals used for routing incoming vehicles in order to balance the channels and organize the vehicles to meet prescribed dispatches.

In Phase II, the software changes are expected to improve vehicle management in the scheduled mode. These changes include initial channel inventory goals and target dispatch rate schedules. The operator will be able to interject revised inventory goals and target schedules to handle an expected deviation in passenger demand. These changes also include an automatic positioning of vehicles when changing to the scheduled mode.

Vehicles travel non-stop to their assigned destination. In the scheduled mode, passengers entering the station register their destination requests in the same manner as for the demand mode. In Phase I these data were only collected and were not used to automatically change the dispatch rate. The software did not permit this function. Future applications might consider the use of such on-line data to effect temporary changes in the dispatch rate and to automatically update overall schedules over the long range.

System parameters set by the operator included calendar date, time, door timing, vehicle (passenger) load parameters, vehicle spacing, vehicle mileage statistics, and schedule type.

The data required for automatic, scheduled-mode passenger service were the timetable records (TTR's). TTR's could be linked together in an arbitrary time sequence called a string, so that once the operator had started the sequence, the rest cycled automatically. If a string erroneously contained an empty or invalid TTR, the system would continue to operate under the last valid TTR and a warning message was sent to the operator.

Demand Mode

In the Phase I demand mode[2], the software responded to selections of destinations by passengers. A passenger selection caused the software to assign a vehicle to the passenger for nonstop transportation to the destination selected. The demand mode was normally used during off-peak traffic periods and could be initiated automatically at a predetermined time each day or by intervention of the operator. The software terminated demand-mode operations when the scheduled mode was initiated. The system had to be operated entirely in either the scheduled or demand mode. Mixed operations were not possible.

System inventory management in the demand mode had two objectives: 1) to ensure that no vehicle was dispatched to a station that did not have an available berth upon vehicle arrival, and 2) to maintain the desired inventory of active vehicles at the various stations in the system. Prior to assigning a dispatch time to a vehicle, a check was made to see that the destination station was operating and that a berth was available. If no berth was available, a vehicle was dispatched from the destination station to the station having the fewest vehicles in relation to its minimum inventory requirement.

When the passenger-carrying vehicle was dispatched, the station from which it departed was checked by the CAP to see if it had fewer vehicles than the assigned minimum, including vehicles which had been dispatched to it from other stations but that had not yet arrived. If there were too few, vehicles were sent from the station having the highest number of vehicles above minimum.

In the demand mode, software responded to a passenger demand as follows:

a. Accepts a passenger destination selection.

b. Assigns a vehicle in a loading berth or, if a vehicle is not available in a loading berth, assigns the first available vehicle.

c. Causes the passenger boarding display to show the selected destination of the vehicle.

d. Controls the door operation.

e. Assigns subsequent passengers making the same destination selection to the current vehicle, if the number of assigned passengers is less than the value set by the system operator and the extended door open time limit, also set by the operator, has not been exceeded.

Transition Mode

In Phase I a transition mode was included in the software to minimize operator intervention and interruptions in passenger service when changing schedules or when changing between scheduled and demand modes. In the demand-to-scheduled transition, the operator selected a special transition mode which redistributed the vehicles to the proper initial conditions of the selected schedule. This process is completely automatic in Phase II. In the schedule-to-schedule transition, the scheduled dispatch rates were usually switched automatically, but the operator could intervene with a dispatch rate different from that scheduled to accommodate a temporary demand change, such as to clear a crowded platform. In the scheduled-to-demand transition, redistribution of vehicles to the prescribed minimum station inventories was performed automatically.

Reduced Service Mode

The non-normal state was simply defined as less than normal operation and typically results from a failure or other abnormal conditions. It was used for failure management and system recovery. The reduced service mode allowed either the scheduled or demand mode to continue at a reduced level of performance. For example, the operator could eliminate passenger service at one station, change the interval spacing (headway), or change system performance levels during system restart. The software changed system performance levels only when all vehicles were stopped. The Phase I reduced performance levels (lower speeds) were not used and are discontinued in Phase II.[9]

Remote Mode

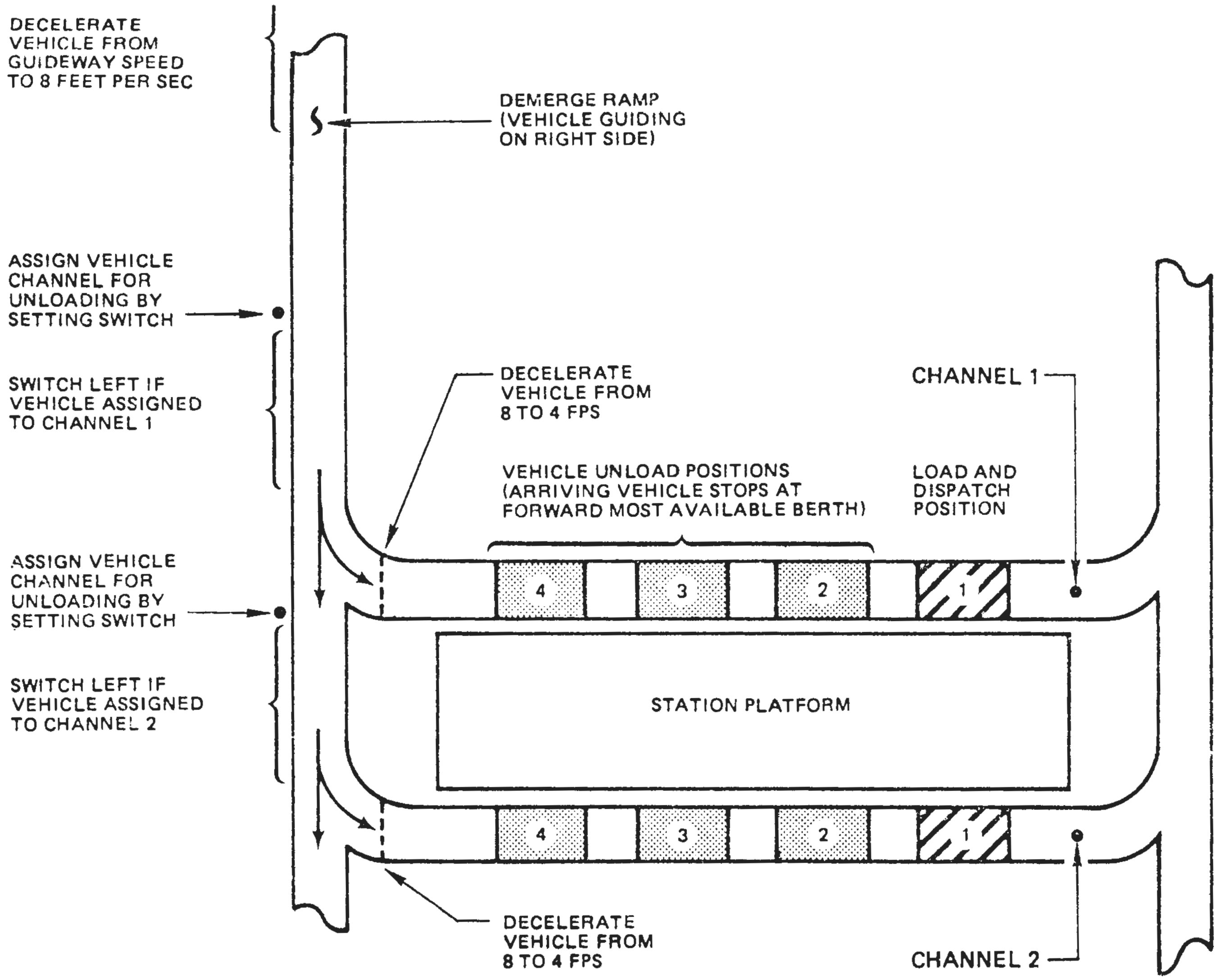
The remote mode is used for anomalous vehicles or when operator control is desired, for example for security reasons or for maintenance. The operator can assign the destination to a vehicle; the software automatically dispatches the vehicle to the assigned destination and responds to vehicle movements, the same as for the scheduled or demand modes.

Manual Mode

A manual mode is used when an on-board operator is required, such as during recovery of a stopped car. The central computer automatically tracks movement of manually controlled vehicles and reports any movement anomalies but does not issue operational commands. Operational procedures preclude other vehicles from operating in the same guideway control zone where one vehicle is being operated in the manual mode. While there is no software constraint that prevents other normal vehicles from operating in that control zone, the CAS continues to protect against a collision should the central operator err. Vehicles operated in the manual mode are limited to speeds of 10 ft/sec.

In-Station Vehicle Management

Figure 3.15 depicts the procedure for in-station vehicle management. Vehicles are processed sequentially through a station channel, since a vehicle can move forward only after the berth in front of it is clear. The total dwell time in the station is longer than if simultaneous movement were allowed, since sequential movement through the station is used for safety reasons. The length of in-station dwell time is irrelevant for periods of low passenger demand when it is preferable that vehicles be stored in the station channels. During high-demand periods, most of the vehicles are en route on the guideway and dwell time is by design lower--just enough time (approximately 1.5 minutes) to unload, move sequentially forward to the loading berth, load and depart.



SOURCE: Boeing Aerospace Company

FIGURE 3.15 : IN-STATION VEHICLE MANAGEMENT

In the Phase I scheduled mode, the dispatch rate for vehicles was slowed during the off-peak period to 40 percent of the peak period rate. Because the peak to off-peak to peak cycle was short (coinciding with change of classes), there was no advantage in adjusting the operating fleet size to coincide with the demand and dispatch rate. Essentially, vehicles were accumulated in the station channels by increasing the in-station dwell time.

Timing measurements were made by the assessment team on Thursday, April 21, 1977, for all vehicles moving through the system for the period 8:15 to 9:30 a.m. This time span was selected because it covered a peak and off-peak demand period representative of a pattern which was repeated over most of the scheduled operating time for Tuesdays and Thursdays. The demand periods for Mondays, Wednesdays, and Fridays were similar, although some peaks were slightly lower. During these measurements there were 16 vehicles in the operating fleet.

Long dwell times were observed in all stations, and these might have been even longer had the fleet been at the maximum of 22. The observations were recorded as follows:

TABLE 3.2: VEHICLE IN-STATION DWELL TIME

Station	Mean (Minutes)	Range (Minutes)
Walnut	2.6	0.77 - 4.92
Beechurst ("A" Platform)	3.1	1.48 - 7.80
Engineering	3.1	1.49 - 6.68

Source: NDL and SNV measurements, April 21, 1977

To determine shorter in-station dwell times realizable under present Morgantown station management procedures, a simulation was performed by the assessment team, assuming the following:

- o Door open time for unloading or loading of 15 seconds
- o Station initially empty of vehicles
- o Unloading of passengers at first, most forward empty unloading berth (berths 2, 3, or 4)
- o Loading of passengers only from the most forward berth (berth 1)
- o Vehicles, when ready, are dispatched at the next most available opportunity (rates of 4 opportunities per minute).

The results yielded an average dwell time of 61 seconds. The simulation also assumed that two consecutive vehicles in a channel could begin moving at the same time. Since this procedure is not allowed for safety reasons, a ten-percent margin for sequential movement was added, resulting in a simulated minimum dwell time of 1.1 minutes. It is realized that shorter dwell times could be achieved by reducing the door open time to a minimum of five seconds. However, such a short door open time is inconsistent with the need to fully load vehicles during high-demand periods.

For urban applications the periods between peak and off-peak demand will be longer than at Morgantown. If the system is designed only for scheduled operations, off-line stations need not be used and "storing" vehicles in the stations would not be necessary. This would permit simultaneous loading and unloading which would improve station and vehicle efficiencies. However, if AGT demand service is provided and off-line stations are used, consideration should be given to the impressions created by empty vehicles queued in stations while patrons wait for trips.

3.2.2 Longitudinal Control

The Longitudinal Control System (LCS) is defined as the vehicle system which converts speed commands from the guideway into a desired vehicle speed/position/time trajectory.

The LCS consists of four major elements:

- o Vehicle Control and Communications System (VCCS)
- o Electric Propulsion Motor
- o Brake System
- o Vehicle.

The key LCS requirements are as follows[5] (taken as $\pm 3\sigma$ limits):

- o Position control of $\pm$ 1.1 seconds in following the moving point
- o Station stop accuracy of $\pm$ 6 inches
- o Over/under speed tolerances of + 3.3, -4.0 fps
- o Acceleration control during speed transitions of 2.0 (+2.4, -0.5) fps^2
- o Jerk control for time intervals equal to or greater than 0.2 seconds of $\pm$0.125 g/sec and time intervals less than 0.1 second of $\pm$0.25 g/sec.
- o Maximum brake drag of 36 ft-lb wheel torque.

At Morgantown the LCS method employed is the synchronous "virtual" point-follower concept (Figure 3.16). A series of moving points, or slots, separated by 15-second intervals (headways), circulates in the C & CS computers referenced to a fixed time base. The vehicles are assigned to respective moving points by controlling their time of dispatch. After dispatch each vehicle is autonomous in following its point and does not receive position control command signals from either the station or central computers. The vehicle operates under velocity control with periodic reports of position to the C & CS computer as it passes presence detectors (PD) in the guideway. This form of longitudinal regulation relies upon accurate on-board measuring and control of velocity.

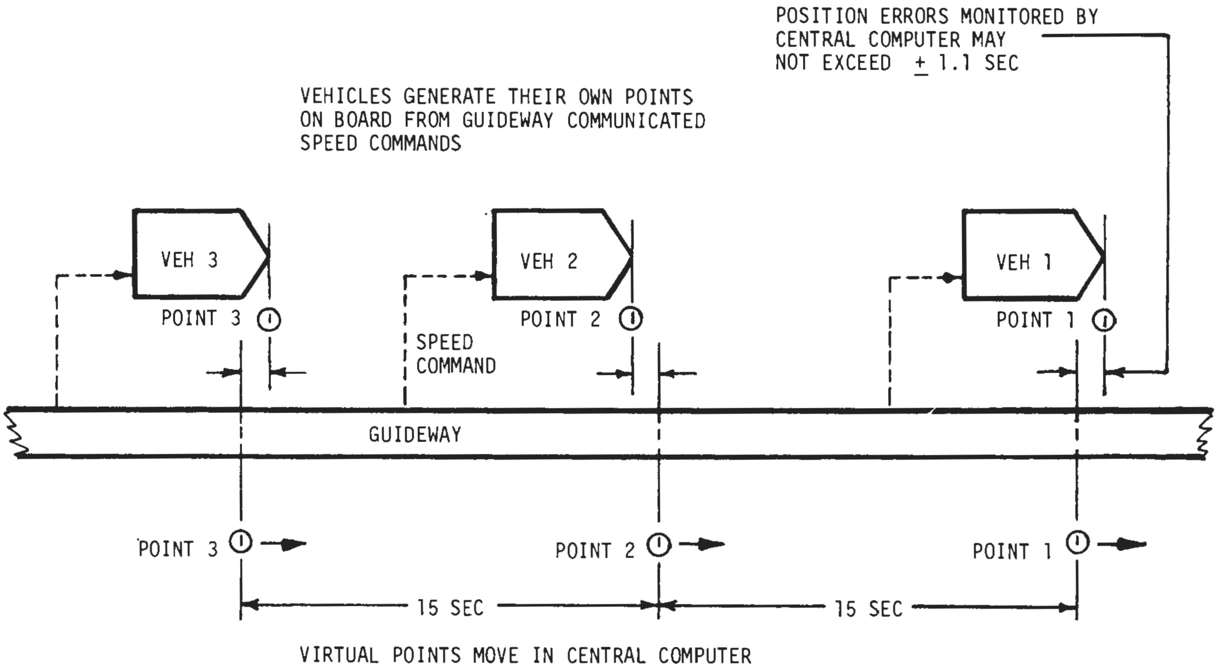


FIGURE 3.16 : SYNCHRONOUS VIRTUAL POINT FOLLOWER HEADWAY CONTROL

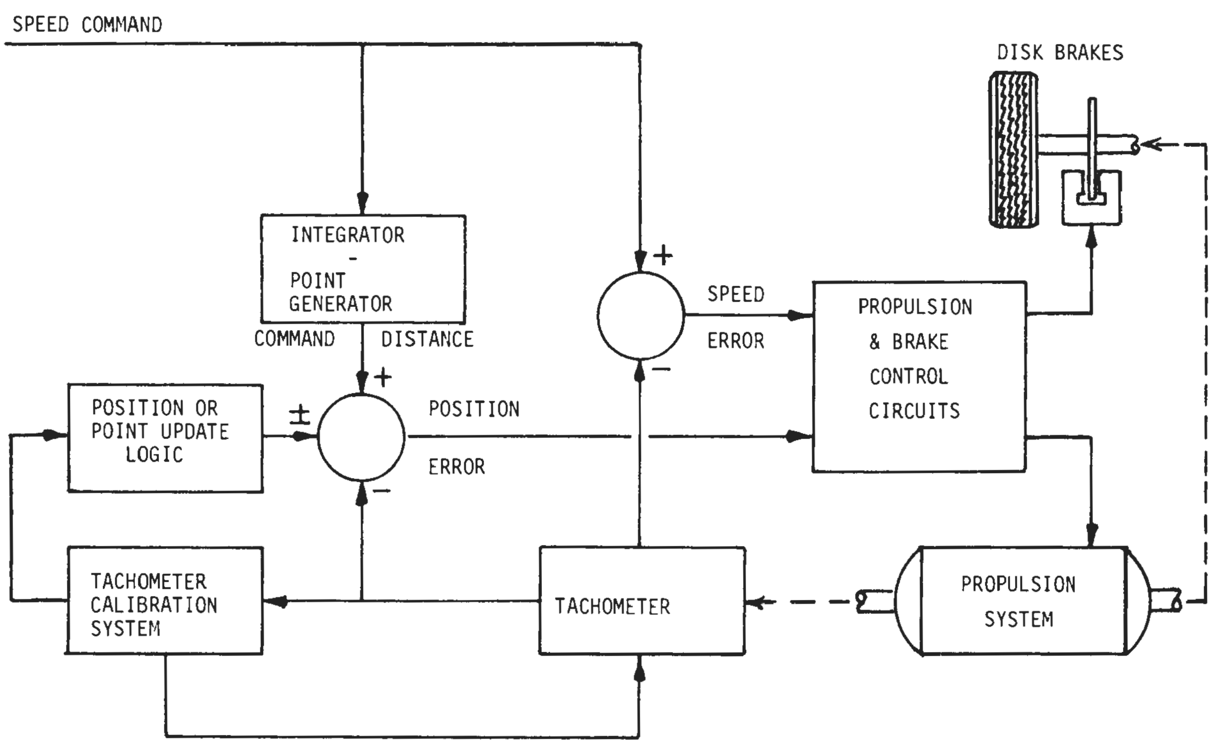


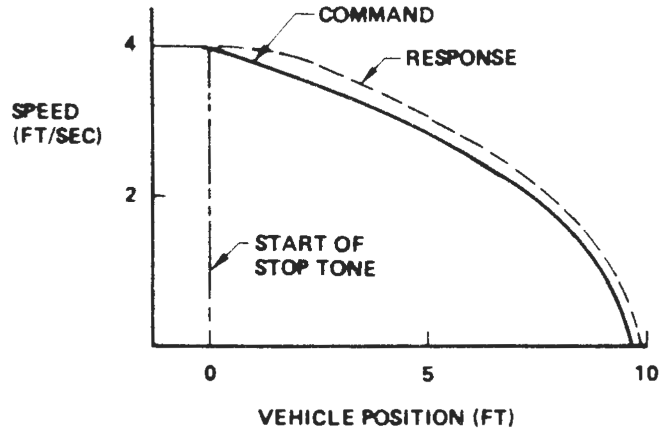
FIGURE 3.17 : SIMPLIFIED ON-BOARD LONGITUDINAL CONTROL SYSTEM

The VCCS generates an on-board train of electronic reference pulses. The rate at which these pulses are generated is based upon the commanded speeds received from speed-tone loops in the guideway. The actual vehicle speed is measured by the rate at which pulses are generated by redundant motor shaft tachometers. The difference between commanded and measured pulse rates from the tachometers is proportional to vehicle speed error. The difference in pulse counts is proportional to position error. The LCS supplies appropriate motor/brake commands so that the actual speed/position/time trajectory of the vehicle matches the trajectory of the theoretical point within prescribed tolerances. Figure 3.17 is a simplified model of the on-board vehicle longitudinal control system.

A position error is generated by integrating the difference between the commanded and measured vehicle speed. This form of integral control results in a zero steady-state velocity error. Speed is measured on board the vehicle via a motor shaft-mounted tachometer. The output of the tachometer is recalibrated periodically along the guideway. After recalibration, a position error update signal is automatically included to adjust for past tachometer inaccuracies. For ride comfort, the motor speed command signal is acceleration and jerk limited, while the brake command is jerk limited. The motor speed command is applied to the closed-loop propulsion control system with negative feedback of motor speed via the tachometer. In addition, an internal closed-loop motor current control is used. The control laws for motor speed and current provide both proportional and integral control to ensure motor speed accuracy of ±13.2 rpm.

An on-board deceleration profile control concept is used to stop vehicles accurately at station berths, as shown in Figure 3.18. Test results shown in Figure 3.19 verify that this method repeatedly stopped vehicles within the ±6-inch requirements.

Overall, the LCS appears to function well as observed or communicated to the assessment team by Boeing engineers or officials from WVU. For future AGT development and deployment it is important, however, to understand some of the problems encountered and their solutions.

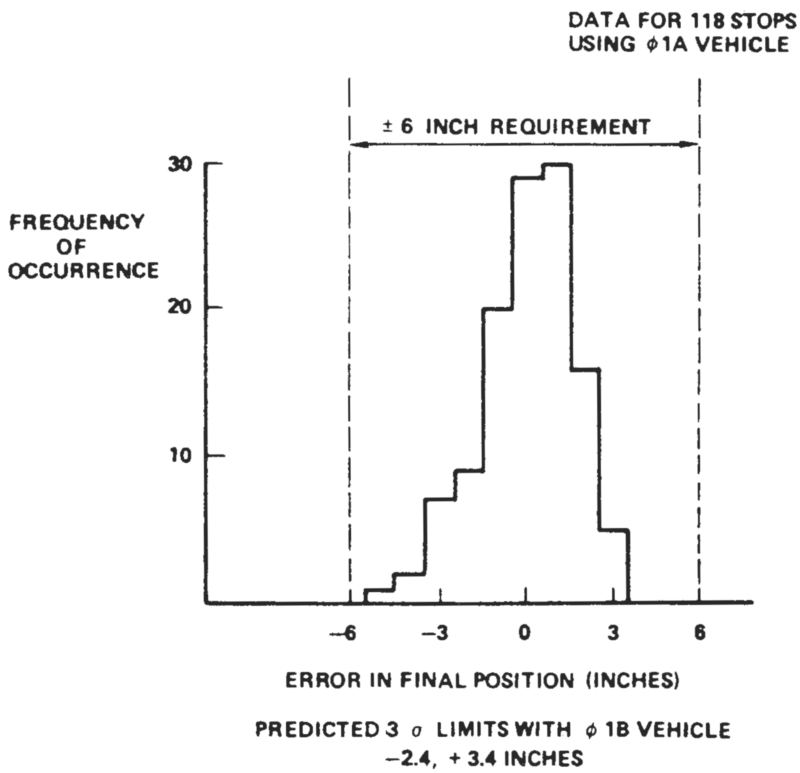


$$\dot{X}_C = 4\left[\frac{X_{SS} - X}{X_{SS}}\right]^{1/2}$$

$$\ddot{X}_c = -0.026 \text{ G's}$$

SOURCE: Boeing Aerospace Company

FIGURE 3.18: IN-STATION STOPPING CONTROL CONCEPT



SOURCE: Boeing Aerospace Company

FIGURE 3.19: IN-STATION STOPPING TEST RESULTS

Design verification testing, both at Boeing's test track at Seattle and at Morgantown, demonstrated good vehicle longitudinal control repeatability, although average errors relative to the theoretical trajectory were larger than expected.[5] Variations in tire rolling radius and errors accumulated at the start of speed transitions predominated over errors due to wind and grades. Variation in tire rolling radius can produce a steady-state headway error of $\pm$7.5 ft at 44 fps, which is the same as that produced by a ten percent grade. While use of steel-belted radial tires would reduce the error, they may not be compatible with the steering concept. Total error was found not to be a strong function of trip length, but of the number and type of speed transitions encountered. Relatively large deviations from the theoretical trajectory (up to 0.9 seconds) plus a nominal steady-state error (0.24 seconds behind point, deliberately implemented to minimize brake/motor interaction) made it mandatory to program a nominal (or average) trajectory in place of the theoretical trajectory. This nominal trajectory constitutes a data base in CCCS operational software for dispatching and monitoring performance. It accounts for nominal systematic errors or biases which can then be excluded from the performance error budget by maintaining position error within $\pm$1.1 seconds of the nominal trajectory. For future applications of the synchronous virtual point-follower concept, it is important to note that each section of guideway will require its own site-specific nominal trajectory.

A very thorough and detailed error analysis of the LCS performance was carried out by Boeing personnel. A major finding in both the Phase 1A and Phase 1B LCS design efforts was that hardware nonlinearities and variations in control system parameters have a significant impact on system performance. The root-sum-square (RSS) method of combining standard deviations from nominal was used throughout the analysis. This assessment has examined the application of RSS in the position control error analysis and finds that it has been applied consistent with its basic theory and requirements.

During Phase 1B an instability problem was experienced in the propulsion speed controller due to drive-line dynamics. The problem was solved by phase stabilization of the motor speed control loop by inserting a lead network in the tachometer feedback and by making several circuit changes, including:

- o Removing the positive feedback loop from measured motor back emf to SCR firing command
- o Changing the circuit time constant to reduce the motor current loop phase lag
- o Reducing the limiter loop gain to reduce the current-rate limiter phase lag.

The lead network results in the vehicle operating at higher than command speed during low-speed operations (4 fps). Mounting the tachometer on the wheels would provide a simpler solution to reducing the effects of drive-line dynamics.

Another problem was encountered with the brake system servo valve maintaining command pressure under some transient conditions due to a limited hydraulic fluid flow capability. The problem was solved by installation of two orifices and bypass check valves which externally limit fluid flow rates to a range within which the servo valve can maintain adequate pressure regulation.

The hydraulic braking system is redundant (primary and secondary pistons acting on the same set of calipers). Gain nonlinearities and differences in gain were encountered between the redundant channels. These problems were solved by brake amplifier readjustments to compensate for the known nonlinearities.

Future applications of the Morgantown LCS concept require consideration of three site-specific features, as follows:

a. The nominal trajectory for the virtual point-follower LCS is empirically derived and is affected most by speed transitions and grades. Any future urban system would require generation of special nominal trajectories for each section of guideway and storage of nominal trajectories in the central computer. For large systems, the number of such trajectories should not be a problem because storage of such a data base occupies only a minor portion of available computer memory.

b. The VCCS contains its own crystal clock which establishes the time base for computation of the on-board point-follower trajectory. A VCCS clock error results directly in a position error which increases with trip time or length. This error at Morgantown is minor (a maximum of 0.08 seconds for a trip between Engineering and Walnut stations). It could become larger for systems where trip lengths are significantly longer, thus making it more difficult to meet the ±1.1-second position error tolerance. The ±1.1-second tolerance was based upon a headway of 7.5 seconds; therefore, the tolerance could be widened for 15-second headways in a new installation. The present VCCS clock accuracy is 0.02 percent. The position error in this case could be decreased by synchronizing the VCCS clock with the station computer clock or central computer clock periodically while the vehicle is en route.

c. The central computer and all wayside computing equipment use the local power-line frequency as a time base. This line frequency was used because of problems experienced with standard clocks included in the computers purchased. Such a time base is considered to be site-specific for two reasons. First, it is considered that more than eight consecutive days of data are required to reliably show that short-term power-line variations will be within ±0.1 percent. Second, the worst case position error (0.28 seconds) results from dispatching a vehicle from Engineering that later merges with a vehicle from Beechurst going to Walnut during a time when the power-line frequency varies over its maximum range. During Phase II the worst case may nearly double the error contribution due to central clock inaccuracy. For larger systems with more stations, longer trip lengths and guideway interchanges, the error contribution could become even more significant. The power-line frequency as a time base may therefore not be considered of sufficient accuracy for very large systems.

The performance requirements for speed and position control are met by the present LCS, even though the system has a relatively low ability to handle expected parameter variations and nonlinearities. To achieve stability it was necessary to reduce the control loop gain and to correct its phase. This correction slowed response of the speed control loop, resulting in a settling time of approximately four seconds due to the natural frequency of 0.213 Hz together with critical damping (i.e., for nominal-weight vehicle). The VCCS contains unnecessary complexity and circuit duplication, as well as nonlinearities within the motor speed control loop and the brake system. This complexity leads to redundant transients due to different control law dynamics in the propulsion and braking systems which aggravate the problem of propulsion and braking interaction. It is important to note that cost and schedule constraints did not permit a second-generation design in which improvements in the VCCS could be made. Many of the problems experienced with the Morgantown LCS do not significantly impact system performance. The resultant headway errors are small compared with the nominal headway of 15 seconds. If shorter headways were required, the current LCS might prove to be inadequate, because many of the steady-state errors are independent of nominal headway and would have greater effect as headway is decreased.

The Boeing Company has suggested the following four significant improvements which should be seriously studied and possibly developed for implementation in a second-generation system:

a. A single point torque control
b. Jerk and accleration limited speed commands
c. Consolidation of control functions within the VCCS
d. Wheel-mounted tachometers to minimize problems with drive-line dynamics.

The Morgantown design uses significantly different control laws to compute brake and motor torque commands. If a single point torque control (with appropriate redundancy) were used, the following advantages would result:

- Reduction of motor/brake interaction
- Reduction of sensitivity and improvement of performance potential via the possibility of increased control loop gain
- Design and analysis simplification by reduction in components, elimination of duplicated control functions, and simplification of interaction between subsystems.

At present, the design uses jerk limitation of the motor speed and brake deceleration commands. The proposed approach is to apply jerk and acceleration limits to the civil speed commands and rely upon the accuracy of the speed control system to prevent excessive jerk. Changing the location of the jerk limiting function requires single point torque control. The advantages of this approach are:

- Increase of speed loop bandwidth
- Reduction of speed error
- Design and analysis simplification by replacing three jerk limiters with a single limiter and eliminating the major nonlinearity in the speed control loop.

Present control functions are widely distributed among the VCCS, braking and propulsion subsystems. Many control functions are duplicated and complex interfaces exist between subsytems. Consolidation of control functions within the VCCS would reduce these problems.

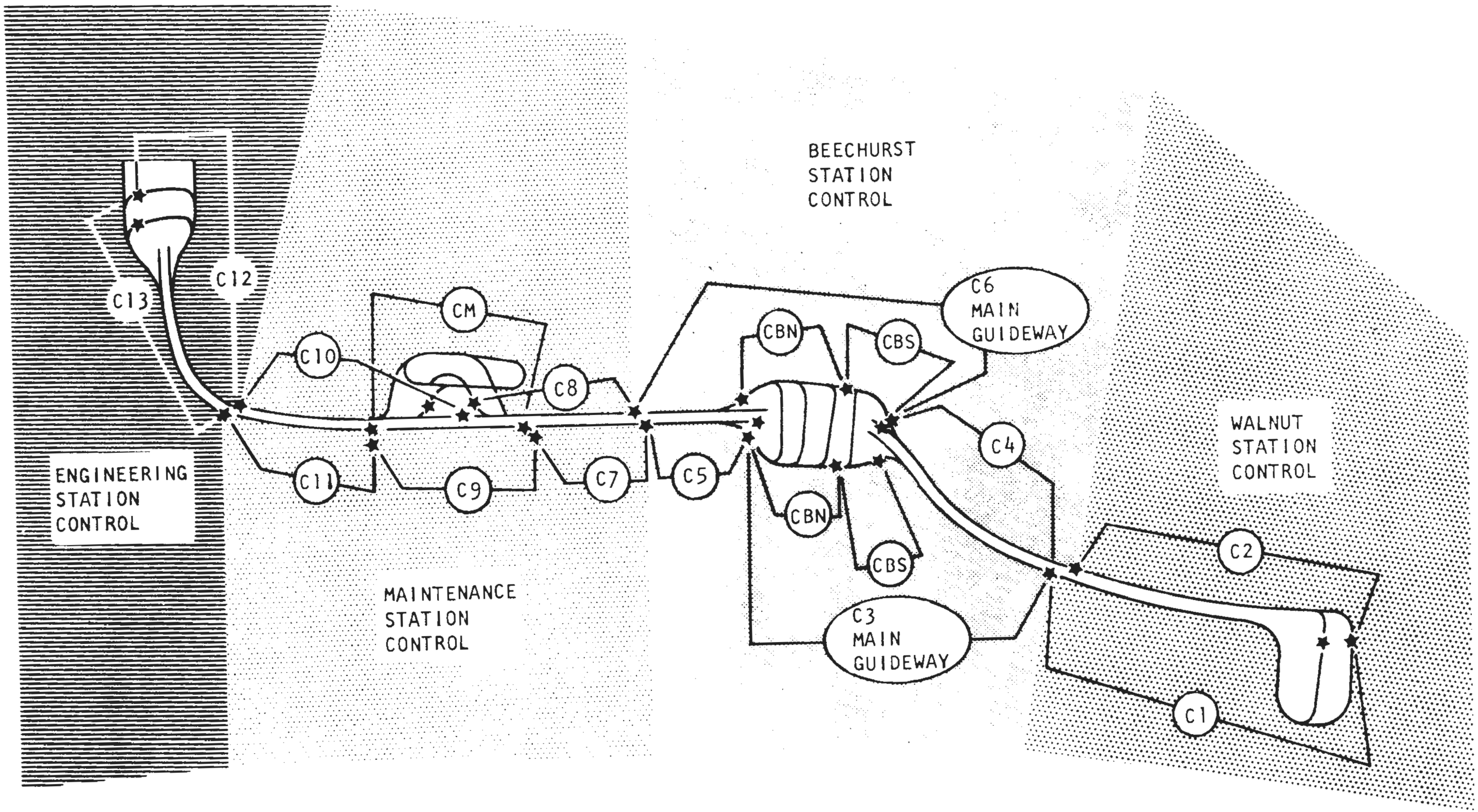
As discussed previously, the use of wheel-mounted tachometers minimizes the effects of drive-line dynamics. In addition, the possibility of a runaway vehicle due to a broken axle is eliminated. Redundant tachometers would be required to protect against false readings in the event of wheel spin. Since the wheel speed is slower than that of the motor shaft, sample rates would be reduced, requiring a change in tachometer design or the method of processing its output data.

Important experience has been gained in the course of the Morgantown system design and deployment which is considered valuable for future designs. A highly detailed and comprehensive analytical model of the LCS has been developed which may considerably expedite future design efforts. The level of detail required in this modeling effort has substantially improved knowledge of the relative importance of various system hardware characteristics. The groundwork has been laid for future work in the development of analytical models and preparation of practical hardware specifications, as well as in the definition and evaluation of proposed AGT applications studies.

3.2.3 Collision Avoidance

The Collision Avoidance System (CAS) protects against inadequate spacing between vehicles and merge conflicts. The CAS has checked redundant hardwired and software configurations and is implemented along all sections of mainline guideway and the acceleration and deceleration ramps as shown in Figure 3.20. It is not implemented in the station channels where vehicles must park nominally 24 inches apart and where vehicle speed is nominally four feet per second.

As presently implemented, the CAS monitors vehicles and prevents their operation if there is not at least one unoccupied block between vehicles. Each block has a minimum length equal to the emergency stopping distance plus the length of a vehicle.



SOURCE: Boeing Aerospace Company

FIGURE 3.20: CAS CONTROL ZONES

The hardwired CAS is entirely solid state, using no relays. For Phase II the discrete solid state circuitry has been replaced with microprocessor circuitry. As such, the Morgantown CAS should be of great interest to those concerned with the use of solid state logic for railroad signaling systems and train protection.

3.2.3.1 Headway Protection

The Morgantown vehicle controls its own velocity and position independent of the rest of the system. To verify proper performance and assure safe headways between vehicles, an independent check upon vehicle spacing is necessary. The Morgantown system is protected by using a hierarchal series of checks with successively more stringent reactions. The first check is performed by the vehicle management software in the station computer, which will command a service braking stop if the vehicle is either sufficiently ahead of or behind its programmed arrival time whenever the adjacent point is occupied. A second check is provided by the CAS, which contains both software and hardwired logic to emergency brake a trailing vehicle encroaching upon the space occupied by the vehicle ahead of it. The software logic in the CAS is assigned the decision-making responsibility, but its logic is double checked by the hardwired logic. If the two do not agree, the safetone is commanded off and all the affected vehicles in the zone will brake to an emergency stop.

Vehicle location information for these headway protection systems is provided by two sets of position detectors (PD's) located periodically along the guideway. The detectors are sealed "reed switches", miniature switches which close their contacts and complete a circuit when in the presence of a magnetic field. The field is provided by magnets located on the front of each vehicle.

Headway protection is thus provided by the following hierarchal sequence:

a. Vehicle Tracking by Software - PD hits are transmitted to the station computer, which is continually calculating the expected position of each vehicle based upon its nominal trajectory. Should the vehicle arrive more than two seconds late at a position detector and if a vehicle is located in the slot directly behind the late vehicle, central is notified and the trailing vehicle is stopped by service braking. Should a vehicle arrive more than two seconds early at a position detector and if a vehicle is located in the slot in front of the early arriving vehicle, the early arriving vehicle will be stopped by service braking.

b. Collision Avoidance System (CAS) - The CAS consists of both software and hardwired logic to prohibit encroachment of a trailing vehicle upon the vehicle in front of it.

Software "Check In Check Out" System - Information from one set of position detectors is analyzed by the station computer CAS software. A separate loop of wire is embedded in the guideway between each set of PD's. The guideway is thus divided into blocks, each of which consists of the wire loop with position detectors at the block entrance and exit points. The loop normally transmits a safetone consisting of a 10 kHz carrier chopped at 50 Hz, which is picked up by a pair of receiving antennae at the forward end of the vehicle. When a vehicle passes over a PD, the station software transmits a command inhibiting the safetone in the trailing block. When the vehicle actuates the next PD, the safetone is restored to the inhibited block and is removed in the block which the vehicle has just vacated. In this way, using a "check in check out" logic, the safetone is always inhibited in the block behind that occupied by a vehicle. If a vehicle moves into a block in which the safetone is inhibited, emergency braking will be immediately commanded. The logic at merge locations is slightly different and will be discussed subsequently.

Hardwired "Check In Check Out" System - Both operational tracking of vehicles and the software "check in check out" CAS involve common elements and are not by themselves considered to be fail safe. As a result, hardwired logic is used to check the proper operation of the software logic. The system consists of solid state switching circuits (Figure 3.21), hardwired to a separate set of position detectors, which serve to independently check block occupancy as explained in the preceding paragraph. The guideway is divided into zones consisting of several contiguous PD's and safetone loops. Should a disparity exist between the block occupancy indicated by software and that indicated by the hardwired solid state logic, the safetone being transmitted will be inhibited in that particular zone. This interruption will stop all vehicles within that zone by emergency braking.

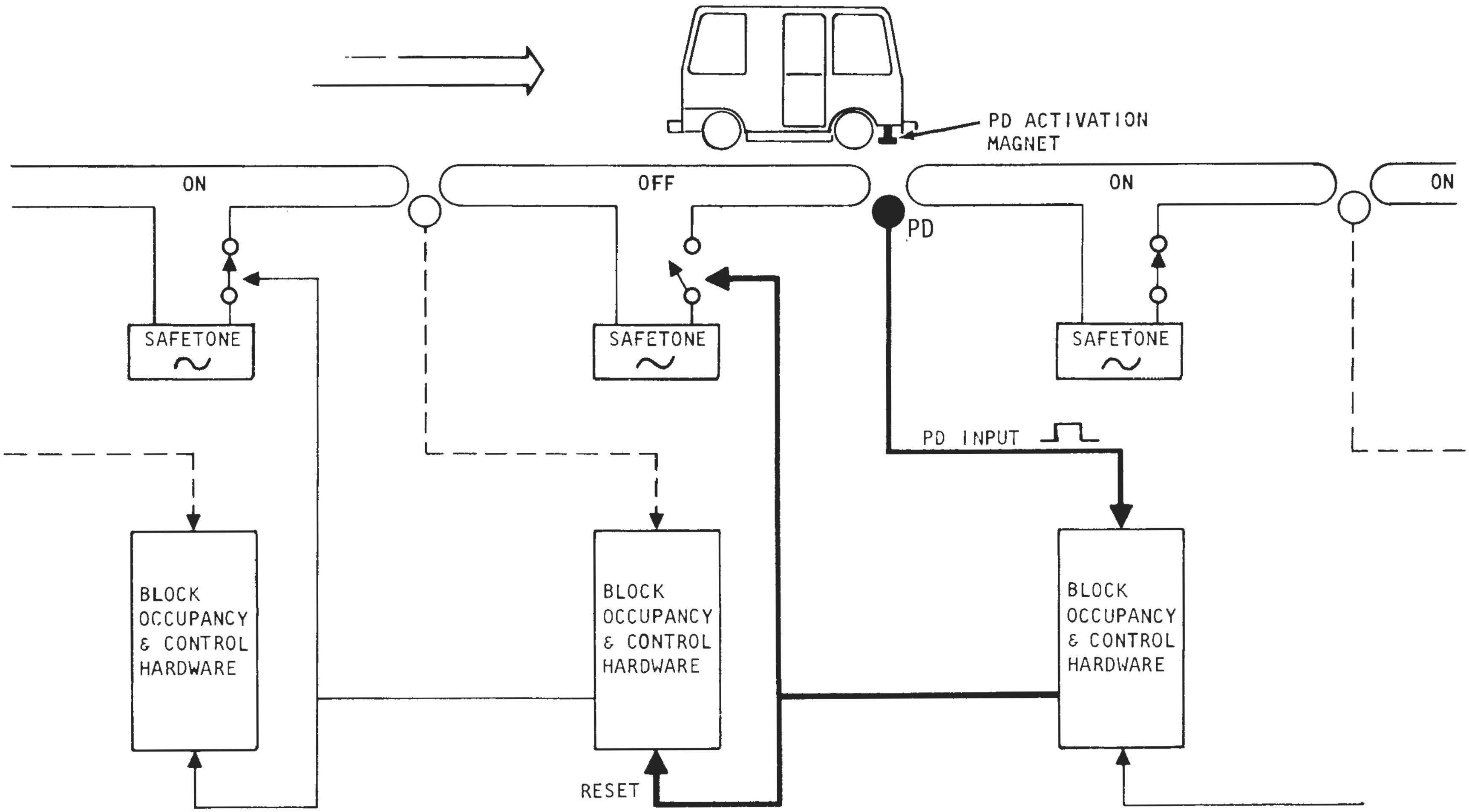
Spacing Regulation Within Station Berths

The trailing berth in each station channel is protected by the CAS against unauthorized vehicle incursions. All other berths are governed by station software.

A normally ON "stoptone" is transmitted through wire loops at all station berths to cause the vehicle to initiate a station stop within the berth. This "stoptone" is inhibited if it is desired to allow the vehicle to pass through a vacant berth or when the vehicle is to move up to the next berth position. The berth stopping profile is precisely controlled to an accuracy of ± 6 inches. Position detectors in the station berths are used to verify that the vehicle has stopped in the proper location. Once it is verified that the vehicle has stopped, the VCCS is signaled to impose a zero speed constraint. When the vehicle is prepared for dispatch, the zero speed constraint is removed from the VCCS and the stoptone is removed from the berth channel, permitting the vehicle to execute an acceleration profile up to four feet per second.

No attempt is made to maintain "brick wall" stopping distances within station berths. Instead, the rule governing software control of vehicle movement in stations is that the lead vehicle must completely clear a berth and provide verification to the software that it has properly stopped in the next berth before the trailing vehicle is allowed to move forward. Thus, simultaneous movement of vehicles in station berths is prohibited--they are required to move forward sequentially, one at a time. This station control system is not fail safe and single point failures can result in low-speed impacts between vehicles. During the first year's operation, station channel incidents where vehicles bumped occurred at a rate of once every 26 days. Not all of these incidents resulted from single point failures and in no case were there any passenger injuries. Accident reports summarized in the Morgantown Quarterly Progress Reports and inspection of the Operator's Manual indicate that these incidents occurred because of improper central operator intervention, failure of the stoptone loop, and defective software patching. The maximum speed at which such incidents can occur is limited by the overspeed protection system to 7.3 feet per second.

In an urban deployment, CAS protection could be provided within station berthing areas at the expense of additional channel length or fewer berths. Such protection was installed for the MPM-type system at Okinawa.



SOURCE: Boeing Aerospace Company

FIGURE 3.21 : CAS BLOCK CONTROL CONCEPT

CAS Protection at Switch Locations

In merge and switching regions, block circuitry normally inhibits the safetone. An approaching vehicle at a merge point is given a safetone only when it is clear from both software and hardwired logic that no conflicts exist. At all switches, a safetone is provided only after the vehicle has transmitted proper switch verification information to the CAS.

3.2.3.2 CAS System Performance

The original CAS was in the early stages of R&D at the time a design decision required its installation. A safety review conducted in 1973 found that the system could not be made fail safe. Major changes were then made in the system design. As a result of schedule and budgetary constraints some compromises were necessary which affected both capacity and safety margins.

Capacity Impacts

The original Morgantown system was designed for 7.5-second headways and this capability remains inherent in the software. However, the CAS was designed so that any vehicle entering the block behind another vehicle is braked to an emergency stop. Each block length must be at least equal to the required vehicle emergency stopping distance. In addition, since the position detector magnets are located at the front of each vehicle, it is necessary that the block length be increased by the length of a vehicle. This length is required because the vehicle will "check out" of a block while all except its front end remains within the block.

The use of this type of CAS limits Morgantown operating headways to 15 seconds. The critical operating condition occurs when the lead vehicle is at the front end of its block. To avoid an emergency stop in this situation, the trailing vehicle must be two block lengths downstream.

System capacity can be increased and headway decreased by using a multiple block system in which a number of smaller blocks behind a vehicle have their safetones inhibited. In this case, the sum of the lengths of the inhibited blocks would equal the emergency stopping distance plus one vehicle length. As the vehicle progresses to the next block, the safetone is restored to the last block in the series of inhibited blocks. According to Boeing engineers, Morgantown was originally laid out for a 7.5-second headway by inhibiting the safetone in three blocks behind the vehicle. However, the headway was increased to 15 seconds and the number of CAS loops in the guideway was reduced to save costs of guideway and station electronics.

For urban applications such a multiple block approach could be used to increase the line capacity.

Safety Margin

The design philosophies for laying out the Morgantown block system were as follows:

a. For speeds of 22 fps or greater, blocks were laid out assuming a maximum-weight vehicle and using worst-case values for deceleration, jerk, grade, vehicle overspeed, and time delay. A tailwind of 30 mph was also assumed. In addition a minimum one car-length stopping margin was required.

b. For speeds between 8 and 22 fps, the one car-length extra stopping margin was waived.

c. For speeds of 4 to 8 fps, worst-case values of deceleration, jerk, grade, vehicle overspeed, time delay, and headwind were not used. Instead, nominal expected values were employed and tolerances with respect to these nominal values were used to compute a "root sum squared" or 3 expected stopping distance. The one car-length stopping margin was waived.

The Morgantown approach does not assume any vehicle acceleration at the time emergency braking is commanded, unless the vehicle would be accelerating as part of a speed change profile. Boeing engineers stated that their studies indicated the effect of such acceleration was negligible for typical failure modes. For Phase II, the emergency braking system has been redesigned so that stopping distances will be shortened to meet worst-case conditions for all operating speeds and at all guideway locations.

Safety margin is defined as the additional block length provided beyond that required by the above-ground rules. In laying out blocks, the Morgantown approach has been to provide as great a safety margin as possible consistent with operating constraints upon block lengths. Safety margins vary widely from as little as 0.1 feet to over 100 feet.[15] In general, the minimum safety margins occur at lower speeds.

Although nominal operating headways on the Morgantown system are 15 seconds, the minimum theoretical headway (not an operational headway) at critical segments of the CAS is as short as 3.5 seconds at speeds of 17 feet per second and 4.2 seconds at a speed of 33 feet per second.[15] Operational software will normally prevent actual headways from dropping below 11 seconds (Section 3.7.4.4.2.1 of Ref. 7). For example, if a vehicle is overdue by 2.0 seconds or more, software will stop trailing vehicles if the adjacent trailing reference point is occupied. If a vehicle is early by 2.0 seconds or more and the point ahead is occupied, the software will stop the early vehicle and all trailing vehicles. This feature is not part of the Collision Avoidance System, but it does diminish the number of braked stops at emergency rates.

It is possible for system personnel to defeat the hardwired portion of the redundant CAS by manually inserting CAS override plugs necessary for carrying out maintenance operations. There were two cases which are cited in the Safety Incident/Accident Report[8] for the first operational year:

1. A CAS override plug was found to have been inserted in Zone 6 at the Beechurst station for a period of 5 days (January 25 to 29, 1976). Zone 6 is the entrance ramp to Beechurst coming from the Walnut station.

2. On August 8, 1976 it was discovered that all CAS override plugs were installed in the Beechurst and Maintenance stations, presumably inhibiting the hardwired CAS under the jurisdiction of these stations.

No accidents were reported that were related to these incidents. The reasons for use of the override plugs were cited in the report as "trouble shooting CAS problems" and "system operator failed to request removal of the plugs". To prevent reccurrence, "personnel were advised to check override plugs every morning". Because of these incidents it is planned to more rigorously follow and enforce operational rules intended to prevent leaving the plugs in place during normal operation. In addition, some form of alarm or lock-out system seems desirable, to assure that the purpose of the CAS is not defeated.

3.3 STEERING AND SWITCHING

The vehicle is provided with double Ackerman steering (front and rear wheels are steered similarly to those in an automobile) allowing it to negotiate sharp turns as short as 30 feet in radius. Figure 3.22a is a functional diagram of the steering system and Figure 3.22b shows the actual steering arm. Switching is an integral part of onboard steering and involves no moving parts in the guideway.

3.3.1 Steering System Description

Steering is based upon a "curb-follower" concept, where guidewheels mounted at the front end of the vehicle follow either the left- or right-hand wall (guiderail) of the "U"-shaped guideway. Guidewheel sensing of force against the guideway wall serves to regulate flow in a power steering control valve which controls the hydraulic power steering actuator. The power steering actuator is constantly countering the steering force being applied by a mechanical spring, referred to as the bias spring. The bias spring is sized to generate sufficient steering force to drive the guidewheel hard against the guiderail in the event of a power steering failure. It is possible that excessive friction in the steering mechanism might require a force greater than is available from the bias spring. Therefore, a "preload spring" is provided which, in the event the guidewheel begins to leave the guiderail, reverses the direction of the hydraulic flow control valve so that the power steering cylinder can assist the bias spring in maintaining guiderail contact. Availability problems caused by the hydraulic control valve and the "preload spring", in particular during cold weather operations, have resulted in a Phase II design that eliminates these two components. For Phase II the guiderail steering force is developed solely by a mechanical spring.

Steering forces exerted by the bias spring and modulated by the power steering actuator work directly upon the guide axle steering linkage. All vehicle wheels are moved through transverse links and a fore-to-aft torque tube. Steering forces on the vehicle are developed, not through force on the guidewheels, but by tire scrubbing forces at the tire/guideway interface, created by turning the wheels at an angle to the direction of vehicle motion in a manner similar to the steering of automobiles and buses.

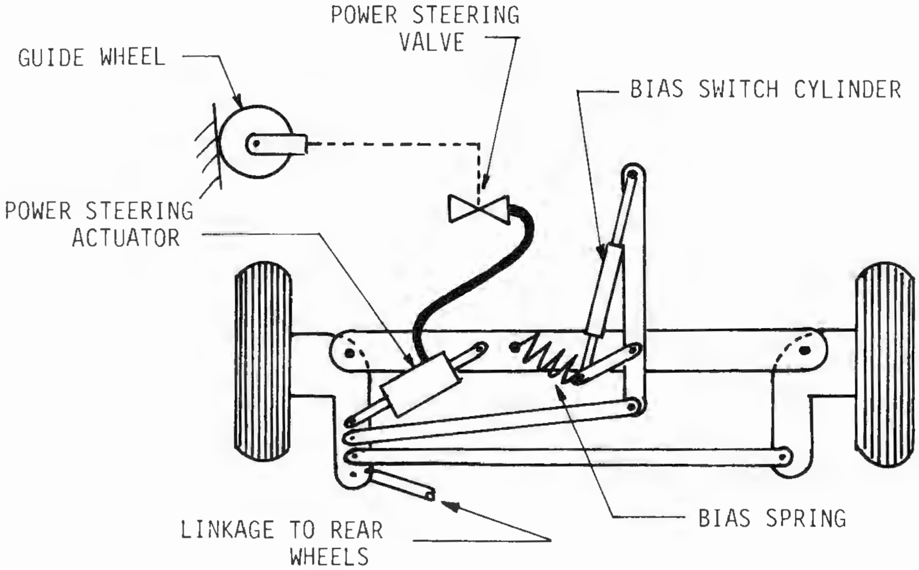
A characteristic of "curb-follower" guidance of this type is its dependence upon tire friction for vehicle control, especially in diverge and merge areas. The presence of ice, brake lock-up, flat tires, or mechanical binding of the steering or suspension systems are hazards which can cause a vehicle using this type of steering to lose directional control. At Morgantown, steps were taken to control these hazards. The guideway is heated during snow or icy weather to prevent ice from forming on the running surface. Double-wall tires are used to protect against flat tires. To guard against other hazards, components were utilized with failure rates designed to be low enough so that switch performance would meet requirements established for system safety. In addition, should the guidewheel depart from the steering rail, the vehicle is immediately emergency braked. Impact drums were placed at high-speed switch frogs and safety guard rails were installed opposite the steering rail for protection in the event that steering control is lost.

3.3.2 Description of Vehicle Switching

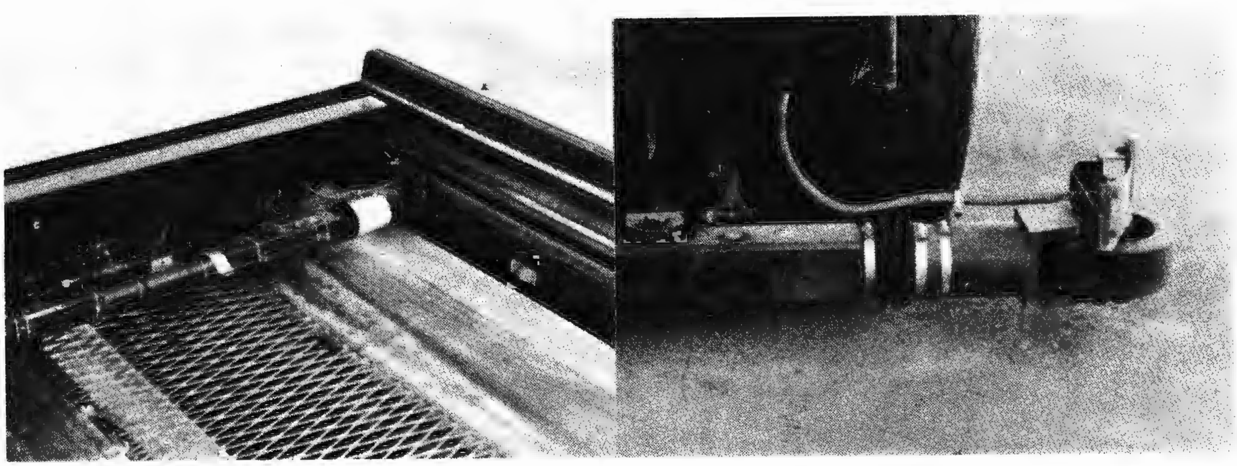
The heart of the Morgantown switching concept is the ability of the vehicle to follow either the left- or right-hand guiderail along the walls of the "U"-shaped guideway. By receiving instructions on which guiderail to follow, the vehicle may be commanded to bear either left or right in a switching maneuver.

Switching is accomplished by extending or contracting the bias switch cylinder piston. This changes direction of the bias spring force which determines whether the bias spring turns the wheels to the left or the right. Movement of the bias spring changes the power steering control valve to apply force in the opposite direction. The switching signal commands the extension or contraction of the bias switch cylinder, which correspondingly changes the steering from following one guiderail to the other.

Switch tones are transmitted from an inductive loop in the guideway surface to command the vehicle to steer left or right. If a change in steering is desired, the switch enable receiver is activated and a switch command is issued to the vehicle. These commands are received at guideway junctions (merge or demerge).



(a) SIMPLIFIED DIAGRAM OF STEERING AND SWITCH SYSTEM



(b) STEERING ARM AND GUIDEWHEEL

FIGURE 3.22

Verification of proper switch orientation is provided in advance of any merge or diverge sections. The verification system checks for contact between the appropriate guidewheel and guiderail, and does not simply verify that the bias spring is properly positioned. Thus, if the steering linkage were to bind and prevent proper switching, a verification signal would not be received and the vehicle would be stopped by emergency brakes through the CAS.

3.3.3 Performance of Steering and Switching System

During the first operational year there were instances when the vehicle left the steering guiderail in small-radius turns at speeds of 4-8 fps. In some of these cases the vehicle contacted the bumper rail, but in all cases the vehicle was braking and no passengers were injured. Four of the instances where steering was lost were definitely weather related (freezing of the preload cylinder). This problem was solved during Phase IB by the installation of heating elements. Three cases were not weather related, while available records for two other failures did not permit accurate assessment.

Non-weather related failures have been caused by the power steering valves and the mechanical elements in the steering system. Such failures can create a condition where there is inadequate force available to move the steering mechanism, so that the guidewheel would not follow the guiderail in a turnout maneuver. This experience was used to improve the Phase II vehicle design.

The failure rate for the power steering control valve was higher than anticipated. It required rebuilding every 470 hours and replacement every 4,300 hours; the predicted rate had been more than 25,000 hours. The predominant cause of steering element failure in Phase IB was the binding of this control valve mechanism. Since the failure rate was higher than predicted, the Phase II steering does not contain a hydraulic steering control valve. The entire steering system has been redesigned for Phase II. Table 3.3 lists the major components of the Phase IB steering system, the failure of which can cause loss of steering control and indicates the design changes made for Phase II.

TABLE 3.3: CRITICAL STEERING FAILURE MODES AND PHASE II MODIFICATIONS

Component	Failure Mode	Phase II Modification
Support Arm Bearings	Seizing and binding	Replace with improved low-friction bearings
Power Steering Control Valve	Binding	Eliminated from design
Preload Spring	Binding due to icing	Eliminated from design
Tracta Joints	High friction	Replace with cardan joints

The Phase II steering system is purely mechanical without hydraulic assist. This change eliminates the power steering control valves, steering actuator and preload spring. The unaugmented bias spring provides the required steering force by itself. The higher force required by the spring in the absence of hydraulic assist will be compensated for by an improved lower force power collector and by use of low-friction bearings so that tire slip angle will remain about the same.

Traction Considerations

Should the vehicle not switch properly, or should the steering drift away from the guidewall, the vehicle will apply emergency brakes. Emergency braking rates for a lightly loaded Phase IB Morgantown vehicle can reach almost 0.5 g on a level pavement with no headwind. For Phase II, a controlled closed-loop emergency brake is being used. The emergency braking rate is to be controlled to a nominal level of 0.34 g, with a maximum limit of 0.45 g.

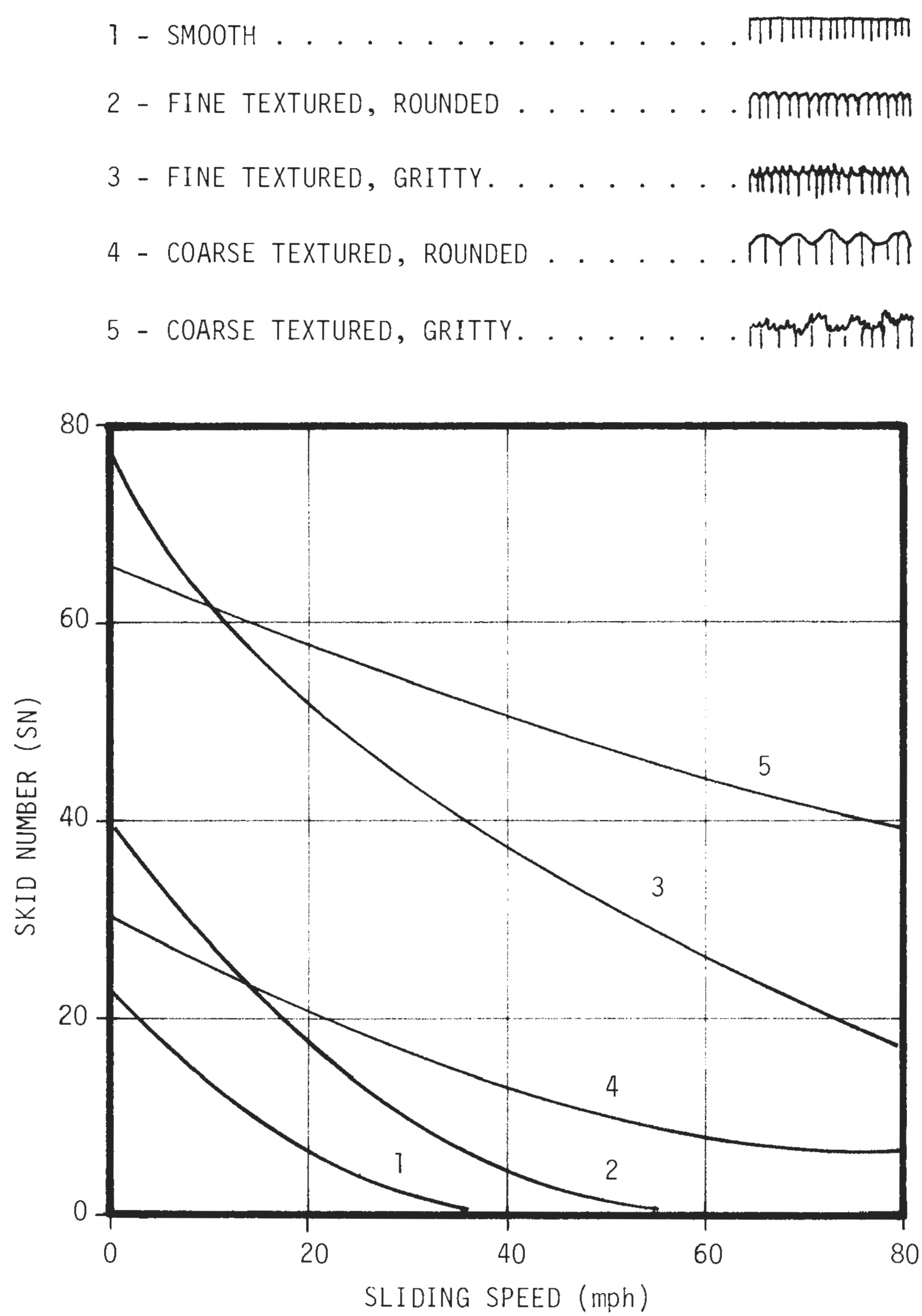
The available traction must be greater than the emergency braking rate on level pavement with no wind to assure that the vehicle will not skid in the open switch area. This section discusses traction levels which can be expected and tests of available traction which have been conducted to date.

Figure 3.23 shows available friction as a function of speed for automobile tires on a variety of wet pavements. The skid number represents 100 times the maximum emergency braking rate, in g's, at which uncontrolled braking will not cause skidding when stopping on the level with wheels pointed straight and assuming equal weight distribution on all tires. The existence of any steering angle or unequal weight distribution will serve to reduce the braking level at which skidding occurs. The curve shows that available traction for the best pavement type can support a deceleration level of about 0.57 g at 20 mph. There is a tendency for pavement surfaces to deteriorate from types 5 and 3 to types 4 and 2 as wear removes the fine texture. This figure illustrates the importance of pavement condition to safe operation of the Morgantown system. In this regard the Traffic Engineering Handbook recommends values for skid numbers at 20-30 mph on wet pavement of 35 to 43.*

Acceptance tests of the Morgantown system included tests of available traction at the Boeing test track in Seattle, but no acceptance tests of traction were conducted on the Morgantown guideway. The tests at Seattle indicated skidding would occur at a braking pressure of 910 psig for a nominally empty vehicle on a wet asphalt track. This pressure is above the nominal 700 psig normally applied for emergency braking and slightly below the 1000 psig which is applied in the event of complete loss of D.C. power. (see subsection 3.4.2).

Since the system opened, the tires used have been changed. To increase tire lifetime the University changed to Bandag recapped tires. On December 3, 1977 the University conducted one test of a vehicle equipped with Bandag tires stopping from 30 mph during heavy rain. Braking pressure was estimated at 1,050 psi. The vehicle stopped in 66 feet and the test personnel observed no sliding or loss of steering control.

*Traffic Engineering Handbook, 3rd edition edited by John E. Baerwalk, Institute of Traffic Engineering, Washington, D. C., 1965, page 32, table 2.8, (Portland cement concrete in wheel tracks)



Source: "Tentative Skid-Resistance Requirements for Main Rural Highways," Kummo, H. W. and Meyer, W. E. National Cooperative Highway Research Program Report 37, Highway Research Board, Washington, D. C., 1967, page 24, Figure 24.

FIGURE 3.23: AVAILABLE FRICTION AS A FUNCTION OF PAVEMENT TEXTURE

Limitations of the Steering System

The steering system as configured for Phase I, while stable above 30 mph, would not provide acceptable ride comfort at speeds greater than that. This limitation may be overcome by the use of a stricter guideway alignment requirement at higher speeds, or by improvements in steering and suspension system design.

At present the vehicle can be operated in only one direction because the Ackerman steering mechanism is inherently unidirectional and guidewheels are provided only at one end of the vehicle. To provide bidirectional operation would require major design changes in the steering geometry.

It may be possible to entrain vehicles using the present steering system by adding couplers and slaving the propulsion and braking controls. It should be pointed out, however, that additional forces would be exerted on vehicles through the coupler. Detailed dynamic analysis of vehicle trains is required to determine any limitations on speed and any possible degradation of lateral ride comfort and safety resulting from coupling. Boeing states that it has run a test of coupling at the Kent, Washington test track and that instrumentation on the guide axle showed no unusual lateral forces which would affect steering, even in curves of 30-foot radius at ten feet per second (note that this is the speed for recovering a vehicle and not for normal operations).

3.4 PROPULSION AND BRAKES

3.4.1 Propulsion

The propulsion system provides traction through the rear wheels from a DC motor. It is shown functionally in Figure 3.24 and consists of the following major subsystems:

a. The power collection subsystem, which interfaces with the wayside power rails to provide electrical power

b. An on-board auto-transformer, which reduces the wayside electrical voltage from 3-phase 575 VAC to 3-phase 61 VAC and 355 VAC to feed the motor controller

c. The motor controller, which uses a 3-phase full-wave SCR converter to provide direct current to the propulsion motor, and which performs other functions such as speed control in response to commands from the VCCS

d. A single propulsion motor, which is a compound-wound DC motor rated at 70 hp at 2,730 rpm with 420 VDC on the armature and 24 VDC on the shunt field; the motor was supplied with a special housing to provide increased strength for installation upside-down

e. The drive train, which consists of a drive shaft connecting the motor to the differential through a universal joint; the differential; and the driving axles and wheels. The differential ratio is 7.17:1 and the tires are 16.5 X 9.5, 10-ply.

The propulsion system is designed for a maximum speed of 30 mph (see performance capability, discussed in Subsection 3.1.6. Greater speeds would require a different motor and possibly a change in the gear ratio. The present differential, however, is designed for highway speeds up to 60-80 mph.

In general the propulsion system functions well--no significant problems have been experienced with the motor or its controller. There have been problems of excessive collector shoe wear where it interfaces with the power rail. There have also been icing problems on the power collector itself, which are to be solved by installation of heaters. The entire power collection system, including power rails and collectors, has been redesigned and replaced for Phase II. The noise level of the power train was noticeable when climbing grades, but was acceptable. There was also some evidence of excessive wear of certain drive train elements, such as tracta joints and axle shaft bushings. Correction for these problems has been made in Phase II by retrofitting all vehicles with new cardan joints and rear axle shafts.

3.4.2 Braking System Description

The braking system for the vehicle consists of disc brakes on all four wheels equipped with completely redundant hydraulic actuation systems. Figure 3.25a provides a simplified schematic of the braking system and Figure 3.25b a photograph of the disc brake.

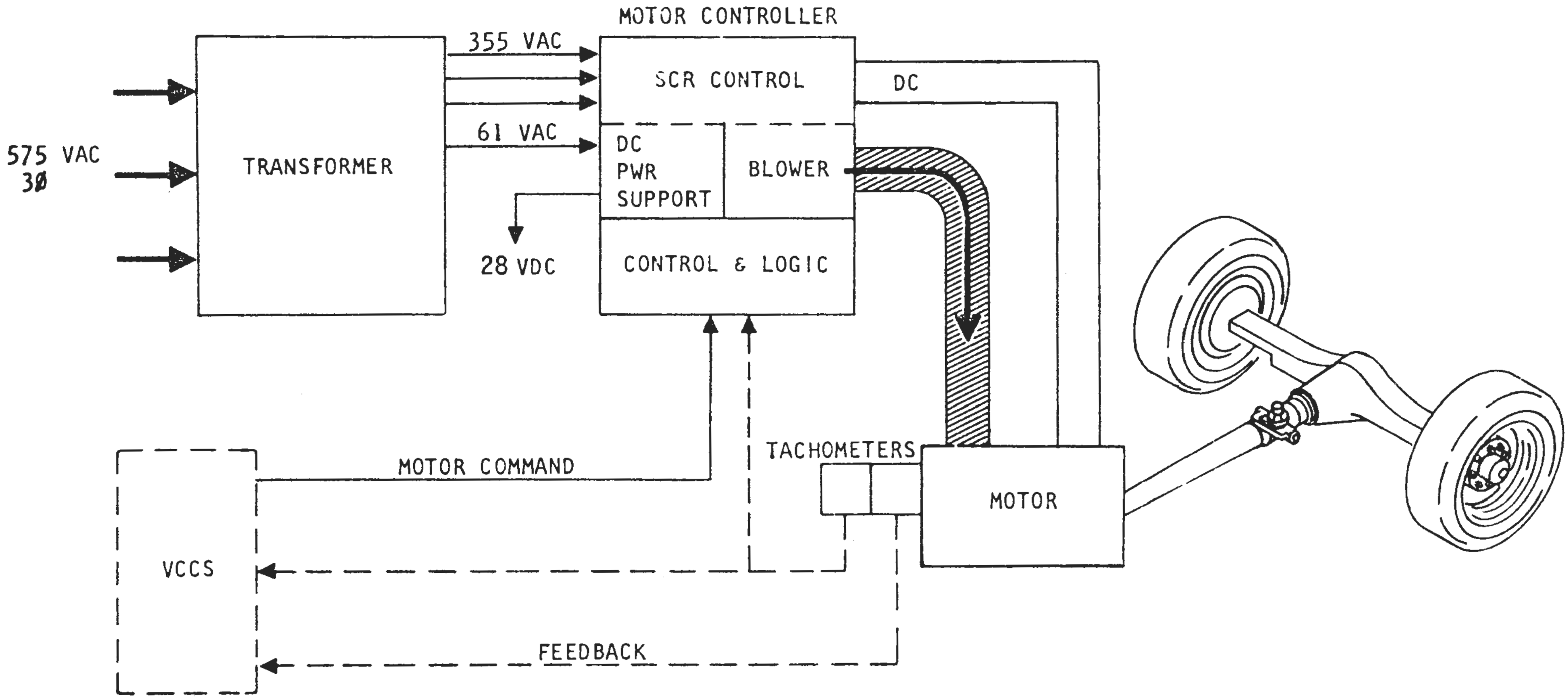
Service Brakes

For service braking, the vehicle command and control system provides a signal based upon the operating vehicle speed or deceleration rate. This signal is amplified and used to control an electrically actuated servo valve which regulates hydraulic pressure to the disc brakes at all four wheels. Two completely independent hydraulic systems are provided, each with its own amplifier and electrically actuated servo valve. Each line is connected to separate sides of a dual piston which actuates the disc brakes. Normally both systems operate, but the piston is designed so that the same force can be obtained with only one of the hydraulic systems operating.

Emergency Brakes

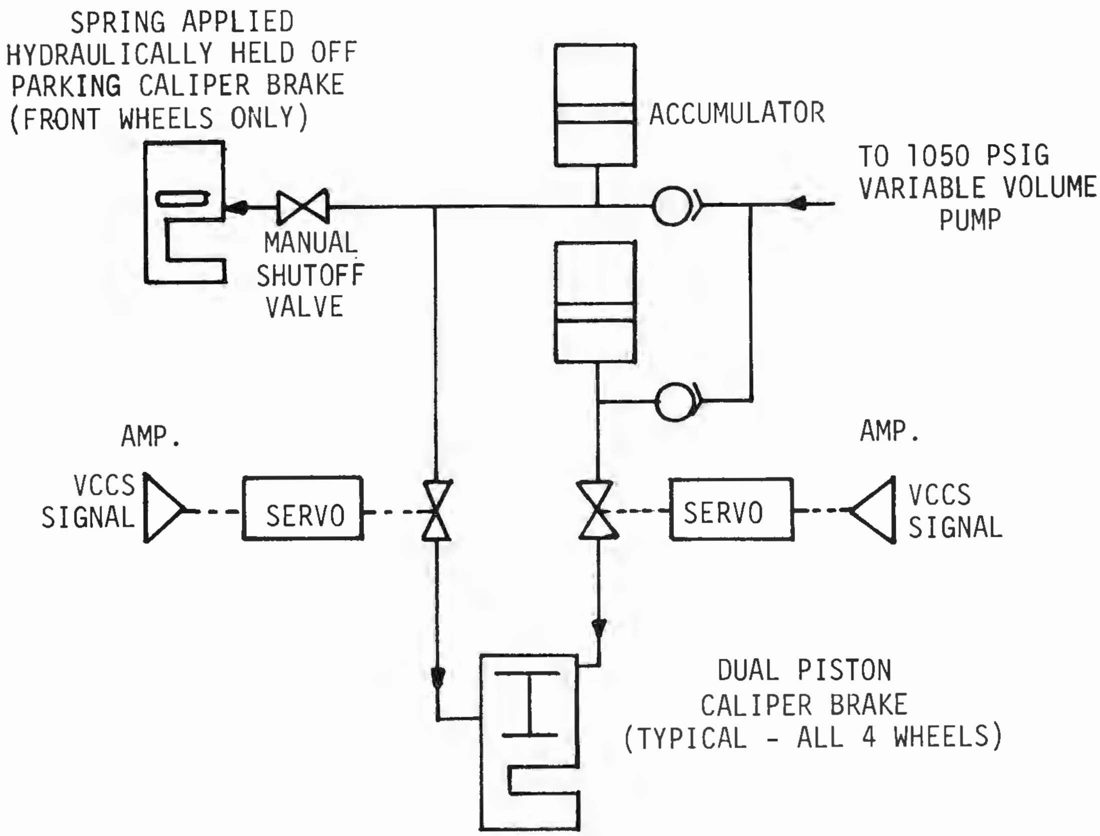
Emergency braking is provided by the same mechanical and hydraulic system hardware employed for service braking. The interruption of a 28-volt DC signal to the Phase I brake amplifier caused normal brake commands to be ignored, removed propulsion prime power, and commanded the brake servo valve to apply a jerk limited hydraulic pressure of 700 psig to the brake caliper.* This pressure produced a higher braking rate than was provided for service stops. While service

*This is a distinct mode from the so-called "Skinner valve" failure mode which applies full hydraulic pressure of 1,000 psig to the brake caliper when the vehicle loses DC power.

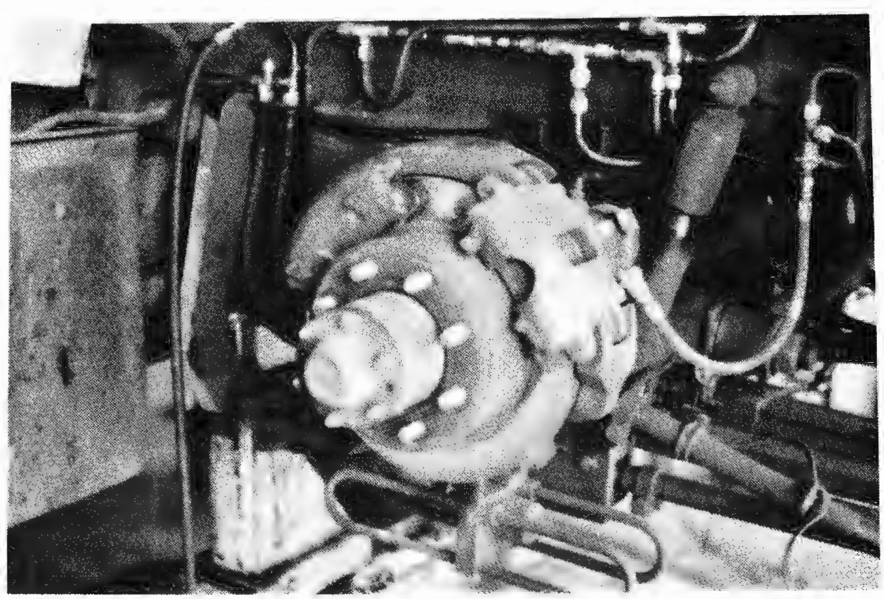


SOURCE: Boeing Aerospace Company

FIGURE 3.24: PROPULSION SYSTEM FUNCTIONAL DIAGRAM



(a) SIMPLIFIED BRAKE SCHEMATIC



(b) VIEW OF HYDRAULIC DISC BRAKE

FIGURE 3.25

stops are controlled at a constant deceleration rate, Phase I emergency braking was accomplished by applying a fixed force applied to each wheel. This force caused the stopping distance to vary with vehicle payload, changes in brake lining condition, head and tailwinds and gravity forces present if the vehicle was on a hill. The emergency braking rate will be controlled to a deceleration level of 0.34 g in Phase II, which will reduce this range of stopping distances and limit maximum emergency deceleration to less than 0.45 g.

Hydraulic pressure must be available for the emergency brakes to function. For this reason, each hydraulic system is provided with its own accumulator and is isolated from the rest of the system by a check valve. If a leak or a pump failure should occur, the accumulator provides sufficient reserve to safely stop the vehicle.

Electric power is also required for emergency braking in order to actuate the servo valve. Should external electric power be lost, the required control power is provided from batteries. In the event battery power is also not available, the absence of voltage will open two normally closed solenoid valves which bypass the servo valves and apply full accumulator pressure directly to the brakes.

Parking Brakes

Parking brake calipers are mounted on each front wheel and engage the same disc as is used for normal braking. The parking brakes are spring-loaded assemblies which are held off by hydraulic pressure. In the unlikely event of pressure losses in both hydraulic systems, these brakes provide a fallback stopping capability to bring the vehicle to a stop at a reduced braking level which is less than the emergency braking rate.

3.4.3 Brake System Performance

In Phase I, the system operated for almost three years with emergency braking rates which could reach twice the levels normally used within the fixed guideway transit industry (see "Traction Considerations" in subsection 3.3.3). In a recent study the Transportation Systems Center of DOT recommends emergency deceleration levels of 0.41 g to 0.478 g for seated passengers and notes these are about twice the level which can be safety experienced by standees.* Morgantown emergency braking rates are probably comparable to those encountered by standing bus passengers. The highest emergency deceleration rate computed from Boeing test data is just under 0.5 g. The apparent lack of passenger complaints or injuries with over 60 emergency brakings per month is encouraging. However, the lack of any significant experience with elderly and handicapped patrons on the MPM system suggests that caution be used in considering these higher rates for urban service. The Morgantown public attitude survey conducted by the assessment team showed that 86 percent of those who had experienced sudden starts or stops did not consider them serious, while 13.8 percent did.

The braking system has dual VCCS amplifiers, dual servo valves, dual accumulators, dual hydraulic lines, and a dual piston-actuated brake caliper. In short, a completely redundant design is employed. The Morgantown concept is well suited to incorporate the design of a controlled deceleration level brake of the type employed for Phase II. Since such a brake is needed for short-headway operations, the Morgantown approach offers growth potential for use with advanced vehicle longitudinal control systems. Simpler spring-applied brakes cannot be adapted as readily to safe closed-loop control.

There were numerous problems with the Phase I brake system, including excessive pad wear, caliper and disc failure, hydraulic leaks, servo valve failures, and hydraulic pump failures. As a result, the brake system has been redesigned for

*"Effects of Deceleration and Rate of Deceleration on Live Seated Human Subjects," C.N. Abernathy, G.R. Plank, E.D. Sussman, Transportation Systems Center of DOT, UMTA-MA-06-0048-77-3, PB 284 653, October 1977.

Phase II. The Phase II system brake amplifier contains the circuitry to effect a closed-loop stop in response to a discrete emergency brake command. This is accomplished by using the tachometer signal prior to emergency braking to generate a voltage proportional to vehicle speed. When emergency braking occurs, this voltage is profiled to zero. During the stop, the vehicle's actual speed is compared with the profile and an error signal is generated. A braking level proportional to the speed error is then delivered to the brakes. The nominal braking rate is set at 0.34 g and limited to a maximum of 0.45 g.

3.5 SUSPENSION

The Morgantown vehicle runs on four rubber tires, mounted on axles suspended from the vehicle by four air-bag springs.

Suspension is provided by air bags at each wheel with conventional telescoping shock absorbers. The air springs are regulated by the pneumatic system (Figure 3.12, shown in Subsection 3.1.5) to provide a constant floor height regardless of the passenger load. A weight overload pressure switch is incorporated in the front wheel suspension which will inhibit vehicle movement if the passenger load exceeds 3,150 lbs. Should an overload occur when passengers are boarding the vehicle, a passenger alarm is sounded and the door is held open so that the vehicle cannot be dispatched until the passenger load is reduced. Overload protection is provided mainly to insure that emergency braking rates will be within safe tolerances.

The front suspension utilizes a solid box-frame axle with steerable hub ends. Independent front suspension is not provided. The rear axle drives the vehicle through an automotive-type differential with a 7.17:1 ratio. Rear wheels are also steerable, with an axle tracta joint at each hub assembly. For Phase II, the tracta joints have been replaced with a cardan joint (more commonly called a universal joint).

Wheels are 16.5 inches in diameter and equipped with 16.5 X 9.5, 10-ply rubber tires. Each tire has an inner chamber which provides support for the wheel in case pressure is lost in the outer chamber.

Since the overload switch was incorporated only in the front suspension, students learned that they could circumvent it by shifting their load to the rear of the vehicle, thereby enabling the vehicle to be dispatched. However, as soon as the load was redistributed, power collector misalignment would cause the vehicle to shut down on the guideway, requiring passenger evacuation. The students soon learned that crowding the vehicles was not desirable. A three-point overload sensing system has been installed in Phase II which should prevent this problem.

Tire wear was initially a problem, with lifetimes on the order of 6,000 to 7,000 miles. This wear occurred at a time before the initial roughness of the guideway surface was worn down and when steering alignment equipment and procedures were not optimal. Later in Phase I, new tires attained lifetimes on the order of 24,000 to 26,000 miles. The University began recapping tires (Bandag recaps) to gain even longer lifetimes of 45,000 to 50,000 miles. Inspection of worn tires showed the tire wear patterns (Figure 3.26) to be similar to those experienced with automotive tires operating with front end misalignment. The bias form of steering could be considered similar to such a condition. Redesign of the steering system for Phase II will reduce the steering force, which should further improve tire lifetimes. (See Section 3.3 for the effects of the recapped tires on steering and lateral control.)

Wheels are balanced at the time of mounting only. Since speeds are 30 mph or less, accurate and periodic balancing is not considered necessary. Wheel alignment is now checked every 350 miles*, which is undoubtedly a major reason for the improvement in tire lifetimes. The alignment check interval is to be greatly increased during Phase II.

There have been eight flat tires since the system began operation. Most have been caused by defective valves and valve stems. There is no signalling of a flat tire--the condition is usually detected only when someone observes the vehicle. Tires are equipped with an internal safety tire which carries the load and permits continued operation. Sometimes a flat tire will cause the power collector to lose contact with the power rail, thus stopping the vehicle. Vehicle performance with a flat tire is to be formally tested as part of the Phase II test program in Morgantown (TP 191-58510 "Vehicle/Guideway Compatability Test").

Tracta steering joints were used in the drive axle. Experience has shown that increased steering friction results as the tracta joint mating surfaces wear. Therefore, the drive axles have been modified for Phase II. The axles were bought

*Per conversation with system maintenance manager April 19, 1977. Wheel alignment is checked with a WVU-made guage as a part of the regular 350-mile checkup.

from NAPCO in accordance with specification control drawings; Boeing performed its own quality assurance tests. The modifications have produced a heavier axle with a cardan steering knuckle design to improve the structural margin and steering friction.

The assessment of ride quality is given in Section 4.3.

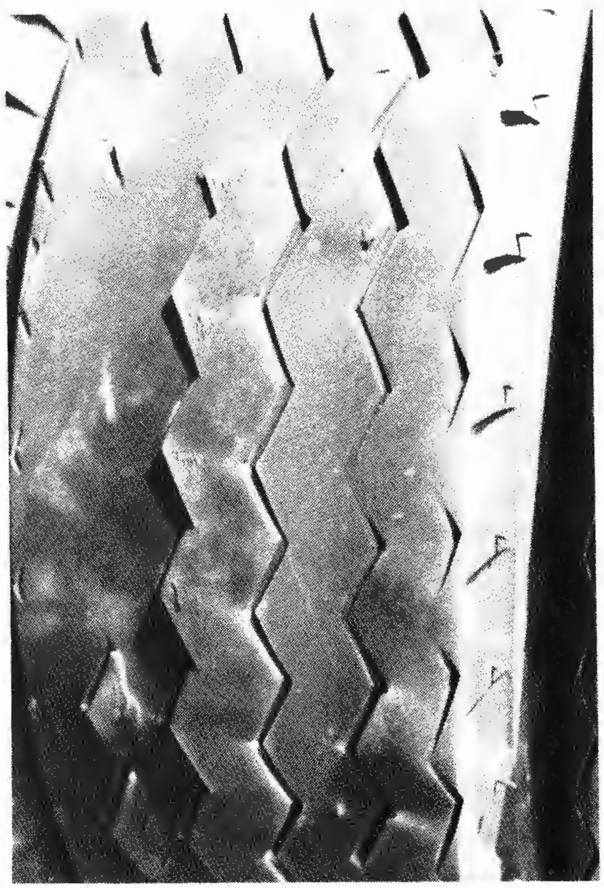


FIGURE 3.26: TIRE WEAR

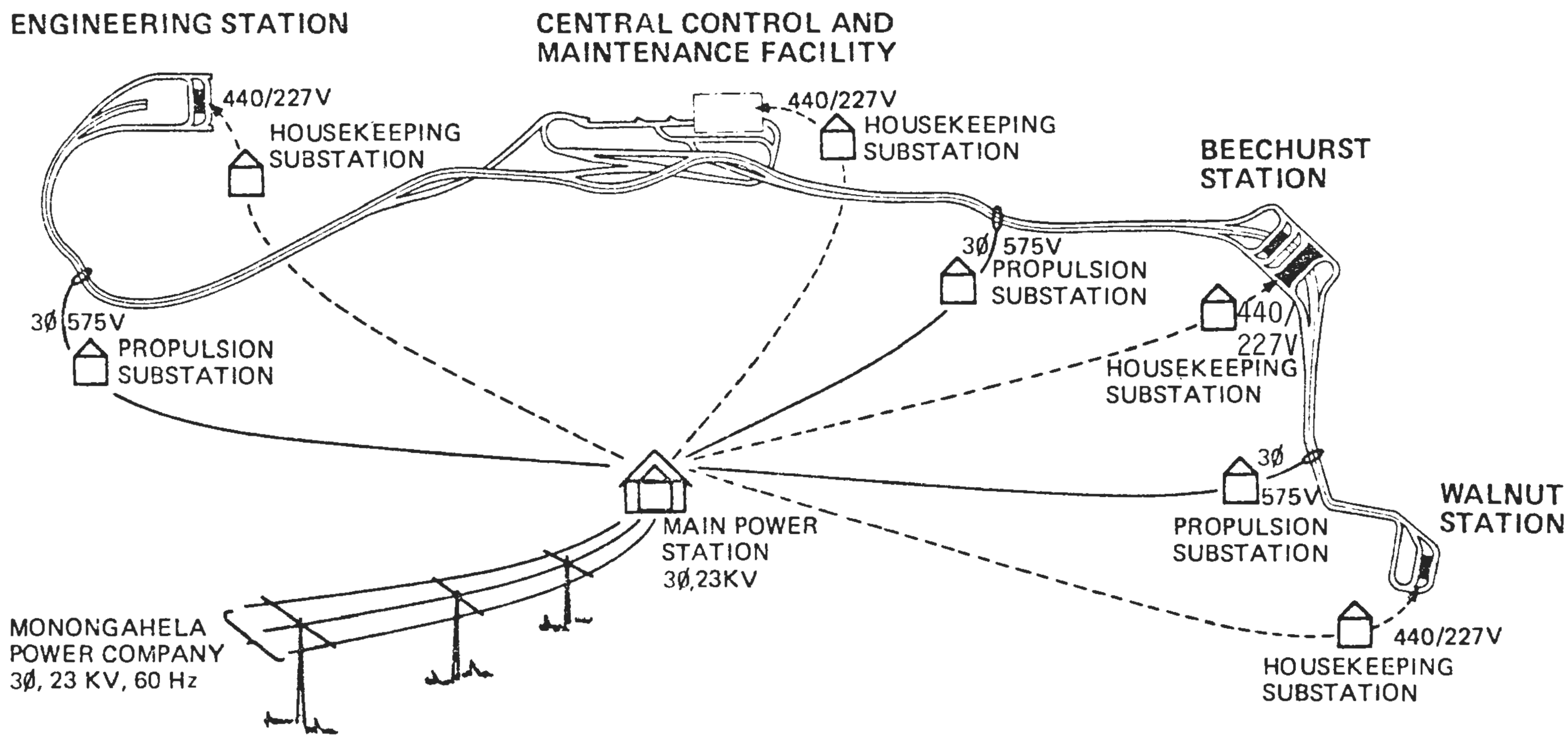
3.6 POWER DISTRIBUTION

The power distribution subsystem (PDS) is shown in Figure 3.27 and is composed of the following elements:

a. The main power station, which receives three-phase, 23 KV, 60 Hz power from a dual-source aerial transmission line of the Monongahela Power Company.
b. High-voltage distribution cables, which carry three-phase 23 KV power from the main power station to propulsion substations and housekeeping substations in two redundant cables.
c. Power distribution substations, which transform the 23 KV input to three-phase, 575 volt, 60 Hz power for distribution on the guideway power rails.
d. Guideway power rails for transfer of three-phase, 575 volt power to the vehicles via the power collector.
e. Housekeeping power substations at the passenger stations and maintenance building which transform the 23 KV input to three-phase, 440/227 volt power for lighting, heating, air-conditioning, non-critical displays and input power to uninterruptable power supplies.

The operation of the power distribution subsystem is controlled, monitored and displayed by the C & CS on the System Operator's console. Graphics indicate the guideway sections and stations with power rails energized. The state of all switches, circuit breakers, and transformers is indicated on the electrification display panel.

A main circuit breaker controls the input of Monongahela Power Company power from the 23 KV aerial transmission line to the main power station. Data on the status of the main primary circuit breaker position are displayed. An automatic selector switch connects either redundant high-voltage distribution cable to the Monongahela Power 23 KV bus. Overvoltage, undervoltage, overcurrent, and smoke/fire detection signals are provided from the main power station output to the control center.



SUBSYSTEMS

- DEDICATED GUIDEWAY
- STATIONS (3)
- CONTROL AND COMMUNICATIONS FACILITY
- MAINTENANCE FACILITY
- POWER DISTRIBUTION

SOURCE: Boeing Aerospace Company

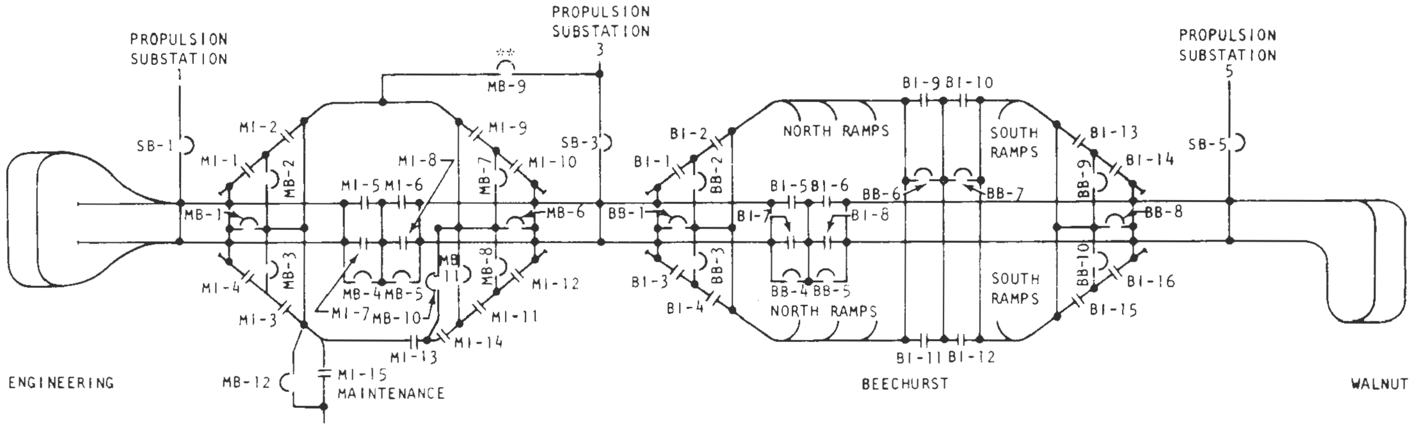
FIGURE 3.27 : POWER DISTRIBUTION SYSTEM

Provisions are made for complete disconnection of the transformer bank from the high-voltage cables by command from the control center. High-voltage fusing is provided on the primary side of the transformer faults. Circuit breakers are provided between the transformer bank and the power rail (Figure 3.28) to protect the substations from rail faults. These circuit breakers are capable of being remotely tripped and reset upon command from the System Operator's console. The station guideway power rails have independent circuit breakers which permit operation of the main guideway in the event of a failure at a station.

Equipment is provided in the propulsion substations for assessment of the electrical status of the substation. Tolerance detectors provide discrete indications of "good" or "bad" conditions to the control center.

The guideway power rails are connected to the PDS transformer secondaries through remotely controlled circuit breakers operated from the control center. Independent circuit beakers are provided so that the main guideway on either side of a passenger station can be operated independently. Station guideways and the maintenance facility guideway can also be independently removed from the main guideway power for maintenance and fault correction. These circuit breakers are also controlled by the software for automatic power removal, should a failure occur which could be hazardous to passengers. The 575-volt bus at each propulsion substation is connected to the transformer secondary by a circuit breaker equipped with reverse power sensing. This breaker protects the propulsion power system from internal transformer faults fed from the other PDS transformers via the guideway power rails. Status data and reset controls are furnished for each circuit breaker. Capability is provided at the maintenance center PDS for control center operation of switch gear for the individual powering of each parking spur and the test track.

The housekeeping substations are located together with the passenger stations and maintenance center. They provide power for lighting, heating, cooling, and operation of noncritical displays and the uninterruptable power supplies. Heavy electrical loads, such as those for cooling and ventilation, are supplied from three-phase, 440-volt power. Lighting is supplied from 230/115-volt circuits.



SEGMENT NO.	SEGMENT DESCRIPTION	CIRCUIT BREAKERS WHICH MUST BE OPENED TO DEPOWER SEGMENT * (X. OPEN)																					**		
		SB-1	SB-3	SB-5	MB-1	MB-2	MB-3	MB-4	MB-5	MB-6	MB-7	MB-8	BB-1	BB-2	BB-3	BB-4	BB-5	BB-6	BB-7	BB-8	BB-9	BB-10	▷		MB-9
A	ENGINEERING RAMPS	X			X	X	X	X	X																
B	GUIDEWAY E - M	X	X					X	X	X	X	X													X
C	M YARD		X		X	X	X			X	X	X													X
D	GUIDEWAY M - B		X		X	X	X	X	X							X	X	X	X						X
E	NORTH RAMPS AT B												X	X	X			X	X						
F	SOUTH RAMPS AT B																	X	X	X	X	X			
G	GUIDEWAY B - W (AND S RAMPS)			X												X	X	X	X						

MPB = MAIN POWER BREAKER
MI = MAINTENANCE ISOLATION
BI = BEECHURST ISOLATION
MB = MAINTENANCE BREAKER
BB = BEECHURST BREAKER
SB = SUBSTATION BREAKER
E = ENGINEERING
M = MAINTENANCE
B = BEECHURST
W = WALNUT

* ASSUMING ONLY ONE SEGMENT TO BE ISOLATED
** MAINTENANCE TRACK POWER BREAKER - MANUAL REMOTE MONITOR & CONTROL - NORMALLY OPEN (NOT PART OF C&CS) MB-9 TRIPS WHENEVER SB-3 IS TRIPPED

▷ MB-10, MB-11, MB-12

SOURCE: Boeing Aerospace Company

FIGURE 3.28: POWER ISOLATION

The housekeeping substations also provide for the operation of pumps for circulating heating fluid to the guideway running surface. Control of the pumps is accomplished from the control center.

Standby power generators are provided at each passenger station and the maintenance facility. These generators have an automatic start capability with manual start override, and can assume the housekeeping loads within one minute of power loss. The following systems are supplied by the standby power generator:

- Station platform emergency lighting
- Guideway emergency lighting (1/3 normal lighting)
- RF voice communication system at Central Control
- Central Control to station public address system
- System surveillance (TV) at station and Central Control
- Passenger assistance telephone

The control center has automatic and manual control capability over the standby power generators. Frequency, overvoltage, undervoltage, and overcurrent signals are provided from the generators to the control center.

The System Operator's console has manual on-off control of:

- Station environmental control power
- Guideway heating pump power
- Guideway lighting

An uninterruptable power supply consisting of batteries, sensors, and switch gear is capable of supplying power to critical loads for 15 minutes in the event of primary power loss. The critical loads include the computers, processors, critical communication circuits, and computer and processor environmental control equipment.

3.7 GUIDEWAYS AND STATIONS

3.7.1 Guideways

In an automated guideway transit installation, the guideway system constitutes the most extensive and the most visible feature. It is also generally the most expensive single component of the entire system. Morgantown is no exception. The guideways have been the subject of considerable comment both locally and nationally. The existing design has been criticized as unnecessarily massive and ponderous. It has also been singled out for special praise. In 1973, for example, the guideway crossing over Monongahela Boulevard shown in Figure 3.29 was cited as one of the most beautiful new steel bridges by the American Institute of Steel Construction.

At the very outset of planning for the MPM system, the guideway routing was the subject of considerable study. The very hilly topography of Morgantown and the location of the activity centers to be served in relation to streets, buildings and readily available real estate established the present alignment along the riverside on the edge of the railroad right-of-way as clearly the most logical choice. Figure 3.30 shows that this routing of the guideway very effectively avoids built-up and residential property. However, the structure is high enough to afford the passengers a very pleasant view of the river (Figure 3.31).

Where the guideway follows the highway, up the hill toward the Engineering Campus, it is constructed at grade on two different levels, as shown in Figure 3.32. This is an aesthetically pleasing design which follows the natural terrain unobtrusively.

As discussed elsewhere in this report, planning and design for the guideways and other facilities were undertaken on a crash schedule basis to meet ceremonial deadlines established by DOT officials. This schedule necessitated concurrent design of the vehicles and guideways, so that guideway structures were delineated before the weight and dynamic characteristics of the vehicles had been established. The resulting design anticipated loads for a pair of entrained vehicles which did not materialize. Further, the tight schedule did not permit adequate time for design

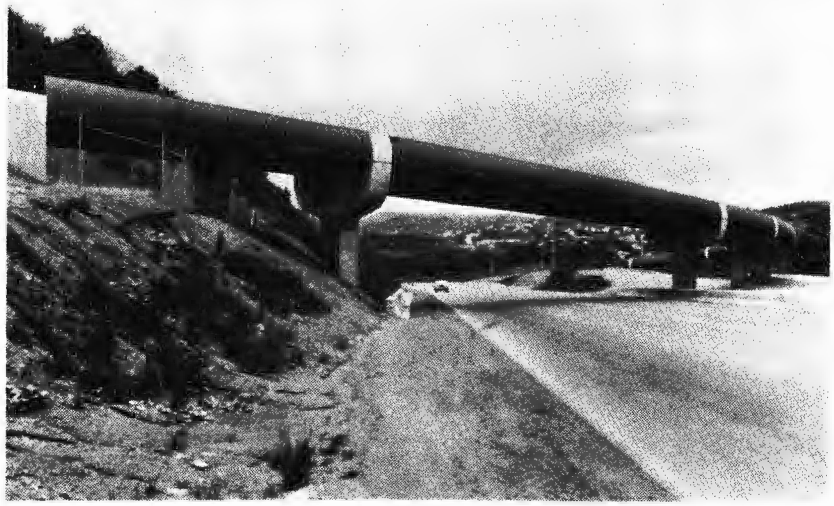


FIGURE 3.29 : ELEVATED GUIDEWAY OVER MONONGAHELA BLVD. -- AWARD OF MERIT BRIDGE, 1973 BY THE AMERICAN INSTITUTE OF STEEL CONSTRUCTION

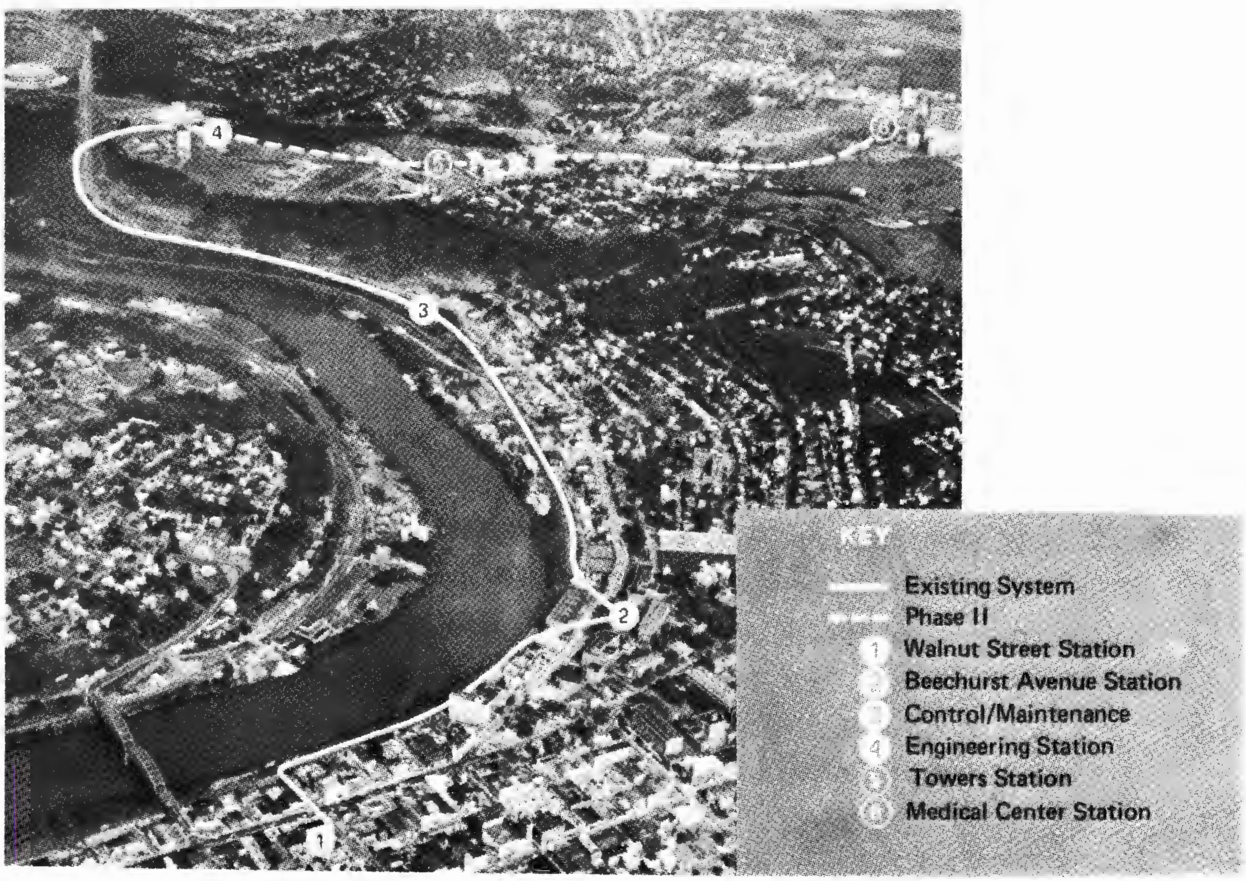


FIGURE 3.30 : GUIDEWAY ALIGNMENT

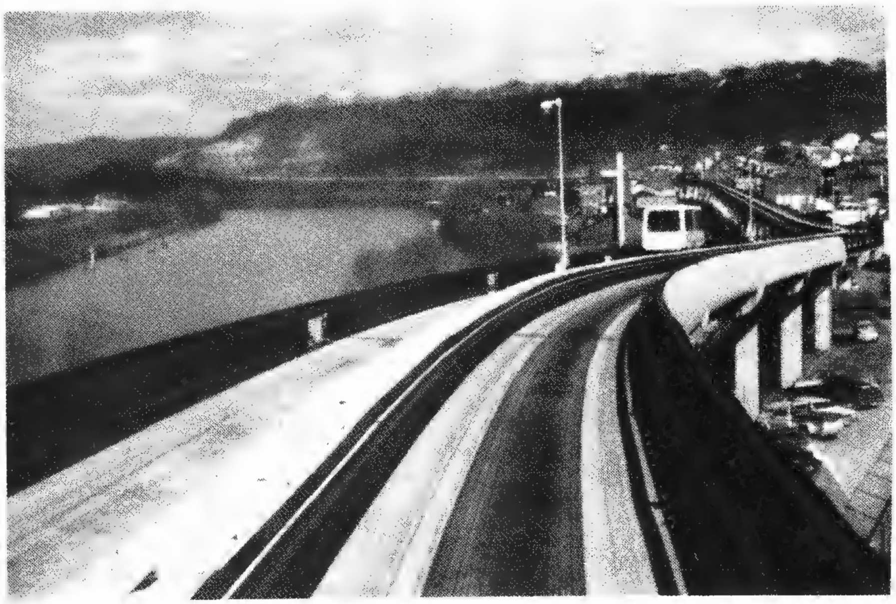


FIGURE 3.31 : PLEASANT VIEW OF THE RIVER FOR PASSENGERS

FIGURE 3.32 : STEPPED DESIGN OF AT-GRADE GUIDEWAY

optimization. On the contrary, important decisions on such difficult subjects as how best to guarantee all-weather operations had to be made under pressure.

Similarly, the accelerated schedule resulted in a decision to reduce the scope of the soil boring program. After construction began, unexpected subsurface conditions were encountered which necessitated costly design changes.

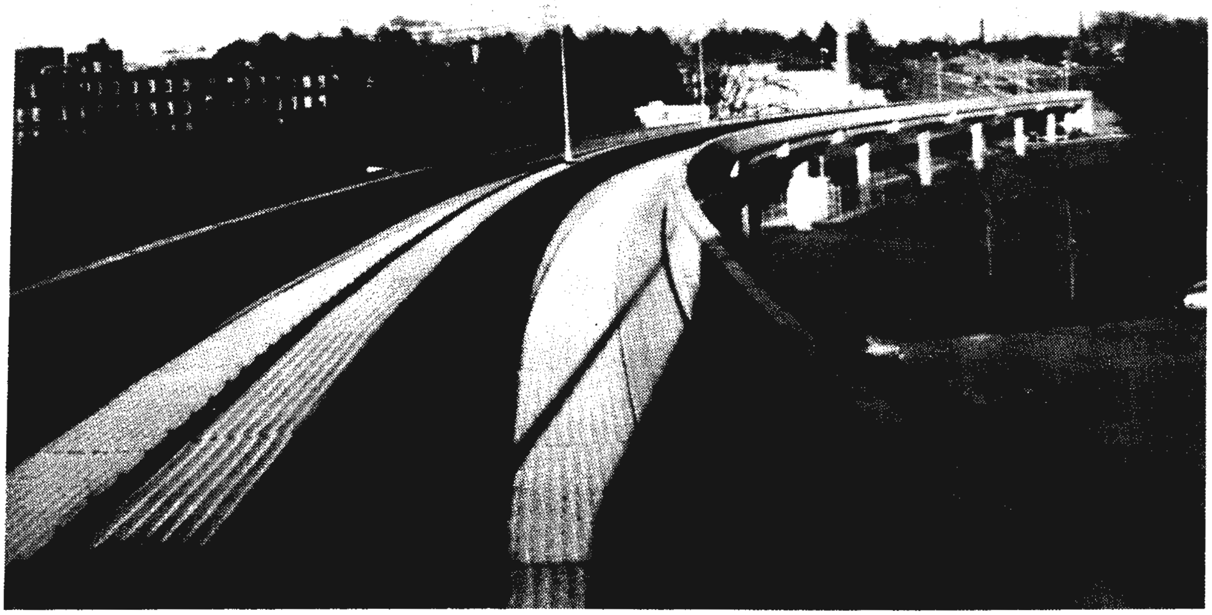
In contrast to the crash program which characterized the design and construction of the initial Phase I guideways, design of the extension to the system was conducted in an orderly manner. As a result a much cleaner design for elevated guideways evolved, as indicated in Figure 3.33.

3.7.1.1 General Description

Elevated Guideways

Connecting the three Phase I stations at Morgantown were 2.1 route miles of two-way guideways. In addition the guideway system includes numerous ramps, turnouts, station channels, a test loop and vehicle storage lanes. These features accounted for approximately 20 percent of the total length of the Phase I guideway, which was 27,776 single lane feet. Figure 3.34 shows the sections of the route which are elevated and at grade and the changes in elevation.

Most of the Phase I guideway system (60 percent) consists of elevated structures supported by substantial concrete pedestals. The structural members are steel beams which in turn support eight-inch thick running surfaces or pads, as illustrated in Figure 3.35. Figure 3.36 presents several views of guideways under construction. Figure 3.35 indicates the arrangement of the running surfaces, and the guiderail and power rail assembly, as well as the safety barrier on either side of the structure. As indicated, a cover plate has been provided above the power and guiderail assembly on the left side of the guideway in the direction of travel, to facilitate exit from the vehicles should emergency conditions so dictate. Where these rails are on the outside of the guideway, as illustrated in Figure 3.37, safety railings have been provided.



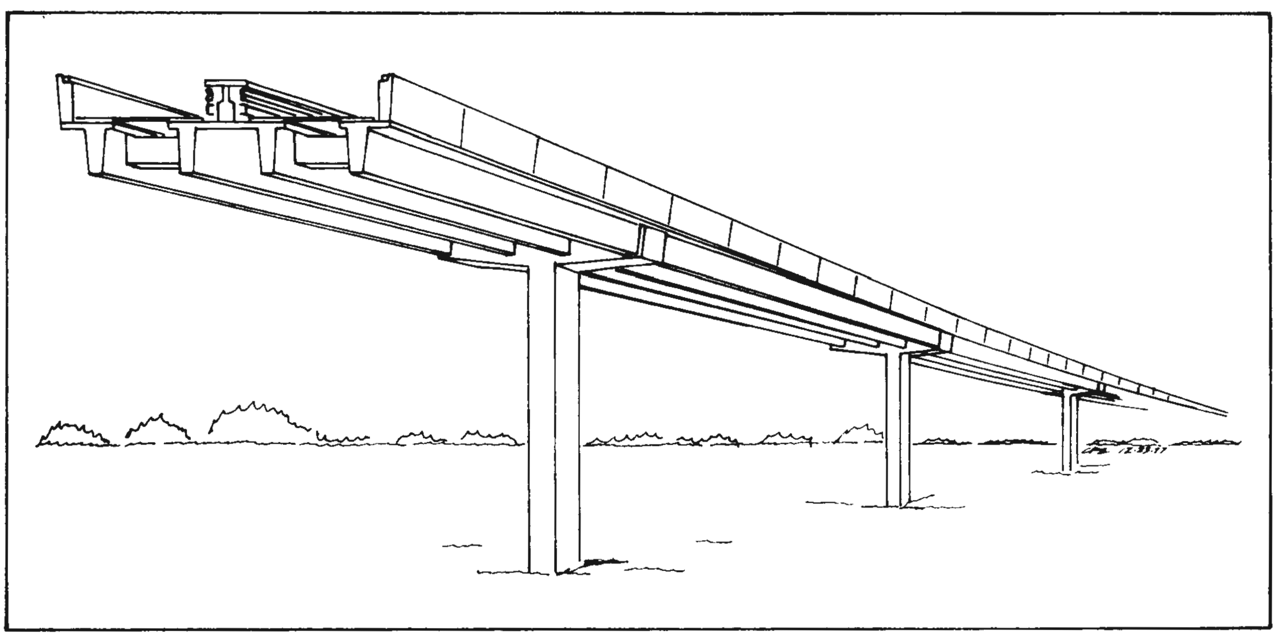
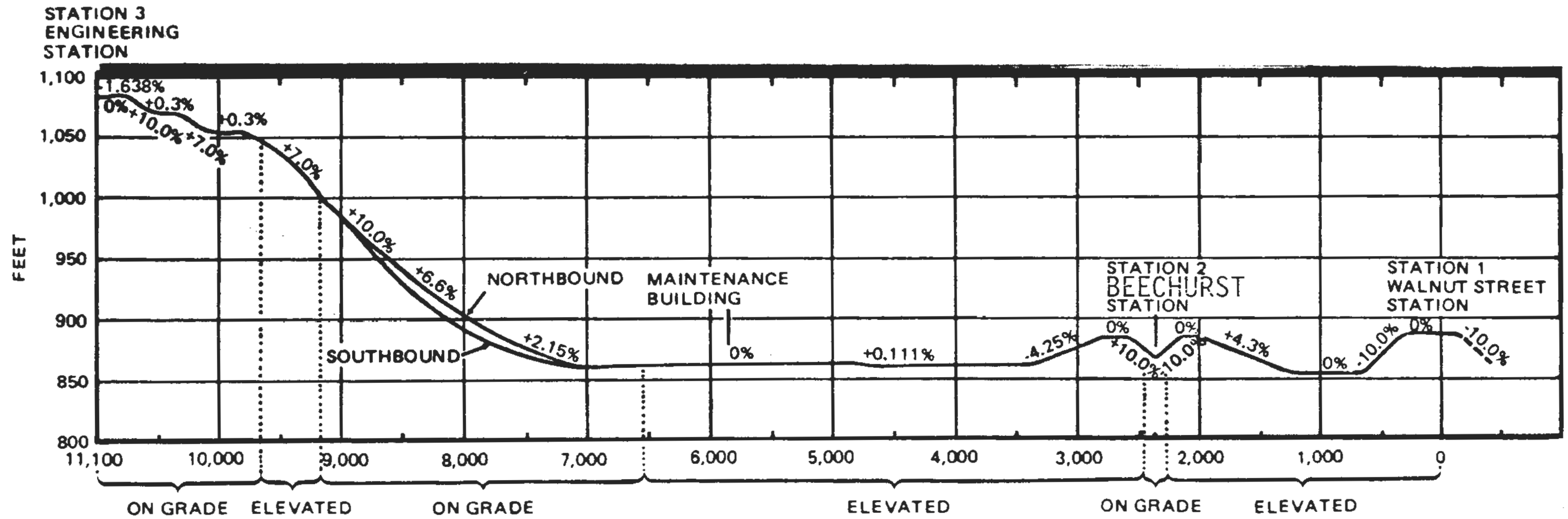
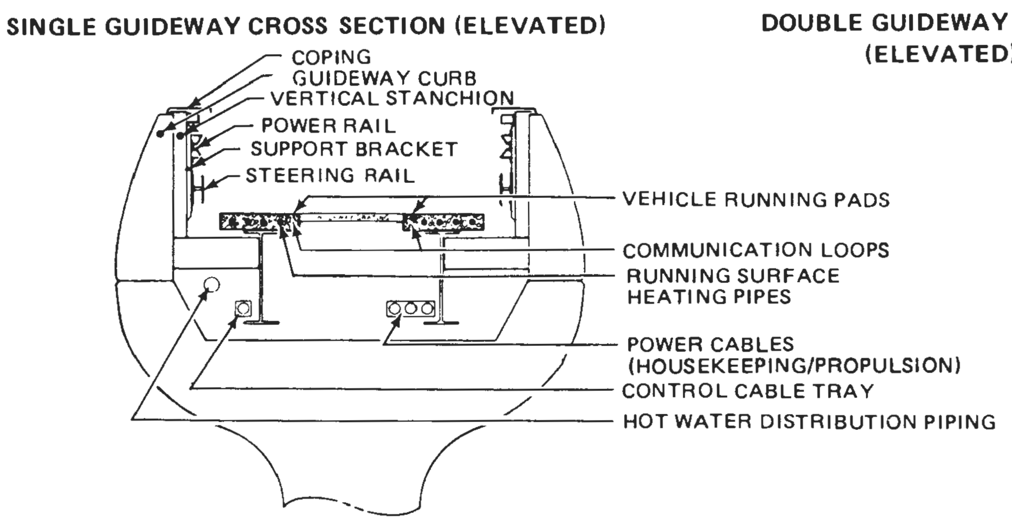


FIGURE 3.33: PHASE II ELEVATED GUIDEWAY



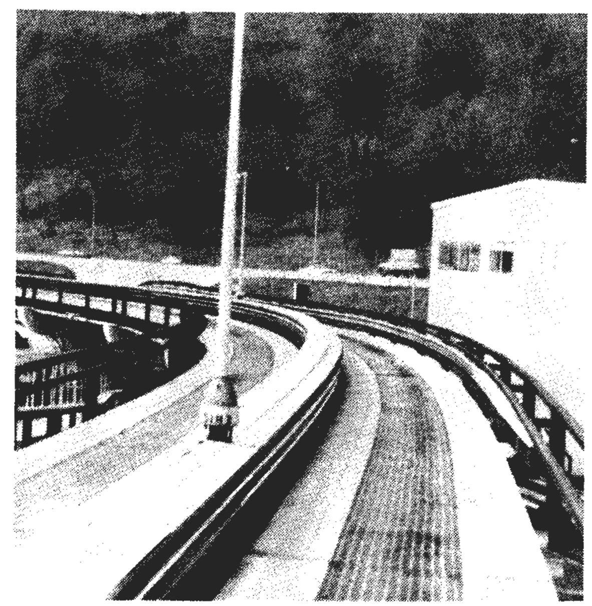
SOURCE: Boeing Aerospace Company

FIGURE 3.34 : PROFILE OF GUIDEWAY ROUTE



NOTE:
THE CROSS SECTION SHOWN IS AT A TRANSITION POINT WHERE DUPLICATE POWER AND STEERING RAILS ARE PROVIDED (MERGE AND DEMERGE POINTS)

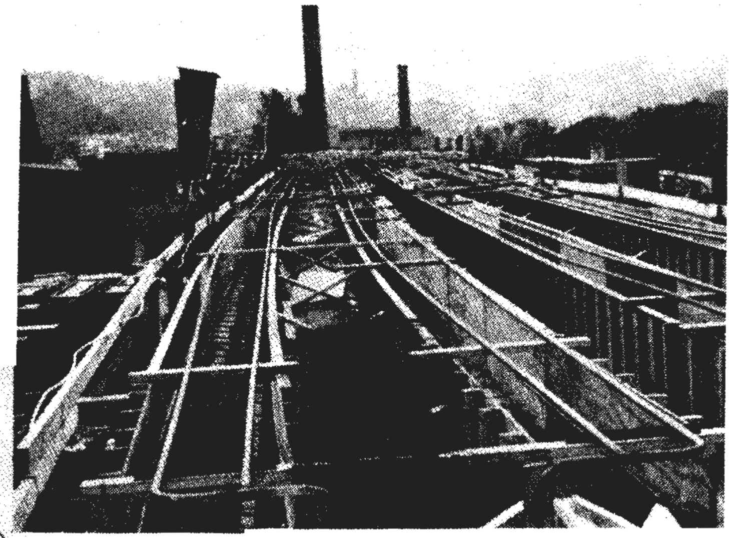
DOUBLE GUIDEWAY
(ELEVATED)

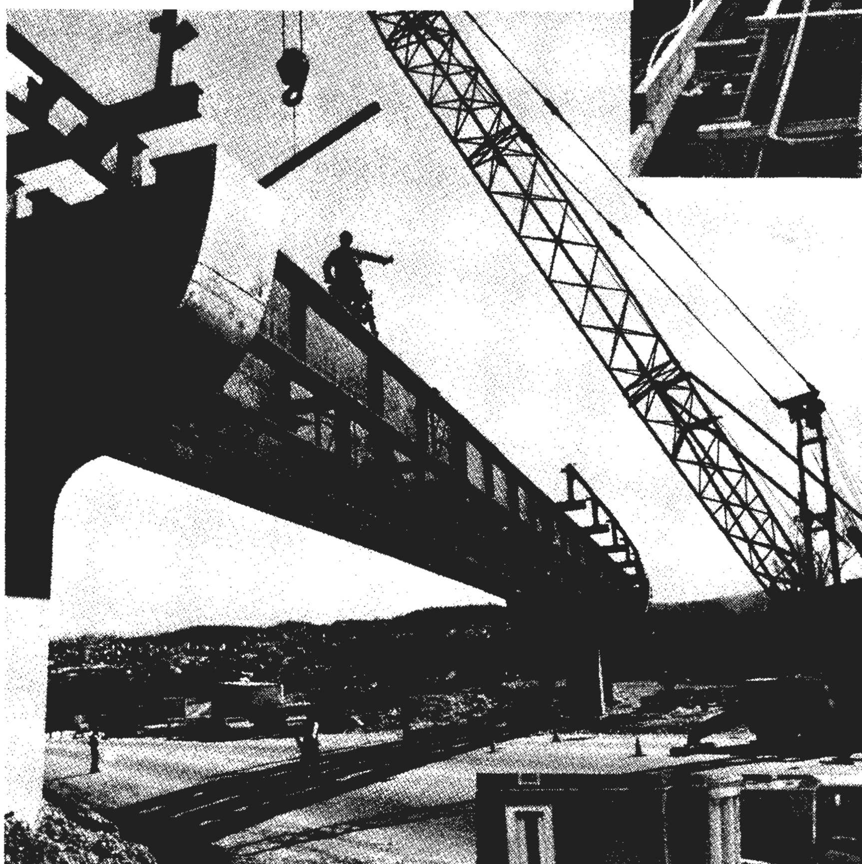


SOURCE: Boeing Aerospace Company

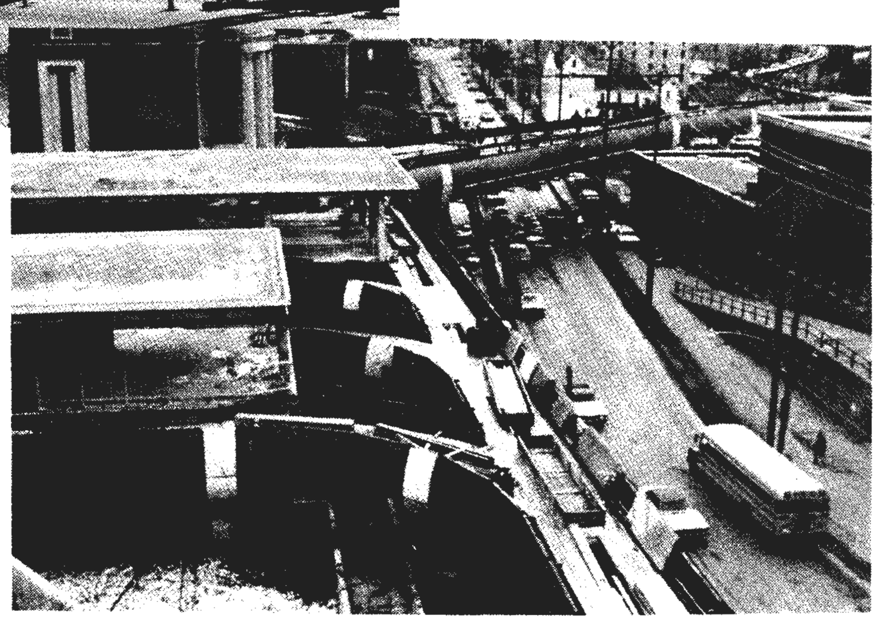
FIGURE 3.35 : ELEVATED GUIDEWAY

(a) RUNNING SURFACE OF ELEVATED GUIDEWAY UNDER CONSTRUCTION





(b) GUIDEWAY BEAMS AND CAST IN PLACE CONCRETE SUPPORTS



(c) PARTIALLY COMPLETED GUIDEWAY AT BEECHURST STATION

FIGURE 3.36

All of the guideway steel is A588 weathering steel, commonly referred to as COR-Ten. This material, which soon develops a rusty-colored protective coating, requires no maintenance painting. This was considered a very desirable feature, since it would eliminate the need for system shut-down for future painting operations.

On some segments of the guideway, curved fascia plates fabricated of light-weight steel have been installed for aesthetic purposes, as indicated in Figure 3.38. These serve to shield from view some of the structural members as well as the vehicle running gear. However, opinion differs as to their net effect on the appearance of the guideway. Painted light beige, they tend to accentuate the presence of the guideway. Much of the fascia work which was originally planned was eliminated in the interests of cost reduction.

The alignment which was finally selected for the guideway was determined by topography, the availability of real estate, and general site conditions. These factors precluded the use of much repetitive design. As a result, span lengths vary and many curves and grades are encountered.

Whereas most of the guideway supports are spaced 60 to 70 feet apart, the system layout selected by the University necessitated three major crossings of Monongahela Boulevard/Beechurst Avenue, each of which required a special structure. In addition to the Monongahela Boulevard crossing, which was singled out for a special award as previously mentioned, there are two very long span crossings over Beechurst Avenue (Figures 3.38 and 3.39) which provide access to and from the Beechurst Station. Of necessity these had to be diagonal crossings and involved clear spans of 132 and 158 feet. The design criteria provided, in part, for bumper-to-bumper static loading and live loads based upon operation of two-car trains. As a result, rather massive structures were required which were quite expensive to build, as shown in Figures 3.40a and b.

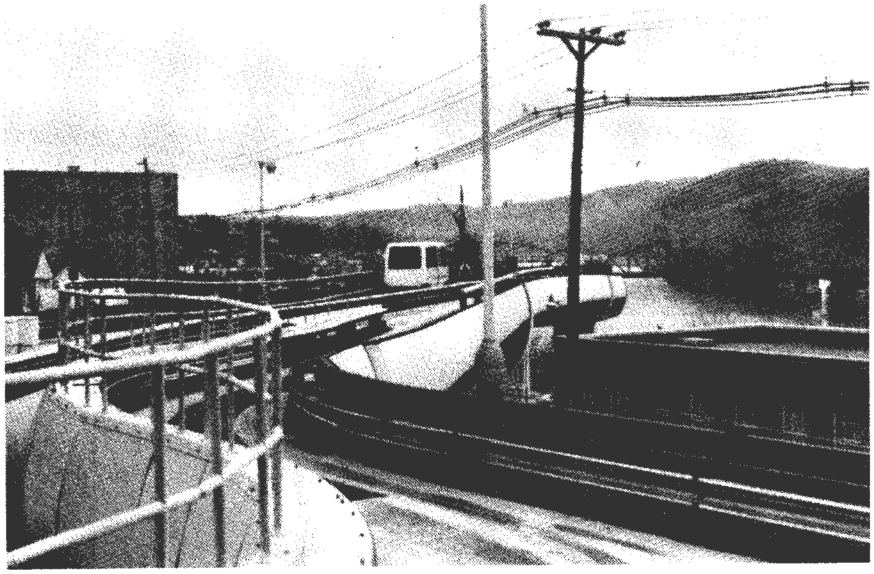


FIGURE 3.37 : SAFETY RAILINGS AND STEP PLATE FOR EMERGENCY EXITING FROM VEHICLES

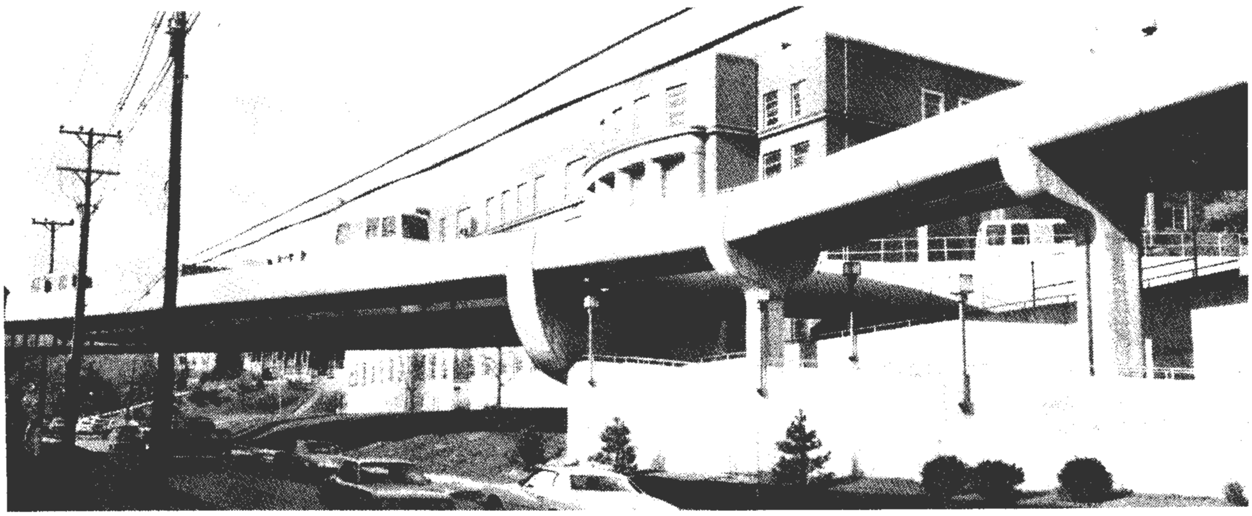
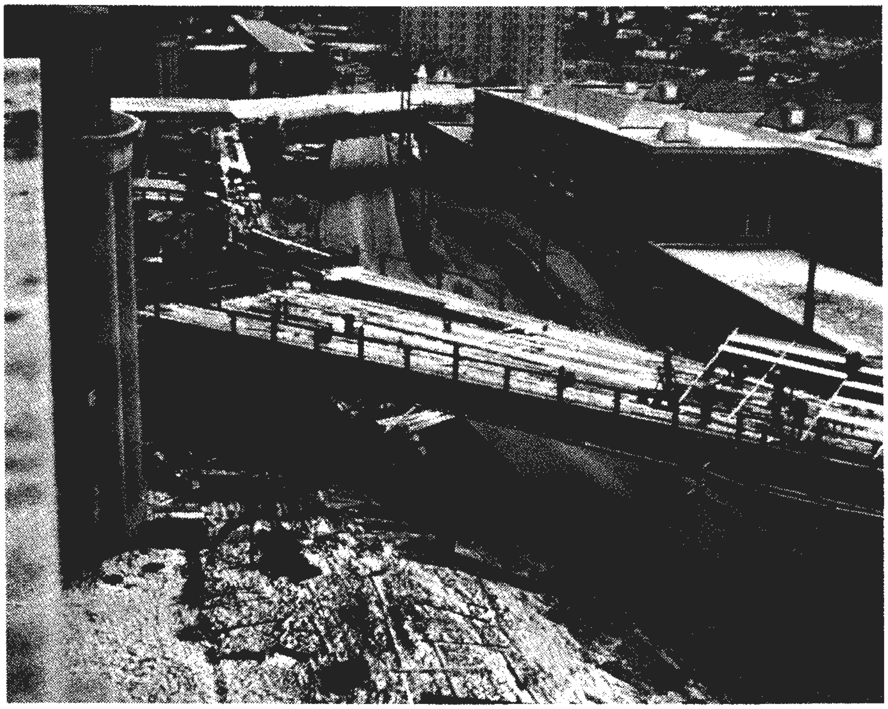


FIGURE 3.38 : NORTHERN LARGE SPAN OVER BEECHURST AVENUE

FIGURE 3.39 : SOUTHERN LARGE SPAN CROSSING BEECHURST AVENUE



(a) SPANS OVER BEECHURST AVENUE

(b) GUIDEWAY UNDERSIDE

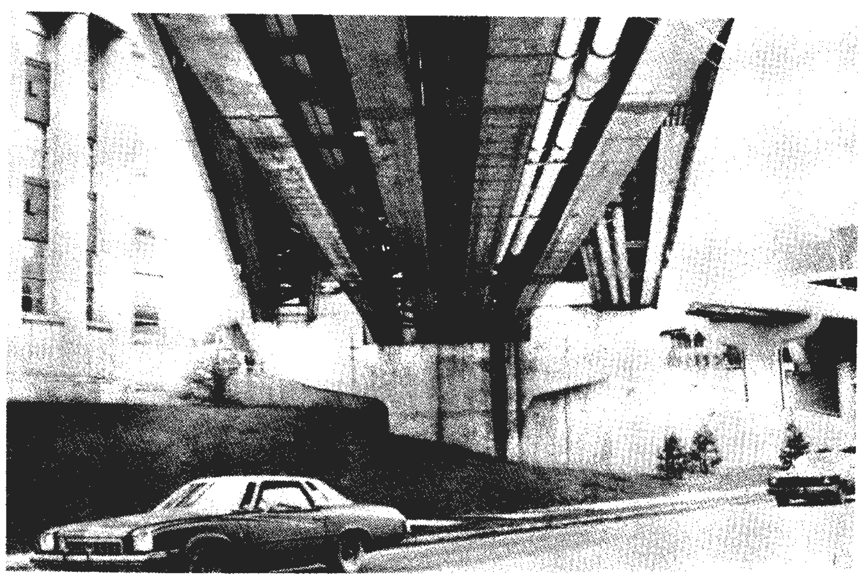


FIGURE 3.40 : MASSIVE CONSTRUCTION OF LARGE SPANS

The general characteristics of the elevated sections of the guideway are as follows:

Overall Cross Section Width	
Single Lane	12.6 ft
Double Lane	22.5 ft
Overall Cross Section Height	5.7 ft
Running Pads Width	2.0 ft
Distance Between Running Pads Centerlines	5.2 ft
Design Load	
Single Lane	840 lbs/ft
Double Lane	1,680 lbs/ft
Typical Span Lengths	60 to 70 ft
Maximum Span Length Used	158 ft
Vertical Deflection Under Load Length	0.1% of span
Horizontal Deflection Under Load Length	0.067% of span
Vertical Fundamental Natural Frequency	2.5 Hz
Envelope (with vehicle)	
Single Lane Width	12.6 ft
Double Lane Width	22.5 ft
Height	12.0 ft
Maximum Grade	10%
Minimum Horizontal Turn Radius	30 ft at 6 mph
Minimum Vertical Turn Radius	60 ft at 30 mph

Guideways At Grade

Of the Phase I guideway network, 11,100 single-lane feet, or approximately 40 percent, are constructed at grade. Most of this ground-level guideway is in the northern part of the system, leading to the Engineering Campus. Additionally, much of the test loop in the maintenance area is at grade.

As indicated in Figure 3.41, the surface guideway consists essentially of a concrete roadway with safety, power and guiderails attached to posts imbedded in the concrete. On flat ground these are relatively inexpensive to build. However, on a sloping hillside such as the one encountered on the steep climb to the Engineering Station, the double guideway had to be built on two levels, with retaining walls, tie backs and special features to facilitate emergency evacuation of vehicles. Figure 3.32 indicates the arrangement used.

The general characteristics of at-grade guideways which are different from elevated sections are as follows:

Overall Width	
Single Lane	11.9 ft
Double Lane	22.0 ft
Overall Height	2.5 ft
Thickness of Concrete Surface	6.0 in
Type of Subgrade	Grade I Aggregate, 3-4 in layers

Switching

The MPM system is unique among AGT systems in that no physical entrapment is involved during the process of switching. The guideway is entirely passive, merely providing sidewall guiderails for the vehicle to follow. The vehicle follows along either of the two possible rails against which it is directed to steer. A complete description and assessment of steering and switching is given in Section 3.3. To minimize damage in the unlikely event of an on-board control or equipment failure which could result in a vehicle's "splitting a switch", plastic drums filled with sand are positioned at the point of each high-speed turnout location, as indicated in Figure 3.42.

FIGURE 3.41 : AT-GRADE GUIDEWAY

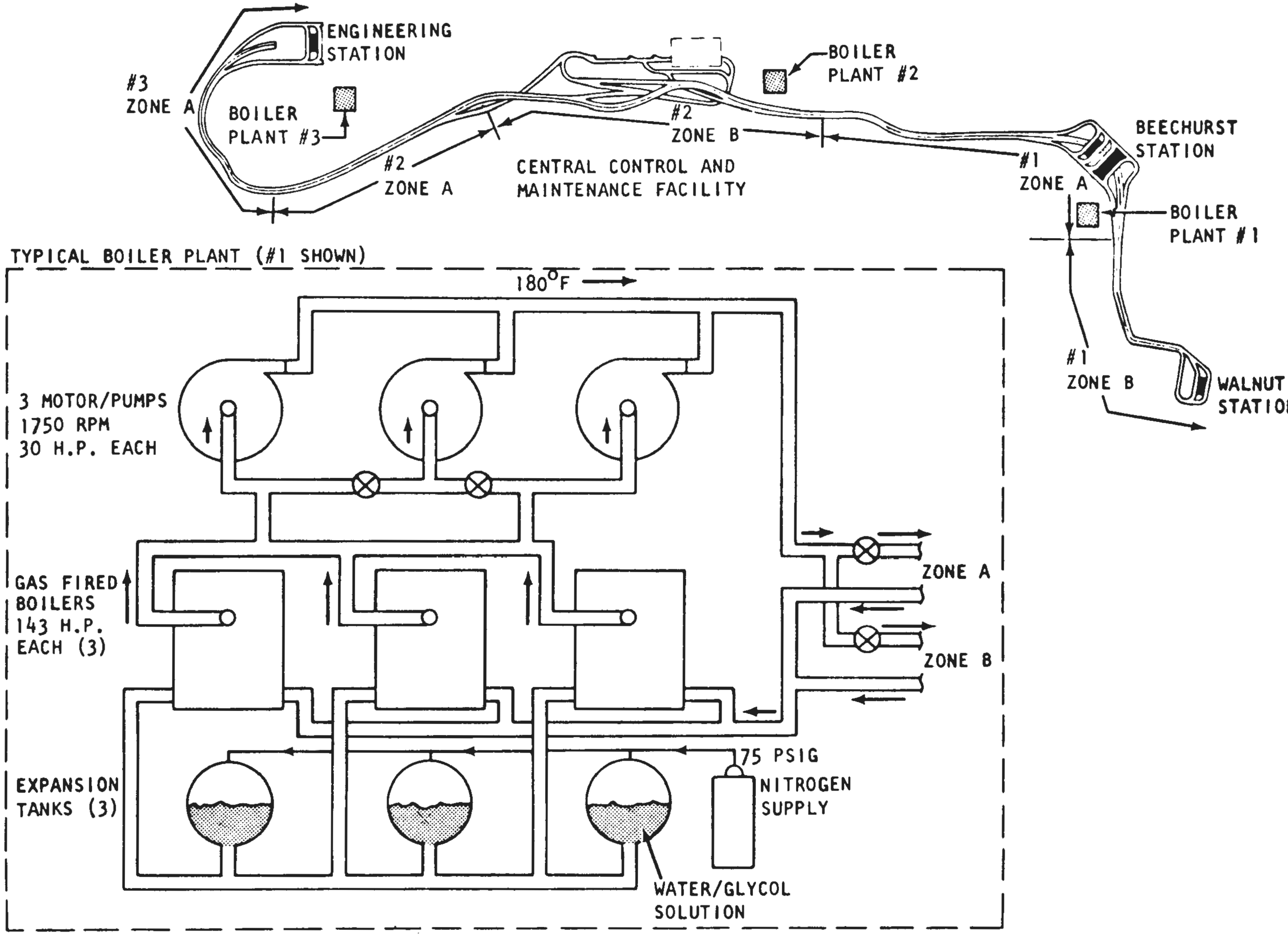
FIGURE 3.42 : SAND FILLED PLASTIC DRUMS AT TURNOUTS

Guideway Heating

Since the system is automated and must maintain headway spacing, even on the steep grades which must be negotiated, it is necessary to keep the guideway surface clear of ice and snow during cold weather operations. After study of alternative methods of melting ice and snow, a guideway heating system was selected which involves the circulation of a hot mixture of propylene glycol antifreeze and water through one-inch pipes embedded in the concrete running surfaces. Figure 3.43 illustrates the arrangement used. In Phase I, three gas-fired boiler plants delivered hot liquid at 180^{o} F to the guideway through an extensive distribution system. Figure 3.44 shows the arrangement of embedded pipes in at-grade guideway sections. For elevated guideway sections, only the two running pads are heated, as indicated in Figure 3.45. The open grillwork between the two concrete strips does not accumulate enough snow or ice to create a problem, as indicated in Figure 3.46a. Where the guideway is at grade, the entire surface width is heated and kept clear of ice and snow, as shown in Figure 3.46b.

The Phase I complex of nine boilers, located in three separate heating plants near the Beechurst station, the maintenance facility and the Engineering station, was designed to furnish a total of 48 million BTU's per hour to the guideway. The guideway heating system is under the control of the System Operator, who remotely turns on each boiler plant from the console at Central Control whenever the weather forecast indicates the probability of snow or ice conditions. Once turned on, the boiler plant operation is automatic, requiring no further intervention by the operator unless there is a malfunction or it is decided to shut down the system.

The guideway heating system was designed long before the Arab oil embargo and subsequent reassessments of energy utilization, especially with regard to natural gas. In the light of these developments, the choice of this inexpensive, clean and convenient fuel was especially fortunate. For system compatibility and to permit rapid response to sudden changes in the weather, the heating system for the Phase II extension to the guideway also uses natural gas as fuel for the new boilers.



SOURCE: Boeing Aerospace Company

FIGURE 3.43 : GUIDEWAY HEATING SYSTEM

FIGURE 3.44: GUIDEWAY HEATING PIPES EMBEDDED IN THE SURFACE OF AT-GRADE GUIDEWAY

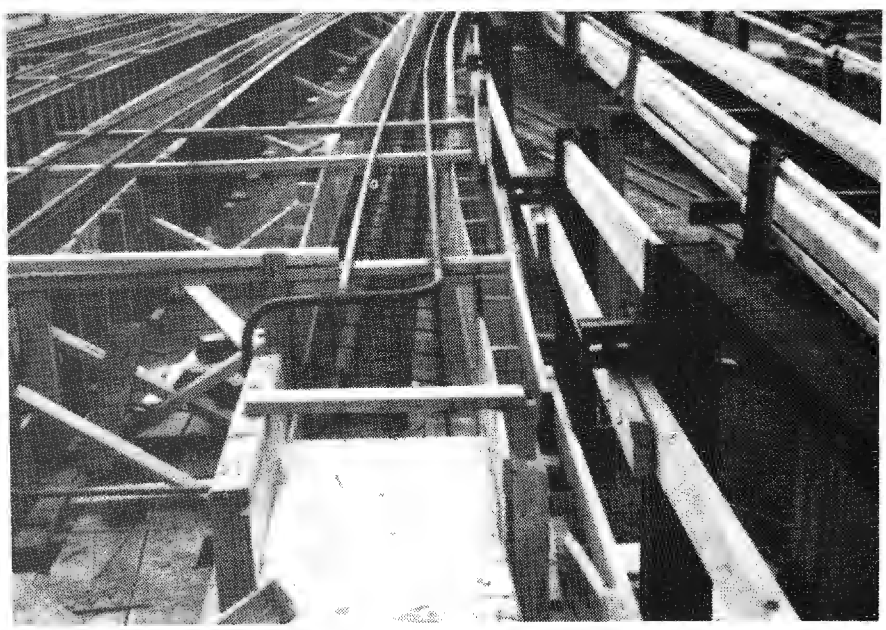
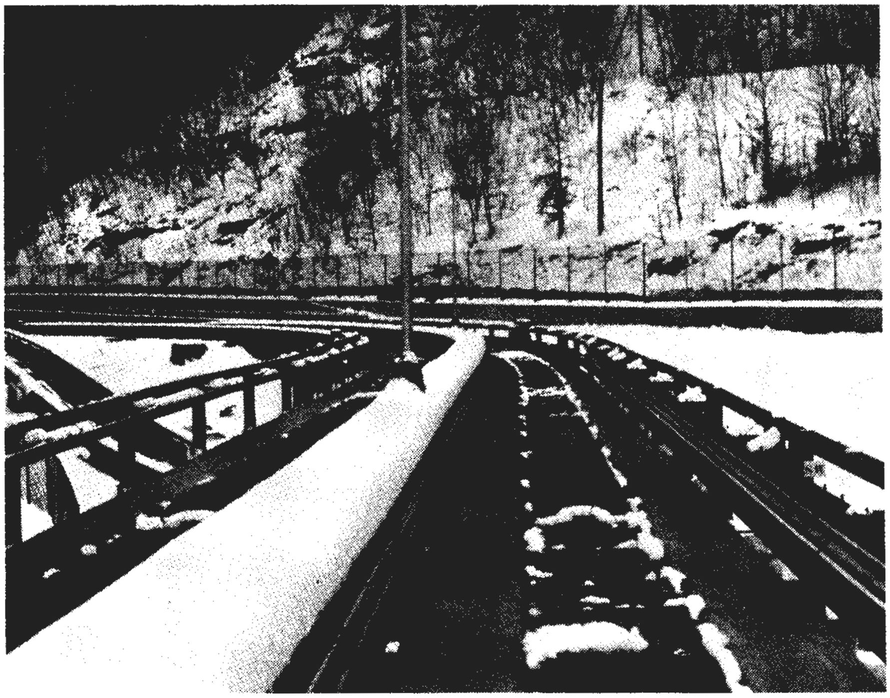


FIGURE 3.45: GUIDEWAY HEATING PIPES EMBEDDED ONLY IN RUNNING PADS OF ELEVATED GUIDEWAY



(a) ELEVATED

(b) AT-GRADE

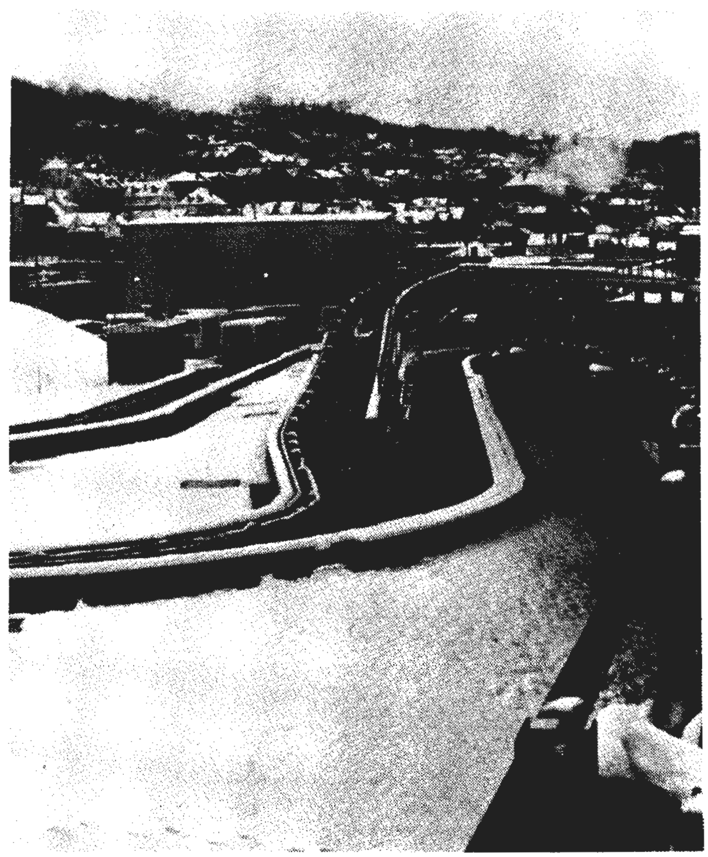


FIGURE 3.46 : GUIDEWAYS ARE EFFECTIVELY KEPT FREE OF ICE AND SNOW

3.7.1.2 General Assessment of Guideways

From an operational point of view, the Morgantown guideway system deserves an overall rating of good to excellent. With very few exceptions the guideway surfaces are smooth and in good condition. The overall quality of the design and construction of the running pads and lateral guiderails is excellent. The geometry has been professionally executed, with spiral entries and appropriate superelevation (banking) used on turns to insure a comfortable ride at the speeds involved. There is one case of misalignment of the lateral steering rail along the high-speed segment between Maintenance and Beechurst which causes noticeable vehicle swaying.

Inspection of representative segments of the guideway reveals no appreciable deterioration of the running surfaces. Expansion joints are clean and generally free from spalling, possibly due to the fact that the effect of freezing and thawing have been minimized by the guideway heating system. Where vehicle wheels come in contact with the concrete guideway surface, there is some evidence of a slight build-up of rubber particles which have worn off the tires. The air intake and filter for cooling the motor are positioned directly over the guideway surface and act as a vacuum, removing much of the tire dust. This air intake has been changed in Phase II. It appears that the rolling pathway has become "polished" and less abrasive through usage. This may account in part for the increase in tire life which has been experienced as the system matured.

A common reaction to the general appearance of the elevated guideway structures is that they seem unnecessarily sturdy, especially when the small vehicles are observed passing by. As mentioned earlier, the curved fascia plates which border much of the guideway increase the vertical profile by about 30 percent and give it a more solid apprearance with smoother and simpler lines (Figure 3.47). There are mixed reactions over what is more aesthetically appealing. The majority of riders surveyed (Section 4.4) found the guideway appearance to be acceptable; however, 27.5 percent considered it to be obtrusive. Placement of the guideway, the angle at which it crosses a street, the surrounding landscape and building architecture, street furniture and signs, the general foreground and background are all important in the resultant aesthetics. Figure 3.48 demonstrates the importance of landscape and placement angle to an acceptable appearance of the guideway. In Figure 3.49 the steam plant in the background and the telephone poles are aesthetically more objectionable than the guideway. The street signs in Figure 3.50 probably have more visual impact than the guideway. In Figure 3.51 the guideway, without curved fascia plates, is almost obscured by the general busyness of the view. Figures 3.52a and 3.52b show that some installations convey an impression of massiveness.

As mentioned elsewhere in this report, the time schedule for this project dictated that design of the guideways and vehicles proceed concurrently. Thus, assumptions had to be made concerning the weight and operating characteristics of the vehicles in order to avoid delaying the design of the guideway structures. This requirement resulted in a very conservative design for the guideways, which served to increase the cost. By contrast, the Phase II guideway design was undertaken with extensive knowledge of the vehicle's dynamic characteristics. Also, time was available for optimization of the Phase II design. The result may therefore be a much more aesthetically pleasing structure which is more cost effective.

Environmental Impact

Since most of the guideway is located either along the railroad right-of-way west of Beechurst Avenue/Monongahela Boulevard or on University property, the impact on the community has been minimal. There are four major highway crossings which, during construction, involved some temporary disruption of traffic. The guideway does penetrate the downtown area for a few blocks en route to the Walnut station, but there has been little impact on the surrounding property. During the construction period along Monongahela Boulevard, traffic was reduced to two lanes. While construction was in progress, there were objections to the congestion and inconvenience from students and local residents. Once foundations were poured and overhead guideways were installed on support columns, three of the four traffic lanes were opened. This action reduced the objections by enabling work to proceed overhead and eliminating most interference with activities on the ground.

The system is inherently very quiet. The vehicles come and go almost without being noticed by those on the ground beneath or nearby. It is virtually pollution-free insofar as the community is concerned, utilizing electrical energy which is generated at a remote location and burning clean natural gas for heating the guideways.

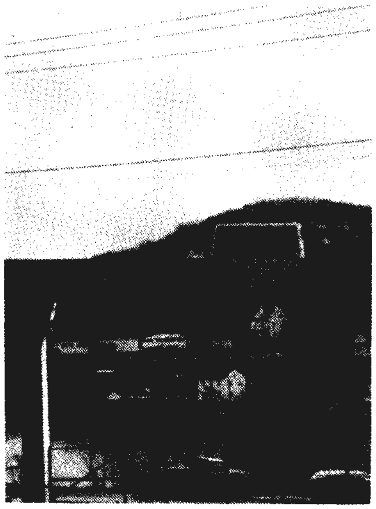
Impact analyses* of traffic in the University Avenue/Beechurst Avenue corridors show no noticeable changes in congestion. The reasons are varied and complex--generally related to growth in the Morgantown area. Also, since the Phase I system did not provide service beyond the Engineering station at the Evansdale Campus, vehicular traffic to the Towers Dormitories and the Medical Center was not greatly affected. Chapter 6 discusses these impacts in more detail.

There has been no discernable impact to date on land values or the utilization of land around the downtown Walnut station. This is not surprising in view of the fact that this is the only station which serves the general public. Beechurst and Engineering are both located upon University property.

Winter Weather Operations

Given the topography and the dependence upon traction for acceleration, steering and safe stopping during all weather conditions, an effective means of melting snow and ice is essential to permit continuity of operation during the winter months. The present system was selected as the result of trade-off studies which included consideration of an electrical heating alternative. The boilers were designed to deliver 70 watts per square foot of guideway running surface, somewhat more than the theoretical value of 60 watts per square foot which was considered necessary to melt the amount of snow anticipated at one inch per hour. During 1975 a representative section of the guideway was instrumented and monitored to determine if design objectives had been met. These tests demonstrated that the basic design objectives had been achieved. They also indicated that peak snow-melting performance occurs four to eight hours after the heating system is turned on, as indicated in Figure 3.53. It is interesting to note

*"Phase I Morgantown People Mover Impact Evaluation", S. Hsiung and M. Stearnes, Transportation Systems Center, U.S. Department of Transportation, Report No. UMTA-MA-06-0081-80-1.



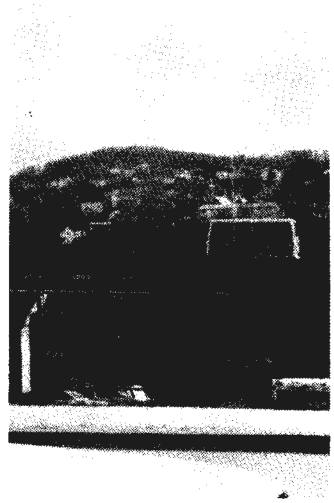


FIGURE 3.47 : ELEVATED GUIDE-WAY WITH AND WITHOUT CURVED FASCIA PLATES

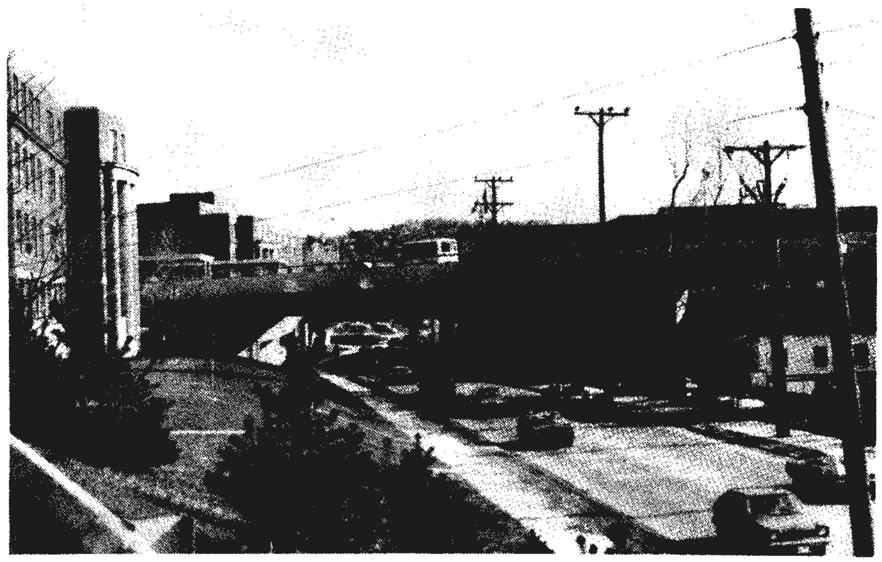


FIGURE 3.48 : PLACEMENT ANGLES AND LANDSCAPING ARE IMPORTANT AESTHETIC CONSIDERATIONS

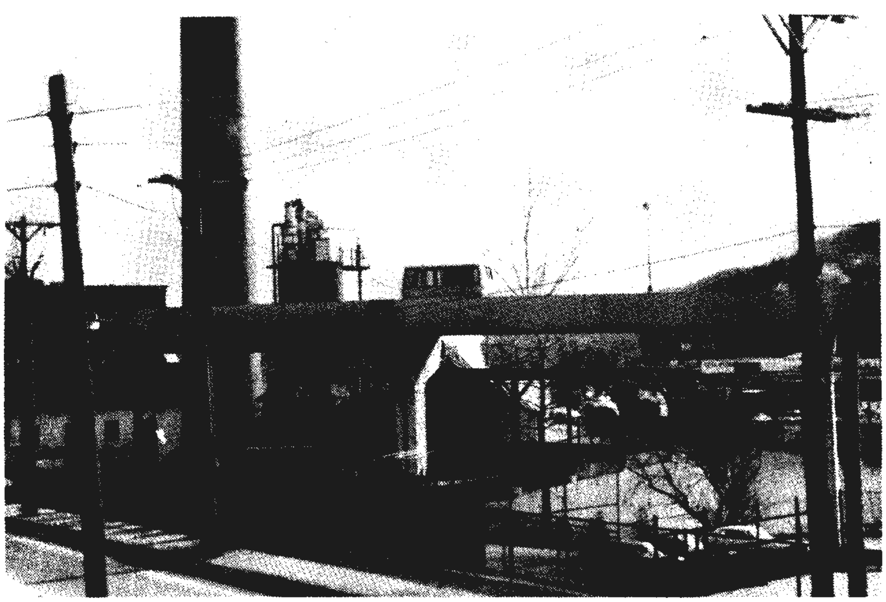


FIGURE 3.49 : STEAM PLANT IS LESS AESTHETICALLY APPEALING THAN THE GUIDEWAY

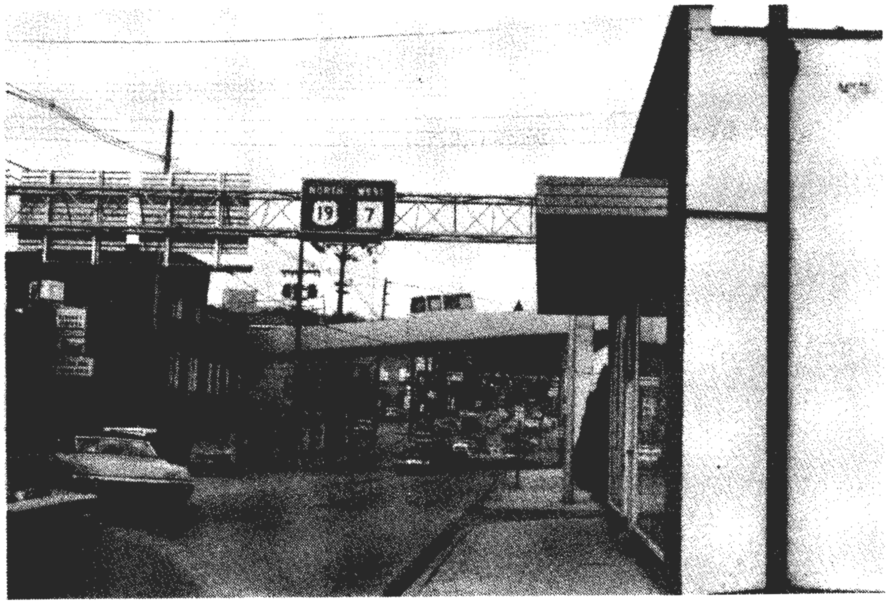


FIGURE 3.50 : STREET SIGNS ARE MORE NOTICEABLE THAN GUIDEWAY

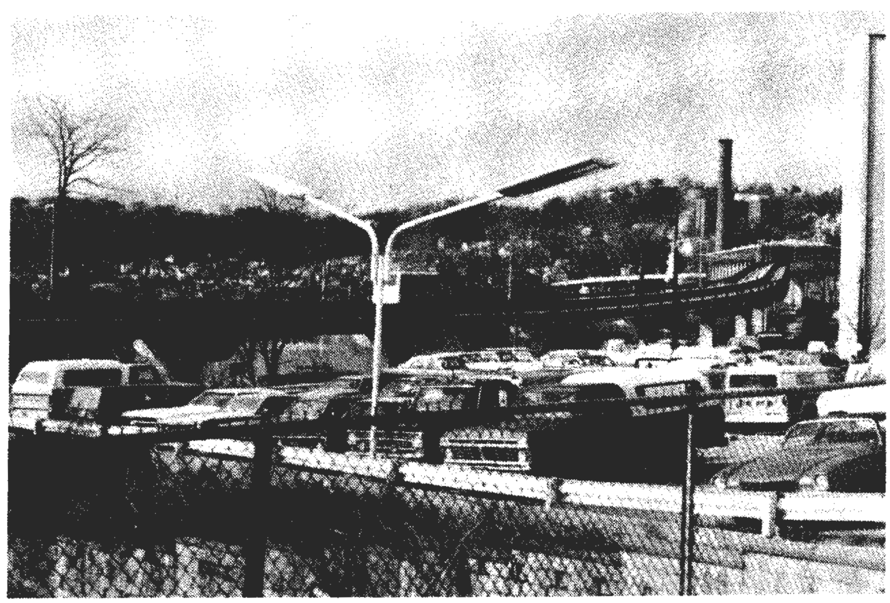
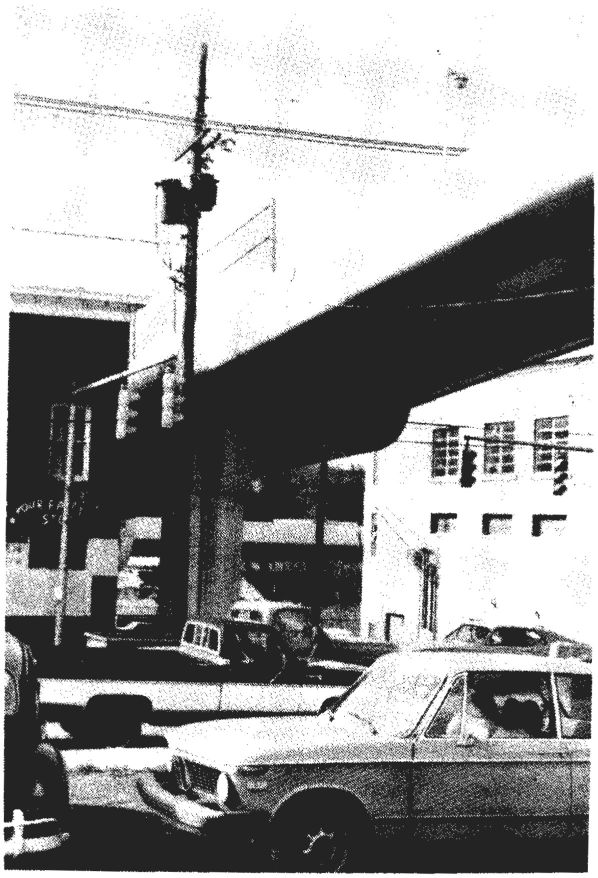
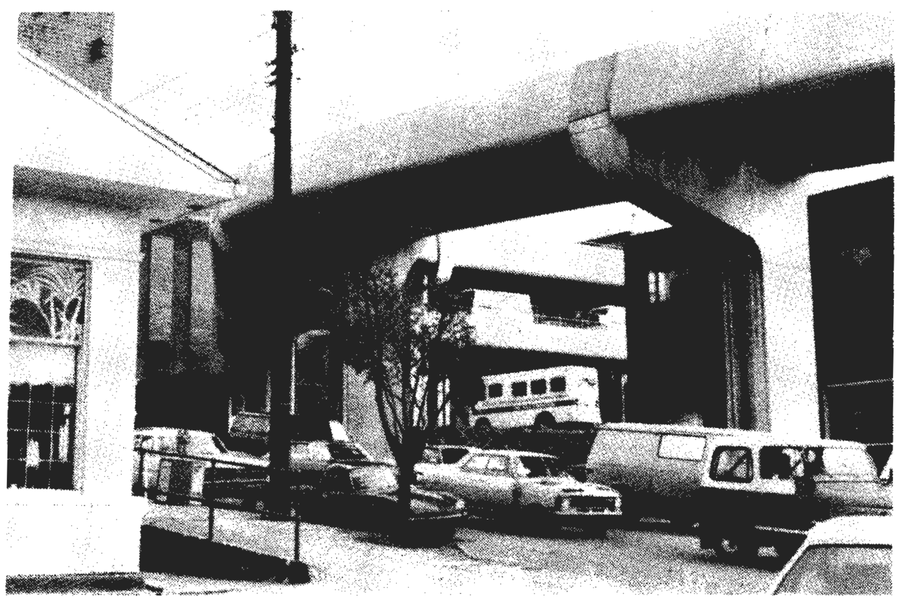


FIGURE 3.51 : GUIDEWAY IS ALMOST OBSCURED BY OTHER ELEMENTS IN THE SCENE

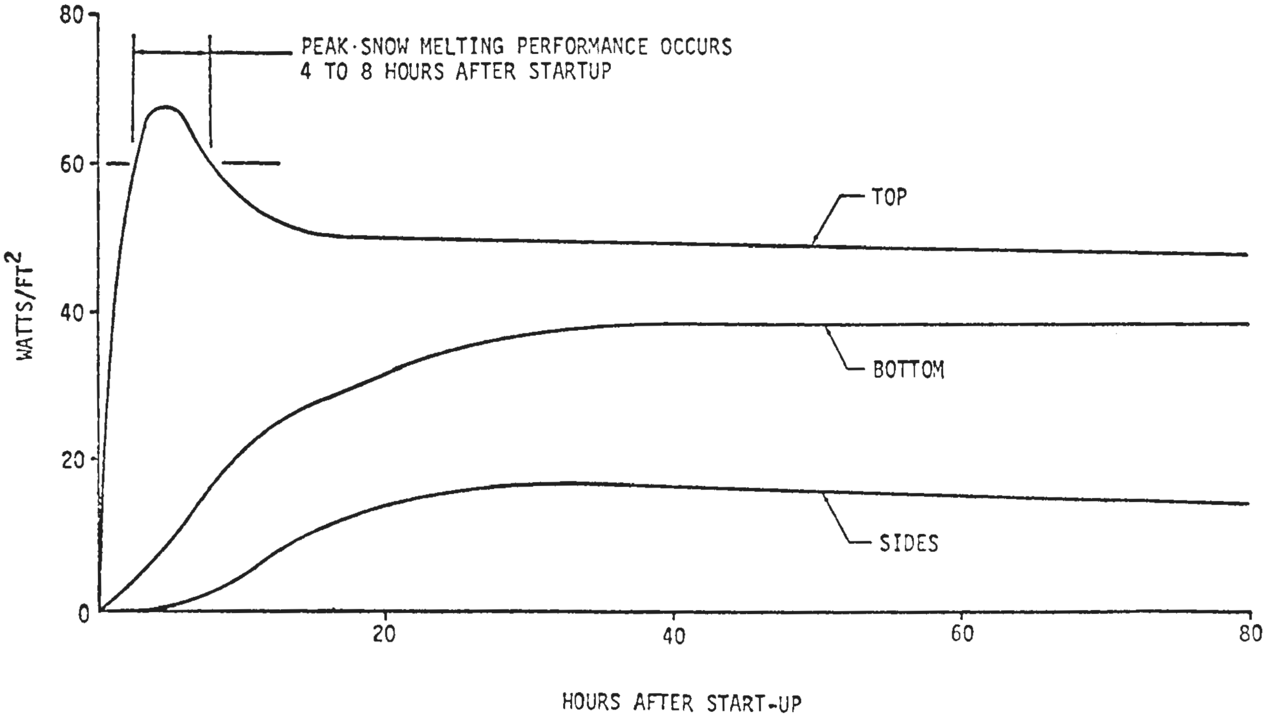


(a) DOUBLE-LANE GUIDEWAY PLACED BESIDE BUILDING



(b) GUIDEWAY LEADING TO WALNUT STATION

FIGURE 3.52 : GUIDEWAY INSTALLATIONS WHICH CONVEY MASSIVENESS



SOURCE: Boeing Aerospace Company

FIGURE 3.53 : GUIDEWAY HEATING SYSTEM - DYNAMICS OF SURFACE HEAT LOSS

that once a stable condition is achieved after nearly 24 hours of continuous operation, about half of the total heat is dissipated through the bottom and sides of the guideway where it contributes nothing to the melting of snow.

The heating system was subjected to a very good test during the unusually severe 1976-1977 and 1977-1978 winter periods. There was only one instance when service had to be suspended due to accumulation of ice and snow combined with steering problems due to severe frost, following a particularly hard snow and ice storm on January 17, 1977. During the month of January 1977, the heating system was in operation almost continuously.

The effectiveness of the guideway heating system in melting accumulations of ice and snow precipitated other problems. As the snow melts, a layer of fog forms immediately above the guideway. This fog in turn condenses in the form of thick frost on the vehicle running gear, power rails and collectors. These ice accumulations caused numerous malfunctions, resulting in several basic design modifications and improvements implemented in Phase II.

Subsurface Soils Investigation

Many of the problems which developed in the course of guideway construction could have been avoided had a more comprehensive program of subsurface soils investigation been conducted during the design stage. Due to the tight deadline which was established by UMTA for this project and in keeping with a concerted effort to limit costs, the Morgantown subsurface boring program was curtailed severely. After excavation began, uncharted utility lines, abandoned footings, and unstable soil conditions were uncovered. This led to numerous foundation design changes during construction, resulting in additional costs.

3.7.2 Stations

During initial substantive planning for an automated transportation system at Morgantown, the University contemplated a sizeable fleet of small vehicles moving at short headways. The Alden Self-Transit System Corporation proposal, which formed the basis for the initial grant application, called for 100 six-passenger vehicles capable of operating at about five-second headways. The concept specified direct origin-to-destination service in "personalized" vehicles, with no stops in between. This required a unique configuration of the stations, with turn-arounds provided to permit vehicle traffic to flow freely between any pair of stations. The proposed arrangement appears to have been adopted for the station configuration which was finally used.

The system concept which ultimately evolved as the result of detailed study, together with compromises dictated by budgetary considerations, still reflected many of the essential features of the University's original plan. Although larger than initially proposed, the vehicles are generally smaller than those used in other AGT applications. The operational strategy was based on the classic PRT concept that all trips should be nonstop. Furthermore, a relatively high flow rate between the principal pair of stations, Engineering and Beechurst, was established as a design and contractual objective. The University's initial objective was to handle 1,100 people in only 10 minutes. Cost and feasibility considerations reduced this requirement to moving the same number in 20 minutes. Nevertheless, to sustain a movement rate of 55 passengers per minute, with 21 passengers per vehicle, three vehicles must be dispatched each minute. The computer must allocate a reasonable dwell time in the station for vehicles to unload, load and await a proceed signal which will insert them safely onto the main guideway at a precise time. Thus, more than one launch channel is required to sustain a departure rate of three vehicles per minute. To give operational flexibility, four channels were provided.

3.7.2.1 General Arrangement and Layout

The station designs were predicated on furnishing on-demand service at a 7.5-second headway, which required that they be off-line stations. While the minimum 7.5-second headways were not finally used, the 15-second headways employed also require off-line stations. The minimum headway generally acceptable for on-line stations is one minute.

Each of the three Phase I stations at Morgantown was arranged differently, but all had similar features. Beechurst was largest of the three, as indicated in

Figure 3.54, with three turn-around channels "facing" in the direction of Engineering and one "facing" Walnut.

As constructed for Phase I, Engineering was equivalent to only one-half of a Beechurst-type station. It had one platform which was served by two turn-back channels, as indicated in Figure 3.55. As completed for Phase II, Engineering now has three turn-around channels "facing" Beechurst and one "facing" the new Towers station.

Walnut (Figure 3.56) is a terminal station with two channels for receiving and dispatching vehicles. Since a lower volume of traffic is anticipated to and from this station, its capacity is considered ample.

Of the two new stations built under the Phase II expansion, Towers is similar in capacity and configuration to Beechurst, with three turn-around channels "facing" Engineering and Beechurst. Medical Center, however, is a terminal station and has the same basic capacity as Walnut.

As indicated, the Beechurst station has a total of 22 berths, with four in each of its turn-back channels. On the outer edges of the larger platform, there are six berths, one for loading and two for unloading in each direction. These side channels provide flexibility in the operation of the system. A vehicle at Walnut, for example, which is scheduled to be taken out of service, could load passengers for Beechurst, discharge them on the side channel and then proceed empty directly to the maintenance area. Alternatively, if the Beechurst-Engineering traffic requires additional vehicles, equipment available at Walnut can be moved after unloading to the side channel at Beechurst for subsequent dispatch to Engineering.

Figures 3.57 and 3.58 are plan views of Platforms "A" and "B" of the Beechurst station, respectively. Platform "B" is typical of the platform arrangements at Walnut and Engineering stations. Passengers enter the stations at the street level and reach the platforms via stairways. There were provisions for elevators for the handicapped, but these were not installed until Phase II. An automatic ticket dispenser was located in the unpaid area (Figure 3.59). Exact change was required

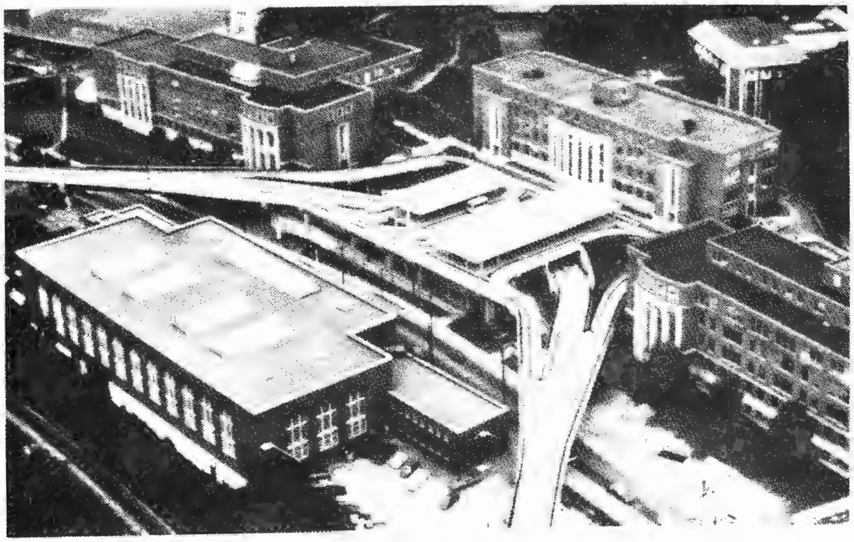
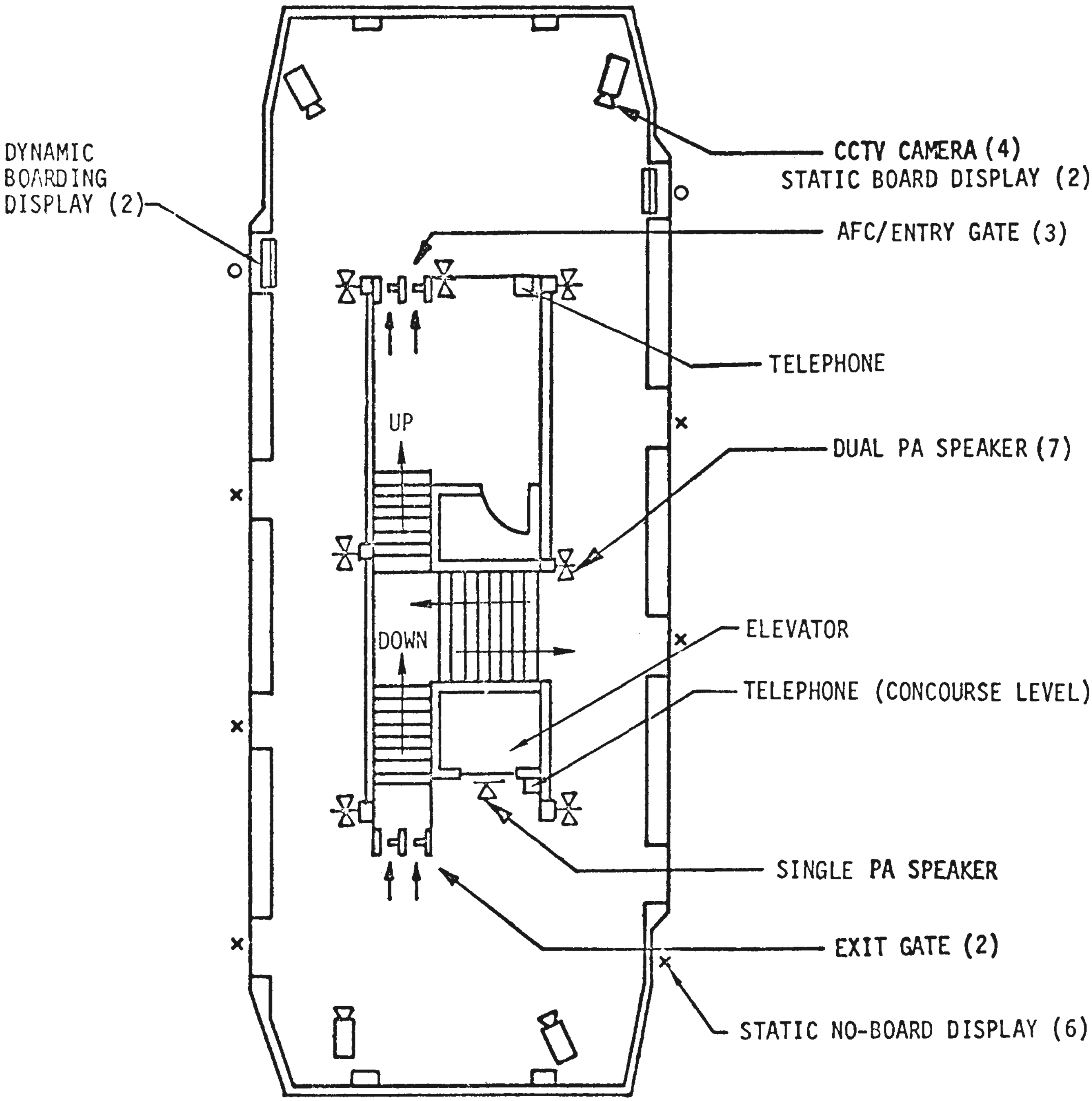


FIGURE 3.54 : BEECHURST STATION

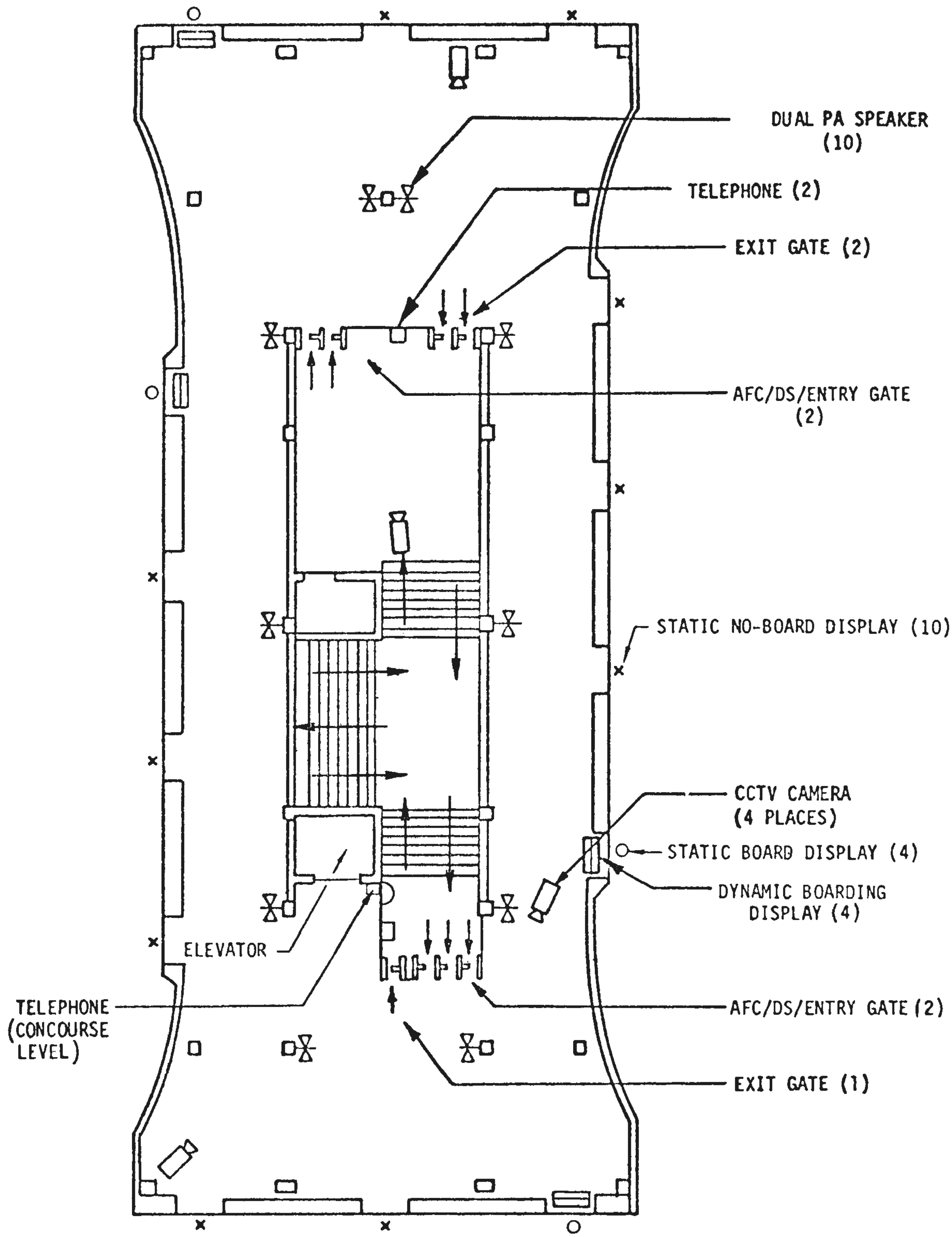
FIGURE 3.55 : ENGINEERING STATION

FIGURE 3.56 : WALNUT STATION



SOURCE: Boeing Aerospace Company

FIGURE 3.57 : BEECHURST PLATFORM "A"



SOURCE: Boeing Aerospace Company

FIGURE 3.58 : BEECHURST PLATFORM "B"

to purchase a single one-way ticket from this machine. Multi-trip cards were issued to the students at the time they registered for classes and paid a transportation fee. Almost 95 percent of the MPM riders use the prepaid fare cards. Also in the unpaid area was a dynamic audio-visual device which, upon activation by a patron, gave instructions on how to use the system. An emergency telephone connected to the central control operator is installed so that it can be used from both the paid and unpaid areas.

The paid area (Figure 3.61) could only be entered by passing through an entrance turnstile. (In Phase II, elevators, intended primarily for use by the handicapped, can deliver passengers directly to the paid platform area.) Each turnstile included a Fare Collection Unit and a Destination Selection Unit. The insertion of a valid magnetically-coded fare card (Figure 3.60) activated the turnstile. After pushing the button for his desired destination, the passenger retrieved his multiple-trip card and manually moved the unlocked tripod to enter the paid area. The turnstiles could also be remotely released from the central control room to allow entry in the event of a failure in the fare collection equipment.

A large portion of the platform is continuously monitored from central control by strategically located TV cameras. Public address speakers for announcements by the operator are provided in sufficient number to reach all passengers on the platform. Static "No-Board" displays are placed at the deboarding berths while dynamic boarding displays are used at the boarding positions. The dynamic displays indicate gate number, instruction to board or not to board, and the destination. The entire platform is separated from the guideway and the moving vehicles by a barrier, except at the boarding and deboarding positions, where there are open gateways. Yellow warning stripes are painted on the platform surface at these positions. The entire platform is covered by a roof. Windscreens have been added to some platforms in Phase II to give additional protection against the weather.

Passengers deboard vehicles at one of three berths (turnaround channel) or two berths (passthrough channel) and leave the paid area through manually operated turnstile exit gates (Figures 3.62 and 3.63). These gates are located on the opposite side from the entrance gates, separating entering and leaving passenger streams.

FIGURE 3.59 : STATION UNPAID AREA

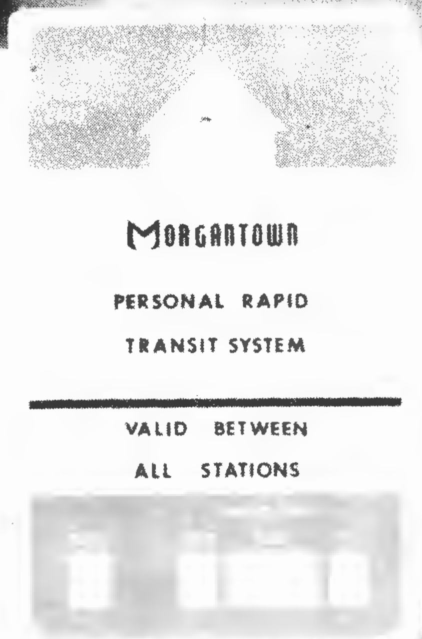


FIGURE 3.60 : MAGNETIC FARE CARD

FIGURE 3.61 : STATION PAID AREA

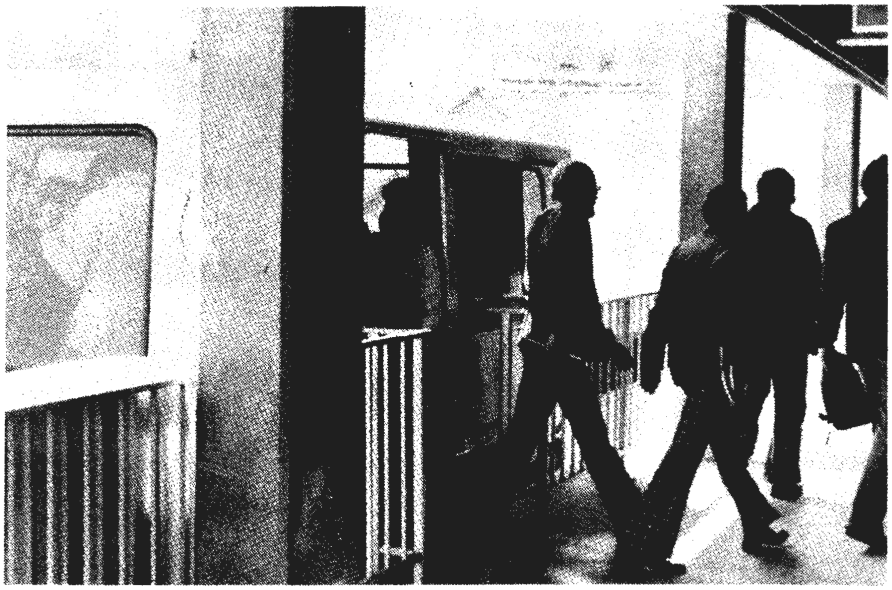


FIGURE 3.62 : PASSENGERS EXIT VEHICLES AT SEPARATE DEBOARDING BERTHS

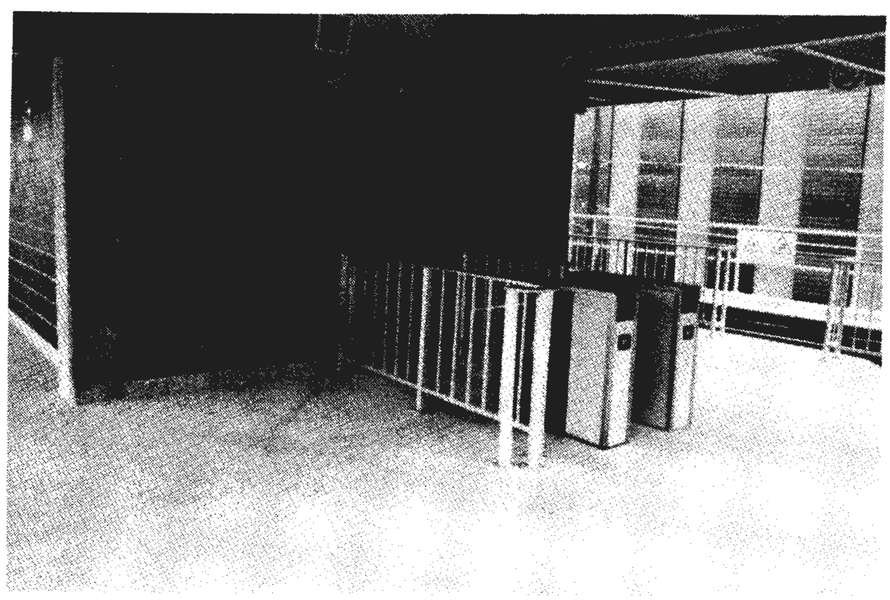


FIGURE 3.63 : PASSENGERS EXIT PLATFORM AT SEPARATE EXIT TURNSTILES

The stations are generally adequate in area and are usually able to accommodate the volume of passengers experienced. However, during the course of the assessment, cases were observed where a slow rate of vehicle dispatch at a time of high travel demand caused severe crowding on the Beechurst platform.

The effective platform area of the north or "A" platform at Beechurst and of the Walnut and Phase I Engineering stations is about 1,850 square feet, which is sufficient to accommodate 100 waiting passengers. The south or "B" platform at Beechurst is larger and capable of accommodating up to 300 waiting passengers, including space for passengers alighting from a total of 10 unloading berths on four channels. These area allocations are essentially the same for the expanded Engineering station and the new Towers station of Phase II. The maximum capacity for loading or unloading passengers through each separate berth is 840 passengers per hour.

The locations of the stations were determined by topography, the availability of real estate, and proximity to activity centers to be served. These factors necessitated elevated construction for all three Phase I stations, which is more costly than at-grade installation. The Beechurst station in particular involved a substantial expenditure because it was necessary to cross Beechurst Avenue twice, requiring long spans and expensive construction.

The cost growth which was encountered throughout the Morgantown program caused several desirable features to be deferred, such as wind screens for protection from the weather, elevators for access by the elderly and handicapped and other similar facilities. As a result, the Phase I stations were somewhat austere. This situation has been altered in Phase II with essential improvements made to the existing stations.

The unique turn-back feature which characterizes the Morgantown stations requires a substantial use of space. The expanded Engineering station, which is elevated, occupies a space of about one-half acre (21,800 square feet), including entrance and exit ramps, bypass guideway and other land taken out of general use. The new Towers station is at grade and the mainline guideways split before reaching the station and pass around it. This arrangement requires even more space, approximately 3.2 acres (138,500 square feet). In both of these cases, state-owned land was readily available. Where space is not so readily available, such as in the vicinity of the Beechurst station, less area was allocated.

All three of the major Morgantown intermediate stations are similar in that they have three channels "facing" in one direction and one in the other. This arrangement was based on the assumption that the peak flow of traffic would be between Beechurst and Engineering and Towers alternately. This assumption appears to be a proper basis for designs at Morgantown. However, for other locations where peak movements in two directions may be anticipated, an expanded configuration would be required, as shown in Figure 3.64. Such a bi-directional station would have a total of eight loading berths and 22 unloading positions.

Plans for Phase II did not include any significant improvements in access to the system. On the contrary, locations of the two new stations, Towers and Medical, will involve relatively long walks. In the case of the Towers station, students will walk about 700 feet from the station to the nearest door into the Towers dormitory complex and 1,100 feet to the main entrance.

The station access situation at Morgantown is probably typical of the problem which may be expected wherever an AGT system is installed to serve existing facilities. It is generally more difficult to fit a new system into an existing environment than to build it as an integral part of a new development, as in the case of some of the airport systems. At Morgantown, the availability of space for guideway alignment and cost considerations prevented the addition of stations to existing buildings. The location of the new stations reflects compromises made in order to keep options open for siting new facilities which may be served by the MPM system.

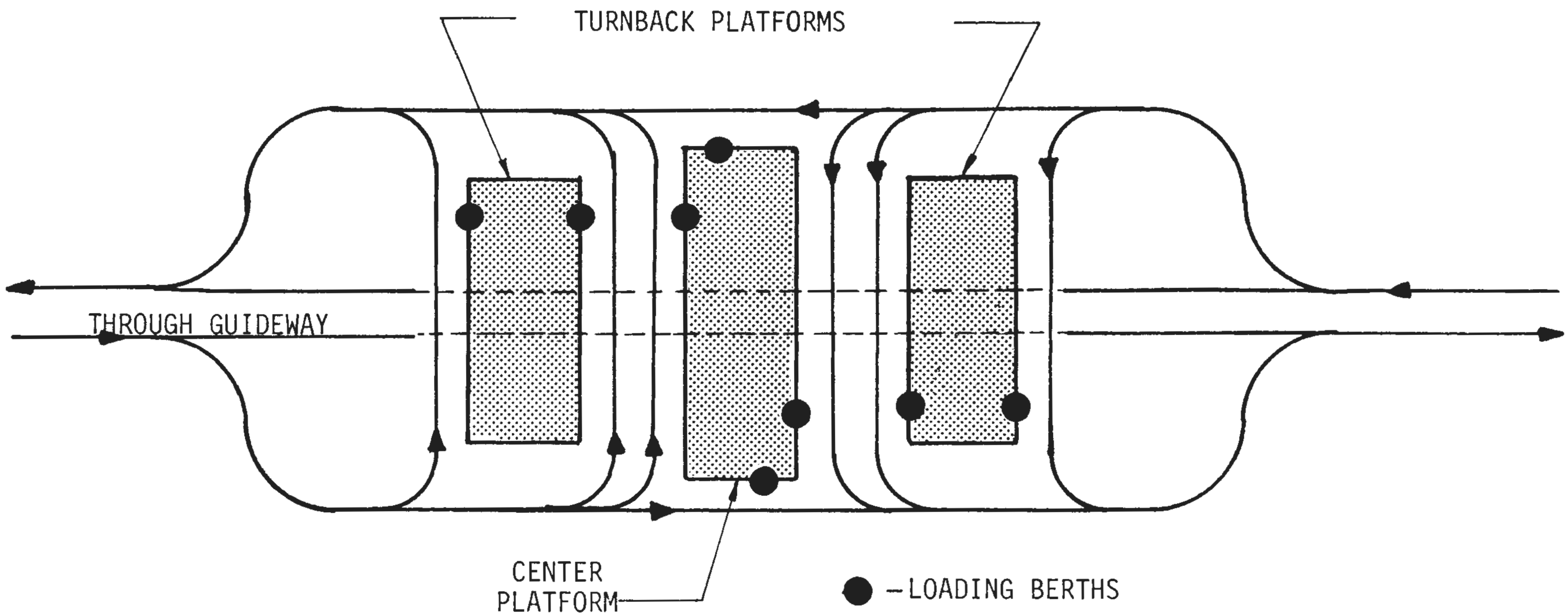


FIGURE 3.64 : MORGANTOWN TYPE BI-DIRECTIONAL STATION

3.7.2.2 Graphics

The vehicles move forward through station channels successively as those in loading berths are dispatched. Once a vehicle moves into a loading berth, an illuminated sign indicates its destination. For new patrons arriving on a platform for the first time, these signs are not easily noticed. To call attention to the boarding signs, WVU has added chimes to the visual displays. During Phase I most of the traffic was between Beechurst and Engineering, so only scant attention was paid to the graphics by the students. For example, the assessment team observed students boarding the wrong vehicle on more than one occasion. However, with the additional stations of Phase II, it is more necessary for passengers to observe the boarding signs. Under Phase II, dynamic signs and separate P.A. systems have been added to each platform. Other human factors aspects of the graphics are discussed in Subsection 4.3.1.

At all times during Phase I except peak travel periods, passengers desiring to go from Beechurst to Engineering entered the north platform. Those who wished to go to Walnut were required to enter the south platform. However, during peak periods, vehicles were also dispatched to Engineering from the south platform. During Phase I there did not appear to be an adequate system for informing passengers approaching the station which platform they should use. However, this problem did not seem to be serious because the students (regular passengers) had learned the characteristics of the Beechurst station. The problem should be corrected in Phase II with dynamic signs added at the concourse level.

3.7.2.3 Visual Impact

The architectural treatment of the three Phase I stations can be characterized as massive. This is primarily due to the extremely sturdy concrete structures which support the existing entry ramps and channels. Actual station structures are of simple functional design. As seen from the loading platform level, they appear to be clean and well executed. The view from underneath the Beechurst and Walnut stations is somewhat overwhelming, whereas the view from above merely conveys a feeling of complexity.

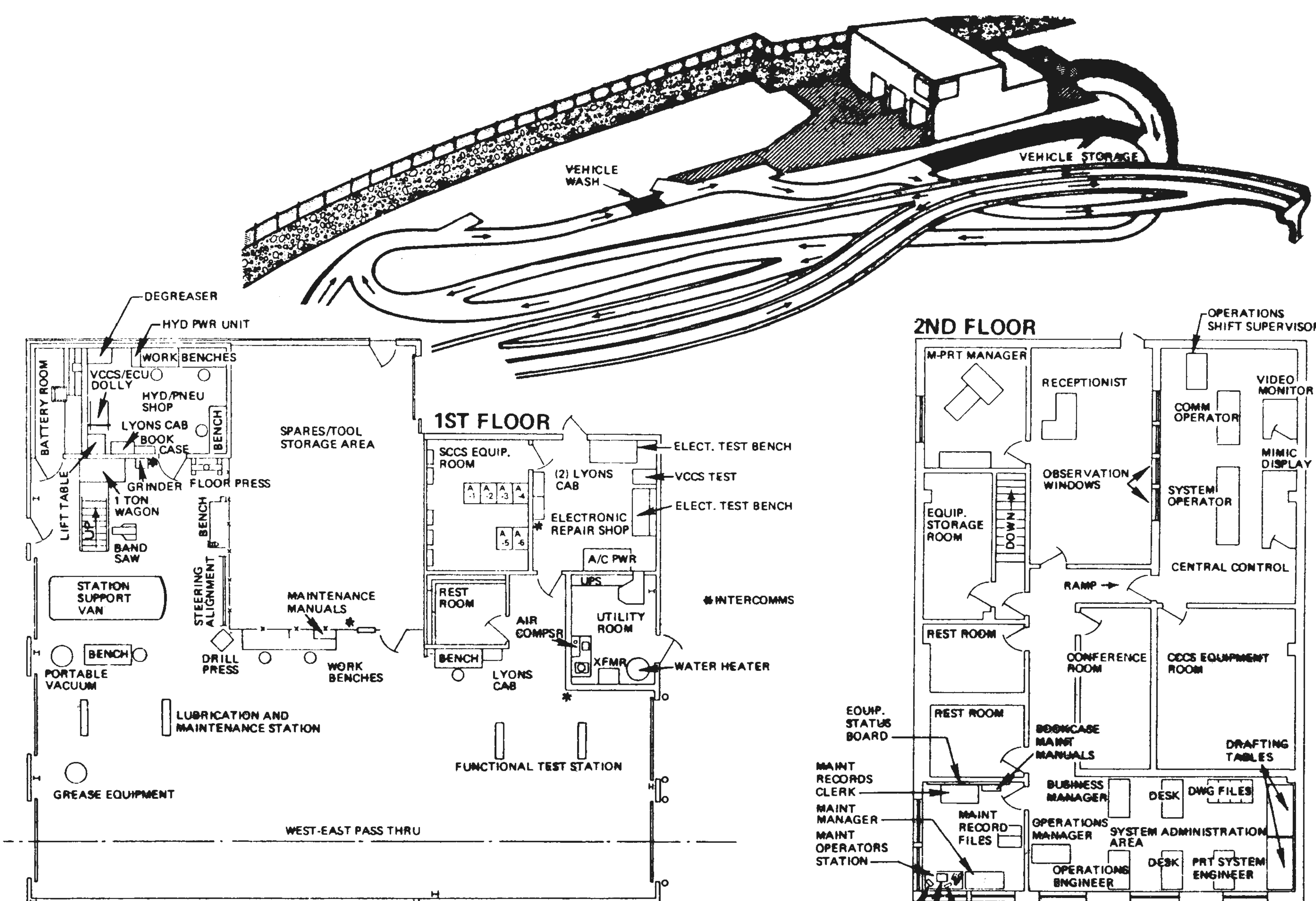
3.8 MAINTENANCE AND CENTRAL CONTROL FACILITIES

The maintenance facility and central control room are located at the same site (Figure 3.65). The second floor of the building houses the administrative offices, the central control room, central computers, and maintenance control room, while the ground floor is the enclosed maintenance area. The other Phase I maintenance facilities include the maintenance area guideway, a test loop, a vehicle wash facility and a computer controlled storage guideway with space for ten vehicles.

The central control room contains work stations for three employees (Figure 3.66). The Operations Supervisor (sitting in between the two consoles in the photograph) is in responsible charge and maintains the logs. Additional desk space is provided for the Operations Supervisor. To his right sits the System Operator. The System Operator's console is equipped with a keyboard/terminal/CRT for monitoring system status and exercising control over the system when required; a guideway/station electrification panel for controlling guideway and station circuit breakers; a maintenance intercom unit for direct communication with the Maintenance Operator; and a mimic display which shows the locations of all vehicles operating and in ready storage.

The Communication Operator sits to the left of the Operations Supervisor. Communications equipment includes a dedicated telephone link from central control to each station, a station public address system, two-way radio communications between central control and all vehicles, and a wall-mounted bank of television screens for monitoring activity in the passenger stations. The equipment also includes entry gate and platform sign control and a fire alarm monitor.

The enclosed maintenance area on the ground floor of the building includes space for conducting both scheduled and unscheduled maintenance. A minimum of five maintenance positions is provided, two of which include hydraulic lifts (Figure 3.67). One maintenance position has a ceiling clearance to allow removal of a passenger module. One hundred ten, 240, and 575-volt, three-phase AC and 28-volt DC power are furnished for service functions in this area.



SOURCE: Boeing Aerospace Company

FIGURE 3.65 : MAINTENANCE AND CENTRAL CONTROL

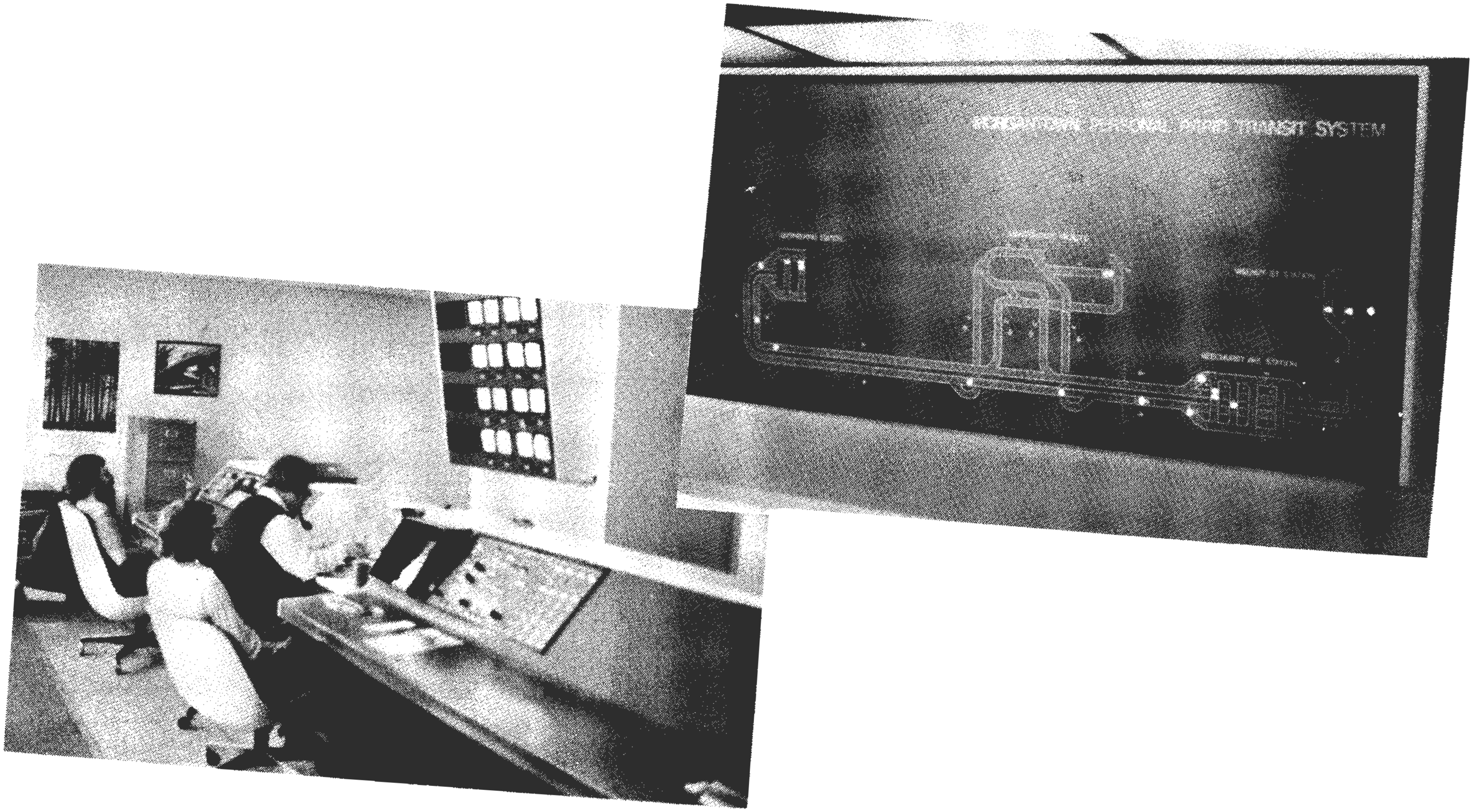


FIGURE 3.66 : CENTRAL CONTROL ROOM

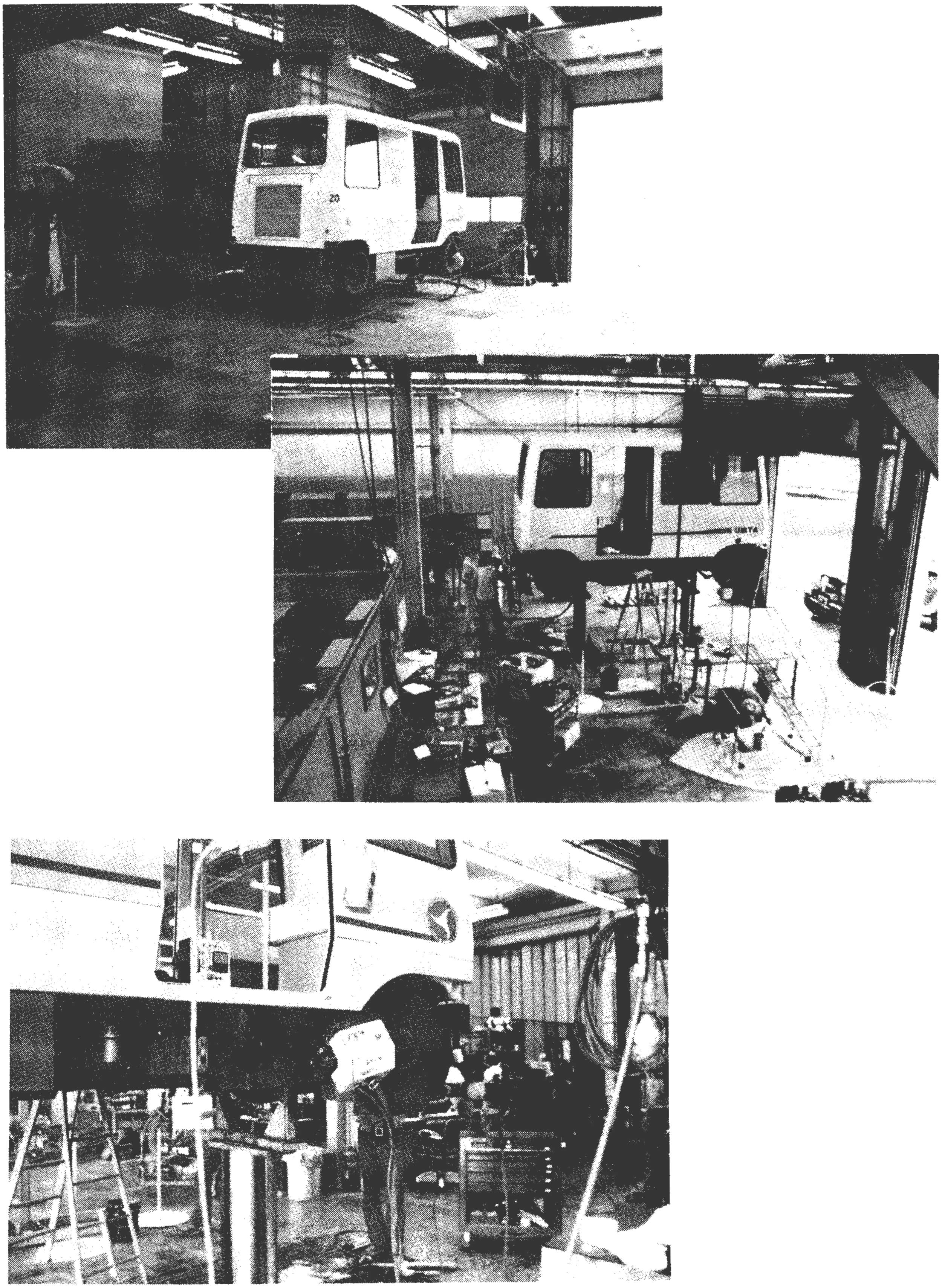


FIGURE 3.67 : VEHICLE MAINTENANCE AREA

Bench space for maintenance/overhaul of mechanical and electrical equipment is provided within the vehicle maintenance area (Figure 3.68). Separate rooms were originally provided for repair and maintenance of electronic and hydraulic equipment. Forced air ventilation with a separate filtration system is provided in the electronic equipment maintenance room.

Storage space (Figure 3.69) is allocated for spares, tools, support equipment, and supplies. This area has a limited/controlled access. The maintenance area also houses the two recovery vehicles. Two jeeps which serve this function are equipped for driving on the guideway to retrieve disabled vehicles, tow vehicles into the maintenance area and for other general maintenance. The jeeps are not equipped with guideway steering devices and must be manually steered. There have been cases where inadvertent contact was made with unenergized power rails and damage resulted.

The stub ends of the guideway leading to and from the maintenance building for at least 25 feet have individual breaker control and "power-on" indicator lights. This feature adds a margin of safety protection for shop personnel while vehicles are powered into and out of the maintenance area. Vehicles operating in the maintenance yard are controlled from the central control room. Vehicles in ready storage positions are also under the control of the operational system.

There was only one "quick-fix" area in Phase I. For Phase II a mini-maintenance facility with quick-fix capacity has been added. The quick-fix area serves three purposes as follows:

1. Initial inspection of vehicles coming in for maintenance and/or repair

2. Performance of the 350-mile check (during Phase I; for Phase II the maintenance inspection interval has been projected to 6,000 miles)

3. Washing and cleaning of vehicles (during Phase I; for Phase II an automatic drive-through car wash has been added).

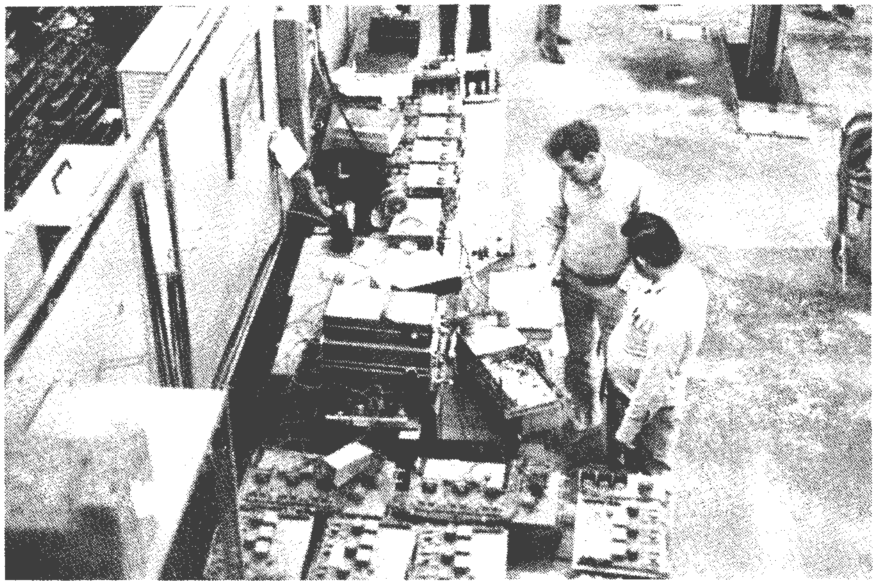


FIGURE 3.68 : BENCH SPACE IN MAINTENANCE BAY AREA

FIGURE 3.69 : STORAGE ROOM

In the Phase I configuration the quick-fix area was considered insufficient in the following aspects:

- Since it was on-line, the test loop could not be used while work was being done at the station. An additional off-line facility will solve this problem in Phase II and also will ensure the possibility of bringing in failed vehicles while the on-line quick-fix area is occupied.
- Vehicles and washing station were not compatible. When vehicles were washed, painted lettering and other signing came off. For this reason the washing station was only used when a large number of vehicles needed washing and there was little time available. Normally vehicles were cleaned only with "bucket and sponge" to the extent necessary. An automatic, bus-type, drive-through washer has been installed during the Phase II expansion.
- The quick-fix area needs lights, weather protection and heat so that it can be utilized at all times, in all seasons and under all weather conditions.

The test loop, in its present configuration, precludes interference with passenger service when testing vehicles. Also, it allows vehicle testing when the regular system is not operating. This last point appears to be most important, where the number of personnel with the skills for on-guideway vehicle testing and high-level maintenance is limited.

The Phase I maintenance facility was not sized adequately and did not allow the efficient use of available resources. Not all parts could be stored in the space provided. Overflow repair work on hydraulic systems and parts was done by one repairman in a section of the storage area because there was insufficient space in the regular hydraulics shop. Also, maintenance of VCCS units was being performed in the open bay area. The supplies receiving area was not equipped with a ramp or roof overhang for weather protection and did not have adequate space for packing, unpacking and stacking of materials. This facility has been expanded in Phase II.

A maximum of seven vehicles can be serviced inside the facility at the same time. There are three service lanes: one for heavy maintenance, which can contain three vehicles (two on lifts); one for light maintenance, which can contain three vehicles (no lifts); and another for maintenance without lift (one vehicle). This type of layout is inefficient because the vehicles in the middle cannot be removed without disturbing other vehicles. Also, when all spaces are filled, working space becomes severely restricted. For future AGT maintenance facilities, parallel vehicle work stations would eliminate this problem.

4.0 SYSTEM PERFORMANCE

The following gives results of an initial assessment regarding MPM system operational performance, system assurance, human interface and safety and security. The system was first placed in limited public passenger service operation on October 3, 1975. The statistics presented in this report cover operating experience from this opening date through July 3, 1978, when the system was shut down for Phase II modification. This 33-month period reflects the initial shake-down period and three seasonal cycles.

It is important to note that the Phase I MPM system was incomplete and is being expanded and improved during Phase II. Only after Phase II is completed and a sufficient period of time allowed for maturity can a final evaluation be made which compares operations on a one-for-one basis with the initial goals and objectives of the system. At that time this initial assessment should be updated to reflect sytem performance of the complete MPM configuration.

The first year of operation was an extension of the system development cycle. Many problem areas were defined and corrective action taken. The major problems were: winter environmental impact on vehicle operation; power rail carrier susceptibility to fire; the inability to isolate vehicle faults; vehicle hydraulic subsystem, pneumatic and electrical power collection subsystem anomalies; and the failure of fare card operated turnstiles. Evidence shows that the second and third years of operation were significantly improved over the first year with respect to passengers served, system availability and efficiency.

The operating system was observed on several occasions by all members of the assessment team. From these observations, from discussions with officials of WVU and Boeing who were responsible for its operation and maintenance and from analyses of operating data, it can be concluded that the Phase I system was operating smoothly and approaching maturity. During the first year of Phase I the major causes of system downtime were low-technology items associated with the vehicle. By the end of Phase I considerable improvements had been made, greatly reducing downtime. During the third year, the lowest average monthly system availability was 94 percent in February, 1978, in contrast with 69 percent for January, 1976. While the guideway heating system is sufficient to keep the guideway surface free of ice and snow, there have been problems with icing of the steering system, the power collector and the power rail, primarily with sliding fit joints in steering hardware and power collectors. These problems have been corrected and improvement is expected during Phase II.

It is important to note that the Phase I system was operated below its performance capabilities, for two apparent reasons. First, passenger demand was lower than anticipated for the Phase I system. Second, it appeared that the University had exchanged a somewhat lower level of service in order to increase the load factor and decrease maintenance costs. Casual observation might, therefore, lead to the erroneous conclusion that the system itself is inefficient. It is also important to realize that the dynamics of demand at the University are much different from those in a typical urban area and thus require a different strategy for vehicle management. This factor is further discussed both in Section 3.2, Control and Communications, and in the following sections.

4.1 SYSTEM OPERATIONS

This section discusses overall system operating statistics, performance and effectiveness. Several performance measures are tabulated in the Appendix to this report in the table of AGT Assessment Measures. The technical performance of specific subsystems has been described and assessed in foregoing sections. Vehicle management and operational strategies are discussed in Subsection 3.2.1 above.

4.1.1 Operating Statistics

The following statistics cover nearly three years during which the Phase I system was operated. During the first year, when systems design corrections were being implemented, the system was operated and maintained by a combined team of Boeing and WVU personnel. In the second and third years, operations and maintenance were performed only by WVU personnel. Table 4.1 gives month by month statistics for ridership, fleet mileage, and system hours of operation from September 15, 1975 until July 3, 1978. Table 4.2 gives summary statistics for each of the three years of operation and cumulative total for Phase I.

At the conclusion of Phase I, the system had accumulated 1,609,062 vehicle miles during 2,019 hours of passenger operation. Figure 4.1 plots the monthly fleet mileage over the entire Phase I opeation. Figure 4.2 is a similar plot for monthly ridership. The statistics for calendar year 1977 are more representative of seasonal variations. The goal for active fleet size was 29 vehicles including seven spares. The average number of vehicles operated had steadily improved from an average of 17.6 during the first year to 21.2 during the third year.

The average number of miles traveled per operating vehicle ranged approximately from 30,100 to 30,800 for the first two years and sharply decreased to about 22,500 vehicle miles during the third year. Because the active fleet is greater than the average operating fleet, the average number of miles traveled by a single vehicle ranged from 18,700 to 20,200 miles per year for the first two years. This number also was significantly reduced to about 16,500 vehicle miles in the third year. These mileage figures are low when compared with buses at 40,000 to 50,000 miles per year and even other AGT systems at 40,000 miles per year.

TABLE 4.1: MONTHLY OPERATING STATISTICS

Month-Year	Ridership Monthly	Ridership Largest Single Day	Vehicle Fleet Mileage	Actual Operating Hours
9-75	0	0	20,853	135.6
10-75	93,644	7,564	46,745	243.4
11-75	93,549	6,089	40,263	243.6
12-75	79,234	9,836	34,907	177.0
1-76	119,407	10,588	45,226	211.7
2-76	38,259	4,479	26,851	135.7
3-76	51,998	3,522	42,837	248.5
4-76	67,512	3,521	52,877	298.8
5-76	32,165	2,113	48,925	303.3
6-76	31,715	1,592	63,011	316.8
7-76	47,864	2,597	68,306	302.6
8-76	116,410	17,116	51,843	239.3
First Year Total	771,756		542,644	2,856.3
9-76	284,335	15,823	72,355	307.0
10-76	267,212	13,780	67,078	320.3
11-76	223,297	13,128	54,078	289.7
12-76	116,568	11,663	37,597	239.4
1-77	152,980	11,673	46,712	254.8
2-77	206,545	11,490	57,162	286.2
3-77	176,710	10,715	51,693	290.9
4-77	187,025	11,068	57,029	308.8
5-77	46,338	5,209	32,839	293.3
6-77	32,261	2,012	32,465	333.3
7-77	47,982	3,119	35,400	311.2
8-77	143,842	18,228	42,665	278.3
Second Year Total	1,885,095		587,073	3,513.2
9-77	308,172	16,442	64,753	317.3
10-77	292,462	15,190	67,123	331.3
11-77	233,672	13,040	58,797	302.5
12-77	115,817	12,106	33,902	190.0
1-78	253,143	15,745	55,664	309.6
2-78	181,352	13,160	40,078	201.5
3-78	180,965	12,643	44,475	186.8
4-78	176,163	9,874	55,257	277.3
5-78	36,615	5,101	22,167	179.4
6-78	37,082	2,345	34,765	329.7
7-78*	1,650	832	2,364	23.8
Third Year Total	1,817,093		479,345	2,649.2
Phase I Total	4,473,944		1,661,449**	9,018.7

* System operated only three days prior to shutdown for Phase II Modification.

** Includes fleet mileage of 52,387 miles for system check out and testing prior to September 1975.

Source: UMTA AGT Applications Office

TABLE 4.2: SUMMARY OPERATING STATISTICS

	Sept, 1975 thru Aug, 1976	Sept, 1976 thru Aug, 1977	Sept, 1977 thru July, 1978*	Cumulative as of July, 1978
Total System Vehicle Miles	542,644	587,073	479,345	1,609,062
Total System Operating Hours	2,856.3	3,513.2	2,649.2	9,018.7
Active Fleet Size (Vehicles)	29	29	29	29
Average Operating Fleet Size (Vehicles)	17.6	19.5	21.2	19.4
Average Miles Per Operating Vehicle	30,832	30,106	22,611	82,941
Average Miles Per Active Fleet Vehicle	18,712	20,244	16,529	55,485
Total Passengers Carried	771,756	1,885,095	1,817,093	4,473,944
Total Passenger Miles	1,249,435	3,051,874	2,941,783	7,243,092
Average Load Factor (%)	11.0	24.8	29.2	21.4
Average Number of Passengers Carried Per Academic Year Day	2,691	5,730	7,571	5,331
Average Number of Passengers Per Weekday Carried in October-A Peak Month Without Holidays	4,071	11,700	12,800	
Average Number of Passengers Carried Per Operating Hour	270	537	686	496
Greatest Number of Passengers Carried in a Single Day	17,116	18,228	16,442	18,228

* System operated only 3 days in July, 1978 after which it was shut down for Phase II modification.

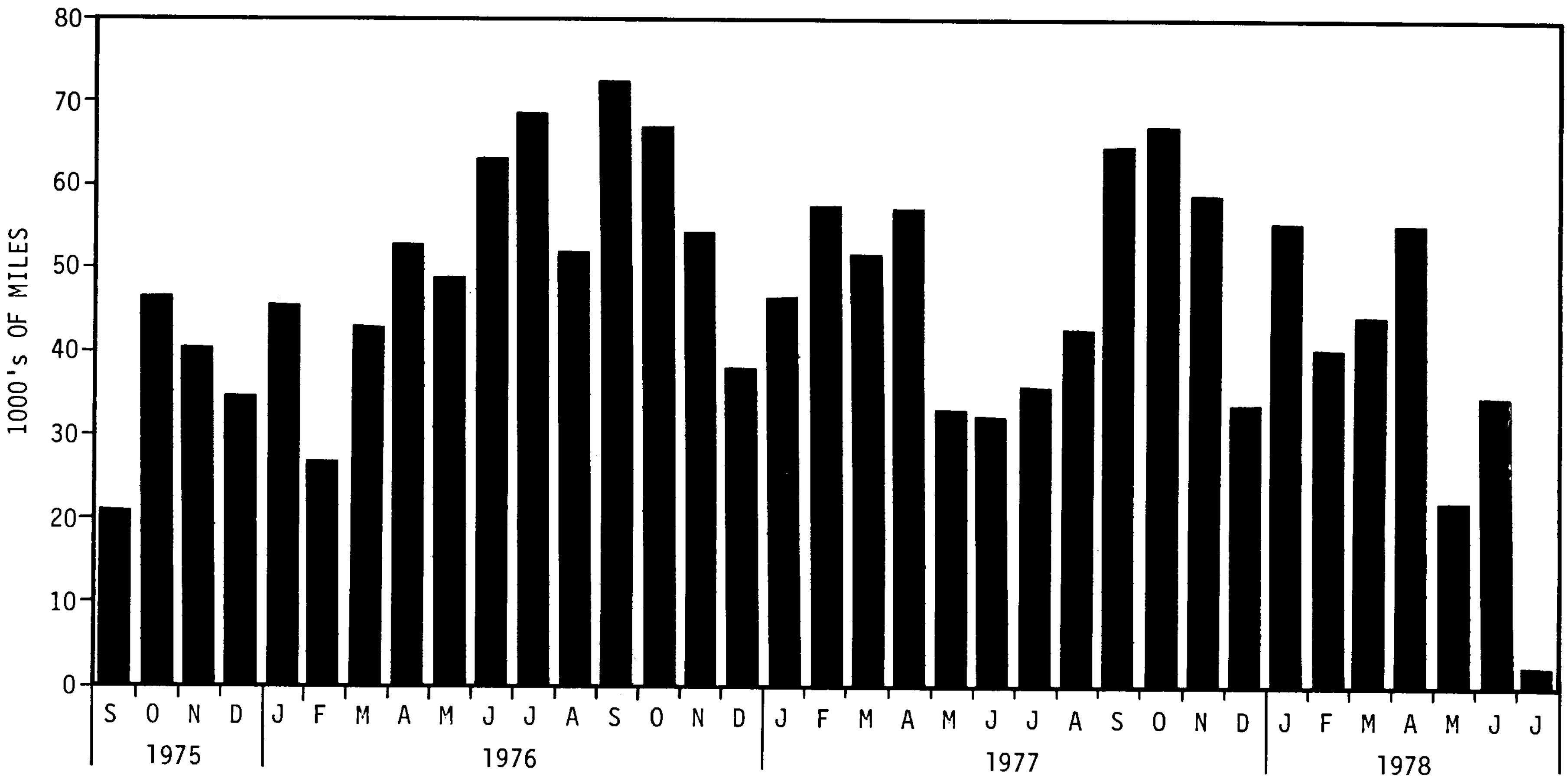


FIGURE 4.1: MONTHLY FLEET MILEAGE

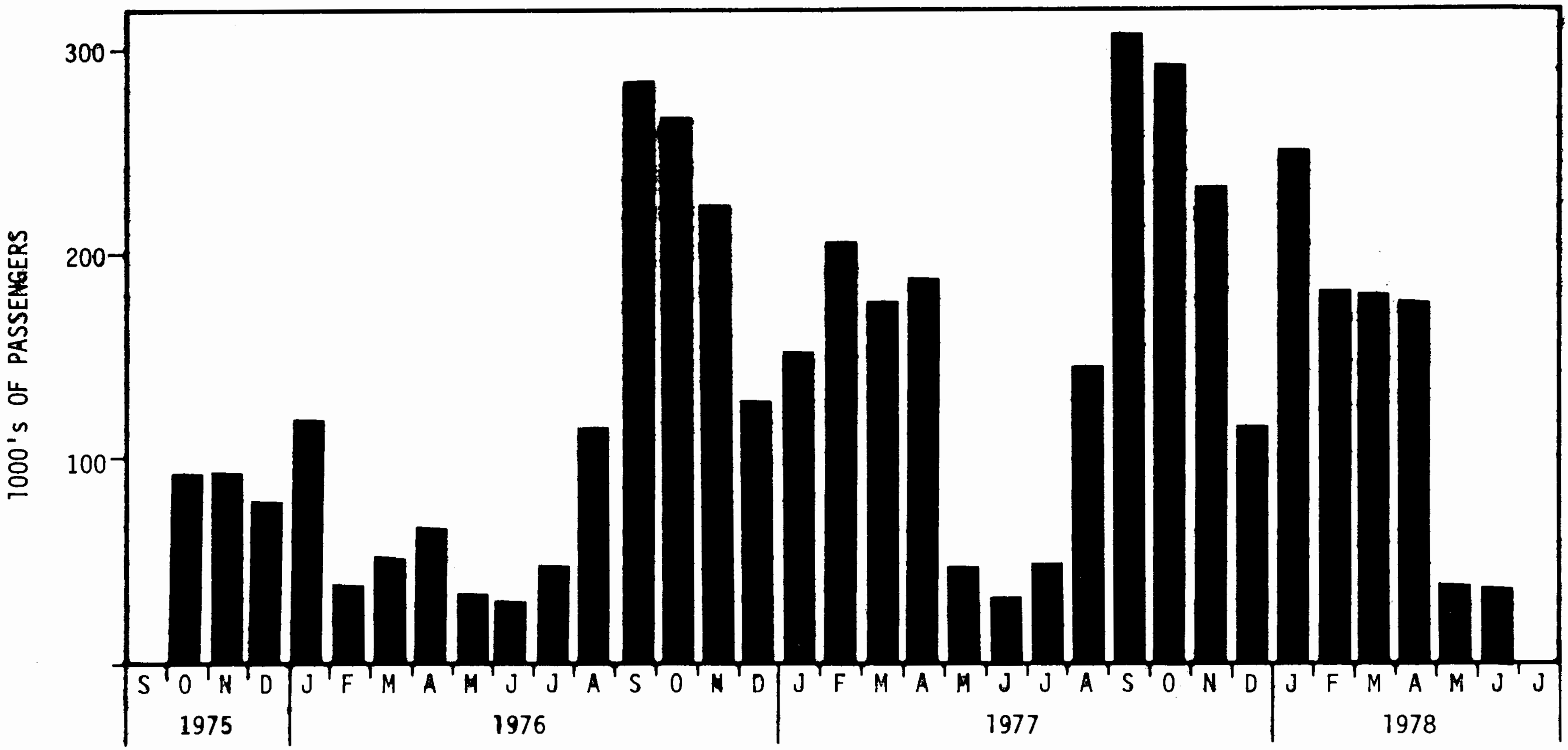


FIGURE 4.2: MONTHLY RIDERSHIP

Average monthly ridership during the second year was 2.2 times that of the first year. Ridership improved another 5.5 percent from the second to the third year, indicating that passenger demand had stabilized. The average number of passengers carried per system operating hour, one measure of productivity, greatly improved to 686 passengers per hour during the third year. This increase is 1.3 times better than the second year and 2.5 times better than the first year. The months of September and October proved to be the highest patronage months. The month of October is a better month to examine daily statistics because campus activities are more normal and there are no holidays in this month. The average number of passengers carried per weekday were 11,700 in October, 1976 increasing to 12,800 in October 1977. The greatest number of passengers carried on a single day was 18,228 during registration for the system's third academic year.

The average vehicle load factor increased from 11 percent for the first year to 25.8 percent in the second year and 29.2 percent in the third year. For a weekday ridership of 11,700 passengers the load factor averages 32 percent. A more detailed discussion of system efficiency and productivity is presented in the next subsection.

4.1.2 Passenger Demand Processing

The MPM system is open for passenger service from 7:15 a.m. to 8:30 p.m. on weekdays and 9:30 a.m. to 3:00 p.m. on weekends. In Phase I, passenger demand was processed either in the scheduled or on-demand modes, as previously discussed in detail in Subsection 3.2.1. Figures 4.3 and 4.4 show the occurrence of Phase I passenger demand for typical Mon./Wed./Fri. and Tue./Thurs. periods, respectively. Demand is shown to peak in a one-hour cycle consistent with class changes. The dispatch rates for the scheduled mode conform to the WVU demand table (as modified by statistical occurence in demand). These rates have dynamic characteristics similar to those shown in Figures 4.3 and 4.4.

Service Requirements

Specifications covering performance characteristics and the traffic model[10] for the MPM system require that it be capable of transporting a minimum of 1,100 passengers from Beechurst to Engineering in 20 minutes. This remains the only capacity requirement for Phase II. For Phase I, the stations were sized to handle the passenger rates given in Table 4.3 with the following requirements:

a. The platform transient time during demand mode operation was not to exceed two minutes. Platform transient time is the period between destination selection and vehicle availability for passenger boarding. This requirement is no longer applicable in Phase II.

b. The platform transient time during scheduled mode operation was not to exceed five minutes. Platform transient time in this case is the period between fare acceptance and vehicle availability for passenger boarding. This requirement is no longer applicable in Phase II.

c. Travel time is the time between closing of the vehicle door at the entry station and opening of the vehicle door at the exit station. Travel time under any normal operating condition for Phase I was not to exceed the times given for the station pairs noted below:

Beechurst and Engineering . . . . 6 minutes

Walnut and Engineering . . . . . 8 minutes

Walnut and Beechurst . . . . . 3.5 minutes

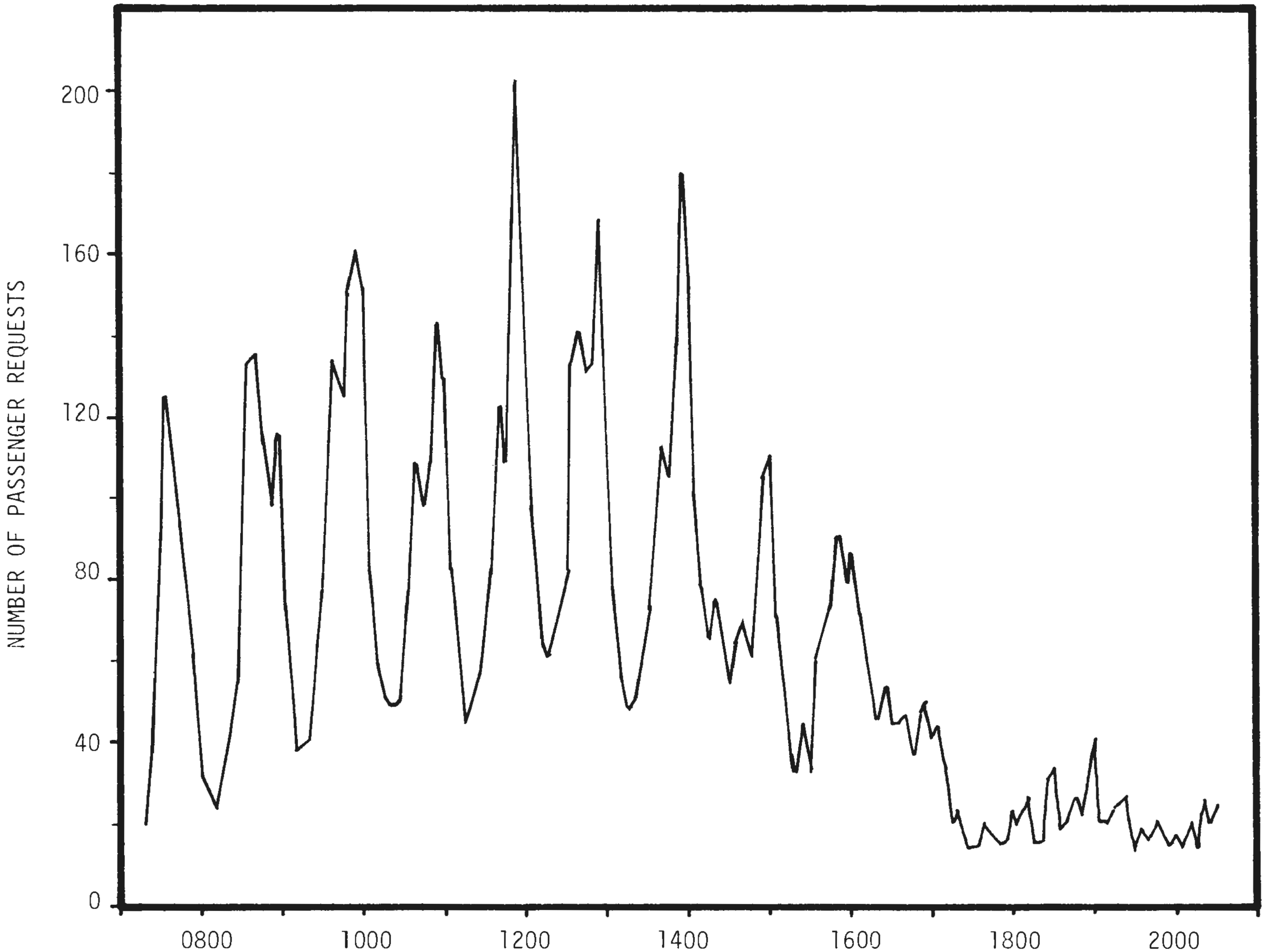


FIGURE 4.3 : PASSENGER REQUESTS AT 5-MINUTE INTERVALS OVER THE FULL OPERATING DAY (MON., WED. & FRI.) - SECOND OPERATIONAL YEAR

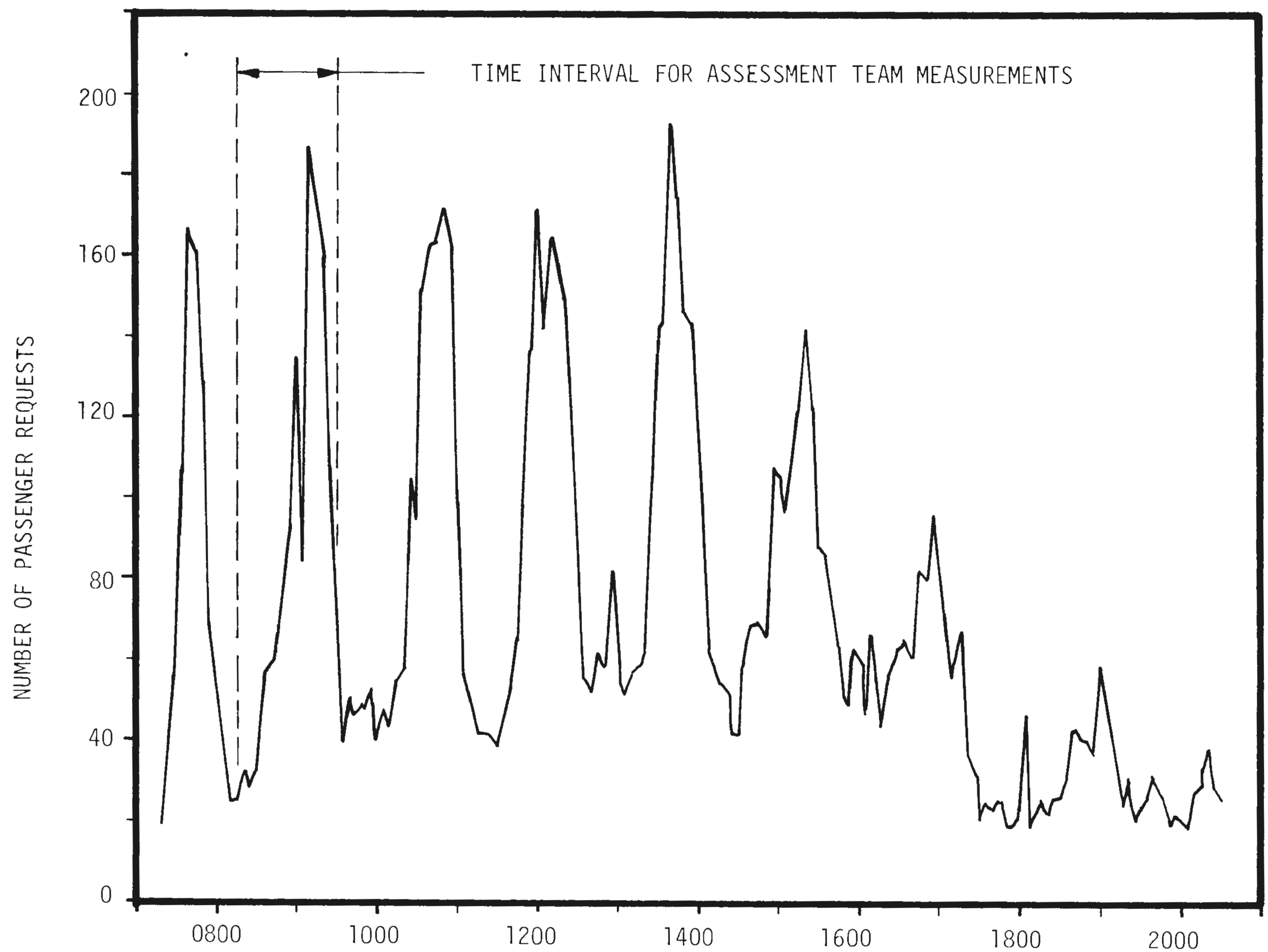


FIGURE 4.4 : PASSENGER REQUESTS AT 5-MINUTE INTERVAL OVER THE FULL OPERATING DAY (TUE. & THUR.) - SECOND OPERATIONAL YEAR

Compliance with these specifications was verified by the results of tests undertaken by Boeing on the operational system in Morgantown. The rate of 140 passengers/minute (8,400 passengers/hour) translates to a peak capacity of 5,040 passengers/hour (the maximum theoretical line capacity) in the direction of Engineering, with the remainder of 3,360 passengers/hour in the direction of Walnut. It is important to note that these are peak rates only. It was not expected that they would be sustained on an hourly basis. Rates given in Table 4.3 are for arriving passengers to be served and for the capacity of the system to deliver passengers to the destination station, not as a line capacity requirement, but for the purpose of sizing the stations.

TABLE 4.3: REQUIRED PEAK PASSENGER RATES

Station	Peak Rate (Passengers/Minute) Phase I	Phase II
Walnut Street	56	56
Beechurst	112	140
Engineering	56	140

Note: Table rates are based upon the following:

a. Load/unload sequence as specified in Paragraph 3.7.1.1.g of the Boeing Specification (see Reference 10)

b. 15-second time for passenger unloading

c. 15-second time for passenger loading

d. 5 -second door cycle time

Measured Dispatch Headways

On Thursday, April 21, 1977 the assessment team made coordinated time measurements at all stations with respect to vehicle management and scheduling. The measurements were taken from 8:15 to 9:30 a.m. in order to obtain characteristic data for both peak and off-peak operation. This sample, as shown in Figure 4.4, covers a demand pattern which was repeated throughout most of the scheduled operational time for Tuesdays and Thursdays. The demand patterns for Mondays, Wednesdays and Fridays (Figure 4.3) were similar, although some of the peaks were lower. The sample period yielded data closely approximating average operational data for the sysem, except for late afternoon and evening hours when demand is very low. Table 3.1 from the previous chapter gives the schedule for the various dispatch rates used in the scheduled mode of operation on Tuesdays and Thursdays. Table 4.4 gives the resulting headways measured against this dispatch rate. The shorter dispatch headways generally coincided with peak demands and the longer dispatch headways occurred between peaks.

TABLE 4.4: MEASURED DISPATCH HEADWAYS

Origin*-Destination	Range (Minutes)	Mean (Minutes)
E - B	0.25-3.32	1.84
E - W	2.02-6.23	4.28
B - E	0.25-3.58	1.77
B - W	1.95-7.60	4.30
W - B	2.25-6.27	4.40
W - E	1.60-6.17	4.03

*E - Engineering, B - Beechurst, W - Walnut

Source: NDL and SNV Measurements April 21, 1977

A comparison was made between the observed and scheduled dispatch rate. During the low demand period (8:15 a.m. to 8:40 a.m.) the scheduled dispatch rate (Engineering/Beechurst of 2 dispatches per 5 minutes) was exceeded by 18 percent. During the higher demand period (8:40 a.m. to 9:05 a.m.) the observed dispatch rate lagged the schedule (Enginneering/Beechurst of 4 dispatches per 5 minutes) by 23 percent resulting in passenger queuing in the Engineering and Beechurst stations. This queuing was found to be a result of an inadequate number of vehicles in the operating fleet for the period -- 16 were operated in the entire system whereas a minimum of 18 were required. The dispatch rate for the period 9:05 a.m. to 9:40 a.m. was scheduled at 5 dispatches per 5 minutes, which required even more vehicles. The higher than scheduled dispatch rate during the off-peak period appeared to be an attempt to make up for the lost dispatches during the peak period.

The maximum specified wait time of five minutes was exceeded where the Walnut station was the trip origin or destination because there were not enough vehicles in operation to meet the scheduled dispatch rate.

Vehicle In-Station Dwell Time

The MPM system was designed to provide both on-demand and scheduled service . However, during Phase I on-demand service was provided only in the evening (5:30 p.m. to 8:30 p.m.). Scheduled service using predetermined dispatch rates was provided during most of the day from 7:15 a.m. to 5:30 p.m. In Phase II, a new demand algorithm incorporating an improved vehicle management system replaces the Phase I demand mode. The efficiency of this new demand mode will be compared with that of the scheduled mode during Phase II to determine which will be used at different times of the day.

As discussed in Subsection 3.2.1, vehicles entering the station channel stop at the most forward available empty berth. In the scheduled mode a dynamic queue of vehicles is created in the station channel, the length of which increases to a maximum of four vehicles as the dispatch rate is decreased. As the length of the queue increases, so does the dwell time. The theoretical minimum dwell time (see subsection 3.2.1) for this form of vehicle in-station management is 1.1 minutes. To the casual observer, such long dwell times for scheduled-mode operations appear to be inefficient. However, at Morgantown, there were good reasons for choosing such a form of vehicle management:

1. Peak demand occurs in short bursts as classes change. This does not allow enough time to pull vehicles from a storage area and have them ready in the station channel. Also, the peak demand period is sufficiently short that it can be handled by a smaller number of vehicles than required for a sustained rate of demand. Therefore, during Phase I there was little need to change the operating fleet size over the peak/off-peak cycle.

2. In off-peak periods, a slower dispatch rate is used, which causes the dynamic queue of vehicles in the station channels to lengthen. The increased dwell time provides the advantage of creating active storage of vehicles in the station channels; otherwise they would have to be removed to a storage area. While not regularly practiced in Phase I, the capability existed to disable certain channels to create inactive storage of vehicles in off-peak periods.

3. The operator elected at times during Phase I to operate the system with more vehicles than were necessary. The reason given for this choice was to reduce the number of miles accumulated per vehicle.

4. During Phase I the peak dispatch rate was used for approximately 40 to 45 percent of scheduled-mode operations. Only during peak periods could the theoretical minimum dwell time ratio be approached.

Line Capacity

Figure 4.5 gives the single lane line capacity as a function of headway and vehicle capacity for the Phase I system, that which is expected in Phase II, and the capacity which might be possible for a modified form in an urban application. The Phase I system at Morgantown could not sustain the specified maximum capacity because the Engineering station was incomplete. Phase II provides two additional

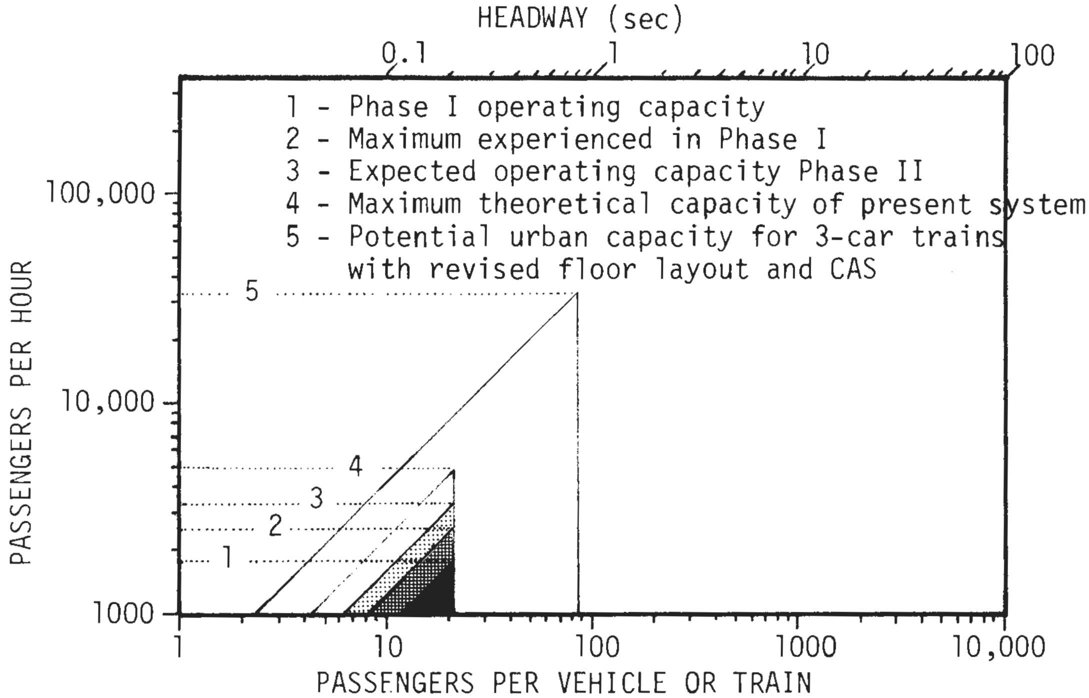


FIGURE 4.5 : SINGLE DIRECTION LINE CAPACITY

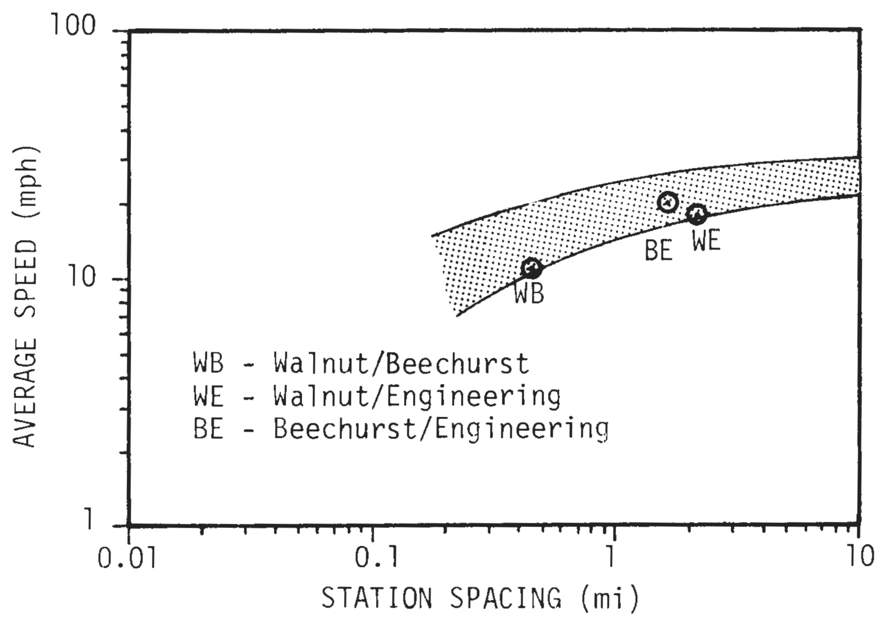


FIGURE 4.6 : AVERAGE TRIP SPEED

channels at Engineering to receive vehicles dispatched from the Beechurst and Walnut stations. It is now expected that the specified capacity of 1,100 passengers in 20 minutes can be achieved and sustained continuously.

A minimum headway of 15 seconds has been demonstrated. In current operations, pairs of vehicles are regularly dispatched at such intervals. Using a 15-second headway, the maximum theoretical single-direction line capacity extrapolated is 5,040 passengers per hour. Mainline guideways cannot be filled with vehicles to such capacities because merging could not take place. With a maximum operating capacity of 3,300 passengers per hour as specified from Beechurst to Engineering, the guideways would be filled to 65 percent of their theoretical capacity, leaving a 35 percent margin for merging vehicles to enter the traffic stream. The highest dispatch rates for regular scheduled service with the Phase I system (Table 3.1 of Section 3.2) produced a flow rate of 72 vehicles per hour in a single direction between the Engineering and Beechurst Stations. This rate resulted in a single direction line capacity of 1,512 passengers per hour. There have been special occasions where higher line capacities have been achieved. After a football game in October 1976, the University claims that approximately 3,500 passengers were carried from the Beechurst Station in one hour, with 90 percent carried in the first 45 minutes. This would produce a peak demand rate of 4,200 passengers per hour. A line capacity of 3,150 passengers per hour would result if 75 percent of the passengers rode to the Engineering station where more parking is available.

Travel Time and Average Speeds

Travel times were verified by Boeing personnel at Morgantown. The assessment team also measured these times (Table 4.5) and found close correlation with the Boeing data.

TABLE 4.5: TRAVEL TIMES (Minutes)

Station Pair	Average Assessment Test Data
Walnut/Engineering	6.6
Beechurst/Engineering	5.0
Beechurst/Walnut	2.5*

* Travel time between Walnut and Beechurst was not measured and has been estimated from Boeing data and assessment data

The actual average trip speeds computed from the Boeing data were as follows:

Walnut/Engineering . . . . . . 18.1 mph
Beechurst/Engineering . . . . . 18.9 mph
Beechurst/Walnut . . . . 9.8 mph

According to the distribution of vehicle trips, the computed Phase I system average trip speed was 16.5 mph.

The average trip length was 1.623 miles yielding an average trip time of 5.9 minutes. Figure 4.6 shows these data graphically as a function of the distance between stations. The upper and lower bands of the curve are determined for the different cruise speeds, 30 mph and 22.5 mph respectively.

Trip Distribution and Load Factors

Table 4.6 compares the distribution of passenger trips with vehicle trips and the resultant average load factors. As shown, 85 percent of the passenger trips were carried between Beechurst and Engineering stations by 52 percent of the vehicle trips. Therefore, the vehicle load factor on this segment was the greatest.

While the total system average load factor increased from 24.8 percent to 29.2 percent (Table 4.2) from second to third operating years respectively, the distribution by origin/destination on weekdays did not change significantly (e.g., weekday ridership increased only by nine percent).

TABLE 4.6: TYPICAL WEEKDAY ORIGIN/DESTINATION AND VEHICLE LOAD FACTORS.

Origin/Destination	Passenger		Vehicles		Avg. Load Factor
	No. Carried	%	Dispatched	%	%
Walnut/Beechurst	281	2.4	214	12.3	6.3
Walnut/Engineering	585	5.0	202	11.6	13.8
Beechurst/Walnut	421	3.6	214	12.3	9.4
Beechurst/Engineering	5,101	43.6	454	26.1	53.5
Engineering/Walnut	480	4.1	202	11.6	11.3
Engineering/Beechurst	4,832	41.3	454	26.1	50.7
ALL TRIPS	11,700	100.0	1,740	100.0	32.0

Source: Analysis of representative O/D data supplied by WVU for both passengers and vehicles during the second operational year.

The typical weekday system vehicle load factor of 32 percent is high compared with conventional urban transit averages of 25 percent. Conventional transit is generally forced by policy to run many lightly loaded vehicle miles resulting in lower load factors. The percentages of vehicle trips between Walnut-Beechurst and Walnut-Engineering at first appear to be out of balance with the percentage of passenger trips, particularly when compared with Beechurst-Engineering. This imbalance is necessary because the minimum level of service between the Walnut station and Beechurst or Engineering stations was one vehicle every five minutes. The peak-hour peak-direction load factor approaches 100 percent.

Productivity

One measure of system efficiency is vehicle productivity, i.e., the number of person-trips carried per vehicle-hour. This is a useful measure because it is directly related to the system's average speed. For example, an increased average speed will allow the same fleet to carry more passengers or the same number of passengers to be carried by fewer vehicles.

The average annual vehicle productivity for Phase I, calculated from Table 4.2, is shown in Table 4.7. A definite improvement of more than 200 percent was experienced over the three operating years. These measures are somewhat penalized because the system was operated in the demand mode for only 3.5 of its 13.25 operating hours per weekday. During demand-mode operations unused vehicles remain active but stand in the station channels awaiting passenger request. Therefore, they necessarily log time even though they are not being used. Also, on weekends passenger demand is much lighter. Approximately two-thirds of the total vehicle-hours per year were accumulated during scheduled mode operations on weekdays, carrying about 90 percent of the annual passengers. Therefore, the average weekday productivity should be 34 percent greater than the annual productivity statistics.

TABLE 4.7: VEHICLE PRODUCTIVITY

	Average Annual (person-trips/vehicle hour)	Average Weekday (person-trips/vehicle hour)
Oct. 1975-Aug. 1976	15.4	20.7
Sept. 1976-Aug. 1977	27.5	36.9
Sept. 1977-Jul. 3, 1978	32.4	43.5

For the month of October, the average weekday patronage was 11,700 passengers in the second operating year and 12,800 passengers in the third operating year. Passenger demand during October is more stable because there are no holidays and campus activity is fairly constant. Again considering that 90 percent of the passengers were carried during scheduled mode operations, the October average weekday scheduled mode vehicle productivity was 54 person-trips/vehicle-hour for both years. Therefore, productivity during the third operational year, at 80 percent of the October productivity, began to approach MPM system maturity.

The peak passenger demand occurred at noon, with approximately 200 passenger requests in a five-minute interval. The productivity during this peak period for an average operating fleet of 21 vehicles was 114 person-trips/vehicle-hour.

The Phase I MPM system, with the addition of the campus bus feeders, served an area of approximately 2.3 square miles. During the third operational year, with a more mature system and an average of 21 operating vehicles, the corresponding passenger-demand densities were calculated as follows:

Weekday Peak Five Minutes	-	1040 person-trips/sq.mi./hour
October Average Weekday	-	493 person-trips/sq.mi./hour
Third Year Average Weekday	-	401 person-trips/sq.mi./hour

4.1.3 Degree of Automation

The system is totally automated without drivers for vehicles or attendants in stations. Staffing consists of the following, which covers a total of three shifts:

Staff/Administrative Personnel	14
Operations personnel	12
Maintenance personnel	31
Store Keepers	4
	61

The 31 maintenance personnel were assigned as follows:

Maintenance Shift Supervisors	5
Mechanical Technicians	10
Maintenance Controllers	2
Utility Workers	3
Electronics Technicians	8
Electrical Technicians	2
Guideway Heating Technician	1
Total	31

Manning per shift is given in Table 4.8.

Measures of the degree of automation and manpower productivity are based upon an active fleet of 29 vehicles (22 operational plus 7 spares) and statistics from the third year of operations; September 1977 through June 1978. While there were 45 vehicles located at Morgantown, 16 were not used. These 16 were not kept up to the current configuration and remained parked on the apron in the maintenance station, waiting to be retrofitted under Phase II.

TABLE 4.8: PRESENT MANNING PER SHIFT

Shift	Time	Days	Staff
1st	6:00 AM – 2:30 PM	Su – Mo	11 Maintenance 2 Store Keeper 4 Operator
1st	6:00 AM – 2:30 PM	Tu – Th	18 Maintenance 3 Store Keeper 8 Operator
1st	6:00 AM – 2:30 PM	Fr – Sa	9 Maintenance 1 Store Keeper 4 Operator
2nd	2:30 PM – 11:00 PM	Mo – Fr	11 Maintenance 1 Store Keeper 4 Operator
3rd*	11:00 PM – 7:30 PM	Su – Th	3 to 4 Maintenance 1 Operator (sometimes)
	8:00 AM – 5:00 PM	Mo – Fr	4 Administrative Staff 5 Engineering Staff 5 Clerical Staff

*3rd Shift: 2 to 3 months during winter only; no additional staff, personnel drawn from other shifts

Note: On Saturdays and Sundays the system is operated by the first shift from 8:00am to 4:30 pm instead of the 6:00am to 2:30pm schedule.

The weekday average number of non-administrative employees per first and second shifts are 23.6 and 16 respectively. The 14 administrative personnel work from 8:00 a.m. to 5:00 p.m.; an average of 9.6 are allocated to the first shift and 4.4 to the second shift. The following measures of the degree of automation are determined from the above manning levels.

Total No. of Employees per Active Fleet . . . . . . 2.10 employees/vehicle

Total No. of Operators per Avg. Operating Fleet . . . 0.57 employees/vehicle

1st Shift Employees per Active Fleet . . . . 1.14 employees/vehicle

2nd Shift Employees per Active Fleet . . . . 0.70 employees/vehicle

System Man-Hour Ratio . . . . 1.79 man-hrs./vehicle hour

Labor Productivity . . . . 101 passengers place-miles/man-hour

Employee Annual Productivity* . . . . 9,099 vehicle-miles/employee

Patronage Productivity . . . . 18.2 passengers carried/man-hour

In Phase II the total number of employees per active fleet is expected to decrease to 1.0 employee/vehicle. This change will occur primarily as a result of improvements made to the operating equipment for Phase II.

4.1.4 Energy Consumption

Available data for energy consumption is not categorized according to propulsion energy, housekeeping and other functional areas. Only the electric and gas meter readings were available for the period October 1976 through June 1978. Boeing personnel have made detailed estimates of energy consumption (Table 4.9) which were included in the post-turnover plan.[11] These data have been used to generate the following energy consumption rates used in factoring actual electric meter readings presented in Table 4.10.

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*for year July 1977 through June 1978

Vehicles Traveling . . . . 2.11 kwh/vehicle-mile

Vehicles Idle in Stations . . . . 0.432 kwh/vehicle-mile, or 8.16 kwh/hour of idle time

Guideway Heating System Pumps . . . . 4.75 kwh/MCF natural gas burned

The gas consumption for guideway heating was estimated in the post-turn over plan as follows:

TABLE 4.9: POST-TURNOVER PLAN GAS COMSUMPTION ESTIMATES FOR GUIDEWAY HEATING (MCF)

J	F	M	A	M	J-S	O	N	D	Total
4,238	3,721	3,187	1,250	159	0	534	2,471	4,238	19,798

Table 4.10 presents the MPM system energy consumption for 21 consecutive months which includes both winter periods 1976-77 and 1977-78. Table 4.11 compares energy consumption for two complete years. While data overlap for three non-winter months, the data for the two winter periods are separated. This table also gives the corresponding operating statistics and the changes which occurred between the two years.

The first part of Table 4.11 gives the total electrical energy used to operate the system, exclusive of that for the guideway heating system pumps. Also shown are three measures of energy efficiency. Total energy decreased by six percent during the third year mainly by reducing the number of vehicle-miles traveled by four percent. Therefore the net decrease in energy consumption per vehicle-mile or passenger-place-mile was only two percent. However, more passengers were carried with the consequence that the energy consumed per passenger-mile was decreased by 10 percent.

TABLE 4.10: ENERGY CONSUMPTION

ITEM	1976 OCT	1976 NOV	1976 DEC	1977 JAN	1977 FEB	1977 MAR	1977 APR	1977 MAY	1977 JUN	1977 JUL	1977 AUG	1977 SEP	1977 OCT	1977 NOV	1977 DEC	1978 JAN	1978 FEB	1978 MAR	1978 APR	1978 MAY	1978 JUN
Vehicle Running (10^3 kwh)*	141.5	114.1	79.4	100.7	120.6	109.1*	120.3	72.3	63.7	74.7	90.0	136.6	141.6	124.0	71.5	117.4	84.5	93.8	116.5	46.8	73.3
Vehicles Idle in Stations (10^3 kwh)*	29.0	23.4	16.3	20.6	24.7	22.3	24.6	14.8	13.0	15.3	18.4	27.9	29.0	25.4	14.6	24.0	17.3	19.2	23.8	9.6	15.0
Guideway Heating System Pumps (10^3 kwh)	1.8	26.3	48.9	141.7	36.9	4.0	2.3	0	0	0	1.6**	0	0.5	6.6	23.0	111.3	51.7	12.4	0	0	0
All Other Electrical Energy (10^3 kwh)	81.7	114.2	121.4	135.0	127.8	99.6	88.8	102.9	117.3	126.0	108.0	87.5	70.9	94.0	126.9	159.3	84.5	98.6	77.7	87.6	91.7
ACTUAL TOTAL ELECTRICAL ENERGY (10^3 kwh)***	254.0	278.0	266.0	398.0	310.0	235.0	236.0	190.0	194.0	216.0	218.0	252.0	242.0	250.0	236.0	412.0	238.0	224.0	218.0	144.0	180.0
ACTUAL NATURAL GAS (MCF)	369	5,547	10,286	29,812	7,768	845	485	0	0	0	347**	5	28	1,387	4,845	23,391	10,876	2,616	0	0	0
Equivalent Delivered Electrical Energy*** (10^3 kwh)	34.1	512.0	949.3	2,751.5	716.9	78.0	44.8	0	0	0	32.0**	0.5	2.6	128.0	447.2	2,158.9	1,003.8	241.4	0	0	0
Electrical Energy Without Guideway Heating Pumps (10^3 kwh)	252.2	251.7	217.1	256.3	273.1	231.0	233.7	190.0	194.0	216.0	216.4	252.0	241.5	243.4	213.0	300.7	186.3	211.6	218.0	144.0	180.0
Electrical Energy Efficiency Without Guideway Heating Pumps (kwh/psgr place-mi)	0.179	0.222	0.275	0.261	0.228	0.213	0.195	0.276	0.285	0.291	0.242	0.185	0.171	0.197	0.299	2.257	0.221	0.227	0.188	0.309	0.247

* Estimated from Boeing Post-Turnover Operational Plan, D191-60011-1, May 1974
** Guideway Heating System Test
*** Volume equivalent converted using 293 kwh/MCF primary fuel and 0.315 generating efficiency factor for converting primary fuel to electrical energy. (i.e., 293 x 0.315 = 92.3 kwh/MCF.) A comparison using electrical energy to perform the same quideway heating would require more energy.

TABLE 4.11: COMPARISON OF ENERGY CONSUMPTION FOR SECOND AND THIRD OPERATING YEARS OF PHASE I*

	Second Year Oct. 76-Sept. 77	Third Year Jul. 77-Jun 78	Change
Electrical Energy Without Guideway Heating Pumps (Mwh)	2,783.5	2,622.9	6% decrease
Vehicle - Miles	579,471	555,046	4% decrease
Passenger Place-Miles	12,168,891	11,655,966	4% decrease
Passenger - Miles	3,090,465	3,249,665	5% increase
Load Factor (%)	25.4	27.9	10% increase
Kwh/veh.-mi.	4.80	4.73	2% decrease
Kwh/place-mi.	0.229	0.225	2% decrease
Kwh/passenger-mi.	0.901	0.80	10% decrease
Elec. Energy for Guideway Heating Pumps (Mwh)	261.9	205.5	22% decrease
Equiv. Elec. Energy for Natural Gas (Mwh)	5,086.6	3,982.4	22% decrease
Total Equiv. Elec. Energy for Guideway Heating	5,348.5	4,187.9	22% decrease
Ratio of total Energy for Guideway Heating to total Elec. Energy without Guideway Heating	1.92	1.60	17% decrease
Total Energy Consumption (Mwh)	8,132.0	6,810.8	16% decrease
Kwh/Veh.-mi.	14.0	12.3	12% decrease
Kwh/place-mi	0.667	0.584	12% decrease
Kwh/passenger-mi.	2.63	2.10	20% decrease

* Energy consumption data were available only for the 21-month period shown. Therefore the two years shown overlap for the non-winter months of July, August and September.

The second part of Table 4.11 compares the energy consumed by the guideway heating system during the second and third year winters of Phase I.

Winter weather conditions of the second and third winters of Phase I were most severe as compared with the first winter, both in record snowfalls and low temperatures. Table 4.12 summarizes these conditions for each winter of the Phase I operation.

The guideway heating system must be turned on before there is snow accumulation if the MPM system is to remain in operation. To a large extent, the number of hours it is turned on is directly related to weather forecasts, the experienced snowfall and freezing temperatures. Detailed records of the weather forecasts were not readily available to the assessment team. However, based upon the statistics given in Table 4.12, the winter of 1977-78 is judged to be as severe as the winter of 1976-77, considering the need to provide guideway heating:

- o The number of heating degree days in the second and third years were 1.29 and 1.24 times greater than in the first year respectively.
- o The number of snow days (either a trace or measured amount) in the second and third winters were 1.40 and 1.16 times greater than in the first year respectively.
- o The worst snowfalls were experienced in the third winter. The measured snowfall in the second and third winters were 1.75 and 2.25 times greater than in the first winter respectively.
- o The average high temperature was lowest in the third winter. The average low temperature was essentially the same in the second and third winters but lower than in the first winter.

While there is no exact single measure to determine the severity of a winter the following formula was chosen, using the winter 1975-76 as a base year:

$W_I = I_1 + I_2 + I_3$

W_I = Winter Severity Index

I_1 = Ratio of heating degree days

I_2 = Ratio of Snow Days

I_3 = Ratio of Measured Snowfall

TABLE 4.12: COMPARISON OF WINTER WEATHER CONDITIONS AT MORGANTOWN DURING PHASE I

OCTOBER THROUGH MARCH	OPERATING YEAR		
	First Winter 1975-76	Second Winter 1976-77	Third Winter 1977-78
Heating Degree Days*	4748	6129	5869
Number of Days with Trace of Snow	33	41	33
Number of Days with Measured Snowfall	24	39	31
Measured Snowfall (inches)	23.3	40.8	52.5
Total Number of Snow Days	57	80	66
Average High/Low Temperature (F^{o})	51.9/32.5	45.0/28.2	43.5/28.3
Rate of Snowfall (inches/measured snowfall day)	0.97	1.05	1.69

Sources: West Virginia University College of Engineering, Personal Rapid Transit System Reports, "1976-77 Winter Operation" and "1977-78 Winter Operation", not dated. -- except*

*Source: National Climatic Center, NOAA, "Climatological Data" July 1976, July 1977, July 1978 issues, reported for measurements taken at Morgantown, WV Lock and Dam on the Monongohela River. -- Annual statistics July through June.

On the basis of this assumed winter severity index (Table 4.13), the winter of the third operating year would be as severe if not worse than the second year.

TABLE 4.13: MEASURES OF WINTER SEVERITY USING WINTER 1975-76 AS BASE YEAR

	OPERATING YEAR		
	1975-76	1976-77	1977-78
Ratio of Heating Degree Days (I_1)	1	1.29	1.24
Ratio of Snow Days (I_2)	1	1.40	1.16
Ratio of Measured Snowfall (I_3)	1	1.75	2.25
Winter Severity Index (W_I)	3	4.44	4.65

During the 1977-78 winter, improvements were made in the procedures for operating the guideway heating system. The importance of these improvements is reflected in a 22 percent reduction of guideway heating energy. The severity of both winters is particularly noteworthy. Natural gas consumption during January of either year far exceeded the total estimated gas consumption for an average winter (Table 4.9).

The experience at Morgantown has shown that energy required to heat a guideway can be very significant. During the second year it was 1.9 times that of the electrical energy to run the system. Though this ratio was reduced by 17 percent in the third year, heating energy was still 1.6 times the energy to operate the rest of the system. While gas consumption data were not available for the first operational year (1975-76), its cost for that year was approximately one-half that for the second year. Considering the 1975-76 winter to have been average, the energy consumption to heat the guideway was nearly equal to the electrical energy needed to run the system. It should be pointed out that the energy to heat the guideway is independent of the traffic which it bears. For example, the average frequency of vehicles at the close of Phase I was far below (25 percent) the system's capability. Therefore, the Phase I system could have carried four times more vehicular traffic which would increase the electrical energy consumption to run the system by a factor of approximately 3.1*. On this basis, the ratio of guideway heating energy to energy for running the system would have been only 0.62 in the second year and 0.52 in the third year. For a year with an average winter, such as 1975-76, the ratio could be as low as 0.32.

The last part of Table 4.11 shows the total energy consumed and measures of energy efficiency, including guideway heating, during the second and third years. During the third year a 20 percent reduction in energy to carry passengers was experienced. Again, it is important to examine the potential reduction in the consumption rate for greater vehicular traffic.

Using the third year as a model, if the vehicular traffic were increased four times to the system's potential full capacity, the vehicle miles would increase by a factor of four; however, the total energy consumption would increase only by a factor of 1.8. The corresponding kwh/vehicle-mile would be 5.5, a 55 percent reduction over the third year's operations. If guideway heating energy during the third year were reduced by 40 percent (appropriate for an average winter) the energy consumption would be 4.8 kwh/vehicle-mile which is 61 percent less than experienced during the third year. If the system were operating at full capacity (four times the vehicle-traffic rate), but without guideway heating, energy would be consumed at the rate of 3.7 kwh/vehicle-mile. Using the Morgantown experience, the need for guideway heating can increase overall energy consumption by about 30 percent.

* Vehicle energy is approximately 70 percent of the total electrical energy without guideway heating pumps: $1 + 0.7(3) = 3.1$.

Phase II incorporates resistance heating of the power rails at 15 watts per foot for each electrical phase -- a total of 45 watts per foot of power rail. The total length of single-lane guideway after Phase II construction is approximately 44,400 feet. Discounting those sections of guideway (merge and diverge sections) which require power rails on both sides of the guideway, the resultant power required will be approximately 2,000 kw. The Phase I system contained 27,776 feet of single-lane guideway, therefore, its power rail heaters would total approximately 1,250 kw. The additional energy consumption for power rail heating cannot yet be assessed because there has been no experience with regard to the amount of time it must be turned on. In any event, the time should be less than that for heating the guideway surface because the wiping action of the power collectors will tend to keep the power rails clean.

The above discussion shows that winter weather can have a very important impact upon energy consumption where guideway heating is employed. This effect appears particularly pronounced on the average energy consumption per vehicle-mile when vehicular traffic is low, as occurred during Phase I operations. It should be noted that vehicle use during Phase I operations was purposely kept low to efficiently match the passenger demand. The expanded Phase II system has 73 vehicles, which is 2.52 times more than the Phase I active fleet. If this larger fleet is operated at optimum efficiency, e.g. with a minimum vehicle in-station dwell time of 1.1 minutes, vehicular traffic could be 3.3 times greater during Phase II than it was during Phase I. For average winter conditions, the resultant energy consumption rate could be as low as 5.18 kwh per vehicle-mile (0.246 kwh/place-mile) a decrease of 58 percent from that experienced during the third year of Phase I operations. Such a system, not considering guideway heating, would consume 3.67 kwh/vehicle-mile. On this basis guideway heating would increase overall energy consumption by only 41 percent in contrast to 160 percent experienced during the third operating year of Phase I.

The experience at Morgantown has been valuable in providing real data concerning energy consumption, particularly for guideway heating. Also, as the foregoing analysis shows, the impact of guideway heating can be minimized for systems with a high rate of vehicular utilization.

4.1.5 Adverse Weather Operation

Table 4.14 summarizes specifications for the natural environmental conditions under which the MPM system is to operate. Boeing engineers state [12] that the system is designed to operate within these conditions, and capability of the vehicle system to meet the temperature extremes has been verified[13]. The heating system for keeping the guideway running surfaces clear of ice and snow is described in Section 3.7 on Guideways and Stations.

There appear to be no problems with operations in rain. The guideway is well drained and puddles do not form on the running surface. Light Rail and Rapid Rail vehicles sometimes have problems operating in heavy rain because water may be ingested into the propulsion motor by the cooling fan. There is no evidence that this ingestion has been a problem at Morgantown, even though the air in-take was immediately above the guideway surface. This intake has been relocated during Phase II vehicle retrofits due to dust ingestion and the short lifetime of the filter element and to improve serviceability.

Conventional transit systems also have problems with ice inhibiting proper door operations. While door failures ranked high during the first nine months of Phase I operations, these failures were not a result of weather or icing. The turnstiles appeared to have failure rates directly proportional to their use by passengers. However, during 1976-77 winter operations, the fare gates were temporarily completely disabled because of their frequent breakdown due to cold temperatures. A completely new fare gate design has been installed for Phase II.

Humidity alone does not appear to be a problem except when coupled with low temperatures. For example, humidity created by guideway heating condenses on the power rail so that frost forms at temperatures below freezing. Power rail icing has been a constant problem during winter operations and has required the use of glycol spraying equipment to keep the system running. De-icing equipment was not a part of the original maintenance equipment. Problems were also encountered when salt, which splashed from the side road or ran off the guideway platform, mixed with the glycol after power rail de-icing. This mixture provided the proper chemical composition, together with the ABS plastic insulation material of the power rails, to cause fires. Salt has since been discontinued for station platform

TABLE 4.14: SPECIFICATION FOR OPERATING ENVIRONMENT

a) Ambient Temperature

AMBIENT TEMPERATURES	95th PERCENTILE	MAXIMUM EXPECTED
High	90^oF	120^oF
Low	10^oF	-30^oF

b) Precipitation

PRECIPITATION	RAIN	SNOW
Continuous	1 in./hr.	10 in./day
Maximum	2 in./hr. for 2 hours	1 in./hr.

c) Constraints

ELEMENT	CONSTRAINT
Sunshine	120 $Watts/ft^2$ at 120^oF
Wind (Safety)	
Vehicles Operating	30 mph from any direction, gusting to 60 mph.
Humidity	100%
Earthquake	Local code
Dust	Shall not adversely affect vehicles or operations.
Lightning	Adequate protection shall be provided for all structures and appropriate equipment.

de-icing and splash guards have been erected along the fence separating the at-grade guideway from Beechurst Avenue. Phase II has completely replaced the power rail with a new design incorporating embedded resistance heaters.

Icing of the steering system and power collector arms has also caused problems, though they have been corrected by adding heaters.

The guideway heating system has proved capable of handling all the snowfall experienced at Morgantown, provided that it was turned on before snow had accumulated. The following paraphrases the procedures for operating the guideway heating system, as given in the Operators Manual[2].

> "Guideway heating is controlled by the System Operator. Guideway heating is normally turned on before weather conditions allow ice and snow to accumulate on the guideway and turned off when guideway - surface reaches 35°F. Guideway heating is controlled by three BOILER circuit breakers on the GUIDEWAY ELECTRIFICATION panel and is accomplished by circulating hot water/glycol, heated in the boiler plants, through pipes imbedded within the concrete guideway as shown in the following table.

Boiler Plant	Control From	Control To
1	Walnut	2/3 way to Maintenance from Beechurst
2	1/3 way to Beechurst from Maintenance	2/3 way to Engineering from Maintenance
3	1/3 way to Maintenance from Engineering	Engineering

NOTE

If the guideway is heated from a cold start (no vehicles running and no heat on guideway) a snow accumulation of three inches will take approximately four hours, and a snow accumulation of six inches will take approximately eight hours to melt to the point that it is safe to run vehicles.

PROCEDURES

1. Determine approximate length of time guideway heating system should be on to reach 35°F (Figure 4.7)

2. Turn on Boilers, as required.

3. When guideway heating is no longer needed, turn off Boilers according to following guidelines:

   a. If snow is heavy (1/4 to 1 inch per hour), leave system on.

   b. If it is raining and ambient temperature is 35°F.

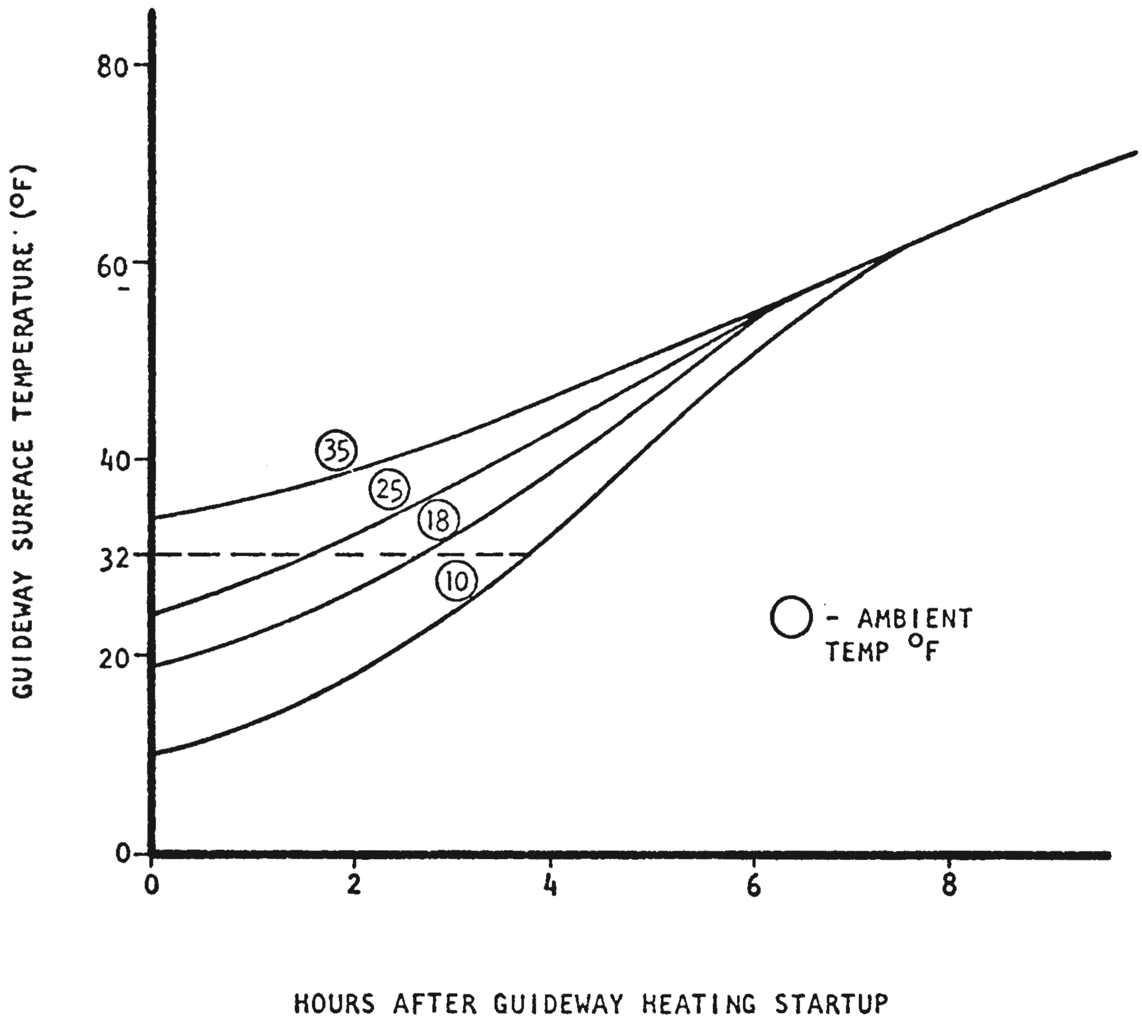
   c. If it has stopped snowing and snow has melted from guideway, turn system off.

   d. Do not leave system ON to dry out guideway for this will drive surface temperature from 70° to 80°F and is very expensive in natural gas consumption.

   e. Check local weather bureau forecasts during cooling trends and try to anticipate weather and system reaction time to cycle boilers ON and OFF as required. This will conserve natural gas and still keep guideway clear of ice or snow."

Earlier discussions (Subsection 4.1.4) showed that energy consumption to heat the guideway is particularly high in comparison with the electrical energy required for regular transit operations. However, this situation was caused by two very severe winters and a low rate of vehicle utilization during Phase I. Improvements were made in operating the boilers which significantly reduced the energy consumption during the third year. Furthermore, analyses indicate that increased operations expected during Phase II, should diminish the impacts of guideway heating, if the system is operated close to its design capacity.

Additional improvements in operating the guideway heating system to minimize energy consumption may be possible. For example, procedures call for the heating system to be turned off when the surface reaches 35°F. This temperature is apparently not measured but is supposed to be determined from characteristic curves (Figure 4.7) relating surface temperature, ambient temperature and the time boilers are left on. A system of automatic controls, using surface temperature sensors to control water/glycol flow and boiler firing times in the range of maximum thermal efficiency, should decrease energy consumption. Operational instructions not to "leave the system ON to dry. . . . ." indicates an attempt to provide these controls manually.



SOURCE: Boeing Aerospace Company

FIGURE 4.7 : GUIDEWAY SURFACE TEMPERATURE AS A FUNCTION OF BOILER ON TIME

Another problem occurred when a water/glycol valve was inadvertently left closed. Ice formed on a localized section of the guideway surface and caused an incident one morning before passenger service began. A vehicle was sent from Beechurst to Engineering to test guideway readiness for service. Though the vehicle slipped on the ice, it was stopped without damage to the vehicle or structure and was recovered manually. This assessment recommends that future AGT systems employing similar forms of guideway heating have some form of electrical continuity alarm system connecting the valves so that they must be in proper position to inhibit the alarm when guideway heating is turned on. Because the present method of keeping the running surface clear of ice and snow consumes considerable energy, it is recommended that efforts be made to improve heating efficiency and/or find alternate methods of snow and ice removal. The following are some possibilities which might be considered for an AGT system relying upon traction propulsion and braking on a exposed surface:

a. Where guideway heating is used, methods of automatic temperature control should be employed that will operate the system in its region of greatest thermal efficiency and minimize energy consumption. Insulation should be used underneath and on the sides of elevated running pads.

b. Boeing engineers have suggested to the assessment team that the guideway might be covered. This approach could require removal of excess heat during the summer. Depending on how well the closures were designed, aesthetics could be an added environmental issue.

c. Another possibility would use existing or planned urban structures to shield the guideway surfaces. Placing the guideway under bridges, inside buildings, under a building roof overhang, or in tunnels are examples. The guideway alignment should consider taking advantage of opportunities to minimize the length of guideway to be heated.

d. Mechanical means of clearing the guideway of ice and snow may be possible during hours the system is not operated. Presently the heating system must be turned on during these hours to insure that it will be clear on the following day. Under this proposed procedure, only the ice or snow residue would be melted by the heating system.

e. There may be opportunities to utilize waste heat as a supplement to or in lieu of a separate guideway heating system. For example, the condensate return of a nearby steam plant might be circulated through pipes imbedded in the guideway surface. Other opportunities for utilizing available industrial waste heat or cooling water from electric generating plants should be explored.

f. Fuel sources other than natural gas, such as coal, should be investigated with regard to costs and their ability to respond quickly to fluctuating demands for heat.

4.2 SYSTEM ASSURANCE

4.2.1 Specification and Goals

The earliest specification reviewed by the assessment team was "Performance/Design and Qualification for the Vehicle - Morgantown PRT System", Boeing Specification S191-90070-2, released November 22, 1971. The specification controlled the design of the Phase IA vehicles. The Quality Assurance section of this specification defined the following types of tests for verification of the vehicle performance:

1. Development, including environmental

2. Type approval, to verify function

3. Acceptance, a formal function test or procedure including inspection

4. System, which were performance tests at the system level

In addition, the vehicle specification described the methods to be used for verification.

A vehicle endurance requirement for a life expectancy of 10 years for the chassis and five years for the passenger module was to be verified by "analysis". The reliability and maintainability requirements were also to be verified by analysis.

The MPM system specification[10] for Phase IB required that the useful life goal (with normal maintenance and overhaul) be 10 years for the vehicle chassis and passenger module. Emphasis was placed on "maximum use of existing state-of-the-art hardware and software". The basic requirement for system reliability was specified as a quantity termed "conveyance dependability". The conveyance dependability was, in turn, defined as the mathematical product of system availability, A(t), and trip reliability, R(t). System availability was defined as "the probability that the system is available for use on passenger demand". Trip reliability was "the probability of successful passenger conveyance on an average trip (t=5 minutes), given the system is available".

Three values of conveyance dependability were levied in the system specification. First, it was specified that "the PRT (now called MPM) system shall meet a conveyance dependability of 0.960 with a mean downtime not to exceed one hour". Next, it was specified that the "conveyance dependability associated with the WVU academic year shall be 0.967. This results in approximately 60 downtime events with a mean downtime of one hour". The academic year was then specified in terms of the annual number and length of academic days and the passenger demand. Finally, it was specified that the "PRT system shall be designed to meet a conveyance dependability goal of 0.981 at system maturity".

The use of conveyance dependability as a system criterion is thought to be a more relevant and meaningful approach than the traditional MTBF requirement. However, the specification suffers somewhat from insufficient emphasis on specific definitions and by not describing how these criteria were to be measured. The "system" in system availability was not defined, although it presumably was the entire MPM system: all stations, all the wayside and central control systems, and vehicles sufficient to meet WVU trip demands. For the purpose of measuring system availability, it was subsequently decided to define the system as that portion of the entire system lying between Beechurst and Engineering, and neglect that portion between Beechurst and Walnut. In the Phase I installation, 85 percent of all passenger trips and 52 percent of the vehicle dispatches were between Beechurst and Engineering. A means for measuring trip reliability would have improved the specification.

The use of a mean downtime, while typical of most specifications for non-transit products, should be discouraged and replaced with downtime histograms. The reason for this recommendation is that a "mean" value, without specifying the distribution of the statistics (i.e., normal, exponential, etc.) and the required variance, is virtually meaningless. Many transit planners believe that delay time is a key social factor in public acceptance of transit sytems. While many people might accept frequent delays of one to two minutes duration, it is doubtful that they would accept even a few delays of thirty minutes or more. The assessment team proposes that future specifications utilize histograms of delay time frequency versus delay time magnitude as a system criterion in lieu of a mean.*

The quality assurance portion of the MPM system specification is well prepared and describes the basis for compliance with the requirements in a methodical and detailed manner. It specified that verification of each requirement be accomplished by employing one or more of the following methods:

1. Inspection - direct examination of the end product of documentation

2. Analysis - provide analytical verification and supporting test data, such as a stress analysis of a structural element and handbook data on material strengths

3. Demonstration - operation of the end product to indicate inherent characteristics

4. Test - measurement of parameters to establish if performance is within specified requirements

In addition, the certification methodology described a procedure for incremental completion of product assurance throughout Phase IA and IB.

A thorough review was made of the Quality Assurance Plan described in Section 3.2.2 of the specification. The specification requirements were classified into the categories shown below:

Characteristics - including performance and physical characteristics, reliability, maintainability, dependability. These requirements specify such things as headways, passenger flow capacity, vehicle dimensions and weights, service life, guideway configuration, power distribution, system assurance, and ride comfort.

Design and Construction - including the requirements for commercial practice, materials, electromagnetic interference, safety, and human engineering.

Documentation -including the requirements for manuals and subsystem specifications.

Logistics - including the requirements for maintenance, accessibility, support equipment, recovery and maintenance vehicle(s), and mechanical/electronic shop equipment.

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*This approach has been employed by UMTA on the Advanced Group Rapid Transit (AGRT) program.

Personnel and Training - including the requirements for the number and kind of operating and maintenance personnel, and their training.

Functional Area Characteristics - including functional requirements for the C & CS: speed control; position control; vehicle door control; power distribution control; system management; system data recording software; vehicle functions; guideway and structures; power distribution voltage levels; and fare collection.

Table 4.15 lists these categories and the number of methods of each kind to be used to verify the detailed requirements. For example, specification requirement 3.2.2 Physical Characteristics, required a total of 49 various checks to determine whether all of the detailed requirements within this section of the specification had been met. Thirty-three of these checks required "Inspection" only as a means of verifying the requirement; nine requirements were met by "Analysis"; four were to be done by "Demonstration" and three required "Tests". Of the 163 detailed requirements, 45 were to be verified by more than one method (e.g., both "Inspection" and "Analysis"), and 118 required verification by only one method.

Analysis of Table 4.15, as well as analysis of the details shown in the specification, shows that about one-quarter of all requirements were to be verified by inspection only; one-tenth by analysis only; one-fifth by demonstration only; one-tenth by test only; and about four-tenths by some combination of methods. Three requirements were to be verified by three or more methods.

Analysis of this data shows:

- o Performance characteristics were generally to be verified by combinations of analysis and demonstration or tests.
- o Three-quarters of all physical characteristics required verification by "inspection only".
- o System reliability requirements were to be verified by "analysis only", and there is no evidence that any reliability testing at any subsystem or component level was contemplated by the specification.
- o Two out of three maintainability requirements were to be verified by inspection plus demonstration, and the third by analysis.
- o Conveyance dependability, perhaps the single most important system requirement (excepting safety) as far as the user is concerned, was to be verified by "analysis only".

TABLE 4.15: SUMMARY OF METHODS REQUIRED TO VERIFY COMPLIANCE WITH THE SYSTEM SPECIFICATION REQUIREMENTS

Requirement Class		Number of Sub-Classes Verified By Method*				
		I	A	D	T	Total
3.2	Characteristics	(37)	(26)	(11)	(16)	(90)
3.2.1	Performance Characteristics	1	12	2	9	24
3.2.2	Physical Characteristics	33	9	4	3	49
3.2.2	Reliability	0	1	0	0	1
3.2.4	Maintainability	3	1	2	0	6
3.2.5	Conveyance Dependability	0	1	0	0	1
3.2.6	System Environmental	0	2	2	4	8
3.2.7	Transportability	0	0	1	0	1
3.3	Design and Construction	(7)	(9)	(1)	(1)	(18)
3.3.1	Materials, Processes & Parts	0	1	0	0	1
3.3.2	EMI	0	1	0	1	2
3.3.3	Nameplates	1	0	0	0	1
3.3.4	Workmanship	1	0	0	0	1
3.3.5	Interchangeability	1	0	0	0	1
3.3.6	Safety	4	3	0	0	7
3.3.7	Human Performance/Engineering	0	4	0	0	4
3.3.8	Computer Memory Retention	0	0	1	0	1
3.4	Documentation Plan	(1)	0	0	(1)	(2)
3.5	Logistics	(10)	(1)	(10)	(21)	(42)
3.6	Personnel & Training	(2)	(0)	(1)	(3)	(6)
3.7	Functional Area Characteristics	(19)	(11)	(41)	(17)	(88)
3.7.1	C & CS	4	2	24	8	38
3.7.1	Vehicle	3	3	7	9	22
3.7.3	Structures & Pwr. Dist.	12	6	7	0	25
3.7.4	Fare Collection	0	0	3	0	3
	TOTALS	(76)	(47)	(64)	(59)	(246)

(*) Note: Verification Method: I - Inspection; A - Analysis; D - Demonstration; T - Test

For future AGT systems, it is the opinion of the assessment team that verification of critical requirements (such as reliability) be performed by more than just inspection, analysis, or a combination thereof. Emphasis must be placed on verification of the design by testing, especially at the subsystem level. It is recognized that such subsystem testing is a costly process and that program funding must be committed if it is to be required by specification. Such testing should prove more economical in the long run by avoiding the more expensive changes and retrofitting resulting from breakdowns during the operational phase.

The Phase IB Master Phasing Schedule contained a high degree of concurrency. Early progress on guideway construction required that C & CS elements be cut, fitted and epoxyed into the concrete surface. By the time C & CS Test Integration was completed at Morgantown, approximately 15 to 18 vehicles were shop complete. Phase II, however, has built upon the experience derived from Phase I. Detailed analyses of Phase I problems and reliability data were used as a basis for identifying Phase II improvements and Phase II conveyance dependability requirements have been set in accordance with these anticipated improvements.

4.2.2 Reliability History of the System

This section discusses the reliability history of the Morgantown system during Phase I as obtained from operator records, the system contractor, WVU documents and interviews with personnel from these organizations. Data for all three years of operation were obtained, analysed and are presented. In comparison, each year shows marked improvements such that the system was very close to maturity by the time Phase I ended. An analysis of maintainability and causes of system downtime are included in a separate subsection which follows.

As an initial measure of system performance the system availability (%A) for each operational year was calculated based on the ratio of actual operating hours and scheduled operating hours in revenue service.

$$\%A = \frac{\text{Actual Operating Hours}}{\text{Scheduled Operating Hours}} \times 100$$

TABLE 4.16: ANNUAL SYSTEM AVAILABILITY

Year	Hours Operated	Hours Scheduled	%A
First Year (Oct.23, 75 - Aug. 31,76)	2,541.5	2887.3	88.0
Second Year (Sep.1,76 - Aug. 31, 77)	3,513.2	3,703.1	94.9
Third Year (Sep.1,77 - June 30, 78)	2,625.4	2,695.5	97.4

From table 4.16 one can see the progress the system has made during the three years of operation. The first year clearly must be considered as a shakedown period for the hardware and a learning period for operating and maintenance personnel. Significant improvement was achieved during the second year through correction of problems discovered during the first year. By the close of Phase I, ten months of the third year, the system was approaching mature status.

As discussed earlier, system performance is determined by system availability, trip reliability, and conveyance dependability. Estimates based on monthly data are given in Table 4.17.

TABLE 4.17: ANNUAL SYSTEM OPERATING ASSURANCE

Year	Availability (%A)	Trip Reliability (%R)	Conveyance Dependability (%CD)
First Year (Oct.23, 75-Aug.31,76)	89.2	97.0	86.5
Second Year (Sep.1,76-Aug.31,77)	95.2	98.9	94.2
Third Year (Sep.1,77-June 30, 78)	97.1	99.5	96.6

The availability averages in this table are slightly different from Table 4.16 due to the weighing factors applied in the estimating procedure. The difference is negligible (0.3 to 1.2 percent).

Table 4.18 delineates the seasonal averages for the same performance measures. In this table a recurring seasonal variation is obvious, which becomes even more pronounced in Figure 4.8 and Figure 4.9 where monthly availability and conveyance dependability are displayed per operating year.

TABLE 4.18: SEASONAL SYSTEM OPERATING ASSURANCE

Season	Availability (%A)	Trip Reliability (%R)	Conveyance Dependability (% CD)
Fall 75* (Oct. 23 - Nov. 30)	86.3	98.9	85.4
Winter 75/76 (Dec. 1 - Feb. 18)	72.0	93.9	67.6
Spring 76 (Mar. 8 - May 31)	94.8	99.4	94.2
Summer 76 (June 1 - Aug. 31)	95.3	96.4	91.9
Fall 76 (Sep. 1 - Nov. 30)	94.7	98.6	93.4
Winter 76/77 (Dec.1 - Feb. 28)	90.0	98.2	88.4
Spring 77 (Mar. 1 - May 31)	96.3	99.5	95.8
Summer 77 (June 1 - Aug. 31)	99.1	99.7	98.8
Fall 77 (Sep. 1 - Nov. 30)	97.8	99.5	97.3
Winter 77/78 (Dec. 1 - Feb. 24)	95.9	99.3	95.2
Spring 78 (Mar. 6 - May 31)	96.3	99.6	95.9
Summer 78* (June 1 - June 30)	99.2	99.8	99.0

* Fall 75 and Summer 78 are incomplete seasons

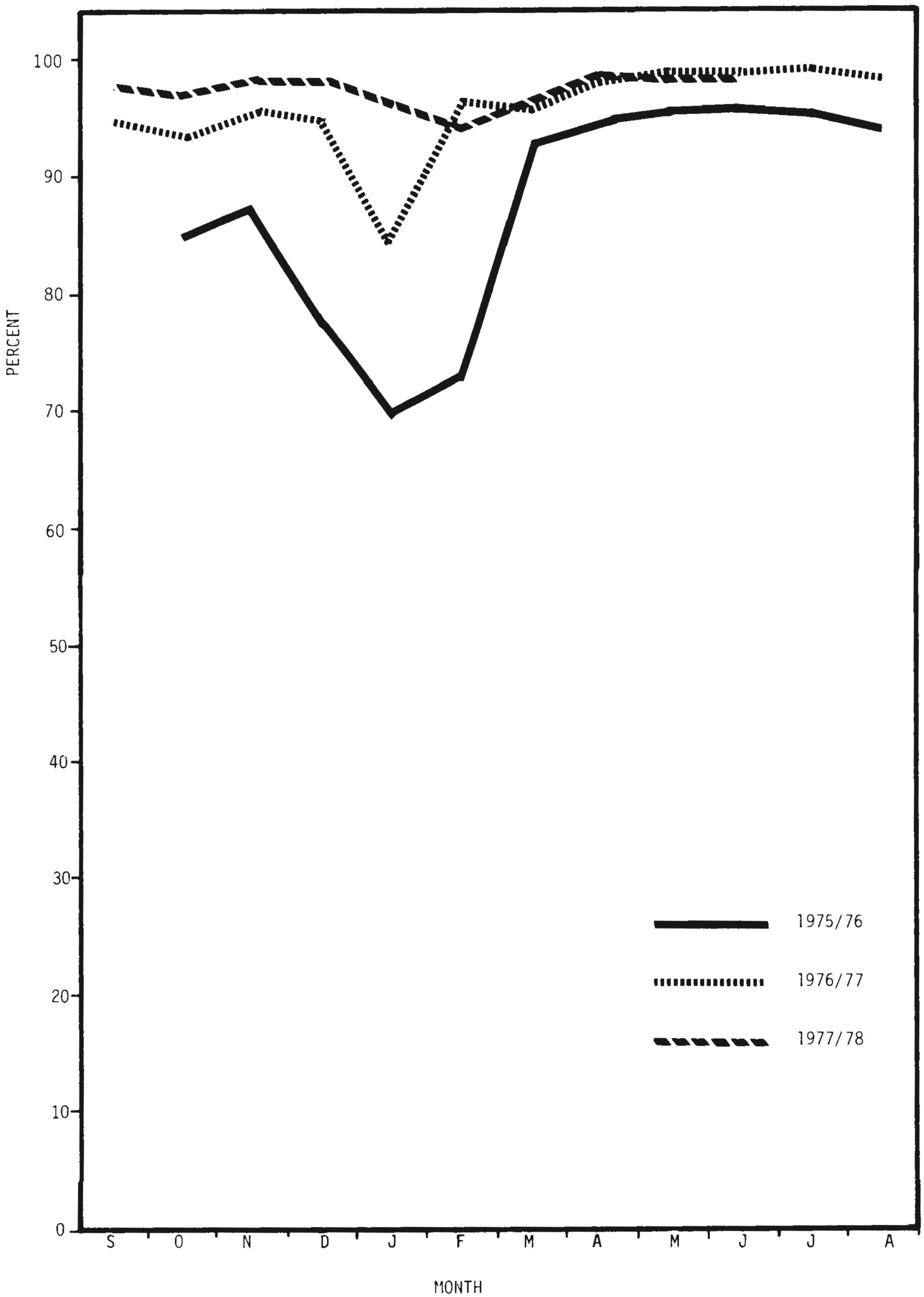


FIGURE 4.8: MONTHLY AVAILABILITY BY OPERATIONAL YEAR
(Not corrected for fleet availability)

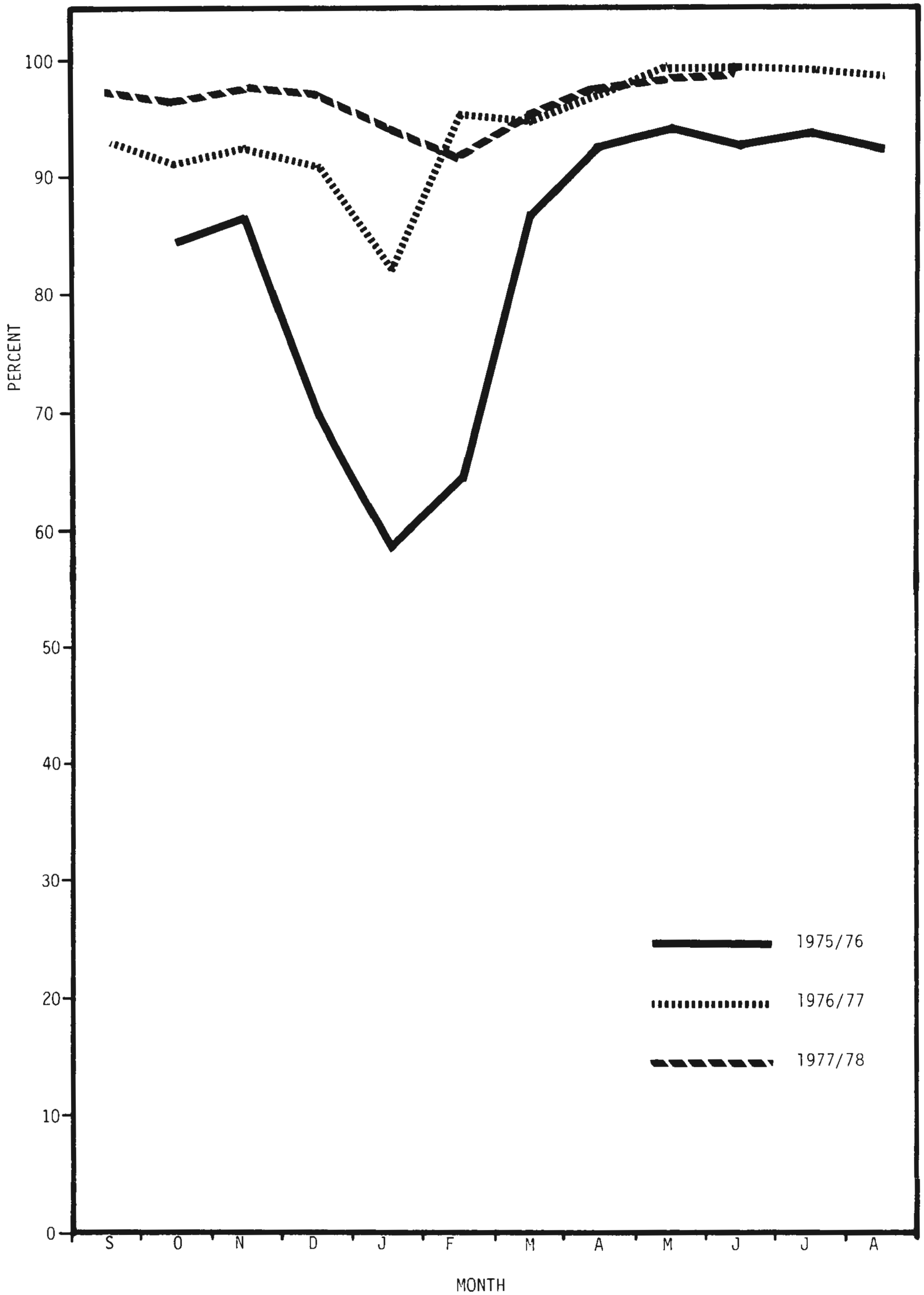


FIGURE 4.9: MONTHLY CONVEYANCE DEPENDABILITY BY OPERATIONAL YEAR

As shown in Table 4.18 and Figures 4.8 and 4.9 winter conditions had a severe impact on performance in the first years. Great improvements were made during the second and third years so that by the third winter only a slight decline was experienced. Since Spring 1977 the system began to meet and exceed the required conveyance dependability of 96.0% on a monthly basis with the exception of January, February and March 1978. During the last year of Phase I operations the system achieved a conveyance dependability of 96.6% which was very close to the specified 96.7% for a WVU academic year. During May through August 1977 and May through June 1978 the system approached or exceeded, on a monthly basis, the conveyance dependability design requirement for system maturity of 98.1%.

Other parameters to consider when evaluating system reliability performance are the measures of mean time between failures (MTBF), mean time to restore (MTTR), and mean miles between failures (MMBF), which are determined as follows:

$$\text{MTBF} = \frac{\text{Actual operating hours per time period}}{\text{Number of downtime events per time period}}$$

$$\text{MTTR} = \frac{\text{Actual down time hours per time period}}{\text{Number of down time events per time period}}$$

$$\text{MMBF} = \frac{\text{Vehicle miles travelled per time period}}{\text{Number of down time events per time period}}$$

TABLE 4.19: ANNUAL DOWNTIME EVENT STATISTICS

Year of Operation	Downtime Events	Operating Time (hrs)	Downtime (hrs)	Vehicle Miles	MTBF (hrs)	MMBF (Miles)	MTTR (hrs)
First (Oct. 23,'75-Aug. 31, '76)	765	2,541.5	345.8	490,768	3.32	641.5	0.45
Second (Sept. 1, '76-Aug. 31, '77)	514	3,513.2	189.9	587,073	6.84	1,142.2	0.37
Third (Sept. 1, '77-June 30, '78)	325	2,625.4	70.1	476,981	8.08	1,467.6	0.22

Continued improvement was experienced in MTBF, MMBF, and MTTR with about constant operating time and vehicle miles over three years of operation. Tables 4.20 and 4.21 show the seasonal and monthly variations for these parameters which are graphically depicted in Figures 4.10 and 4.11. Again improvements are observed throughout each year of operation.

The time period between downtime events and the time to restore operations after downtime events is of particular importance because of the impression it makes upon passengers. Throughout Phase I continued improvements were made which increased the time between downtime events and decreased the restoration time. Analysis of the seasonal data for MTBF and MTTR in table 4.20 illustrates these improvements. MTBF in the spring of the first year was 90 percent greater than the previous fall when operations began. MTBF in the fall of the third year was approximately 174 percent better than in the fall of the first year. The best record of MTBF was achieved in June 1978, near the close of Phase I, when the system achieved an MTBF nearly equal to two days of operation. Winter conditions had its greatest impact to shorten MTBF. This was greatly improved by 213 percent in the second winter and 254 percent in the third winter compared with the first winter's experience. During the third year of Phase I the winter MTBF was only 29 percent lower than in the fall. Corresponding improvements were experienced in MTTR. For example, at the end of Phase I the non-winter MTTR was nearly 40 percent of that experienced in the fall of the first year and winter MTTR had become nearly equal to the non-winter MTTR.

Figures 4.12 (a) and (b) show the distribution of downtime event statistics for representative sample periods during the second and third years. During the time interval from zero to two hours significant improvements were achieved. Figures 4.13 (a) (b) are distributions of time durations to restore the system for the same representative months as used for the distributions of Figure 4.12. Here the time intervals used are the same as used by UMTA for the AGRT Program. The greatest frequency of occurrence remains unchanged in the 3 to 24 minute interval, however, the MTTR has improved significantly, especially for winter operation.

TABLE 4.20: SEASONAL DOWNTIME EVENT STATISTICS

Season	Downtime Events	Operating Time (hrs)	Downtime (hrs)	Vehicle Miles	MTBF (hrs)	MMBF (miles)	MTTR (hrs)
Fall 75* (Oct.23-Nov.30)	109	320.7	51.3	55,985	2.94	513.6	0.47
Winter 75/76 (Dec.1-Feb.18)	326	524.4	205.2	106,984	1.61	328.2	0.63
Spring 76 (Mar.8-May 31)	153	850.6	47.1	144,639	5.56	945.4	0.31
Summer 76 (June 1-Aug. 31)	177	845.8	42.2	183,160	4.78	1,034.8	0.24
Fall 76 (Sep.1-Nov.30)	208	917.0	51.1	193,511	4.41	930.3	0.25
Winter 76/77 (Dec.1-Feb.28)	155	780.4	95.5	141,471	5.04	912.7	0.62
Spring 77 (Mar.1-May 31)	96	893.0	34.6	141,561	9.30	1,474.6	0.36
Summer 77 (June 1-Aug.31)	55	922.8	8.7	110,530	16.78	2,009.6	0.16
Fall 77 (Sep.1-Nov.30)	118	951.1	20.7	190,673	8.06	1,615.9	0.18
Winter 77/78 (Dec.1-Feb.24)	123	701.1	30.0	129.644	5.70	1,054.0	0.24
Spring 78 (Mar.6-May 31)	71	643.5	16.8	121,899	9.06	1,716.9	0.24
Summer 78* (June 1-June 30)	13	329.7	2.6	34,765	25.36	2,674.2	0.20

* Fall 75 and summer 78 are incomplete seasons

TABLE 4.21: DOWNTIME EVENT STATISTICS

Month	Downtime Events	Oper. Time (hrs)	Downtime (hrs)	Vehicle Miles	MTBF (hrs)	MMBF (Miles)	MTTR (hrs)
10-75	34	77.1	16.9	15,722	2.27	462.4	0.50
11-75	75	243.6	34.4	40,263	3.25	536.8	0.46
12-75	99	177.0	56.8	34,907	1.79	352.6	0.57
1-76	150	211.7	98.1	45,226	1.41	301.5	0.99
2-76	77	135.7	50.3	26,851	1.76	348.7	0.65
3-76	51	248.5	18.5	42,837	4.87	839.9	0.36
4-76	58	298.8	18.2	52,877	5.15	911.7	0.31
5-76	44	303.3	10.4	48,925	6.89	1,111.9	0.24
6-76	44	303.9	13.1	63,011	6.91	1,432.1	0.30
7-76	56	302.6	14.4	68,306	5.40	1,219.8	0.26
8-76	77	239.3	14.7	51,843	3.11	673.3	0.19
9-76	76	307.0	16.8	72,355	4.04	952.0	0.22
10-76	66	320.3	22.0	67,078	4.85	1,016.3	0.33
11-76	66	289.7	12.3	54,078	4.39	819.4	0.19
12-76	31	239.4	12.9	37,597	7.72	1,212.8	0.42
1-77	67	254.8	73.0	46,712	3.80	697.2	1.09
2-77	57	286.2	9.6	57,162	5.02	1,002.8	0.17
3-77	53	290.9	12.6	51,693	5.49	975.3	0.24
4-77	24	308.8	19.0	57,029	12.87	2,376.2	0.79
5-77	19	293.3	3.0	32,839	15.44	1,728.4	0.16
6-77	17	333.3	2.2	32,465	19.61	1,909.7	0.13
7-77	14	311.2	2.3	35,400	22.23	2,528.6	0.16
8-77	24	278.3	4.2	42,665	11.59	1,777.7	0.18
9-77	41	317.3	7.0	64,753	7.74	1,579.3	0.17
10-77	53	331.3	8.7	67,123	6.25	1,266.5	0.16
11-77	24	302.5	5.0	58,797	12.60	2,449.9	0.21
12-77	22	190.0	3.5	33,902	8.61	1,541.0	0.16
1-78	60	309.6	13.2	55,664	5.16	927.7	0.22
2-78	41	201.5	13.3	40,078	4.92	977.5	0.32
3-78	28	186.8	8.0	44,475	6.67	1,588.4	0.29
4-78	30	277.3	5.7	55,257	9.24	1,841.9	0.19
5-78	13	179.4	3.1	22,167	13.80	1,705.2	0.24
6-78	13	329.7	2.6	34,765	25.36	2,674.2	0.20

Note: 7-78 was eliminated, system operated for 3 days only, no details available; system was shut down for Phase II modifications.

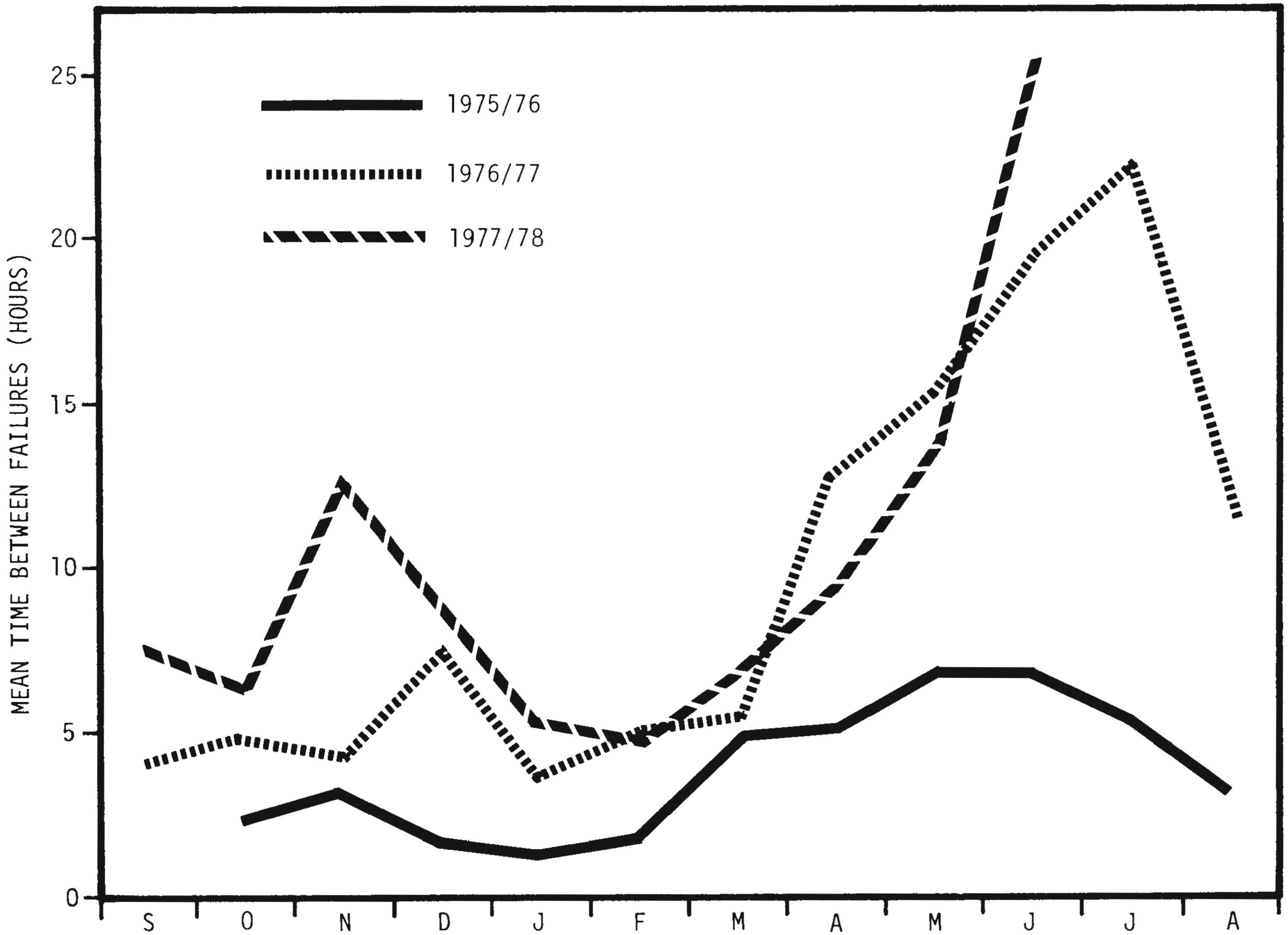


FIGURE 4.10: MONTHLY MEAN TIME BETWEEN FAILURES BY OPERATIONAL YEAR

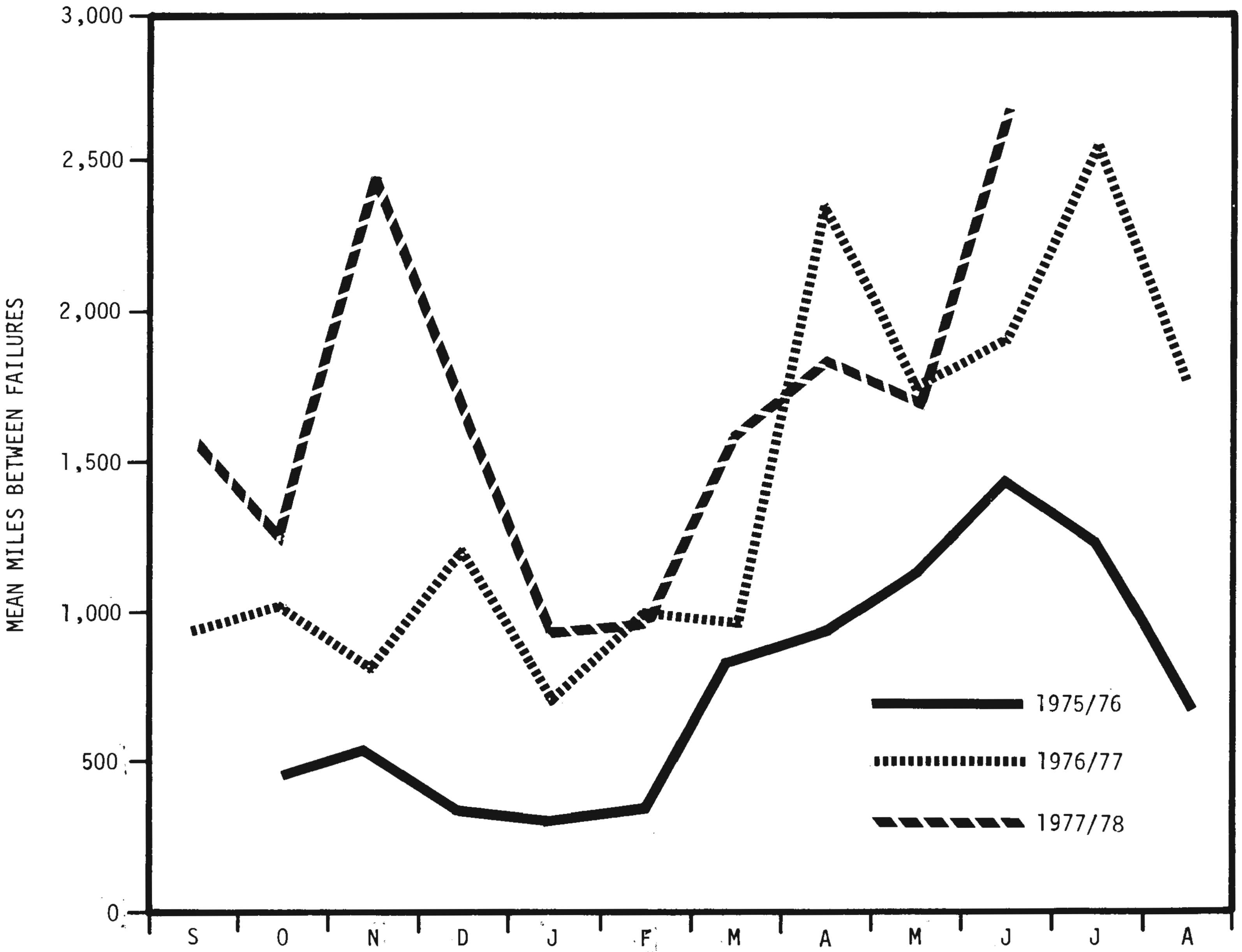
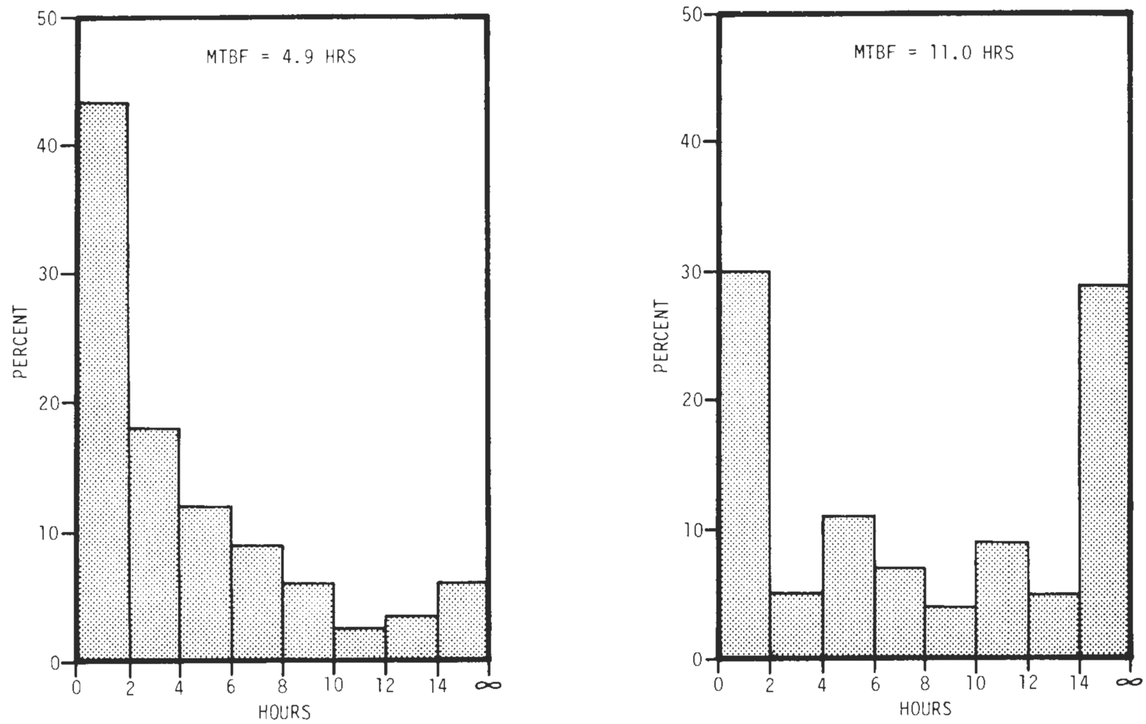


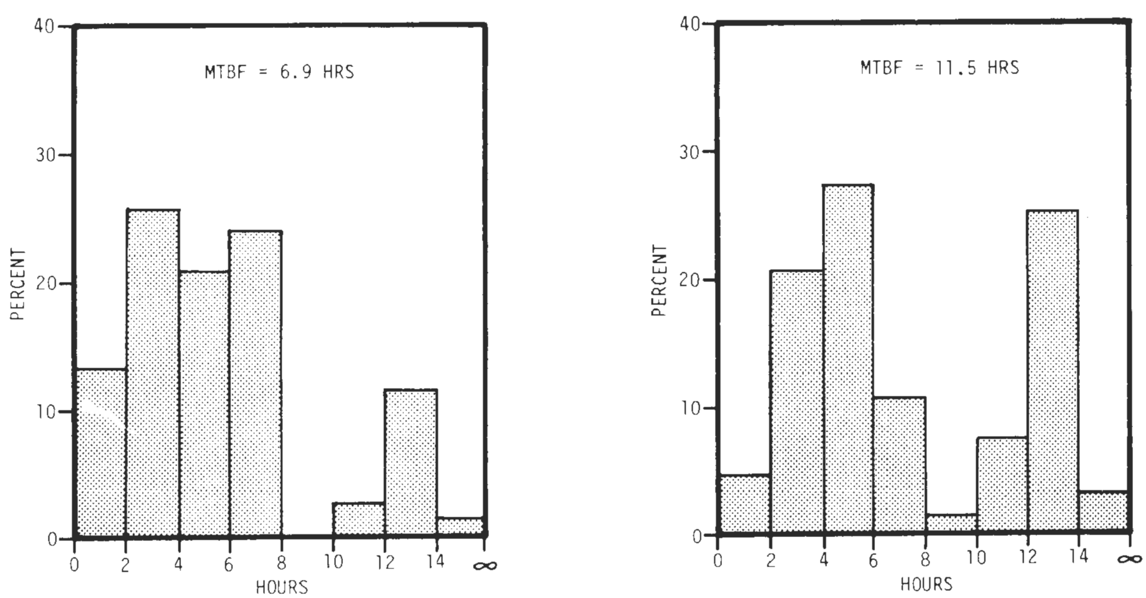
FIGURE 4.11: MONTHLY MEAN MILES BETWEEN FAILURES BY OPERATIONAL YEAR

Second Operational Year



(a) Winter (b) Non-Winter

Third Operational Year



(a) Winter (b) Non-Winter

FIGURE 4.12: DISTRIBUTION OF TIME BETWEEN DOWNTIME EVENTS

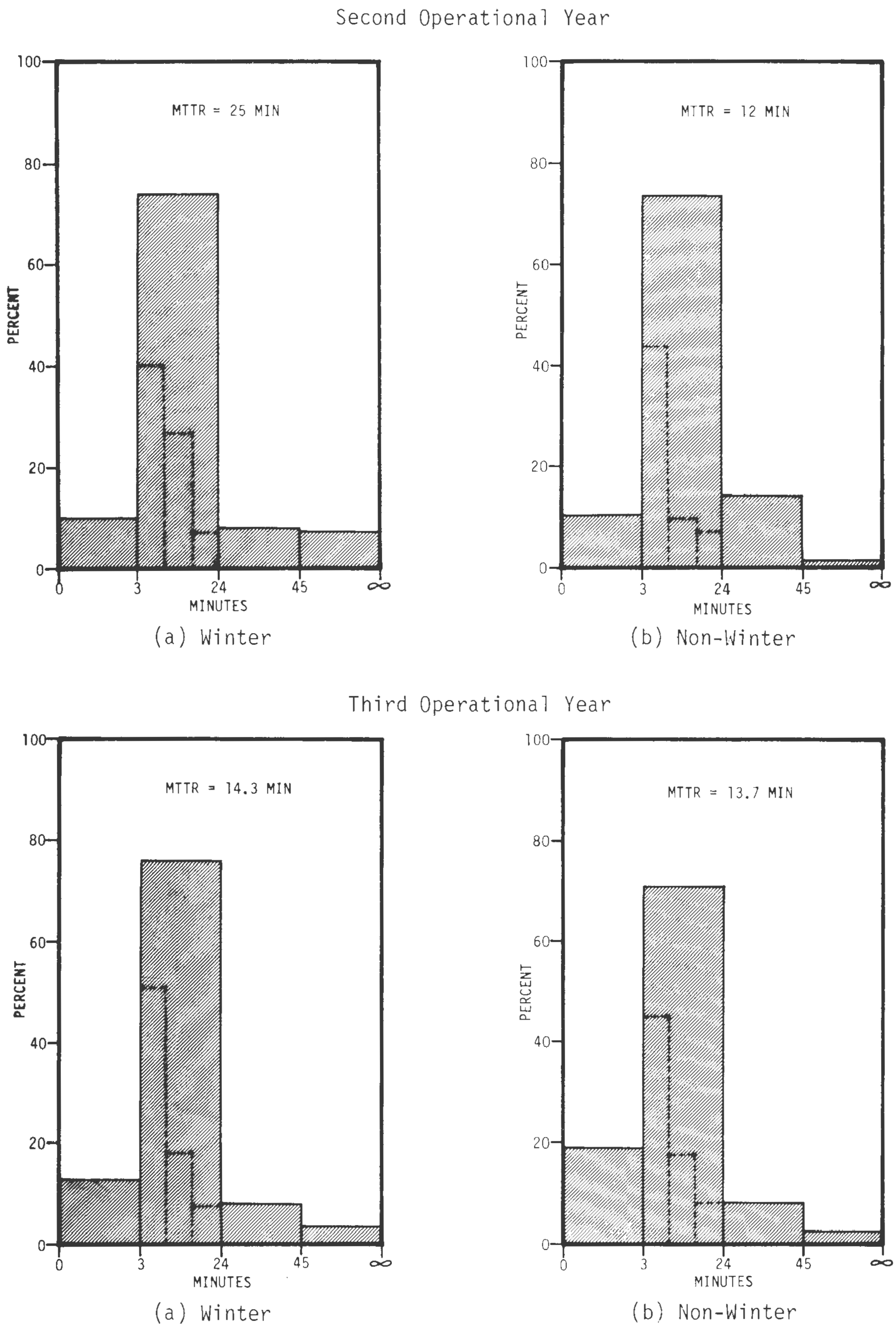


FIGURE 4.13: DISTRIBUTION OF DOWNTIME DURATION

The broken lines in the 3 to 24 minute interval show a fine distribution in seven minute increments, indicating that the majority of the restoration time periods fall in the 3 to 10 minute interval.

In an additional evaluation, the causes of downtime events for the last 12 months of operation were identified and grouped into four major classifications: Vehicle (non-control related), Control and Communications, Weather and Others. Only the last 12 months are considered relevant because the system was in the process of maturing during the previous months of Phase I operations. Table 4.22 shows the results. The greatest cause of system downtime was the control and communications system with 38.4 percent of the events and 44.8 percent of the downtime (exclusive of the fare gates, which did not cause any downtime, but were the source of unscheduled maintenance problems, as will be discussed). Control and communications also had the highest average downtime at 14.9 minutes per event. It is important to note that the on-board vehicle electronics, including electronics associated with steering/switching, has been included by the assessment team with control and communications and not with vehicle statistics. In the following subsection on maintainability, it is shown that unscheduled maintenance actions, which are directly related to downtime, remained nearly constant over Phase I. Resolution of ordinary hardware problems during the first two years have made the control and communications problems appear to increase in the third year. This has been done to provide greater insight into the performance of AGT systems.

The fact that control and communications caused the greatest amount of downtime must not be considered alone. For example, as Phase I closed the average number of downtime events were about one per operating day causing a delay of less than 14 minutes. By simple extrapolation the number of downtime events caused by control and communications would not have averaged more than one every two days of operation. Also 60 percent of C & CS unscheduled maintenance actions were for the fare gates. The following subsection on maintainability also shows that maintenance actions associated with the vehicle were almost 60 percent of those for the entire system -- an experience very similar to conventional rail transit systems.

TABLE 4.22: DISTRIBUTION OF DOWNTIME BY MAJOR CAUSE DURING LAST OPERATING YEAR OF PHASE I (July 1, 1977 through June 30, 1978)

Cause of Downtime	Downtime Events (Number)	Downtime Events (% of Total)	Downtime (Min)	Downtime (% of Total)	Average (Min)	Man-Hours to Restore (Hrs)	Man-Hours to Restore (% of Total)	Average (Hrs)
Vehicle (Non-Control Related)	121	33.4	1227	26.5	10.1	460.1	43.0	3.8
Control & Communications	139	38.4	2069	44.8	14.9	514.5	48.0	3.7
Weather	12	3.3	306	6.6	25.6	12.4	1.2	1.0
Other	90	24.9	1023	22.1	11.4	83.6	7.8	0.9
TOTALS OR AVERAGES	362	100.0	4625	100.0	12.8	1070.6	100.0	3.0

SOURCE: West Virginia University, Monthly Maintenance Summary Reports, July 1977 through June 1978.

Definitions:

Vehicle - All mechanical and electrical gear including the steering system, propulsion, and brakes. It does not include the vehicle control and communication system (VCCS) or the propulsion and braking amplifiers which were classed under "Command and Control".

Control & Communications - All communications (except voice), computers, detectors, collision avoidance, control room, VCCS and the electronics for the steering mechanism (e.g., switch verification).

Weather - Generally ice and snow except for one thunderstorm event.

Other - All of these items are considered to be similar to other non-AGT fixed guideway systems.

Also shown in Table 4.22 are statistics on the number of maintenance man-hours used to restore the system to service after a downtime event. The vehicle and the control and communications system required the majority of the restoration efforts (91 percent) at nearly the same levels.

4.2.3 Maintainability

This section discusses the maintenance activity associated with the first and third years of operation during Phase I. Maintenance activity during the second year is not important because it was an interim experience. As the system matured and operators and maintenance personnel gained experience, a shift in the number of maintenance actions can be observed. The following table summarizes the maintenance activity during the last full operational year of Phase I.

TABLE 4.23: MAINTENANCE ACTIONS FOR LAST OPERATIONAL YEAR OF PHASE I

(July 1977 through June 1978)

Major Subsystem	Maintenance Actions Scheduled	Maintenance Actions Unscheduled	Total
Vehicle	1,605	2,728	4,333
Control And Communications	145	1,683	1,828
Computer	183	88	271
Structures and Power Distribution	346	393	739
Support Equipment	20	169	189
Totals	2,299	5,061	7,360

Unfortunately, there were no similar data available for the full first operational year. Table 4.23, however, indicates clearly that the most significant subsystem, for both scheduled and unscheduled maintenance, was the vehicle accounting for close to 60 percent of all maintenance performed.

Tables 4.24 (a) and (b) allow a comparison of unscheduled maintenance actions by major subsystems between the first and third year of operations. It shows that although there was a significant decrease in vehicle maintenance, vehicles still constitute the major maintenance item. From the first to the third year a shift is noticed in maintenance actions caused by excessive wear, adjustments and undefined causes to maintenance actions caused by failures. Since the total number of unscheduled maintenance actions were only slightly decreased (7 percent) this shift is believed to have occurred because of better recognition of failures where the causes could not be easily identified during the first year. Essentially it indicates the learning experience of maintenance personnel. This shift is particularily noticeable for the C & CS which is the most sophisticated of the major subsystems and required the greatest degree of learning. Also shown is a decrease in vehicle unscheduled maintenance actions of 20 percent.

Tables 4.25 (a) and (b) rank the unscheduled maintenance actions of the top ten items for the two years under comparison by number of maintenance actions. It is obvious that the most significant problem experienced was with the fare collection system. Also listed close to the top in both years is the vehicle electrical system (i.e., mainly caused by the power collectors, which have been replaced by a new design for Phase II operation). Not expected for a modern system is the appearance of the "Operator Control System" as an item ranked fourth in the top ten in the third year, where during the first year it was included under "Other CCS Subsystems". One would expect new technology problems to appear during the first year and be gradually replaced by failures of heavy use items in the third year. From the tables it is obvious that off-the-shelf hardware items (e.g., power collectors, brakes and hydraulics) created more significant problems during the first year. Also, control and communications problems become more noticeable in the third year by better recognition and solution of the low technology problems.

TABLE 4.24a: UNSCHEDULED MAINTENANCE ACTIONS
FIRST OPERATIONAL YEAR
(Oct. 23, 1975 - Aug. 31, 1976)

Subsystems	Action Due To Failure	Action Due To Other*	Total	% of Total
Vehicles	1,228 (70.1%)	1,909 (51.5%)	3,137	57.4
C&CS**	313 (17.9%)	1,487 (40.1%)	1,800	33.0
Computer	118 (6.7%)	99 (2.7%)	217	4.0
S&PDS	50 (2.8%)	168 (4.5%)	218	4.0
Support Equipment	43 (2.5%)	45 (1.2%)	88	1.6
TOTAL	1,752 (100.0%)	3,708 (100.0%)	5,460	100.0

TABLE 4.24b: UNSCHEDULED MAINTENANCE ACTIONS
THIRD OPERATIONAL YEAR
(Sept. 1, 1977 - June 30, 1978)

Subsystems	Action Due To Failure	Action Due To Other*	Total	% of Total
Vehicle	904 (38.2%)	1,597 (59.2%)	2,501	49.4
C&CS**	1,260 (53.3%)	686 (25.4%)	1,946	38.5
Computer	41 (1.7%)	47 (1.7%)	88	1.7
S&PDS	88 (3.7%)	269 (10.0%)	357	7.1
Support Equipment	71 (3.1%)	98 (3.6%)	169	3.3
TOTAL	2,364 (100.0%)	2,697 (100.0%)	5,061	100.0

* Other refers to actions caused by excessive wear adjustments and other undefined causes.
** Includes VCCS.

TABLE 4.25a: UNSCHEDULED MAINTENANCE ACTIONS
TOP TEN ITEMS: FIRST OPERATIONAL YEAR

Subsystems	Maintenance Actions	% of Total
1. Fare Collection System	1,188	21.8
2. Vehicle-Electrical System	901	16.5
3. Vehicle-Braking System	374	6.8
4. Vehicle-Hydraulics	325	6.0
5. Vehicle-Psgr. Module	302	5.5
6. Vehicle-Steering System	278	5.1
7. Vehicle-General/Unclassified	237	4.3
8. Vehicle-CCS	205	3.8
9. Vehicle-Propulsion	198	3.6
10. Structures and Power Distribution	197	3.6
11. Other Vehicle Subsystems	522	9.6
12. Other CCS Subsystems	407	7.5
13. Other Remaining Subsystems	326	6.0
TOTAL	5,460	100.0

TABLE 4.25b: UNSCHEDULED MAINTENANCE ACTIONS
TOP TEN ITEMS: THIRD OPERATIONAL YEAR

Subsystems	Maintenance Actions	% of Total
1. Fare Collection Systems	1,181	23.3
2. Vehicle-General/Unclassified	532	10.5
3. Vehicle-Electrical	523	10.3
4. CCS-Operator System	431	8.5
5. Structures and Power Distribution	312	6.2
6. Vehicle-Psgr. Module	300	5.9
7. Vehicle-Steering System	253	5.0
8. Vehicle-CCS	227	4.5
9. Vehicle-Propulsion	185	3.7
10. Vehicle-Braking	180	3.6
11. Other Vehicle Subsystems	528	10.4
12. Other Remaining Subsystems	302	6.0
13. Other CCS Subsystems	107	2.1
TOTAL	5,061	100.0

Appendix B tabulates (Tables B.1-B.3) a finer breakdown of unscheduled maintenance actions ranked according to components of the major subsystems. Tables B.4 and B.5 show the causes of unscheduled maintenance due to failures, excess wear, adjustments and undefined problems for components within the major subsystems. Tables B.2 (a) and (b) essentially reflect the performance of equipment pertinent to automated operation (i.e., automated fare collection, automated vehicle operation, and automated system management).

Tables 4.24 (a) and (b) show that unscheduled maintenance actions for C & CS accounted for 33 percent and 38.5 percent of the unscheduled maintenance for the first and third year, respectively; however, 60 percent of these actions were caused by the fare collection system. Discounting the fare collection system, which is not solely AGT-related technology and has been completely replaced for Phase II, the number of maintenance actions for AGT-related C & CS repairs would be reduced to 14.3 percent and 19.7 percent of all unscheduled actions, respectively.

Table 4.26 shows the scheduled vehicle maintenance actions for the third year. There are two separate scheduled maintenance procedures involved. Each vehicle undergoes checks at short mileage intervals (187.5, 375, 750 miles) and each vehicle is thoroughly inspected every 3,000 miles. Figure 4.14 relates maintenance man-hours expended at each inspection interval. Here it is obvious that every second 3,000-mile inspection calls for major work. The figure also points out major overhaul work at 30,000 miles and 60,000 miles. Due to a change in reporting procedures, a comparison with the previous two years was not possible. Such a correlation of man-hours with scheduled vehicle maintenance is of less consequence when the system was going through a period of shakedown and problem correction.

From Table 4.23 unscheduled maintenance actions during the last 12 months of Phase I outnumbered scheduled maintenance actions slightly over two to one. While this ratio was 1.7:1 for the vehicle it was 11.6:1 for Control and Communications. Again it must be remembered that 60 percent of the C & CS unscheduled maintenance actions was for the fare gates which when discounted reduces that ratio to 4.6:1. This remaining large ratio suggests additional

TABLE 4.26: SCHEDULED VEHICLE MAINTENANCE ACTION
LAST FULL OPERATIONAL YEAR

Maintenance Action (miles)	Number of Vehicles	Total Man Hours	Average Man Hours Per Action
187.5*	62	30.9	0.5
375*	356	193.1	0.5
750*	433	234.5	0.5
6,000	2	41.0	20.5
18,000	1	20.7	20.7
24,000	3	53.5	17.8
27,000	7	84.4	12.1
30.000	8	251.1	31.4
33,000	9	81.4	9.0
36,000	12	199.8	16.7
39,000	15	153.2	10.2
42,000	16	345.8	21.6
45,000	15	204.3	13.6
48,000	17	326.8	19.2
51,000	13	200.3	15.4
54,000	11	237.1	21.6
57,000	11	146.0	13.3
60,000	11	461.2	41.9
63,000	4	59.2	14.8
66,000	3	55.2	18.4
TOTAL	1,009	3,379.5	3.3

*Internal checks; i.e., vehicle is checked at these intervals, in addition vehicle is checked at 3,000 accumulated miles.

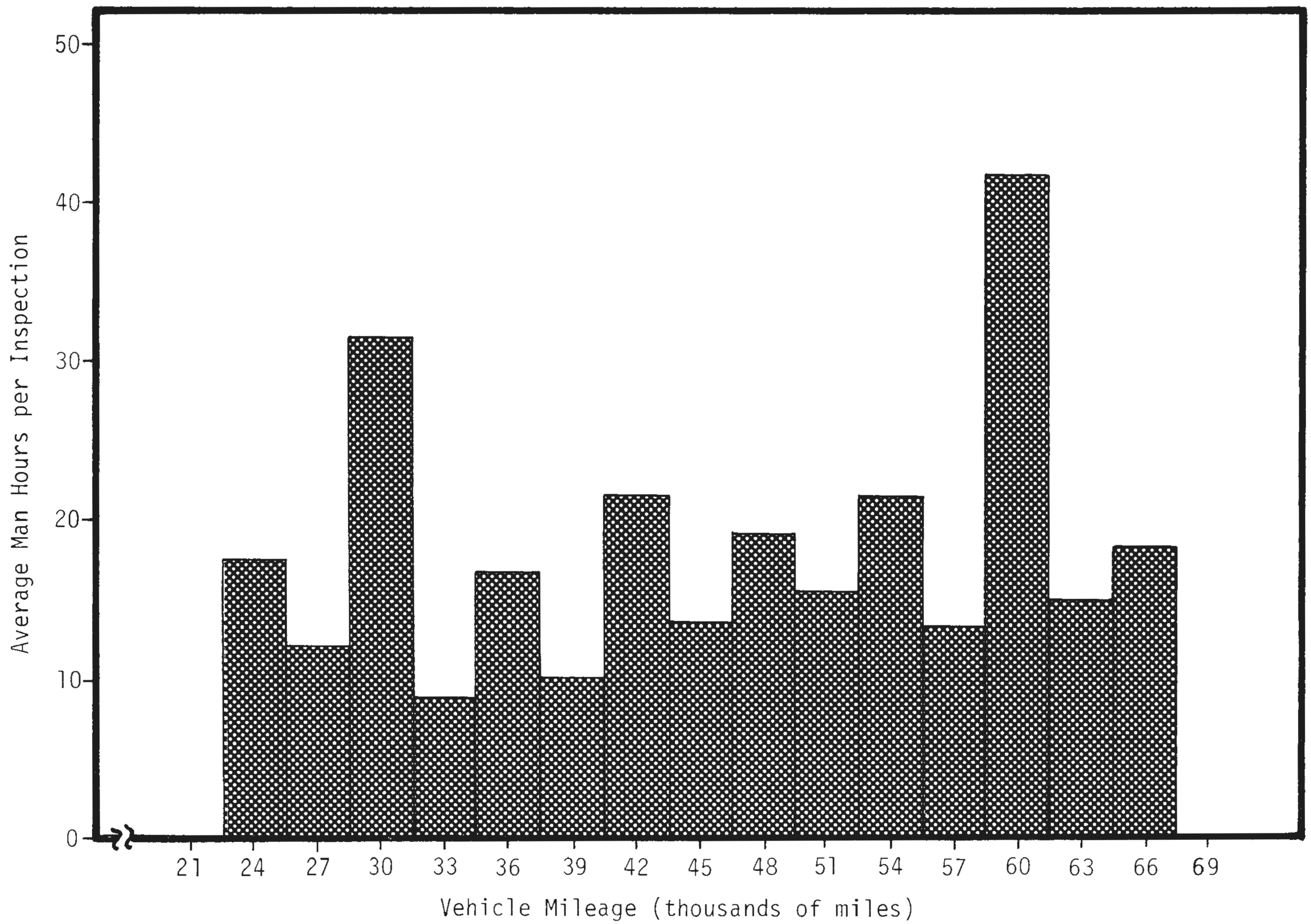


FIGURE 4.14: SCHEDULED VEHICLE MAINTENANCE - AVERAGE MAN HOURS PER 3,000-MILE INSPECTION

improvement can be expected during Phase II to reduce unscheduled maintenance of the C & CS. WVU and UMTA program staff expect that eventually unscheduled and scheduled maintenance actions should be about equal.

4.2.4 Summary of System Assurance Assessment

The following summarizes the assessment of system assurance:

- The reliability and maintainability of the Morgantown system shows successive improvement during the three years of operations. During the third year the system operated near maturity and very nearly reached the conveyance dependability design goal of 98.1 percent.

- The major source of system downtime events during the last 12 months of Phase I was the control and communications system. However, resolution of ordinary hardware problems during the first two years have made the control and communications problems appear to increase where they remained nearly constant. Sixty percent of the unscheduled maintenance required for the control and communications system was to correct fare gate problems, which did not contribute to downtime. The fare gates have been completely replaced in Phase II. The second greatest cause of downtime were non-automatic control problems (low technology) associated with the vehicle. Winter conditions had the effect of doubling the number of downtime events, but experience over the nearly three-year period showed a marked decrease in downtime events and the periods of down time. For example, by the close of Phase I operations MTBF had improved by about a factor of three and MTTR had been reduced to less than half the first three months of operation. Also MTTR during winter months of the first two years was almost three times greater than non-winter months and was reduced to be nearly equal to the non-winter MTTR during the last year. The distribution of downtime event statistics became more "normal", indicating greater stability and not skewed towards greater frequencies of failure.

- The Phase IB program schedule had a high degree of concurrency which precluded "feed back" into the design from a planned endurance test program. Phase II will benefit from almost three years of operation of Phase I.

- Reliability testing or "hard" test data of some specific components were not required for Phase IB system verification. Generic data were used in the analysis, which may have attributed to the following experience.

- The components and subsystems that produced the highest frequency of downtime events or unscheduled maintenance actions were generally ordinary hardware (e.g., fare gates, power collectors, hydraulics, brakes). The "higher technology" items became relatively more important in the third year as problems with ordinary hardware were resolved. A stronger quality assurance program at the component level may circumvent recurrence of such problems in future AGT applications.

- o There were many engineering design changes incorporated during the first year and for Phase II. These changes probably could have been avoided had there been an opportunity to place more emphasis on subsystem tests under simulated operational and environmental conditions prior to system integration. A reasonable development test and demonstration phase would have permitted this increased emphasis.

- o This assessment confirms that a system of the complexity of the MPM operating under severe environmental conditions requires an extended period of time to mature, especially since it is one of the first such systems. Experience gained from the MPM project will help anticipate the stabilization process and will significantly assist in implementating future urban applications of AGT systems.

4.3 HUMAN INTERFACE

Passenger capacity of the vehicles, both seated and standing, and passenger occupancy are discussed in Section 3.1. The following subsections concentrate upon the human factors aspects of stations, ride quality, environmental comfort, and noise.

4.3.1 Stations

The three Phase I Morgantown stations -- Engineering, Beechurst, and Walnut -- are all island platforms which require passengers to enter or leave through central stairwells from underpasses or overpasses (Figure 4.15). Fare control areas for the three stations are at the platform level. The stations are designed for directional flow, with arriving passengers segregated from departing passengers in separate passenger flow lines.

The type of stations used at Morgantown, with center island platforms and turn-back vehicle ramps, restrict the flexibility in designs for passenger access. Attempts were made at Morgantown to adapt the station design to local situations. For example, Engineering is located on a hillside so that passenger access is gained by an overpass from an adjacent parking lot and bus stop. Site conditions at Walnut and Beechurst required that passenger access be gained through underpasses.

The large platforms resulting from the need for station channels permitted the segregation of arriving and departing passenger flow (Figure 4.16). The MPM vehicle size is comparable to many office building elevators, some of which are larger. Arriving and departing passengers are not segregated in elevator lobbies which does not inhibit orderly passenger flow. The large 55-person capacity elevators in the New York World Trade Center operate at volumes higher than MPM vehicles (1,400 passengers per hour per elevator). The practical capacity of these elevators is about 35 persons. During the unload/load cycle in the main elevator lobby 70 passengers are handled in about 30 seconds in a common space where columns present additional constraints. The segregation of passenger flow at Morgantown has resulted in the duplication of turnstiles, requiring separate turnstile control for both entering and leaving passengers. Consolidation of

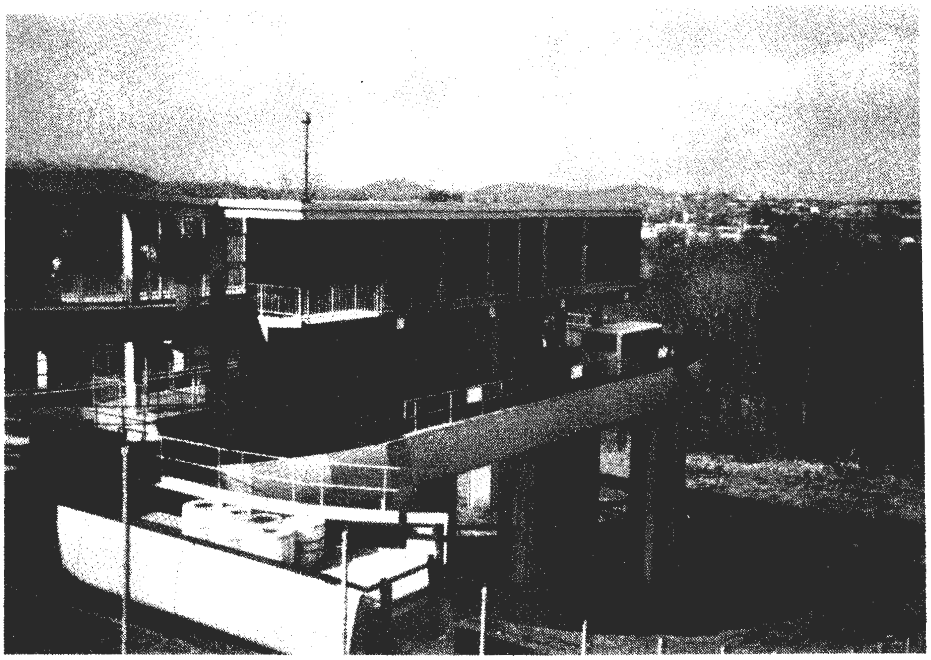


FIGURE 4.15 : CENTER ISLAND PLATFORM STATIONS REQUIRE VERTICAL ACCESS

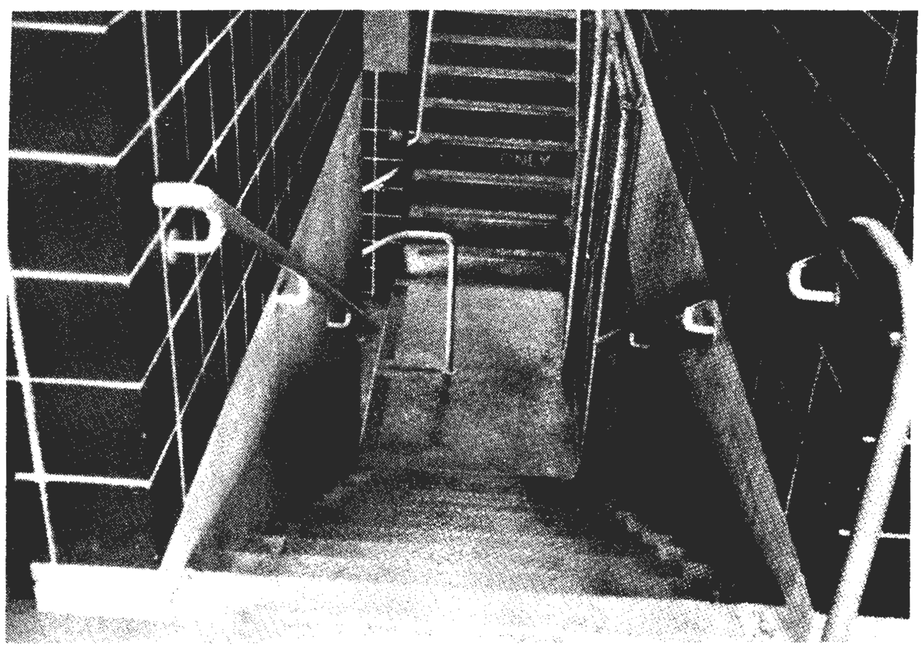


FIGURE 4.16 : SEGREGATED PASSENGER FLOW

turnstiles, as done at the Washington, D.C. Metro, would have the effect of putting more turnstiles "on line". This arrangement would provide greater allowance for malfunctioning units, a problem observed at Morgantown.

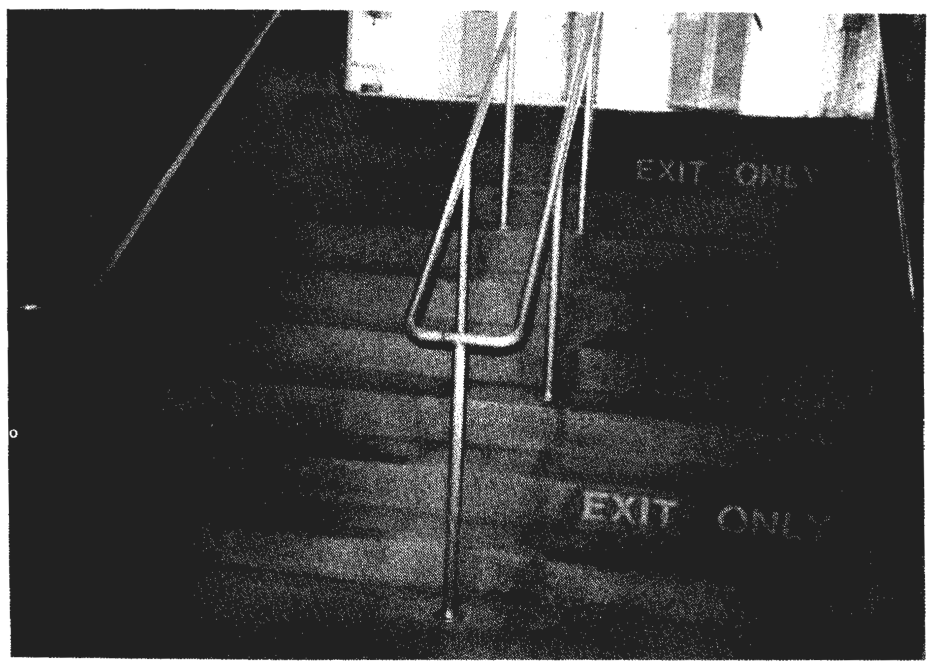
A considerable amount of stair climbing is required in the Morgantown system. The Walnut station requires climbing 26 risers from street level, divided by an intermediate landing. An additional 14 steps are required at Walnut to reach the bus stop for the county transit system located on an adjacent, but lower level, parking lot. The two Beechurst station platforms are 25 stair risers above the street grade. The Engineering station, the most convenient in terms of vertical access has 21 risers.

This amount of stair climbing has not been an impediment to most student patrons. Those with limiting mobility handicaps find that the stairs make the MPM system inaccessible. Phase II includes the installation of elevators in spaces provided earlier to eliminate this problem.

Stairways in Morgantown stations are found to follow the recommended building code standard of 22-inch lane increments with the clear distance between handrails dimensioned at 44 inches for the typical two-lane stairs. In practice, it has been found that this minimum stair-lane width does not function well in urban transit stations, particularly where two-way traffic occurs (Figure 4.17a). As discussed in a subsequent section, the larger male shoulder width exceeds 22 inches. With consideration of additional heavy clothing, the natural swaying that occurs during locomotion, hand carried packages and the traffic frictions of opposing pedestrian flows, center to center handrail dimensions of 30 inches (762 mm) are being recommended for transit stairs. Adherence to the building code in Morgantown has led to the narrowing of an otherwise functionally well dimensioned stair at the Beechurst Station by the insertion of a double handrail (Figure 4.17b).

Information aids in the Morgantown stations were intended primarily for the college population which is familiar with campus locations. Visitors experience minor problems locating the Walnut station in Morgantown because there are no directional signs from the town's main street. The system maps in stations (Figure 4.18a) for Phase I were too complicated with conflicting colors and were covered by a reflecting surface causing a glare which made them difficult to read. Figure 4.18b shows other signing used in the stations, including the active boarding sign.

(a) STAIRWAYS ARE SINGLE LANE ONLY



(b) EFFECTIVE STAIRWAY WIDTH REDUCED BY DOUBLE HANDRAIL

FIGURE 4.17

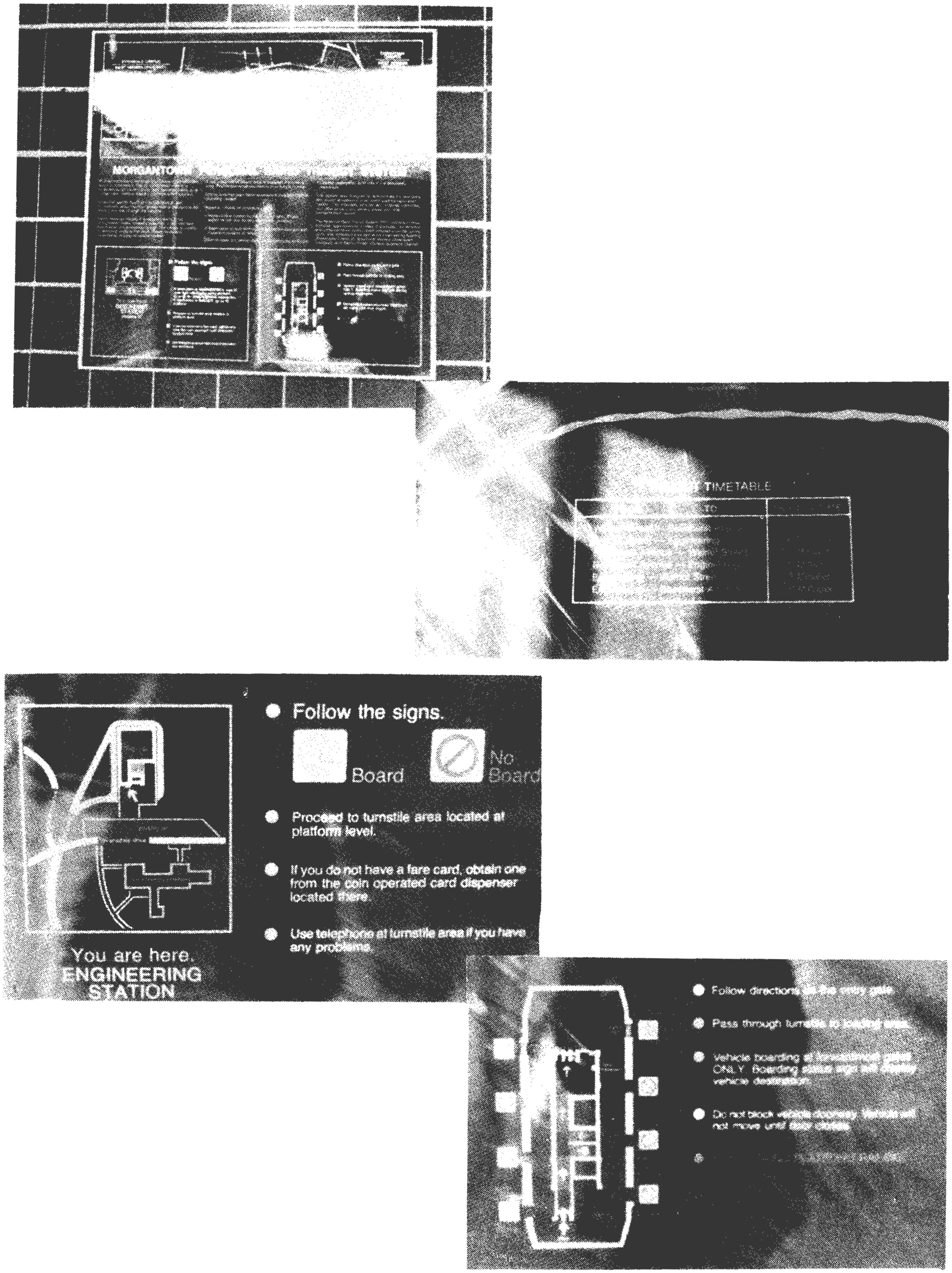


FIGURE 4.18 a : SYSTEM MAP AND PASSENGER INSTRUCTIONS IN STATIONS

One-time patrons appeared to have difficulties understanding the turnstile sequence which required insertion of a card and selection of the destination station before entry was permitted (Figure 4.19). A number of first-time patrons were observed requesting instructions on this procedure from other passengers. Instructions for dealing with turnstile and ticket dispensing equipment malfunctions were not clearly displayed. For example, some patrons hesitated to obtain system operating information by using the station telephone (Figure 4.20) because of its restrictive labeling: "Emergency Telephone - Use only to report emergencies. . . ." The man in Figure 4.21 was greatly irritated because the fare card dispenser was inoperative. Because he did not consider the situation an "emergency", he used the telephone only after other riders urged him to do so. Relatively frequent malfunctions of the automatic turnstiles added to the frustrations of the MPM system patrons (Figure 4.22). A completely new fare collection system has been installed for Phase II.

4.3.2 Ride Comfort

Considerable research has been done on the criteria for ride comfort with respect to vibration. A widely cited standard for transit vehicles appears to be the proposed criterion of exposure duration for given vibration levels by the International Organization for Standardization (ISO). The ISO standards give criteria for vertical and lateral vibrations as in Figures 4.23 and 4.24.

Each line in these two figures represents an estimate of the upper limit of the amplitudes of vibrations at the center frequencies of one-third octave bands. These are levels which humans can tolerate for specific time limits before fatigue effects occur. ISO distinguishes between three main criteria for vibration exposure. These are based on functions of frequency and amplitude of vibration to derive the time limits for safe human exposure.

- The Fatigue - Decreased Proficiency Level: Exposure to vibrations above this limit results in reduced efficiency to execute various tasks.
- Safe Exposure Limit: The safe exposure limits are about 6dB higher than the fatigue-decreased proficiency level. Above this limit there is the risk that vibrations may injure the human body. The safe exposure limit is about one-half the pain limit.
- Reduced Comfort Boundary: Amplitudes of about 10 dB less than the fatigue-decreased proficiency level tend to characterize the upper boundary of comfort.

FIGURE 4.18 b : PASSENGER INFORMATION IN STATIONS

FIGURE 4.19 : TURNSTILE

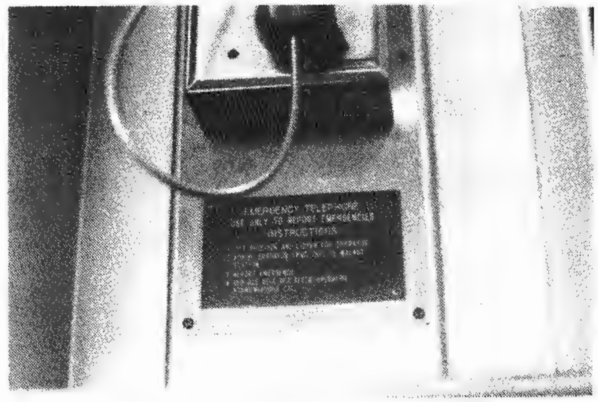


FIGURE 4.20 : EMERGENCY TELEPHONE

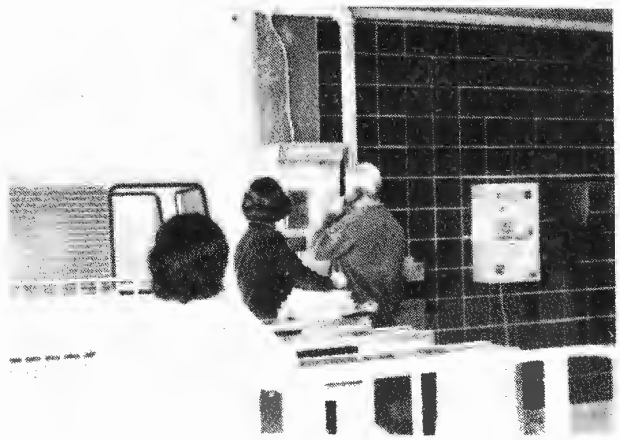


FIGURE 4.21 : PASSENGER USING EMERGENCY TELEPHONE

FIGURE 4.22 : PASSENGER QUEUE CAUSED BY ONE TURNSTILE OUT OF SERVICE

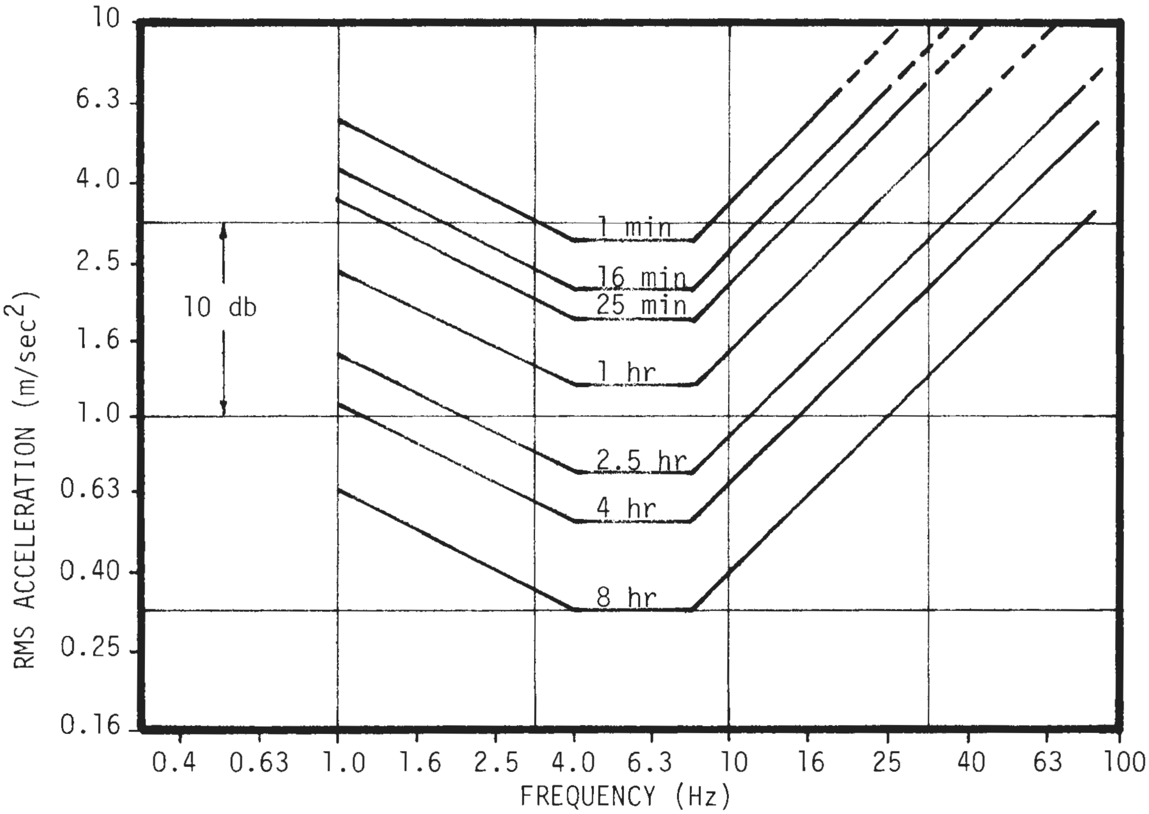


FIGURE 4.23 : VERTICAL ACCELERATION FATIGUE-DECREASED PROFICIENCY BOUNDARIES BY THE ISO

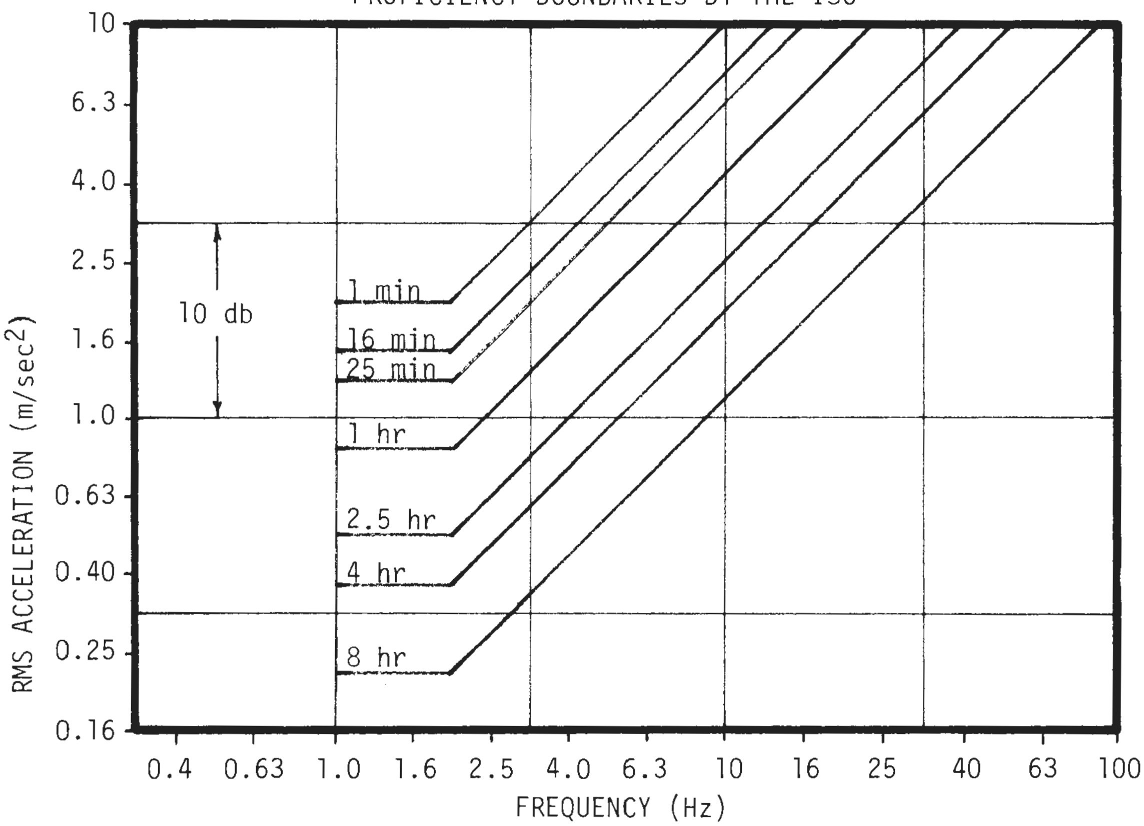


FIGURE 4.24 : HORIZONTAL ACCELERATION FATIGUE-DECREASED PROFICIENCY BOUNDARIES BY THE ISO

While the fatigue-decreased proficiency level is applicable for vehicle operators, the reduced comfort boundary can be used as a comfort criterion for passengers.

Specification and Test Results

The requirements chosen for the Morgantown system ride quality specifications were modeled after guidelines proposed by Matsubara in 1946, primarily for high speed trains used by the Japanese National Railways. The resultant specifications for g-level versus frequency for vertical and lateral ride comfort are shown on Figures 4.25 and 4.26 as the 1.5 Matsubara index curves. Also shown are the maximum envelopes of representative Fourier transfer functions resulting from Boeing comfort tests conducted at Morgantown during March 1975.

Vertical ride quality, as shown on Figure 4.25, exceeds specification (level 1.5) in a range 5.5 to 12 Hz, centered at 9 Hz, and again slightly at 17 Hz. This deviation was caused by guideway surface roughness in certain localized areas.

The Boeing Final Report states that lateral ride comfort test results exceeded specifications in the natural frequency range of the sprung mass of the passenger module (see 1.2 to 2.8 Hz range of Figure 4.26). Excessive lateral accelerations were caused by misalignments of the guiderail. Oscillations can be observed with the unaided eye at a section of the elevated guideway behind the Seneca Glass Factory where vehicles cruise at a velocity of 30 mph. Misalignment is measured by the distance the guiderail is displaced from a predetermined line or curve for a given length of track. To keep lateral instabilities within tolerable limits, the amount of displacement from misalignment must be reduced as vehicle speeds are increased.

The results of both vertical and lateral ride comfort tests exceeded the specifications as set forth in the System Specification[10] and the System Acceptance Test Plan [14]. The Boeing Final Report recommends that the measured vertical and lateral ride comfort shown in Figures 4.25 and 4.26 be approved by waiver. After officials from both UMTA and WVU actually rode the system and experienced the deviations, the waiver was agreed to.

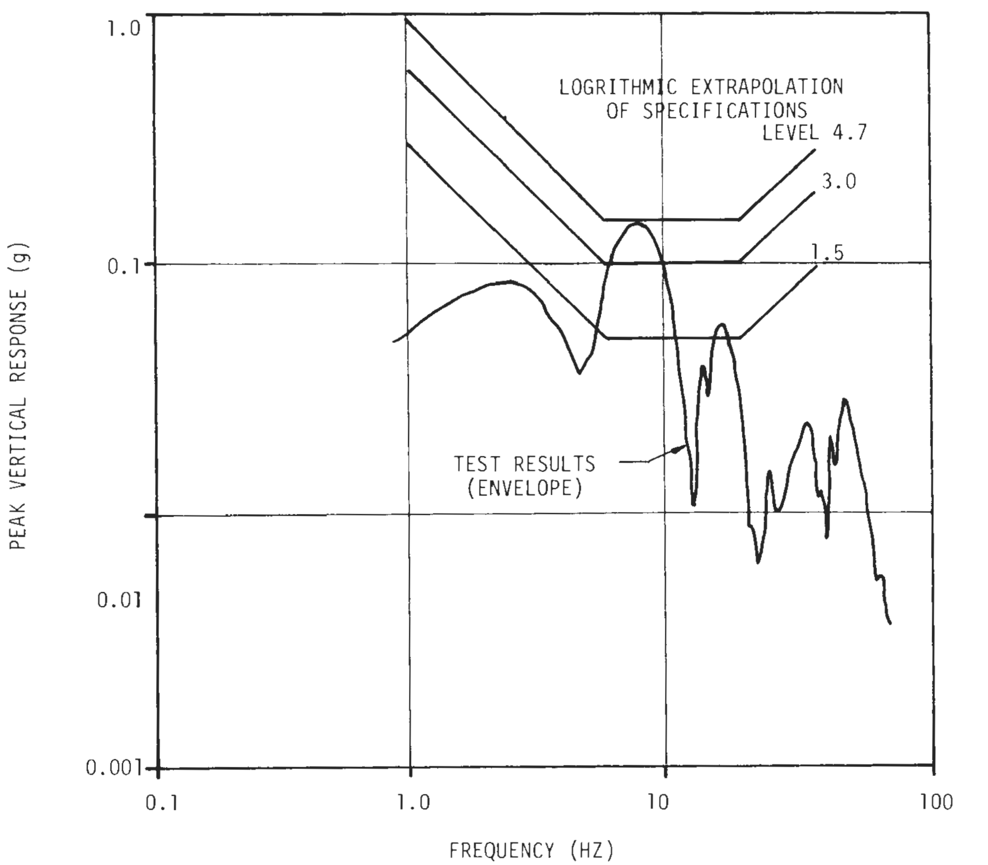


FIGURE 4.25 : MAXIMUM ENVELOPE OF REPRESESTATIVE FOURIER TRANSFER FUNCTIONS FOR VERTICAL RESPONSE, BOEING RIDE COMFORT TESTS

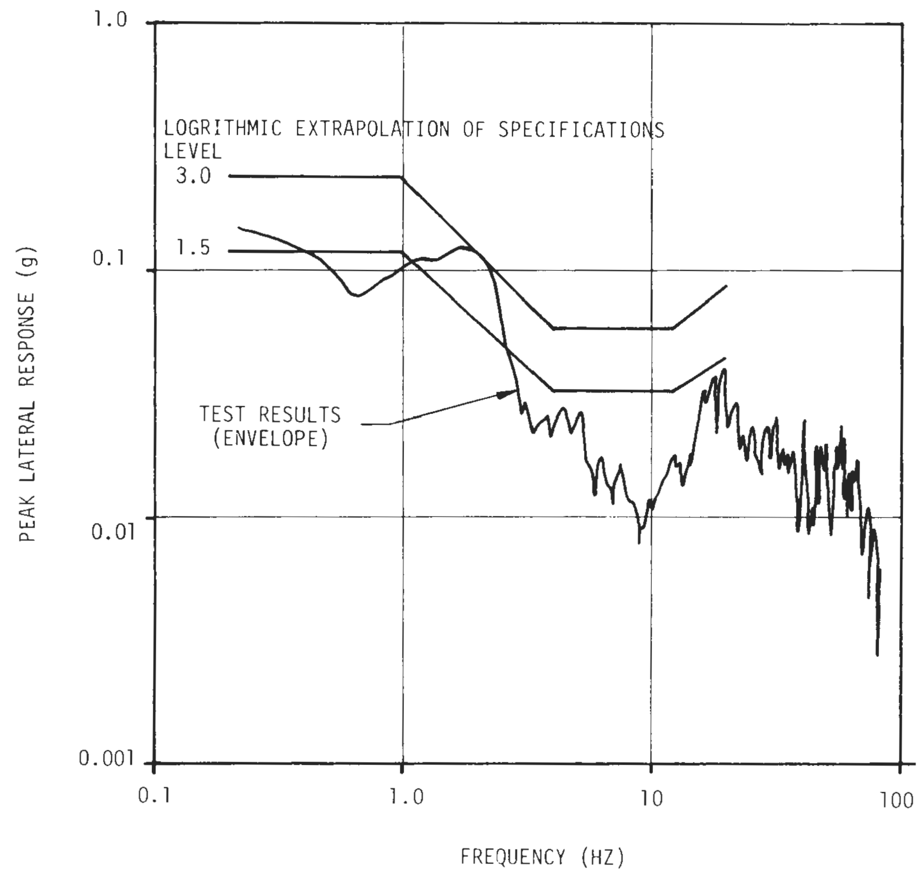


FIGURE 4.26 : MAXIMUM ENVELOPE OF REPRESENTATIVE FOURIER TRANSFER FUNCTIONS FOR LATERAL RESPONSE, BOEING RIDE COMFORT TESTS

Boeing tests employed accelerometers, direct recording oscillograph recorders and analog tape recorders. Ride comfort data was evaluated by performing Fourier analysis using the Fast Fourier Transform (FFT) algorithm in the laboratory. These detailed spectral results are useful for testing the design of equipment to identify areas for redesign and/or mechanical adjustment.

For this assessment portable compact instrumentation not requiring subsequent data processing was employed. The Ride Comfort Meter used by the assessment team is a compact 4.5 lb device. Accelerometer output is weighted directly according to the ISO comfort criteria by an electronic filter. Separate filters are used for vertical and lateral acceleration. These filter characteristics are shown in Figure 4.27 depicting the ISO curves which they approximate. The resultant values correspond to the ISO weighted RMS values of effective acceleration, namely Ride Index (RI).

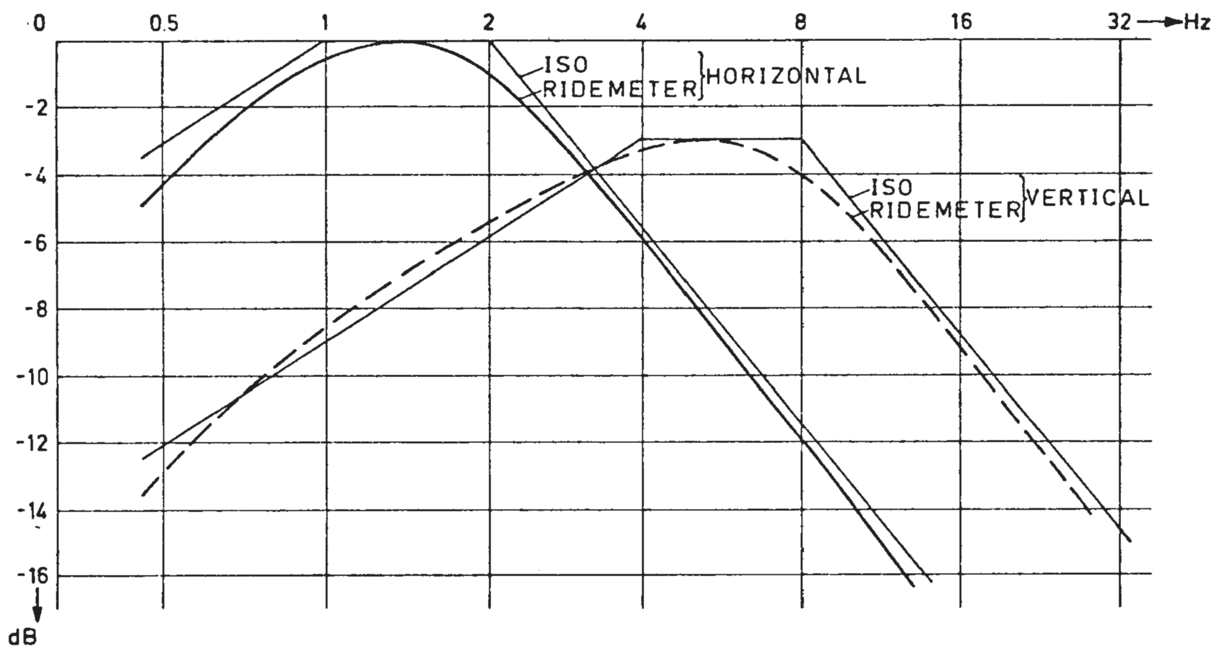


FIGURE 4.27: COMFORTMETER FILTER CHARACTERISTICS

Public Attitude Survey Results Regarding Ride Quality

As part of this assessment, questions regarding comfort were asked of riders during the public attitude survey. Responses concerning temperature, drafts, humidity, noise, crowding, and bumpy or swaying rides were requested. An interesting finding was that riders were less critical as age increased. The following results were obtained with respect to ride comfort:

TABLE 4.27: RESULTS OF PUBLIC ATTITUDE SURVEY

ANSWERED YES TO	Age (Years) 25 and Under (%)	26-40 (%)	Over 40 (%)
Bumpy Ride?	64.4	40.8	27.3
Does the Vehicle Sway?	52.8	44.3	36.4

The ride was considered bumpy by 62.5 percent of the respondents and 56.5 percent of the subjects believed that the vehicles swayed from side to side. These results indicate some rider dissatisfaction with respect to vehicle motion. The public attitude survey and its results are described in Section 4.4.

NDL Instrumentation

In August 1977, the NDL assessment team, in collaboration with SNV, made ride comfort measurements at Morgantown, using the new Ride Comfort Meter Type II developed by Delft (Holland) University of Technology. This meter has been developed specifically for transit applications. The ride comfort meter enables less complicated measurements and analyses to be made which are especially useful for studies of ride comfort with socio-economic emphasis.

Data Collection

Ride quality of the Morgantown system was measured with the Ride Comfort Meter on August 8, 1977, by a team from NDL and SNV. Operations were typical, average summer weather conditions prevailed, and no special anomalies were recorded. Measurements were taken on two randomly selected vehicles, numbers six and nine. After selection of these vehicles, assurance was obtained from the maintenance manager that neither vehicle had recently experienced any problems with the steering mechanism or suspension system which could adversely affect its behavior with respect to ride quality. While making measurements, passengers were allowed to ride the vehicles, so that the measurements were taken with random vehicle loadings as found under normal operating conditions. For all measurements the instrument was placed at the centerline of the vehicle on the floor above the front axle. Ride comfort data were taken for vertical and lateral accelerations at 15 mph, 22.5 mph, and 30 mph over the entire main guideway, in both directions, at different curvatures and on near straight and straight sections. The objective was to cover all vehicle performance conditions which passengers normally experience.

Data Analysis

Statistical methods were used to analyze the ride-comfort data. Figure 4.28a shows the resultant means for vertical Ride Indices versus vehicle speeds in guideway curves and on straight and near straight sections from Engineering to Walnut stations and from Walnut to Engineering stations. The numerical vertical and lateral mean values are given in Tables 4.28 and 4.29.

Linear regression using all collected data points, yields the Ride Index (RI) equation,

$$\text{RI Curve} = 34.76 + 1.24v \text{ (mph)},$$

which describes the relation of the vertical RI to vehicle speed in curves as shown with the solid line in Figure 4.28a. The equation relating vertical RI to vehicle speed at near-straight sections of the guideway is:

$$\text{RI Near Straight} = 3.51 + 2.26v \text{ (mph)},$$

and is shown in Figure 4.28a with a broken line.

In a similar manner the correlation between lateral RI and vehicle speed is illustrated in Figure 4.28b. The corresponding lateral RI equation for curves is:

$$\text{RI Curves} = -14.31 + 3.27v \text{ (mph)}$$

and for near-straight guideway sections is:

$$\text{RI Near Straight} = -35.25 + 3.30v \text{ (mph)}$$

Testing of the data confirmed the conclusion that there exists a positive correlation between RI and vehicle speed in all cases.

Higher values for RI means a less comfortable ride caused by higher vibration levels. As can be expected, the lines for Ride Indices in curves lie significantly above the lines for Ride Indices on a near straight guideway for both vertical and lateral vibrations. In addition, superimposing Figures 4.28a and 4.28b shows that ride comfort is more adversely affected by vertical vibrations than by lateral vibrations.

NDL Ride Comfort Test Results

Results of the NDL ride-comfort tests are illustrated in Figure 4.29 as the percentage of trip time during which the vertical and lateral RI values were exceeded. The percentage of trip time is correlated with the RI encountered by a passenger on a typical trip from Engineering to Walnut. These also give approximations of the comfort levels experienced on other trips. For example, on a typical ride from Engineering to Walnut, a passenger will experience levels of

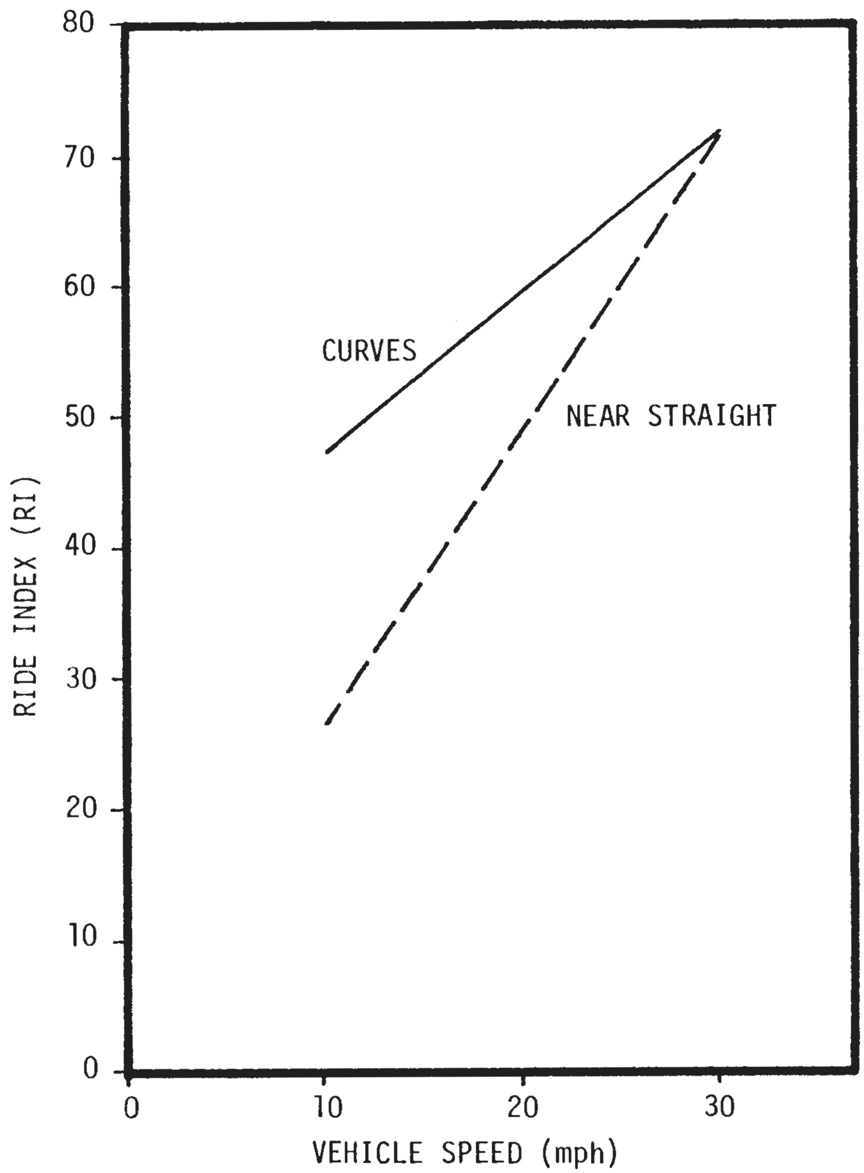


FIGURE 4.28a : MORGANTOWN VERTICAL RIDE INDEX VS VEHICLE SPEED

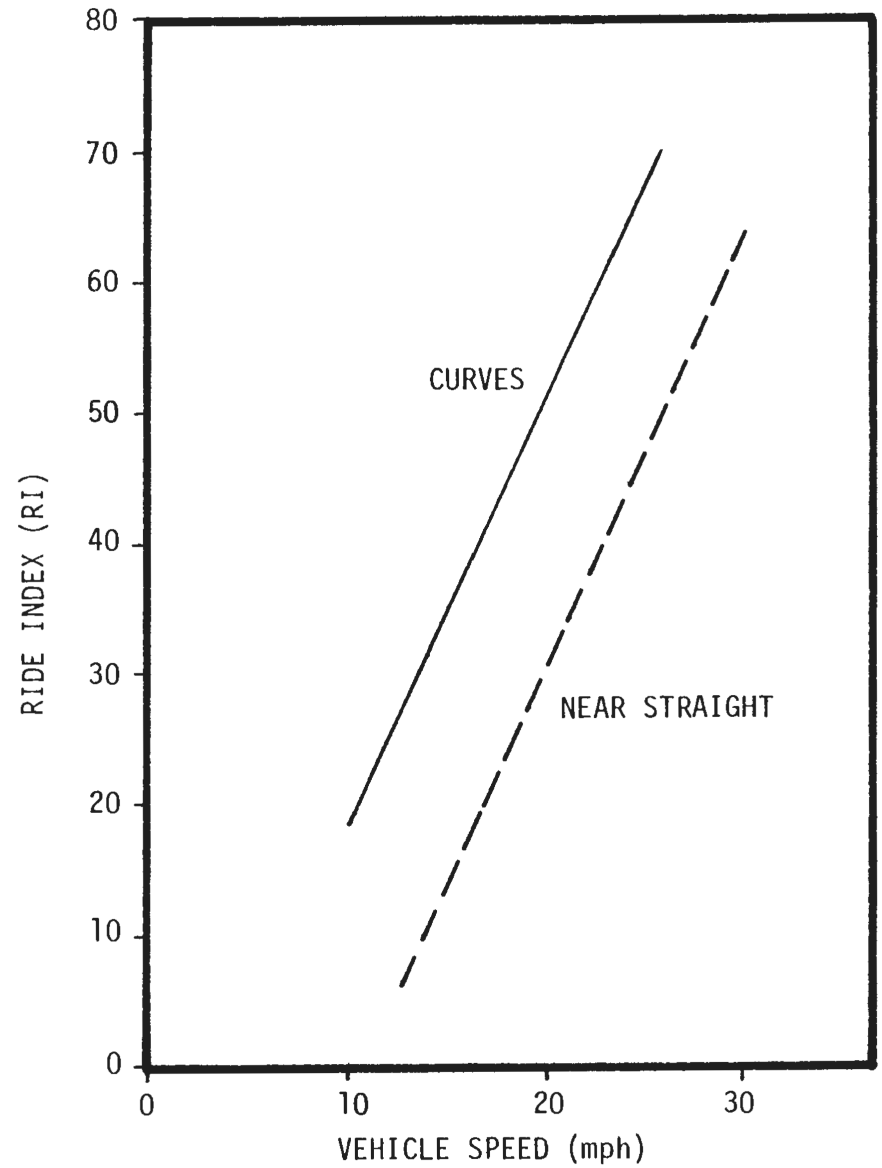


FIGURE 4.28b : MORGANTOWN LATERAL RIDE INDEX VS VEHICLE SPEED

TABLE 4.28: VERTICAL RIDE INDEX MEAN VALUES FOR MPM SYSTEM UNDER DIFFERENT OPERATING CONDITIONS

Vertical Ride Indices					
15 mph		22.5 mph		30 mph	
Near Straight	Curve	Near Straight	Curve	Near Straight	Curve
38.3	53.4	53.1	62.8	71.6	*

* At present, speeds in excess of 22.5 mph do not occur in curves.

TABLE 4.29: LATERAL RIDE INDEX MEAN VALUES FOR MPM SYSTEM UNDER DIFFERENT OPERATING CONDITIONS

Lateral Ride Indices					
15 mph		22.5 mph		30 mph	
Near Straight	Curve	Near Straight	Curve	Near Straight	Curve
21.0	34.8	31.3	59.4	66.0	*

* At present, speeds in excess of 22.5 mph do not occur in curves.

lateral vibration equal to or less than 31 RI for 50 percent of his travel time and equal to or less than 54 RI for 90 percent of his travel time. Vertical vibrations will be equal to or less than 46 RI for 50 percent of the travel time and equal to or less than 63 RI for 90 percent of the travel time. Put another way, the curves in Figure 4.29 assess the maximum amount of discomfort experienced on a typical trip on the Morgantown system.

At the University of Technology in Delft (Holland) the RI readings from the Ride Comfort Meter Type II have been correlated with the fatigue-decreased proficiency levels for different exposure times as proposed by ISO. This correlation is shown in Figure 4.30. According to ISO, the reduced comfort boundary is 10dB lower than the fatigue-decreased proficiency level.

Superimposed on Figure 4.27 are the upper limits of the 95% confidence intervals of the ride-comfort data given below with the same reference numbers.

1. Average vertical RI @ 30 mph: 76.6
   95 percent confidence interval: $69.7 < RI < 83.5$

2. Average lateral RI @ 30 mph: 66.0
   95 percent confidence interval: $63.1 < RI < 68.9$

3. Average vertical RI @ 22.5 mph: 59.4
   95 percent confidence interval: $57.5 < RI < 61.3$

4. Average lateral RI @ 22.5 mph: 50.0
   95 percent confidence interval: $46.4 < RI < 53.6$

Examination of the RI data for the MPM system plotted against their maximum time of occurrence on any trip, reveals that all points lie well below the ISO proposed reduced comfort boundary. Furthermore, even longer exposure times than presently encountered at the MPM system would be acceptable according to these standards. It should be noted that this ISO standard was used to measure the comfort levels of the MPM system because it presently is the only generally accepted standard available. All other ride-quality criteria studied for this report, including the original MPM system specifications, are more restrictive with regard to acceptable vibration levels.

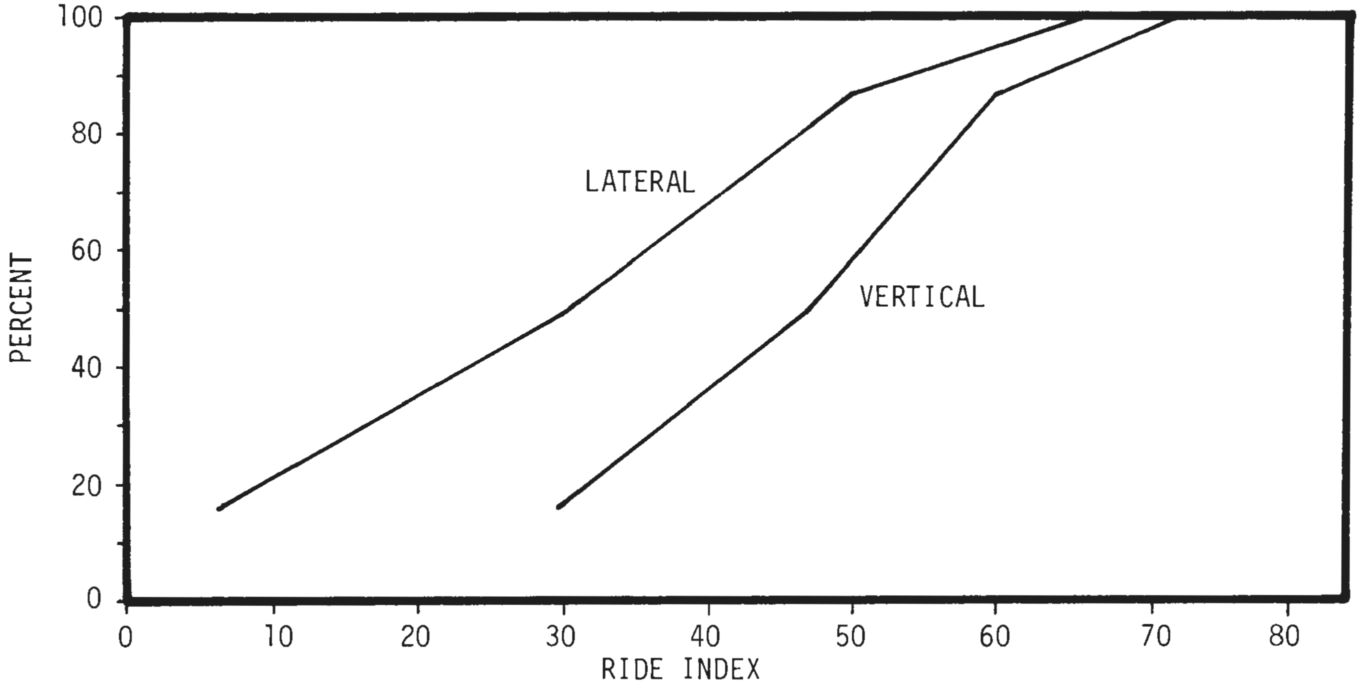


FIGURE 4.29 : PERCENTAGE OF TRIP TIME DURING WHICH VERTICAL OR LATERAL RIDE INDEX IS NOT EXCEEDED (ENGINEERING - WALNUT)

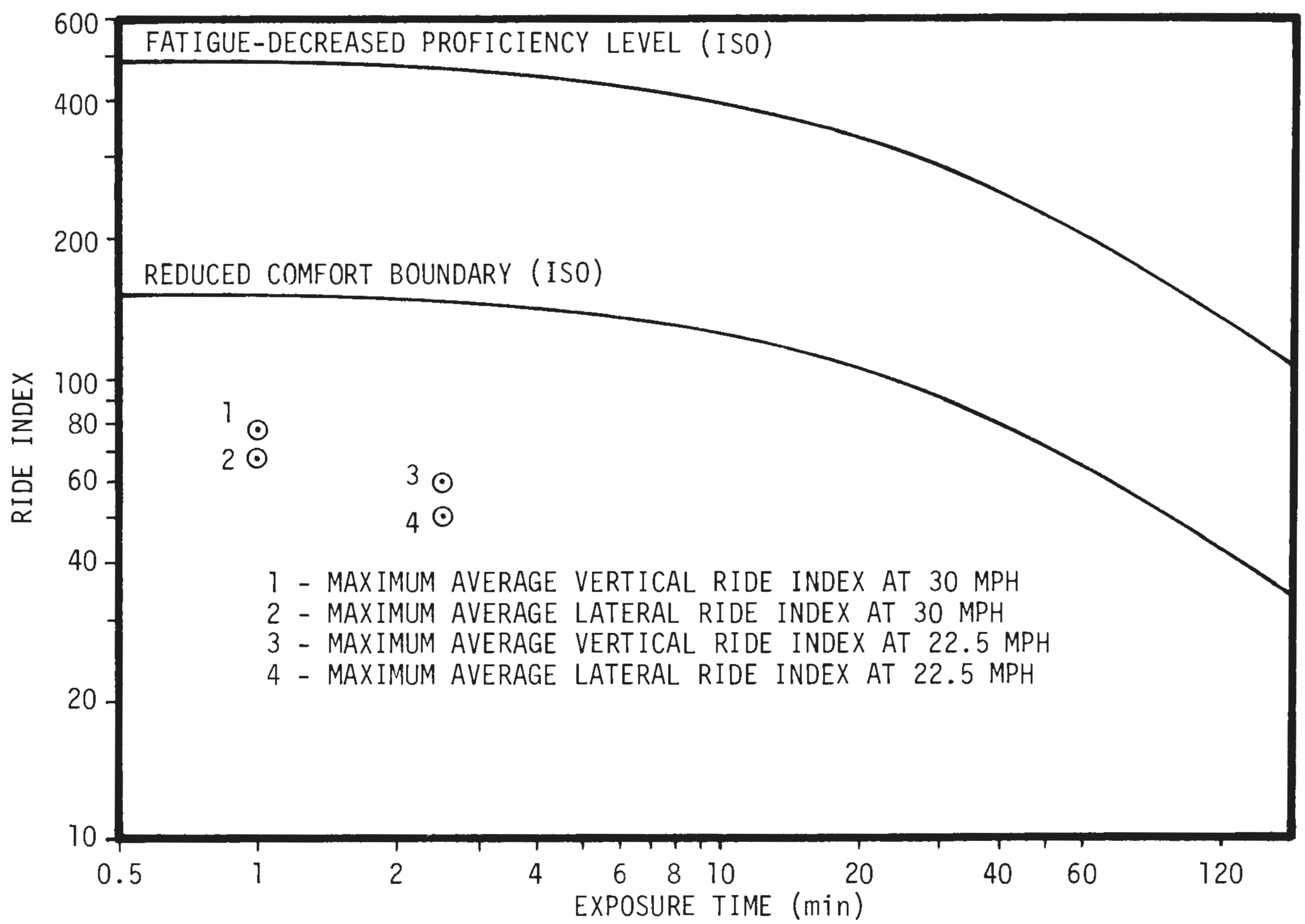


FIGURE 4.30 : MORGANTOWN RIDE QUALITY COMPARED WITH ISO STANDARDS

Comparison of Morgantown Ride Comfort Versus Other Transit Vehicles

To provide a basis for comparison with the MPM system, NDL and SNV personnel made additional ride-comfort measurements on other modern transit systems. Some results of these measurements are shown on Figure 4.31 for lateral vibrations and on Figure 4.32 for vertical vibrations in relation to speeds.

The following are the systems on which ride-comfort measurements were performed:

Automated Guideway Systems:

- -- Morgantown People Mover, Morgantown, WV (USA)
- -- Airtrans, Dallas/Fort-Worth Regional Airport, TX (USA)
- -- Cabinentaxi KK12 (suspended 12-passenger vehicles), Test facility, Hagen, Germany
- -- H Bahn, Test facility, Erlangen, Germany

Buses:

- -- AMC and GMC Metro buses from Washington, D.C. (USA)

Rapid Transit Systems:

- -- BART, Bay Area Rapid Transit, San Francisco, CA (USA)
- -- Metro, Washington, D.C. (USA)
- -- S-Bahn (Vehicle ET 472), Hamburg, Germany
- -- Subway (Vehicle DT3), Hamburg, Germany

All measurements were taken at that place in the vehicle where worst conditions prevail. Figure 4.33 shows the results. For each system the average lateral and vertical RI values of all measurements are given. As a reference, RI values for private automobiles are provided as measured by the Delft University of Technology, Holland. RI measured for both vertical and lateral vibrations are higher for the MPM system than for the other systems shown on Figure 4.33.

The ride quality on the MPM system was found to be outside the original specification. The measurements demonstrated that RI values correlated with exposure time stayed well within the ISO proposed reduced comfort boundary for trip times as they occur at the present system. Vertical vibrations impair ride comfort more than lateral vibrations.

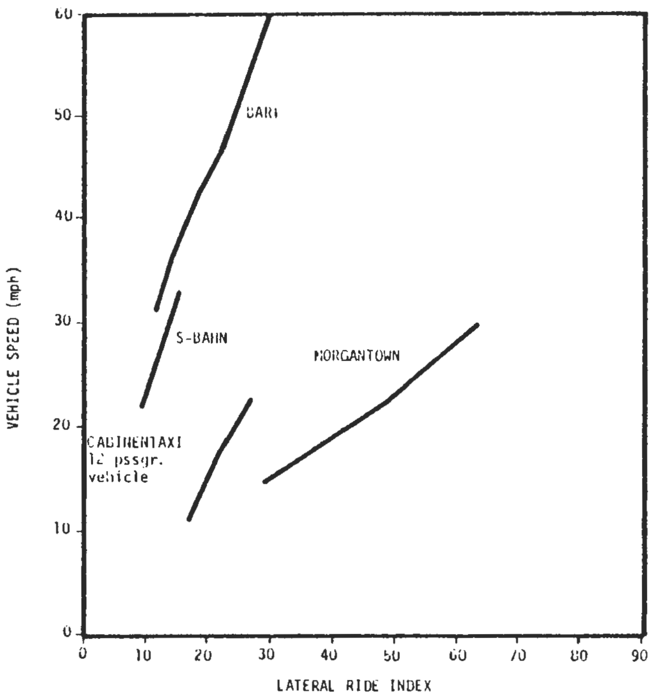


FIGURE 4.31: COMPARISON OF LATERAL RIDE QUALITY FOR DIFFERENT TRANSIT SYSTEMS

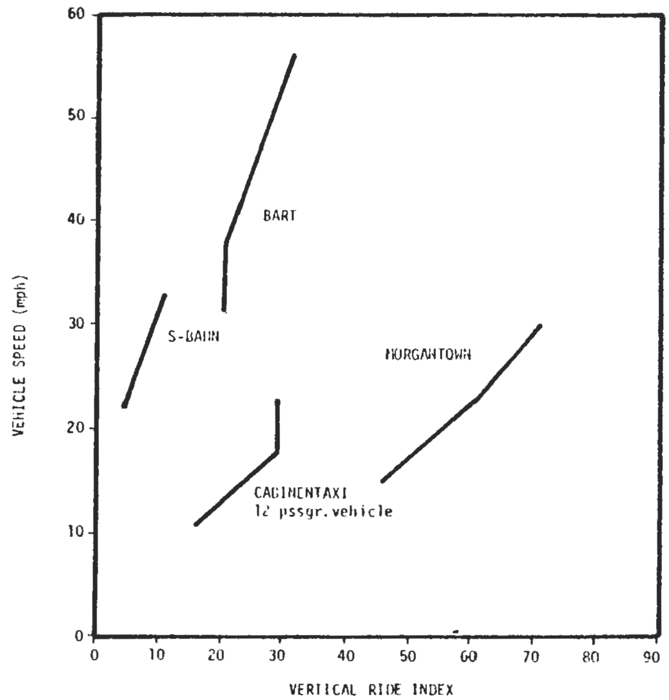


FIGURE 4.32: COMPARISON OF VERTICAL RIDE QUALITY FOR DIFFERENT TRANSIT SYSTEMS

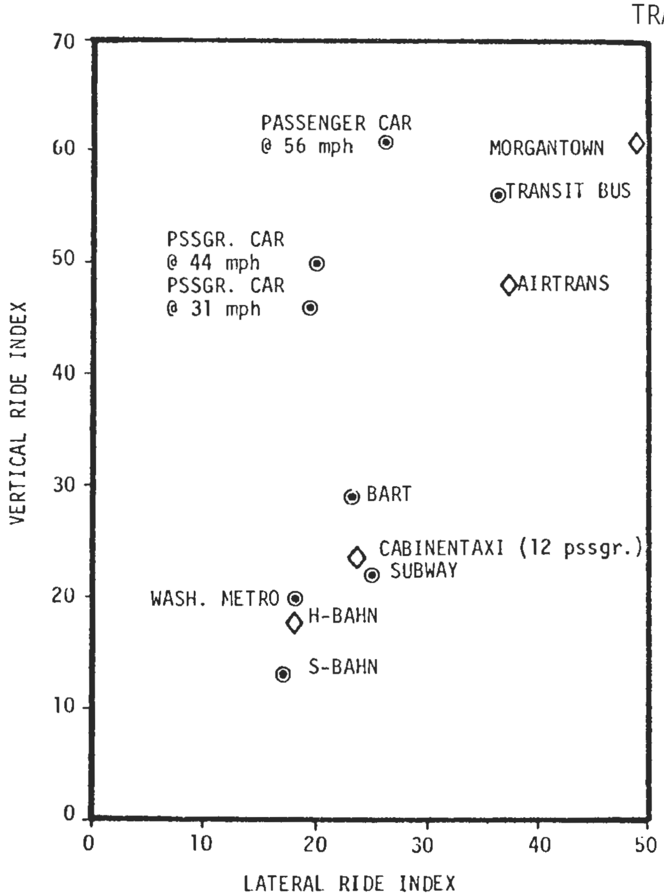


FIGURE 4.33: AVERAGE LATERAL AND VERTICAL RIDE INDEX VALUES FROM ALL MEASUREMENTS

The results of a public attitude survey performed in Morgantown indicate some dissatisfaction with ride comfort on the part of the passengers confirms the comparisons shown in Figure 4.33.

4.3.3 Environmental Comfort

Vehicle interior temperature and humidity specifications[7] are summarized in Table 4.30. Boeing tests in September 1974 at the Surface Test Track Facility (STTF) and at Morgantown in August 1975 showed compliance with the specification, except the vehicle interior was too warm when the outside temperature range was from 10^{o} to $65^{o}F$. For this test the thermostats had been improperly adjusted. Interviews with the system operator verify satisfaction with the heating and cooling capacity of the Environmental Control Unit (ECU). During Phase I, problems were cited with thermostat and humidity controls. These have been modified for Phase II.

There may be some question of the applicability of the specification where a period of three minutes is allowed from the time doors close until compartment temperature specifications are to be met. For example, the ride time between Walnut and Beechurst is only 2.5 minutes; therefore, the ECU has not sufficient time to regain losses from open doors at the station. Response to the user survey, however, indicated 85 to 95 percent were satisfied with interior temperatures.

Station platforms are covered but the sides are open to the environment. Radiant heaters are provided immediately over the vehicle doors at the loading berths which do provide some comfort during extremely cold weather. At Morgantown winds generally accompany cold weather, making waiting for vehicles uncomfortable. Light snow was observed blowing upon an already very polished concrete platform surface making it extremely slippery. Puddles are usually found on station floors after snow melts or rain blows in. These conditions have been corrected in some instances during Phase II by the installation of wind screens to partially enclose the platforms at Engineering and at the two new stations. Phase II has also added heaters over all of the waiting areas.

TABLE 4.30: VEHICLE INTERIOR ENVIRONMENTAL CONTROL REQUIREMENTS

Outside Ambient		Inside Vehicle*		
Dry Bulb To (°F)	Wet Bulb (°F)	Temp °F	Relative Humidity, %	Additional Constraints
90		To minus 10 (approx.)		
90 ③	77	80	60	1. 8 seated plus 7 standing adult 2. Solar heat factors. Vertical surfaces, 24 Watts/Ft^2 Horizontal surfaces, 53 Watts/Ft^2
75 to 90		70 to 80 ⑤	60	
65 to 75		①		
10 to 65		50 to 70 ②		
10 ④		50		1. 1 passenger.
10		To plus 40 (approx.)		

*Inside vehicle conditions shall return to design conditions within three minutes after a 45 second door opening.

In addition to the environmental constraints identified above, all applicable Federal, State, and Local regulations shall be met.

① From 65° to 75° - Ventilation only (no cooling or heating).

② From 10° to 65° - Heating only to be supplied

③ Cooling design point

④ Heating design point

⑤ From 75° to 90° - Cooling and humidity control.

4.3.4 Exterior and Interior Noise

Verification of compliance with external and internal noise requirements was undertaken by Boeing engineers at the Boeing Surface Transportation Test Facility (STTF). Requirements and test results are compared below.

TABLE 4.31: NOISE REQUIREMENTS AND TEST RESULTS BY BOEING[3]

	Requirement	Test Results
External (in station 3 ft. from vehicle)	70 dBA	70 dBA
External (during vehicle passing at 30 mph at distance of 25 ft.)	70 dBA	71 dBA (STTF test track with no guideway structure)
Internal		
Noise Level	70 dBA	78 dBA
SIL	65 dB	72 dB

Compliance with external noise-level requirements was confirmed through an agreement between Boeing and the DOT Office of Noise Abatement.[13] This agreement stipulated that the 71 dBA measured along the at-grade guideway at STTF with no side structure satisfies a 70 dBA noise level at Morgantown where there are side structures or elevated guideways.

There were difficulties in complying with the internal noise-level specifications. The major causes for exceeding specifications for internal noise levels were the hydraulic system and the environmental control unit (ECU). Installing an acoustic filter in the air return to the ECU and an acoustic blanket under the vehicle floor to reduce hydraulic pump noise resulted in a reduction of approximately 4 dBA while the vehicle was parked in the station. These modifications did not significantly reduce noise levels at guideway speeds due to road-tire and drive-train noise which increased to levels that masked any improvement in the ECU and hydraulic pump noise levels. Boeing officials requested a performance waiver, reasoning that:

- o Installation of the ECU acoustic filter and acoustically soft interior cause space encroachment in the module working in opposition to other desired module design features;
- o An opinion poll conducted with 15 riders made up of the WVU President's staff and the WVU Student Council perceived no difference (all but one) in noise levels between having the hydraulic pump acoustic blanket and the ECU acoustic filter installed and then removed; and
- o Normal conversation would not be strained.

UMTA and WVU approved the requested waiver.

On April 6, 7, and 8, 1977, the assessment team made noise measurements* of the Morgantown system to obtain noise data on the operational system. Using the same instrument, personnel and procedures, additional noise measurement samples were taken aboard other transportation vehicles, including a Washington Metro car, a Flexible transit bus, and a typical family car (1971 Ford station wagon) to obtain a basis for comparison.

The randomly obtained data on the MPM vehicles were categorized as follows:

- o Vehicle exterior noise
  - -- At-grade guideway, non-reflecting surrounding, at 25 feet from center line, northbound lane
  - -- At-grade guideway, non-reflecting surrounding, at 25 feet from center line, southbound lane
  - -- Elevated guideway, non-reflecting surrounding, at 25 feet from center line
  - -- Elevated guideway, directly underneath centerline.
- o Vehicle interior noise
  - -- Standing in station, zero velocity
  - -- Cruise 15 mph with handgrip poles rattling
  - -- Cruise 30 mph with handgrip poles rattling
  - -- Cruise 15 mph with handgrip poles not rattling
  - -- Cruise 30 mph with handgrip poles not rattling

*Measured with Brüel & Kjoer Model 2203 with octave filter set type 1613, SN 123663, in accordance with Boeing, General Specification for Performance Design and Qualification for the Morgantown Operational Personal Rapid Transit System, SS191-90000-3C, 11-6-73, p. 48.

External noise was measured in a non-reflecting environment along the guideway, 25 feet from center line, during the passage of vehicles traveling at cruise speed. Procedures used were those set forth in the General Specification for Performance/Design and Qualification for the Morgantown Operational Personal Rapid Transit System[3] and, therefore, allowed comparisons with test results obtained by Boeing personnel.

The A-weighted mean values for external noise emission as measured by the assessment team along the guideway at Morgantown were:

TABLE 4.32: MEASURED EXTERIOR NOISE

Location		Ambient (dBA)	Emission (dBA)
At-grade guideway	25 feet from center line	55	71
Elevated guideway	25 feet from center line	52	73
	Underneath center line (approximately 12 feet)	53	77

An analysis of the sample data having a 95-percent confidence level showed that there is no significant difference between the noise emissions measured 25-feet from the center line of the elevated guideway and the at-grade guideway. The noise-emission levels measured under the elevated guideway are significantly higher than in the other positions as illustrated in Figure 4.34.

Interior noise in the MPM vehicles was measured approximately four feet above the floor at positions toward the center of the vehicle -- once in the forward section and once in the rear section where the air conditioning unit is located. No passengers were aboard except for the three persons making the measurements. Figure 4.35 shows the noise levels measured in decibels (dB) in randomly selected vehicles over the octave band center frequencies. All levels lay in a fairly narrow band except some very few "chance" points as can be expected. Emissions from standing vehicles begin to deviate from cruising vehicles only at the lower frequencies of 125 Hz and less. Interior noise levels for vehicles traveling at maximum velocity (30 mph) are slightly higher than for vehicles traveling at 15 mph (Figure 4.36).

The preferred speech interference level (PSIL) of 69 dB resulting from the mean sound pressure level requires a raised voice in order to communicate a distance of three feet. A very loud voice is required at distances greater than three feet, as can be seen from Figure 4.37.

One isolated source of noise found in most vehicles were rattling handgrip poles. An analysis of variance of the randomly obtained, weighted noise measurements in vehicles was made with handgrip poles rattling and not rattling. The results revealed that the noise levels are significantly raised where these poles are loose, with ranges from 73.9 dBA to 77.3 dBA.

Since interior noise data were sampled from other transporation vehicles besides the MPM vehicles, it is possible to make some comparisons. Measurement position was in the middle of the vehicle in the Washington Metro car, the Flxible bus, and above the front seat on the passenger side in the Ford station wagon. The Washington Metro cars were loaded to approximately one-third capacity, but passengers were quiet, not talking or shuffling. Figure 4.38 shows that the interior levels of the Washington Metro, a Flxible bus at average speed of 10 mph and a 1971 Ford station wagon at 30 mph are all below the interior of the MPM vehicle. There is one exception where the level in the Washington Metro car rises slightly above the vehicle measurements at octave band center frequencies of 2000 Hz and 4000 Hz. This condition occurs only while the Washington Metro cars are inside tunnels; all interior noise values for the Metro cars outside tunnels do not exceed the Morgantown readings. Figure 4.39 illustrates how the A-weighted measurements for interior noise levels compare for the above vehicles once while driving and once at zero velocity. In both cases the Morgantown vehicle registered the highest interior noise levels.

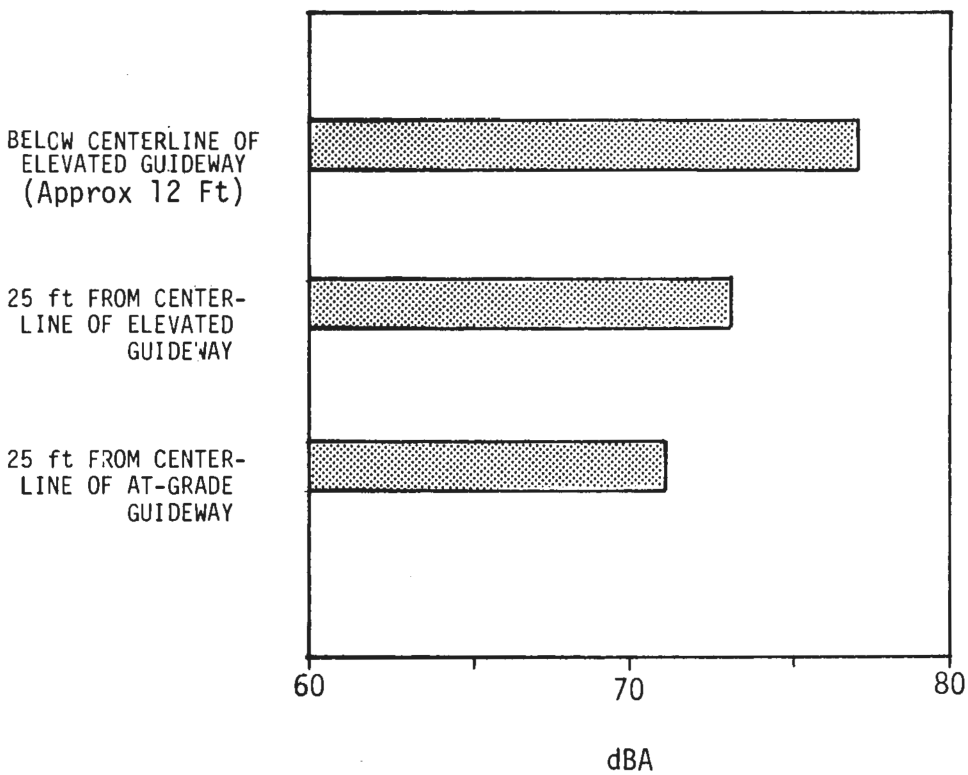


FIGURE 4.34: EXTERIOR NOISE FROM MPM VEHICLE

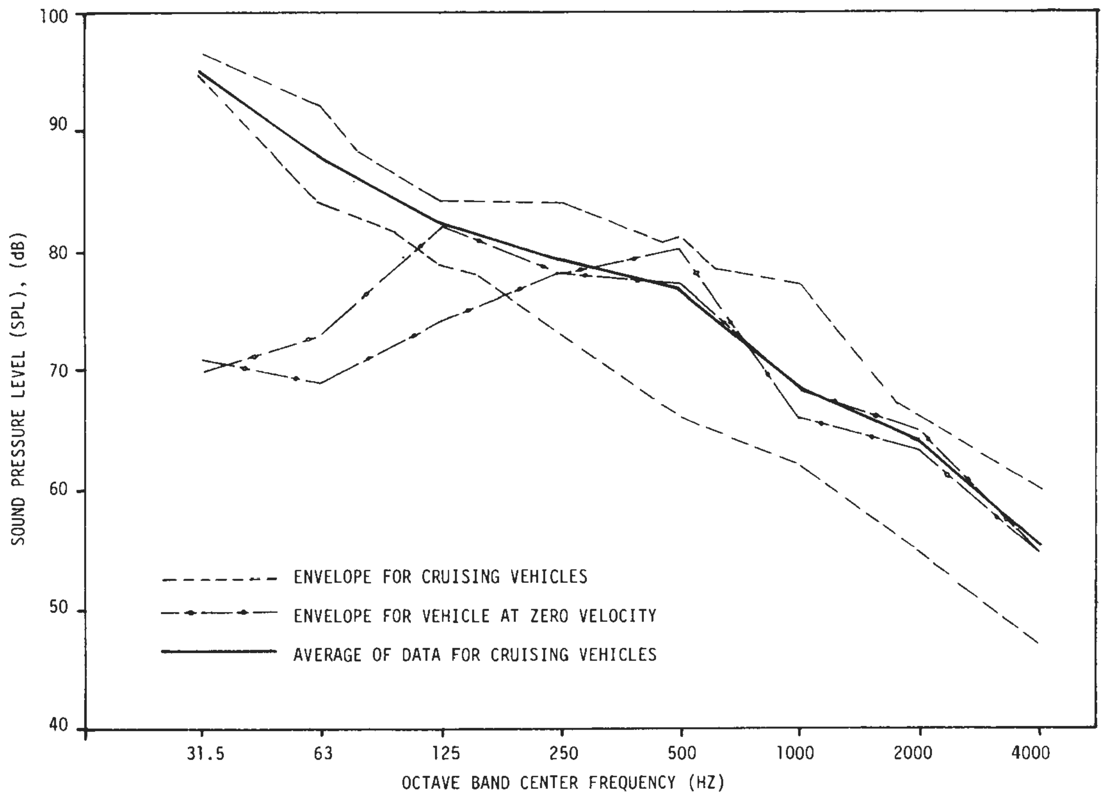


FIGURE 4.35 : INTERIOR NOISE IN RANDOMLY SELECTED VEHICLES AT VARIOUS SPEEDS AND CONDITIONS

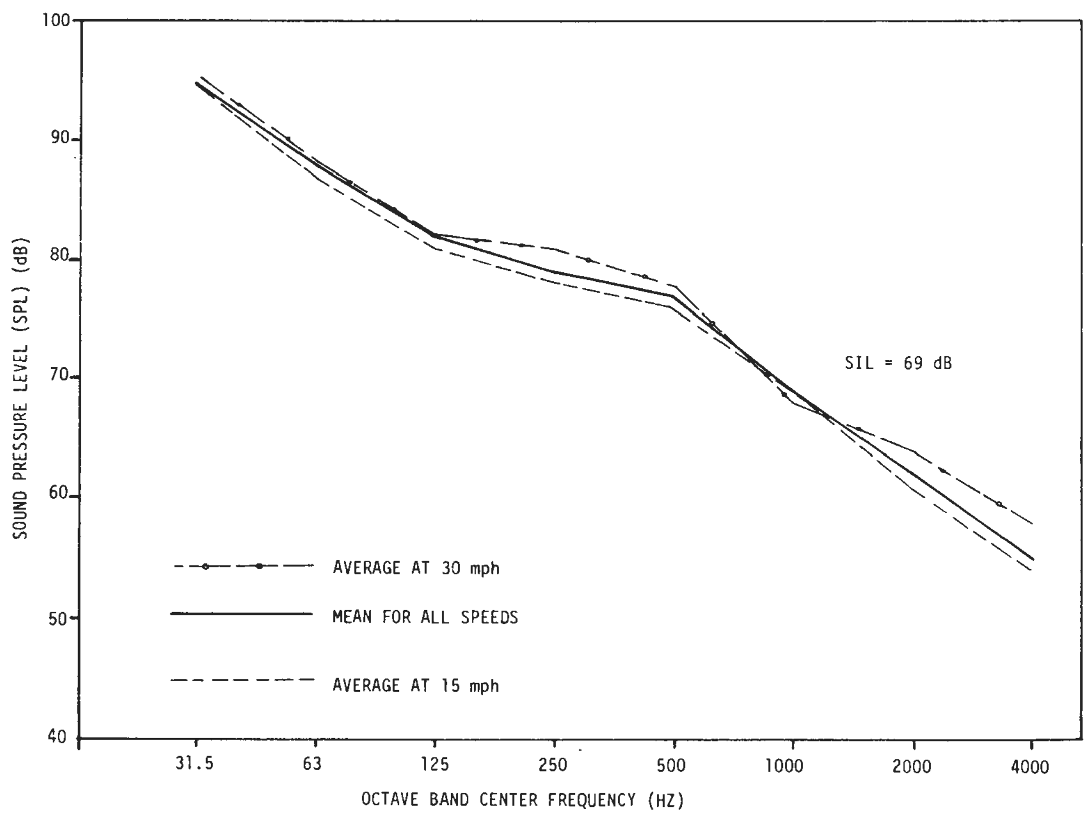
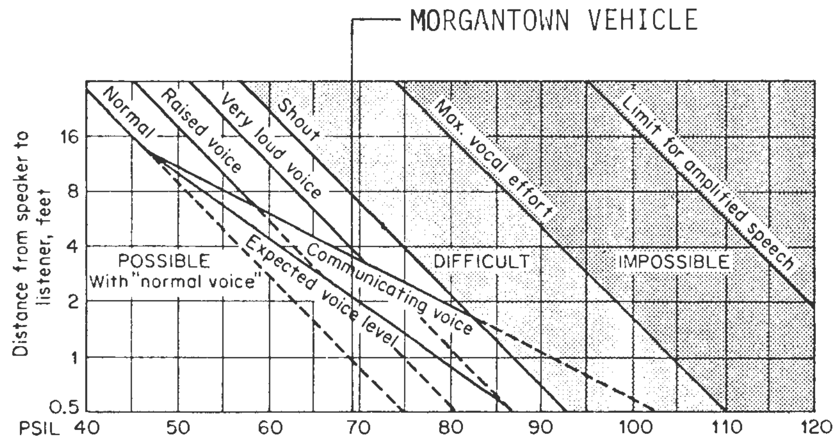


FIGURE 4.36 : AVERAGE VALUES OF NOISE INTERIOR TO MORGANTOWN VEHICLES



Source: Peterson, A.P.G. and Gross, E.E., Handbook of Noise Measurements, Seventh Edition, 1972, General Radio Company, Concord, MA.

FIGURE 4.37: VOICE LEVEL AND DISTANCE BETWEEN TALKER AND LISTENER VS. AMBIENT NOISE LEVEL

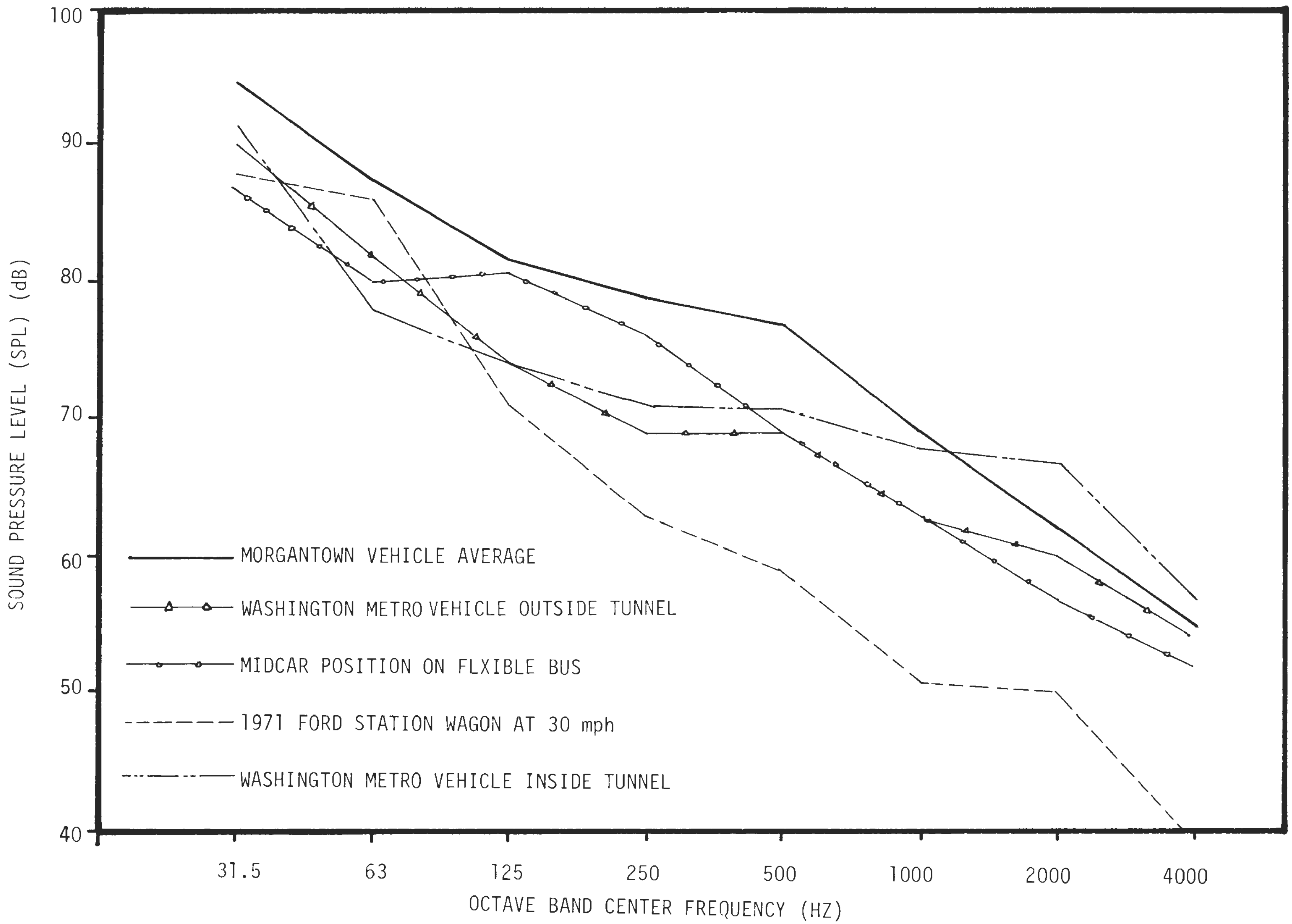


FIGURE 4.38 : COMPARISON OF INTERIOR NOISE FOR DIFFERENT TRANSIT VEHICLES

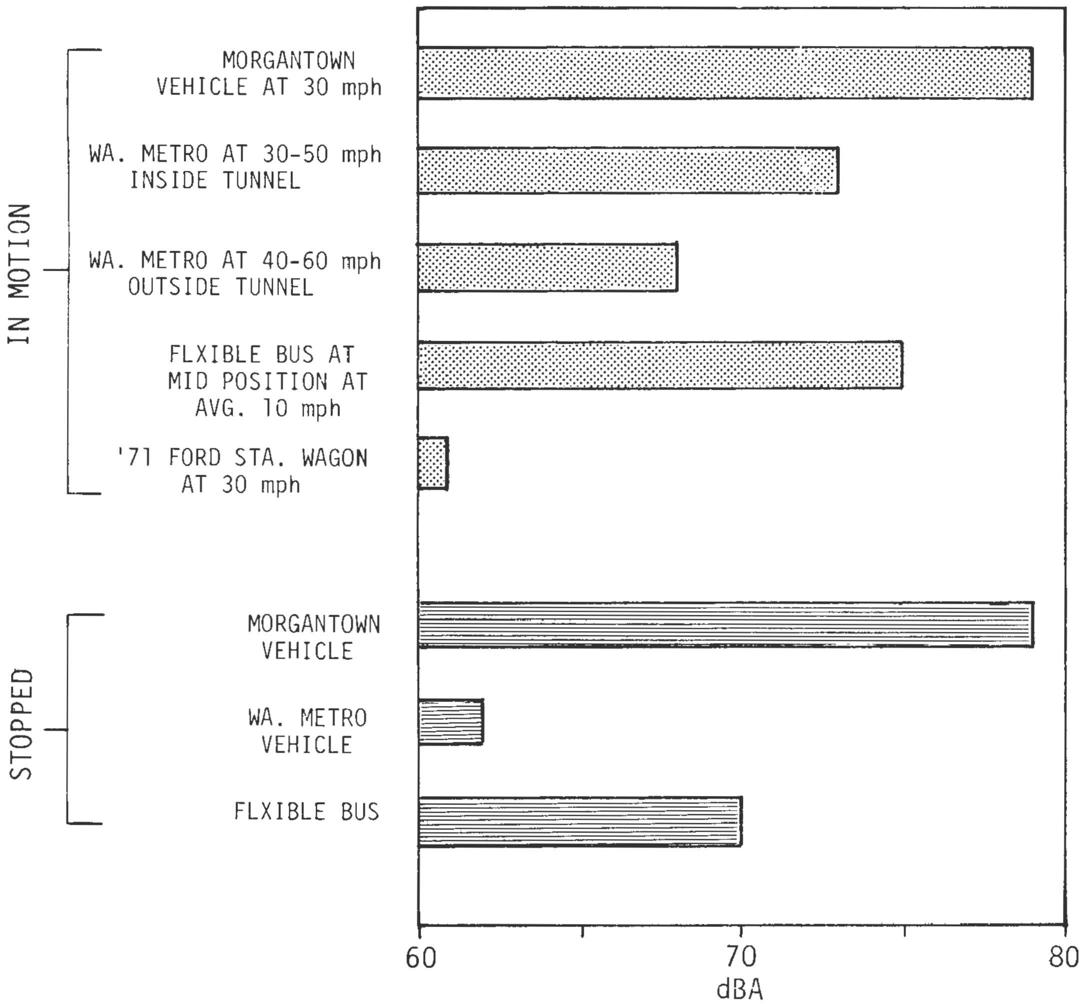


FIGURE 4.39: COMPARISON OF INTERIOR NOISE (dBA) FOR DIFFERENT TRANSIT VEHICLES

The interior noise levels for the MPM vehicles, while not particularly objectionable, are higher than is usually experienced with other transit vehicles. An SIL level of 65dB, originally specified for the MPM vehicles, ensures easy face-to-face communication of up to three feet with normal voice levels. Application of long experience with standard automotive design practices, more careful selection of key components, and better location of the environmental control unit should make this goal obtainable, if it is considered worth the effort. Exterior noise levels found at the MPM system were found acceptable for the circumstances in which the system is used.

4.3.5 Accessibility by the Elderly and Handicapped

Section 16 of the Urban Mass Transportation Act, added on October 15, 1970, declared it to be the national policy that elderly and handicapped persons have the same rights as other persons to utilize mass transportation facilities and services. Section 12 of the Act defines a "handicapped person" as any individual who, by reason of illness, injury, age, congenital malfunction, or other permanent or temporary incapacity or disability, including any person who is wheelchair bound or has semiambulatory capabilities, is unable without special facilities or special planning or design to utilize mass transportation facilities and services effectively.

Section 504 of the Rehabilitation Act of 1973 states: "No otherwise qualified handicapped individual ... shall solely, by reason of his handicap, be excluded from the participation in, be denied the benefits of, or be subjected to discrimination under any program or activity receiving federal assistance." DOT circulated proposed regulations to implement these requirements on June 8, 1978 and published its regulations as 49 CFR Part 27 in the Federal Register for May 31, 1979 (Vol. 44, No. 106).

The Morgantown People Mover (MPM) system of West Virginia University (WVU) should not be considered a model with which to assess how transportation requirements of elderly and handicapped (E&H) patrons can be met. Preliminary engineering of the system was underway at about the time Section 16 was added to the Urban Mass Transportation Act. Phase IA of the system, including most of the facilities construction, was complete when the Rehabilitation Act became Federal law. At the time the MPM system was being designed and built, there were no guidelines defining mandatory accessibility requirements for E&H patrons or public transit systems. Nevertheless, UMTA and WVU officials recognized the obligation to insure that the system built at Morgantown would not preclude eventual use by those with mobility limitations.

Other circumstances at Morgantown warrant consideration of the environment for E&H accessibility. In general, WVU has a young, physically able population. The hilly terrain and remote separation of the three campuses does not entice students whose mobility is impaired. During the 1977-78 academic year, there were slightly more than 150 students at WVU with a variety of physical disabilities. Of these, only two students required the use of wheelchairs. With an enrollment of over 15,000 students, the handicapped comprise less than one percent of the university population. Students who use wheelchairs represent only 0.01 percent of the enrollment. For these students, getting to and from university facilities with long flights of stairs and steep sidewalks, can be as large a problem as access to and access within the MPM system.

In consideration of the circumstance discussed above, this assessment has concentrated only on those features of the Phase I MPM system which either provided for or inhibited use by the E&H, and the improvements that could be made. Phase II modifications and additions to correct accessibility problems have been identified, but not evaluated. The following sections present two different assessments. The first summarizes findings from an assessment of the system by the WVU Self-Study Committee for Nondiscrimination on Basis of Handicapped. The second section covers findings by the NDL assessment team, and reinforces many of the needs identified by the student group.

Findings of the WVU Self-Study Committee

In their assessment of transportation facilities for the handicapped, the committee considered the automobile to be the "present most cost efficient means of transporting individuals with mobility impairment." Nevertheless, "there is still a need to provide handicapped students transportation that is equivalent to that provided for non-handicapped students." The present fleet of buses are not fully accessible by the handicapped and "consideration definitely needs to be given to this factor (wheelchair accommodation) in the purchase or leasing of new buses."

Officials involved with the People Mover system have assured "that it will be fully accessible upon completion of Phase II. However, we need to insure that university transportation which connects with or supplements the PRT (the local name for the People Mover) is also accessible."

Recognizing that Phase II is to provide full accessibility by the handicapped, the committee made a number of recommendations based upon "sight visits" and "walk throughs" of the Phase I system. They also had a meeting on October 31, 1977, with the Chief Engineer for DMJM-PRT. At this meeting the Chief Engineer reviewed plans for Phase II modifications and noted that the Boeing Company was developing scenarios of possible problems and solutions involving use of the system by patrons with a complete spectrum of disabilities. It was the committee's understanding that the "solutions" would be incorporated in the final (Phase II) system. Recommendations made by the committee were as follows:

> "All five stations should have level or ramped approaches to the elevators that permit access to the loading platforms. Present and future ramps should be made 'non-skid' and conform to ANSI standards for slope, grade, and surface. Also, wheelchair parking should be available and integrated with the system.
>
> Since present plans call for elevators at all five stations to facilitate people in wheelchairs, the 'turnstile problem' is essentially eliminated. The elevators will also be available to people other than those in wheelchairs if their condition makes negotiating stairs difficult or impossible. Entrance to the elevator is gained by pushing an external button. Once on the elevator, the individual is monitored by a closed circuit TV camera and can communicate with 'central control' by a 'push-to-talk' telephone system. The individual is brought to the loading platform and directed to the proper car. (Continuous monitoring by TV is possible from the elevator to the car.) Egress is a simple reverse of the procedure.*
>
> Although this appears to be a workable solution, it seems rather cumbersome. Care must be exercised to insure proper and standardized location of control panels and buttons so that they can be reached by someone in a wheelchair. The 'touch to talk' system may also present problems for quadraplegics. (A voice-activated system would seem worth exploring.)
>
> Car destination is presently shown visually by a sign that lights up over the loading zone. This should be supplimented (sic) by an audio system that announces car destination.
>
> PRT cards should be punched, notched, or embossed in such a manner as to facilitate their use by the blind.

---

*Author's note: Actual elevator implementation is somewhat different, as described in the following subsection -- NDL Assessment Team Findings.

All buttons controls, signs, etc. should be standardized and Brailled when possible and pertinent.

Textured guide surface should be considered to facilitate the blind using the PRT.

Car access by wheelchair is possible by slight modification of the edge of the loading platform. However, there appears to be a possibility of the front swivel wheels of a wheelchair dropping into the slight opening between the platform and the car. This needs to be checked out. If necessary, further modification should be able to make the cars easily and safely accessible.

There appears to be a slight possibility for an electric shock hazard if a metal-tipped guide cane was accidently inserted between a car and the loading platform. Phase II modifications will eliminate this, but there is presently a need for this to be brought to the attention of the blind in their orientation session.

The problem of getting a person in a wheelchair or with other mobility limitations out of a PRT car in case of a breakdown or emergency was discussed, but not really answered except to say that they would have to be assisted from the car by other passengers if available and capable or by the PRT emergency personnel.

Communicating with the deaf in case of breakdown or emergency also poses a problem in the PRT cars as presently operating. A visual display of possible instructions, i.e., 'stay in car', 'leave car', etc. is suggested.

The restrooms shown in the PRT plans are presently designated for employees only. It is strongly suggested that they be constructed or modified to be accessible to the handicapped and be so designated.

The maintenance and control complex of the PRT can be made accessible by several minor modifications. This should be done as part of Phase II."

NDL Assessment Team Findings

For wheelchair patrons and those with marked walking disabilities the stairs at stations have been supplemented by elevators installed during Phase II. Space for elevators was included in the design and construction of existing Phase I stations. For those persons with minor walking disabilities, access may have been improved somewhat by reducing the height of stair risers and increasing the tread depth. This has also been pointed out as a feature that would be helpful to the able-bodied. Because of the hilly terrain there remains the problem of accessibility to the station which is outside the jurisdiction of organizations directly involved with the design and construction of Phase II.

Use of the elevators is controlled by the System Operator at the control center. A passenger desiring to use an elevator may request to do so via a special intercom at the entrance to the elevator. Since it will take longer to reach the MPM system by elevator, their use by regular passengers is not expected to be excessive or to impede the handicapped. This approach would also ease problems for those who find the turnstiles too narrow, such as obese persons, those carrying bulky articles or children, and persons on crutches.

After reaching the platform level, passengers can be viewed by the System Operator on closed-circuit television. This allows further assistance from the control center if required.

The Phase I turnstiles and destination selection procedures are deemed marginal, even for the able-bodied and experienced riders to use quickly. These turnstiles have been completely replaced in Phase II. Performance could be even further improved by better machine design which allows location of ticket slots and selection buttons by feel. Also the ticket (fare card) should be shaped and/or texture coded so that it can be inserted properly, with little thought or effort. Such ticket redesign should aid the E&H and able-bodied as well as speed entry to the system. The Phase II turnstiles are capable of accepting coins as well as fare cards.

Unprotected waiting platforms can be hazardous for the firm and infirm alike, especially when the floors are slippery with snow or ice; and there were many complaints from even robust passengers about the cold and wind in stormy weather. For Phase II, glass windscreens have been added to the Engineering station platforms and incorporated in the new Towers and Medical stations.

The type of platform railing installed in Phase I, with openings at the boarding areas, might be considered a problem for children, the blind, the careless, and possibly for the handicapped. For example, Figure 4.40 shows a small child playing on the platform fence. Just before this picture was taken she had swung around the fence corner, through the opening and onto the guideway side. These railings have been partially replaced by glass windscreens for Phase II, as described above, but the openings at the berthing areas remain. Platform doors which work in unison with the opening and closing of the vehicle doors is one method of controlling this problem, but could cause other problems. Texture coding and highly visible markings to warn of platform edges would at least be an improvement for those with sight deficiencies.

Audible signals and announcements for the arrival and departure of vehicles, as well as for the opening and closing of doors, would be an aid to the blind and probably for others, as well. WVU has added chimes to the boarding signs. The lighted boarding and destination signs (Figure 4.41) are barely adequate for MPM system users because they are relatively dim against a frequently bright background. Their placement high above departure gates, instead of at eye level, means that some new users may not even realize they exist. The need to continually monitor departure signs on opposite sides of the platform is also irksome.

The colors used with many of the signs might be changed to improve legibility for the color-blind. This change would apply primarily to the greens and reds on the passenger-direction signs. Generally, the context of the sign sufficiently indicates its meaning, but redundant codes are beneficial. It would seem that arrows pointing to entrances and exits or color-coded lines for passengers to follow would be advantageous. Station identification signs are missing or are not sufficiently conspicuous, either inside or outside the stations. This deficiency did not detract materially from the convenience of using the Phase I MPM system because it was simple and had few stations.

While the Phase I MPM system attempted to avoid barriers that would make the system inaccessible to E&H patrons, budget and time restraints precluded implementation of the elevators. When possible, improvements and corrections are being made in Phase II according to standards consistent with the new Federal sensitivity to this problem.

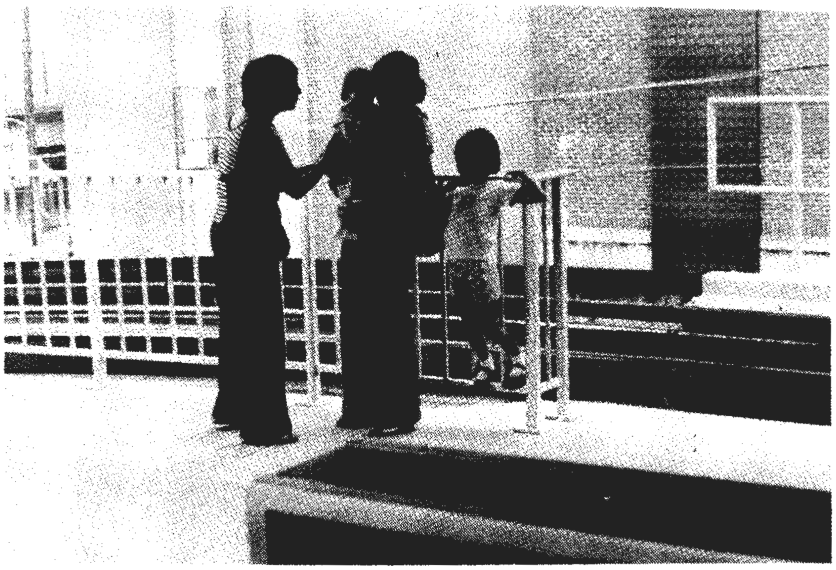


FIGURE 4.40 : SMALL CHILD PLAYING ON PLATFORM BARRICADE

FIGURE 4.41 : HARD TO READ BOARDING SIGN

4.4 PUBLIC ACCEPTANCE SURVEY

During the period April 23 through May 5, 1977, Century Research Corporation, under subcontract to N. D. Lea & Associates, Inc., surveyed public reaction to the MPM system. The following summarizes the results of that survey. The detailed results and discussions have been submitted to UMTA as a separate report.

At the time of the survey the Phase I system had been in operation for only 20 months. Many of the students riding the system were at West Virginia University during the first year demonstration period when reliability was low. Therefore, the results of the survey may be considered somewhat biased by the lingering memories of unfortunate experiences in using the system. The results derived from this survey are interim judgements which yield insight into how attitudes might evolve in an urban installation which is built in stages. Final attitudinal judgment cannot be made at this time for a number of reasons. First, the system was not complete and had not yet matured in its reliability; second, the Phase II expansion will provide greater accessibility to a larger area; third, there is a four year cycle over which the majority of the riders will change so that a completed and mature system will have a ridership who have not experienced the early operational difficulties; and fourth, a number of improvements are being made in Phase II.

The purpose of the survey was to determine levels of public acceptance of the Phase I system, what people liked and disliked about it, and why they did or did not ride it. The survey was also intended to help understand factors important for gaining public acceptance of AGT in other urban areas. The research was to investigate the issues concerned with: comfort, convenience, accessibility, cost, safety and security and aesthetics as perceived by the respondents. The survey gave an insight into the extent these perceptions promote or retard ridership.

It was recognized that the Morgantown case did not ideally characterize a typical urban situation because the system was not yet complete and it was deployed to serve the students of a university rather than to serve a general urban population. If some prevailing faults were found at Morgantown that tended to discourage its maximum use, it is reasonable to expect that these faults would detract from the use of AGT by the general public, anywhere. Conversely, if features were identified which enhanced acceptance and use, these same features could appeal to potential AGT users in other cities.

The vehicles, the guideway, the command and control system, and the stations were the chief components of the system evaluated. Some attention was given to the reasons for using the system and to other means of transportation used in conjunction with or instead of it, but these factors were not explored intensively. Automobile parking was not considered an integral part of the system, but perhaps should have been, as parking availability may influence use of the MPM system. Parking will definitely have an important influence on other AGT urban applications.

4.4.1 Survey Sample Size and Description

A total of 906 interviews were obtained, 673 riders and 233 non-riders. Only 384 responses would have been required to meet a 95 percent confidence level; therefore, the extra interviews enhanced confidence in the survey. A structured questionnaire was administered to the riders. A shorter questionnaire was administered to the non-riders in residences and businesses within one-half mile of each of the three stations. Non-riders were defined as persons who had never ridden the system or had not ridden it recently. Copies of both questionnaires are included in an appendix to this report. Riders were asked 26 questions and non-riders were asked nine questions. Seven of the questions appeared on both questionnaires. Demographic data were obtained from both groups for comparison purposes.

The riders were interviewed during the period April 26 through May 1, 1977, between 7:30 a.m. and 8:30 p.m. The majority of the interviews took place on weekdays. Riders were selected at random as they alighted from vehicles onto the station platform. Non-riders were interviewed from May 1 through May 5, 1977. Interviewers were instructed to visit a home, store or office at each mid-block within assigned areas within one-half mile of each station. Since there was no systematic bias in this sampling method, the result was equivalent to random sampling.

Table 4.33 provides a summary description of riders and non-riders who responded to the survey. The typical rider respondent was a young male student whose permanent residence was located outside Morgantown, and whose family had a moderate income. About one-half the riders had a car available for their use in Morgantown. About one-half of the non-riders were young students probably living off-campus, while the other one-half consisted of a random mix of older residents of Morgantown. Three quarters of the non-riders had the use of a car in the city. About 40 percent of the riders drove their own car at least twice a week, while nearly 75 percent of the non-riders drove that often.

4.4.2 Survey Results

Figure 4.42 gives the percent of riders who have used the system for various purposes and the relative frequency of such trips. Since the system was designed primarily to provide transporation between the separated university campuses, it is not surprising that school-connected uses predominate. Of the respondents 82.6 percent used the system either occasionally or frequently to go to classes, and 71 percent used it to change classes. Uses for personal business (64 percent) and social-recreational purposes (55.5 percent) were also high, since the system connects the University with Morgantown's central business district. However, only 14.4 percent and 11.5 percent said they used the system frequently for these purposes. Of those interviewed 38.1 percent used the system to go shopping, 6.4 percent frequently. Only 16.5 percent of the riders have taken the system to jobs, 10.5 percent frequently.

Overall, most riders and non-riders considered the system to be satisfactory (Figure 4.43). Both riders and non-riders were asked to rate the MPM system on a one-to-five scale from "very unsatisfactory" to "very satisfactory". More than 80 percent of riders rated the MPM as adequate or better (ratings 3, 4, and 5), while only 1.6 percent of riders gave the system the lowest rating (1), 15 percent of non-riders called the system very unsatisfactory. Very few riders surveyed

TABLE 4.33: SUMMARY DESCRIPTION OF POPULATIONS INTERVIEWED

(percent)

Group	Age		
	Under 26	26-40	Over 40
Riders	85.0	10.6	3.3
Non-riders	50.6	24.0	24.0

	Sex	
	Male	Female
Riders	61.2	38.8
Non-riders	54.5	45.5

	Permanent Residence	
	Morgantown	Elsewhere
Riders	35.5	64.5
Non-riders	73.0	27.0

	Occupation			
	Faculty	Students	Staff	Other
Riders	1.9	87.7	3.1	7.1
Non-riders	9.0	41.2	3.8	51.0

	Family Income		
	Less than $10,000	$10,000- $30,000	More than $30,000
Riders	16.9	58.9	18.1
Non-riders	31.3	44.2	10.7

	Automobile Availability	
	Have	Have Not
Riders	49.6	50.4
Non-riders	76.4	23.6

	Usual Travel Modes (at least twice a week)				
	Car	Carpool	Bus	Taxi	Other*
Riders	39.7	10.4	17.7	3.4	62.0
Non-riders	73.8	6.4	11.2	1.7	32.2

* Other modes given were: MPM, Walk, Hitchhike, Bicycle, or Motorcycle and miscellaneous other.

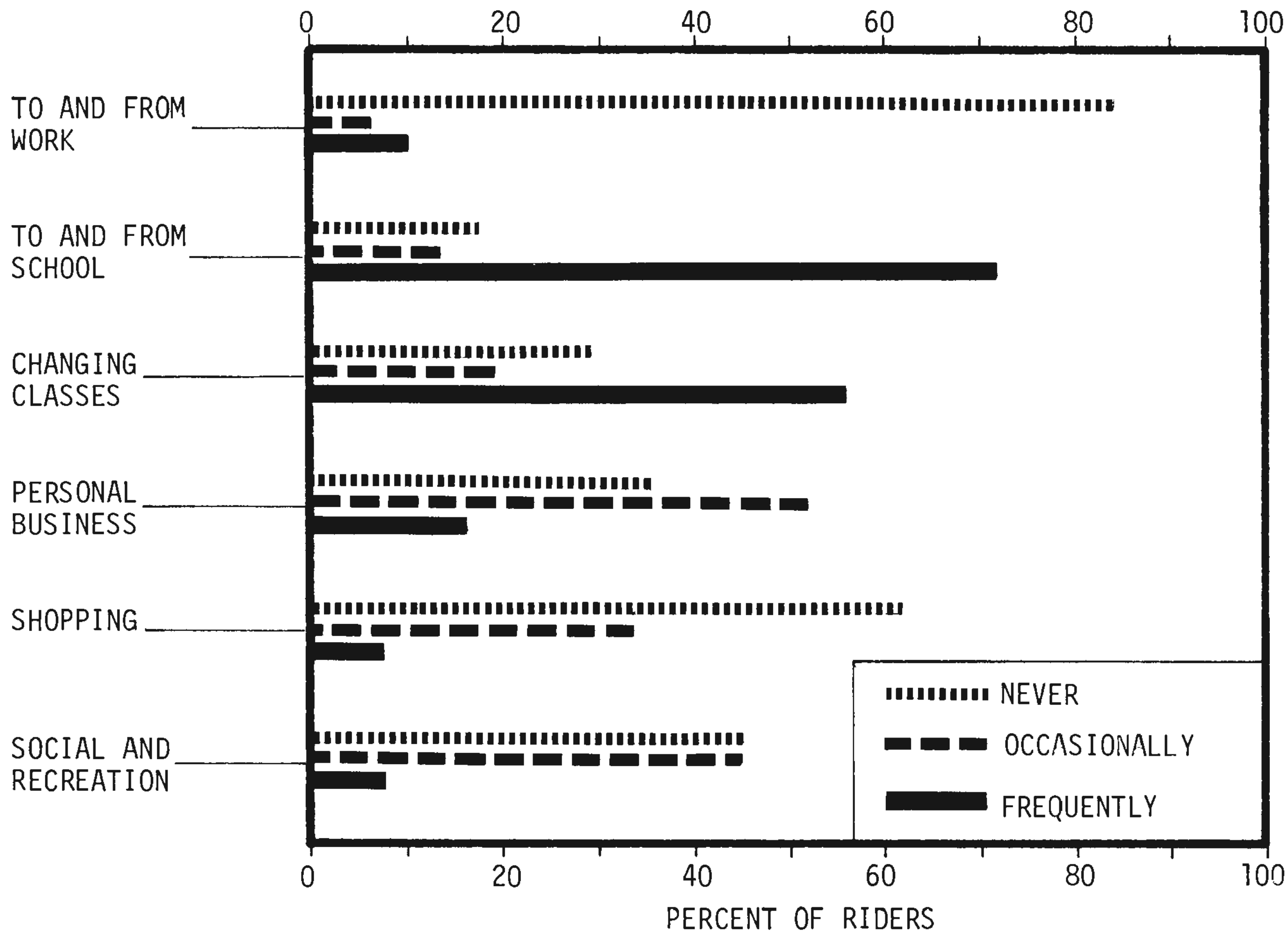


FIGURE 4.42 : PERCENT OF RIDERS USING SYSTEM FOR VARIOUS PURPOSES AND FREQUENCY OF USE

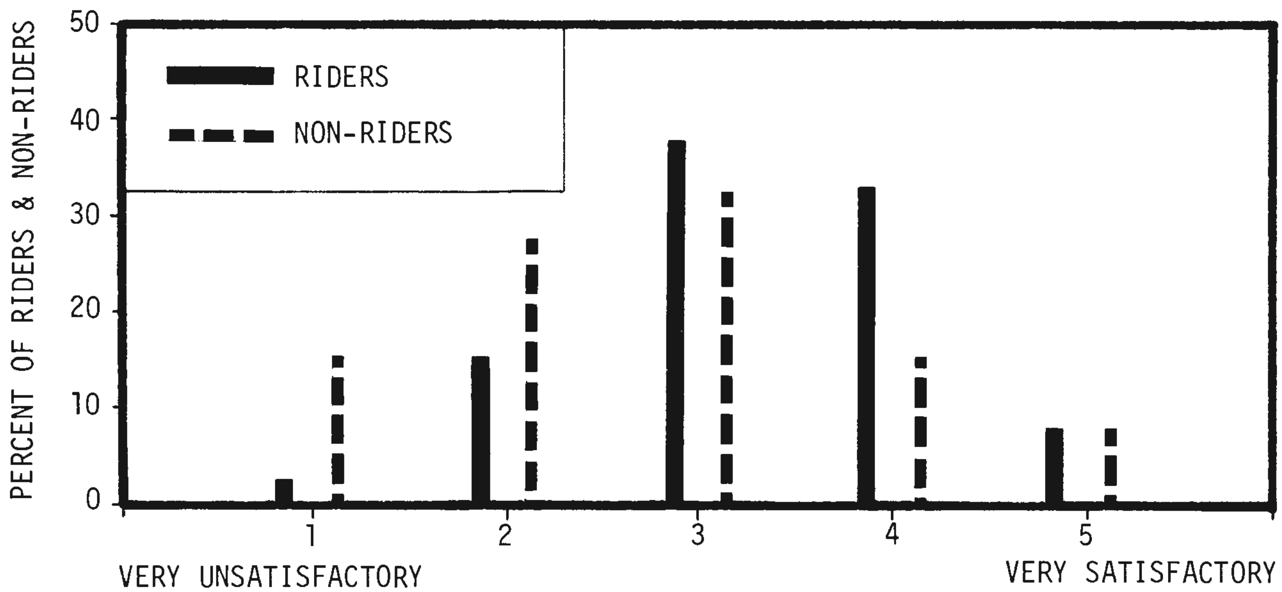


FIGURE 4.43 : OVERALL SYSTEM RATING

revealed deep-seated objections to the system, while more non-riders did so. Non-riding students objected especially to the university policy that requires all students to purchase semester passes, regardless of their need or desire to use the system. Both riders and non-riders often remarked that the project cost too much to build, but this probably affected the ratings of non-riders most, since they derive no direct benefit from its existence.

Other frequent comments were that the stations were cold and drafty during inclement weather, and that delays and stoppages continued to cause annoyance among riders.

The overall ratings by riders were compared with the frequency of use (Table 4.34). The number of times a person had ridden the system did not appear to make any difference in the overall rating when the two unsatisfactory ratings (1 and 2) were combined, and when the two satisfactory ratings (4 and 5) were combined. However, almost 70 percent of those who had ridden the MPM only once or twice gave the system a rating of five, and 12.5 percent gave it a rating of one. The opinions of the most experienced riders (more than 10 riders) were less extreme, with 8.7 percent giving the system a rating of five and 3.1 percent giving it a rating of one.

TABLE 4.34: OVERALL RATINGS BY RIDERS IN RELATION TO FREQUENCY OF USE

	Number of Times Ridden			
Overall Rating Subjective (Numerical)	1-2	3-4	5-10	Over 10
Unsatisfactory (1 or 2)	25.0	13.3	22.3	18.5
Adequate (3)	29.2	33.3	38.8	38.0
Satisfactory (4 or 5)	45.8	53.4	38.9	43.5

The results related to specific issues and concerns are summarized in the following paragraphs.

Comfort

There were no serious objections to comfort aboard the vehicles, as shown in Figure 4.44. However, significant unfavorable responses were made in regard to ride quality and platform crowding. Figure 4.45 compares rider responses with regard to vehicle layout, size and seating preference. The vehicle layout was adequate or very satisfactory according to 86.6 percent. One-half the riders did not appear to care in which direction they sat, reinforcing the notion that the layout of the vehicle is satisfactory. There were, however, write-in responses complaining over a lack of adequate leg room.

Non-riders were asked if they thought that the MPM would be too crowded for comfort, and 92 percent did not think so. They were also asked if they thought the ride would be more uncomfortable than is generally acceptable to them and 98.3 percent thought it would not be. In general both riders and non-riders appeared to be satisfied with vehicle comfort. No data were obtained which could assess whether this same degree of satisfaction with vehicle comfort would prevail as to longer trips.

Riders were asked to rate certain station amenities on a scale from one to five, where an item rated four or five was considered "very much" desired. Over 50 percent very much wanted trash containers, heating and schedules in the stations and over 40 percent wanted seats, drinking fountains and bulletin boards. About 30 percent desired rest rooms and slightly over 25 percent would like air conditioning. Write-in responses indicated that side shelter from the weather while waiting on the platform was highly desired, which correlates with 65 percent who very much wanted heated platforms.

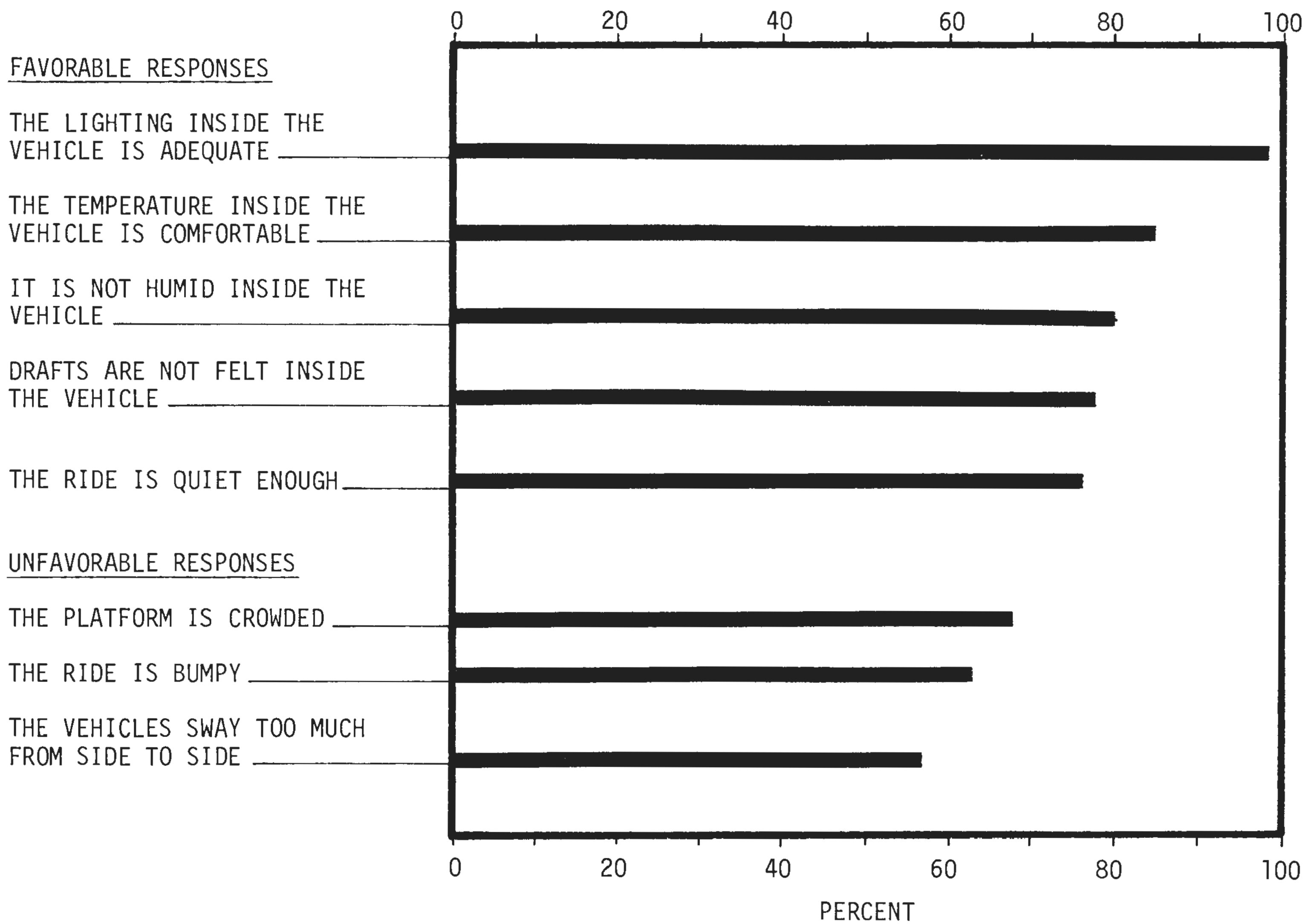


FIGURE 4.44 : RIDER OPINIONS REGARDING COMFORT

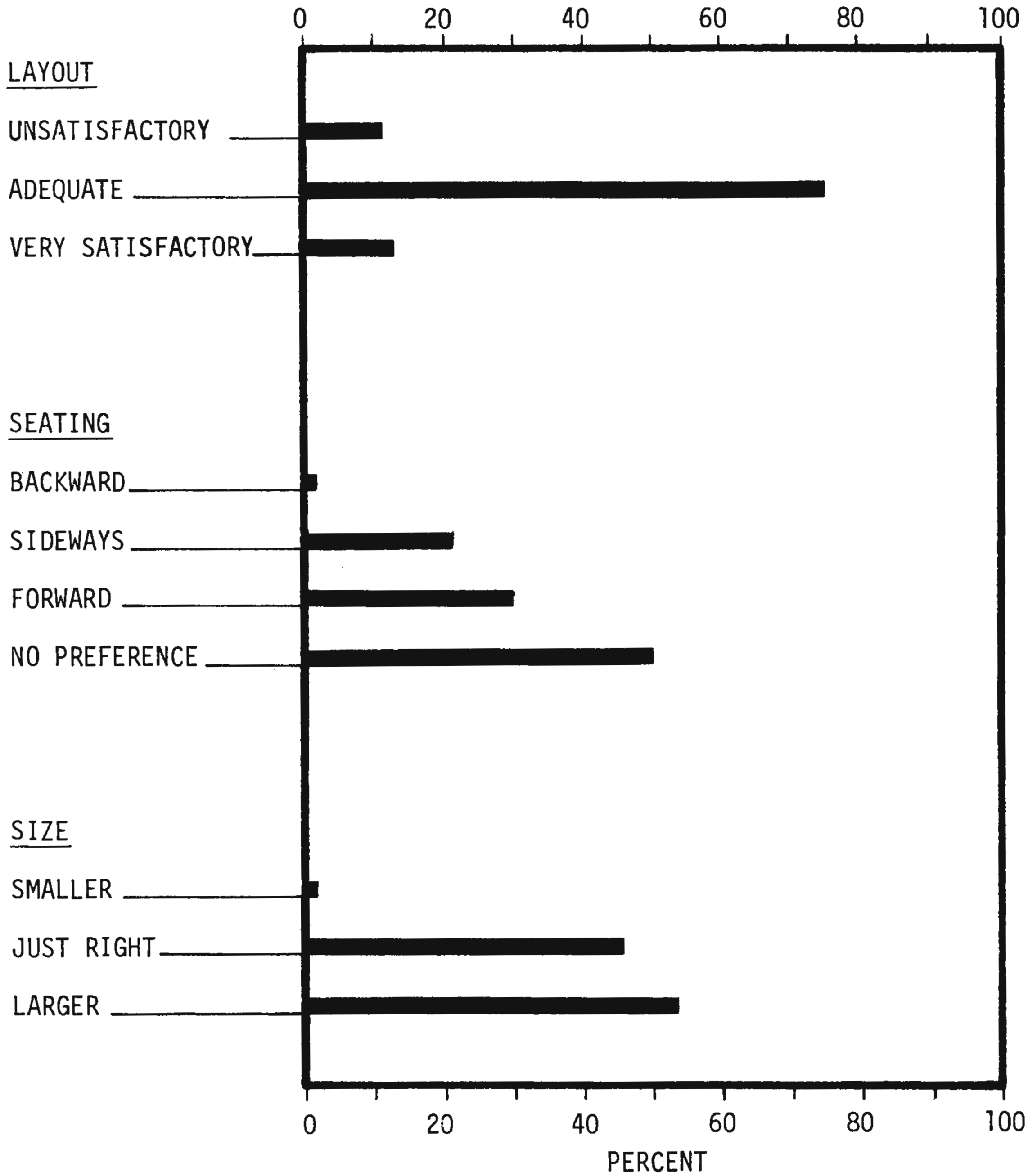


FIGURE 4.45 : RIDER OPINIONS ON VEHICLE LAYOUT, SEATING AND SIZE

Convenience

The most frequent criticism of the system was its unreliability. Most riders had experienced the inconvenience of frequent system failures and delays that caused them to be late for classes. However, much of this criticism is believed to have referred to breakdowns during the first year of operation. Delays, system downtime and excessive waiting time had been greatly reduced by the time of the survey.

In answer to the question "How often have you had to wait longer than you thought reasonable?", 28 percent said "very often", 51 percent said "sometimes" and 21 percent said "very rarely". About one-half of those who rode the system frequently thought that "sometimes" they had to wait an unreasonable length of time. Income level and automobile availability did not appear to make any difference with respect to their answers about waiting time. It is important to note that write-in responses and conversations with riders indicated that some included system downtime as a part of waiting time.

Non-riders were also asked how they perceived waiting time; 26.3 percent gave "waiting too long" as a reason for not riding. It is interesting to note that this response was more critical as income inceased: 20.5 percent for incomes less than $10,000, 24.5 percent for incomes of $10,000 to $29,000, and 40 percent where incomes are greater than $30,000. Also, younger non-riders were more critical of waiting time, listing "waiting too long" as reason for not riding: 41 percent aged 25 years or under, 16.1 percent aged 26-40 years, and 7.1 percent aged over 40 years.

In regard to vehicle speed, about two-thirds of the riders consider the speed is about right and 27 percent said it was too slow. Only 1.5 percent said it was too fast. Speeding up the vehicles appeared to satisfy only the younger riders.

Accessibility

Riders and non-riders responded almost the same with respect to the distance they would walk to the station. A quarter of a mile was generally regarded as acceptable to 68.7 percent of riders and 73 percent of non-riders. Distances of one-half mile would be walked by about 21 percent of both groups. Only about 10 percent said they would walk more than one-half mile to a station.

The most frequent reason given by non-riders for not using the system was that they simply had no reason to travel where the system runs. Non-riders giving this as the reason were: faculty and staff -- 100 percent; students -- 80 percent; other -- 82.4 percent.

Fares

Most respondents thought fares of 25¢ per ride and $15.00 for a semester pass were not excessive, but there were some objections to the University policy that all students must purchase a semester pass. About 40 percent of both riders and non-riders considered the present 25¢ fare to be reasonable. Only 5.9 percent of riders though one-way fares in excess of 25¢ were reasonable while 18.5 percent of non-riders thought so. On weekly fares, 69.1 percent of riders and 58.4 percent of non-riders believed these fares should be $2.00 or less. Weekly fares in the range of $2.01 to $3.00 were considered acceptable to 15.8 percent of the riders and 24.9 percent of non-riders.

Semester passes less than $20.00 were considered reasonable by 64.9 percent of riders and 78.9 percent of non-riders. As many as 17.5 percent of riders and 11.1 percent of non-riders considered that a semester pass in the range of $20.00 to $30.00 was reasonable.

Safety and Security

There were no serious objections to the apparent safety and security provided by the MPM system. Figure 4.46 gives the responses to various questions concerning any fears or worries that riders might have had in using the system. It is significant to note that all respondents "never" or "hardly ever" had such fears more than 50 percent of the time.

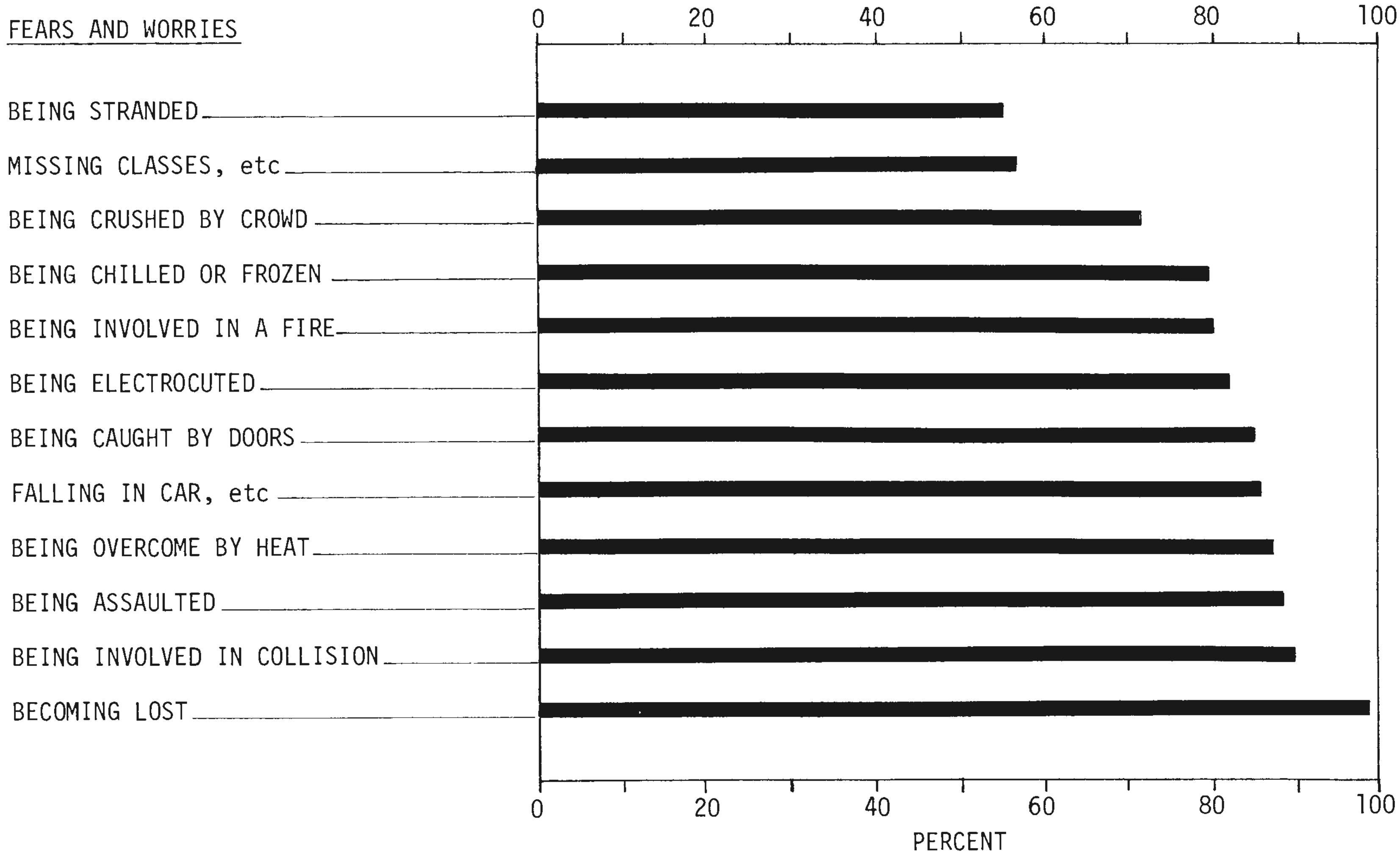


FIGURE 4.46 : RIDER RESPONSE OF "NEVER" OR "HARDLY EVER" HAD SUCH FEARS

It was found that 62.9 percent of the riders had experienced sudden stops or starts, but only 13.8 percent thought them to be serious. Riders were also asked to rate their confidence in coping with emergencies, such as being able to get out of doors, rear windows or off the guideway and in getting help. The majority of riders rated their confidence from medium to high, but the minority that gave a low confidence to handling emergencies was significantly large (21 percent). The 48 percent who had compunction about getting off the guideway probably reflected what would appear to be an actual difficulty due to the design of the guideway where few, if any, ladders or other egress devices are provided.

Responses that considered the vehicles mechanically unsafe or that riders might be molested or be made victims of a crime were negligible.

Aesthetics

The majority of riders found the appearance of the stations and guideway acceptable (approximately 70 percent). However, the minority who did not like the station architecture and considered the guideway to be obtrusive is sizeable, 27.5 percent and 34.9 percent respectively (Figure 4.47).

Respondents were asked their preference for guideway location and the reasons behind their preference. Only 10-15 percent wanted the guideway underground. The most frequent reasons was that "you wouldn't have to look at it", or "it would hide the mess". Another reason was to save ground level space for streets and traffic. Over one-half of the respondents preferred the guideway the way most of it has been built in Morgantown -- elevated. The primary reasons given were that it saves ground for other uses, especially traffic, and that it affords passengers a good view of the river and the town. Finally, 26 percent of riders and 16.7 percent of non-riders preferred a ground-level guideway because it was considered safer, as well as easier and less expensive to build.

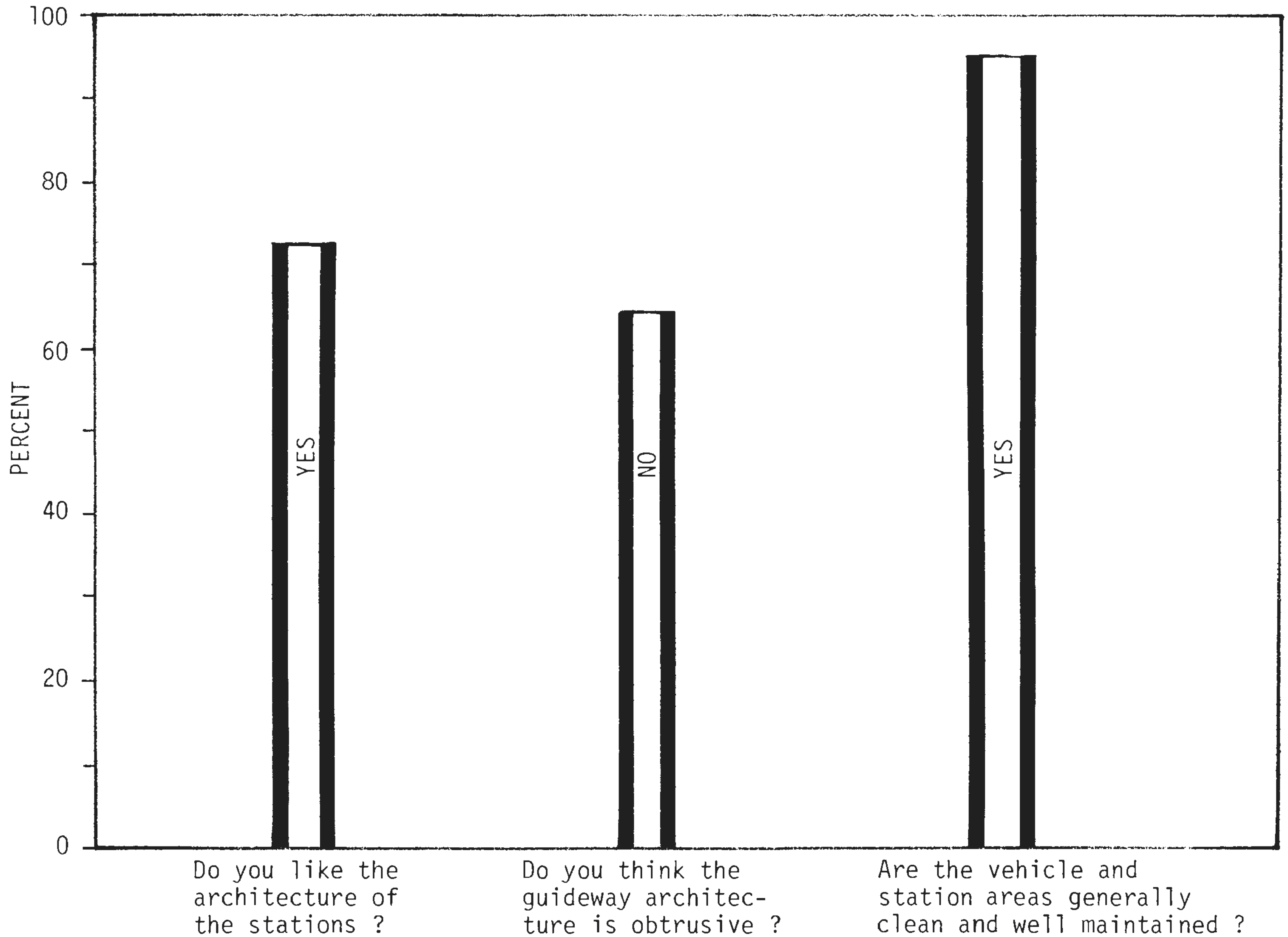


FIGURE 4.47 : PERCENT OF RIDERS GIVING FAVORABLE RESPONSES TO SYSTEM APPEARANCE

4.5 SAFETY AND SECURITY

This section describes and assesses system safety and security. It includes an analysis of all incidents reported during operations of the Phase I system.

4.5.1 Specifications

Paragraph 3.3.6.1 of the Phase I system specifications contained the following safety requirements:

> "3.3.6.1 Design Safety -- fatalities or serious injuries. The total probability of accidental fatality of passengers on AGT vehicles, authorized personnel on the guideway and on-duty system personnel shall be no greater than 1×10^{-4} (one in ten thousand) per operational day.
>
> The total probability of serious injuries of passengers on AGT vehicles, authorized personnel on the guideway, and on-duty system personnel shall be no greater than 5×10^{-2} (one in twenty) per operational day. A serious injury is as defined in Handbooks of Systems and Product Safety."

The following paragraph (3.3.6.2) of the specifications established a probability limit of 2.8×10^{-4} (one in 3,571) per operational day for serious accidents (property damage over $5,000 in 1972 dollars). Specification Change Notice 9-54 dated September 4, 1975, revises the serious injury probability from 5×10^{-2} (one in twenty) per operational day downward to 6×10^{-3} (one in 167) per operational day.

Expressed another way, these probabilities mean that the system fatality rate should not exceed one death for every 10,000 days or about 27 years of operation. This goal seems conservative and perhaps ambitious in light of other transit system experiences. The allowable "serious injury" rate equates to one serious injury every 167 operational days. Similarly, major damage should not occur more than once every 3,751 operational days, or every 10 years. It should be pointed out that these rates apply to all passengers, system operations personnel, and the system maintenance force.

The Product Assurance Plan initially characterized a "serious injury" as that which:

- o requires more than 48 hours of hospitalization within seven days of injury, or
- o involves lacerations which cause severe hemorrhages, nerve, muscle or tendon damage, or
- o involves injury to an internal organ, or
- o involves second or third degree burns, or any burns affecting more than five percent of the body surface.

This definition was modified when the rate was changed to 6×10^{-3} serious injuries per operational day.

4.5.2 Safety and Security Experience During Phase I Operations

This section summarizes and discusses the safety experience of the system during operations from October, 1975 through July, 1978. A review of all the "M-PRT Safety Reports" shows a total of 120 recorded incidents. Of these, 18 were security incidents which can affect intruders' safety if exposed to powered equipment, and 21 were safety incidents which were not system related. Security incidents involve intrusions of guideways or stations by persons or animals, some of which could have been avoided if coordinated platform/vehicle doors were in use. The 21 safety incidents involved parking lot accidents, employee accidents on the way to and from work (although not relevant to MPM proper), anomalies of auxiliary equipment, such as boilers, and non-system related accidents by maintenance vehicles on parking lots or public roads. For the sake of completeness all reports have been listed in Table 4.35.

Damage was classified as minor when replacement or repair was not immediately necessary (e.g., scratches or dents). Damage was considered moderate if replacement or repair was necessary which did not exceed the "serious accident" limitations but was substantial enough to cost several man-hours and caused several items to be replaced. An injury was classified as light if only first aid was required, such as flushing eyes, or letting the employee rest.

TABLE 4.35: SUMMARY OF SAFETY AND SECURITY INCIDENTS

Description	No. of Reports	Classification	Damage (1)	Damage (2)	Damage (3)	Damage (4)	Injury (1)	Injury (2)	Injury (3)	Injury (4)	Caused by (1)	Caused by (2)	Caused by (3)	Caused by (4)		System Related Yes	System Related No
Intrusion	20	SAF/SEC	20	-	-	-	20	-	-	-	-	-	15	4	1	20	-
Collision	23	SAF	17	4	2	-	23	-	-	-	3	15	4	-	1	23	-
Malfunction	37	SAF	20	8	9	-	37	-	-	-	1	32	4	-	1	34	3
Other Incidents	40	SAF	32	4	4	-	8	19	11	2	1	5	13	-	21	22	18
TOTAL	120		89	16	15	-	88	19	11	2	5	52	36	4	23	99	21

SAF - Safety related.

SEC - Security related, safety hazard to intruder may be involved.

DAMAGE - (1) = none; (2) = minor; (3) = moderate; (4) = major.

INJURY - (1) - none; (2) - light; (3) - moderate; (4) - serious.

CAUSED BY - (1) - human error; (2) equipment; (3) - negligence; (4) - malicious action; (5) - other.

If medical attention was necessary beyond rendering first aid, the injury was considered moderate. To be classified as a serious injury, the person either suffered broken bones, or required prolonged medical attention and, in either case, warranted the absence from the assigned duty in excess of two working days.

The causes of incidents were classified as follows:

- o Human error, if the person involved followed a procedure, but did not react quickly enough or thoroughly enough;
- o Malfunction, if equipment failed;
- o Negligence, if warning signs were ignored or if procedures and instructions were not followed;
- o Malicious, if warnings, procedures or instructions were purposefully ignored or violated.

The "other" category includes incidents which could not be assigned to one of the four groups, for example: an intrusion caused by a dog or an injury due to a snake bite.

Table 4.36 summarizes the intrusions into vehicles, stations or guideway which were reported to have been experienced by the system during Phase I operations. In all instances, the possibilty of electrocution or other serious accidents was prevented by the alertness of operators -- aided with television surveillance equipment -- and by other employees who telephoned the operators.

System surveillance consists of closed-circuit television in stations with monitors in central control, public address systems in stations and vehicles, telephones in stations, and a two-way radio system activated by push button which allows vehicle passengers to talk to the system operator. The system has helped to keep intrusions from becoming major accidents. System surveillance has also discouraged misuse of the system. For example, vehicles were dispatched to the nearest station or to the maintenance facility to resolve the following kinds of episodes:

- o Intoxicated students cruising the system.
- o Boys shouting obscenities over the vehicle emergency radio system.

TABLE 4.36: SUMMARY OF REPORTED INTRUSIONS

Description	No. of Reports	Classification	Damage (1)	Damage (2)	Damage (3)	Damage (4)	Injury (1)	Injury (2)	Injury (3)	Injury (4)	Caused by (1)	Caused by (2)	Caused by (3)	Caused by (4)	Caused by (5)	System Related Yes	System Related No
On Vehicle by Psgr.	1	SEC	1	-	-	-	1	-	-	-	-	-	1	-	-	1	-
On Station by Psgr.	4	SEC	4	-	-	-	4	-	-	-	-	-	-	4	-	4	-
On Guideway by Psgr.	12	SEC	12	-	-	-	12	-	-	-	-	-	12	-	-	12	-
On Guideway by Animal	1	SEC	1	-	-	-	1*	-	-	-	-	-	-	-	1	1	-
On Guideway by Employee	2	SAF	2	-	-	-	2	-	-	-	-	-	2	-	-	2	-
TOTAL	20		20	-	-	-	20	-	-	-	-	-	15	4	1	20	-

SAF - Safety related.

SEC - Security related, safety hazard to intruder may be involved.

DAMAGE - (1) - none; (2) - minor; (3) - moderate; (4) - major.

INJURY - (1) - none; (2) - light; (3) - moderate; (4) - serious.

CAUSED BY - (1) - human error; (2) equipment; (3) - negligence; (4) - malicious action; (5) - other.

*Dog was killed by a vehicle.

- o Girls insisting on bringing bicycles on board a vehicle, after being warned not to, by the operator.
- o A man, wearing a mask and brandishing a gun as he entered the vehicle, was reported by other passengers. The individual apprehended turned out to be an overzealous drama student using a toy gun to seek a reaction.

The surveillance system has served as a deterrent to further misuse, once miscreants learned that apprehension in captive vehicles was assured.

Table 4.37 is a breakdown of collisions occurring during Phase I operations. The vehicle-to-vehicle collisions occurred in stations where one vehicle was advancing between berths and collided with the next berthed vehicle. All of these collisions were very slow speed bumps where the impact was absorbed by the vehicle bumpers with the result that there were no damages or injuries. Vehicle-to-rail collisons resulted from malfunctions in steering mechanisms, which were caused mostly by cold weather. Malfunctions also occurred with retrieval equipment or inexperience or negligence of the retrieval crew. With the modifications being made in Phase II, most of these kinds of problems should not recur.

Table 4.38 summarizes the malfunctions which had the potential to cause damage or injury and were, therefore, reported in an incident report. Override plugs are used for test purposes or to disengage the hardwired portion of the CAS in disabled vehicle recovery operations. Leaving these plugs in during regular operations defeats the independent redundancy of the CAS. As part of a pre-operational check, the locations of these plugs is normally verified. A software routine has been established to cope with changes in vehicle identification when this occurs.

Steering malfunctions are similar to those which caused vehicle-to-rail collisions resulting from cold weather. Improvements are expected in Phase II which will eliminate these incidents. Fires, such as those reported in the incident reports on power rails, have been caused by arcing which results from high resistance between two conducting circuits. Phase II redesign of the power rail and vehicle collector has considered the prevention of this arcing.

TABLE 4.37: COLLISION SUMMARY

Description	No. of Reports	Classification	Damage (1)	Damage (2)	Damage (3)	Damage (4)	Injury (1)	Injury (2)	Injury (3)	Injury (4)	Caused by (1)	Caused by (2)	Caused by (3)	Caused by (4)	Caused by (5)	System Related Yes	System Related No
Vehicle to Vehicle	10	SAF	10	-	-	-	10	-	-	-	1	6	3	-	-	10	-
Vehicle to Rail	13	SAF	7	4	2	-	13	-	-	-	2	9	1	-	1	13	-
TOTAL	23		17	4	2	-	23	-	-	-	3	15	4	-	1	23	-

SAF - Safety related.

DAMAGE - (1) - none; (2) - minor; (3) - moderate; (4) - major.

INJURY - (1) - none; (2) - light; (3) - moderate; (4) - serious.

CAUSED BY - (1) - human error; (2) equipment; (3) - negligence; (4) - malicious action; (5) - other.

TABLE 4.38: SUMMARY OF SYSTEM MALFUNCTIONS

Description	No. of Reports	Classification	Damage (1)	Damage (2)	Damage (3)	Damage (4)	Injury (1)	Injury (2)	Injury (3)	Injury (4)	Caused by (1)	Caused by (2)	Caused by (3)	Caused by (4)	Caused by (5)	System Related Yes	System Related No
Override Plugs Not Removed	3	SAF	3	-	-	-	3	-	-	-	-	-	3	-	-	3	-
Boiler Anomalies	3	SAF	3	-	-	-	3	-	-	-	-	3	-	-	-	-	3
Vehicle ID Error	8	SAF	8	-	-	-	8	-	-	-	-	7	1	-	-	8	-
Misalignment of Vertical Points	1	SAF	1	-	-	-	1	-	-	-	1	-	-	-	-	1	-
Vehicle Failed to Steer	8	SAF	5	-	3	-	8	-	-	-	-	8	-	-	-	8	-
Power Rail Fire	11	SAF	-	5	6	-	11	-	-	-	-	11	-	-	-	11	-
Power Collector Fire	2	SAF	-	2	-	-	2	-	-	-	-	2	-	-	-	2	-
Equipment Room Fire	1	SAF	-	1	-	-	1	-	-	-	-	1	-	-	-	1	-
TOTAL	37		20	8	9	-	37	-	-	-	1	32	4	-	-	34	3

SAF - Safety related.

DAMAGE - (1) - none; (2) - minor; (3) - moderate; (4) - major.

INJURY - (1) - none; (2) - light; (3) - moderate; (4) - serious.

CAUSED BY - (1) - human error; (2) equipment; (3) - negligence; (4) - malicious action; (5) - other.

An assessment of injury reports (Table 4.39) shows three incidents involving passengers, none of which involved serious injuries. Two of these resulted in light injuries -- one to a hand (scratches) and one to a leg (swelling). In both cases the passenger was struck by a closing vehicle door. Although the doors functioned properly, the injuries occurred from abrasions against the door edge. Diagnosis of the hand injury found that the scratches were caused by rapid movement of the hand against the door edge. The leg injury was believed to have been caused when the door edge struck an area previously injured on the passenger's leg and the aggravation produced the swelling. The third passenger injury occurred when a passenger hurried to catch a vehicle and tripped in the station. This fall required ambulatory care. Incidents like falling in stations or passengers being struck by doors are common with other transit modes. (Prevention of such injuries is generally limited to caution signs.)

Several cases of employee eye and face injuries were caused when eye protection equipment was not worn. In four cases, injuries were not system related but were caused by either wind-borne particles or undetermined incidents away from the work place, followed by irritation during work. In two cases falls were the cause of injury, one attributable to a spill, the other to improperly carrying equipment and tripping. This latter case caused prolonged absence from work, since the injury required corrective surgery. The one snake bite has prompted employees working out-of-doors along the rights-of-way to be aware of this potential problem.

There was only one incident during Phase I in which a person was injured by a vehicle and this did not occur during passenger service. The injury was sustained by a system employee in the course of a routine maintenance action. The maintenance crew was manually moving vehicles from a Beechurst channel to a ramp to accomplish power rail maintenance. An operator on board the vehicle was unable to stop the vehicle while the crew was physically moving it into place behind another vehicle. A worker was caught between the two vehicles and was struck. He suffered a broken right collarbone and a bruised left knee. Slight damage occurred to the passenger modules of the two vehicles. The cause of the incident was believed to be either operator error or equipment malfunction. It was considered possible that the brake release failed to function due to rust in the

TABLE 4.39: SUMMARY OF REPORTED INJURIES

Description	No. of Reports	Classification	Damage (1)	Damage (2)	Damage (3)	Damage (4)	Injury (1)	Injury (2)	Injury (3)	Injury (4)	Caused by (1)	Caused by (2)	Caused by (3)	Caused by (4)	Caused by (5)	System Related Yes	System Related No
Passenger	3	SAF	3	-	-	-	-	2	1	-	-	-	-	-	3	3	-
Employee-Eye, Face	11	SAF	11	-	-	-	-	9	2	-	-	2	3	-	6	7	4
Employee-Falls, Legs	5	SAF	5	-	-	-	-	-	4	1	-	-	1	-	4	4	1
Employee-Hands	4	SAF	4	-	-	-	-	1	3	-	-	1	1	-	2	3	1
Employee-Snake Bite	1	SAF	1	-	-	-	-	1	-	-	-	-	-	-	1	1	-
Employee-Struck by Vehicle	1	SAF	-	1	-	-	-	-	-	1	-	-	-	-	1	1	-
Employee-Over Exposure	2	SAF	2	-	-	-	-	2	-	-	-	-	-	-	2	2	-
Employee-Office Work	3	SAF	3	-	-	-	-	3	-	-	-	-	-	-	3	-	3
Employee-On Way to Work	2	SAF	2	-	-	-	-	1	1	-	-	-	2	-	-	-	2
Employee-Electric Shock	1	SAF	1	-	-	-	1	-	-	-	-	1	-	-	-	-	1
TOTAL	33		32	1	-	-	1	19	11	2	-	5	7	-	21	21	12

SAF - Safety related.

DAMAGE - (1) - none; (2) - minor; (3) - moderate; (4) - major.

INJURY - (1) - none; (2) - light; (3) - moderate; (4) - serious.

CAUSED BY - (1) - human error; (2) equipment; (3) - negligence; (4) - malicious action; (5) - other.

parking brake piston or overpressurization of the caliper. As corrective action, the operators were cautioned against this possible hazard, gauges and longer hoses were added to the brake kit and an Interim Maintenance Instruction put into effect to check the entire fleet for the problem. This kind of accident is not rare in transit operations and can only be avoided through alertness and extreme caution. In guideway-based systems such an accident is difficult to escape because the guideway wall is an added obstacle in the escape route, which is not necessarily present in rail or bus systems.

Over exposure to extreme temperatures is a common occurence among track workers and requires awareness to the circumstances by employees and supervisory personnel. Outside work during extreme weather conditions demands shorter schedules with frequent rest periods and proper attire. Injuries to office workers and injuries on the way to work are much the same as in other businesses.

The one incident of exposure to electric shock was not system related, since this was caused by a faulty lawn mower -- no injury resulted.

As mentioned earlier, the category "other incidents" lists accidents which involved truck or car movements of employees in the parking lots or on public roads. One exception was an incident where a maintenance crew was manually moving a vehicle and due to inexperience struck a protective post at the maintenance facility entrance. Only this one latter incident is considered system related -- the others are listed for the sake of completeness only. However, incidents that occur, but which are not system related, give an indication of the kinds of occurrences which an AGT system operator has to deal with.

This summary of the Morgantown experience during Phase I suggests the kinds of system and non-system related incidents associated with a people-mover system. Vigilance on the part of operators and constant training of operations and maintenance personnel is essential, if these incidents are to be kept from growing into major accidents.

4.5.3 Safety for Passengers

Safety for pasengers using the system can be divided into five areas:

- o Ingress and egress at stations
- o Passage within stations
- o Embarking and disembarking vehicles
- o On board vehicles
- o Emergencies

Ingress and egress at stations is concerned with the parking facilities, transfer points from other transit modes and passage to and from stations. Ideally, parking lots and transfer points should be on the same side of a major thoroughfare to eliminate interference with road traffic. These circumstances are site-specific and may have to be solved by passageways over or under a street. In Morgantown, access to stations is not curtailed by public roads. Passage to stations is by walkways and at Beechurst by stairs.

In Phase I, stairs were the only means of passage within stations to and from the platforms. Phase II provides elevators for use by the elderly and handicapped. Due to the geographical location of Morgantown, ice and snow can cause approach difficulties if walkways and stairs are not maintained properly. The station platforms which are neither enclosed nor climatized are subject to the same problems. Although provided with roofs (and wind screens in Phase II) platforms are exposed to wind-blown rain and snow as illustrated in Figure 4.48. If not cleared adequately, ice on the platforms can be a safety problem and can impair access and egress to and from vehicles.

Since no station attendants are employed, security has to rely on closed circuit television which is used to monitor boarding and deboarding activities and some passenger movement in stations. The television system cannot observe passengers on stairways or on station approaches. Passengers can report safety or security problems over the station emergency telephone to the operator who can inititate immediate action by maintenance personnel, the campus police and

FIGURE 4.48 : WATER PUDDLES ON PLATFORMS

ambulance personnel as required. Phase II also affords the elderly and handicapped an opportunity to ask for assistance via telephone.

Except at boarding and deboarding positions, passengers are separated from guideways and vehicles by barriers along the entire platform. As the incident reports show, passengers have on several occasions entered the guideway. Quick reactions by the operators or other system personnel have in all cases prevented accidents.

Entering and leaving poses no problems since platforms and vehicle floors are at the same level, the gap between platform and vehicle door sill is minimal and accessible by wheelchairs. The vehicle door height is 73.9 inches. Considering that the 95th percentile for the male population is 72.8 inches in height, some passengers must stoop to avoid head contact with the door frame, especially when allowing for footwear and normal body movement. By comparison, the Small Bus Transit Bus Requirements Study, undertaken for UMTA, recommends a door height of 80 inches.

In Phase I the vehicle door configuration allowed for some doors to open up to about six inches while the vehicle was in motion. Doors have been observed by the assessment team to slide open up to two inches when the vehicle was travelling on a slope. This opening could allow passengers to throw items on the guideway or beyond; children could stick arms out of the moving cars. Phase II modifications should eliminate this hazard.

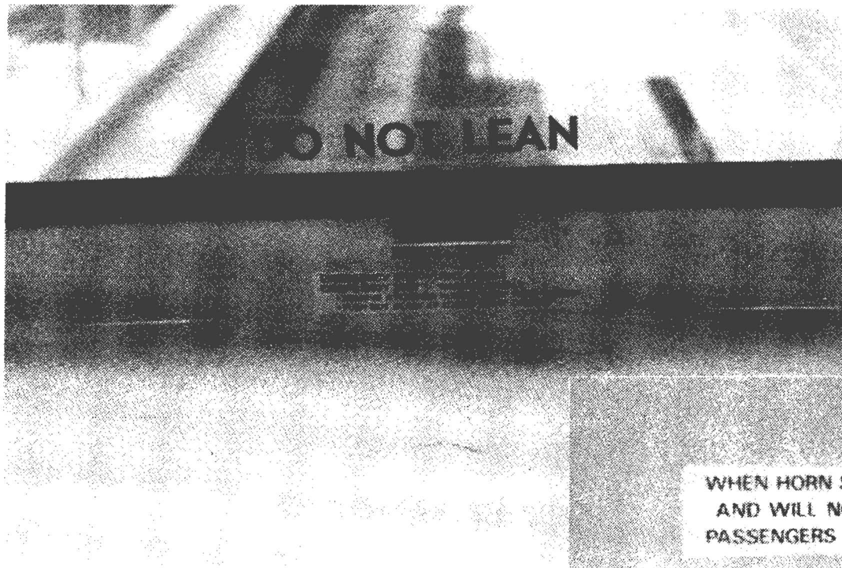
The vehicle is equipped with bumpers and mainline switch frogs with plastic impact drums to absorb collision energy. The vehicle interior provides smooth plastic seats and rounded edges on interior wall coverings to minimize injury. Jerk and acceleration of the vehicle are set to minimize risk to standing passengers. However, the emergency deceleration rate is deemed too high, as discussed in subsection 3.9.3.

Emergency communication with central control is available by two-way radio. Emergency evacuation is possible through the left vehicle door and the back window. The left door can be opened from the inside only when the vehicle has stopped. Both doors can also be opened from the outside. Emergency disembarkation through the left door is accomplished by stepping on the center side walls of the double guideway and down onto the guideway surface; and through the rear window by stepping onto the bumper and down onto the guideway, which serves as an emergency walkway to the nearest station. This procedure will require that elderly and handicapped persons be assisted by other passengers or system personnel. Emergency exit features are shown in Figure 4.49. The two-way vehicle radio is used by the operator to give instructions in the event vehicle evacuation is necessary. Under such conditions passengers are advised to remain in the vehicle until maintenance personnel have arrived. The CAS will not permit MPM vehicles to be pushed or pulled by another vehicle. Therefore, if a disabled vehicle cannot be restarted, passenger evacuation is necessary.

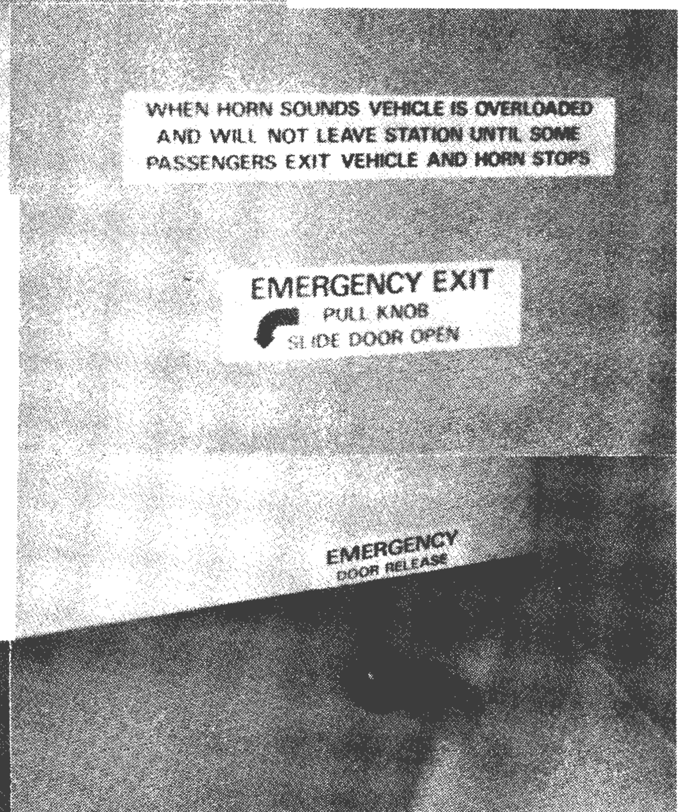
4.5.4 Safety for Employees

Since automated operation eliminates the use of drivers, vehicle attendants, and station attendants, this section limits discussion to safety for maintenance personnel. Employees perform maintenance work on fixed facilities such as the guideway, stations, and other fixed structures, on vehicles inside and outside the maintenance building, and they retrieve stranded vehicles.

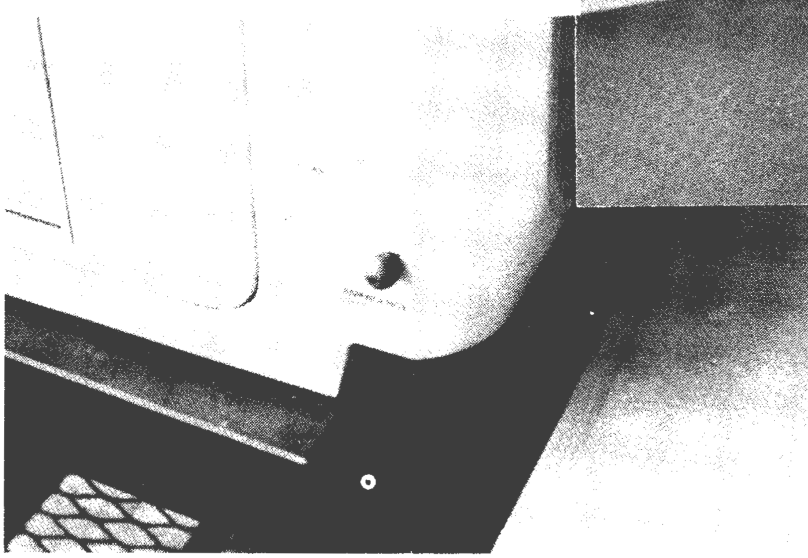
Employee safety throughout Phase I has been particularly challenging. This period has seen the start-up of operations with a new experimental system. These operations were conducted under the limelight of public demonstrations, often with high government officials in attendance. The large number of visitors who wished to witness operations of the MPM placed extra burdens on operating and maintenance personnel. During this phase, there were more than 500 visitors from 34 foreign countries in addition to thousands from the United States. Phase I also experienced the shift in responsbilities for maintenance and operations from contractor to university employees. It is remarkable that throughout this period there was only one serious system-related employee injury and no fatalities.



(a) REAR WINDOW EXIT



(b) KNOB FOR OPENING LEFT SIDE VEHICLE DOOR



(c) KNOB FOR OPENING VEHICLE DOOR FROM OUTSIDE

FIGURE 4.49 : EMERGENCY EXITS

Maintenance facilities available during Phase I were marginal. There was not sufficient employee work space when the maximum number of seven vehicles were being serviced. These crowded conditions posed particular problems around the two work stations where maintenance was performed on energized vehicles. Safety precautions consisted of a red indicator light on the portable power connector box and a rope supported on stands placed around the energized vehicle. No other physical barriers were placed around the vehicle and there was no available signal to alert employees in the area that power had been turned on.

A certain amount of the tight working conditions should be eliminated during Phase II by the additional space provided. Relocation of maintenance clerical functions from the shop area should also contribute to less congestion. The on-line guideway inspection station has been used as a working facility. The new facility should eliminate the possible exposure of employees to the 575-volt power rail. The inspection station has been given some weather protection by the addition of a free-standing roof, but no wind screens have been provided to further reduce exposure.

Most repairs which produce hazardous fumes (welding, painting) are performed outdoors. When this work must be conducted within the shop, ventilation can only be provided by open doors and fans.

The number of eye injuries associated with maintenance suggests that better enforcement of eye protection requirements is necessary. Also, spills and misplaced equipment have contributed to falls in this area. A new ventilation system has been installed in the battery charger room for Phase II.

4.5.5 Safety for the General Public

AGT systems, with their grade-separated guideways, afford the general public excellent protection from collisons with vehicles. However, this protection depends upon public adherence to warning signs and restrictions imposed by protective rails and fences, as used at Morgantown (Figure 4.50 and 4.51).

The vehicles are not positively entrapped on the guideway. This has caused some concern about the confinement of a possible overturned vehicle. Protection is afforded by the guard rails of the MPM system, which could prevent an overturned vehicle operating at allowed speeds from leaving the guideway. In addition, guideway copings, where these exist, are specified to withstand a vertical load of 2,800 pounds and a horizontal load of 1,000 pounds.

The elevated guideway design has conservatively approached the risks associated with static and dynamic loads of vehicles and environmental influences. Special attention has been given to earthquake effects and other geological phenomena. The supporting columns are considered sufficiently massive, that collision by a truck or other transport vehicle should not cause a serious displacement of the elevated guideway or vehicles.

The most likely safety risk to the general public stems from the possibility of items falling from elevated sections of the guideway onto persons below. The slack in door closers has been removed during Phase II, which should virtually eliminate the possibility that a passenger could throw something out of a vehicle door without interfering with vehicle operation. Objects cannot fall directly from the guideway -- they must drop from the edge, or be tossed over the guideway walls. A hazard could still occur if care is not taken during guideway repairs where areas underneath the edges of the guideway are accessible to the public.

4.5.6 Summary

Throughout the Phase I operations, there were no fatalities, no serious injuries to passengers, and no accidents which caused major damage. The only serious injury was to an employee, and this did not occur while the operations were under automatic control.

A safety committee was established early in the design phase. Safety review procedures were followed in monitoring designs, construction and operations. Hazard analyses were conducted in an endeavor to understand the consequences of a possible equipment or operational malfunction. A safety operations plan was prepared as guidance in the event one of the hazards materialized.

FIGURE 4.50 : GUARD RAILS AT SIDES OF GUIDEWAY

FIGURE 4.51 : FENCED IN AT-GRADE GUIDEWAY

As a result of the experiences during Phase I, the safety standards for Phase II were changed to the following:

- The probability of an accidental fatality shall not exceed 2.536×10^{-4} (one in 11 years) per operational day, where the system operates 1.56 million vehicle-miles per year, and prorated accordingly.

- The probability of serious injuries shall not exceed 6.0×10^{-3} (one in 167 days) per operational day.

- The probability of an accident causing damages exceeding $20,000 shall not be greater than 7.1×10^{-4} per operational day (one in 3.5 years).

The efficacy of these revised standards can only be judged after the Phase II system has undergone a sustained period of operation.

4.6 URBAN APPLICATIONS

Many lessons have been learned about the performance of the Morgantown People Mover system from this assessment of initial operations. In retrospect, many of the observations seem obvious; nevertheless, they have been documented in this section to insure that the lessons learned are not lost during planning, installation and operation of future AGT systems in urban areas.

4.6.1 System Operations

Operating experience with the MPM system provides a valuable insight into measures that could make the performance and effectiveness of an AGT system more relevant to the needs of an urban area. The more significant of these considerations are summarized below.

Shake-Down

The MPM has experienced nearly six years of operations -- from its initial tests and documentation starting in 1972 through an extensive shake-down period in 1973 and 1974, and finally almost three years of passenger carrying operations from September of 1975 through June of 1978. Six years is not an unreasonable period of time in which to translate a new technology from a demonstration system into a publicly acceptable operational system. Half this period of time -- up to three years -- could normally be expected for shaking down a commercially available transit technology when implemented in an urban setting.

Public officials responsible for implementing an AGT system should be cognizant of the time and effort required to bring an initial installation up to a reliable, high level of performance. As the foregoing discussion has indicated, the MPM system -- because of the new technologies and operating concepts involved -- required extensive efforts and modifications to achieve the third-year performance levels that have been documented. A second-generation system, using proven or simpler technologies, should be able to achieve maturity in a relatively shorter time period. Even so, implementation plans should anticipate schedule and budget for a reasonable shake-down period.

Equally important, the public users of the new transit system should not be misled to expect an immediate high level of performance. During the shake-down period, special efforts will be required to achieve reasonable levels of system availability. Premature expectations of unrealizeable performance can lead to public disenchantment with the system. The public acceptance survey of the Morgantown People-Mover found that a bias, critical of system reliability, persisted for more than a year, even though early start-up difficulties had largely been corrected.

Operating Strategies

The MPM system was designed to operate with both scheduled and on-demand service strategies. The full potential of on-demand service will not have been exploited until the Phase II system has received extensive use. However, some observations from experiences with the Phase I system are valuable.

Planning for an urban application requires an early decision on whether scheduled, on-demand, or a combination of both service strategies are required.

- Where only schedule service is necessary:
  - Off-line stations may not be required, unless non-stop service is to be offered a variety of destinations, such as the service provided by AIRTRANS at the Dallas-Ft. Worth Airport.
  - Simultaneous passenger unloading and loading at a single berth position is acceptable. Nominal dwell times in the stations of 30 seconds, with minimums of 20 seconds, are achievable. By avoiding larger dwell times associated with sequential unloading and loading operations, greater vehicle productivity and a smaller fleet size can be realized for a given demand density.
- When on-demand services are to be provided, consideration should be given to the use of this mode in peak periods, as well as for off-peak services. Also, the management of vehicle queues to minimize dwell time requires careful attention.

For both scheduled and on-demand services, management of the empty vehicles must also be anticipated. At Morgantown, where several peak periods are closely spaced throughout the day, it is more economical to increase the vehicle queues in the stations rather than to return them to the maintenance storage area or to continue circulating them around the guideways. This solution has caused some misunderstandings by patrons who see empty cars in stations while they wait for service. Urban areas with two, perhaps three, peak periods spaced at longer intervals and with a high peak-to-base ratio, may find that storing vehicles in stations during periods of low demand is not an acceptable solution, and is not practical where only on-line stations are available. Thus, system planning must accommodate the storage of excess off-peak vehicles and anticipate the redistribution of these vehicles between peak periods.

Energy Consumption

Experience with the MPM guideway heating system indicates that energy consumption for this function can be a major part of utility costs during winter months. Morgantown experienced two successive severe winters in 1976-77 and 1977-78 (second and third years of passenger operation). During the second year energy for guideway heating was nearly twice the electric energy required for all other system operations. During the third year, improvements in operating the boilers were achieved such that energy used for guideway heating was reduced to about 60 percent of the total utility requirements, even where the winter was as severe if not worse than the year before. The addition of resistance heating for the power rails in Phase II will increase the rate of energy consumption and the maximum power load.

For the Phase II MPM system, with 73 vehicles operating at optimum efficiency, energy consumption with no guideway heating is estimated at 3.67 kwh/vehicle-mile (see Subsection 4.1.4). The addition of guideway heating, assuming a normal winter, could increase this consumption by 41 percent to 5.1 kwh/vehicle-mile. Heating the guideway and power rails is a fixed operating burden that is independent of the numbers of vehicles or passenger loads carried. Thus, for urban applications with higher demand densities than exist with the MPM system, the energy consumption per vehicle-mile would be proportionately lower.

Cold Weather Operation

Specifications for operating the MPM system in adverse weather require that it perform in temperatures down to $-30^{\circ}F$ and with continuous snowfall of 10 inches per day at rates up to one inch per hour. With these capabilities, under the extreme conditions which prevailed during the two worst winters analyzed, the MPM system functioned during a heavy snowstorm during its third year where no other transportation modes could get passengers to or from it.

This situation suggests that specifications for cold weather operations in urban areas might be made less stringent. At some point, under the severest of conditions, most operations are likely to cease. The extra cost of achieving high AGT system availability under circumstances when feeder systems are inoperative and when few patrons can reach or use the system may not be justifiable.

Measures which could reduce the energy impact of cold weather operations in urban areas include:

- Plan the installation of stations and guideways as part of existing or new structures to minimize exposure to inclement weather.
- Consider alternative methods for snow and ice removal.
- Provide automatic controls for sensing guideway surface temperatures and for insuring that all segments of a heating system are operated for the optimum thermal efficiencies.
- Design the guideways, and provide insulation on the sides and the underneath of elevated sections, to minimize heat losses through all but the running surfaces.

Most important, reliable operations during adverse weather conditions depend upon the availability of a competent, highly motivated, operations and maintenance crew. Under the worst circumstances, those persons will be depended upon to physically remove accumulations of snow and ice from guideways and power rails. They will be expected to push inoperative vehicles from the system. Their ingenuity will be called on to restore service with all the work-around tricks at their disposal. In the final analysis, success of a highly automated system -- when confronted with operations in severe winter weather - requires the dedication of skilled operating and maintenance personnel.

4.6.2 System Assurance

One of the more interesting findings from the initial assessment of Phase I operations concerned the causes of vehicle downtime. Most of the problems which required corrective changes to permit the system to function, or to reduce unscheduled maintenance actions, were associated with relatively low technology hardware. Commercially available items such as hydraulic line clamps, collector brush braids, brake pads, and similar electro-mechanical components caused most of the reliability problems. Few modifications to the high technology subsystems, such as control system software, were required. By the third year, after most of the problems with ordinary production hardware had been resolved, the high-technology items began to appear as the leading contributors to downtime, though at a considerably lower failure rate than the mundane items.

The automated fare-card turnstiles remained as the greatest reliability problem throughout Phase I, leading to the decision that they be completely replaced with new design equipment for Phase II. A similar experience has resulted with the automated fare collection/passenger entry system at the Washington Metrorail System. Any advantages in using such sophisticated equipment and its potential reliability problems must be weighed against a more simple fare system using proven conventional equipment -- or even use of an honor fare system. This is particularly relevant since revenue from fares generally covers only a small percentage of operating and maintenance costs.

For urban applications, this finding has two important lessons.

- It points out the need for a sound quality assurance program at the subsystem and component level. Common ordinary components must be adequately specified. The means for assuring the required performance quality must be spelled out in the procurement documents.

- Testing of the components for use in vehicle production should be a condition of acceptance, rather than analysis or manufacturer's certification. Procurement of certain components and parts through a testing laboratory has been suggested by Boeing management as one means for assuring reliability; though more costly, this procedure may reduce overall costs by improving system dependability and reducing the number of deadline vehicles.

Adequate maintenance records and data analysis are essential for monitoring system reliability and maintainability. Knowledge of which items are failing and the frequency of repairs or replacements is necesary if the procurement of new parts is to improve reliability.

4.6.3 Human Interface

Modifications in an MPM-type system, beyond those being incorporated in Phase II, considered suitable for improving the human interface in urban applications, are described below.

Capacity

The maximum theoretical single-direction line capacity for the MPM system is 5,040 passengers per hour. Practically, the line capacity is 3,150 passengers per hour, which may be too low for many urban applications.

Capacity of the MPM system for urban applications could be increased through the following measures:

- o Revise the CAS to accommodate shorter headways with multiple blocks. (See Section 3.2.3.2)
- o Change the passenger module design to increase the capacity to 29 passengers. (See Section 3.1.1)
- o Entrain the vehicles -- up to three cars per train.

These revisions could provide a potential urban line capacity up to 34,800 passengers per hour. (See Figure 4.5, Section 4.1.2)

Vehicles

Rearrangement of seating within the existing vehicle chassis could increase the capacity from 21 to 25 pasengers. Widening the doors to 50 inches would permit loading and unloading passengers two abreast. Both of these changes could permit the vehicle to be loaded in about 15 seconds.

Relocation of the ECU and VCCS from the interior of the vehicle shell could further increase its capacity to 29 passengers. The ECU is also a major contributor to interior noise and its relocation would reduce this problem. Consideration should also be given to the elimination of humidity controls on ECU's for urban systems. The increased capacity which could result from these changes would affect brakes, propulsion and control systems. The ECU and VCCS are easily reached in their present locations and moving them could make maintenance more difficult.

Stations

Designs using side access to platforms would eliminate vertical passenger access. Where there are opportunities for direct access to abutting buildings, stairways, escalators and elevators in these buildings could be used for station access, thereby reducing station requirements and costs.

As a general urban station design premise, the inherent operational flexibility of small vehicle systems -- short turning radius and steep grade capability -- should be capitalized upon. These features should make the system more easily adaptable to site conditions. They could be used to improve passenger accessibility by reducing interface walking distances and station size.

Stair risers at Morgantown were measured at seven inches and treads at 11 inches. In recent years, there has been a tendency to reduce riser heights and increase tread widths in deference to the handicapped. Risers as low as five inches and treads as wide as 14 inches have been advocated for this purpose. It is believed that such stairs are easier to climb and less likely to cause accidents because of the greater foot clearance provided by the lower riser, and the larger foot placement as afforded by the wider tread. A disadvantage of these stairs is the increased number of risers and the larger area occupied by the stair. A six-inch riser with a 12-inch tread design would be recommended as a standard for urban station design.

Where side access platforms cannot be provided, serious consideration should be given to the use of elevators as the primary means for vertical passenger movement in future urban AGT stations because:

- One elevator will be required to fulfill handicapped design requirements in any event.
- Elevators provide two-way service, whereas escalators are unidirectional.
- Escalators generally provide excessive vertical passenger capacity in most people-mover applications.
- Elevators can be programmed more easily than escalators to control passenger flow in the event of failures.
- Escalators occupy larger areas than elevators and tend to "stretch out" the length of station access routes due to their 30-degree incline. Elevators result in more compact vertical passenger movement and offer economies of space.
- Comparing paired escalators with paired elevators, when one unit is out of service, elevators can continue to accommodate two-way passenger movement whereas escalators cannot.

The basic disadvantages of elevators in transit service have been security problems and their batch service characteristics. It is believed that security problems can be significantly reduced by using glass enclosures, TV station surveillance and other similar measures. It should be emphasized that these factors must be considered with the provision of an elevator for the handicapped. Batch service refers to the fact that elevators provide intermittent service, causing passengers to queue and wait, whereas escalators provide continuous "no-wait" service. The disadvantages of elevator batch service can be significantly mitigated by programming elevators to meet arriving AGT vehicles and by providing matching capacities with higher speed units and elevator platform areas related to AGT vehicle size.

Future urban AGT systems might consider enclosed waiting areas that are heated and cooled. The enclosed spaces would provide a more favorable environment for patrons. Coordinated platform/vehicle doors would inhibit heating and cooling losses from vehicle interiors while passengers were loading and unloading. By sustaining more constant temperatures over the duration of the trip, passenger comfort would be improved and overall enegy consumption might be reduced. The coordinated vehicle doors could prevent passenger incursions onto the guideway. Depending on station design arrangements, these doors could also screen from passenger view any vehicles temporarily held in the loading berths during periods of low demand.

Elderly and Handicapped

Plans for an AGT system in an urban setting should incorporate features which would allow its use by patrons who are mobile, but who experience some form of dysfunction. Transportation handicapped groups include those with hearing difficulties, those who require mechanical aids (braces, crutches), the wheelchair users, the blind -- including patrons with impaired sight, and those who experience some difficulty in movement (stooping, kneeling, climbing stairs) and those who are temporarily burdened (pregnant women, limbs in casts, or carrying packages).

There is ample professional literature available which describes measures which should be taken to eliminate transportation barriers which prevent using a transportation mode by patrons with mobility dysfunctions. The purpose of the following discussion is merely to recapitulate the specific experiences with the MPM system which would be applicable for elderly and handicapped access to an urban installation.

- Access. Station entries should be as close as possible to mode change points to reduce long walking distances. Changes in elevation should be avoided. Where vertical access is necessary, it should be accomplished by means of ramps, stairs with risers as low as five inches and treads as wide as 14 inches and elevators.

- Turnstiles. Either separate processing points should be provided, or the aisle space through the turnstiles should be made wide enough to accommodate wheelchairs, obese persons or those with other burdens. The turnstile design, with accompanying fare collection, change making and station selection devices should anticipate the special needs of riders with crippled hands or arms, and those with visual difficulties.

- Orientation. Measures are required to facilitate the movement of patrons with hearing and seeing disabilities in getting through the stations to and from vehicles. A station layout permitting natural flow of passengers (e.g., minimized obstacles and changes of direction) aids the blind as well as non-handicapped patrons.

  - For the hard-of-hearing: Visual aids must be located conspicuously, should be intensely lighted and explicit in the information provided. Graphics which display car loading points and destinations must be especially obvious.

  - For the blind and near blind: Audio announcements should be made, which are clear and concise, and which use sound equipment free of distortion and reverberations. Sound-activated communication links between stations, vehicles and central control could aid many handicapped groups. Textured paths in stations could help direct patrons between cars and entry points. Control buttons on elevators, fare-card machines and other similar devices should use Braille and should be placed at standardized, convenient locations.

Persons with transportation disabilities should be given ample instructions on use of the system prior to their first encounter.

- Environmental Protection. Snow, ice and accumulations of rain on open platforms can be hazardous to all patrons, particularly those with walking and/or visual difficulties. Platforms as well as access stairs and ramps should be enclosed or at least protected in ways that eliminate these hazards.

- Car Access. The space between the platform edge and car door threshold should be small enough (less than two inches) so that a wheelchair can navigate the space without lodging the front swivel wheels in the opening. The car door should open sufficiently to simultaneously load/unload a wheelchair and another patron. The vestibule area inside the doors should be clear of stanchions that would restrict the maneuverability of a wheelchair.

- Maintenance/Control Areas. These areas should be made readily accessible so that they can employ handicapped persons.

- Other Considerations. Planning should address the problems of getting emergency instructions to blind and deaf passengers in disabled vehicles. Planning must also anticipate the problems of removing a patron with mobility limitations from cars during an emergency. Other considerations include protection of metal guide canes from electric hazards, CCTV monitoring to aid the transit of patrons with special problems, and the avoidance of obstructions or sharp protrusions which further add to the mobility difficulties of these groups.

Attention to the measures described above will not only aid patrons with transportation-handicapped dysfunctions but will facilitate use of the system by all patrons.

Safety and Security

Experience during Phase I with the MPM system has established that a fully automated transport system can provide a safe and secure public service. This notion has been reinforced by the realization that patrons who misuse the system face almost certain apprehension due to the capability to route cars directly to locations where authorities are waiting. Generally, the lessons learned have parallels in conventional transit systems. Safety and security considerations in the design of station vehicles and operations are well understood and are not repeated here.

Specific object lessons having relevance to urban applications are reviewed below with respect to the groups of reported safety and security incidents.

Malfunctions comprised the highest percentage of incidents (31 percent), though no injuries resulted. The high rate of malfunctions at the onset of service eroded some confidence in its performance. Public authorities must be prepared for this reaction during the start-up of a new service. Malfunctions which stop service or strand passengers in vehicles should be anticipated with thoroughly prepared plans. Alternate modes of transport should be made available within a reasonable period of time. It should be possible to remove a disabled vehicle or to safely evacuate passengers from the vehicle and guideway. Capabilites that do not exist at Morgantown, but which might be considered for urban applications include the ability of one vehicle to push or pull another, and the ability to back up along the guideway. The flexibility in meeting certain emergency situations should be weighed against the costs and design problems such capability would entail.

Injuries accounted for nearly 28 percent of the incident reports. Of these, only three (9 percent) involved passengers, though these were system related. More than 20 percent of the injuries affected employees -- 60 percent were system related and 40 percent were not. This distribution suggests that their safety and security interests, as well as their caution in using the system, are adequately represented. The percentages of employee injuries underscores the need for a safety program which includes:

- o The assignment of responsibilities to an individual who will monitor practices and who can win support from employees and management for safe performance.
- o Training for new employees and retraining for the older ones on safety procedures.
- o Briefings, shop talks, and other means to keep safety from lapsing into complacency.

Collisions were the subject of nearly 20 percent of the incident reports. Almost 44 percent of these were vehicle-to-vehicle bumps in stations. These "bumps" occurred at low speed and no injuries resulted. Urban areas contemplating off-line stations where vehicles are queued might consider extending the collision avoidance system into the stations, if such low-speed collisions were found objectionable. The remaining collisions -- between vehicles and rails -- could be avoided by a different steering concept. A steering system which physically confines the vehicle on the guideway would also reduce the possibility that a vehicle, out of control, could leave the guideway.

Intrusions, while comprising only 17 percent of the reported incidents, were potentially the most hazardous. Seventy percent of these intrusions were by passengers and employees onto the guideway. Not only were these persons exposed to the power rails and moving vehicles, but they endangered the lives of other passengers. At-grade guideways are fenced and warning signs are posted in the station. Nevertheless, the number of intrusions suggests that other means for securing the guideways should be considered for urban applications.

For patrons with hearing or seeing disabilities, pancake lights and distinct changes in floor texture, as used in the Washington Metro subway stations, can warn patrons of platform edges. Coordinated station doors should also be considered as one way of preventing both accidental and deliberate intrusions. Such doors inject their own set of problems -- more equipment to malfunction and to maintain, and possible accidents which catch passengers between station doors and vehicles. On balance, for urban applications, these disadvantages appear to be outweighed by the safety and security from guideway intrusions afforded by a postive barrier-type door.

Other incidents, mostly non-system related, substantiate one of Murphy's Laws: "If something can go wrong, someone will find a way to do it wrong." These incidents were burdensome in that they caused damage (one was major) and otherwise distracted from routine operations. For urban applications, they point up the need for training and motivation to reduce such incidents as well as alertness on the part of system operators to keep them from becoming serious problems.

Safety and security is fundamental to the concept of AGT operations. If the advantages of automated transit are to be realized in urban applications, safety and security must be planned for, it must be built into the system, and it must be continually monitored throughout maintenance and operations.

5.0 SYSTEM COSTS

5.1 Capital Cost

The amount spent to build the first phase of the Morgantown People Mover System has been the subject of a number of reviews during the past several years. Based upon data from various investigative reports, together with information obtained from discussion with cognizant personnel at Boeing, West Virginia University, the West Virginia Board of Regents, and UMTA's Morgantown project staff, the total cost of the Phase I installation has been broken down as follows:

Vehicles	$ 9,209,000
Guideways	16,946,000
Stations	2,282,000
Control and Communications	15,513,000
Power and Utilities	2,066,000
Maintenance and Support Facilities and Equipment	822,000
Engineering and Project Management	17,404,000
TOTAL	$64,242,000

In its budget justifications, UMTA has reported this total as the amount committed to the Morgantown People Mover from FY 1975 and prior year appropriations. The Office of AGT Applications has confirmed that this amount reflects the capital costs incurred.

Because of the unique nature of the Morgantown project and the accelerated schedule which was dictated for its implementation, a duplicate installation would have cost substantially less. The reasons for a significantly lower replacement cost are summarized as follows:

- Morgantown is a first-of-a-kind AGT system, far more sophisticated than any full scale operational system undertaken in the U.S. Neither Boeing, the system manager, nor its major hardware subcontractors had built anything like it previously. Much of the early work was of a research and developmental nature. For example, the first five vehicles which were demonstrated in October 1972, less than 18 months after Boeing was awarded its initial contract, were essentially operational prototypes. They were discarded after having served their purpose, which was to test and demonstrate the first design concepts in actual practice.

- o There was lost motion in the early stages of the project, particularly when the Jet Propulsion Laboratory's role as system manager was terminated.

- o An artifically tight schedule was imposed on the project, involving a highly visible operational demonstration just prior to the 1972 Presidential election. This compelled those responsible for planning, design, fabrication, and construction to act in haste -- there was not sufficient time for design optimization. Thus, in the interests of early contract awards, guideway design was undertaken before the weight of the vehicle was known.

To duplicate the facilities and equipment installed at Morgantown during Phase I of the program, it is estimated that a capital investment of approximately $45 million would have been required during the 1971-1975 time frame for implementation of this project. The derivation of this estimate is indicated in some detail in Table 5.1. As will be noted, the reported expenditures have been adjusted allowing for the factors outlined above. The total of these adjustments is about one-third of the total amount actually spent on the project.

Escalation to 1978 Price Levels

Capital expenditures for Phase I of the Morgantown project were distributed over the period 1971-1975, with the bulk of the outlays for construction occuring early in this four-year period. To adjust the capital cost to a 1978 price level, the following indices were used:

a) The Engineering News Record (ENR) 20-City Construction Cost Index was used to adjust the cost of guideways, stations, maintenance shops, and the other fixed facilities.

b) The Wholesale Price Index for Machinery and Motive Products was applied to the cost of the vehicles, control equipment, and associated transportation hardware.

c) The Consumer Price Index for Urban Wage Earners and Clerical Workers was applied to adjust the cost for professional services such as engineering and project management.

These indices together with the escalation factors used to adjust costs to a 1978 level are shown in Table 5.2.

For each of the capital cost categories an estimate was made of the timing of expenditures. This is shown in Table 5.3, which illustrates how the

TABLE 5.1: ESTIMATE OF REPLACEMENT COST -- MORGANTOWN PHASE I
(Amounts in Thousands)

Cost Category	Reported Expenditures (1)	Amount of Adjustment	Basis for Adjustment	Estimated Replacement Cost
VEHICLES	$ 9,209	-2,135	This is about half of the amount spent on the first 5 prototype vehicles - Considered to be non-recurring R&D expense.	$7,074
GUIDEWAYS				
Basic Cost	10,811	-2,400	It is estimated that about $2.7 million was spent to expedite construction. Of this about 90% related to the guideways.	
Site Preparation	1,450			
Steering Rails	425			
Heating	3,341			
Restoration (pro rata)	919 (2)			
	16,946			14,546
STATIONS				
Basic Cost	2,100	- 300	Estimate 10% of the extra $2.7 million spent to expedite construction was for the stations	
Restoration (pro rata)	182 (2)			
	2,282			1,982
CONTROL & COMMUNICATIONS	15,513	-7,760	Estimate about half of the amount spent for Command & Control was for non-recurring R&D	7,753
POWER & UTILITIES				
Power Distribution	1,066			
Power Rails	1,000			
	2,066	--		2,066
MAINTENANCE & SUPPORT				
Maintenance Building	484			
Support Equipment	304			
Restoration	34 (2)			
	822	--		822
ENGINEERING & PROJECT MANAGEMENT				
A&E Services	1,432	-1,200	This is 60% of the amount spent by JPL before their activities were terminated.	
System Project Management	6,921			
System Test, Eval, Instr.	4,439			
Integration Assemb & Test	2,390			
SUB-TOTAL Reported by Boeing	15,182	-5,350	About a third of the amount expended for Engineering & Project Management (excluding the above JPL expenditures) is considered to have been of a non-recurring R&D nature	
Non-Boeing Costs	2,222			
TOTAL	17,404			10,854
GRAND TOTAL	$64,242			$45,097

NOTES: (1) This cost breakdown was provided by Boeing's letters of 5-24-77 and 7-21-77.
(2) Boeing estimated that $1,135,000 was spent for the Restoration of Facilities and Utilities. This amount has been distributed to the Guideways, Stations and Maintenance & Support.

TABLE 5.2: COST INDICES FOR ESCALATING AGT COSTS

Year	Hardware (Wholesale Price Index for Machinery and Motive Products)		Construction (Engineering News Record Construction Cost Index for 20 cities)		Professional Services (Consumer Price Index for Urban Wage and Clerical Workers, U.S. City Average	
	Index	Conversion Factor (1978 Prices)	Index	Conversion Factor (1978 Prices)	Index	Conversion Factor (1978 Prices)
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

TABLE 5.3: ADJUSTMENT OF MORGANTOWN PHASE I REPLACEMENT COST TO 1978 PRICE LEVELS
(Amounts in Thousands)

Cost Category	Estimated Replacement Cost	Time Phasing of Expenditures		Escalation		Estimated 1978 Duplication Cost	
		Year	%	Index	Multiplier	Calculated	Rounded to three Significant Digits
VEHICLES	$7,074	71	5	WPI	1.64	580	
		72	30	"	1.60	3,396	
		73	10	"	1.56	1,104	
		74	35	"	1.39	3,442	
		75	20	"	1.21	1,712	
						10,234	$10,200
GUIDEWAYS	14,546	71	10	ENR	1.74	2,531	
		72	50	"	1.57	11,419	
		73	20	"	1.46	4,247	
		74	15	"	1.37	2,989	
		75	5	"	1.25	909	
						22,095	22,100
STATIONS	1,982	72	40	ENR	1.57	1,245	
		73	40	"	1.46	1,157	
		74	20	"	1.37	543	
						2,945	2,950
CONTROL & COMMUNICATIONS	7,983	71	5	WPI	1.64	655	
		72	25	"	1.60	3,193	
		73	20	"	1.56	2,491	
		74	30	"	1.39	3,329	
		75	20	"	1.21	1,932	
						11,600	11,600
POWER & UTILITIES	2,066	71	10	ENR	1.74	359	
		72	40	"	1.57	1,297	
		73	30	"	1.46	905	
		74	20	"	1.37	566	
						3,127	3,130
MAINTENANCE & SUPPORT FACILITIES	822	72	40	ENR	1.57	516	
		73	40	"	1.46	480	
		74	20	"	1.37	225	
						1,221	1,220
ENGINEERING & PROJECT MANAGEMENT	10,624	71	20	CPI	1.61	3,421	
		72	20	"	1.56	3,315	
		73	20	"	1.47	3,123	
		74	20	"	1.33	2,826	
		75	20	"	1.21	2,571	
						15,256	15,300
TOTAL	$45,097						$66,500

adjusted historical costs have been converted to 1978 price levels. These calculations indicate a total 1978 capital cost of $66.5 million for Phase I. Figure 5.1 shows graphically how this cost is distributed among the major categories. As might be expected, the largest single component is the guideway system, which accounts for about one-third of the total cost. Adding the other "brick and mortar" features, i.e., the stations, maintenance and support facilities, power and utilities, brings the cost of the fixed facilities to nearly half of the total cost.

Hardware, including rolling stock and control equipment, accounts for 32.7 percent of the total cost. Engineering and project management is estimated at 23.1 percent, a relatively large share of the total cost due to the complexity and sophistication of the system.

Since Morgantown is essentially a "free-standing" system with virtually no joint use of facilities, as contrasted with airport systems where stations are generally integral parts of terminal buildings, the costs for each major subsystem can be readily identified. However, it would not be correct to assume this distribution of costs to be typical for AGT systems in general. As discussed elsewhere in this report, the stations are much larger and more complicated than for any other existing AGT system. Similarly, the guideway heating system selected for Morgantown accounted for about 20 percent of total guideway cost. Thus, these allocations of costs should be used only as a very broad indication of how total system costs would be distributed.

Unit Costs

The following unit costs applicable to Morgantown Phase I may be derived from the 1978 estimates described above:

Cost per Vehicle $10,200,000 ÷ 45 Vehicles =	$ 227,000
Guideway Cost per Lane Mile $22,100,000 ÷ 5.26 Lane Miles =	$4,200,000
Total System Cost per Lane Mile $66,500,000 ÷ 5.26 =	$12,600,000
Total System Cost per Passenger Space Provided $66,500,000 ÷ (45 x 21) =	$70,400

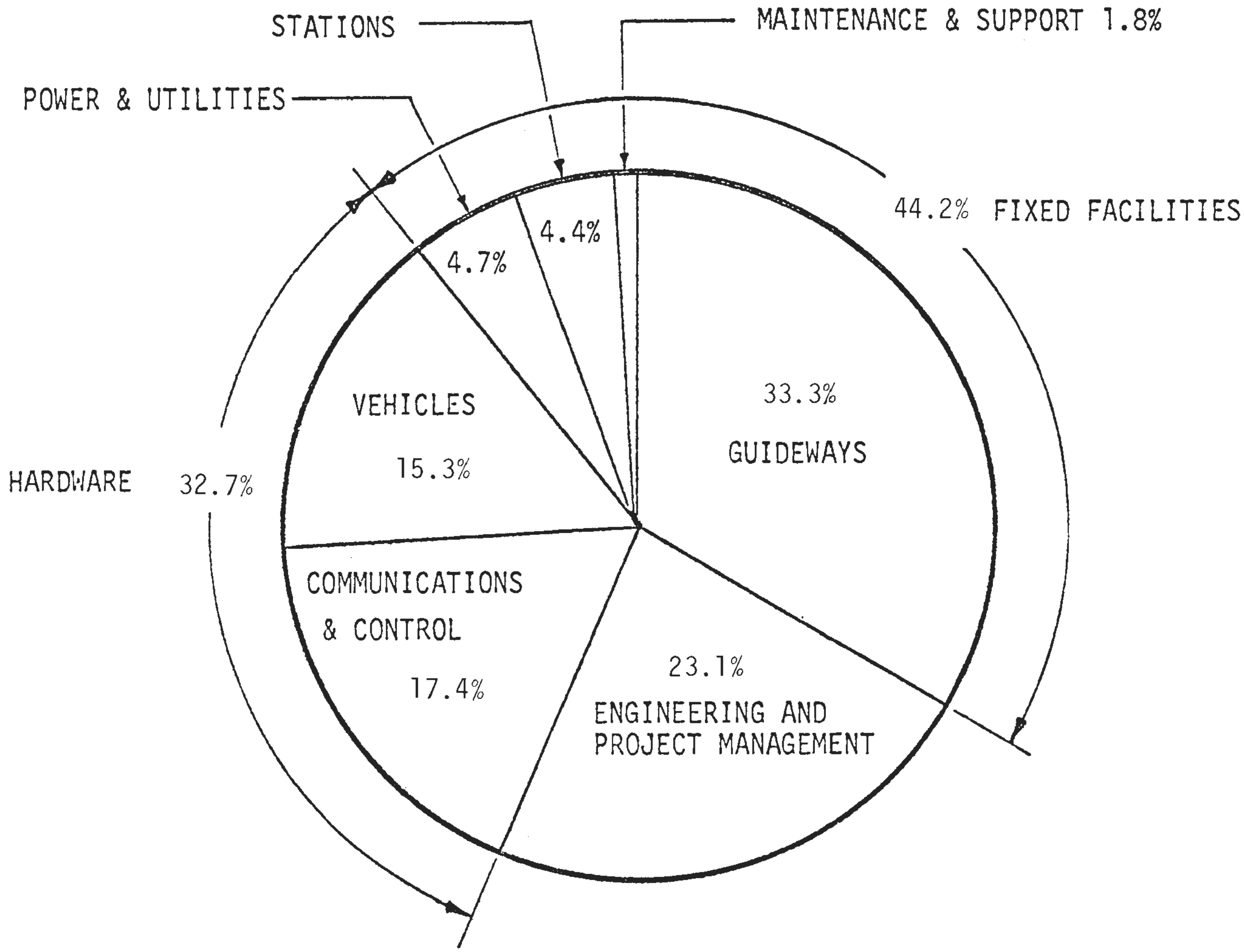


FIGURE 5.1: DISTRIBUTION OF MORGANTOWN PHASE I CAPITAL COSTS

5.2 Operations and Maintenance Cost (O&M)

The Morgantown People Mover began regular passenger service in October 1975 and during its first year of operation, both the University and Boeing were involved in O&M functions. Since this was essentially a break-in period, during which time the WVU staff was learning how to maintain and operate this highly sophisticated system, it was considered preferable to ignore the cost record for the first year. Accordingly, O&M costs as well as performance data presented in Table 5.4 begin with October 1976, the start of the second operational year. By this time WVU had established its organization and had trained personnel in place.

Unlike other AGT systems at airports, the Morgantown People Mover is essentially a seasonal operation. Since the vast majority of the Phase I passengers were either students or members of the WVU staff, the system's operation closely paralleled the University's pattern of activity. Thus, the fall period was generally the busiest, and the summer the lightest. This tempo of operation is indicated in Figure 5.2 which shows how fleet mileage as well as total O&M costs fluctuated during the 21-month period of operation by WVU from October 1976 until the system was shut down in early July 1978 for Phase II modification and expansion. Also shown on this chart is the cost of natural gas used for melting snow and ice from the guideways during wintertime. As will be noted, the cost of natural gas contributed significantly to the O&M cost peaks which were experienced during the winter periods. The 1976-1977 winter was the more severe of the two, which resulted in higher guideway heating costs. The following were additional factors which contributed to differences in wintertime O&M costs:

- As a result of the high guideway heating cost experienced during December 1976 - February 1977, improved procedures were developed for coordinating boiler plant operations with weather forecasts. This resulted in more effective natural gas consumption for the next winter, 1977-78.
- Severe icing problems developed with the vehicle steering mechanisms as well as with the power rails, which prompted several modifications and improvements. These were implemented before the 1977-78 winter season and eliminated some of the maintenance problems which had contributed to the prior winter's high costs.

TABLE 5.4: MORGANTOWN PHASE I OPERATIONS AND O&M COST DATA (AT ACTUAL PRICES)

	1976			1977								
	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
OPERATIONAL DATA:												
Vehicle Miles Traveled	67,078	54,078	37,597	46,712	57,162	51,693	57,029	32,839	32,465	35,400	42,665	64,753
Passengers Carried	267,212	223,297	116,568	152,980	206,545	176,710	187,025	46,338	32,261	47,982	143,842	308,172
Passenger Miles (1)	434,220	362,858	189,423	248,593	335,636	287,154	303,916	75,299	52,424	77,971	233,743	500,780
COSTS: ($)												
Labor (2)												
Operations (Incl. benefits)	12,203	12,441	11,952	11,807	12,340	12,318	12,313	12,866	12,453	12,702	12,728	13,136
Maintenance (Incl. benefits)	27,307	27,636	29,021	35,894	26,842	27,314	28,321	28,410	26,216	28,700	31,857	34,883
Materials & Services	84,764	31,357	41,233	58,513	87,011	27,206	49,006	35,633	20,222	25,448	17,251	47,489
Utilities												
Electricity	7,969	8,787	8,405	11,383	10,370	7,817	7,829	7,153	6,108	6,696	7,848	8,264
Natural Gas	588	8,904	18,341	54,679	15,024	1,653	964	8	0	0	661	13
G&A	10,612	10,612	10,612	11,481	11,604	11,608	11,785	12,259	12,259	12,932	13,235	10,631
TOTAL O&M:	143,443	99,737	119,564	183,757	163,191	87,916	110,218	96,329	77,258	86,478	83,580	114,416
MAN HOURS:												
Operations	2,010	2,087	1,920	2,003	2,078	2,076	2,076	2,141	2,086	2,048	2,175	2,101
Maintenance	5,689	5,869	5,819	6,618	5,215	5,711	5,757	5,691	5,505	5,058	5,858	6,019
G&A	1,512	1,584	1,656	1,632	1,600	1,840	1,720	1,936	1,936	2,016	2,016	1,760
TOTAL	9,211	9,540	9,395	10,253	8,893	9,627	9,553	9,768	9,527	9,122	10,049	9,880

(1) Average passenger trip length assumed to be 1-5/8 miles.
(2) Fringe benefits distributed on pro-rata basis to operations and maintenance labor.

Source: West Virginia University

TABLE 5.4: CONTINUED

	1977			1978						
	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	TOTAL
OPERATIONAL DATA:										
Vehicle Miles Traveled	67,123	58,797	33,902	55,664	40,078	44,475	55,257	22,167	34,765	991,699
Passengers Carried	292,462	233,672	115,817	253,143	181,352	180,965	176,163	36,615	37,082	3,416,203
Passenger Miles	475,251	379,717	188,203	411,357	294,697	294,068	286,265	59,499	60,258	5,551,332
COSTS: ($)										
Labor										
Operations (Incl. benefits)	13,686	13,053	12,994	12,246	12,698	12,002	11,884	10,999	11,377	260,190
Maintenance (Incl. benefits)	32,458	35,201	33,002	44,039	39,692	33,630	32,058	31,387	33,816	667,692
Materials & Services	43,879	27,468	32,929	20,514	47,768	10,360	30,244	43,360	14,709	796,364
Utilities										
Electricity	8,060	9,372	8,868	12,357	8,744	8,757	8,067	5,202	5,915	173,971
Natural Gas	191	2,320	8,104	41,095	18,280	4,228	0	0	0	175,053
G&A	13,748	12,925	12,925	12,957	14,509	14,257	14,257	14,257	14,257	263,722
TOTAL O&M:	112,022	100,339	108,822	143,208	141,691	83,234	96,510	105,205	80,074	2,336,992
MAN HOURS:										
Operations	2,067	2,087	2,136	2,001	1,858	2,042	1,816	1,896	1,748	42,452
Maintenance	5,831	6,168	6,453	6,713	6,439	6,001	5,047	5,661	5,611	122,733
G&A	1,968	1,936	1,936	1,936	1,952	2,208	1,920	2,208	2,112	39,384
TOTAL	9,866	10,191	10,525	10,650	10,249	10,251	8,783	9,765	9,471	204,569

Source: West Virginia University

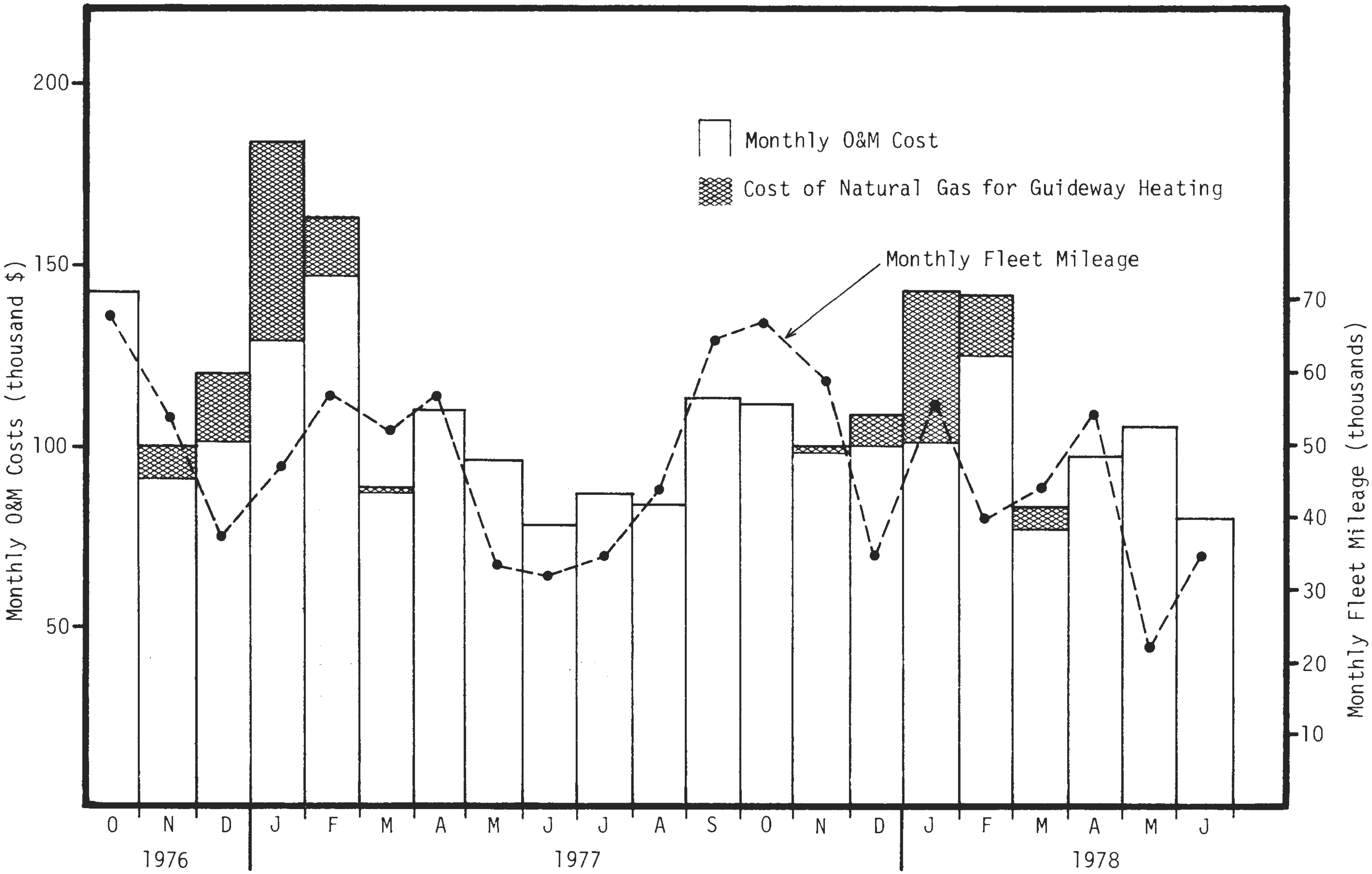


FIGURE 5.2: MORGANTOWN MONTHLY FLEET MILEAGE AND OPERATIONS AND MAINTENANCE COSTS (Actual Price Level)

Figure 5.3 indicates the distribution of O&M costs during the period October 1976 through June 1978. As shown, labor accounted for about half of the total cost to operate and maintain the system. Materials and services amounted to 34 percent and utilities 15 percent. Included in the category of materials and services are: spare parts and consumable supplies, maintenance contracts for special equipment such as the central control computers and communications equipment, vehicle tires, equipment rental, hand tools, and miscellaneous items.

Whereas Figure 5.3 shows about equal expenditures for electrical energy and natural gas for guideway heating, it should be recognized that only 21 months' data was available for analysis. Two full winter seasons were included in this period, but only nine months of the second year. If allowance is made for an additional three months of electrical energy consumption, the cost of natural gas would amount to a smaller share of the total utility cost, probably about 40-45 percent, which would be about six to seven percent of the total O&M costs.

5.2.1 Manpower

Even though the system is automated, labor accounted for over half of total O&M expenditures. During 1978, the Morgantown People Mover's authorized organization totaled 61 people, subdivided into three major categories as follows:

General Supervision and Administration	
Director	1
Secretary	2
Business Manager	1
Office Assistant	1
Storekeeper	4
System Engineering Manager	1
System Engineer - Electrical	1
System Engineer - Mechanical	1
System Engineer - Industrial	1
Engineering Aide	1
	14
Operations	
Operations Manager	1
Operations Shift Supervisor	4
System/Communications Operator	8
Operations Engineer	1
System Programmer	1
	15

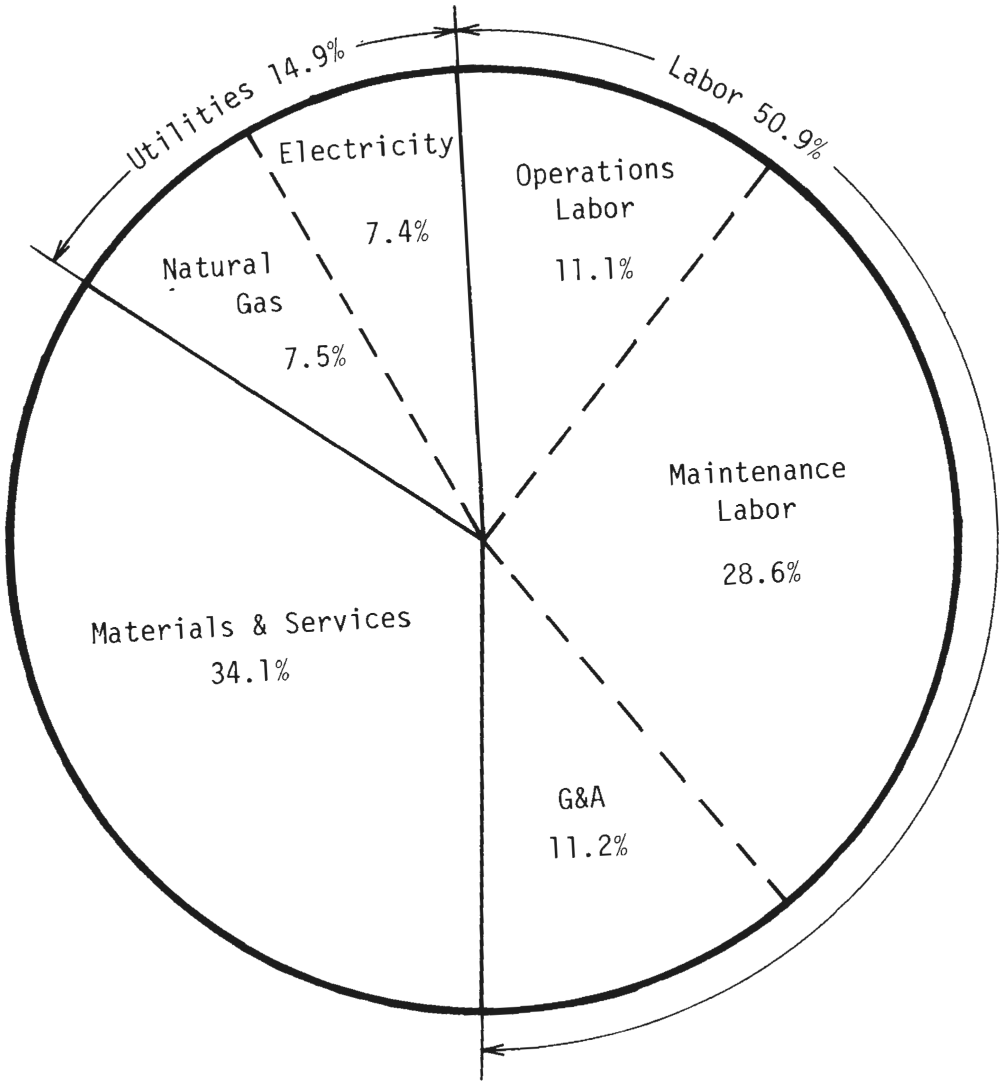


FIGURE 5.3: DISTRIBUTION OF O&M COSTS, OCT 76 - JUN 78

Maintenance	
Maintenance Manager	1
Shift Supervisor	5
Electronic Technician	8
Electrical Technician	2
Mechanical Technician	10
Utility Worker	3
Maintenance Controller	2
Guideway Heating Technician	1
	32

Because of labor turnover and the lag in filling vacancies, the effective staffing level was usually somewhat below the authorized limit, averaging 2-4 people short of 61.

Figure 5.4 reflects the utilization of operations, maintenance, and G&A manpower during the 21-month period of operations by West Virginia University. Because it is customary to use overtime during peak periods of activity, the overtime hours used each month are indicated by crosshatching. Review of these manpower utilization data indicates the following:

- There is little correlation between the use of manpower and the level of system activity as reflected by operating hours and fleet mileage. This is illustrated graphically by Figure 5.5, which reflects how manpower, operating hours, and mileage have fluctuated over the 21-month period observed. As will be noted, manpower peaks occurred in January of 1977 and 1978 when difficulties were encountered in keeping the system operational. Low manhours were recorded in February and July of 1977 and April 1978 for no apparent reasons.

- G&A and operations labor remained almost constant throughout the 21-month period. The minor fluctuations recorded were probably the result of events unrelated to the level of system activity, such as staff resignations, additions, and vacations.

- To a significant extent, peak maintenance manpower requirements have been satisfied by the use of overtime. This was particularly true during the two winter periods, when substantial amounts of overtime were recorded.

- There has been no significant trend in the utilization of manpower during the period observed. During the 21 months for which data were recorded, the average was 9,741 manhours per month. The lowest monthly usage was 8,783 manhours in April 1978 and the highest was 10,650 in January 1978. Although manpower utilization increased slightly from 9,211 manhours in October 1976 to 9,471 in June 1978, it would appear that the University maintained a relatively level work force throughout the post-shakedown Phase I operational period.

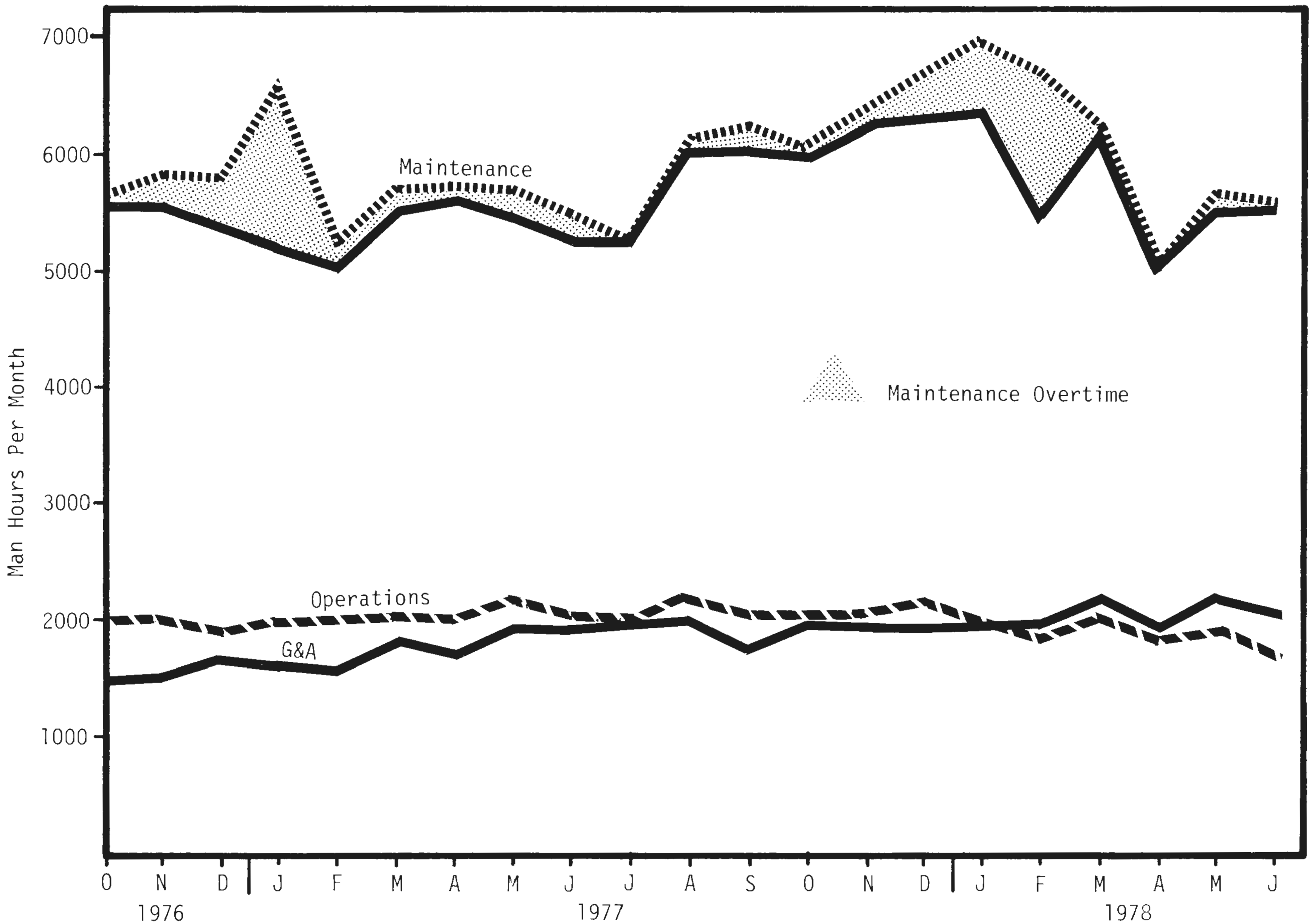


FIGURE 5.4: O&M LABOR MAN HOURS

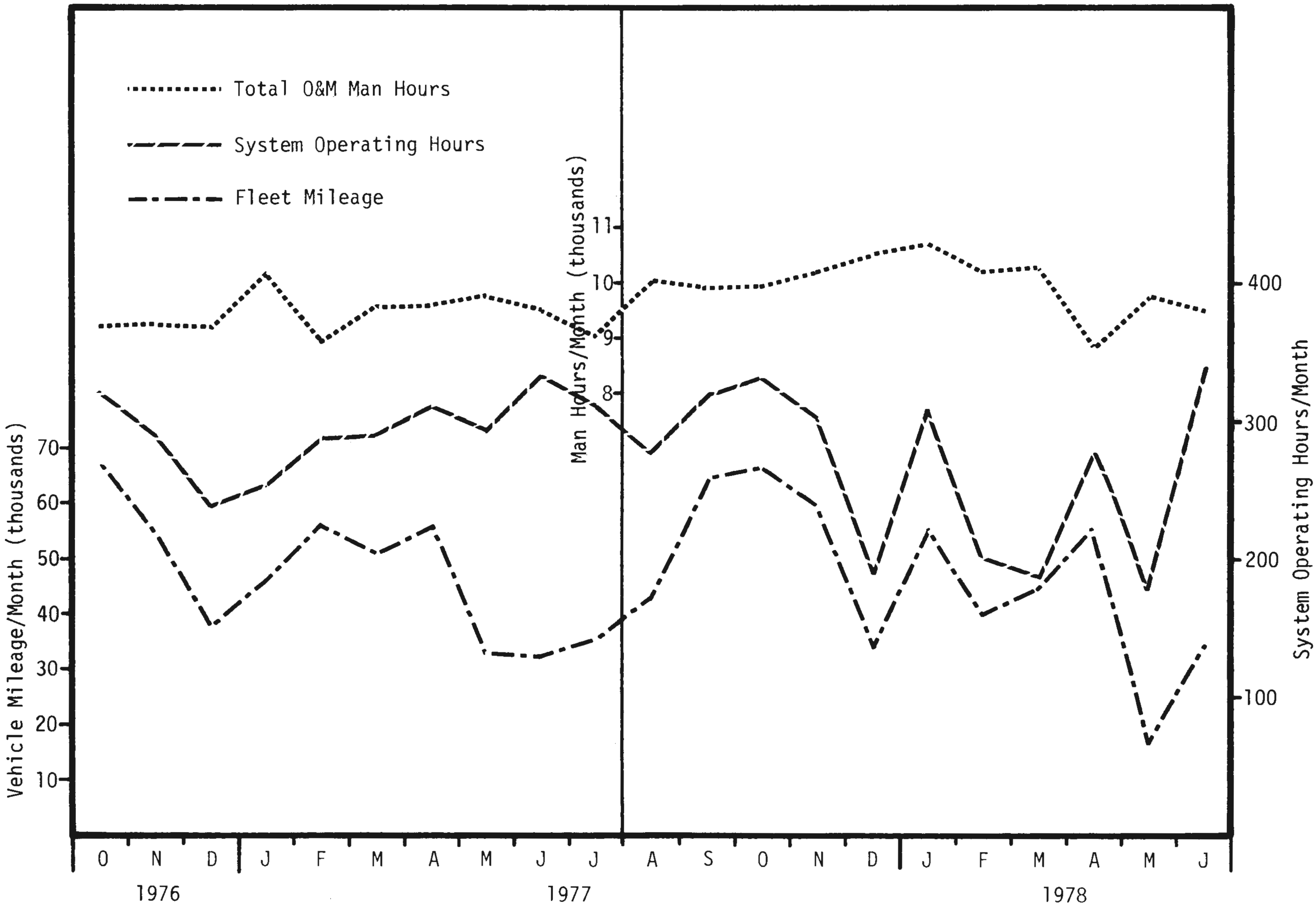


FIGURE 5.5: MANPOWER UTILIZATION, OPERATING HOURS AND FLEET MILEAGE

5.2.2 O&M Unit Costs

The recorded O&M costs which have been tabulated in Table 5.4 may be adjusted to 1978 price levels as indicated below:

Expenditure Period	Recorded O&M Cost $	Escalation Factor	1978 O&M Cost $
Oct-Dec 1976	362,744	1.12	406,273
Jan-Jun 1977	718,669	1.09	783,349
Jul-Dec 1977	605,657	1.06	641,996
Jan-Jul 1978	649,922	1.02	662,920
21-Month Total	2,336,992	1.07	2,494,538
Last Year Total	1,225,579	1.04	1,304,916

For escalation purposes, the average Consumer Price Index for Urban Wage Earners and Clerical Workers, U.S. City Average (CPI) for the expenditure period in question has been used. These adjusted O&M costs in turn have been used to calculate the following unit costs:

Unit of Measure	21-Month Period Oct 76-Jun 78 $	Last Operational Year Jun 77-Jun 78 $
Cost per Vehicle Mile	2.52	2.35
Cost per Vehicle Mile	0.12	0.11
Cost per Place Mile (21-Passenger Vehicle)	0.12	0.11
Cost per Passenger Carried	0.73	0.65
Cost per Passenger Mile (Assumes avg. trip of 1.625 mi.)	0.45	0.40

These unit costs are somewhat higher than those experienced at other AGT installations. There are a number of reasons for Morgantown's relatively high O&M costs and these are summarized as follows:

- In contrast to AGT systems at airports, where service is generally provided around-the-clock, seven days a week, Morgantown operates on a relatively restricted schedule. On normal weekdays 13.25 hours of service are available, with only 5.5 hours on weekend days; and the system does not normally operate on holidays or at times when the university is closed, such as over the Christmas vacation. Hence the system utilization is lower and the vehicles log significantly less annual mileage than the airport systems, which average about 60,000 miles per year per vehicle.

- Morgantown is the most advanced of the AGT systems in passenger operation, capable of providing short-headway, on-demand service, non-stop from origin to destination. To achieve a high service level requires very sophisticated electro-mechanical and control equipment which is more costly to operate and maintain than the simpler systems in operation elsewhere. Also because of the inherent system complexity, the debugging process is necessarily longer. Numerous design modifications resulted from difficulties experienced during the Phase I operational period. These product improvements, most of which should eliminate maintenance problems, were to be incorporated in the Phase II system modifications.

- The Morgantown operating environment is the most demanding of all the AGT systems in current service. Steep grades of up to 10 percent are encountered and the system must operate in cold weather, under ice and snow conditions. The guideway heating system consumes a large amount of energy in the form of natural gas, at a cost almost equal to that of the electricity for vehicle propulsion and normal housekeeping. Additionally, there are numerous maintenance problems associated with cold weather operations, such as the buildup of frost and ice on vehicle moving parts. All of these factors have contributed to high wintertime O&M costs.

- As discussed elsewhere in this report, there was a conscious effort during the Phase I operational period to minimize the number of miles accumulated per operating vehicle. This resulted in longer waits on station platforms by passengers, but higher load factors. It also contributed to higher costs per vehicle mile and per place mile traveled.

Phase I of the Morgantown People Mover project was far from optimum insofar as the scope of operation or per-vehicle ridership was concerned. Once the system is expanded to its full design size and the full complement of 73 vehicles is shaken down and debugged, the unit costs to provide transportation service should decrease markedly.

6.0 SYSTEM DEVELOPMENT PROCESS

6.1 PROJECT HISTORY

This section traces the development process of the Morgantown project and documents the major decisions that affected the direction of system development. The endeavor has been to identify both the sequence and rationale of decisions in a way that may simplify the process for future AGT installations.

6.1.1 The Morgantown Transportation Problem

The campus of West Virginia University (WVU) is located in the small coal-mining and manufacturing town of Morgantown, West Virginia, nestled in the valley of the Monongahela River. Student enrollment rose during the 1960's from 10,000 in 1964 to over 15,000 in 1970, with a staff of 6,200.

University officials were faced with the dilemma of expected increases in demand for student enrollment during the 1970's and 80's and a severely limited expansion potential to meet these demands on the small main campus. The most obvious choice available to officials was to develop new campus facilities on a 260-acre tract of land owned by the University, approximately 1.5 miles from the main downtown campus. In effect, this established three campuses: the Downtown Campus, the Medical Center, and the new Evansdale Campus.

Transportation between these locations became an immediate problem. The hilly terrain of the city made walking and bicycling between campuses very difficult. Automobile congestion on the limited connecting streets quickly eliminated motor vehicle travel as a viable alternative. In 1965, University officials purchased ten buses and leased six more for service between the remote campuses. Despite class schedule adjustments and rerouting of traffic, the problem of connecting the facilities persisted. The bus system proved inadequate to handle the magnitude of riders during the five distinct peak periods each day and was unable to adhere to an acceptable schedule, primarily due to traffic congestion.

A Morgantown TOPICS report by the State Road Commission of West Virginia in 1969 substantiated the severity of the University's transportation problem with documentation of the high accident rate, extremely low vehicular speeds, frequent travel delays, low service levels, and reduced vehicular capacities on all major facilities in the CBD and campus areas.

6.1.2 The Introduction of Automated Guideway Transit

Background

In the summer of 1967 at WVU, two seminars were conducted with transportation engineers and management officials of rail and bus transit systems. One significant topic of discussion, for Morgantown, was the potential of providing rapid transit systems for small cities. During this same period, the U.S. Department of Housing and Urban Development (HUD) undertook an extensive study of new systems in urban transportation. One of the more promising concepts identified in this study, Personal Rapid Transit (PRT), utilized small, fully automated vehicles on exclusive guideways at short headways. This concept is now included in the general category of Automated Guideway Transit (AGT). The seminar discussions, coupled with the interest in new systems generated by the HUD study, prompted Dr. Samy E. G. Elias, Benedum Professor of Transportation at WVU, to suggest an AGT system as a possible solution to the University's transportation problems.

A proposal dated June 27, 1967 was submitted to HUD, which at that time was administering the urban mass transportration grant programs. HUD was completing a study of possible transportation systems for the new town of Columbia, Maryland. An AGT concept was under serious consideration and planning for the new town was proceeding with the reservation of rights-of-way for such a system. As a result of the limited transportation funds available to HUD and its interest in other projects, such as Columbia, the Morgantown proposal made little progress.

In July 1968, most of the urban mass transportation program was transferred from HUD to the newly created Urban Mass Transportation Administration (UMTA) in the U.S. Department of Transportation, in accordance with President Johnson's Reorganization Plan No. 2. The elections in November 1968 brought a change in administration and a new Secretary of Transportation, John A. Volpe. In his earliest public statements, Secretary Volpe expressed his belief that new technologies could help solve the nation's transportation problems. He was determined to show demonstrable results from the urban transportation research and development program.

Dr. Elias regarded these statements as indicative of a favorable climate in which to obtain reconsideration of the Morgantown proposal. With help from state and University officials, a meeting with the new Transportation Secretary was arranged in May 1969. The Secretary was inclined to proceed with the feasibility study. A review of other available opportunities found that the Columbia New Town was a private development and ineligible for UMTA grant funds. The developer was unable to finance design and construction of an AGT system. No local public agency was forthcoming with the authority or resources to take on the demonstration of an AGT system in Columbia. As a result of these circumstances, the Morgantown proposal was approved on June 20, 1969.

Feasibility Study

The purpose of the study was "to determine the feasibility of demonstrating a new mass transportation technology for West Virginia University and the adjacent areas of the city of Morgantown, West Virginia." The total estimated cost of the study was $133,500. Funding was provided by a Federal grant of $100,900 and a University contribution of $32,600. The study addressed the three initial phases of a five-phase design for the transit demonstration project:

- Phase I: Concept Validation -- to validate the applicability of new transportation concepts from the standpoint of the present state of technology and to match the advertised transportation roles of new concepts in the urban environment to the defined transportation needs of the University.

- o Phase II: System Sorting -- to identify a set of alternative concepts which could demonstrate the highest relative probability of successful implementation and demonstration.
- o Phase III: System Definition and Preliminary Design -- to determine the system's ability to provide:
  - -- technical feasibility
  - -- adequate consideration for human-factors design and environmental control
  - -- an aesthetically pleasing design
  - -- economic feasibility
  - -- successful implementation.

In Phase I, the University staff conducted the demand analysis and prepared evaluation criteria for the subsequent two phases. The firm of Barton-Aschman Associates, Inc., of Chicago, Illinois, was retained to evaluate the capability of candidate systems to meet the projected transportation requirements of the University as part of Phases II and III. The Barton-Aschman analyses concluded that:

- o An AGT system would be an attractive and economically competitive alternative to a University bus system necessary to accommodate adequately the projected inter-campus trips.
- o In terms of dollar value benefits alone, the University could justify development of an AGT system requiring an investment of up to $90 million over a 10-year period at prevailing interest rates.
- o West Virginia University provided excellent potential as a demonstration site based on the topographic characteristics of the area and the number of peak periods or "rush hours" each day.

The University evaluation of potential systems initially reduced the number to nine for further consideration. These nine companies were invited to visit the site and to submit formal proposals outlining what they could accomplish in the way of a Preliminary Engineering Design Study in a period of three months. Five proposals were submitted and their evaluation resulted in the selection of three companies to conduct the Preliminary Engineering Design Studies. The original grant from UMTA was increased by $20,000 on March 13, 1970, so that contracts for these studies could be awarded to:

Alden Self-Transit System Corporation -- Alden Capsule Transit System
Varo, Inc. -- Varo Monocab System
Dashaveyor Company -- Dashaveyor System.

Results of these design studies were evaluated by both the University and Barton-Aschman. Both evaluations concluded that the Alden system could best meet the University's transportation need and was most suitable for installation in Morgantown.

In a staff study of the Morgantown project, the General Accounting Office found that:

"The University's study was extensive and resulted in the decision that the Alden Self-Transit System Corporation PRT proposal would best meet their transportation objectives. This selection was substantiated by a consultant retained by the University."

Grant Application

The feasibility study, completed on August 5, 1970, served as the basis for the demonstration grant application, submitted by the West Virginia Board of Regents to UMTA on August 15, 1970, on behalf of the University. The scope of the project, based on the Alden system, included 3.6 miles of guideway, six stations, and 100 vehicles with 12-seat capacity.

The sources and amounts of funds required were summarized as follows:

	Item	Non Federal	Federal	Total
1.	Rights-of-Way	$3,985,500		$ 3,985,500
2.	Proposed System	491,000	$12,286,000	12,777,000
3.	Project Administration at WVU		544,000	544,000
4.	Technical Management Consultant		500,000	500,000
5.	Contingencies		170,000	170,000
	Total	$4,476,500	$13,500,000	$17,976,500

The grant application contained the following footnote:

> "Due to the size of the project and the fact that final design has not been completed yet, these are approximate figures which will be re-evaluated and submitted no later than six months after project approval."

Upon review of the grant application, UMTA decided to retain for itself management responsibility for the project because of the need to achieve tighter experimental design and the development of reproducible equipment, facilities, and methods which would have national relevance. WVU was advised that, because of this decision, the grant application of August, 15, 1970, was no longer considered to be an active candidate for approval as submitted. WVU's role would have to be rethought. In the meanwhile, however, it was also decided that the common interest of UMTA, the University, and the community and the groundwork already laid formed an adequate basis for immediately starting work on the project. The University agreed to make its own real estate available at no cost and to acquire additional properties or rights-of-way as necessary. With the decision to proceed, an operational demonstration of the system was set for October, 1972.

6.1.3 System Manager

In order to meet the pressing time schedule and to initiate project activities, UMTA required technical support services immediately. The organization selected could have no hardware conflicts and should be retained quickly through non-competitive contracting procedures. Several "non-profit" firms were considered. However, DOT already had the Jet Propulsion Laboratory (JPL) of the California Institute of Technology under contract through an interagency agreement with NASA. On September 3, 1970, DOT approved an expanded interagency agreement which added $160,000 for 15 man-months of work by JPL on the Morgantown project, to be completed by November 30, 1970. NASA accepted this amendment to the interagency agreement on September 11, 1970, and JPL accepted it on September 24, 1970.

JPL immediately initiated two actions to get the project underway:

1. JPL Contract No. 539249 was negotiated with Alden for descriptions of the total system -- including vehicles and the requirements for power, command and control, and other support equipment. These descriptions had a delivery date of October 9, 1970. Alden was also to prepare procedures for development tests, acceptance, and evaluation; to identify critical areas and configuration controls; and to develop a work breakdown structure and schedules, resource requirements, organization, and a documentation and reporting plan. This task had a delivery date of November 3, 1970.

2. JPL Contract No. 953027 was negotiated with Frederic R. Harris, Inc., for five tasks covering route confirmation; preliminary and final geological and foundation studies; support activities for such features as station passenger flows, reliability and safety, costs, vehicle/guideway interface requirements, and overall plans and schedules; and written reports covering the system guideways and stations. Discussions with Harris began on September 10, 1970. The scope of work was approved by UMTA on October 12, 1970. The contract was recommended for JPL approval on October 16, 1970.

On September 25, 1970, the UMTA Administrator decided that the hardware and construction elements of the Morgantown project would be let by competitive contract. JPL was advised that continued participation by Alden with JPL would very probably put Alden in a corporate conflict of interest that would jeopardize their being able to participate in future competition. JPL cancelled the contract with Alden by telephone on September 29, 1970. Alden officials expressed surprise and concern over the action, since they believed their selection through the competition conducted by WVU had satisfied all of the competitive requirements. Though the action was protested, Alden finally acknowledged the cancellation on October 17, 1970.

The JPL management role was originally envisioned as one of technical support only; however, as the pace of activities increased, it became apparent that this role would have to be expanded. On December 8, 1970, the UMTA administrator approved an amendment to the JPL task order from NASA to include preparation of a Project Development Plan and requests for proposals for defined subsystems, evaluation of proposals, awarding of contracts for subsystems, and management of "follow-on" design and construction activities. The cost of these activities through June 30, 1971, was budgeted at $5,910,000, including the

$160,000 previously committed. The initial allocation of $1,353,000, with $600,000 for A&E services was made to carry the project through March 31, 1971. The UMTA amendment of December 11, 1970 was accepted by NASA and JPL on January 4, 1971.

With their expanded role, JPL focused on four primary endeavors:

1. **Project Requirements and Constraints Document** -- This document attempted to incorporate the system performance requirements of WVU together with station locations and guideway routes. It reflected the technical features of the proposed system as well as practical limitations necessitated by the budget and time schedule. The document represented a cooperative effort among WVU, UMTA, JPL, and the latter's contractors (Harris and others).

   After many reviews and revisions, the Requirements and Constraints Document was approved by the three parties on December 17, 1970. Thereafter, it became the point of reference for procurements and changes in the scope of the Morgantown project.

2. **Communications and Control System** -- On January 31, 1971, JPL issued an RFP to 62 prospective bidders for the communications and control system. The Bendix Aerospace Corporation was selected from among eight proposals -- precontract discussions were initiated on April 30, 1971.

3. **Vehicles** -- The Boeing Aerospace Company was selected by JPL from 45 prospective bidders and seven proposals for the system's vehicles -- precontract discussions took place on May 3 and 4, 1971.

4. **System Definition** -- In January, 1971, JPL submitted to UMTA a revised project estimate of $37 million which considerably exceeded UMTA's expectations for an R&D project. JPL was immediately requested to reduce the scope of the project to fit a $20-million budget. This meant a reduced guideway length (from 3.5 to 2.0 miles) and fewer stations (from six to three). The number of vehicles was reduced (from 100 to 15) and the number of passengers per car was increased (from six to 21). Headways were also increased to 15 seconds between vehicles.

It was agreed that consideration would be given to future system expansion to full project scope using capital-grant funds. However, since the reduced project would not meet University transportation needs and an expanded system was contingent upon uncertain future capital-grant financing, WVU insisted on the right to reject ownership of the system if technical performance were unsatisfactory or if future capital assistance for system completion were not forthcoming. From this point onward, system design, procurement, and construction proceeded on the basis of this agreement.

System Management Contract

The original contracting procedure which retained JPL through an existing interagency agreement between DOT and NASA proved to be a quick and convenient way to obtain technical support services. However, as the project progressed, this arrangement proved cumbersome; financial adjustments and accounting procedures were burdensome. UMTA considered that tighter administrative controls could be exercised through a direct contract with JPL. Since December 1970, JPL had been aware of UMTA's intent to negotitate a direct contract. Between March and July 1971, UMTA attempted to negotiate such a contract; however, no agreement with JPL could be reached on terms and conditions considered necessary to assure adequate control of cost, system design, and schedule. JPL would not agree to the clause required by UMTA which gave the government a unilateral right to take over any or all of JPL's subcontracts, though it had been used in other DOT contracts to insure continuity and progress on a project through subcontractors, in the event difficulties arose with the prime contractor. On August 11, 1971, JPL was advised of Boeing's selection as project manager by UMTA, after competitive negotiations with Boeing and Bendix. JPL was requested to continue as project manager until "phase-over" was completed, scheduled for October 1, 1971.

The major concern during contract negotiations with Boeing was the cost and scope of the Morgantown project. As a result of revised cost estimates submitted in January 1972, UMTA made further system reductions, including: deletion of the maintenance building, revision of the maintenance track, reduction in the number of vehicles (from 15 to five), and various economies in construction materials and techniques. On February 8, 1972, contract negotiations with Boeing were completed on the statement of work, time schedule, the project costs, and fees. At this time, the R&D cost for the demonstration project was estimated at $37 million, of which $25.9 million was to be the Boeing contract share.

Boeing continued in the role of system manager through completion of the demonstration phase (Phase IB), and is now responsible for vehicles, C&CS, and system integration during Phase II expansion.

6.1.4 Project Phasing

The Morgantown project has been accomplished in a series of discrete phases. These phases were necessitated by the availability of funds and the requirement to produce discernible results by specific dates. Early estimates of project costs indicated the desirability of conserving R&D funds by accomplishing early phases under Section 6 of the Urban Mass Transportation Act and then completing the system with capital-grant funds (Section 3). This strategy required that staging fit the overall program objectives to:

1. Demonstrate the feasibility of an automatic, personalized urban transit system;

2. Demonstrate the applicability of the concept to national urban needs; and

3. Qualify the concept for other locations by establishing eligibility for Federal capital assistance.

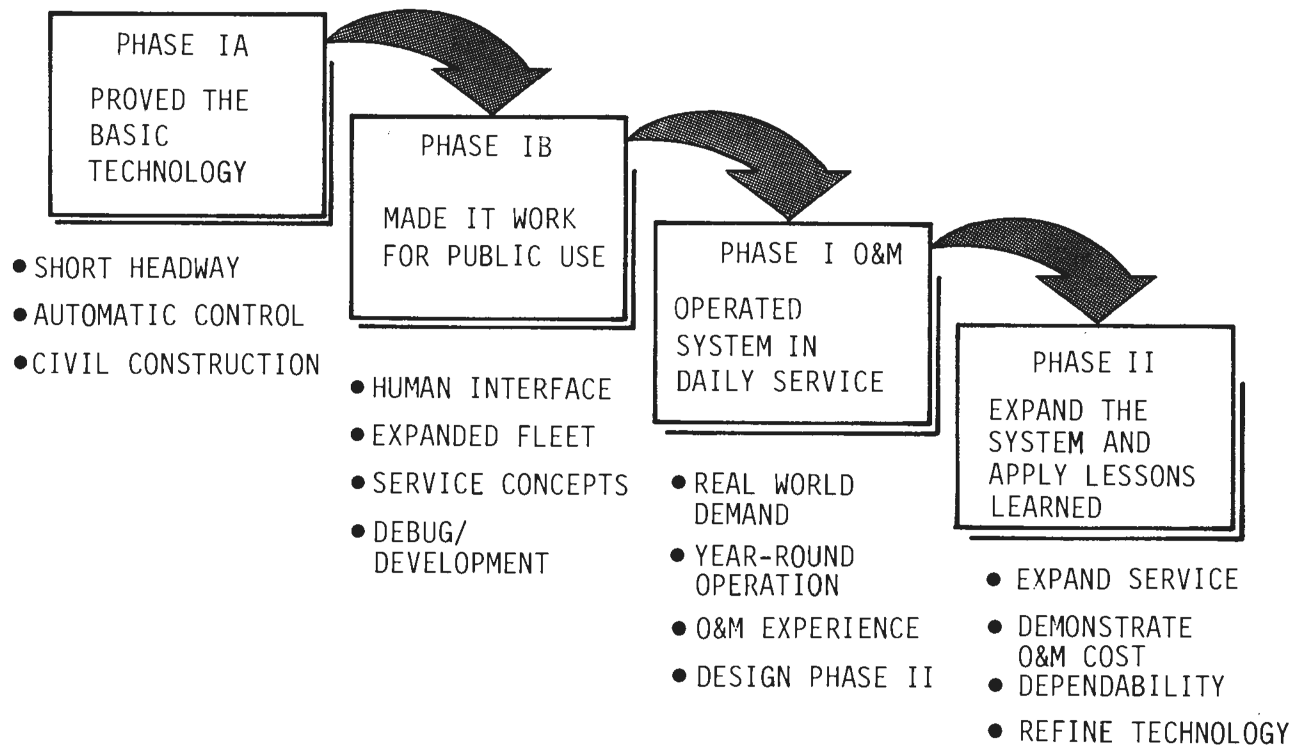
The scope and scheduling of phases for the Morgantown People Mover project are depicted in Figure 6.1 and are summarized below.

Phase I, December 1970 - July 1978

The goal of this phase was to demonstrate the feasibility of a fully automatic, demand-responsive, advanced-technology transit system in daily public service. Phase I was undertaken in three parts.

Phase IA, December 1970 - September 1973

This phase encompassed all the engineering, fabrication, procurement, construction and installation necessary to prove the technical feasibility of the system. Critical technical features to be addressed included short vehicle headways and fully automatic system controls. Three stations, approximately two miles of double-lane guideway, and five vehicles comprised the Phase IA system. This phase also included limited operational software and associated equipment to test the system.



(Source: Adapted from Boeing Automated Transportation Systems Presentation, Oct. 1977)

FIGURE 6.1: MORGANTOWN PEOPLE MOVER PROJECT PHASING

At the time Boeing became the system manager, it had essentially one year in which to complete an operational demonstration system. Ground was broken for the first construction contract at WVU on October 9, 1971.

On March 6, 1972, the first vehicle was completed and tested under manual control at the Surface Transportation Test Facility (STTF) near Seattle, Washington. Vehicle No. 2 was the first to operate at STTF under completely automatic control in May 1972. By September, Vehicle No. 1 had successfully completed manual-control test runs at WVU between the Maintenance facility and the Engineering Station.

During this year the West Virginia Supreme Court ruled that the University had the authority to condemn an unused Baltimore and Ohio Railroad right-of-way for use in guideway construction. The issue had been in dispute since November 1971. A union jurisdictional dispute between the International Brotherhood of Electrical Workers (IBEW) and Boeing technicians, who belonged to the International Association of Machinists and Aerospace Workers, nearly threatened meeting the October dedication date. The question was resolved in September when the IBEW withdrew their claim.

The dedication and public demonstration of the Morgantown People Mover System took place on October 24, 1972. The ceremony was held at the Engineering station with demonstration rides between the Engineering station and the Maintenance area. Three vehicles (Nos. 3, 4, and 5) were used for the rides. One vehicle malfunctioned early in the demonstration and was pushed out of service. The other two performed without serious problems for the remainder of the demonstration.

Between January and May 1973, an intensive system safety review was carried out, prompted by an apparent failure of the BART "fail-safe" system to prevent an accident from occurring. The review was conducted by Boeing and Bendix with assistance from the Battelle Memorial Institute. Several deficiencies were found which led to design changes for correction in Phase IB. The most significant change was the addition of a redundant collision-avoidance system.

Other accomplishments during this period included completion of Phase IA construction, installation and check-out of the control and communications system, completion of system integration testing, incorporation of system design changes, and preparation for the "follow-on" Phase IB. During this period, the highest rainfall ever recorded in West Virginia delayed construction five months. There were also labor problems, delays in deliveries from steel suppliers, and shortages of electricians.

System integration testing was initiated for that portion of the system between Engineering station and the Maintenance facility and was extended to Beechurst and Walnut as construction of these segments was completed. Prequalification testing was completed in June and established the technical feasibility for the system concept. However, test results showed that significant redesign was required to meet the system's public service reliability objective and to satisfy the safety study recommendations. In order to establish a sound basis for Phase IB design, Phase IA testing was continued until September 26, 1973. On that date, the objectives of Phase IA were satisfied with the operation of four vehicles.

Phase IB, September 1973 - September 1975

The objective of this phase was to successfully conduct an operational demonstration of the MPM technology in public, passenger-carrying service. Principal concerns were human interface, an expanded fleet of vehicles, testing variations in service concepts, and improving system equipment.

Phase IB provided for 45 redesigned vehicles; completion of the guideway heating system; development of hardware and software for a fully operational, automatic control and communications system; maintenance facility expansion; and accommodations for a revenue service demonstration. UMTA initiated Phase IB with a letter contract to Boeing on September 4, 1973. A definitive contract was signed on April 3, 1974, with completion and start of operations scheduled for April 1, 1975.

A series of critical design reviews was initiated in October 1973. Guideway and facilities design reviews were completed in November, permitting the advertisement of construction contracts in December. The first contract was awarded and construction under Phase IB started in January 1974. Reviews of other elements were completed in March 1974.

By June, the first production vehicle rolled off the assembly line and began tests on the STTF. Tests of the vehicle control and communications system revealed problems with brakes and propulsion system related to maintaining longitudinal control accuracy, which could affect operations but not safety. There were construction delays during Phase IB due to weather and shortages of materials and skilled workmen. However, the major problems during this phase occurred in two important areas which caused 45 days' delay in testing:

1. **Software** problems began to accumulate to the extent that software development activities had to be reorganized and work around programs devised in order to meet contract schedules. Several software task forces were formed to provide independent assessments of the problems and to help resolve the anomalies that were impeding the test program. Dual computers were installed at Morgantown to insure sufficient reliability to sustain system testing. A parallel capability was maintained at Seattle to generate software tapes and to test the software packages.

2. **Short circuits** of control loops installed in the guideway during Phase IA were found to be the cause of a vehicle guidance accident on January 16, 1975. These shorts were found to occur when control loop wires in the guideway expansion joints were pinched by movement of the guideway segments. Correction required a new design of all the expansion joints throughout the guideway to provide clearance for these wires as the expansion joints closed.

The last production vehicle was delivered to the STTF in February 1975 for acceptance testing. However, the need to use the STTF for software development delayed vehicle acceptance testing and deliveries to Morgantown. Shipments were completed in July 1975, although one vehicle was retained at the STTF for developmental testing.

In March 1975 system testing again got underway at Morgantown and was scheduled to be finished in June. Delays caused by software and the incorporation of disputed changes extended the completion of system testing. On August 29, 1975, the system completed a test demonstration by accumulating 60 hours of continuous operation with 25 vehicles. Acceptance of the system by UMTA on September 12, 1975, indicated that it had met contractual requirements and project objectives for Phase IB.

Phase I O&M, October 1975 - July 1978

Though UMTA had accepted the MPM system delivered by Boeing, acceptance by WVU was another matter. The conditions upon which transfer to the University was effected are discussed in a following section. A key element in the resulting agreement was that Phase I would be extended so the system could be operated and maintained to the University's satisfaction. The objectives of this one-year operating period were to ascertain whether the system could meet mutually acceptable criteria, covering: operating and maintenance costs, conveyance dependability, safety, and other performance tests. This phase included the start of some capital improvements to the Phase IB system. Engineering design of the Phase II extension was initiated during Phase I O&M so that the scope and cost of the follow-on project could be reflected in the capital grant application.

Experience with the MPM system during the first operational year is documented elsewhere in this report. These operations provided an excellent opportunity to shake down the system. Operation and maintenance responsibility was effectively transferred from Boeing to University personnel in July 1976. The experience gained from this phase, together with the results of Phase IB, established the requirements for changes and improvements to be incorporated in Phase II.

With assurance that these modifications would be made when technically feasible and within Congressional budget limitations, the West Virginia Board of Regents and UMTA agreed on a capital-grant contract that started Phase II. The amendatory agreement, approved on September 30, 1976, provided $63.6 million for upgrading and expanding the system. Both parties agreed that the Phase I system had been delivered in compliance with contractual requirements and that it would not be necessary to revert the system to UMTA.

Phase I O&M operations continued until July 3, 1978, at which time the system was shut down so that the modifications and expansion under Phase II could take place.

Phase II, October 1975 - March 1980 (planned)

This phase, financed with capital-assistance funds by UMTA, calls for engineering design, construction, and fabrication of an expanded system as follows:

- Two additional stations (Towers Dormitory and Medical Center)
- Expansion of the maintenance facility
- Addition of a mini-maintenance facility
- Completion of the Engineering station
- Extension of the guideway to 3.4 miles of double-lane track
- Addition of 28 vehicles and retrofit of 45 vehicles for a total fleet of 73 vehicles
- Modifications to existing facilities, vehicles, and controls.

The objectives of this phase are to complete the system in accordance with WVU's basic needs, to refine the system technology, and to verify operations and maintenance costs.

The West Virginia Board of Regents, as the recipient of the capital grant, is serving as system manager. The Board engaged a three-member panel of engineering consultants and also retained the firm of Daniel, Mann, Johnson and Mendenhall to provide technical support services. The Boeing Aerospace Company contracted to build the new vehicles, to supply the automated computer control system, and to integrate all technical elements of the system. The Frederic R. Harris Company designed the guideways and stations and supervised their construction.

Operations of the expanded Phase II system started with the fall academic term in 1979.

6.1.5 Project Funding

The following tabulation endeavors to summarize funding for the various phases of the Morgantown project. Since grants extended over more than one phase, reliance has been placed on UMTA's budget requests and Congressional Appropriations Committee hearing records to establish project commitments. Only Federal funds are reported: amounts are in thousands of dollars.

Schedule		Fiscal Years									
Phase	Dates	1969	1970	1971	1972	1973	1974	1975	1976	1976TQ (3)	TOTAL
		(Thousands of Dollars)									
Planning	6/69-12/70	101	20	250							371
IA	12/70-10/73			5,741	23,521	14,173					43,435
IB	9/73-9/75						14,060	6,380			20,440
I O&M	10/75-7/78								5,833		5,833
II	9/76-3/80									63,600	63,600
TOTAL	6/69-3/80	101	20	5,991	23,421	14,173	14,060	6,380	(1) 5,833	(2) 63,600	133,679

Notes:

(1) Includes $1,500,000 in RD&D funds and $4,332,628 in capital grant funds

(2) Capital grant approved on September 20, 1976

(3) FY 1976 Transition Quarter

The above amounts include Federal funds for planning studies, engineering, technical support, development, construction, fabrication, procurement, testing, system operation, monitoring, and evaluation. The total commitments for Phase I, including the early feasibility study, the concluding period for system operations, and A&E services for the start of Phase II, amounted to $70.1 million. This amount incorporates $65.8 million in Section 6 RD&D funds and approximately $4.3 million in Section 3 capital funds. Phase II, including engineering, start-up costs, construction, fabrication, procurement, and monitoring is currently budgeted at $63.6 million in Section 3 capital funds. The total expected Federal expenditure for the Morgantown People Mover project, from its inception through Phase II, is thus established at $133.7 million. A more detailed analysis of system costs is given in Chapter 5.

6.2 SYSTEM ACCEPTANCE

Achieving system acceptance proved almost as difficult as designing and building the system. Two issues surfaced concerning acceptance of the system:

- o What constituted acceptable contract compliance, and how would this compliance be determined?
- o What system performance was acceptable to the University?

These issues were made complex by the realization that satisfactory contract compliance would not necessarily assure a system which the University would accept responsibility for operating. Furthermore, the system delivered at the end of Phase IB was not what WVU considered UMTA had promised at the start of the project or what WVU considered necessary to meet transportation needs between the campuses.

Contract Compliance

Verification of compliance with system specifications required agreement on such aspects as: tests to be performed, data to be collected, how measurements would be taken, procedures to be used in analyzing data, and the time periods in which compliance would be verified. In order to verify that the system was ready for passenger-carrying service, a combination of methods were used involving inspection, analysis, testing, and demonstration. Verification by these procedures was backed up by formal acceptance tests.

The Phase IB system Acceptance Test Plan was submitted to UMTA for approval and released in April 1972. This test plan identified those requirements in the Phase IB System Specification that would be verified by a formal test program. The test plan specified the success criteria for each requirement, the location where the test was to be conducted, the number of tests to be conducted for each requirement verification and the number of vehicles to be used during each verification. Detailed test procedures were developed which defined the manner in which the requirements were to be satisfied. The chronology at the end of this section includes the significant test activities, and indicates the magnitude and duration of efforts necessary to substantiate specification compliance.

The accumulation of 60 hours of running time completed the demonstration testing. The system was delivered by Boeing to UMTA on August 29, 1975, and accepted by UMTA on September 12, 1975. This acceptance was conditional upon the completion of certain open items and upon the resolution of waivers issued during the test program.

This test and specification verification program established contract compliance and marked the end of Phase IB. The program did reveal several necessary design changes to be incorporated in Phase II. These changes are described where appropriate in the technical assessment (see especially Chapters 3 and 4).

University Acceptance

Problems associated with University acceptance of the Morgantown People Mover system occurred early in the project. These problems arose over two concerns:

1. The UMTA decision to proceed with the project on terms other than those contained in the August 1970 WVU grant application, while retaining management control, created doubts about the University's role in the project and eventual ownership of the system.

2. The necessity for reducing project costs by limiting the scope of the system (number of stations and cars) and changing features of the system (increasing vehicle size and headways) raised questions about the capability of the system to meet WVU transportation requirements.

These concerns were expressed as early as November 12, 1970, in a letter from the President of WVU to UMTA. The reply, dated December 31, 1970, assured WVU that it was not UMTA's intent to commit the University beyond its ability to pay -- settlement was to be based on the residual value of the equipment and facilities. The response further explained that JPL was to be the overall system manager with the University participating in accordance with the project plan and work program.

Concerns about limiting construction were stated again in a letter from WVU dated February 10, 1971. UMTA replied on March 12, 1971, that it intended to carry out the project generally in accordance with present plans. At the same time, UMTA was searching for ways to reduce the total cost and impact of the project on R&D budgets for FY 1971 and FY 1972. The University was advised that it might be useful to consider the possibility of building and testing the first section with R&D funds. If this section proved satisfactory, the second section might be built and equipped with capital grant funds.

Considerably increased cost estimates for the full system (six stations and 100 vehicles) caused UMTA to separate the project into two phases. The Phase I grant contract between UMTA and WVU, to be financed under the R&D budget, was signed on September 4, 1971. Under this contract the installation would be limited to three stations connected by two miles of double-track guideway, and a control and communications system "required for automatic operation of the total transit system, designed to accommodate further expansion up to 100 vehicles and six stations."

This grant contract also stated: "UMTA will test and evaluate the system, and generate the necessary data to insure the reproducibility and utility of the system in nation-wide locations that may have similar transportation needs. Successful completion of this project will qualify this system concept for capital grants in appropriate locations."

This language was too ambiguous to satisfy WVU officials who felt that a complete transportation system had been promised. Since a three-station system would be unacceptable to WVU, they wanted assurance that a capital grant for completing the system would be guaranteed. Without this assurance, provisions were to be made for removal of the system. The following conditions were added to the 1971 grant contract:

> "Possession of all Personal Rapid Transit System-connected facilities and equipment shall rest in the Public Body (the West Virginia Board of Regents) after completion of the UMTA Technical Evaluation of the system. The Public Body may request removal of the facilities, if the system does not meet the intent of the specifications described hereafter and cannot be brought up to minimum performance standards within one year. Under these circumstances UMTA will take the necessary steps to remove the facilities."

After the 1972 elections a new administrator was appointed for UMTA. One of his first endeavors was to make an objective assessment of the problem. On assistance and an amendment to the Urban Mass Transportation Demonstration Grant Contract. Key provisions of this offer are summarized below:

1. In anticipation of successful completion of acceptance of the system by UMTA from the Boeing Aerospace Corporation, UMTA to receive and process a Capital Grant Application for:

    a. Eighty percent of the net project cost of:

        (1) System start-up costs and training during the first year of operation

        (2) A&E costs for Phase II consisting of:

            - two additional stations
            - connecting guideway
            - certain support facilities
            - costs of a three-member engineering consultant panel to be selected by the Board with concurrence of UMTA
            - costs of any system engineering for provision of necessary A&E support data.

    b. Subject to the availability of funds, UMTA to also approve a demonstration grant, providing for:

        - operating costs, including associated maintenance costs during the one-year start-up, training, and operations period
        - continued testing, monitoring and evaluation of the system
        - reporting the results of such testing, monitoring and evaluation.

2. A capital grant to be made to the Board for Phase II, providing for extension to a five-station configuration, provided, after a one-year operation period, the M-PRT system meets the specifications dated November 6, 1973, revised 12/20/73, 2/1/74, and 2/25/74, and that the estimated cost is reasonable and less than $53,800,000 in purchasing power as of July 1, 1974.

3. Upon completion of Phase I acceptance testing the Board agrees to accept the M-PRT system -- three stations, 45 vehicles and connecting guideway. If the system is not satisfactory at the end of the operating period, ownership is to revert to UMTA. UMTA has the option, with consent of the Board, to extend the operating period one additonal year during which it may attempt to provide a satisfactory system.

March 2, 1974, a telegram was sent to the West Virginia Board of Regents offering to amend the agreement of September 19, 1971, as follows:

- o Performance/Design Specification dated November 6, 1973 substituted for Requirements and Constraints Document.
- o Number of vehicles increased from 15 to 45.
- o UMTA and the Systems Contractor establish a comprehensive series of acceptance tests designed to verify compliance with system characteristics identified in detailed requirements of the performance/design specification.
- o Successful completion of acceptance testing to constitute the UMTA "technical evaluation" of the system by the University. UMTA to take steps to remove the system, at the request of the University, if the system fails the UMTA acceptance tests and cannot be made to satisfy the UMTA specification requirements within one year from scheduled acceptance test completion, planned for April 1975.
- o Parties agree to the maximum acceptable operating and maintenance costs and test criteria. Costs not to exceed $850,000 per year for the system. Conveyance dependability and safety to be verified by analysis at critical design reviews.
- o UMTA to fund 12 months of level-of-effort support by Boeing at the end of acceptance testing. During this period UMTA to conduct a system demonstration study to gather data necessary to establish user acceptance and system economics.

In the meantime, the question of University acceptance of the MPM system had been escalated to the Congressional level. In testimony during hearings on the FY 1975 appropriations before the Senate Committee on Appropriations on April 24, 1974, the UMTA Administrator stated:

> "I have indicated to the University that if we decide that a $50-million extension is not reasonable and the University then says they won't accept the three-station system, then we will take it out. I do not want the University to feel that we are not willing to take it out under any circumstances and that they can essentially ask us for anything they want. I feel we have to draw the line somewhere and express our willingness to live up to the original contract and take it out. If the system cannot be justified, then I would rather spend $7 million on taking it out than to spend $50 million on building a system that I cannot justify to you."

Negotiations continued throughout the following year to find an equitable basis for resolving the system-acceptance problem. On May 15, 1975, UMTA sent the West Virginia Board of Regents a letter containing an offer of contractual

4. The Board and UMTA mutually agree that compliance with the M-PRT Specification will be deemed to constitute satisfactory performance of Phase I.

5. UMTA and the Board agree that if the system does not perform satisfactorily and cannot be, or is not, made to perform satisfactorily during the one-year period, or the permitted one-year extension, ownership of the system, excluding land on which it is placed, is to revert to UMTA.

6. The Board agrees that at all times the contract is in force it will provide qualified monitoring and evaluation staff and will collect and record all pertinent data.

7. UMTA agrees to exercise all contract rights with Boeing Aerospace Company in order to bring about construction of the system in accordance with the M-PRT Specification.

Acceptance of the above offer (Amendment No. 4 to the Grant Contract) by the West Virginia Board of Regents on May 16, 1975 set the stage for system acceptance and the start of Phase II. On October 20, 1975, the UMTA Administrator approved Amendment No. 5, which stipulated that:

1. The Boeing Aerospace Company had completed its contract with UMTA and the government had accepted the system in accordance with provisions of the M-PRT Specification.

2. The University had agreed to accept ownership of the system.

3. The purpose of the amendment was to provide funds to the University to demonstrate the capability of the system -- $1,280,777 in addition to $695,000 previously provided under the grant.

4. Pursuant to Amendment No. 4, dated May 15, 1975, the government granted and conveyed to the Board, and the Board accepted, ownership of the Phase I system. Both parties agreed that the system operated satisfactorily during the test period from August 25, 1975 to August 29, 1975, inclusive.

5. The demonstration was to be carried out in accordance with the work statement dated October 16, 1975.

Acceptance of this amendment by the West Virginia Board of Regents on October 23, 1975 resolved most of the major issues and made it possible to proceed constructively with bringing the system up to full operational capability.

6.3 PROJECT MANAGEMENT

The Morgantown People Mover project has been subjected to a variety of project management methods and organizational arrangements. For example, since the start of the feasibility studies in 1969, there have been four different UMTA Administrators, Associate Research Directors, and Project Managers. The project is currently being administered by the third system management agency. The fact that the project progressed can be attributed to a few individuals within UMTA, the West Virginia Board of Regents, the University, Boeing and other suppliers, together with the engineering consultants of Frederic R. Harris, Inc. and the many construction contractors, all of whom were dedicated to the concept and mutually determined to see the project successfully completed.

There were both formal and informal organizational arrangements among the participants in the project. The formal relationships were required as a condition of the grants and contracts which financed the installation. Progress reports and reviews, control documentation, procedures for disposing of engineering change proposals, and reporting relationships among the organizational staffs comprise some of the formal relationships. The informal relationships grew up among the concerned individuals who had the authority, ability, and interest to see the project finished. These relationships are reflected in the ability to obtain timely information by telephone or to resolve technical issues through mutual professional respect and confidence in advance of documentation. It was the informal organizational relationships which made possible the accomplishments within tight time schedules. Formal contractual procedures, with the necessity for documentation, tended to delay decisions.

This project is the largest single development effort undertaken by UMTA. Much pioneering was done in sorting out appropriate roles for UMTA, the University, the West Virginia Board of Regents, system management, contractors, and suppliers.

6.3.1 Roles and Responsibility

One of the earliest problems occurred when UMTA decided to proceed with the project, but to retain management responsibility. The University grant application had anticipated local control of the project through a project director under the University President's Office. UMTA's decision to retain JPL left the University with an uncertain role. Discussions and correspondence between the principals began almost immediately and continued throughout the following five months. UMTA reiterated its intention to rely on a system manager with the University participating in accordance with the project plan and work program. The University was concerned about eventual ownership of the system and, though UMTA expressed its intent not to commit the University beyond its ability to pay for the system, UMTA was also concerned about reducing total costs. It was during an exchange of correspondence in March 1971 that UMTA suggested the possibility of building and testing the first section with R&D funds. If this section proved satisfactory, the second section would be built with a capital grant.

Through a series of MPM-related grants from UMTA, which ultimately reached a total of $2,096,777, the University acquired a continuing role. WVU was to make suggestions on design features, particularly those which affected architecture. In cooperation with the system manager, WVU would define system and major subsystem requirements as well as establish locations for the guideway, stations and other ground facilities. The University would take action to obtain the rights-of-way, perform liaison with the local community and hold public hearings. It would develop capabilities to take on the operating responsibility for the system.

The early fears that UMTA would not respond to the University's suggestions and recommendations and that the demonstration system, when completed, would not meet transportation requirements, led the University to insist on the right to reject the system and have UMTA remove the facilities if it did not meet certain conditions. The roles, relationships and responsibilities were eventually embodied in a grant contract which both parties signed on September 4, 1971. Until this contract was signed, an uneasy truce prevailed.

Discussions of roles, relationships and responsibilities were picked up by JPL when that organization was made system manager. JPL quickly learned that it would become the arbiter in disputes between UMTA and the University on technical features of the system, on the scope of the project and on costs. UMTA was determined to reduce the scope and cost to proportions manageable within budget limits. The University was equally determined to preserve as much of the original PRT concept as possible and the architectural integrity of the facilities. JPL, with engineering support from Frederic R. Harris, Inc., was required to "see what can be built for $20 million." With each answer, the scope and cost grew and the results never satisfied any of the parties.

JPL's recommended solution to this dilemma was the formation of a triumvirate consisting of UMTA, the University and JPL. Under this arrangement, there would be three-way responsibility for management decisions, with each party having an equal voice. UMTA rejected this arrangement and insisted on bilateral agreements. Relationships between UMTA and the University were defined by grant contract. Roles and responsibilities of JPL were defined in the interagency agreement between DOT and NASA. UMTA preferred to manage the project through these bilateral arrangements.

The requirement for an operational demonstration by October 1972 certainly did not permit the luxury of spending much time in clarifying roles, relationships, and responsibilities. However, had these issues been clearly resolved at the outset, the eventual threats to dynamite the system which surfaced in Congressional hearings could probably have been avoided.

6.3.2 Project Development Plan

The initial interagency agreement with JPL, approved on September 3, 1970, contemplated a study contract in which JPL was to provide technical support. JPL's primary effort was to prepare a Project Development Plan which was to be completed by November 30, 1970.

Events overtook this effort and on December 8, 1970, JPL's role was expanded to provide system management support. The first task in the amended interagency agreement was to prepare a Project Development Plan. While drafts of such a plan were attempted, the assessment team could not establish whether JPL ever completed an acceptable document.

The value of such a plan is that it provides a "road map" to help in managing a large, complex project. A Project Development Plan is one management tool to aid in reaching agreements among participants on roles, responsibilities, and relationships, as well as on project costs, scope, and time schedules. The process of preparing and getting concurrence on a Project Development Plan surfaces many problems and issues that are too easily overlooked, until they become major problems. Such plans often get out of date soon after they are prepared. Even so, they serve a useful second purpose. The Project Development Plan becomes a point of reference for changes, which are inevitable. The consequence of slipped time schedules, additions, or deletions to the scope, or the effects of high contract cost proposals can be judged. A Project Development Plan can help keep in perspective the myriad adjustments which occur in a dynamic undertaking, such as the MPM Project.

The lack of a Project Development Plan in the primitive stages of the project is considered to have contributed to some of the early difficulties. Only through considerable efforts in subsequent stages of the project was it eventually possible to resolve questions on the scope, scheduling, and cost of the project.

6.3.3 Control Documentation

The selection of the Boeing Aerospace Company as project manager in August 1971 brought extensive experience in the system management of military contracts to the MPM project. This experience was particularly reflected in the procedures used for management control documentation. Boeing established three types of documents:

1. Technical Requirements -- A set of specifications covering contract deliverables.
2. Program Compliance -- Descriptions of procedures to be used in proving that requirements were met.
3. Program Management -- Plans and reports for both external and internal use to control performance on scope, schedule and costs.

The following discussion summarizes the hierarchy of the three types of control documents. They do not represent all of the MPM project documentation.

Technical Requirements

The specifications followed a military-type format which established all requirements, described the quality assurance program to meet the requirements and tied down any unique designs chosen. The system specification for Phase IB was documented in "Morgantown PRT Specification SS-191-90000-3, Revision C," dated February 25, 1974.

Since the specification was a contractual document, revisions were governed by formal procedures. If a change became necessary, an "Engineering Change Proposal" was prepared and circulated. As soon as all parties agreed to the proposal, the change was made through a "Specification Change Notice." The change notices were distributed to specification holders. Revisions to the specifications were issued when enough Specification Change Notices had accumulated to make reprinting and distribution necessary.

The system specification was augmented by six subsystem specifications covering:

1. Software
2. Construction and Installation of Structures and Power Distribution System
3. Developmental Specification for Vehicles
4. Developmental Specification for Control and Communications System
5. Developmental Specification for Maintenance Facility and Equipment
6. Interface Control Specification.

The above were also contractual documents and were subject to required change procedures. Under each of these subsystem specifications there were second-tier specifications. For example, within the vehicle group there were specifications covering such items as the power collector, environmental control unit, and power train.

The function of the sixth item, the Interface Control Specification, was to maintain interface control among the other five specifications. As work progressed, there were increasing numbers of subsidiary specifications. Interface controls were necessary to insure concurrence throughout all the affected design specifications.

Detailed drawings accompanied each tier of specifications. They also became part of the documentation and were subject to the configuration control procedures.

Program Compliance

For Phase IB, compliance was demonstrated through three documents:

1. Phase IA Test Report, T-191-51000-10
2. System Acceptance Test Plan, 191-53000

3. Analysis Documentation: Reports covered longitudinal and interval controls, the collision avoidance system, passenger services, and the guideway structural analysis.

Four areas were documented under the System Acceptance Test Plan:

1. Morgantown Test and Demonstration Plan, D-191-54500. This plan set forth test procedures and test reports in such documents as "System Specification Test Requirements" and "System Acceptance Test Plan." These documents were related to the basic system specifications through the Morgantown Test and Demonstration Plan. In all, 28 test procedures were written covering all aspects of the system.

2. Factory-Level Tests and Qualification Tests. Sufficient factory-level acceptance tests were required to show that uniform quality and functional performance met requirements. Functional testing was required of such items as the propulsion system. An example of this documentation is "Qualification Test Bed Report for Vehicles," D-191-13501-1.

   Factory-level tests were conducted on the vehicles before they were moved to the Surface Transportation Test Facility (STTF) for vehicle acceptance tests.

3. Surface Transportation Test Facility. This test track, located at Kent, Washington, consists of a control and communications building, an asphalt track with control wiring, merges, and demerges. It was used for testing proposed changes to vehicles and for acceptance testing of vehicles before they were shipped to Morgantown. Two types of documentation resulted from STTF tests.

   a. Special Tests on Vehicles No. 1 and No. 2, TP-191-53602

   b. Vehicle Acceptance Tests, TP-191-53601

4. Electromagnetic Compatibility Test Plan, D-191-93005-1. An EMC analysis was covered by report D-191-93005-2. Three test plans covered:

   a. EMC Qualification, Brake Amplifier, TP-191-93006-1

   b. EMC Qualification, Vehicle Control and Communication System, TP-191-93006-2

   c. EMC Qualification, Surface Test Track Facility, TP-191-93006-3

   Report No. PP-191-54518 covers results of EMC tests at Morgantown.

Prescribed procedures were used throughout the system qualification and acceptance tests to resolve anomalies, failures, or other unplanned events. Each anomaly was reported in an "Unplanned Event Record" (UER). Once a UER was written, it had to be disposed of by a Material Review Board. Members of the engineering and quality control divisions, as well as a representative of the customer, comprised this board. If the anomaly required design changes, the UER was held open until the design was completed, accepted, and approved by the Material Review Board.

The same procedures were used for discrepancies in fabrication, testing, and operations. All were under supervision of the quality control division, which had to be satisfied that correct procedures had been followed and that results met requirements. Each of the test procedures set up its own requirements for logs and reports.

Program Management

Some program management documents were required by the contract, others were generated by Boeing for internal control. The following are examples of the 10-15 kinds of program management controls that were used.

1. Project Development Plan, D-191-60000-1. This plan described how the system was to be developed -- including personnel, relationships, methods, and procedures. It was regarded as a disciplined approach to project management. The plan provided guidance to A&E consultants, contractors, suppliers, and other project participants.

2. Project Configuration Management Plan, D-191-62410-1. This plan prescribed the management of hardware and software development and fabrication. It described procedures for making Engineering Change Proposals, for coordinating design changes, and for documenting the changes. It also covered requirements for changing test plans and procedures.

3. MPM Quality Control Plan, D-190-11101-1. The purpose of this plan was to insure that products reflect established engineering requirements. It also covered quality control requirements of subcontractors, manufacturing, and test organizations.

4. Operational Safety Plan, D-191-93300-1. This plan had two purposes:

a. It described the operational system at Morgantown for use by local emergency personnel so that they understood what the system was and how to respond to emergencies.

b. It was to be used by system operating personnel to take care of emergencies -- for example, where they could expect to encounter high voltages.

5. Morgantown Installation and Check-Out Plan, D-191-54000-1. This was a master plan for assembling the hardware at Morgantown, including how to do it, check it and then how to use the test procedures to prove it worked.

6. Vehicle System Manufacturing Plan, D-191-40000-1. This plan spelled out requirements for setting up production lines, parts, and material flow necessary to complete the assemblies.

7. Product Assurance Plan, D-191-60010-1. Product assurance covered reliability, maintainability, and safety. A separate staff organization oversaw the designers to insure these three factors were considered and addressed. This staff, while part of the Engineering Division, was separate from the designers. It reviewed and signed off on drawings, changes, and test plans. Another technical group within engineering was concerned with such subjects as the strength of materials for structures, the control of weight growth, and hazardous materials.

8. MPM Phase IB Maintenance Concept, D-191-94300. The system specification set out the general maintenance concepts. This document became the guide for equipment designers to insure the design could be maintained. For example, it required consideration of how a vehicle will be jacked or lifted so that accessibility could be designed accordingly.

9. Post Turnover Operations Requirements Plan, D-191-60011-1. This plan covered a phased transition from the system supplier to the operator.

10. Training Plan -- MPRT, D-191-60012-1. The plan for training WVU personnel for operating and maintaining the PRT system covered training classes, schedules, instructors, and curricula.

11. Procurement Plan, D-191-68000-2. This was a "make-or-buy" plan for Boeing guidance. Once a make-or-buy decision was made, it required top-level internal management review to change.

The following are two types of internal documentation:

12. Engineering Statement of Work and Schedule, D-191-60003-2. This document provided a complete description of all tasks. It included the overall schedule and all second, third, and fourth-tier subsidiary schedules.

13. Work Breakdown Structure and Dictionary, D-191-60004-1. The dictionary defines each unit of the breakdown so that costs can be collected on each element, subassembly, component, subsystem, and system. This control is established early in a project for managing costs.

In addition to the above, preparation of maintenance manuals was an important part of the documentation. The Maintenance Concept Manual, D-191-94300-1, was intended to document the maintenance requirements of the system as it was actually delivered. It required close coordination with configuration management to insure that the maintenance concepts reflected the delivered system. Preparation of these manuals was the responsibility of maintenance engineering.

Five basic types of maintenance manuals were prepared, covering:

1. Central Control and Communications System (four operator's manuals)
2. Station Control and Communications System (two maintenance manuals)
3. Vehicle Systems (one operator and four maintenance manuals)
4. Facilities, Power, and Ancillary Systems (one descriptive manual and three maintenance manuals)
5. Support Equipment (three operating and maintenance manuals)

Three major system operating manuals were prepared:

1. System Operations Description Manual
2. System Scheduled Maintenance Manual
3. Operational Safety Manual

Two additional documents covered:

1. Support Equipment Provisioning List, D-191-60013-1. This listed all support equipment delivered with the program.
2. Spares Provisioning List, D-191-60014-1. This defined the spare parts required for six months of operations.

From the above, it can be seen that the documentation required to effectively control and manage a project of this magnitude is extensive. The MPM project has acquired valuable experience with this type of control -- the requirements for and usefulness of such documents are now known. Other project sponsors and system suppliers can profit from this experience to better understand these management controls before embarking on similar projects.

6.4 PROJECT CHRONOLOGY

The following chronology of events lists the significant milestones which paced the MPM project. It depicts both the tightness of the schedules which governed the project and the magnitude of tests and other accomplishments during the time period.

June 27, 1967	WVU submits proposal to HUD to study transportation system for Morgantown.
March 28, 1969	Letter from Senator Robert C. Byrd to the Secretary of Transportation forwards a letter from WVU President and the Mayor of Morgantown soliciting support for the demonstration project.
April 3, 1969	Letter from Congressman Harley O. Staggers to the Secretary of Transportation requests a meeting with University and city officials.
April 28, 1969	Secretary Volpe agrees to a meeting.
June 20, 1969	UMTA approves demonstration grant for feasibility study of Morgantown transportation system.
August 5, 1970	Feasibility study completed, recommending the Alden Self-Transit System as the most suitable.
August 15, 1970	WVU grant application for an estimated $18-million project ($13.5 million Federal and $4.5 million local contributions) to demonstrate the feasibility of a new system concept of public transportation is submitted to UMTA.
September 3, 1970	DOT selects JPL for system design and development of a Project Development Plan. (Accepted by NASA -- September 11, 1970 and by JPL -- September 24, 1970).
October 20, 1970	Frederic R. Harris, Inc. is retained to provide preliminary engineering support.
December 1, 1970	UMTA requests data from WVU for Environmental Impact Statement (EIS).
December 8, 1970	UMTA approves task order amendment for JPL to provide system management support (approved by DOT -- December 11, 1970; by NASA and JPL -- January 4, 1971).
December 17, 1970	M-PRT Project Requirements and Constraints Document is issued.

January 13, 1971	JPL issues RFP for control and communications system.
January 19, 1971	JPL issues RFP for vehicle system.
February 11, 1971	First notices of public hearings published.
February 26, 1971	Public hearings on PRT project are held in Morgantown.
March 10, 1971	Frederic R. Harris, Inc. contract is amended to provide A&E services for surveying, mapping, soil borings, and preliminary engineering design.
March 15, 1971	WVU submits proceedings of public hearings and draft EIS.
April 21, 1971	At meeting with Congressman Staggers, President Harlow of WVU, Dr. Pickering of JPL, and UMTA Administrator Villarreal discuss necessity for reducing project costs to $20 million; directed JPL to review what can be done and to present results on April 29, 1971.
April 29, 1971	UMTA and University officials agree to reduction in scope. Consideration is given to future expansion with capital grant funds. WVU retains the option to reject the system if it is not satisfactory.
April 30, 1971	Morgantown Project Safety Program Plan is completed, submitted to UMTA on May 6, 1971.
May 6, 1971	Boeing and Bendix are selected as vehicle and control and communications contractors, respectively.
July 8, 1971	Decision is made to retain four-wheel steering due to sharp curves at stations.
July 14, 1971	"Tin" building located on WVU campus and on system right-of-way is demolished.
July 30, 1971	Telephone call to JPL advises that contract negotiations have ceased and that DOT/UMTA has selected another contractor for project management.
August 16, 1971	Selection of the Boeing Aerospace Company as system manager is announced.
September 4, 1971	Phase I grant contract between UMTA and WVU is signed.

September 15, 1971	Draft EIS is circulated (comments due October 30, 1971).
September 30, 1971	JPL contract is terminated.
October 9, 1971	Ground-breaking ceremony is held near the Engineering Sciences Building.
October 11, 1971	First construction contract is awarded to Frank Irey, Jr., Inc.
October 15, 1971	Second construction contract is awarded to Melbourne Brothers Construction Co.
December 20, 1971	Trumbull Corporation submits low bid for third construction contract covering the maintenance building, three stations, and a segment of guideway. The bid exceeds cost estimates, necessitating a review of future phases of the project.
January 4, 1972	Final construction contract awarded for Phase IA.
February 8, 1972	Definitive contract signed with Boeing for system management.
March 1972	First vehicle is factory complete and tested under manual control at STTF.
May 1972	Second factory-complete vehicle is the first to operate under complete automatic control at STTF.
September 5, 1972	Vehicle No. 1 successfully completes manual-control test runs between the Maintenance Facility and Engineering station at Morgantown.
September 20, 1972	First tests of vehicle operations with automatic controls are started at Morgantown.
September 26, 1972	Last two of four vehicles arrive at Morgantown (fifth vehicle is to remain at Seattle for testing).
October 24, 1972	Dedication and public demonstration of MPM system with three vehicles. Federal, state, and local officials participate.
January 1973	Major system safety review is initiated.
March 15, 1973	Electric power applied to rails between the Maintenance Facility and Beechurst station.
May 11, 1973	Vehicles tested over full 2.2 miles of guideway.

May 23, 1973	The Consulting Engineers Council of the U.S. (now the American Consulting Engineers Council) announces Client Honor Award to UMTA and Engineering Firm Honor Award to Frederic R. Harris, Inc. for the Morgantown System as one of the top 10 engineering achievements.
June 1973	Phase IA construction is completed. Control and communications system installation is completed and checked out. System integration testing and prequalification testing is completed.
July 10, 1973	Elevated guideway over Monongahela Boulevard is given an Award of Merit as one of the 18 most beautiful steel bridges erected in 1972, by the American Institute of Steel Construction.
September 4, 1973	Letter contract is issued to Boeing to start Phase IB.
September 26, 1973	Phase IA testing is completed with four vehicles operating continuously. During Phase IA, the system has accumulated 17,332 miles of operation.
October-November 1973	Critical design reviews for Phase IB are completed.
December 1973	Phase IB testing initiated at the Boeing facility in Kent, Washington, with the start of VCCS Engineering Model functional testing; completed in six weeks.
January 1974	Testing of vehicle elements started at a qualification test bed facility in Kent, Washington; completed in April 1974.
	Construction contract for Phase IB guideways and structure awarded to Frank Irey, Jr., Inc.
March 1974	Beginning of software development and system simulations to verify software characteristics and capabilities; continued throughout Phase IB.
April 3, 1974	Phase IB definitive contract is signed by Boeing and UMTA.
June 1974	Qualification testing of production model VCCS units is started; completed in July 1974.
	Checkout of the Control and Communications System (C&CS) and the Structures and Power Distribution System (S&PDS) installation at Morgantown is begun; completed in November 1974.

	Tests of first production vehicle are started at STTF; tests of first two vehicles completed in September 1974.
September 1974	The first two production vehicles complete formal acceptance tests at STTF and are delivered to Morgantown in October 1974.
October 15, 1974	Running tests with production vehicles are started at Morgantown.
November 1974	Guideway heating system is completed and filled with propylene glycol. System integration testing with one instrumented vehicle starts at Morgantown.
	Integrated system testing initiated at Morgantown. Tests begin with one instrumented vehicle. Successful completion of system testing with one vehicle followed by tests with 2, then 3, 6, 16, 23, and 25 vehicles.
January 1975	Review of software development problems reveals need for significant changes in organization and activities.
January 16, 1975	Vehicle fails to switch left, impacts on bumper rails. Investigation finds short-circuits in control-loop wiring in guideway expansion points.
February 1975	Final vehicle is rolled out from factory for STTF acceptance testing.
May 16, 1975	UMTA and the West Virginia Board of Regents agree on the conditions for accepting the Phase I MPM system and on the scope and terms for completing Phase II.
July 1975	Balance of production vehicles is shipped to Morgantown.
August 15, 1975	All system testing except five-day test is completed.
August 25-29, 1975	Five-day operational system demonstration testing is satisfactorily completed with accumulation of 60 hours of running time. A fleet of 25 vehicles used to verify the capability of the system under control of the final software. System is delivered from Boeing to UMTA.
September 12, 1975	UMTA conditionally accepts the MPM system.
October 3, 1975	MPM is opened for limited public use.

October 23, 1975	UMTA conveys, and the West Virginia Board of Regents accepts, the Phase I MPM system. UMTA issues grants for support of one-year operating period and engineering design of the Phase II system. Full public passenger service commences.
December 11, 1975	MPM ridership reaches a peak of 9,836 in one day.
January 21, 1976	MPM ridership reaches a new daily maximum of 10,588.
February 19, 1976	Extreme winter weather, condensation on the power rails and a fire on the power rail supports shut the system down for 17 days while repairs are made.
March 8, 1976	MPM service begins, but with shuttle bus back-up to insure students can get to classes.
April 28, 1976	Second semester of 1975-1976 academic year ends. Ridership during this semester ranges from 2,295 to 4,220 per day.
September 28, 1976	MPM system has carried one million passengers and transports about 12,000 passengers each week day. The Morgantown bus system also reaches the million-passenger mark.
September 30, 1976	UMTA and West Virginia Board of Regents agree on capital-grant contract. UMTA provides $63.6 million for system expansion; the Board of Regents agrees that the MPM has been delivered in compliance with contractual requirements. Phase II is inaugurated.
February 25, 1977	Proposal to raise student transportation fee to $35 per semester causes protests.
March 2, 1977	Plans and specifications for Phase II construction are released.
April 21, 1977	West Virginia Board of Regents ratifies a $41.7-million contract with Boeing for vehicles and control systems. Low bid received from the Dick Corporation for construction of guideways, stations, power distribution systems, and mechanical heating systems.
July 3, 1978	MPM system is shut down for Phase II modifications. Phase I O&M is ended.

FOOTNOTES AND REFERENCES

1. Kobe Steel has the license from Boeing to manufacture and sell the system in Japan.

2. Boeing Aerospace Co., Central Control Operators Manual, M-PRT-2-2.1, March 1, 1975.

3. Boeing Aerospace Co., Morgantown Personal Rapid Transit System Final Report, D191-60016-1, November 1975.

4. Calculated from Boeing test data. Assessment team measurements for Walnut/Engineering and Beechurst/Engineering correlate well with Boeing data; however, measurements were not made for Walnut/Beechurst.

5. Boeing Aerospace Co., Morgantown Personal Rapid Transit Longitudinal Control System Design Summary, Final Report, Report No. UMTA-MA-06-0048 75-4, December 1975.

6. West Virginia University, Morgantown Personal Rapid Transit System Progress Reports - First, Second, Third, Fourth Quarters of the First Operational Year.

7. Boeing Aerospace Co., Performance/Design and Qualification for the Phase IB Control and Communication System of the Morgantown PRT System S191-93002-2, January 1974.

8. West Virginia University, Morgantown Personal Rapid Transit System Progress Reports - Second Quarter of the Initial Operating Year and Fourth Quarter of the Initial Operating Year.

9. Interview with Boeing personnel.

10. Boeing Aerospace Co., General Specification for Performance/Design and Qualification for the Morgantown Operational Personal Rapid Transit System, SS191-90000-3C, November 6, 1973.

11. Boeing Aerospace Co., Post-Turnover Operational Requirements Plan, D191-60011-1, May 1974.

12. Boeing Aerospace Co., Design Data Book, Volume I - MPRT System Description, Phase IB, September 1975.

13. Department of Transportation Memorandum dated February 7, 1975 from Acting Director, Office of Noise Abatement, TST-50 to Mr. S. A. Barsony, Acting Director, Morgantown Division, URD-30.

14. Boeing Aerospace Co., System Test Acceptance Plan, D191-53000.

15. Boeing Aerospace Co., Collision Avoidance System Analysis Report, D191-93012, Table IA pp 15-22.

16. Dahir, S. H. and Lantz, H., Laboratory Evaluation of Pavement Surface Texture Characteristics in Relation to Skid Resistance.

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Boeing Aerospace Co., System Operation Description Manual, M-PRT-1-1,

Boeing Aerospace Co., Construction Management Program Plan, Morgantown PRT System Development, D191-70000-1, September 8, 1971.

Boeing Aerospace Co., M-PRT System Test/Demonstration Report, T191-51000-10, July 20, 1973.

Boeing Aerospace Co., M-PRT Phase IB Maintenance Concept, D191-94300, October 18, 1973.

Boeing Aerospace Co., Morgantown PRT Project Configuration Management Plan - Phase IB, D191-62410-2, March 9, 1974.

Boeing Aerospace Co., MPRT Phase IB Product Support Critical Design Review, March 25 and 26, 1974.

Boeing Aerospace Co., Product Assurance Plan - Morgantown PRT Program, D191-60010-1, April 19, 1974.

Boeing Aerospace Co., Procurement Plan (Make/Buy Plan) Morgantown PRT Project Phase IB, June 5, 1974.

Boeing Aerospace Co., Product Specification for Detailed Design for Maintenance Application Modules - Morgantown Personal Rapid Transit System, S191-93508-2, August 7, 1974.

Boeing Aerospace Co., Training Plan - Morgantown PRT Program, D191-60012-1, August 29, 1974.

Boeing Aerospace Co., Morgantown System Test and Demonstration Plan, D191-54500, September 19, 1974.

Boeing Aerospace Co., Phase-Over Plan - Morgantown PRT Program, D191-60015-1, December 20, 1974.

Boeing Aerospace Co., M-PRT STTF/Vehicle Special Test S/N 6 & 7 (Vehicle #1 & #2), TR191-53602, May 29, 1975.

Boeing Aerospace Co., *M-PRT Anomaly Reaction*, TP191-54529, July 3, 1975.

Boeing Aerospace Co., MPRT System Checkout - 23 Vehicles, TR191-54528, August 8, 1975.

Boeing Aerospace Co., *Software Operating Instructions Manual*, D191-93513-1, August 11, 1975.

Boeing Aerospace Co., *M-PRT Passenger Service and Traffic Model Analysis Report*, D191-93013, August 21, 1975.

Boeing Aerospace Co., *M-PRT Longitudinal Control System Analysis Report*, D191-93010, August 22, 1975.

Boeing Aerospace Co., *EMC Analysis - Morgantown PRT System - Phase IB*, D191-93005-2, September 8, 1975.

Boeing Aerospace Co., *MPRT Phase II Demonstration Plan*, D191-94101-1, January 7, 1977.

Martin, James E.; *An Assessment of the Operational Readiness of the Morgantown PRT (MPRT) System*, Report No. UMTA-WV-06-0009-75-1, October 1975.

UMTA, Memorandum from Associate Administration for Transit Assistance to the Administrator; *Subject: Approval - UMT Capital Grant Project No. WV-03-0006*, Amendment No. 2, September 30, 1976.

West Virginia Board of Regents, *General Specification for Performance/Design and Qualification for the Phase II Morgantown Operational Personal Rapid Transit System*, Specification No. WVBOR-TD-001 Exhibit E, December 20, 1976.

APPENDIX A: AGT ASSESSMENT MEASURES, MORGANTOWN

AGT ASSESSMENT MEASURES

MORGANTOWN
PHASE I

1.0 GENERAL SYSTEM DESCRIPTION

1.1 FLEET SIZE

Total Number of Vehicles	45 (B5a1)*
Peak Hour Operating Vehicles	16-22 (G8d)
Off Peak Operating Vehicles	16-22 (G8d)

1.2 TRAVELING UNIT SIZE

Maximum Number Vehicles/Train	1 (B5a1)

1.3 STATIONS

Number of Stations	3 (B5a1)
Average Station Spacing (mi)	1.05 (B5a1)
Number of Type, On-Line	2 (B5a1)
Off-Line	1 (B5a1)
Capacity (psgrs/hr.), Boarding	1680- 5040 (B5a1)
De-Boarding	1680- 5040 (B5a1)
Train Screens	Yes (E8d)
Coordinated Station/Vehicle Doors	No (E8d)
Number of Vehicle Channels/Station	2 or 6 (E8d)
Maximum Number of Vehicles/Channel	4 (E8d)

1.4 GUIDEWAY/NETWORK CONFIGURATION

Type (shuttle, loop, line-haul,radial, grid)	line-haul (E8d)
Length (mi), Below-grade	0 (B5a1)
At-grade	0.7 (B5a1)
Above-grade	1.4 (B5a1)
Single-lane	0 (B8a1)
Double-lane	2.1 (B8a1)
Total	2.1 (B8a1)

* Data reference code - see p. A-14 for definition

1.0 GENERAL DESCRIPTION (con't)

1.5 SYSTEM PERFORMANCE

Maximum Theoretical Single Direction Line Capacity (psgrs/hr/lane)	5040 ((F1d)
Maximum Practical Single Direction Line Capacity (psgrs/hr/lane)	3300 (B5a1)
Minimum Theoretical Headway (sec)	15 (B5a1)
Maximum Grade (%)	10 (H8c)
Uni- or Bidirectional Service	Bi (E8d)
Cruise Velocity (mph)	15;22.5;30 (B5a1)
Maximum Velocity (mph)	30 (B5a1)
Average Velocity (mph)	9.8 - 18.9 (F7d)

1.6 MODES AND HOURS OF OPERATION

Fixed Schedules, peak/off-peak (hrs/day)	None (E8d)
Variable Schedules, peak/off-peak (hrs/day)	10/0 (H8d)
Demand Responsive, peak/off-peak (hrs/day)	0/3.5 (H8d)
Mixed Modes, peak/off-peak (hrs/day)	0/0 (H8d)
Fixed Routes, peak/off-peak (hrs/day)	0/0 (H8d)
Variable Routes,peak/off-peak (hrs/day)	6.75/6.50 (H8d)
Dispatching, peak/off-peak (hrs/day)	6.75/3.0 (H8d)
Total Operating Hours/Day, peak/off-peak	6.75/6.50 (H8d)
Total Days of Operation/week/year	7/341 (H8d)
Seasonal Adjustment to Operation Time and Mode	Yes (H8c)

1.7 DEGREE OF AUTOMATION

Total Employees 1st Shift/2nd Shift/Total.	33.2/20.4/61 (F1d)
Employee/Vehicle Ratio 1st Shift/2nd Shift (Employees per Shift/Active Fleet Size	1.14/0.70 (E8d)
System Man-Hour Ratio (monthly manhours/monthly vehicle hours)	1.79 (E8d)

1.7 DEGREE OF AUTOMATION (con't.)

Total Employee Breakdown, (Staff and Administration/Operators/Maintenance/Store-keepers) 14/12/31/4 (H8c)

1.8 PASSENGER ADMISSION PROCESSING

Fare Payment Location
Pre- or On-Board . . . . Pre - (E8d)

Fare Payment Method
To Attendant, Automatic, Honor System . . . . Automatic (E8d)

Fare Payment Value Type; C-cash, EC-exact coins,
TO-token, TI- ticket, CA- card, P-pass . . . . EC,CA,P (E8d)

Fare Computation
Predetermined or Variable . . . . Predetermined (E8d)

Method of Admission Control
Gate, Turnstile, etc. . . . . Turnstile (E8d)

Barrier Operation Initiation; C-coin,
TO-token, TI-ticket, CA-card, P-pass . . . . CA, P (E8d)

Barrier Activation by, M-mechanical,
PH-photoelectric, MA-magnetic . . . . MA (E8d)

Passenger Information Aids; PA/PV-Pre-
recorded Audio/Visual, S-signs,AG-active graphics . . . . . . PA, PV, S, AG (E8d)

Passenger Flow, Method: Controlled or Uncontrolled . . . . Controlled (E8d)
Type; S-signs, M-markings,
R-railings . . . . S (E8d)

1.9 SERVICE AREA DESCRIPTION

Type Center Served ; CBD, Employment
Commercial, Educational, Airport, etc. . . . . CBD, University (E8d)

Interface with Other Transit Modes . . . . Bus (E8d)

Service Area (mi^2) 2.33* (F8d)

Service Area Density, daytime
(persons/mi^2) 7200 (F8d)

* Includes area served by feeder bus

2.0 SOCIOLOGICAL CHARACTERISTICS

2.1 PASSENGER COMFORT

Privacy: Total Vehicle Floor Space (ft^2)	67.7 (B8d2)
Total Seats/Vehicle	8 (B5a1)
Total Standees/Vehicle	13 (B5a1)
Area/Seat (ft^2)	7.0 (B8d2)
Area/Standee (ft^2)	2.0 (B8d2)
Seat Availability, peak/off-peak (%) (Number of Seats available/mean number passengers carried)	40/100 (E8d)
Seat Availability, average per weekday	100 (F8d)
Temperature (F^o)	65-75 (B2a3)
Humidity, during A/C (%)	60 (B2a3)
Heating (total kw, kw per passenger).	4.5, 0.21 (B8a4)
Cooling (Tons/Tons per psgr at__^{o}F)	2/0.1 @ 100 (B8a4)
Total Air Circulation (cfm)/% Makeup Fresh Air	
Maximum Vertical Acceleration (g) @___H_z)	0.14 @ 8 (B5a1)
Lateral Acceleration (g)	0.12 @ 2 (B5a1)
Longitudinal Jerk (g/s)	0.33 (B5a1)

2.2 CONVENIENCE/LEVEL OF SERVICE

Mean Number of Transfers (Number of psgrs required to transfer/total psgrs)	0 (B8a1)
Mean Wait Time, peak/off-peak (min)	0.5-2.5/1.25-2.5 (F8d)
Maximum Wait Time (min)	5 (B5a1)
Mean Travel Time (min)	2.75,5.25,6.95 (F8d)
Boarding Time (sec/psgr)	1.08 (F8d)
Special E & H Provisions	None[1] (E8d)
Station Access via L-level, S-stairs, E-elevator, ES- escalators	S, E[2] (E8d)
Non-Stop or Multistop Service	Non-stop (E8d)
Ratio of Seats to Standing Spaces	0.62 (B8d1)

[1] Being incorporated in Phase II
[2] Elevators to be added During Phase II

2.0 SOCIOLOGICAL CHARACTERISTICS (con't.)

2.3 CONVENIENCE/LEVEL OF SERVICE (con't.)

Trip Lengths (mi) 0.447, 1.655, 2.102 (B8a1)
Mean Trip Length (mi) Weekday/Weekend 1.625/1.667 (F8d)
Trip Speeds (mph) 9.8/18.9/18.1 (F8d)
Average System Speed including in-station
Dwell time (mph) 10.6 (F8d)

3.0 OPERATIONAL STATISTICS

Patronage (average Psgrs. carried),	per Month[1]	181,709	(F8d) (H8d)
	per Year[2]	1,885,095	(H8d)
Average Vehicle-Miles Traveled,	per Month[1]	47,935	(H8d)
	per Year[2]	587,073	(H8d)
Average Vehicle Hours Operated,	per Month[1]	5,616	(F8d)
	per Year[2]	68,507	(F8d)
Average Passenger-Miles Traveled,	per Month[1]	294,178	(F8d)
	per Year[2]	3,051,874	(F8d)

4.0 COSTS

4.1 DUPLICATION CAPITAL COSTS (1000's of dollars, 1978)

Total System, Total $66,500 (F8d)
per single-lane mile $12,600 (F8d)

Maintenance & Support Equipment, Total $1,220 (F8d)
Cost/Vehicle . . . . $ 42 (F8d)

Control & Communication System, Total $11,600 (F8d)
Cost/single-lane mile $ 2,205 (F8d)
Guideways, Total $22,100 (F8d)
Average cost per single-lane mile . . . . $ 4,200 (F8d)
Power & Utilities, Total . . . . $ 3,130 (F8d)
Average cost per single-lane mile $595 (F8d)
Stations, Total $2,950 (F8d)
Average cost per station $983 (F8d)
Vehicles, Total $10,200 (F8d)
Average cost per vehicle $227 (F8d)
Engineering & Project Management, Total $15,300 (F8d)
Percent of Total $23% (F8d)

Notes: [1]Average for period Sept. 1977-July 1978
[2]Second operational year, Sept. 1976-Aug.1977

4.2 O & M COSTS (July 1977 - June 1978)

Total O&M Cost	$1,225,579	(G8c)
per average non-winter month[1]	95,762	(F8d)
per average winter month[2]	131,240	(F8d)
Maintenance Labor Cost	410,723	(G8c)
per average non-winter month	32,666	(F8d)
per average winter month	38,911	(F8d)
Operations Labor Cost	149,505	(G8c)
per average month	12,459	(F8d)
Electrical Power Cost	98,150	(G8c)
per average non-winter month	7,576	(F8d)
per average winter month	9,990	(F8d)
Guideway Heating Cost	74,892	(G8c)
per average winter month	13,464	(F8d)
Average O&M Cost Performance		
per vehicle-mile	2.26	(F8d)
per passenger place-mile	0.11	(F8d)
per passenger carried	0.63	(F8d)
per passenger-mile	0.38	(F8d)

Notes:
[1]Non-winter months include March through November
[2]Winter months include Dec, Jan, Feb.

5.0 MAINTENANCE AND DEPENDABILITY

5.1 CONVEYANCE DEPENDABILITY

1976	Winter	67.6	(E8d)
	Non-Winter	94.3	(E8d)
	Annual Average	86.5	(E8d)
1976-77	Winter	88.4	(E8d)
	Non-Winter	96.1	(E8d)
	Annual Average	94.2	(E8d)
1977-78	Winter	95.2	(E8d)
	Non-Winter	97.2	(E8d)
	Annual Average	96.6	(E8d)

DOWNTOWN EVENT STATISTICS

1975-76	No. of Events	765	(G8d)
	MTBF (hrs.)	3.32	(F8d)
	MTTR (hrs.)	0.45	(F8d)
1976-77	No. of Events	514	(G8d)
	MTBF (hrs)	6.84	(F8d)
	MTTR (hrs)	0.37	(F8d)
1977-78	No. of Events	325	(G8d)
	MTBF (hrs)	8.08	(F8d)
	MTTR (hrs)	0.22	(F8d)

5.0 MAINTENANCE AND RELIABILITY (con't.)

5.1 RELIABILITY (con't.)

Mean Time to Restore System (hr)(CV), Winter	0.42 (390%) (G8d)
Non-Winter	0.21 (90%) (G8d)
Average Number of Vehicles Available for Service	17.5

5.2 MAINTENANCE

Active Fleet Storage, Total Ready Vehicle Spaces	10 (B8a4)
ft^2 per vehicle	230 (F8d)
Average Number of Ready Vehicles in Storage Peak/Off-Peak	3/3 (E8d)
Area of Enclosed Maintenance Facility (ft^2), Total . . .	12,600 (F8d)
per active vehicle . . .	434 (F8d)
Maintenance Labor Total (man-hours/month)*, Winter . . .	6,535 (F8d)
Non-Winter . . .	5,695 (F8d)
Vehicle Wash Bays, Total	1 (E8d)
Number of Vehicles per bay	29 (E8d)
Vehicle Maintenance Lifts, Total	2 (E8d)
Number of Vehicles per lift	14.5 (E8d)
Total Vehicle Maintenance Bays	7 (E8d)
Number of Vehicles per bay	4.1 (E8d)
Average Number of Vehicles Through Maintenance/day . . .	7 (H8c)

* Averages for July, 1977-June 1978

6.0 ENVIRONMENT

6.1 NOISE (Exterior to Vehicle)

Maximum Noise in station, 3 feet from closed vehicle doors	NCA 60 (B2a3)
Maximum Noise at 25 feet from side of Guideway centerline (dbA)	73 @ 30 mph (F7d)

7.0 LAND USE

7.1 SPACE REQUIREMENTS

Single-Lane At-Grade Guideway with vehicle, Overall Envelope Width (ft)	12.6 (C8d5)
Overall Envelope Height (ft)	10 (E8d)

---

* Averages for Oct., 1976 - June, 1977

7.0 LAND USE (con't.)

7.1 SPACE REQUIREMENTS (con't.)

Single-Lane Elevated Guideway with vehicle, Overall Envelope Width (ft)	12.6	(C8d5)
Overall Envelope Height (ft)	12	(C8d5)
Double-Lane At-Grade Guideway with vehicle, Overall Envelope Width (ft)	22.4	(C8d5)
Overall Envelope Height (ft)	10	(E8d)
Double-Lane Elevated Guideway with vehicle, Overall Envelope Width (ft)	22.4	(C8d5)
Overall Envelope Height (ft)	12	(C8d5)
Stations Space Requirements, Completed Engineering station, including ramps, (acres)	2	(F2d)
Maintenance and Other Facilities space Requirements, Total Area (acres)	4	(E8d)
acres/ system mile	1.9	(E8d)

8.0 SAFETY & SECURITY

8.1 INCIDENTS (October 1975-July, 1978)

Incidents/10^6 passenger-miles	16.5	(F8d)
Fatalities/10^6 passenger-miles	0	(G8c)
Injuries/10^6 passenger-miles	4.6	(F8d)
Assaults	0	(H8c)
Vandalism	0	(H8c)

No. of Incidents with,

o no damage per 10^6 vehicle-mile	55.3	(F8d)
o minor damage per 10^6 vehicle-miles	9.94	(F8d)
o moderate damage per 10^6 vehicle-miles	9.32	(F8d)
o serious damage per 10^6 vehicle-miles	0	(F8d)

9.0 OPERATIONAL/TECHNICAL PERFORMANCE

9.1 EFFICIENCY (Sept 1977-July 1978)

Routing efficiency (%) (Minimum O/D mileage/ actual trip mileage)	100	(E8d)
Average Load Factor (%) (psgr. trip miles/psgr. place miles)	29.2	(F8d)
Average Vehicle Productivity (psgr. trips/veh hrs)	32.4	(F8d)
Labor Productivity (psgr. place mi/person-hrs)	101	(F8d)
Employee Productivity (monthly veh-mi/employee)	785	(F8d)
Operating Fleet Dwell Time (%) (Total station dwell time/total operating time)	41	(F8d)

10.0 OPERATION/TECHNICAL DESCRIPTION & PERFORMANCE

10.1 VEHICLE

Overall Length (ft)	15.5	(B8a2)
Overall Width (ft)	6.67	(B8a2)
Overall Height (ft)	8.75	(B8a2)
Empty/Gross Weight (lbs)	8578/11,800	(B8a2)
Number of Seats	8	(B8a2)
Number of Standing Places	13	(B8a2)
Max. Accel. Capability (g)	0.14	(B4a8)
Average Service Acceleration (g)	0.0625	(B8a1)
Average/Maximum Emergency Deceleration (g)	0.35/0.50	(B8a1/H8c)
Average Service Deceleration (g)	0.0625	(B8a1)
Maximum Speed Capability (mph)	30	(B8a1)
Maximum Cruise Speed (mph)	30	(B8a1)
Vibration Acceleration (RMS g's), Vertical	0.14	(B5a1)
Lateral	0.12	(B5a1)
Maximum Interior Noise at Vehicle Center (dbA), At Cruise speed	79	(F8d)
Speech Interference Level (SIL in db)	69	(F8d)
Maximum Jerk (g/s), Accelerating	0.33	(B5a1)
Decelerating	0.3	(B2a3)

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*Includes trips to football games on 2 out of 8 weekend days

10.1 VEHICLE (con't.)

Tire Life, New/Recapped (mi)	25,000/50,000 (H8c)
Design Load (lbs)	3150 (B8a1)
Design Life (yrs), Chassis	10 (B2a7)
Passenger Module	10 (B2a7)

10.2 VEHICLE COMMAND & CONTROL

Normal Accel/Decel Limit (g)	0.0625 (B8a1)
3 σ Velocity Control Error (ft/sec)	$\pm$ 1.98 (B3a6)
Maximum Velocity Safety Error (ft/sec)	+ 3.3, -4.0 (D8a)
Maximum Headway Control Interval Error (sec)	$\pm$ 1.1 (B8a1)
Stopping Precision, Max Deviation (in).	$\pm$ 3 (B5a1)

10.2 STEERING & SWITCHING

Type Steering, DA-double ackerman, SA-single ackerman DW-double wagon, SW-single wagon	DA (B8a1)
Type Guidance, A-active, or P-passive, U-unconstrained, or C-constrained	A, U (B8a1)
Preload to Guideway Steering Rail (Lbs)	180 (B8a4)
Minimum Radius of Curvature (ft)	30 (B8a1)
Inherent Uni- or Bi-Direction Capability	Uni- (B8a1)
Guidewheel Liftime (mi)	4500 - 7500 (G8c)
Type Switch, VB-vehicle based or GB-guideway based, PE-positive entrappment, NE- no entrappment	VB, NE (B8a1)
Switch Response Time, Lock-Lock plus verification (sec).	1.28 (B8a4)

10.4 PROPULSION & BRAKES

Type Motor.	Rotary DC (B8a1)
Motor Rating kw @ rpm continuous	94/2730 (B8a1)
Type of Service Brakes	Hydraulic/Disks (B8a1)
Brake Life (mi)	1500 - 2000 (G8c)
Maximum Brake Delay (sec)	0.19 (B4a1)
Type Emergency Brake	Hydraulic/Disks (B8a4)
Brake Redundancy	Yes (B8a4)

10.0 OPERATION/TECHNICAL DESCRIPTION & PERFORMANCE (con't.)

10.5 POWER DISTRIBUTION

Type Power Distributed Along Guideway	575 vac, 3ϕ, Δ (B8a4)
Power Pickup Brush Lifetime (mi)	1500-3000 (H8c)
Voltage Regulation, Full to No-Load (%)	+5, -10 (B8a4)
Number of Propulsion Power Supply Substation/Rating (KVA).	3/1000 (B8a4)
Number of Housekeeping Power Supply Substation	4 (B8a4)
Standby Power Generation for Propulsion	No (B8a4)
Standby Power Generation for Lighting or Other Safety Reasons	Yes (B8a4)
Total Electrical Power Consumption (kwh), Average Winter Month*	297,000 (H8d)
Non-Winter Month*	218,500 (H8d)

10.6 SUSPENSION

Automatic Leveling, Yes or No	Yes (B8a1)
Air Suspension, Yes or No	Yes (B8a1)
Average Vehicle Floor Height Variation in Station (in)	Negligible (E8d)
Type Overload Protection	Limit Switch (B8a4)

10.7 GUIDEWAY

Type Materials, Structural	COR-ten Steel (E8d)
Type Support Columns	Concrete (E8d)
Type Running Surface	Concrete (E8d)
Maximum Elevated Span (ft)	158 (C8e5)
Maximum Deflection (% of span length) Horizontal	0.067 (D2a)
Vertical	0.10 (D2a)
Maximum Static Load (lbs/ft length) Single Lane Elevated Section	840 (C2e5)
Double Lane Elevated Section	1,680 (C2e5)
Guideway Heating System for Ice & Snow Removal	Gas Fired Boilers/ Hot Water & Glycol (B8a4)

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* Averages over Oct., 1976 - June, 1977

10.8 STATIONS

Type, F-freestanding or I-incorporated in other structure	F (E8d)
Type Construction	Concrete (E8d)
Capacity, per loading berth (psgrs/hr)	840 (F8d)
Capacity, per unloading berth (psgrs/hr)	840 (F8d)
Maximum Passengers that can be handled at any one time on platform	100 (F8d)
Information/Graphics; S-signs, AG-active graphics	S, AG (E8d)

10.9 VEHICLE DOORS

Type, S-sliding, P-plug, F-folding	S (E8d)
Number of doors per vehicle side	1 (E8d)
Door Capacity (Number of psgrs abreast)	1 (E8d)
Number of Steps/Step Height (in)	0/0 (E8d)
Number of Door Failures/1000 veh-mi*	0.42 (G8d)
Type Door Actuator & Control	Electric Motor, force Level Recycle (B8a4)

* Average for Sept. 8, 1975 - May 15, 1976

DATA REFERENCE CODE FOR MORGANTOWN ASSESSMENT

The coding system is intended to aid in qualifying the data by giving some information regarding its source, method of generation, and interpretation. In addition, where a document or other report serves as a source, its reference number is given.

First Level (The Source)

A - Publication sponsored by manufacturer, developer, or supplier (e.g., paper, report, brochure, etc.)

B - Official document prepared by manufacturer, developer, or supplier (these may be deliverable reports required by the contract or detailed engineering documentation)

C - Technical study by independent (third-party) individual or organization (e.g., this assessment falls within this category)

D - Correspondence or interviews with manufacturer, developer, or supplier

E - Estimate or observation by the assessment contractor

F - Study, calculation, survey, or other measurement by the assessment contractor

G - Documentation, logs, or data tabulation prepared by system owner or operator

H - Correspondence or interviews with system owner or operator

Second Level (How Data Was Generated)

1 - Results of study (e.g., preliminary engineering) or simplified calculations

2 - Results of in-depth, detailed engineering design or rigorous calculations

3 - Results of simulation

4 - Results of prototype tests (typically, engineering tests at a test track) performed by manufacturer or developer

5 - Results of tests of operating hardware on-site by manufacturer or developer (typically, these tests are full system integration such as might be performed before customer acceptance)

6 - Same as (5), except performed by system owner or operator

7 - Results of tests performed on a system or item of equipment after at least one year of operational service

8 - Results of an operational system (e.g., operating characteristics and statistics, O & M costs, capital costs, etc.)

Third Level (By Whom Data Interpreted)

a - By manufacturer of developer

b - By independent (third-party) individual or organization

c - By system owner or operator

d - By the assessment contractor

e - By UMTA

Fourth Level (Actual Document Reference)

If data is taken from a document or a report, it will be referenced with a number and included in the list of references to the report.

EXAMPLE:

(B2a42)

B: Manufacturer's engineering documentation

2: Resulting from detailed engineering

a: Interpreted by manufacturer

42: Numbered reference giving author, title, report no., publisher, date

REFERENCES TO ASSESSMENT MEASURES TABLE

1. Boeing, Final Report, D191-60016-1, November 1975.

2. Boeing, Vehicle Drawing

3. Boeing, Performance/Design and Qualification for the Morgantown Operational Personal Rapid Transit System, SS 191-9000-3C, November 6, 1973

4. Boeing, Design Data Book - Vol I, MPRT System Description - Phase IB, D191-93000-1, September 9, 1975

5. N. D. Lea Transportation Research Corporation, Lea Transit Compendium Vols II & III No. 3, 1975 and 1976.

6. Boeing, Morgantown Personal Rapid Transit Longitudinal Control System Design Summary, Report No. UMTA-MA-06-0048-75-4, December, 1975.

7. Boeing, Development Specification for Performance/Design and Qualification for the Vehicle - Morgantown Personal Rapid Transit System, S191-90070-2, November 22, 1971.

8. Boeing, STTF/Vehicle Special Test S/N 6 & 7 (Vehicles No. 1 and 2) TR 191-53602, May 29, 1975.

APPENDIX B: ADDITIONAL MAINTAINABILITY DATA

TABLE B.1a: RANKING OF UNSCHEDULED MAINTENANCE ACTIONS FOR VEHICLE SUBSYSTEM: FIRST OPERATIONAL YEAR

Subsystem	Maintenance Actions	% of Subsystem Total
1. Electrical	901	28.7
2. Braking	374	11.9
3. Hydraulics	325	10.4
4. Psgr. Module	302	9.6
5. Steering	278	8.9
6. General/Unclassified	237	7.5
7. Propulsion	198	6.3
8. Pneumatics	188	6.0
9. Chassis	178	5.7
10. Environmental Control	156	5.0
TOTAL	3,137	100.0

TABLE B.1b: RANKING OF UNSCHEDULED MAINTENANCE ACTIONS FOR VEHICLE SUBSYSTEM: THIRD OPERATIONAL YEAR

Subsystem	Maintenance Action	% of Subsystem Total
1. General/Unclassified	532	21.3
2. Electrical	523	20.9
3. Psgr. Module	300	12.0
4. Steering	253	10.1
5. Propulsion	185	7.4
6. Braking	180	7.2
7. Pneumatics	165	6.6
8. Chassis	154	6.1
9. Hydraulics	134	5.4
10. Environmental Control	75	3.0
TOTAL	2,501	100.0

TABLE B.2a: RANKING OF UNSCHEDULED MAINTENANCE ACTIONS FOR CONTROL AND COMMUNICATIONS SUBSYSTEM: FIRST OPERATIONAL YEAR

Subsystem	Maintenance Actions	% of Subsystem Total
Fare Collection	1,188	66.0
VCCS	205	11.4
Communication	141	7.8
CAS	83	4.6
Operator System	72	4.0
Surveillance	62	3.5
DHU/DA	49	2.7
TOTAL	1,800	100.0

TABLE B.2b: RANKING OF UNSCHEDULED MAINTENANCE ACTIONS FOR CONTROL AND COMMUNICATIONS SUBSYSTEM: THIRD OPERATIONAL YEAR

Subsystems	Maintenance Actions	% of Subsystem Total
Fare Collection	1,181	60.7
Operator System	431	22.1
VCCS	227	11.7
CAS	39	2.0
Surveillance	34	1.7
Communication	23	1.2
Station and Guideway CCS	6	0.3
DHU/DA	5	0.3
TOTAL	1,946	100.0

TABLE B.3a: RANKING OF UNSCHEDULED MAINTENANCE ACTIONS FOR OTHER SUBSYSTEMS: FIRST OPERATIONAL YEAR

Subsystem	Maintenance Actions	% of Total
Structures and Power Distribution	197	37.7
Software	127	24.3
Computer	90	17.2
Support Equipment	88	16.8
Boiler Plants	21	4.0
TOTAL	523	100.0

TABLE B.3b: RANKING OF UNSCHEDULED MAINTENANCE ACTIONS FOR OTHER SUBSYSTEMS: THIRD OPERATIONAL YEAR

Subsystem	Maintenance Actions	% of Total
Structures and Power Distribution	312	50.8
Support Equipment	169	27.5
Computer	88	14.3
Boiler Plants	45	7.3
TOTAL	614	100.0

TABLE B.4: UNSCHEDULED MAINTENANCE
FIRST OPERATIONAL YEAR

Subsystem	Total Actions	Failure	Excess Wear	Adjust-ments	Undefined Actions
VEHICLE:					
Unclassified	237	72	0	0	165
Psgr. Module	302	30	0	133	139
Hydraulics	325	211	0	100	14
Pneumatics	188	91	0	80	17
Chassis	178	123	10	9	36
Steering	278	102	0	121	55
Braking	374	138	78	113	45
Electrical	901	334	276	96	195
Propulsion	198	99	11	43	45
ECU	156	28	0	88	40
TOTAL	3,137	1,228	375	783	751
C&CS:					
VCCS	205	94	0	92	19
Operator System	72	26	0	4	42
CAS	83	7	0	52	24
DHU/DA	49	16	0	4	29
Communication	141	85	0	24	32
Fare Collection	1,188	72	0	145	971
Surveillance	62	13	0	28	21
TOTAL	1,800	313	0	349	1,138
COMPUTER:					
Computer	90	42	0	11	37
Software	127	76	0	3	48
TOTAL	217	118	0	14	85
S&PDS:					
S&PDS	197	44	0	34	119
Boiler Plants	21	6	0	9	6
TOTAL	218	50	0	43	125
OTHER:					
Support Equipment	88	43	0	13	32
FIRST YEAR TOTAL	5,460	1,752	375	1,202	2,131

TABLE B.5: UNSCHEDULED MAINTENANCE
THIRD OPERATIONAL YEAR

Subsystem	Total Actions	Failure	Excess Wear	Adjust-ments	Undefined Actions
VEHICLE:					
Unclassified	532	4	0	11	517
Psgr. Module	300	84	5	58	153
Hydraulics	134	72	21	21	20
Pneumatics	165	71	29	27	38
Chassis	154	59	35	26	34
Steering	253	97	54	51	51
Braking	180	59	41	39	41
Electrical	523	296	101	19	107
Propulsion	185	125	6	17	37
ECU	75	37	5	12	21
TOTAL	2,501	904	297	281	1,019
C&CS:					
VCCS	227	133	2	19	73
General C&CS	4	0	0	0	4
Passenger Display	3	1	0	0	2
CAS	39	16	0	4	19
Operator Console	428	122	2	194	110
Communication	23	16	0	4	3
DHU/DA	5	3	0	0	2
Fare Collection	1,181	947	11	77	146
G/W C&CS	2	0	0	0	2
Surveillance	34	22	0	0	12
TOTAL	1,946	1,260	15	298	373
COMPUTER:					
Computer	88	41	4	5	38
Software	0	0	0	0	0
TOTAL	88	41	4	5	38
S&PDS:					
S&PDS	312	78	6	21	207
Boiler Plants	45	10	2	9	24
TOTAL	357	88	8	30	231
OTHER:					
Support Equipment	169	71	11	16	71
THIRD YEAR TOTAL	5,061	2,364	335	630	1,732

APPENDIX C: QUESTIONNAIRES USED IN THE PUBLIC ATTITUDE SURVEY

QUESTIONNAIRE

USED IN THE PUBLIC ATTITUDE

SURVEY OF RIDERS

PHASE I ASSESSMENT

OF THE MORGANTOWN PRT SYSTEM

(8)

PERSONAL INFORMATION

So that we can group answers for people with similar backgrounds, we would like to get some information about you. Could you check the items that apply to you? [Interviewer hands the questionnaire form to the interviewee for him to supply this information.]

26. In a typical week, for trips to work, school, shopping, or other locations, do you usually (twice a week or more): [CHECK ALL THAT APPLY]

1 __ Drive your car alone or with family? __

2 __ Car pool or van pool? __

3 __ Take bus transit? __

4 __ Take subway or railroad? __

5 __ Take taxi? __

6 __ Other ______________________ __

27. What is the zip code of your permanent residence?

______________________ __

28. What is your occupational classification?

1 __ Faculty 2 __ Student __

3 __ Staff 4 __ Other ______________ __

29. What was your immediate family's income (before taxes) in 1976?

1 __ Less than $5,000 2 __ $5,000-$9,999 __

3 __ $10,000-$14,999 4 __ $15,000-$19,999 __

5 __ $20,000-$29,999 6 __ $30,000-$49,999 __

7 __ Over $50,000 __

30. Do you have the use of an automobile in Morgantown?

1 __ Yes 2 __ No __

31. What is your age? ______________________ __

32. Sex: 1 __ Male 2 __ Female __

OMB No. 04-S77011
Approval Expires 9/30/77

U.S. DEPARTMENT OF TRANSPORTATION

URBAN MASS TRANSPORTATION ADMINISTRATION

CENTURY RESEARCH CORPORATION

1977 AGT ACCEPTANCE SURVEY

Interview No. _______ __

Interviewer No. _______ Name ____________ __

Date: ____________________ __

Day of Week: 1 __ M 2 __ T 3 __ W 4 __ Th __

5 __ F 6 __ Sat 7 __ Sun __

Starting time: ______________ __

Interview location: ______________________ __

Hello! I'm ____________. The Century Research Corporation of Arlington, Virginia is conducting a survey of riders and non-riders of the Morgantown Personal Rapid Transit (PRT) system for the U. S. Department of Transportation. We would appreciate it if you would give us your opinions so that this transit system, or future systems to be installed elsewhere, can be most useful.

This survey is authorized by Section 6 of the Urban Mass Transportation Act of 1964 as amended through November 26, 1974 wherein the Secretary of Transportation is authorized to request and receive such information or data as he deems appropriate from public or private sources. While you are not required to respond, your cooperation is needed to make the results of this survey comprehensive, accurate, and timely.

1. How many times have you ridden the Morgantown PRT?

1 __ Just once or twice __

2 __ 3-4 times __

3 __ 5-10 times __

4 __ More than 10 times __

5 __ Never [Proceed to NON-RIDER SURVEY, Q. 19] __

2. Have you ridden the PRT in the past two months?

1 __ Yes 2 __ No [If No, proceed to Q. 19] __

(2)

3. About how often have you used the PRT for the following purposes?

		Never	Occas-ionally	Fre-quently	
a.	Going to/from work	1	2	3	—
b.	Going to/from school	1	2	3	—
c.	Changing classes	1	2	3	—
d.	Personal business	1	2	3	—
e.	Shopping	1	2	3	—
f.	Social/Recreation	1	2	3	—
g.	Other [SPECIFY]	1	2	3	—

______________________ —

4. Most of the time when you ride the PRT:

		Yes	No	
a.	Is the temperature inside the vehicle comfortable?	1	2	—
b.	Do you feel drafts?	1	2	—
c.	Is it humid inside?	1	2	—
d.	Is the lighting inside the vehicle adequate?	1	2	—
e.	Is the ride quiet enough?	1	2	—
f.	Is the platform crowded?	1	2	—
g.	Is the ride bumpy?	1	2	—
h.	Does the vehicle sway much from side to side?	1	2	—

5.a. Does the vehicle speed usually seem:

1 __ Too slow? 2 __ Too fast? —

3 __ About right? 4 __ DK/No opinion —

Comment: ______________________ —

b. Is the vehicle layout (seating arrangement, entry and exit provisions, etc.):

1 __ Unsatisfactory? 2 __ Adequate? —

3 __ Very satisfactory? 4 __ DK/No opinion —

[If Unsatisfactory,] In what way?

______________________ —

6.a. Which way would you prefer to be seated during a trip on this type of vehicle?

1 __ Forward 2 __ Backward —

3 __ Sideways 4 __ No preference —

b. Would you like to have the PRT vehicles in Morgantown larger, smaller, or are they about the right size?

1 __ Larger 2 __ Smaller 3 __ Right size —

(3)

7. Here are some possible features of a PRT station. How much would you want these features within the station? [SHOW CARD]

		Very little				Very much	
a.	Rest rooms	1	2	3	4	5	—
b.	Drinking fountain	1	2	3	4	5	—
c.	Food dispensers	1	2	3	4	5	—
d.	Drink dispensers	1	2	3	4	5	—
e.	Comfortable seats	1	2	3	4	5	—
f.	Air conditioning	1	2	3	4	5	—
g.	Heating	1	2	3	4	5	—
h.	Trash containers	1	2	3	4	5	—
i.	Bulletin board	1	2	3	4	5	—
j.	Schedules	1	2	3	4	5	—
k.	Reading Material	1	2	3	4	5	—
l.	Television	1	2	3	4	5	—

What else would you want in the stations?

______________________ —

8.a. How often have you had to wait longer than you thought was reasonable for the PRT?

1 __ Very rarely 2 __ Sometimes 3 __ Very often —

[If sometimes or very often,]: To what extent do the following delay situations bother you:

		Not at all	Moder-ate	Very much	DK/No opin.	
b.	Having to wait for the vehicle to arrive?	1	2	3	4	—
c.	Having to wait excessively for the vehicle to move to the loading platform?	1	2	3	4	—
d.	Having to wait excessively for the vehicle to open its doors after it has arrived at the loading position?	1	2	3	4	—
e.	Having to wait excessively for the vehicle to move after you have boarded it?	1	2	3	4	—
f.	Having to wait excessively because there are crowds waiting for transportation?	1	2	3	4	—

g. About how long have you had to wait?

______________________ —

9. a. Do you think passengers should be allowed to carry bicycles, skis, wheelchairs, band equipment, or other bulky items on the PRT?

1 __ Yes 2 __ No [If No,] Why not? __________ —

b. Are there special times when transporting such items would be most desirable?

1 __ Yes 2 __ No [If Yes,] When? __________ —

(4)

10. With regard to fears or worries you might have had when using the PRT, please indicate the frequency of the following: [SHOW CARD]

	Never				Frequently	
a. Being caught by a door	1	2	3	4	5	__
b. Falling (in car, station, or on guideway)	1	2	3	4	5	__
c. Being assaulted	1	2	3	4	5	__
d. Being crushed by the crowd	1	2	3	4	5	__
e. Being electrocuted	1	2	3	4	5	__
f. Being stranded (vehicle stopped at remote location)	1	2	3	4	5	__
g. Collision	1	2	3	4	5	__
h. Being chilled or frozen	1	2	3	4	5	__
i. Being overcome by heat	1	2	3	4	5	__
j. Fire	1	2	3	4	5	__
k. Missing classes or appointments	1	2	3	4	5	__
l. Being lost	1	2	3	4	5	__

Any other fears or worries? ______________ __

11.a. Have you experienced sudden stops or starts while riding the PRT?

1 __ Yes 2 __ No [If YES,]: __

b. Did you consider the sudden stops or starts serious, or just an annoyance?

1 __ Serious 2 __ Just an annoyance __

12. Under usual circumstances (loads you would be carrying, weather, etc.), what is the farthest that you think is reasonable to walk to reach the PRT?

1 __ Less than ¼ mile 2 __ ¼ mile 3 __ ½ mile __

4 __ 3/4 mile 5 __ 1 mile 6 __ Over 1 mile __

13. How confident do you feel about being able to take emergency action if necessary on the PRT: [SHOW CARD]

	Low confidence				High confidence	
a. Getting out of doors?	1	2	3	4	5	__
b. Getting out of rear window?	1	2	3	4	5	__
c. Getting on or off the guideway?	1	2	3	4	5	__
d. Getting help for injured or ill passengers?	1	2	3	4	5	__

(5)

	Yes	No	
14.a. Do you like the architecture of the stations?	1	2	__

Why do you say that? ______________ __

b. Do you think the guideway architecture is obtrusive?	1	2	__

Why do you say that? ______________ __

c. Are the vehicle and station areas generally clean and well maintained?	1	2	__

In what respects? ______________ __

15. Would you prefer the PRT guideway to be:

1 __ Underground? 2 __ Elevated? __

3 __ At ground level? __

Why is that? ______________ __

16. What would you like to hear from the public address system in the vehicle or station?

1 __ Official announcements 2 __ News __

3 __ Weather forecasts 4 __ Music __

5 __ Time signals 6 __ Advertising __

Other [SPECIFY] ______________ __

17. What is the maximum that you think is reasonable to pay for:

a. A one-way ride on the PRT?

1 __ 0-10¢ 2 __ 11-15¢ 3 __ 16-20¢ 4 __ 21-25¢ __

5 __ 26-30¢ 6 __ 31-50¢ 7 __ 51-75¢ 8 __ Over 75¢ __

b. A weekly pass or ticket?

1 __ 0-$1.00 2 __ $1.01-$2 3 __ $2.01-$3 __

4 __ $3.01-$4 5 __ $4.01-$5 6 __ $5.01-6 __

7 __ $6.01-$7 8 __ Over $7.00 __

c. A one semester pass or ticket?

1 __ 0-$5.00 2 __ $5.00-$10 3 __ $10.01-$20 __

4 __ $20.01-$30 5 __ $30.01-$40 6 __ $40.01-$50 __

7 __ $50.01-$60 8 __ Over $60 __

18. As an over-all rating, how would you rate the PRT? [SHOW CARD]

Very unsatisfactory				Very satisfactory	
1	2	3	4	5	__

[Proceed to PERSONAL INFORMATION]

NON-RIDER SURVEY

We would like to find out why you don't use the PRT (or why you have stopped using it).

19. Here are some possible reasons for not riding the PRT. Please tell me which are reasons why you do not presently ride the PRT. (CHECK ALL THAT APPLY)

1 __ The PRT does not go where you want to travel.

2 __ You don't understand how to use the system to get to your destination.

3 __ The PRT does not run at the times you could use it.

4 __ You do not think the ride is worth the fare.

5 __ You do not think the PRT is mechanically safe.

6 __ You think you might be molested or a victim of a crime in a station or vehicle.

7 __ You think the PRT would be too crowded for comfort.

8 __ You think the ride would be more uncomfortable than is acceptable to you.

9 __ Your physical condition would make it difficult to enter or leave a station or vehicle.

10 __ You think you would have to wait longer than is reasonable for a vehicle.

11 __ You think you might be stranded because of a stoppage.

12 __ You think it would be difficult to take tools, packages, or other bulky items on the PRT.

13 __ Any other reasons? [SPECIFY] ____________

____

20. Here are a few statements some people have made about the PRT. To what extent do you agree with these statements? [SHOW CARD]

The system is so complicated that people have trouble using it.

Strongly agree				Strongly disagree		Don't know/ No opinion
1	2	3	4	5	6 __	

The PRT vehicles are attractive.

Strongly agree				Strongly disagree		Don't know/ No opinion
7	8	9	10	11	12 __	

21. Would you prefer the PRT guideway to be:

1 __ Underground? 2 __ Elevated?

3 __ At ground level?

22. If you were to ride the PRT, under usual circumstances (loads you would be carrying, weather, etc.), what is the farthest you would be willing to walk to catch the PRT?

1 __ Less than ¼ mile 2 __ ¼ mile 3 __ ½ mile

4 __ 3/4 mile 5 __ 1 mile 6 __ Over 1 mile

23. If you were to ride the PRT, what would you like to hear on the public address system in the vehicle or at the station?

1 __ Official Announcements 2 __ News 3 __ Weather forecasts

4 __ Music 5 __ Time signals 6 __ Advertising

Other? ______________________________

24. What is the maximum that you think is reasonable:

a. To pay for a one-way ride on the PRT?

1 __ 0-10¢ 2 __ 11-15¢ 3 __ 16-20¢ 4 __ 21-25¢

5 __ 26-30¢ 6 __ 31-50¢ 7 __ 51-75¢ 8 __ Over 75¢

b. To pay for a weekly pass or ticket?

1 __ 0-$1.00 2 __ $1.01-$2 3 __ $2.01-$3

4 __ $3.01-$4 5 __ $4.01-$5 6 __ $5.01-$6

7 __ $6.01-$7 8 __ Over $7.00

c. For a student to pay for a one-semester pass or ticket?

1 __ 0-$5.00 2 __ $5.01-$10 3 __ $10.01-$20

3 __ $20.01-$30 5 __ $30.01-$40 6 __ $4.01-$50

7 __ $50.01-$60 8 __ Over $60

25. As an over-all rating, how would you rate the PRT? [SHOW CARD]

Very unsatisfactory				Very satisfactory
1	2	3	4	5

[Proceed to PERSONAL INFORMATION]

QUESTIONNAIRE

USED IN THE PUBLIC ATTITUDE

SURVEY OF NON-RIDERS

PHASE I ASSESSMENT

OF THE MORGANTOWN PRT SYSTEM

(4) PERSONAL INFORMATION

So that we can group answers for people with similar backgrounds, we would like to get some information about you. Could you check the items that apply to you? [Interviewer hands the questionnaire form to the interviewee for him to supply this information.]

26. In a typical week, for trips to work, school, shopping, or other locations, do you usually (twice a week or more): [CHECK ALL THAT APPLY]

1 __ Drive your car alone or with family? __

2 __ Car pool or van pool? __

3 __ Take bus transit? __

4 __ Take subway or railroad? __

5 __ Take taxi? __

6 __ Other ____________ __

27. What is the zip code of your permanent residence?

____________ __

28. What is your occupational classification?

1 __ Faculty 2 __ Student __

3 __ Staff 4 __ Other ____________ __

29. What was your immediate family's income (before taxes) in 1976?

1 __ Less than $5,000 2 __ $5,000-$9,999 __

3 __ $10,000-$14,999 4 __ $15,000-$19,999 __

5 __ $20,000-$29,999 6 __ $30,000-$49,999 __

7 __ Over $50,000 __

30. Do you have the use of an automobile in Morgantown?

1 __ Yes 2 __ No __

31. What is your age? ________ __

32. Sex: 1 __ Male 2 __ Female __

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Approval Expires 9/30/77

UNITED STATES
DEPARTMENT OF TRANSPORTATION
URBAN MASS TRANSPORTATION ADMINISTRATION

CENTURY RESEARCH CORPORATION

1977 AGT ACCEPTANCE SURVEY

Interview No. ________ __

Interviewer No. ______ Name __________ __

Date: ____________ __

Day of Week: 1 __ M 2 __ T 3 __ W 4 __ Th __

5 __ F 6 __ Sat 7 __ Sun __

Starting time: ____________ __

Interview location: ____________ __

Hello! I'm ____________. The Century Research Corporation of Arlington, Virginia is conducting a survey of riders and non-riders of the Morgantown Personal Rapid Transit (PRT) system for the U. S. Department of Transportation. We would appreciate it if you would give us your opinions so that this transit system, or future systems to be installed elsewhere, can be most useful.

This survey is authorized by Section 6 of the Urban Mass Transportation Act of 1964 as amended through November 26, 1974 wherein the Secretary of Transportation is authorized to request and receive such information or data as he deems appropriate from public or private sources. While you are not required to respond, your cooperation is needed to make the results of this survey comprehensive, accurate, and timely.

1. How many times have you ridden the Morgantown PRT?

1 __ Just once or twice 2 __ 3-4 times __
3 __ 5-10 times 4 __ More than 10 times __
5 __ Never [Proceed to NON-RIDER SURVEY, Q. 19] __

2. Have you ridden the PRT in the past two months?

1 __ Yes 2 __ No [If No, proceed to Q. 19] __

We would like to find out why you don't use the PRT (or why you have stopped using it).

*U.S. GOVERNMENT PRINTING OFFICE : 1980 0-622-968/1305

(2) 19. Here are some possible reasons for not riding the PRT. Please tell me which are reasons why you do not presently ride the PRT. (CHECK ALL THAT APPLY)

NON-RIDER SURVEY

1 __ The PRT does not go where you want to travel.

2 __ You don't understand how to use the system to get to your destination.

3 __ The PRT does not run at the times you could use it.

4 __ You do not think the ride is worth the fare.

5 __ You do not think the PRT is mechanically safe.

6 __ You think you might be molested or a victim of a crime in a station or vehicle.

7 __ You think the PRT would be too crowded for comfort.

8 __ You think the ride would be more uncomfortable than is acceptable to you.

9 __ Your physical condition would make it difficult to enter or leave a station or vehicle.

10 __ You think you would have to wait longer than is reasonable for a vehicle.

11 __ You think you might be stranded because of a stoppage.

12 __ You think it would be difficult to take tools, packages, or other bulky items on the PRT.

13 __ Any other reasons? [SPECIFY] ____________

20. Here are a few statements some people have made about the PRT. To what extent do you agree with these statements? [SHOW CARD]

The system is so complicated that people have trouble using it.

Strongly disagree				Strongly agree	Don't know/ No opinion
1	2	3	4	5	6 __

The PRT vehicles are attractive.

Strongly disagree				Strongly agree	Don't know/ No opinion
1	2	3	4	5	6 __

(3) 21. Would you prefer the PRT guideway to be:

1 __ Underground? 2 __ Elevated?

3 __ At ground level? Why? ________________

22. If you were to ride the PRT, under usual circumstances (loads you would be carrying, weather, etc.), what is the farthest you would be willing to walk to catch the PRT?

1 __ Less than ¼ mile 2 __ ¼ mile 3 __ ½ mile

4 __ 3/4 mile 5 __ 1 mile 6 __ Over 1 mile

23. If you were to ride the PRT, what would you like to hear on the public address system in the vehicle or at the station?

1 __ Official Announcements 2 __ News 3 __ Weather forecasts

4 __ Music 5 __ Time signals 6 __ Advertising

Other? ____________________

24. What is the maximum that you think is reasonable:

a. To pay for a one-way ride on the PRT?

1 __ 0-10¢ 2 __ 11-15¢ 3 __ 16-20¢ 4 __ 21-25¢

5 __ 26-30¢ 6 __ 31-50¢ 7 __ 51-75¢ 8 __ Over 75¢

b. To pay for a weekly pass or ticket?

1 __ 0-$1.00 2 __ $1.01-$2 3 __ $2.01-$3

4 __ $3.01-$4 5 __ $4.01-$5 6 __ $5.01-$6

7 __ $6.01-$7 8 __ Over $7.00

c. For a student to pay for a one-semester pass or ticket?

1 __ 0-$5.00 2 __ $5.01-$10 3 __ $10.01-$20

3 __ $20.01-$30 5 __ $30.01-$40 6 __ $4.01-$50

7 __ $50.01-$60 8 __ Over $60

25. As an over-all rating, how would you rate the PRT? [SHOW CARD]

Very unsatisfactory				Very satisfactory
1	2	3	4	5