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Summary of DPM Winterization Test Activities

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Final Report

U.S. Department of Transportation
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16. Abstract

This report describes and summarizes the test activities and presents the results of a 2-year winter-operation test program. Three potential candidate Downtown People Movers (DPM) systems were evaluated in suitably cold environments under a variety of severe winter weather conditions to determine each system's capabilities and limitations. Separate reports for each contractor contain the detailed results of their test program. The three contractors involved were as follows:

Westinghouse Electric Corporation - Report No. UMTA-MA-06-0081-81-2
Otis Elevator Company - Report No. UMTA-MA-06-0081-81-3
Universal Mobility, Incorporated - Report No. UMTA-MA-06-0081-81-4

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PREFACE

This report describes and summarizes the test activities and results of a 2-year winter-operation test program for three technologically-different automated guideway transit systems (AGT's). The program was funded by the U.S. Department of Transportation's Urban Mass Transit Administration through its Office of New Systems Applications. The program was managed by the Transportation Systems Center (TSC) of Cambridge MA, and Lawrence P. Silva and Neil G. Patt served as technical monitors for the program. George Anagnostopoulos of TSC provided technical site support throughout the test portion of the program.

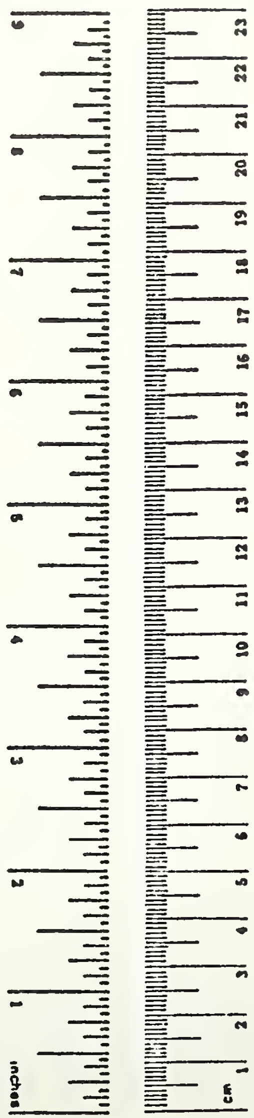
The objective of the program was to determine if fully-automated Downtown People Mover (DPM) systems could provide reliable urban transportation in severe winter climates. The demonstration documented the operational capabilities and limitations of the Westinghouse, Universal Mobility and Otis People Movers through a series of subsystem and system-level tests over a range of naturally occurring and man-made winter weather conditions. The testing included such diverse areas as traction and propulsion, braking and steering, power collection, vehicle and guideway electronics, switching, door operation and overall system performance. The information derived from the program should be of benefit to other AGT manufacturers and the candidate DPM cities in the northern United States.

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

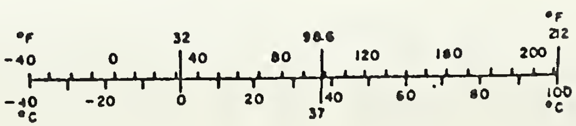
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	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	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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LIST OF ABBREVIATIONS

AGT	Automated Guideway Transit
ATO	Automatic Train Operation
ATSS	Auxiliary Traction Subsystem
DPM	Downtown People Mover
ECU	Environmental Control Unit
ISO	International Standardization Organization
LIM	Linear Induction Motor
MSV	Maintenance Support Vehicle
MTBF	Mean Time Between Failures
MTTR	Mean Time to Restore
MZG	Minnesota Zoological Garden
NOAA	National Oceanic and Atmospheric Administration
PRFCS	Power Rail Feedback Control System
TSC	Transportation Systems Center
TTD	Transportation Technology Development
UMI	Universal Mobility, Inc.
UMTA	Urban Mass Transportation Administration
VCU	Vehicle Control Unit
WTD	Westinghouse Transportation Division

EXECUTIVE SUMMARY

INTRODUCTION

This report describes and summarizes the test activities and presents the resulting data from the 2-year winter test program sponsored by the U.S. Department of Transportation's Urban Mass Transportation Administration (UMTA) and monitored by the Transportation Systems Center (TSC) located in Cambridge, Massachusetts. The program was comprised of three contracts to three potential Downtown People Mover (DPM) system suppliers: Westinghouse Electric Company at West Mifflin, Pennsylvania; Otis Elevator Company at Denver, Colorado; and Universal Mobility, Inc. (UMI) at the Minnesota Zoological Garden (MZG) in Apple Valley, Minnesota.

OBJECTIVES

The basic objective of this program was to conduct winterization test activities whereby the performance of potential DPM systems in severe winter environments could be observed and analyzed. Specifically the program was to determine the capabilities and the limitations of the suppliers' developments in the areas of traction and propulsion, braking and steering, power collection, vehicle and guideway electronics, switching, door opening and overall system performance in severe winter weather. The program addressed these areas through a combination of subsystem and system-level testing that allowed extrapolation of the results into a quantitative measure of system capability under various winter conditions.

SCOPE OF PROGRAM

As outlined in the statement of work for the three contracts awarded under this program, the major tasks performed were as follows:

Item 1 - Submission of a Detailed Plan and Schedule

The plan included the details of the specific test sequences, procedures, and schedules which were to be followed while testing the subsystems most critical to the dependable winter operation of the DPM system.

Item 2 - Installation of Test Equipment

Upon approval of the test plan, the contractor acquired, installed, and calibrated the test equipment to perform the tests and installed snow guns to supplement the ambient conditions and increase the number of test dates and severity of test conditions.

Item 3 - Conduct Winterization Test Program

The contractor began the winterization test in December 1978, and was responsible for monitoring the test sequences and keeping accurate records of vehicle/system operation and ambient conditions. Testing focused on the following:

a) Guideway Surface Control

The contractor employed thermal and mechanical methods of controlling snow and ice accumulation on guideway surfaces. Accurate measurements of the effort made to assist system operation such as the amount of mechanical equipment employed, modifications made, and efforts to insure proper operation were recorded.

b) Power and Control Rails

The contractor employed methods for the control of ice on power and signal rails. Accurate measurements of heating requirements, solutions added, and mechanical scraping were recorded.

c) Other Vehicle Systems

Critical subsystems such as those affecting door, switch, lateral guidance, suspension and communication operations were observed during system operation to identify potential problem areas. Appropriate measures of system and subsystem performance were monitored to determine if equipment, instrumentation, etc., were suitable for winter operation.

Item 4 - Analysis of Tests Results

The contractor was to summarize, analyze, and evaluate the test results and prepare the final test-evaluation report. The reports define the winterization methods and operational limitations or conditions that the supplier would propose for use in a northern DPM city.

PROGRAM IMPLEMENTATION

In order to supplement the expected naturally-occuring snowfall events, the contractors were required to install artificial snowmaking equipment at the test site to augment the number and severity of test conditions. Some flexibility in snow rates and consistency in production was possible, so the contractors prioritized the subsystem tests to ensure proper utilization of the limited test seasons. Accurate measurements of various meteorological parameters were kept for correlation of measured weather conditions.

Periodic on-site visits were made to monitor each contractor's progress. Biweekly status reports and extensive photographic coverage (slides, 16mm film, and video) were utilized for test documentation.

TEST PROGRAM SUMMARY

The results of the test program are summarized in this section by discussing each contractor separately. More detail is provided in the following sections in a format consistent with that found in each of the individual contractor reports.

Otis Elevator Company

Otis Elevator Co.- Transportation Technology Division (Otis-TTD) conducted its test program at the Otis-TTD test facility in Denver, Colorado. The track consists of a loop, 2500 feet in length, with an offline siding and station. The at-grade guideway consists of a steel reaction rail centered between two wide concrete air-suspension flying surfaces. Outside these surfaces are 6-inch-wide heated brake strips which are used for emergency braking. The winterization test area was a 250-foot segment of guideway configured like the recently-constructed Duke University system. Otis utilized two different vehicles for the program: one, a vehicle currently operating at the Duke University Medical Center in Durham, North Carolina; and the second, a composite with Duke-type hardware and an older body which lacked some passenger-comfort features. The vehicles are powered by linear induction motors (LIM), are suspended by air pads and are guided by retention rails positioned along the side of the guideway. The Otis system, which utilizes a channel guideway configuration, is the most vulnerable to accumulations of snow along the guideway. During the program, Otis experimented with snow removal via vehicle-mounted shrouds (debris guards), and a large V-shaped plow. Otis demonstrated that periodic circulation of a vehicle with debris guards is sufficient for extremely high snowfall rates. For example, if snow is falling at 3.0 in/hr, and a vehicle is circulated every 30 minutes, 1.5 inches of snow will be removed with each pass. To be effective, however, the guideway would have to be modified to include open sidewalls. Otis demonstrated the capability of their V-plow for large accumulations. Depths in excess of 2 feet were plowed successfully, although some snow did circumvent the blade, causing problems with the proper operation of the power-collection assembly. If such a concept is to be deployed, the collector assembly would have to be relocated toward the rear of the vehicle or the plow vehicle would require an independent propulsion source.

Operations on an ice-covered guideway proved to be relatively easy since the Hovair® system does not rely on friction resistance for traction. The main concern of Otis was what depth of ice would cause a significant loss of thrust for the LIM. As testing demonstrated, over 0.5 inch of smooth ice could be negotiated without any problems, and only when there were discontinuous ice patches on the guideway did an operational problem surface. In the latter case, the air pads, which suspend the vehicle above the guideway, "dump" (lose their air) causing the vehicle to drop to the guideway surface. This observation showed the need for maintaining the surface clear of any precipitation as a precautionary measure.

Westinghouse Electric Corporation

Testing of the Westinghouse People Mover was accomplished at their test facility in West Mifflin, a suburb of Pittsburgh, Pennsylvania. The track consists of 1480 feet of guideway, 250 feet of which is on a 10-percent grade. Four platform stations and one permanent facility provide stopping points for vehicle operations. A guideway switch provides access to the storage siding and assembly plant. The guideway is comprised of two concrete running pads, each nearly 2 feet in width and a steel I-beam which is located between the running surfaces. The steel beam provides lateral guidance for the vehicle's guidance assembly and supports the power and signal rails. Guideway heating is provided along the 250-foot grade and along a 30-foot section of at-grade guideway. The Westinghouse test vehicle is a rubber-tired vehicle which has two axles with two dual-tired wheels per axle, four sets of biparting doors, and a capacity of 103 persons.

Westinghouse Electric Corporation experimented with scrapers, vertical- and horizontal-axis brushes, and bogie-mounted scoop plows for guideway snow and ice removal. Test results showed that the most effective of the mechanical devices were the horizontal-axis brush with shroud and the scoop plow configuration. Westinghouse preferred the plow and will propose it for winter operation of their DPM system. The narrow 22-inch-wide concrete running surface can only sustain about 1.5 feet of snow which can be handled by the plow system. Westinghouse also evaluated different methods of heating the guideway surface in order to combat ice. Heating elements were cast into the concrete directly, installed in embedded pipes containing glycol, and sealed with polyurethane and sand. The latter system performed better and could be installed and maintained with relative ease. Other tests evaluated winter performance of vehicle and station doors, power and signal rail heating, switch operations, and overall system performance.

Universal Mobility, Incorporated

The MZG system located in Apple Valley, Minnesota, was utilized by UMI during the 2-year test program. The monorail is a revenue-service system which was only partially completed during the first season, so a 1000-foot section was utilized for testing. The entire system was available for use in the second year of the program. The completed system consists of 6628 feet of guideway, a switch, and a 350-foot-long maintenance spur. The trackbeam, a welded box beam fabricated of Cor-Ten (TM) plates, is 40 inches wide. The primary traction surface (top) extends 4 inches outside the beam walls to provide a sheltered overhang for the inverted power and control rails that are mounted two to a side. The test vehicles which UMI used at MZG were 6-car UNIMOBIL trains which are powered by eight 7.5-hp DC traction motors. The steel and fiberglass vehicles are steered by guide mechanisms attached to each bogie. These mechanisms consist of rubber guidewheels which engage guidance surfaces located on either side of the guideway.

UMI, like Westinghouse, has a narrow primary traction surface (40 inches wide) which must be maintained clear of ice and snow. This was accomplished by utilizing a snow module which consisted of two vertical-axis brushes and a small V-plow. The module was capable of removing snow depths in excess of 2 feet, which is the limit that can actually accumulate on the steel guideway. For grades in excess of 2.5 percent, the UMI system may need supplemental traction force when ice is present on the guideway. For this case, UMI successfully demonstrated that its auxiliary traction unit, which consists of powered guidewheels reacting against the sides of the monorail, can provide the necessary traction to negotiate steeper grades. Another major effort of UMI was the development and testing of a power rail feedback control system (PRFC). Essentially, this system controls the on/off switching of the power rail heaters by monitoring the difference between the rail temperature and dew point. When they approach each other (within 4 degrees), the heaters are activated, preventing frost from developing on the rails. This method of regulating the heater system minimizes the system's operating cost. Other tests conducted by UMI included switch operation tests, which showed that the hydraulics are slowed by cold temperatures, and vehicle door and environmental control unit tests.

FINDINGS AND CONCLUSIONS

The successful operation of an AGT in severe winter weather is dependent upon the operating strategy employed. For snow events, periodic circulation of vehicles outfitted with brushes or plows significantly reduces the depth of snow to be handled with each pass. If vehicles are circulated only twice an hour, the interim snow depth would not exceed 1.5 inches. Obviously, situations arise when system operation during a storm may be interrupted because of a power outage or other failure, thereby creating a need for a special snow maintenance vehicle to handle large depths.

Heating of guideways, power and signal rails, door tracks, etc., is an expensive method of winterization, but with proper management and accurate weather forecasting, heating can be initiated just prior to the onset of precipitation, thereby preventing accumulations. Timeliness is the key to administration of any winterization techniques and, if done properly, can assure near-normal operations even in the worst of winter weather conditions.

RECOMMENDATIONS

Although this DPM winter test program did not provide answers to all winter-related operating problems, it did permit UMTA, the DPM cities, and the DPM industry to gain considerable knowledge about the perils of winter operation, alternative protective and preventive measures, and possible operating strategies and techniques. Using the information and knowledge gained during the program, UMTA and the cities can assess the limitations of present system designs, from which should evolve DPM systems capable of providing safe, dependable transportation in harsh winter environments.

1. INTRODUCTION

This report describes and summarizes the test activities and presents the resulting data from the 2-year winter test program sponsored by the U.S. Department of Transportation's Urban Mass Transportation Administration (UMTA) and monitored by the Transportation Systems Center (TSC) located in Cambridge, Massachusetts. The program was comprised of three sole-source contracts to three potential Downtown People Mover (DPM) system suppliers: Westinghouse Electric Company at West Mifflin, Pennsylvania; Otis Elevator Company at Denver, Colorado; and Universal Mobility, Inc. (UMI) at the Minnesota Zoological Garden (MZG) in Apple Valley, Minnesota.

1.1 BACKGROUND

DPM deployments are planned in several urban locations, some of which include operating environments of moderate to severe winter conditions. Because the existing deployments of AGT's have generally been in benign environments (airports, amusement centers, etc.), their operating experience has not included sufficient severe-weather operations to permit the level of confidence required for these cold-climate urban DPM installations.

In March of 1978, at a meeting between UMTA, the DPM cities, and system suppliers, a winterization test program was first suggested by UMTA and supported by the affected DPM cities. Industry response was to formulate programs addressing winterization test issues, and to submit them to UMTA. UMTA agreed to cost share with those potential systems suppliers whose proposals met the basic objectives described below and who had a test facility available which was located in a cold climate and which was suitable for the type of testing desired. Three contractors, Westinghouse Electric Co., Otis Elevator, and UMI, met the requirements and began preliminary work just prior to the winter of 1978-79. Because installation of specialized test equipment took longer than anticipated, only a portion of the planned testing was completed that winter, and it was necessary to complete the testing in the winter of 1979-80. The data and experience gathered during this program can benefit the industry as a whole and provide the level of confidence necessary to properly select AGT technologies for severe-weather deployments.

1.2 OBJECTIVES

The basic objective of this program was to conduct winterization test activities whereby the performance of potential DPM systems in severe winter environments could be observed and analyzed. Specifically the program was to determine the capabilities and the limitations of the suppliers' developments in the areas of traction and propulsion, braking and steering, power collection, vehicle and guideway electronics, switching, door opening, and overall system performance in severe winter weather. The program addressed these areas through a combination of subsystem and system-level testing that allowed extrapolation of the results into a quantitative measure of system capability under various winter conditions. The results of the individual test programs are presented in these reports to assist in the evaluation of winter protection methods proposed by potential DPM system suppliers.

1.3 SCOPE OF PROGRAM

The winterization test program was scheduled such that the results of the study could be made available to other system suppliers and candidate DPM cities prior to the evaluation of supplier proposals for cold-climate applications. The contractors initially concentrated on subsystem testing to refine winter protection concepts and then concluded with system-level testing to determine their success in integrating concepts to produce a viable winter operating system.

As outlined in the statement of work for the three contracts awarded under this program, the major tasks performed are described in Sections 1.3.1 through 1.3.4.

1.3.1 Submission of Detailed Plan and Schedule

The plan included the details of the specific test sequences, procedures, and schedules which were to be followed while testing the subsystems most critical to the dependable winter operation of the DPM system. The areas of most concern included those subsystems which affected vehicle traction and propulsion for braking and steering, power and signal collection, switching and those subsystems specifically identified in the contractor's proposal.

1.3.2 Installation of Test Equipment

Upon approval of the test plan, the contractor acquired, installed, and calibrated the test equipment to perform the tests and installed snow guns to supplement the ambient conditions and increase the number of test dates and severity of test conditions.

1.3.3 Conduct of Winterization Test Program

The contractor began the winterization test in December 1978, and was responsible for monitoring the test sequences and keeping accurate records of vehicle/system operation and ambient conditions. Informal biweekly reports were submitted to the technical monitor, each containing a synopsis of the test sequences run during the preceeding 2 weeks and potential test activities scheduled for the coming 2 weeks. Periodic visits were made to the test site by the technical monitor to observe the testing and data-collection procedures and to insure that they were compatible with those tests being conducted at the other test locations. The areas on which testing focused are described in Sections 1.3.3.1 through 1.3.3.3.

1.3.3.1 Guideway Surface Control - The contractor employed thermal and mechanical methods of controlling snow and ice accumulation on guideway surfaces. Accurate measurements of the effort made to assist system operation such as the amount of mechanical equipment employed, modifications made, and efforts to insure proper operation were recorded. In addition, the amount, duration, and timing of guideway heating were also observed. The resulting level of performance was measured by determining acceleration and deceleration rates, available braking power, steering response, or other appropriate parameters.

1.3.3.2 Power and Control Rails - The contractor employed methods for the control of ice on power and signal rails. Accurate measurements of heating requirements, solutions added, and mechanical scraping were recorded. The continuity of signal and power between the rail and the vehicle collector was the principal performance indicator.

1.3.3.3 Other Vehicle Systems - Critical subsystems such as those affecting door, switch, lateral guidance, suspension, and communication operations were observed during system operation to identify potential problem areas. Appropriate measures of system and subsystem performance were monitored to determine if equipment, instrumentation, etc., are suitable for winter operation.

1.3.4 Analysis of Tests Results

The contractor was to summarize, analyze, and evaluate the test results and prepare the final test-evaluation report. The reports define the winterization methods and operational limitations or conditions that the supplier would propose for use in a northern DPM city. Included in their reports are a synopsis of each test, the specific requirements which were to be verified, and results obtained. This report summarizes the work conducted under the program, and the contractors' reports detail the work done by each individual contractor.

2. DESCRIPTION OF TEST FACILITIES

2.1 TEST TRACK LOCATIONS

Of the three contractors participating in the test program, two -- Otis Elevator Company and Westinghouse Electric Corporation -- had test facilities suitable for winter testing of their proposed DPM systems. The third, UMI, utilized the recently-constructed people mover that it had installed at MZG in Apple Valley, Minnesota.

2.1.1 Otis

The Otis Hovair transit system was tested at the Otis Elevator test facility in Denver, Colorado. The Otis Transportation Technology Division (TTD) test track comprise approximately 2500 feet of at-grade concrete guideway with steel guidance curbs (Figure 2-1) configured in a collapsed loop with an additional off-line siding and station. A steel secondary reaction rail is located in the center of the guideway and is flanked on either side by 2-foot-wide concrete air-suspension flying surfaces. On the outer edge is a sandblast-textured area of approximately 6-inch width used for the vehicle emergency-braking system. Power distribution to the vehicle is provided by three distribution rails supported by stanchion posts at 7.5-foot intervals. A winterization test area approximately 250 feet in length includes the addition of guideway hardware to the north side, representative of the Duke University system guideway and potential DPM deployments. Heating is provided for the power-distribution rails, and shrouding by a plastic insulative cover was provided for the noncontacting surfaces of the rails. Heating was also supplied to the concrete surface in the area of vehicle brake/skid contact to assure the integrity of the emergency-braking system during snow and ice accumulations. The test area was also provided with an installation of a guidance/ground rail system representative of the one at Duke University, signal rail and continuous communications antenna. The ground rail and signal rail were also provided with heating to maintain a reliable

FIGURE 2-1. GUIDEWAY AT OTIS TEST TRACK

signal-block contact with the vehicle.

2.1.2 Westinghouse

Testing for the Westinghouse winter test program, performed during the winters of 1978-79 and 1979-80, was conducted at the test track located at the Lebanon Church site in West Mifflin, a suburb of Pittsburgh, Pennsylvania.

The test track consists of 1480 feet of guideway, 1230 feet of which is the original portion and 250 feet of which is an extension added in the fall of 1978, prior to the beginning of the winter test program. The extension (Figure 2-2) consists of two spans of at-grade guideway and six spans of elevated guideway; included within the expansion is a maximum grade of 10 percent and a superelevated 190-foot-radius curve. A guideway switch is utilized for traffic routing between the main track and the 130-foot spur leading into the manufacturing plant.

Five stations are located along the guideway. Stations 1, 2, 4, and 5 are basically boarding platforms, while Station 3 is a permanent structure housing all the controls for automatic operation of the facility. Also included at Station 3 is an operational set of standard station doors which can be operated in a normal mode or can be placed in an accelerated cycling mode.

Guideway-surface heating is provided over the entire length of the 250-foot extension, as well as in a 30-foot test surface west of Station 3. Controls, which allow adjustment of heat up to 90 watts/ft^2, are located in Station 3. Power and signal rails are located along a steel I-beam positioned between the nearly 2-foot-wide concrete running surfaces. Each power, signal, and ground rail is equipped with two 1-ohm/ft resistive heating wires.

These are connected in such a manner that various heating levels can be maintained concurrently. A central time-on/-off control is located in Station 3, and power-on/-off control boxes are located along the guideway, each controlling approximately 500 linear feet of guideway-rail heating.

FIGURE 2-2. PORTION OF GUIDEWAY EXTENSION AT WESTINGHOUSE TEST TRACK

2.1.3 Universal Mobility

The MZG system, located in Apple Valley, Minnesota, was used by UMI for the 2-year test program. The monorail (Figure 2-3) is a revenue-service system which was designed, manufactured, and constructed for daily operations. Because the facility was under construction at the start of the test program, only a portion of the entire system was available for testing. A 1000-foot section of guideway was made available for testing and operation; it included over 500 feet of the main guideway, the main guideway/maintenance-spur switch, and the spur from the main guideway to the entrance of the maintenance building. In addition, the maintenance building, transfer beam, outside storage facilities, and the weather measurement/recording instruments were all available for both winters.

The completed test track consists of: (1) a single-lane main loop that is 6628 feet in length; (2) a 358-foot-long maintenance spur; and (3) a guideway switch that connects the main guideway with the spur to the maintenance building and its outside facilities. Approximately 730 feet, including the maintenance transfer beam, of the total 6986 feet of guideway is at-grade. The remaining 6256 feet of guideway is elevated on steel columns.

The top of the guideway, a welded box beam fabricated of COR-TEN plates, tubes, and surface is 40 inches wide. The primary traction surface extends 4 inches outside the beam walls to provide a sheltered overhang for the inverted power and control rails that are mounted two to a side.

The guideway is supported on at-grade concrete foundations and on COR-TEN columns in the elevated sections. At selected support points, the guideway is free to slide horizontally in either one (tangent sections) or all (curve sections) directions. At the remaining supports, the guideway is fixed by clamps (at-grade) or welds (above-grade).

FIGURE 2-3. UMI MONORAIL SYSTEM AT MZG

2.2 TEST VEHICLES

Since the contractors involved in the winter test program represent three distinct technologies within the automated transit field, the vehicles utilized in the program vary in physical appearance, size or capacity, material construction, and functional characteristics. In addition, the vehicles tested are not exact prototype DPM vehicles but are considered closely representative of the vehicles to be utilized for DPM deployment.

2.2.1 Otis

Otis-TTD utilized two existing test vehicles that are similar to their proposed DPM concept. One was a vehicle that is currently operating at the Duke University Medical Center in Durham, North Carolina. The second vehicle used Duke-type hardware but had an older body type lacking some passenger-comfort features.

Each vehicle consists of a chassis containing the operating components of the vehicle including the propulsion, suspension, lateral-guidance, switching, power-collection, and emergency-braking subsystems. The Duke body includes normal passenger loading of 22 persons and seating for 4 persons. The body has wide biparting doors on either side and includes emergency-exit egress through the windows at the ends of the vehicles. Heating, air conditioning, and ventilation are provided within the body to maintain a comfortable climate for passengers. The vehicle also contains the electronic control systems, which are housed in a cabinet at the end of the vehicle. The vehicle doors are normally operated automatically but for test purposes were operated manually from on board the vehicle. During the winter season of 1978-79, a Duke production vehicle was undergoing final test and checkout at the Denver test track prior to shipment to the customer. This vehicle was used to provide the winterization system operations for that season which included the test, evaluation, and demonstration of all associated vehicle hardware and subsystems, particularly those critically affected by severe winter weather. During the winter season of

1979-80, Otis-TTD developed a test vehicle for use in that year's testing.

The test experiences utilizing the Duke vehicle in 1978-79 indicated that no critical problem areas existed with the operation of the Duke body and related hardware subsystems in cold temperatures or winter precipitation. Therefore, the test vehicle deployed in 1979-80 included a "test only cab" used to house and protect personnel and instrumentation on board the vehicle. The test vehicle chassis itself was the same chassis configuration as the one used in the Duke production vehicles. Slight differences in vehicle/guideway interfaces between the Duke University system and the test track required that both of these test vehicles be provided with special test-track adaptors for retention and lateral suspension guidance on one side of the vehicle chassis, but retain normal power-collection hardware.

The other side of the vehicle contained the production lateral suspension and guidance, signal collection, grounding, and communications interfaces as specifically found at Duke University in the Otis-TTD People Mover system. Because of the mechanical limitations imposed by the test-track adaptors, the ride quality and lateral control exhibited by the vehicles used in the winterization test program were not representative of those occurring at Duke University or those proposed for DPM installations. During the test program, the vehicle was equipped with debris guards which interface the leading edge of the vehicle chassis and the guideway flying surfaces and protective shrouds which cover the ends of the vehicle chassis. This equipment is in the normal vehicle configuration. Also, various protective shrouds, boots, and covers were tried to reduce the effects of winter-precipitation accumulations. Additionally, a specialized maintenance snowplow was developed for vehicle installation for removing snow accumulations from the guideway.

2.2.2 Westinghouse

The Westinghouse test vehicle is a rubber-tired vehicle which operates on concrete running surfaces and utilizes a center steel guidance beam. The vehicle has two axles with two dual-tired wheels per axle and is positively steered and permanently locked to the guideway through the guidewheels positioned along each side of the I-beam.

The basic vehicle design is flexible and has been adapted to suit several different installations. The vehicle has an aluminum superstructure and steel underframe and is powered by electric motors that receive current from wayside power rails. The vehicle is equipped with four sets of biparting doors which, for this program, had different characteristics in order to evaluate their operating performance. Although no seats were provided on the test vehicle, the flexible design did permit optional seating arrangements for up to 34 people and the vehicle-design capacity is 103 people for an allowable passenger load of 17,510 pounds. The critical dimensions of the standard Westinghouse vehicle are presented in Table 2-1.

TABLE 2-1. WESTINGHOUSE STANDARD VEHICLE

Weight	Unit
Empty Car	30,000 lb (13,500 kg)
Passenger Load	17,510 lb (7879.5 kg) (103 people at 170 lb)
Dimension	
Height	11 ft 1 in. (3.38 m)
Width	9 ft 4 in. (2.84 m)
Length	36 ft 4 in. (11.07 m)
Interior Area	249 ft^2 (22.41 m^2)
Interior Height	7 ft 2 in. (2.18 m)
Interior Width	7 ft 9 in. (2.36 m)

2.2.3 Universal Mobility

The test vehicles which UMI used at MZG were three UNIMOBIL

Tourister Trains (Figure 2-4). Each train consists of six cars or vehicles supported by seven bogies; the lead and last two trailing bogies are idlers, while the remaining four bogies are electrically powered.

The propulsion system utilizes two 7.5-hp DC electric traction motors for each powered bogie. The primary power is 3-phase 60-cycle 480-volt AC which is collected by three sets of paired brushes on bogie-mounted pantographs at the front of each train; a motor/generator set converts the primary power for use by the traction motors.

In addition to the three sets of power collectors, sets of control-signal brushes are mounted at the front (one pair) and rear (two pairs) ends of each train. These latter three sets of brushes apply the signals used for both train separation and speed control as well as for checking the diode networks that provide the guideway-condition (occupancy) responses.

Each vehicle has a steel frame and a body shell and interior constructed of fiberglass-reinforced plastics with fire-retardant resins. There are four partially-contoured bench seats in each vehicle that can accommodate four to five adults; they are placed in facing pairs with each pair served by a door on either side of the vehicle.

The vehicles are steered by the support bogies which are guided by mechanisms attached to each bogie. These mechanisms consist of hard-tired, vertical-axis guidewheels that are mounted in sets of two to engage guidance surfaces located on either side of the guideway. Each set is arranged so that one guidance wheel leads and the other trails the bogie support wheels. All of the guidewheels are spring-held against the guidance surfaces; these wheels are contained by housings that are pivot-connected to frames attached to the bogie structure and have limited travel in the horizontal direction.

The trains used during the 1979-80 winter are each designated by numbers (1, 2, and 3). Train 1 was available in its entirety

FIGURE 2-4. UNIMOBIL TOURISTER TRAIN

during the 1978-79 winter, while only the last two cars of Train 3 (containing auxiliary traction module), and none of Train 2, were available during this period. Trains 1 and 2 are baseline trains while Train 3 can be configured as a baseline train or, when desired or necessary, can be traction-augmented by an auxiliary traction subsystem (ATSS).

2.3 SNOWMAKING EQUIPMENT

To supplement the naturally-occurring snowfall events, artificial snowmaking equipment was utilized at the test sites to augment the number and severity of test conditions. The snowmaking facilities, shown in Figure 2-5, consisted of an air compressor, water pump, snow towers and guns, air and water hosing, and miscellaneous valves and gauges. A pre-chiller was used at several sites to decrease water temperature prior to the mixing of water with compressed air. Strict procedures were followed to insure proper operation of the snowmaking system to prevent freeze-up of lines and valves and to create a range of snow qualities from dry to wet snow, ice, and freezing rain.

2.4 METEOROLOGICAL INSTRUMENTATION

Meteorological parameters such as temperature, relative humidity, barometric pressure, wind speed, wind direction, precipitation type and rate, snow density and accumulations, and other pertinent parameters were monitored during the winter test programs. All of the climatological observations were made with instrumentation as specified by TSC (see memo in Appendix A) and in accordance with the guidelines prescribed in the Federal Meteorological Handbook #1. Snow-measurement kits supplied by the U.S. Army Cold Regions Research and Engineering Laboratory of the Corps of Engineers were used to sample snow accumulations.

Predictive weather services and local National Oceanic & Atmospheric Administration (NOAA) weather stations provided weather-forecasting information throughout the test period in order to help schedule testing and snowmaking operations and to correlate actual parameter values with those recorded on site.

FIGURE 2-5. SNOWMAKING FACILITIES

Operational strategies also relied on the accurate recording of various parameters, such as temperature, etc., for the initiation of such winter protection methods as guideway and power- and signal-rail heating.

3. TEST ENVIRONMENT

3.1 DESIRED CLIMATOLOGICAL EXTREMES

Extremes in winter weather, comparable to those experienced in the northern DPM cities, were specified as the operating parameters to which the performance of the three systems was to be compared. Parameters, such as temperature and wind speed, were site dependent and therefore uncontrollable, but snow and consistencies were varied by utilizing snowmaking equipment to supplement the natural precipitation which could be expected to occur. Figure 3-1 displays the relative location of the test sites and the candidate DPM cities.

In order to establish baseline climatological characteristics with which the performance of the three systems was to be compared, the historic weather data for candidate northern DPM cities were assembled. A summary of this information for St. Paul, Minnesota, and Detroit, Michagan, is included in Appendix A. Based on this information, a matrix was developed which displayed the desired weather parameters and extremes under which the systems were to be tested. These figures were not requirements for testing but rather goals that each contractor attempted to attain during the 2-year program. In order to judiciously utilize the naturally-occurring weather extremes, supplemental snowmaking facilities were included, and blocks within the matrix were prioritized to insure that the critical tests were completed.

System-performance characteristics in moderate temperatures (50°F) were considered to be representative of the system performance without the effects of winter. These baseline characteristics were compared to the system performance in extreme cold temperatures (without precipitation) and with different snow and ice types, precipitation rates, wind speeds, and cold temperature extremes. The desired test conditions for evaluating system operation are shown in Table 3-1.

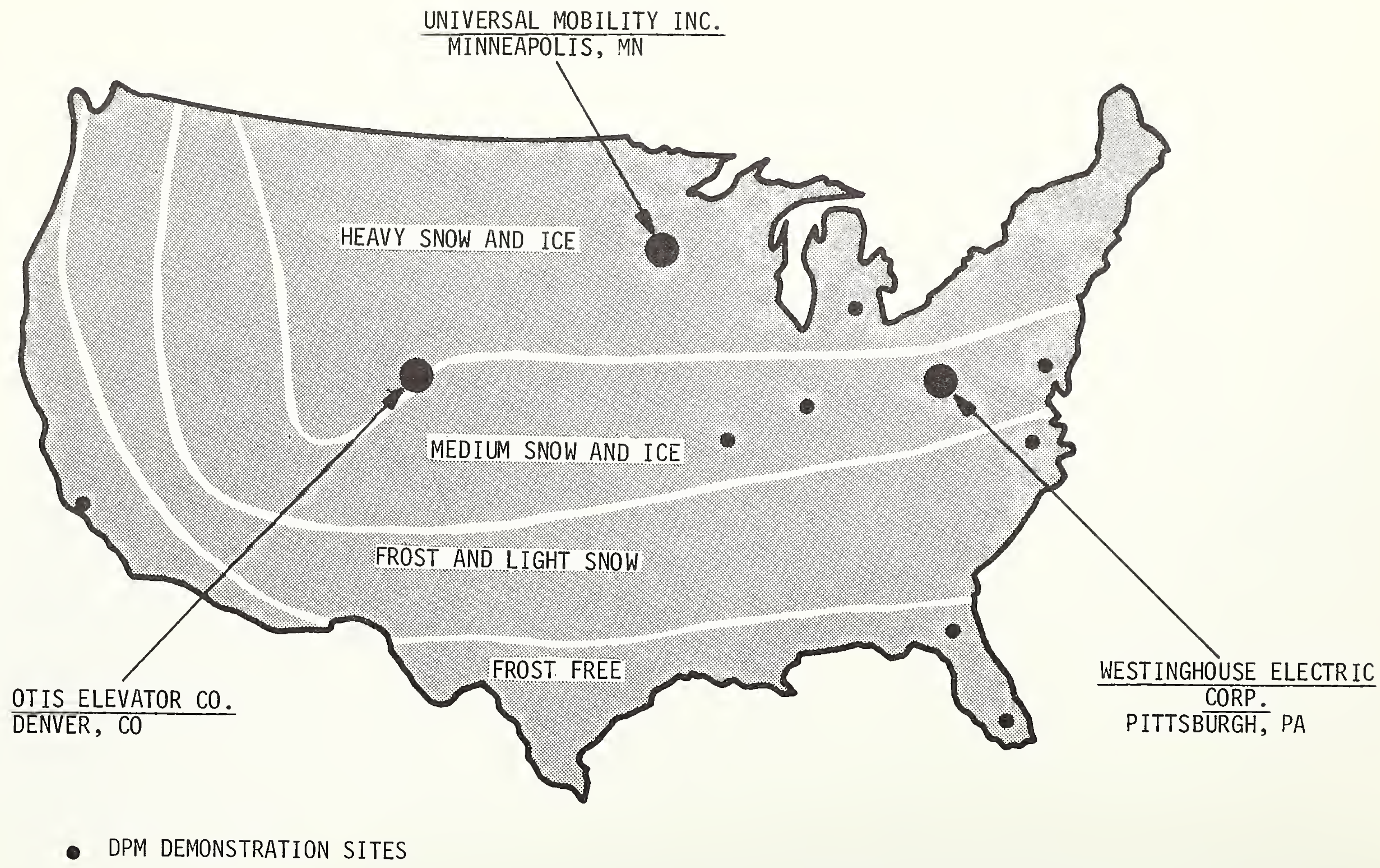

FIGURE 3-1. TEST-SITE LOCATIONS AND DEMONSTRATION SITES

TABLE 3-1. DESIRED TEST CONDITIONS

SNOW TYPE	SNOW DEPTH (in.)	SNOWFALL RATE (in./hr)	TEMP. (°F)	WIND VELOCITY (mph)
Dry, Powdery	16	0.5,1.0,2.0	0	40
Moist, Sticky	16	0.5,1.0,2.0	0	40
Wet, Slushy	8	0.5,1.0	32	20
Ice, Freezing Rain	2	0.5	32	0

3.2 CLIMATOLOGY OF TEST LOCATIONS

Historic Weather Data

The availability of sufficiently cold and serve winter-weather conditions was the key to a successful test program. Even though smowmaking equipment was utilized to supplement natural precipitation, the ambient temperature had to be less than 26°F to produce quality snow. Wet snow and freezing rain could be produced in temperatures between 26°F and 32°F. Detailed descriptions of the climates of the test locations are contained in the individual contractor reports and only a comparison of significant statistics is presented here (Table 3-2).

3.3 SUPPLEMENTAL MEASURES

In order to increase the number of test dates and give the suppliers better control over test conditions, snowmaking equipment was utilized to produce various types of snow, slush, and freezing rain. Typically, one could expect snowfall events ($\geq$1.0 inch) to occur from 14 to 20 times each winter at the sites. By utilizing the artificial snowking equipment, this figure was increased two-fold or more depending on the test site and severity of the winter. The two most important factors contributing to the production of quality snow were temperature and relative humidity. Temperatures less than 26°F for a sustained period (8 hours) were needed to produce snow. Relative humidity

TABLE 3-2. SIGNIFICANT WEATHER DATA

PARAMETER TEMPERATURE	WESTINGHOUSE W. MIFFLIN, PA	OTIS DENVER, CO	UMI APPLE VALLEY, MN
Record low temperature (°F)	-20	-30	-34
Avg cold season (days)	185	163	198
Avg number days/yr			
Max temp 32 or less	42	21	83
Min temp 32 or less	124	163	158
Min temp 0 or less	5	10	35
Snow Event/Yr			
Amount of Snow/Event			
1.0 to 2.5 in.	10.1	9.7	9.3
2.6 to 5.0 in.	2.4	5.9	2.8
5.1 to 10.0 in.	1.1	2.0	1.7
10.1 in. or greater	0.4	0.4	0.2
Consistency of Snow/Event			
Dry, powdery	9.4	13.9	11.5
Moderately heavy	3.4	3.2	1.9
Heavy wet	1.2	0.9	0.6
Total/Yr	14.0	18.0	14.0

levels, if low, lent themselves to the fabrication of lower-density snows. For the most part, however, the snow produced was of significantly higher densities than natural snows and it should be realized that removal of an amount of man-made snow indicated that at least that amount of natural snow could be removed in the same manner.

4. DEVELOPMENT OF DETAILED TEST PLAN

4.1 IDENTIFICATION OF CRITICAL SUBSYSTEMS

The contractors chosen for the test program represent three distinct technologies: (1) Westinghouse, a rubber-tired system operating on an open concrete-and-steel guideway; (2) Otis, an air-suspended system on a concrete channel guideway; and (3) UMI, a monorail system which travels along a narrow steel guide-beam. The only real common denominator among the three is that they are all defined as automated transit systems. For that reason, certain key system-performance parameters and major subsystems were identified, the winter performance of which became the focal point of comparison during the winter test program. The contractors made initial evaluations and prioritization of these areas to determine which ones were system-specific and required detailed examination under this program. The guidelines given to the three suppliers for determining which subsystems and measurements were to be included are described in Sections 4.1.1 and 4.1.2.

4.1.1 Guideway Traction

The adhesion characteristics of the vehicle were to be determined by the following system-performance measurements.

4.1.1.1 Emergency Deceleration - Stopping distance and time shall be measured from the time of velocity command; velocity shall be measured by means of an independent sensor, i.e., fifth wheel; and longitudinal acceleration shall be measured to determine if the maximum permissible value (0.15 g's) for standing passengers is exceeded.

4.1.1.2 Service Braking - Stopping distance and time shall be measured from the time of braking command; and velocity and acceleration profiles shall be utilized.

4.1.1.3 Acceleration - time and distance to achieve maximum velocity of a vehicle shall be measured from a standing start; and acceleration and velocity profiles shall be utilized.

4.1.1.4 Snow and Ice Removal - The effort and time required for snow removal by either mechanical, chemical, or heating means as a function of snowfall rate, temperature, wind velocity, and humidity shall be determined.

4.1.1.5 Longitudinal Control -

a. Communication - A measure of the reliability of communications under winter conditions as well as system implications of communication dropouts shall be determined.

b. Power Rail - The reliability of power pickup shall be determined; the number of power dropouts with and without power-rail heating shall be determined; the energy required to achieve no adverse winter-weather effects shall be determined; and the system implications of power dropouts shall be determined.

4.1.1.6 Lateral Guidance -

Switching - The reliability of switching with either wayside or on-board switches shall be determined; and the travel time and positive positioning of switches shall be measured to determine if the switching system is functioning correctly.

4.1.2 <u>Vehicle</u>

4.1.2.1 Traction Motors - The drawbar pull associated with the traction systems shall be determined; in the case of a linear induction motor (LIM), the secondary shall be allowed to accumulate ice until traction is essentially eliminated or the LIM encounters interference from the ice.

4.1.2.2 Brake Systems - Brake systems shall be evaluated for their functional operating capability under the most severe weather environments to insure that no freezing conditions exist which can cause malfunctions; and brake systems in the station area shall be tested to insure that vehicles can stop at the appropriate berth and within acceptable tolerance limits.

4.1.2.3 Door Systems - The operability of door systems shall be determined under the most severe weather conditions to insure proper functioning.

4.1.2.4 Operational Strategies - At the completion of subsystems and component testing above, an evaluation shall be made to determine the best operating strategies for each system under each set of conditions. Overall system tests insuring headway maintenance shall be performed to demonstrate this operation.

4.2 DEVELOPMENT OF POTENTIAL SOLUTIONS

After identifying the critical systems and subsystems, the contractors assessed the extent of the subsystems' vulnerability to severe winter weather and developed potential solutions which were to be evaluated during the test program. Solutions, depending on the subsystem, included mechanical, thermal, or chemical methods and alternative design configurations or passive solutions. The selection and evaluation of winter protection methods were based on the performance, associated capital and operating costs, environmental effects, and practicality of such methods for urban application. Since only a limited amount of testing could be performed, the potential solutions and critical subsystems had to be prioritized prior to the initiation of testing.

4.3 PRIORITIZATION OF TEST ACTIVITIES

Those subsystems which had a direct influence on the safe operation of the system were given the highest priority. Other tests involving new or unproven winter-protection methods were also given high priority. A test matrix was developed by each contractor and priorities assigned so that when a given set of environmental conditions was present, the contractor could easily decide which test to conduct. The repetition of tests was not specified, that is, the contractor was not told he must run each test a specific number of times but rather the "perceived confidence" in the results was the governing factor. In addition, it was not actually possible to duplicate a given test because the environmental parameters generally differed from test to test in some manner. A typical test matrix is shown in Figure 4-1.

4.4 TEST PLANS AND PROCEDURES

All three contractors were responsible for formulating test plans and schedules. Prior to the start of testing, the contractors prepared for submission and approval a detailed test plan for conducting and monitoring the winter testing of their DPM systems.

The plan included the following items:

a) Detailed description of all subsystems to be tested

b) Description of tests to be conducted

c) Outline of test procedures

d) Description and specifications of testing equipment to be used

e) Outlined or list of all measurements to be made, including weather statistics and vehicle subsystem-performance indicators

f) Sample of data-collection and compilation formats

g) Description of how data would be collected, compiled, analyzed and summarized

h) Detailed test schedule

i) Description of test facility with details of modifications made for test program.

		BASELINE	SYSTEM OPERATION											
	SYSTEM TESTS / SNOW TYPE	N/A	1			2			3		4		5	
	RATE	N/A	0.5	1	2	0.5	1	2	0.25	0.5	0.25	0.5	0.25	0.5
	VEHICLE													
1	LONGITUDINAL CONTROL	1*	3	2	1	3	2	1	2	1	2	1	2	1
1	THRUST CONTROL	1	3	2	1	3	2	1	2	1	2	1	2	1
1	SUSPENSION	1	3	2	1	3	2	1	2	1	2	1	2	1
1	LATERAL CONTROL	1	3	2	1	3	2	1	2	1	2	1	2	1
1	POWER COLLECTION	1	3	2	1	3	2	1	2	1	2	1	2	1
2	DOORS	1	4	3	2	4	3	2	3	2	3	2	3	2
	WAYSIDE													
1	POWER DISTRIBUTION	1	3	2	1	3	2	1	2	1	2	1	2	1
1	COMMUNICATION	1	3	2	1	3	2	1	2	1	2	1	2	1
1	MAINTENANCE SUPPORT VEHICLE	1	3	2	1	3	2	1	2	1	2	1	2	1
1	SNOW REMOVAL	N/A	3	2	1	3	2	1	2	1	2	1	2	1

*The lower the number, the higher the priority.

FIGURE 4-1. TYPICAL TEST MATRIX

5. GUIDEWAY-RELATED TESTING

5.1 OTIS

In an effort to develop winter protection-methods which would de-emphasize heating as a "panacea" for winter operation of AGT systems, the contractors successfully developed mechanical snow-removal methods. The Otis system, which utilizes a channel guideway configuration, is the most vulnerable to accumulations of snow along the guideway. During the program, Otis experimented with snow removal via vehicle-mounted shrouds and a massive V-shaped plow, shown in Figure 5-1. Adopting a philosophy of periodic circulation of vehicles with shrouds as the primary method of keeping the guideway clear, Otis recorded the performance of the shroud and observed the circulation times required for this operating mode. Based on a severe 2-in/hr snowfall, circulated vehicles had only 1 inch of snow to plow with each pass (30-minute intervals). After several passes, snow builds up along the sides of the guideway, presenting a potential problem to the proper operation of the power and signal rails and the emergency-braking strips. For this reason, a closed-guideway arrangement has serious drawbacks, and adoption of an open-sidewall arrangement must be considered for this method to be plausible. Taking into account the situation where a large accumulation of snow precedes the commencement of removal activities, Otis developed and tested a large V-shaped plow which was mounted to the front of the vehicle. More than enough thrust was available from the LIM propulsion system to plow in excess of 2 feet of snow. Assuming that the guideway would have sidewalls, the plow was designed to lift the snow over the guideway to the street below. Problems were encountered with the power-collection system during these test runs, as snow compacted along the collector assembly and rails causing interruption to power and signal pickup. Modifications to the plow reduced the amount of snow which circumvented the plow blade, but for deployment, reliable operation of the plow will require either relocating the collector assembly toward the rear end of the vehicle or utilizing a self-propelled vehicle for this function.

FIGURE 5-1. OTIS VEHICLE WITH PLOW

Emergency-braking tests were conducted and consisted of heating two 6-inch strips to remove ice and snow. In this braking mode, the vehicle's air pads release, causing the vehicle to skid along the braking surface. Different wattage levels were tried and a value of 25 watts/ft (each strip) is necessary to maintain a clear braking surface. Within 45 minutes of actuation, all frozen precipitation is melted, and after about 2 hours, the equilibrium temperature is attained. In general, a temperature rise of 25°F above the ambient was recorded.

Operations on an ice-covered guideway proved to be quite favorable. Since the Otis system is an air-cushioned system, there is no physical contact between the vehicle and guideway needed in order to obtain traction. On smooth ice (>0.5 inch), the system functioned satisfactorily, exhibiting more-than-adequate thrust levels. On guideways covered with discontinuous ice or frozen slush patches, however, the vehicle would dump air from its air pads, prohibiting proper operation. It is imperative in this design that such deposits are not allowed to remain on the guideway.

5.2 WESTINGHOUSE

In keeping with the philosophy of minimizing winterization-by-heating, Westinghouse evaluated several mechanical snow-removal techniques, namely: scrapers, vertical- and horizontal-axis brushes, and plows. Tests conducted with scrapers revealed that the spring-mounted arrangement was too flexible to be effective. The vertical-axis-brush design removed snow but splattered the center-mounted power and signal rails with snow and slush. More effective was the horizontal-axis brush with spiral-strand design which successfully removed snow from the guideway. In the process, a significant amount of snow coated the undercarriage, and, subsequently, a shroud was designed to minimize these accumulations.

Even more successful than the brush systems was a simple scoop-plow arrangement which was able to remove any accumulated snow with relative ease. A rubber edging was attached to reduce the effect plowing would have on the concrete running surface, and various plow pressures were tried to arrive at a value where the plows were effective but did not chatter on dry pavement. It was demonstrated that the maximum snowfall capable of accumulating on the narrow running surface is about 16 inches, and this is easily removed by plows if sufficient traction for the rubber tires is present.

Since the operation of the Westinghouse system requires frictional resistance between the guideway surface and running wheels, ice poses the greatest concern for successful winter operation, especially on grades and in acceleration and deceleration areas (Figure 5-2). Recognizing that some guideway heating would be needed to supplement the mechanical devices described above, Westinghouse experimented with several methods and power levels for guideway heating. Along the 10-percent grade which was constructed for this program, electric resistance heaters were imbedded directly in the running surface and others were placed in pipes containing an ethylene-glycol solution. The heating elements were encased in an insulated metal sheath which contained two electrical conductors. Maintainability of the piped elements was good but the heating capability of that arrangement was less than that for the directly-imbedded elements. This arrangement could not be repaired without tearing the guideway apart, so a third method was evaluated and proved successful. This method consisted of using a concrete cutter to cut grooves for the heating wires which were then covered with various sealants. The most successful sealant tried was one of sand topped with polyurethane. In addition, because of proximity to the running surface the retrofitted heating elements out-performed those cast in place during construction of the track extension.

The guideway switch used at the test track is a pivoting guide-beam unit similar to that installed at the Atlanta Airport. When commanded, the guide beams are hydraulically driven to the desired position and locked to provide safe guidance in negotiating the vehicle to either the tangent or spur tracks.

FIGURE 5-2. WESTINGHOUSE VEHICLE BRAKING ON ICY SURFACE

Testing conducted during the first winter included producing a 7.5-inch snow accumulation on the switch, which hampered proper operation of the switch unit. The beam traversed all but 0.25 inch of the distance. Snow had compressed on the stop beam, thus preventing the switch from locking in position. After the first year's testing five major switch components were updated, including replacement of the beam-stop assembly. No further problems were experienced but a small mechanical cover is being designed to protect the stop-plate assembly from snow accumulations.

5.3 UNIVERSAL MOBILITY

The "Slimline Guideway," the steel monorail utilized by UMI, is made of COR-TEN and produces a heat-gain capability which, during the daytime, can be from 20° to 50°F warmer than the ambient temperature. Because of this tendancy, and the fact that slight breezes prevented the accumulation of snow on the monorail, snow-removal tests were performed on cold, calm nights. Snow removal was accomplished using a vehicle-mounted snow module (Figure 5-3), which consisted of a small V-shaped plow and a pair of vertical-axis brushes. The module clearly demonstrated that it was capable of removing accumulations of snow over 2-feet deep from the 40-inch-wide running surface with no apparent problems. The plow blade bears the brunt of the removal effort while the brushes sweep the remaining few inches to the sides of the guideway. For small accumulations only the brushes were required.

Operations on icy surfaces were evaluated using drawbar-pull tests. During the static drawbar-pull tests the drive wheels did not slip, indicating that the available traction-drive power, rather than adhesion, was the limiting factor on static tractive effort for extremely cold conditions. Dynamic tests revealed significant differences in frictional resistance for dry ice and ice with a wet film. The train could operate and accelerate on those sections of the track which were level, but could not negotiate even a 0.71-percent gradient without some loss of

FIGURE 5-3. UMI VEHICLE-MOUNTED SNOW MODULE

traction. For applications requiring operation on grades in excess of 2.5 percent, beyond which tractive loss is excessive without supplemental efforts, UMI designed and demonstrated the auxiliary traction subsystem (ATSS). This system allows power to be diverted to selected guidewheels to supplement the efforts of the primary traction system. The ATSS can supply 2000-pound force for short periods (under 5 minutes) and 1000-pound force for long-term operations.

Guideway-switch modifications for this program included the addition of an aluminum coverplate and the replacement of the hydraulic fluid with one suitable for cold temperatures. For temperatures about -20°F, a complete switch operation takes approximately 30 to 35 seconds. At somewhat warmer temperatures (just below freezing) the operating time was 20 to 30 seconds, and when ice covered the switch, operation was satisfactory, completing a cycle in 30 seconds. UMI concluded that the presence of ice or snow did not have any significant effect on switch operations and even when ambient temperatures were measured at less than -20°F the switch cycle time increased but functioned adequately.

6. VEHICLE-RELATED TESTING

6.1 OTIS

The test vehicle and related equipment were exposed to subfreezing temperatures and various types and accumulations of frozen precipitation to determine the effect on vehicle operation and performance. Prior to the test period some vehicle equipment changes or modifications were made to try to reduce the effects of severe winter-weather conditions. The tests included:

a) Vehicle cold-soak/test

b) Effects of precipitation

c) Vehicle-mounted winter shrouds and debris guards

d) Vehicle power and signal collection

e) Vehicle guidance switching

f) Vehicle doors

g) Vehicle propulsion and control.

The vehicle cold-soak test evaluated the Otis-TTD Duke vehicle subsystem performance at low temperatures (below 0°F for 4 hours). Some of the results of this particular test sequence are as follows: the opening times of the forward emergency door increased from 2.5 seconds for moderate temperatures to about 4.0 seconds for subzero temperatures; the chasis-body secondary-suspension shear mounts were hard, showing little elastic properties and adversely affected vehicle ride quality.

The implication of the results of low-temperature operation is that subsystem and system-level specifications for northern DPM applications should be considered early in the design process.

The effects of winter conditions, such as snow and freezing rain or sleet, on vehicle hardware and equipment were observed. The vulnerable components of interest were specifically the suspension, guidance, switching, power collection, vehicle doors, and the seal provided by the vehicle chasis enclosure. Several tests were conducted but no significant operating problems were discovered. When snow or ice had seeped into window hatches and door tracks, however, they had to be cleared manually before the doors could be operated automatically.

Optimum performance of the vehicle on snow-covered guideways was dependent on the proper design and installation of the debris guards. Modifications to the guards included the addition of reinforcement to prevent them from distorting when plowing snow. Also the guards were provided with a thicker rubber lip to fill the gap between the shroud and guideway surface to increase their performance. For periodic circulation of the vehicles in snow events the modified shrouds proved quite successful.

The operation of vehicle power collectors was successful along the heated portion of the test track, but when the plow attachment was employed some problems did develop. The power-collection assembly, located on the right front corner of the vehicle, is positioned under the plow's extended wing and during plow operations was subject to spillage from the blade. Based on the experience gained during these test sequences, the power collector should be installed at the opposite end of the vehicle away from the plow assembly. In addition, it is advisable that shrouds be developed to protect the power-collector assembly from falling and plowed snow.

The switch mechanisms were winterized to insure proper operation by sealing vulnerable areas with high-density foam and flexible boots which protected the switch-arm/slide-bearing interface. Initially, testing showed that heavy wet snows refroze, subjecting the switch arms to higher loads, but this was remedied by heating the flexible boot. With the boot heated no operational problems were observed.

Vehicle door tests were performed on the Otis-TTD Duke vehicle which is equipped with biparting passenger doors on either side of the vehicle. These doors are operated by mechanisms located in the roof of the vehicle body. Although cycle times were slowed by the effects of low temperatures on the mechanism, no discernible impacts resulted from heavy wet snows. For deployment Otis plans to shelter vehicle doors from the effects of winter weather by providing a station docking berth.

During the winter test program the propulsion power levels representing the thrust required to maintain the vehicle velocity through the test area typically varied from values equivalent to the normal cruise thrust up through the maximum capability of the propulsion system. During freezing rain and sleet conditions, ice accumulated on the guideway flying surface and LIM reaction rail surface to a depth of 0.5 to 0.75 inch. When this occurred, typical LIM power requirements were higher than those for normal operations, but the resulting thrusts were roughly equivalent. This is due to the fact that ice accumulations increased the propulsion-motor air gap from its normal 0.75 inch to almost 1.5 inches. When this occurred, more power was consumed in the motor to yield the same thrusts. During freezing rains and sleet, the maximum power consumed in the propulsion system occurs when operating on ice which has started to melt and break away from the surface. The resulting patches of discontinuous ice cause compressed-air losses and exessive propulsion-thrust requirements.

6.2 WESTINGHOUSE

Westinghouse's C-100 vehicle was used for the vehicle performance tests which included cold soak, cold start-up, and longitudinal and lateral guidance tests. The test vehicle's door-track configurations were varied in order to evaluate and compare their relative performance. For one set of doors the sill was changed to include more drain holes, similar to that of the Atlanta-type vehicles. Teflon (TM) coating was provided on one half of this door track and electrical heating was provided on both the old and modified door tracks. Testing revealed that the new door-track design (Figure 6-1) allowed maximum area for snow and water to be drained or pushed away as doors opened. The Teflon coating of sills did not result in any appreciable difference in door performance and although heating proved successful for removing ice and snow in the door tracks, not enough data

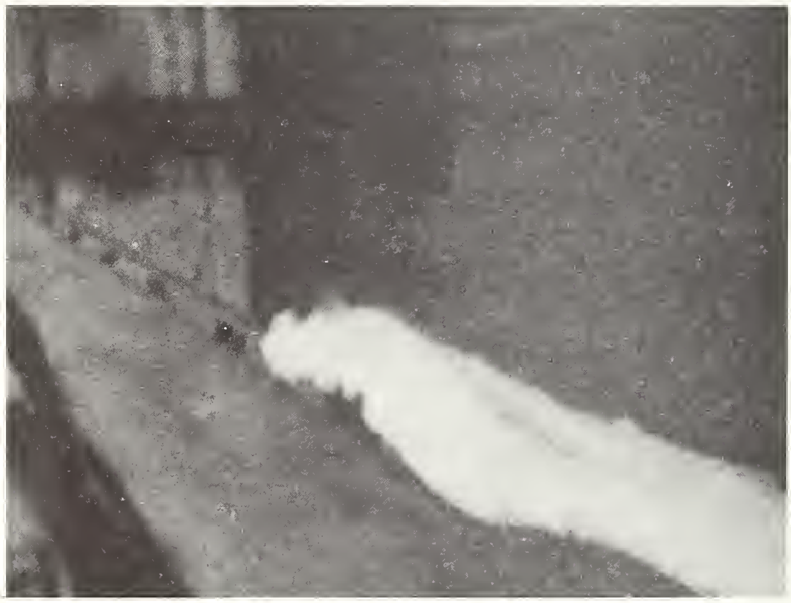

FIGURE 6-1. NEW WESTINGHOUSE DOOR-TRACK DESIGN

were collected to identify how much, if any, heating would be required if vehicles were stored for prolonged periods.

Cold car start-up tests were conducted in order to assess the effort required to attain normal automated operation of a vehicle which had been stored outside in various winter conditions. To achieve this, an operator would have to board the vehicle, turn on equipment breakers, check proper operation of the compressor, and check the operation of vehicle doors. Manual operation is required to position vehicles from the storage area through a switch to the main line, requiring visibility through the end windows. For this reason, window deicers, brake heaters, and an air dryer were tested.

The performance of the window deicers was satisfactory and will be incorporated on vehicles destined for use in areas subject to ice and/or snow conditions. Brake heaters were installed because of shoe/drum freeze-ups during the first test season. Two types, a strip heater mounted on the axles below the brake area, and a cylinder heater mounted to the spring brake units, were installed, but because of the mild winter experienced in 1979-80 no conclusive data on their operation could be obtained. Likewise the addition of air dryers to prevent frozen airlines appears to have merit but conclusive information about their performance was not obtained. Westinghouse plans further evaluation of these concepts during the winter of 1980-81.

Longitudinal and lateral motion of the vehicle were monitored during acceleration and braking to determine the performance and ride quality of the vehicle. Using the International Standardization Organization (ISO) specifications for evaluation, the vertical-axis accelerations were comparable to the "reduced comfort boundary" and for longitudinal and lateral axes the vibration levels were 8.0 and 3.5 times lower than the "reduced comfort boundary", respectively.

The vehicle demonstrated it could climb a 10-percent grade under all winter conditions tested except on smooth ice. On ice the wheels lost adhesion and in the locked position slid backwards down the grade. The importance of maintaining a dry guideway was thus demonstrated as was consideration for an emergency brake which acts upon the center guide beam instead of relying on the frictional interface between tires and pavement.

6.3 UNIVERSAL MOBILITY

Four major vehicle-related subsystems were tested during the program, namely the steering and guidance, primary traction, environmental control unit (ECU) and vehicle door unit. On the subject of steering and guidance, both the bogies and hinge and bearing connections were investigated for winter-induced problems. With the exception of ice fragments that collected on the lead guidance mechanisms as icicles were broken from the drip lip, no ice accumulated on these mechanisms. No easily-detectable difference in steering forces was noted over a wide range of temperatures. The only other steering-related observation made was that a slight possibility exists for heavy ice to form on vehicle ends or the shields between connecting cars. If this were to happen the fiberglass bodies might be damaged during cornering or ice could fall to the street below, so their removal would be necessary.

The primary-traction subsystem relies on guideway/tire friction and, based on the winter performance of the system, reduced traction can result if snow or ice is allowed to accumulate on the primary-traction surface. To supplement the tractive forces available from the primary-traction subsystem, UMI developed an ATSS, which put simply, powers the guidewheels to provide additional traction. The results of its testing are discussed in Section 8.3.

Since the UMI system was being evaluated while in revenue service at MZG, the performance of the vehicle's ECU, which provides heating and air conditioning, was observed. The test indicated a satisfactory level of comfort, but it should be recognized that the passengers were properly dressed for the ambient winter conditions. Measurements taken over the course of the winter showed that the ECU system in general maintained the temperature level within the vehicle 30^{o} above the ambient. Upon activation of the ECU, the interior temperature increased at a rate of about 0.2^{o}F/minute.

The MZG trains have a total of 24 sliding doors on a 6-car consist; 2 doors are located on each side of every vehicle. The 27.5-inch-wide door openings are designed to allow 108 passengers to deboard within 15 seconds. Each door is supported by ball-bearing tracks treated with low-temperature grease and their proper operation is essential for reliable system performance. Testing showed that cold temperatures affect the rate of door openings and that if ice is allowed to cover the doors and tracks, overload breakers disrupt the door-opening/-closing circuit whether the attempt is made to open one pair or all six pairs. Although a limited number of subsystem door tests was performed, it was concluded that the ECU must be operating for normal door operation in severe winter weather. It should be noted that no door-opening problems were experienced during the 1979-80 testing.

7. POWER AND SIGNAL RAIL TESTING

7.1 OTIS

At the Otis-TTD test track in Denver, vehicle power is provided by a 3-phase 500-volt AC distribution system. The rails are Howell 100-amp aluminum rails that have an inserted stainless steel face. A 230-foot section of the test track had heated rail provided by a resistance heater wire in the extruded slot in the front edge of the power rail. Testing of the power and signal rail system was conducted in a range of temperatures from 15°F to 45°F, with various snowfall types and accumulation rates. Glaze ice and rime ice were also produced.

Since only a portion of the test track had heated rails, it was quite obvious that operation in icing and frost conditions was impossible without heating capability, as can be seen in Figure 7-1. Vehicle operations were possible in unheated sections under conditions of extremely cold temperatures, light or dry snow events, with little or no associated winds. Snowfalls coupled with wind speeds in excess of 5 mph and ambient temperatures just below freezing created operational problems for those unheated power rails, making them unsuitable for operation.

Otis concluded that power-rail heating is essential to assure complete reliability of the power distribution system. Based on the experiments conducted, a power level of 8 to 10 watts/ft is sufficient for reliable system operations. If this level of heating is initiated at the onset of precipitation or frost, only 15 to 20 minutes of operation is required to warm the rails and ensure reliable system operations. Anticipation of inclement conditions was an important objective since successful prediction and activation of the heating system some time ahead of precipitation will virtually eliminate service interruptions or delays.

Observations were made of the power-rail-heating system's performance during the test program and it was found that no

FIGURE 7-1. ICE ACCUMULATIONS ON UNHEATED POWER RAILS

power-distribution-related shutdowns occurred due to winter precipitation. The installation of a resistance heater wire in the power rail and the routing of the wire through power-rail joints and expansion joints provided some potential problems which need to be solved prior to the installation of heaters in a DPM system. The wire insulation needs to be thin to allow sufficient heat transfer characteristics but is susceptible to shorts and insulation faults that might occur because of thermal expansion and contraction of the rails.

The physical location of the presently-configured power distribution rails (three rails vertically stacked, as shown in Figure 7-2) may need to be redesigned to aid snow-removal efforts by plow or debris guard. Based on the observed performance of the rails, improvements would consist of changing the contact-surface orientations to the horizontal plane or to a higher elevation than present. This change to the power-rail configuration would improve the operational capabilities of the Otis-TTD DPM system.

7.2 WESTINGHOUSE

The objective of the testing conducted by Westinghouse was to demonstrate the ability of the power-rail-heating system to control frost and the buildup of ice and snow (Figure 7-3). Among the features evaluated were the case of installation, reliability, and efficiency of the system, as well as the types of winter conditions which necessitate heating.

Initially tests were run to determine the ability of the electric heaters to maintain the rails free of snow during light snows falling at 0.3 in/hr and the heaters powered at only 5 watts/ft. Frequent failures were experienced with early tests of the heating elements. As a result, 30-foot sections of heater rail were layed alongside the guideway and tests conducted on them for the remainder of the first winter season. It was observed that the new groove shape and heater wire purchased from

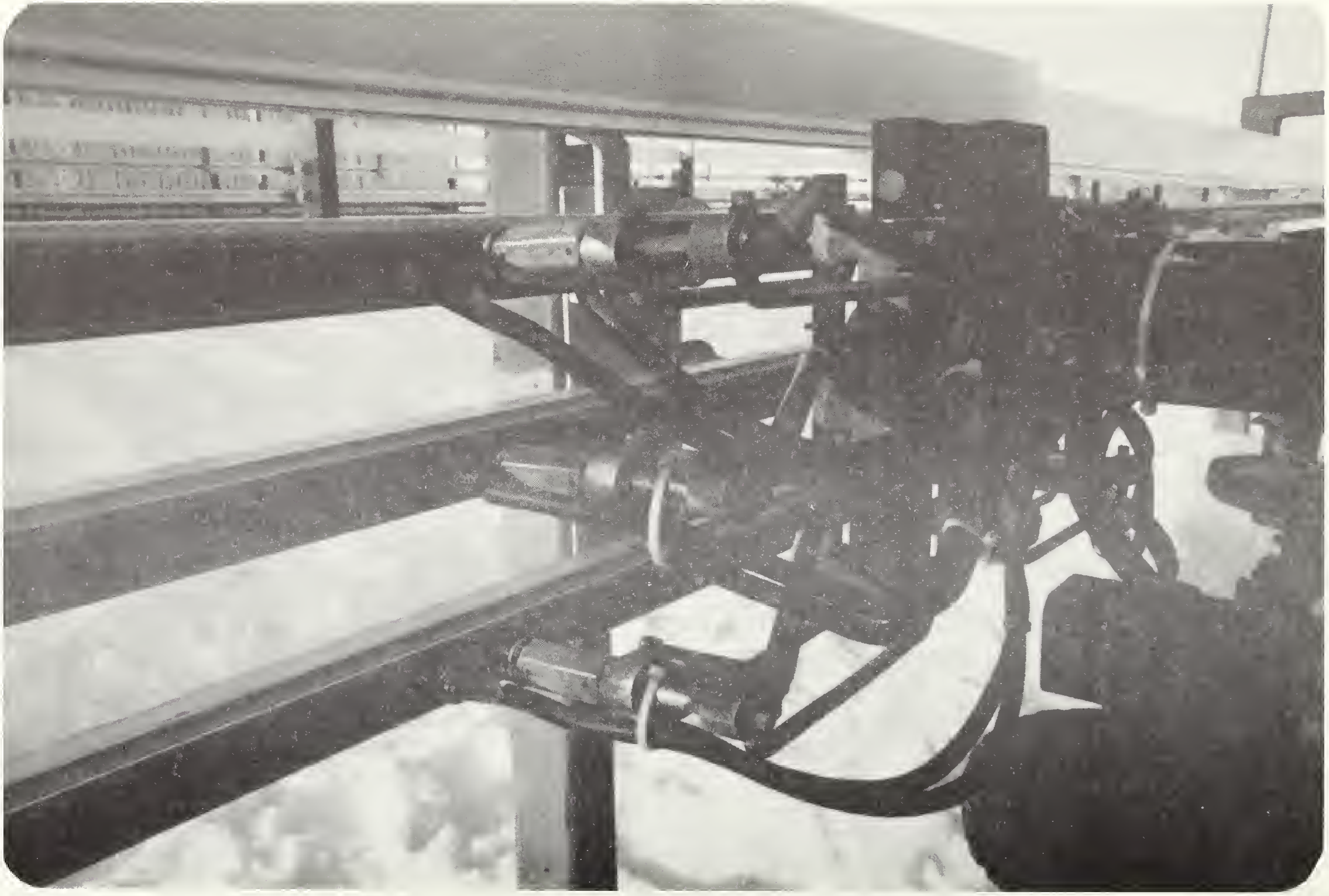

FIGURE 7-2. TYPICAL POWER-DISTRIBUTION-RAIL CONFIGURATION

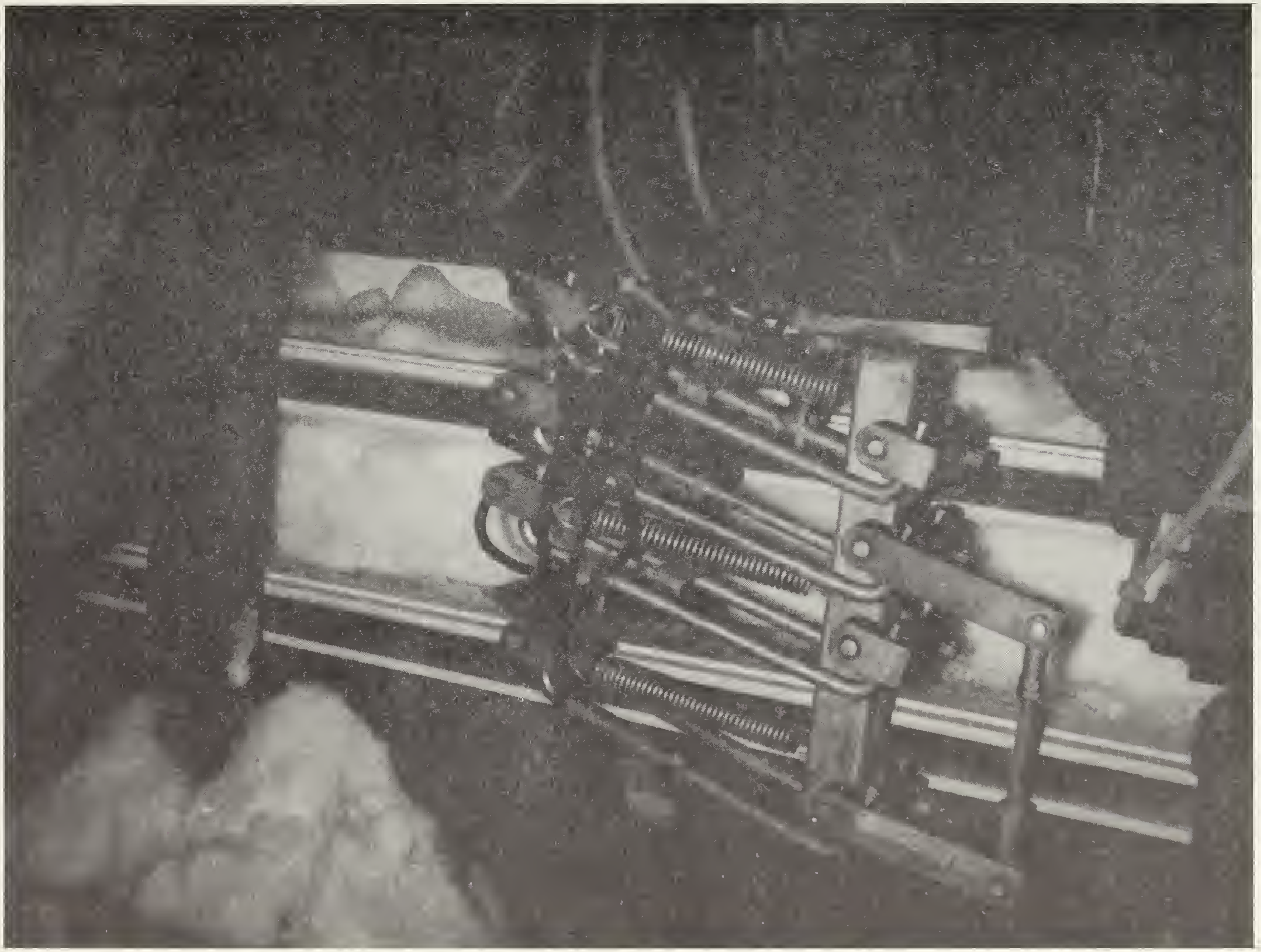

FIGURE 7-3. RAIL-HEATING SYSTEM MAINTAINING RAILS FREE OF ICE AND SNOW ACCUMULATIONS

Howell performed as designed, both at normal power levels and at levels five times the maximum design level. There was no sign of heater wire popping out of the grooves. Heater wire which was not enclosed showed a tendancy to overheat.

During 1978-79 testing, the following problems were identified:

1) Inadequate size of grooves in rail

2) Heating wire with poor expansion characteristics

3) Rail joints slipped

4) Inadequate wire-installation tool.

These areas were redesigned for 1979-80 testing, with the result that most problems were eliminated. The new groove configuration and wire-expansion characteristics are suited for use in a winter city DPM environment. The rail joints no longer slip, and expansion gaps and power-feed ramps are adequately heated. The wire-installation tool has also been significantly improved. However, one area remains to be perfected for ease of maintenance and operational reliability for a large-scale DPM application. This one problem is the splicing technique needed to join adjacent heater-wire sections securely without exposing heater-wire ends to the air. Westinghouse Transportation Division (WTD) plans life-cycle tests on the rail-heating system installed at the test track to demonstrate the effectiveness of new splicing techniques to improve mean time between failures (MTBF) and mean time to restore (MTTR).

7.3 UNIVERSAL MOBILITY

The demonstrations and tests that were performed by UMI during the 2-year program provided strong indications that, while vehicle snow and ice can adversely affect some power- and control-rail configurations, frost affects the performance of all unheated rails. Because of the orientation and location of the rails, as well as the additional protection provided by the drip lip, frost accumulations on the rail contact surfaces posed the only operational problem for this subsystem. Moderate to heavy frost caused arcing of increased severity as the power-collector accumulations increased; light to moderate frost reduced the effectiveness of all power rails, in particular, the control rail. Although it appears that frost-induced arcing will reduce the expected life of brushes and rails, no assessment was made during this program since only limited information was available.

The application of heating wire to selected sections of power and control rails provided 100-percent availability of these sections when heated to a maximum of 13 watts/ft using the 430-volt AC power supply. The heater wire was installed on one side of each of the operating rails as well as on one side of a set of side-mounted rails which were installed along the guide-beam for comparative purposes. During one specific test sequence, ice formed on the side-mounted rails, rendering them inoperable for 120 hours while the inverted sheltered rails remained clear of ice (Figure 7-4) and remained in service.

Power-collection and -control signals interface between the vehicles and the power and control rails via 6-inch copper-alloy brushes set on Insul-8 pantographs mounted on bogie frames. Three areas of concern relative to the proper functioning of brushes and pantographs included its susceptibility to ice, affecting the motion of the pantograph; ice or frost effects on the brush/rail interface; and winter-induced wear on the brushes.

Lubricants, such as Dow Corning No. 33 and Lubriplate, were administered to the collector once every 2 weeks and no collector-freezing problems were observed. The lubricants successfully improved the movement of the collector arms. Ice or frost on the brush/rail interface causes a reduction or elimination of the current flow and increases the potential of power brush/rail arcing due to intermittent current flow. Except for frost and dew on warmer days, no naturally-occurring moisture accumulated on either the power or control rails.

The winter-induced wear on brushes is greater because of reduced rail/brush lubrication and other mechanical actions.

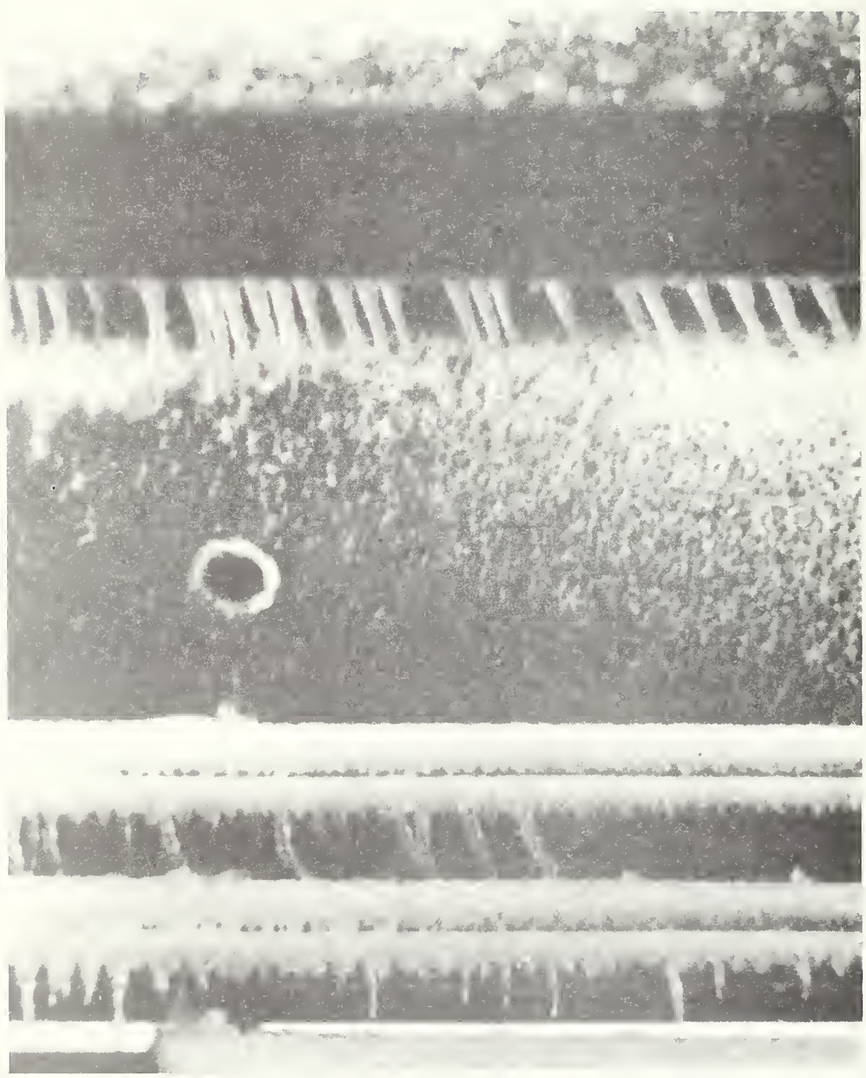

FIGURE 7-4. COMPARISON OF SIDE-MOUNTED AND INVERTED RAILS

Lubrication was reduced because cyclic frost-accumulation/-melting process prevents the necessary buildup of brush-alloy lubricating fraction deposited on the rail-contact surfaces. In addition, much of the power- and control-rail installation was accomplished in severe cold temperatures (below 0°F) and the installers did not chamfer the leading edges at joints and switches, leaving sharp edges which increased brush-wear rates.

Later in the test program the rails were realigned, edges chamfered and expansion joints fastened to reduce the rate of brush wear. The life expectancy for copper/graphite brushes in winter operation was much lower than anticipated. On new rails, with a frequency of frost incidents, brush life was about 150 hours (one-train operation). With two-train operation and less severe frost conditions the brush life might be extended to 250 hours, and 300 hours for three-train operation.

Brush-heating tests utilizing a power level of 12.6 watts/brush showed that even at low speeds of 5 ft/sec, the frost/ice buildup exceeded the melting rate and degraded operation resulted. UMI developed a solution to this problem, namely their power rail feedback control system (PRFCS), which is discussed in Section 8.3.

8. OTHER SUBSYSTEM TESTING

Testing activities which do not fall under the headings of Sections 5 through 7 are included in Section 8 of each contractor's report. This report includes a brief discussion of the activities; if additional detail is desired, refer to the contractors' reports.

8.1 OTIS

A specific area of interest that was outside the scope of the OTIS-TTD winterization test and demonstration program was the effects presented by the snows that were removed from the guideway and deposited outside the guideway areas. The guideways designed for at-grade installations need room for placing removed snows from the guideway running-surface areas. Accumulated snow needs to be melted or removed during an extremely long winter season to allow the continued and additional removal of snow accumulations. Consideration must be given in the DPM system to make allowance for providing these specific services. The effects of snow removal on surrounding property must be evaluated and the effects understood, particularly in the case of elevated guideway, but also in view of the potential problems that might exist in at-grade installations.

An evaluation of DPM system stations was not a part of the OTIS-TTD winterization program but some general recommendations can be made based on winter climatic experiences and results achieved from guideway precipitation accumulations. A certain amount of heating, shrouding, and enclosing of critical station-related equipment should be considered. These winter modifications would be easier to install and more cost effective than guideway-winterization modifications in that they would be confined to a small local area where ready provisions for some of these modifications would already be available. The effects of precipitations and their accumulations, winds, and cold temperatures would be somewhat naturally reduced in station areas because of their proximity to building structures and other types of construction. The wayside controls such as signal and block control, track and interlock, mode and dispatch, central control operations, and communications were not evaluated because the equipment for these controls is installed in station buildings or other enclosed and climatically controlled areas where the effects of winter conditions are not felt. Thus, the only elements of the wayside controls susceptible to winter conditions are the remote vehicle- and guideway-mounted hardware. This hardware was evaluated during the winterization program.

It would seem to be a requirement from the experience gained in the winterization test and demonstration program to include a reliable weather-forecasting capability as part of a DPM system-deployment operational philosophy. This weather forecasting, if provided from more than one source, could be considered fairly reliable and somewhat independent from potential man/machine-error influences. The weather-forecasting information could then be utilized to anticipate specific types of winter conditions and take preventative or corrective actions early enough to prevent drops in system availability that might be imposed by these conditions. For a winter-climate DPM installation, an experience base with this type of weather-forecasting information should be gathered approximately 2 years prior to system performance. It is possible that once this forecasted weather information is obtained it could be utilized to automatically control some of the winterization corrective measures that would need to be taken to assure a reliable system operation.

8.2 WESTINGHOUSE

In addition to the subsystem tests previously discussed, tests were also conducted on station doors and vehicle storage areas. The station doors slide within an inverted T-shaped, 16-foot-long, open-channel metal guide. The door track was heated by placing elements inside the door-track channel. Thermocouples were placed at each end and at the center of the door track to determine the track temperatures when heated. None of the operating parts of the door are exposed to the direct effects of winter precipitation because of the "pocket door" configuration.

The objective of the testing was to determine the ability of the station doors to function reliably and smoothly during winter conditions, with and without the use of electrical snow-removal systems for the door track. With heating levels of 8 watts/ft, the door track and a narrow 1-inch strip of concrete in front of the track were maintained free of accumulation and no problems were observed. When tests were conducted without heat, the doors were cycled once every minute during automatic operation of the People Mover system. The only problem encountered during the entire 1979-80 winter season was a frozen airline on the safety edge. This was a result of the airline losing ductility at subfreezing temperatures. This malfunction does not interfere with door operation, but only with edge-triggered recycle.

Overnight storage of vehicles on an unprotected siding (Figure 8-1) was considered a possible trouble spot so tests were conducted by Westinghouse to determine if freeze-up would occur and, if so, what measures should be taken to get the vehicles in service. A parking area was designated on the test-track spur. Thermostatically-controlled heaters were installed beneath the axles of the parked vehicles. The objective of this test was to determine whether radiant heaters in the parking area reduce the possibility of brake-shoe/-drum freeze-up overnight in cold weather. During the winter testing of 1979-80 it was determined that vehicle-storage-area heaters are not needed at temperatures down to 0°F. Although there was no evidence to support the need for parking-area heaters, the WTD radiant heater system was demonstrated to keep the bogie temperatures above freezing. Tests with sub-zero temperatures, however, would be necessary to draw conclusions about the necessity of such heaters under those conditions.

FIGURE 8-1. WESTINGHOUSE VEHICLE AFTER OVERNIGHT STORAGE ON UNPROTECTED SIDING

8.3 UNIVERSAL MOBILITY

Several other UMIMOBIL system features and subsystems were tested or demonstrated during the 2-year program. These items are discussed here and include: the maintenance support vehicle, snow module, auxiliary traction subsystem (ATSS), and power rail feedback control system (PRFCS).

Initially a maintenance support vehicle (MSV), designed specifically for construction of the MZG guideway was outfitted with a snow module (brush/plow attachment) to maintain the guideway clear of ice and snow and perform routine and emergency maintenance on the system. This interim MSV was later replaced with a permanent vehicle which had the capability of moving a disabled train from the guideway but was not equipped with a snow module.

Snow removal for the first season was accomplished with the interim V-shaped splitter plow, 48 inches in width, and 2 counter-rotating vertical-axis nylon brushes, 24 inches in diameter. The brushes adequately removed 2 inches of snow (density = 6.25 lb/ft^3); depths above 2 inches were handled by the plow action. Accumulations of up to 30 inches were removed from the guideway with this arrangement.

Glare ice was removed from the guideway when surface temperatures were at or above 32°F. Because of the characteristics of the COR-TEN steel guideway the surface temperature generally exceeded the ambient temperature by 20° to 50°F during sunlight hours.

For the second season snow modules were attached to the revenue-service trains. Typically the plow blade was set to remove all but 3/8 inch of accumulated snow, the remainder of which was removed via the brush system.

Another unique feature tested by UMI was their auxiliary traction subsystem (ATSS) which powers guidewheels to obtain additional traction to supplement the primary traction during severe icing conditions. Since wind-driven snow and freezing rain are unlikely to affect both guidance surfaces simultaneously, additional traction is virtually guaranteed.

The ATSS was designed to overcome a train-rolling resistance of 2000 pounds. This value was derived from observing deceleration characteristics of a rolling UNIMOBIL train at temperatures in the near 0°F range. A concern for the ability of only four guidewheel rubber tires to withstand an applied force of 2000 pounds combined with the availability of eight guidewheels from the two trailing idler bodies, was the basis for selecting the ATSS configuration. The guidance-mechanism thrust against the guidance/auxiliary traction surface was adequate for the desired forces along the guideway; the space above the idler bogies was sufficient for the electric motors and hydraulic pumps.

Subsystem testing during the 1978-79 winter was conducted using cars 5 and 6 of Train 3, which were equipped with ATSS modules. The gearing of these test units restricted operating speeds to 5.5 ft/sec. This test unit was sufficient to demonstrate that the 2000-lb thrust level was obtainable. The ATSS modules were equipped with a positive-traction device which could develop full thrust even though one or both wheels on one side of the guideway slipped. For the 1979-80 test season, gear modifications were incorporated in the ATSS which permitted operations at the maximum guideway speed; however, the available propulsion thrust was then limited, by allowable traction motor currents and heating, to 2000 pounds for short-term applications and 1000 pounds for long-term operations. This ATSS configuration contained clutches to permit revenue service with or without ATSS operation. The ATSS drive motor was activated by single-switch operation. The ATSS installation was configured so that the drive wheels would function in all emergency-brake applications even though the ATSS drive mode may not have been selected.

A proprietary development of UMI, the power rail feedback control system (PRFCS), maintains power and control rails clear of frost or ice accumulations at an extremely low energy cost. The system monitors the power-rail and dewpoint temperatures and initiates power-rail heating when they closely approach one another (within 4°F), an indication that a frost situation is possible. This 4°F differential is maintained by the heating system by cycling "on/off" as needed. During a 16-week period of continuous service there was no occurrence of frost, ice, or snow which disrupted system power or communications, nor were there any electrical or mechanical failures at the system, subsystem, or component levels. During this period the heaters were energized 9.07 hours of the 2000 in-service hours, and during the same period there were frost conditions on 75 days totaling 268 hours.

9. SYSTEM-LEVEL TESTS

9.1 OTIS

The OTIS-TTD DPM winterization operational philosophies considered the system-level-performance evaluations as being the most significant and most important in demonstrating successful severe-winter-weather operations. The Otis test vehicle was operated on over 20 different days in a range of severe winter-weather conditions. The vehicle was shuttled through the test area in the on-board automatic mode through a range of speeds utilizing the vehicle control unit(VCU) to operate the vehicle at a pre-selected velocity by providing the thrust control in acceleration and jerk control. The test conditions that the system was subjected to during these circulation-test runs ranged from snow accumulations of less than 15-percent moisture content, man-made snows of 15- to 30-percent moisture content, man-made and natural snows of greater than 30-percent moisture content, glaze-icing conditions simulating freezing rains, and rime-icing conditions simulating sleet- and water-refreeze conditions. It was determined from previous experience in utilizing Otis vehicles to remove snows from the guideway and through information developed in the winterization test and demonstration program that a circulating OTIS-TTD DPM vehicle could adequately remove up to 1 inch of snow accumulation regardless of the type and water content of the snow, the ambient temperature, and the guideway conditions. This led to a criterion based on the requirements imposed for the winterization demonstration that vehicles be circulated through the snowfalls at intervals of 1/2 hour. In many different cases during the winterization program, snow accumulations of significantly more than 1 inch were satisfactorily removed from the guideway by the normal system-level vehicle operations.

The test scenario for demonstrating system-level operation and the continuous circulation of vehicles during winter precipitations was based on the modifications to the winterization-test section and the capability of the snowmaking equipment to produce suitable winter conditions over a given length of guideway. This resulted in a 250-foot length of guideway which was described as the winterization-test area where the vehicle circulation took place and where documentation, either by on-board recorders or photographic and video recorders, verified the demonstration of the system-level tests. The actual vehicle-circulation operations and attendent snowmaking were generally conducted in approximately 7- to 8-hour periods starting with the coldest portion of the day, which usually occurred between 3 and 5 o'clock in the morning, and continuing through the morning hours to take advantage of the cold temperatures and the improved lighting conditions during the morning hours. Supplemental lighting was provided in the winterization-test area for photographic and video-tape documentation prior to sunrise. As the system-level tests progressed, the vehicle-mounted shrouds and debris guards were modified to improve the capability of the vehicle operation during the system operation. It wasn't possible during the winterization program to catch very many natural conditions that satisfied the requirements of the test matrix for the various test-procedure scenarios in the system-level tests. Therefore, most of the system-level-test operations were conducted with man-made precipitations that could be produced and controlled at will, providing an optimization of the test-crew and test-track usage. In three cases (under different sets of conditions) test were conducted over three successive test days representing significant on-guideway accumulation of snows and simulated snow-storm events depositing precipitations at the maximum rate specified for in excess of 20 consecutive hours. These test series, which were performed successfully, exceeded the requirements specified in the desired climatological extremes based on a deployment in the regions of Minneapolis/St. Paul or Detroit.

9.2 WESTINGHOUSE

Westinghouse performed system-level tests, those tests which utilize the maximum number of subsystems at one time, in both manual and fully-automatic modes of operation. Manual operation of the WTD People Movers at the test track requires that all wayside equipment be operational in the manual mode. This includes route selection through the switch, train detection, and power distribution. Also for manual operation, all vehicle equipment must be operational with the exception of the on-board automatic-train-operation (ATO) package. Automatic operation requires that all wayside and vehicle equipment must be functioning properly.

During 1978-79 testing, manual operation was used almost exclusively, due to the heavy emphasis on subsystem testing and to low reliability of portions of the vehicle and wayside automatic equipment, which was all prototype equipment. Extensive updating of both wayside and vehicle equipment was accomplished after the first year's testing, resulting in a system which closely simulates functional operating systems marketed to WTD People Mover customers. The test objective was to demonstrate reliability of this type of system in adverse winter conditions. To this end, automatic operational procedures were established. These included various automatic schedules representing peak and non-peak passenger demands in a typical DPM and accelerated cycling of guideway switch and station doors.

Testing periods from 2.5 to 14.5 hours were scheduled for a total operating time of 184.75 hours. The test vehicle traveled a total of 904.4 miles on 7001 trips, the guideway switch cycled 2744 times, and the station doors were cycled 7155 times. Prior to the beginning of each testing period, the existing weather conditions or the forecasted conditions were considered with the desire to select that schedule which would reflect various conditions to which a typical DPM system would be subjected. Operating personnel were required to maintain the assigned schedule as closely as possible, recording all downtime events or failures and taking corrective action to return the system back to the schedule.

Measured system availability was 87.7 percent with schedule adherence of 83.9 percent, both figures quite good for a test car and test system which are constantly usee to test and debug new designs. Although the 1979-80 winter was not as severe as was expected, either in cold extremes or snowfalls, significant automatic-operational data were gathered. In those cases where a glaze of ice was allowed to form on running surfaces within acceleration or deceleration zones, there were chances of slip/spin occurring. Reduction of acceleration/deceleration rates in cases where slip/spin is expected minimizes the probability of slipping.

Of the incidents reported during this period, only seven were winter-related. Six incidents were caused by the motor-overload breaker tripping due to wheel spin during acceleration, and one incident was caused by a broken piece on a non-energized heater wire producing a false occupancy.

In conclusion, the results of the automatic operation demonstrate that the WTD People Mover system operated reliably in the winter environment encountered during the 1979-80 winter test period.

9.3 UNIVERSAL MOBILITY

System-level testing encompassed the bulk of the UMI 1979-80 winter activities. This complemented the subsystem and component-level testing which had been necessary during the previous winter. Other than frost, no naturally-occurring winter temperature or precipitation condition caused the UNIMOBIL system, or any of its subsystems, to become non-functional at MZG during either the 1978-79 or 1979-80 winters. Extreme cold in the range of -20°F had only limited impacts on any parts of the system; these impacts were on the various hydraulic drives and were essentially compensated for by the use of low-viscosity winter fluids.

The trains to be used in revenue service were stored outside with system power totally shut down overnight. This approach was selected to minimize moisture-related problems resulting from condensation that would accumulate on cold components brought into a warm and relatively humid building. The moisture-related problems include corrosion of electrical and mechanical components as well as possible mechanical constraints when the condensate is exposed to outside freezing temperatures. The ECU was able to provide sufficient heat to overcome the extreme overnight cold temperatures for daytime passenger comfort; there was no need to maintain heat in the trains when they were not in revenue service.

During both winters, the only specific winter-stress-operability procedures that were required, and demonstrated, for MGZ service were snow removal and recognition of slower hydraulic-equipment operations. For the former condition, a snow module was used before instituting revenue service if overnight snow accumulations could be expected to remain during either the 7:00 a.m. to 10:00 a.m. testing periods or after the 10:00 a.m. start of revenue service. A snow module was also used if, during daytime operations, the snowfall or icing rate exceeded the melting rate and might allow buildups on the bogie (tires) tracking surfaces. This was primarily a comfort response since the UNIMOBIL-system trains can accommodate compacted ice or snow depths of up to 0.5 inch.

With regard to the effects of extreme cold on the hydraulic subsystems, the procedure was simply to allow an extra 5 to 30 seconds for them to operate in sub-zero weather. If their response time should become a critical item, their performance could be improved by additional procedures (e.g., continuous standby operations to keep heat circulated) or modifications (heat-tracking lines). The system characteristics, including guideway geometry and on-board control configurations, limited the impact of all winter stresses. Only frost, which could have been eliminated by a system-wide PRFCS, prevented continuous automatic-mode operations in revenue service.

The optional PRFCS, while providing snow- and ice-removal benefits, is also applicable as a low-energy-consuming frost controller/preventer. As indicated in Section 8.4.2, the direct electric costs for a 3-mile-long loop of single-lane guideway with four power and control rails subjected to the recorded 1979-80 winter conditions would be less than $1000. If the weather conditions were twice as demanding and the DPM system had dual-lane guideways over a 5-mile route, the direct annual costs, based on $0.05/kw-hr would still only be in the range of $6000 for a winter of continuously frost-free operations. In addition to the low electric-energy costs, other PRFCS benefits include: lower power- and control-rail maintenance costs (compared to high-energy and/or manual recovery methods such as scraping or heated-liquid applications); better system operability (no frost-caused delays); and improved collector-brush life since the deposited lubricating fraction is not lifted or washed from the rails.

The comfort of the UNIMOBIL system at MZG was investigated with a basic orientation towards satisfactory vehicle-interior temperatures. The ECU maintained the train interiors at a comfortable temperature (recognizing the typical passenger's winter attire) and precluded any condensation from forming inside the train; condensation also did not form on the vehicle exteriors. The ECU, and the vehicle construction, provided this comfort while the vehicle-interior noise level was sufficiently low for passengers to maintain normal conversations.

10. FINDINGS AND CONCLUSIONS

The following findings and conclusions summarize the experiences of the 2-year winter test program:

<u>Guideway Related Testing</u>

- Open, narrow guideway designs discourage large snow accumulations and facilitate the problem of snow removal.
- Maximum snow depths for open-guideway designs are approximately 2/3 of the surface width.
- Plows and brushes can effectively remove expected accumulations provided their designs account for possible effects on other subsystems, such as power and signal collection and undercarriage components.
- Rubber-tire systems which rely on frictional resistance for traction require a clean running surface, especially on grades and in acceleration and deceleration areas. Guideway-heating or auxiliary-traction systems are needed to ensure that the necessary traction is available when icing conditions exist.
- For concrete guideway, electrical-heating elements can be installed by casting them in place, inserting them in glycol-filled pipe embedded in the guideway, or by sealing the elements in grooves cut in the running surface. The latter method is preferred because it provides more efficient heating and is easier to repair.
- Unheated steel guidebeams extract sufficient warmth from solar-radiation heating to raise the daytime temperature of the guideway about 20° to 50°F above the ambient. Often times this is sufficient to prevent the accumulation of ice or snow.
- Air-suspended systems can be operated on an ice layer of nearly 0.75 inch using a linear induction motor with an

insignificant reduction in vehicle thrust. Brake strips, however, must be kept clean by heating to insure sufficient frictional resistance for braking.

- Switch operations can be slowed by the onset of cold temperatures. Lubricants suitable for sub-zero environments should be utilized on switch components, and additional capabilities such as heating should be available for ensuring proper switch operation. Switch designs should provide sufficient opening for snow removal and utilize boots or covers to protect moving parts from compacted ice and snow.

Vehicle-Related Testing

- Boots, shrouds, insulation, and other passive winterization measures should be provided to protect vulnerable components from the effects of snow and ice.
- Vehicle-door design should be such that it precludes places for snow and ice to accumulate. Door tracks should contain sufficient drainage to eliminate the accumulation of water which may freeze and hamper door operation. Heating of the door tracks will ensure the proper operation of doors.
- The lateral-guidance mechanisms, in general, are able to tolerate some ice accumulation along the guidance rail with only minor degradation of ride quality. For rubber-tire systems, about an inch of compacted snow or ice can be accommodated without affecting the operation of the guidance mechanism.
- Longitudinal control of some AGT's requires accurate knowledge of the position of the vehicle at all times. When tires skid on ice the computer senses an unsafe situation and commands the initiation of emergency braking.

Power and Signal Collection

- The vulnerability of this subsystem to winter weather is generic to all systems and is the major obstacle to dependable winter operation of an AGT.

- Ice and snow can adversely affect power- and signal-rail performance, especially when unprotected rails are arranged vertically along the center or side of the guideway. Utilizing a horizontal arrangement of rails and providing shrouds or protective covers can significantly reduce operational problems.
- Frost accumulations on power and signal rails can occur where rails are protected and inverted and is the biggest operational problem, especially for the signal rail which carries a lower voltage than the power rails.
- Rail heating by means of resistance wire in a slot within the rail can adequately melt frost and all but heavy ice accumulation. Control of the heating system by monitoring rail temperature and dew point to anticipate a frost potential will help reduce the operating cost of such heaters.

Operating Strategies

The successful operation of an AGT in severe winter weather is dependent upon the operating strategy employed. For snow events, periodic circulation of vehicles outfitted with brushes or plows significantly reduces the depth of snow to be handled with each pass. If vehicles are circulated only twice an hour, the interim snow depth would not exceed 1.5 inches. Obviously, situations arise when system operation during a storm may be interrupted because of a power outage or other failure, creating a need for a special snow maintenance vehicle to handle large depths.

Heating of guideways, power and signal rails, door tracks, etc., is an expensive method of winterization, but with proper management and accurate weather forecasting, heating can be initiated just prior to the onset of precipitation, thereby preventing accumulations. Timeliness is the key to administration of any winterization techniques and, if done properly, can assure near-normal operations even in the worst of winter-weather conditions.

11. RECOMMENDATIONS

Although this DPM winter test program did not provide answers to all winter-related operating problems, it did permit UMTA, the northern DPM cities, and the DPM industry to gain considerable knowledge about the perils of winter operation, alternative protective and preventive measures, and possible operating strategies and techniques. Using the information and knowledge gained during the program, UMTA and the cities can better assess their expectations of such systems and limitations of their present designs, from which should evolve DPM systems capable of providing safe, dependable transportation in harsh winter environments. It is recommended that this winterization effort be the initiating effort to further refinement of snow- and ice-removal techniques, improved guideway and vehicle designs, and more efficient heating systems keyed to accurate forecasting of inclement winter weather.

APPENDIX

CLIMATOLOGICAL ANALYSES

Report No.: PM-74-U-106-39

CLIMATOLOGICAL ANALYSIS OF THE MINNEAPOLIS-ST. PAUL ENVIRONMENT

APPROVED FOR DISTRIBUTION: ______________________

Prepared by

Lawrence Silva

July 27, 1978

CONSTRUCTION ENGINEERING BRANCH
VEHICLES AND ENGINEERING DIVISION
OFFICE OF GROUND SYSTEMS
U.S. DEPARTMENT OF TRANSPORTATION
TRANSPORTATION SYSTEMS CENTER
KENDALL SQUARE
CAMBRIDGE, MA 02142

UNITED STATES GOVERNMENT

Memorandum

DEPARTMENT OF TRANSPORTATION
TRANSPORTATION SYSTEMS CENTER
KENDALL SQUARE
CAMBRIDGE, MA 02142

DATE: July 27, 1978

In reply refer to: DTS-741

SUBJECT: Climatological Analysis of the Minneapolis-St. Paul Environment

FROM: L. P. Silva
Thru: Chief, Construction Engineering Branch, DTS-741

TO: Neil Patt

In conjunction with the Downtown People Mover Program (DPM), the climate of the St. Paul region was examined to determine the severity and recurrence interval of the various weather phenomena. Information about the historical weather data was obtained from several sources as follows:

(1) National Oceanic and Atmospheric Administration (NOAA), U.S. Department of Commerce "Monthly Summary Data," Minneapolis-St. Paul, Minnesota (1949-1976).

(2) National Oceanic and Atmospheric Administration, U.S. Department of Commerce," Climatic Atlas of U.S." 1975.

(3) U.S. Department of Commerce "Technical Paper #40, Rainfall Frequency Atlas of United States" 1961

The results of this study are summarized in this memo:

The Twin Cities region of Minnesota similiar to the remainder of the state is a dynamic area which experiences frequent weather changes and extremes in most climatic elements. Weather phenomena ranging from extreme cold to dust storms and tornados occur from time to time due to the migration of disturbances from northwestern United States and the introduction of polar air masses from Canada.

Temperature

Seasonal variation in temperature is quite large. Recorded temperature extremes cover a range of 142° from -34° (Jan 1936 and 1970), to 108° in July 1936. Temperature related statistics are as follows:

Range of Temp. (Max.)	142°
Largest Cold Spell (below zero)	36 days
Longest Hot Spell (90° +)	11 days
Avg Cold Season (32°-)	198 days

Average Number of Days

Max Temp 90° +	15 days
Max Temp 32° -	83 days
Min Temp 32°-	158 days
Min Temp 0°-	35 days

Recurrence Interval	200 yr	100 yr	50 yr	25 yr
Maximum Temperature	112°	109°	107°	104°
Minimum Temperature	-36°	-35°	-34°	-33°

Rainfall

On the average the St. Paul region receives approximately 26" of precipitation annually. The range of monthly totals varies considerably from a low near zero to a high near 9.31 inches. The heaviest amounts of rain occur from May to September and often come in the form of thunderstorms. Approximately 37 such events occur annually.

Rainfall intensities associated with single events vary with the duration of the storm. Recurrence intervals for storms of 1/2 to 24 hour durations are as follows:

	Rainfall (inches)				
Recurrence Interval (yrs)	100	50	25	10	1
Duration 30 min	2.1	1.9	1.7	1.5	.8
1 hour	2.7	2.5	2.1	1.9	1.0
2 hours	3.2	3.0	2.7	2.2	1.2
3 hours	3.5	3.2	2.9	2.5	1.3
6 hours	4.1	3.8	3.3	2.9	1.6
12 hours	4.9	4.3	3.9	3.4	1.8
24 hours	5.5	5.0	4.5	3.9	2.1

In addition the probable maximum 6 hour precipitation for a 10 square mile area is 23 inches which is 5.5 times greater than the 6 hour, 100 year precipitation.

Wind Speeds

In general, the prevailing wind direction is the northwest. Winds from this direction dominate from November to April at which time the southern and southeastern air masses provide a shift which signifies the arrival of the warmer weather. The recurrence of record wind speeds was examined, the results are as follows:

Recurrence Interval (yrs)	200	100	50	25	10
Wind Speed (mph)	100	90	82	74	63

Snowfall

The severity of winter in St. Paul is marked by its length and extremes in cold temperatures and for snow events of great magnitudes. Record snowfall figures indicate that monthly snowfall amounts can be as high as 40.0 inches with seasonal totals averaging about 46.0 inches. The highest individual snow event, however, reached a maximum of 16.2 inches. Using the snowfall data accumulated from 1949 thru 1976, 66.7% of those storm events producing measurable snowfall were less than 2.5 inches.

Another 20% of the snowstorms results in up to 5 inches of snow, while 12% of the events had totals of 5-10 inches. Only 1.3% of measureable snow accumulations have exceeded 10 inches. The recurrence interval of major storm events is as follows:

Recurrence Intervals (yrs)	200	100	50	25
Snowfall (inches)	20	18	16	14

The rate that snow falls was also examined and it was found that the rates are lower than that for an eastern seaboard state such as Massachusetts which may be influenced by the Atlantic Ocean. The rates and recurrence intervals are as follows:

Recurrence Intervals (yrs)	200	100	50	25
Snowfall Rate (in/hr)	1.5	1.0	.9	.7

The consistency of snow is also a major item which was studied. A rule of thumb when comparing snow depths and water equivalents is that you get 10" of snow for every inch of rainfall. This is true for dry or powdery snow but often times a rain-mixed snow or "heavy snow" event occurs. Taking the ratio of snowfall to water equivalent as a measure of snowfall consistency, 83% of measureable snowfalls have a ratio greater than 10 to 1. This means that only 17% or about 2.5 times a winter one would expect wet snow. Of the 17%, over 76% have ratios $\geq$ 5.0.

Other Weather Phenomena

The Twin Cities lie near the northern edge of the influx of moisture from the Gulf of Mexico. Severe storms such as tornadoes, dust storms, freezing rain (glaze) and hail, though not frequent are not uncommon. Five severe tornadoes have struck Minneapolis-St. Paul.

Recommendation

It is my recommendation that any DPM system proposed for St. Paul be capable of normal operation in the environment described herein, for meteorological phenomena with recurrence intervals of 100 years of less. After you have reviewed this summary we can discuss this matter further.

Report No.: PM-74-U-106-40

CLIMATOLOGICAL ANALYSIS OF THE DETROIT ENVIRONMENT

APPROVED FOR DISTRIBUTION: ______________________

Prepared by

Lawrence Silva

August 31, 1978

CONSTRUCTION ENGINEERING BRANCH
VEHICLES AND ENGINEERING DIVISION
OFFICE OF GROUND SYSTEMS
U.S. DEPARTMENT OF TRANSPORTATION
TRANSPORTATION SYSTEMS CENTER
KENDALL SQUARE
CAMBRIDGE, MA 02142

UNITED STATES GOVERNMENT

Memorandum

DEPARTMENT OF TRANSPORTATION
TRANSPORTATION SYSTEMS CENTER
KENDALL SQUARE
CAMBRIDGE, MA 02142

DATE: August 31, 1978

In reply refer to: DTS-741

SUBJECT: Climatological Analysis of the Detroit Environment

FROM: L.P. Silva

TO: N. Patt, DTS-723

In conjunction with the Downtown People Mover Program (DPM), the climate of the Detroit, Michigan region was examined to determine the severity and recurrence interval of various weather phenomena. Information about the historic weather data was obtained from several sources as follows:

(1) National Oceanic and Atmospheric Administration (NOAA), U.S. Department of Commerce "Monthly Summary Data," Detroit, Michigan (1949 - 1976)

(2) National Oceanic and Atmospheric Administration, U.S. Dept. of Commerce, "Climatic Atlas of US" 1975

(3) U.S. Department of Commerce "Technical Paper #40, Rainfall Frequency Analysis of United States," 1961.

The results of this study are summarized in this memo:

Detroit's climate is influenced by two major factors; its location relative to major storm tracks and its poximity to the Great Lakes. Located in the middle of the storm track region, winter storms pass south of the city while summer disturbances choose a more northern route. This results in periods of snow or rain during the colder months and severe thunder storms during the remainder of the year. The Great Lakes have the effect of taming or reducing the intensity of various weather extremes.

Summers in Detroit are warm and sunny with frequent showers and rare periods of drought. Short hot spells of 90+ temperatures and high humidity occur occassionally but for the most part summer days are quite comfortable. Winter storms bring rain, snow and sometimes freezing rain and sleet in steady continuous periods of several hours. Snow storms average about three inches, but heavier amounts accumulate several times each year.

Detroit Michigan - Weather Profile

Temperature

Range of Recorded Temperatures:	129°

High, 105°F, July 1934

Low, -24°F, December 1872

Average Cold Season:	184 days
Avg Date of First Freezing Temp	Oct. 21st
Avg Date of Last Freezing Temp	April 23rd

Distribution of Temperatures (# of Days/yr)

Highest Daily Temp exceeds 90°F - 12 days

Highest Daily Temp is less than 32°F - 48 days

Lowest Daily Temp is less than 32°F 138 days

Lowest Daily Temp is less than 0°F - 7 days

Graphic Display of Daily Temperature

	High - 12 days
90°	
32°	
	High - 48 days Low - 138 days
0°	
	Low 7 days

Average Temperatures (°F)

Month	Daily Maximum	Daily Minimum	Monthly
J	31.9	17.3	24.6
F	34.3	18.8	26.6
M	43.8	26.7	35.3
A	58.1	37.3	47.7
M	69.1	47.0	58.1
J	79.4	57.2	68.3
J	83.4	61.1	72.3
A	82.0	59.5	70.8
S	74.8	52.3	63.6
O	64.1	42.1	53.1
N	47.8	32.3	40.1
D	35.4	21.5	28.5

Return Interval of Temperature Extremes (°F)

Recurrence Interval (yr)	200	100	50	25	10	5	1
Max Temp (°F)	108°	106°	104°	102°	100°	96°	92°
Min Temp (°F)	-11°	-10°	-9°	-8°	-6°	-4°	10°

Precipitation

Monthly Normals and Extremes (inches)

Month	Normal	Maximum Monthly	Minimum Monthly
J	1.91 inches	3.63 inches	.27 inches
F	1.75	2.87	.15
M	2.47	4.48	.92
A	3.22	5.40	.92
M	3.31	5.88	1.15
J	3.42	6.60	2.12
J	3.10	6.02	.59
A	3.28	7.83	1.06
S	2.16	5.83	.43
O	2.48	4.87	.35
N	2.32	3.31	.79
D	2.27	6.00	.46
Annual	31.69		

Rainfall (inches) for Various Durations

Recurrence (years) Interval	100	50	25	10	1
Duration 30 min	1.9	1.8	1.6	1.4	.8
1 hour	2.6	2.3	2.0	1.8	1.0
2 hours	2.9	2.7	2.4	2.1	1.2
3 hours	3.3	2.9	2.6	2.2	1.3
6 hours	3.8	3.3	3.0	2.7	1.6
12 hours	4.4	3.8	3.5	3.1	1.8
24 hours	4.8	4.4	4.0	3.5	2.1

In addition the probable maximum six hour precipitation for a 10 square mile area is 24.5 inches which is 6.75 times greater than the six hour, 100 year precipitation.

Wind

In general, the prevailing wind direction is the west-southwest. Winds from this direction dominate during the entire year with minor shifts to the west or southwest. The recurrence of record wind speeds was examined, the results are as follows:

Recurrence (years) Interval	200	100	50	25	10
Wind Speed (mph)	82	78	73	69	62

Snowfall

Record snowfall figures indicate that monthly snowfall amounts can be as high as 24.0 inches with seasonal totals averaging about 32.0 inches and distributed as follows:

Month	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May
Avg. Snowfall (inches)	Trace	2.5	7.1	7.9	7.7	5.4	1.1	Trace

The highest recorded snowfall event was a maximum 19.2 inches. Using the snowfall data accumulated from 1949 thru 1976 at the Detroit City Airport, 72% of the storm events producing measurable snowfall had accumulations less than 2.5 inches.

Another 16% of the storms resulted in up to 5.0 inches of snowfall while 10% of the events had totals between 5 and 10 inches. Only 2% of measurable snow accumulations have exceeded 10 inches. The return period of major snow storms is as follows:

Recurrence (years)	200	100	50	25	10
Snowfall (inches)	22"	19"	16"	13"	9"

The consistency of snow is also a major item which was studied. A rule of thumb when comparing snow depths and water equivalents is that you get 10" of snow for every inch of rainfall. This is true for dry or powdery snow but often times a rain-mixed snow or "heavy snow" event occurs. Taking the ratio of snowfall accumulation to water equivalent (inches) as a measure of snowfall consistency, 77% have a ratio greater than 10 to 1. This means that 23% or about 3.0 times a winter one would expect wet snow of the 23%, over 65% have ratios greater than 5.0.

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