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Downtown People Mover (DPM) Winterization Test Demonstration: UMI

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Final Report

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16. Abstract

This report documents that simple Downtown People Mover (DPM) systems can satisfactorily perform in harsh winter environments. It describes the climatic and operating conditions under which the UNIMOBIL System was both tested and demonstrated at a site just south of Minneapolis - St. Paul Minnesota. The tests were performed during the winters of 1978-79 and 1979-80; revenue service performance was demonstrated during the latter winter. The climatology of this site provides frequent sub-0°F temperatures and an average annual snow accumulation of nearly 50 inches.

The characteristics of the baseline UNIMOBIL vehicle and its Slimline Guideway were utilized to demonstrate that neither snowfalls nor extreme cold should necessarily constrain DPM operations; appropriate system designs and operating procedures can preclude costly responses to either of these weather conditions. It was determinded that frost on the power and/or control rails can produce more frequent and lasting impacts on DPM operations; a satisfactory and cost-efficient solution to this problem was also demonstrated.

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PREFACE

This report was prepared by Universal Mobility, Inc. (UMI), Salt Lake City, Utah under contract DOT-TSC-1585 to the U.S. Department of Transportation's Urban Mass Transportation Administration Office of Technology Development and Deployment. The contract was managed by the Transportation Systems Center (TSC), Cambridge, Massachusetts; Neil G. Patt and Lawrence P. Silva were the contract technical monitors. The principal UMI participants were Donald P. Sullivan, who was responsible for initial program organization, all field activities and development of test data, and James Zaenger, P.E., who was responsible for technical review and assistance as well as preparation of the major report documents.

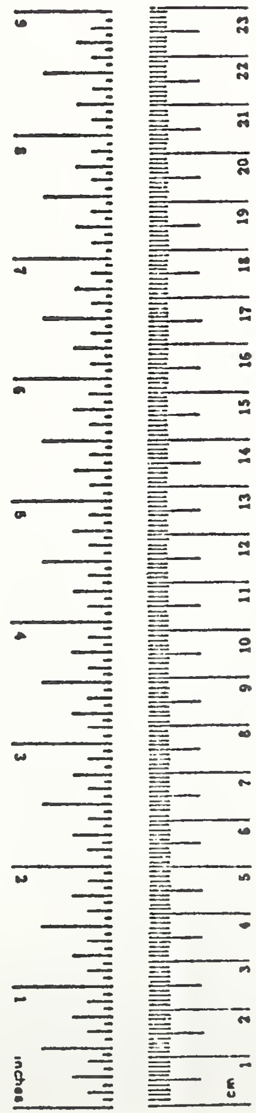
The objective of the program was to demonstrate that fully-automated and simple DPM (Downtown People Mover) Systems can be a reliable urban transit alternative in severe cold climates. This demonstration was intended to determine the capabilities and limitations of UMI's UNIMOBIL Systems through a combination of system and subsystem level testing. This testing was to include such diverse areas as traction and propulsion, braking and steering, power collection, vehicle and guideway electronics, switching and overall system performance. The test results can be used or extrapolated for quantitative design and performance criteria to be applied by DPM candidate cities located in areas of severe winter weather.

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

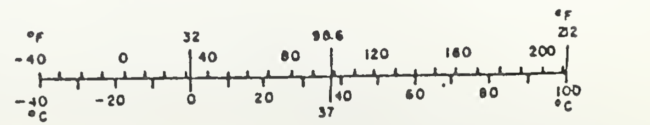
Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2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

Universal Mobility, Inc. (UMI) participated in the Downtown People Movers (DPM) Winterization Test Demonstrations during the 1978-79 and 1979-80 Winters. The UMI testing and demonstration program was performed utilizing the UNIMOBIL System at the Minnesota Zoological Garden (MZG) located at Apple Valley, Minnesota -- a suburb of Minneapolis-St. Paul.

PROGRAM

The Program was nominally divided into two parts; subsystem and component testing was performed during the 1978-79 Winter while system-level testing was the major 1979-80 Winter activity. The primary emphasis was placed on tests and demonstrations of UMI's baseline UNIMOBIL System, although there was limited testing and demonstrations of two optional UMI features. These optional features, the power rail feedback control system (PRFCS) and the auxiliary traction subsystem (ATSS), are somewhat more applicable to DPM Systems in harsh winter environments than to the MZG installation.

DEMONSTRATION SITE DESCRIPTION

The MZG site is well-suited for the required DPM Winterization Test Demonstration because it frequently experiences sub-0°F temperatures for extended periods and is often subjected to snow, ice and frost conditions. A primary test area was established using an over 500 foot long section of the 1.25 mile long main MZG guideway. An on-site weather station which measures eight basic meteorological parameters was installed on a hill adjacent to the primary test area; the on-site station's elevation approximated the average of the entire main guideway. A service contract was established with a nearby back-up weather station that has data processing capabilities. This contract made it possible to have: verification of data collected on site; continuity assurance in the event of local power outages; and a source of comparable data organized for easy reference to significant on-site weather condition values.

The naturally-occurring on-site precipitation conditions were augmented by artificial snow and ice. Snow accumulations were created by three mobile professional snow guns placed at various locations in the primary test area as well as using snow throwers and natural snow; the primary test area is a main guideway section adjacent to the MZG maintenance facilities. A variety of icing conditions were created by adjustments to the snow guns or using water flowed from hoses.

UNIMOBIL SYSTEM DESCRIPTION

The UMI System used at MZG was the UNIMOBIL Tourister; UMI also has a similar UNIMOBIL Transporter System. The Tourister is a relatively slow (top speed of 7.5 mph at MZG) six-car train configuration developed for recreational and educational purposes, while the Transporter is a DPM vehicle that operates up to 35 mph in single or multiple car consists. The Tourister normally functions in the automatic mode with an on-board guide/narrator, in the lead car, who initiates start up from the station(s) and some door operations; the guide/narrator provides a commentary on outside activities and exhibits. The guide/narrator, who can carry on two-way discussions with passengers in all six cars, has the ability to stop a train, even in the automatic mode, for interesting exhibits or activities; the Tourister trains can also function in a totally manual mode. The UNIMOBIL Transporter System's DPM vehicle will provide fully-automated operations with no on-board personnel.

The baseline UNIMOBIL System tested at MZG consisted of three trains; each has a seating capacity of 96 to 120 adults. The trains, which began revenue service on September 20, 1979, have steel frames and flame-retardent fiberglass reinforced plastic bodies. Every train is supported by seven bogies that each have dual, pneumatic-tire wheels; the lead, second and trailing (last) bogies are idlers while the four intermediate bogies are powered.

The UNIMOBIL System at MZG utilizes the Slimline Guideway that consists of a welded box structure fabricated of COR-TEN steel; the guideway has developed, by intent, a naturally oxidized surface which requires no maintenance. The guideway provides the fixed support, traction and guidance surfaces as well as the four power and control rails required for train operations. The guideway's (top) primary traction/support surface is a flat plate welded at all field joints to provide a continuously smooth riding surface for the trains.

The MZG UNIMOBIL System utilizes 480 VDC, three-phase power supplied to the trains by three power (one electrically-grounded) rails. The power is transferred from the rails to the trains by means of collectors at the front of each train. Both the power rails and the collector mechanisms are in sheltered locations that essentially preclude any problems associated with naturally-occurring snow or ice.

FROST-RELATED DEMONSTRATIONS

Although cold by itself affected neither the rails nor collectors, the frost associated with below-freezing temperatures did cause problems; radiational heat losses increase the rails' susceptibility to frost. The frost on the rails inhibited the power transfer to the collectors and decreased the rail/collector brush effectiveness as the brushes accumulated increasing buildups; the brushes acquired these accumulations while traveling over the frosted rail contact surfaces. Rail frost can be prevented by the PRFCS; accumulated frost dissipates from solar heat absorbed by the COR-TEN guideway or from increases in daytime ambient (and therefore rail) temperatures.

The vehicle motion control subsystem (VMCSS) is also unaffected by snow or ice since the control rails and collectors are sheltered in the same manner as the power rails and collectors. However, frost seems to have a greater affect on the control collector brush/rail interface than on the power collector/brush interface. Whether this greater affect was due to the lower voltages and currents associated with the VMCSS, as compared to the power rails and collectors, or more frost collected on the control rail, frost-interrupted power was satisfactorily available to the trains earlier every frost-affected day than were the signals to the autopilot for the VMCSS.

The optional PRFCS operated continuously, and without maintenance, from February 8, 1980 until after the April 30 ending of the 1979-80 (active) demonstration and testing period. Had the PRFCS been available for the entire main guideway, rather than just a 420 foot long special test section, no frost would have accumulated on any of the power or control rails. Without frost accumulations, the UNIMOBIL System could have performed in either the automatic or the manual mode at all times during the 1979-80 Winter -- or any winter. Based on electricity purchased at $0.05/kwh and extrapolated demand data, the PRFCS could have prevented any rail frost accumulations on the entire 1.25 mile long MZG guideway from November 1, 1979 to April 30, 1980 for less than $400. The resulting benefit would have been a three percent increase in automatic mode operability; this improvement would have occurred entirely in the early morning hours. The low operating costs for the PRFCS resulted from its feedback capabilities which cause minimal energy consumption.

SNOW-RELATED DEMONSTRATIONS

In addition to frost accumulations, obvious problems for DPM Systems in harsh winter climates are snow and/or ice accumulations. During the 1979-80 Winter Demonstrations at MZG, the advantages of UMI's Cold Guideway Concept (CGC) were evident; simply stated, the CGC is an approach which utilizes passive capabilities of the Slimline Guideway. The CGC advantages include: (1) minimal snow accumulates on the primary traction surface because it is flat and entraps neither precipitation nor debris; (2) snow is easily removed by brushing and/or plowing the flat primary traction surface; (3) snow removal leaves a dry surface when the guideway structural temperature is below freezing; (4) solar heat gained through the sidewalls and/or top plate can melt and/or evaporate snow, rain or ice residues from the top surface.

Snow removal was accomplished using a snow module or an interim MZG maintenance support vehicle (MSV). Either unit can function utilizing its steel V-shaped plow blade and/or pair of vertical-axis, counter-rotating brushes; the interim MSV could operate in a self-propelled configuration, while either can be pushed by a train. Applying a timely response to anticipated snow accumulations as a procedure, it was possible both to limit the quantity of snow removed during each pass and to keep the guideway clear of snow. By limiting the amount of snow removed in each pass, brushing proved to be a totally effective removal technique. With relatively small quantities removed in each pass and distributed by the brushes over an area perhaps 12 times that of the snow's guideway origin, the impact on people and facilities near and under the guideway was slight to essentially non-existant. The UNIMOBIL System can also respond to snow accumulations to depths in excess of 20 inches; in a single pass, these depths can be completely cleared using plow and brushes.

ICE-RELATED DEMONSTRATIONS

Naturally-occurring ice was practically never encountered because snow accumulations or residues had only limited opportunities to melt and refreeze; instances of freezing rains or sleet were less frequent. If the guideway structural temperatures were not too cold and the ice was of less than uniform density and surface finish, the plow could be used for ice removal. Otherwise, passive collection of solar heat on the guideway's sidewalls and, when possible, top surface melted the ice and evaporated the melted fraction which did not runoff. Guideway structural temperatures exceeded ambient temperatures by about 50^{o}F; even on overcast days, there were instances of solar heating in sufficient quantities to melt ice or snow.

Recognizing that both steeper gradients and higher probabilities for ice-covered primary traction surfaces can be expected in DPM (as compared to MZG) environments, an optional ATSS has been developed by UMI. The ATSS is an alternative (to artificial heating or mechanical removal) DPM System response to icing conditions which would adversely impact System safety or reliability. The ATSS is basically a method for using specially-modified train guidewheels for propulsion and braking; ATSS energy is redirected from selected traction motors' power supplies. All train guidewheels contact the vertical guidance/auxiliary traction surfaces that are connected to the sidewalls on each side of the guideway; there are four guidewheels, two on each side, connected by guidance mechanisms to each bogie. The guidance/auxiliary traction surfaces are in sheltered positions infrequently reachable by rain or snow; their vertical alignments further reduce snow or ice accumulation probabilities. Positive contact between the guidewheels and the guidance/auxiliary traction surfaces is further enhanced by the facts that: (1) these surfaces can be heated to melt ice or snow accumulations; and (2) wind-driven rain or snow should contact, at most, one of these two surfaces for a given storm incident -- thus providing one clear ATSS surface.

COLD-RELATED DEMONSTRATIONS

The other major aspect of winter DPM operations, extreme cold, had only minimal impacts on the UNIMOBIL System at MZG. The MZG trains, which are stored outside, required only a pre-service period for warming the train interiors to a level that was satisfactory for the passengers; this was accomplished by turning on the environmental control unit (ECU) for each vehicle. The ECU's also provided warm bleed air for each vehicle's doors and thresholds; as a result, neither cold nor precipitation had an adverse affect on train door operations.

Extreme cold did reduce the operating speeds of hydraulically-powered devices such as the guideway switch and the transfer beam; at MZG, these devices are related to maintenance functions, rather than operations, and speed is not imperative. Significant operating improvements resulted from changing the hydraulic fluids to low-viscosity, winter weight fluids. Procedures, such as precycling and recognizing longer cycling times, were established which proved to be a satisfactory response to these conditions.

SUMMARY

The results of the two winter seasons of testing and demonstrations showed that simple DPM systems can provide safe, reliable and comfortable service in harsh winter environments. This is only possible when sound designs and capable management practices are applied. The entire baseline UNIMOBIL System performed satisfactorily at MZG; the described UMI System options, PRFCS and ATSS, can economically overcome any other winter-related conditions that could be expected in a northern DPM candidate city.

1. INTRODUCTION

This report describes the pertinent activities and presents the resulting data from the 1978-79 and 1979-80 periods of Demonstration and Data Sharing of UNIMOBIL DPM Winterization Testing; a Program sponsored by the United States Department of Transportation's (USDOT) Urban Mass Transportation Administration (UMTA) and performed at the Minnesota Zoological Garden (MZG). Universal Mobility, Inc. (UMI), of Salt Lake City, Utah, is the contractor responsible for conducting the part of this Program which involves its UNIMOBIL Tourister System at MZG.

1.1 BACKGROUND

In August of 1977, UMI entered into an agreement to design, manufacture and install/construct a UNIMOBIL Tourister System at MZG in Apple Valley, Minnesota -- a southeastern suburb of Minneapolis - St. Paul. This system was to provide year-around service in comfort and safety to MZG patrons who wished to escape the heat of summer and the extreme cold of winter while viewing animals in their natural habitats along MZG's Northern Trek.

On September 28, 1978, UMI submitted a proposal to the USDOT Transportation Systems Center (TSC) for Demonstration and Data Sharing of UNIMOBIL DPM Winterization Testing. The results of the activities that were proposed would be real data and accompanying evaluations on both winter conditions and the system stresses which would be encountered by DPM (Downtown People Mover) operations in a historically-harsh winter environment. The initial demonstration/test period was for November 1, 1978 to April 30, 1979; the same calendar period was used for the 1979-80 Winter Program.

It should be noted that all of the train-oriented or vehicle-oriented data are for the UMI Tourister System; UMI's Transporter vehicles/trains would be used in a DPM application. The Transporter shares nearly all of its components with the Tourister, but it incorporates higher speed operations and more central supervisory/control elements than the lower-speed, recreation-oriented Tourister.

1.2 PROGRAM OBJECTIVES

The primary objective of this program was to demonstrate that the UNIMOBIL System, a fully-automated and simple DPM System, can be a reliable urban transit alternative in a severe winter climate. To accomplish this objective, records were kept of both the performance levels and any necessary support activities, such as snow removal or special procedures, that were required to attain these performance levels.

Of nearly equal importance was the maintenance of climatological inventories which could provide data on generic performance obstacles to any DPM System which might result from harsh winter weather. A major item in these inventories is the frequency and extent of frost accumulations on the power and control rails. The implications of such data are the adverse impacts and/or the responses associated with desired or acceptable levels of DPM System operability.

1.3 SCOPE OF PROGRAM

The scope of this Program was to relate the climatic conditions encountered to the performance of the UNIMOBIL System. During the 1979-80 Winter, this relationship was established using both revenue service operations under MZG control and pre-revenue service operations normally conducted by an MZG guide/narrator; an MZG guide/narrator acted as a UMI subcontract employee prior to the Zoo's morning opening. Specific system and subsystem tests were also performed during the 1979-80 Winter generally in accordance with the schedule presented as Figure 1. Natural adverse conditions were utilized to the extent possible; artificial snow and ice conditions were also created for testing and/or demonstration purposes. In addition, artificial snow accumulations were placed on the guideway, and subsequently removed, during February for film records of UMI demonstrations by a TSC subcontractor (Raytheon).

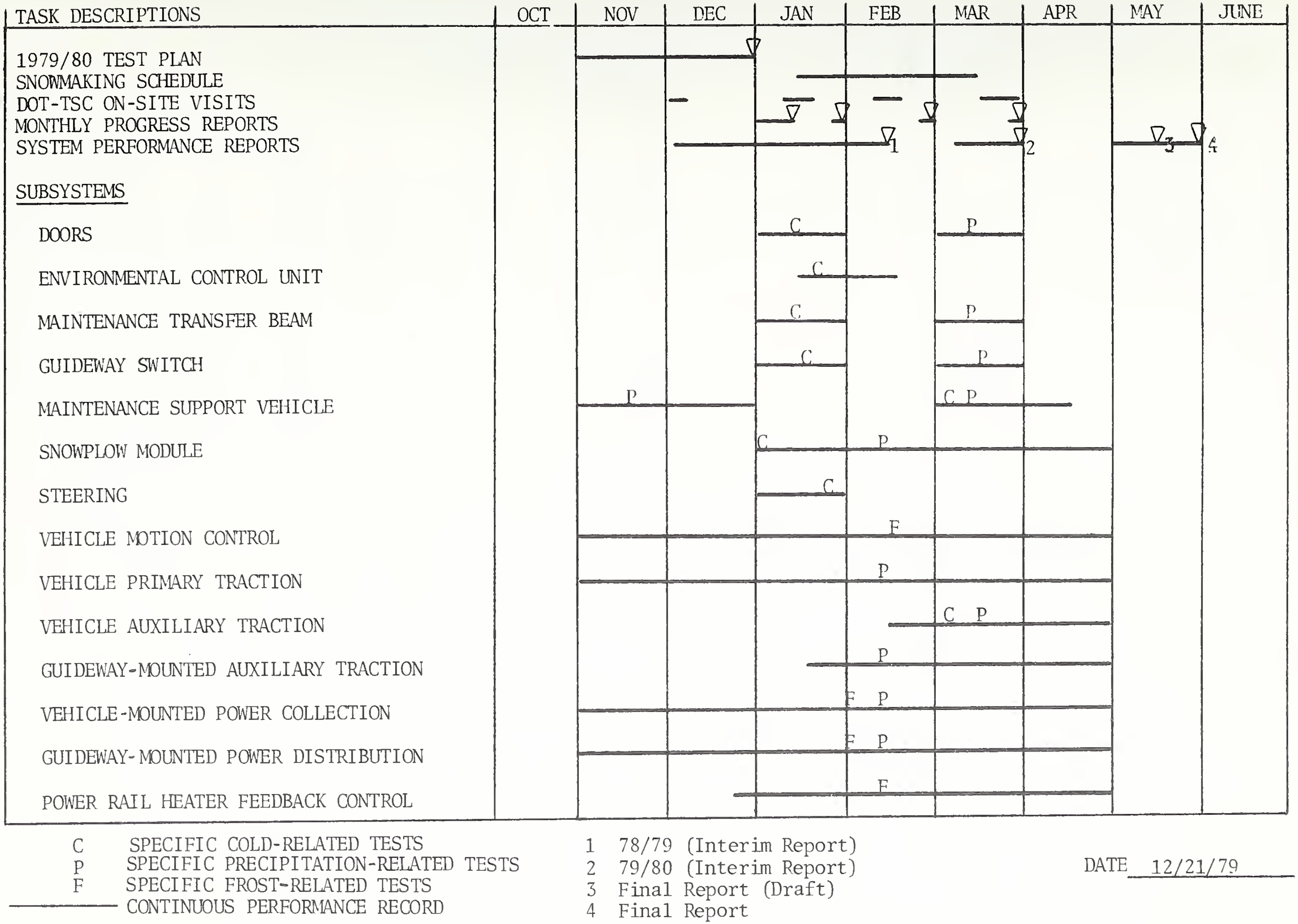

FIGURE 1. 1979-80 SCHEDULE FOR DPM WINTER DEMONSTRATION AND TEST PROGRAM

Guideway construction for the UNIMOBIL Tourister System was started in early Fall, 1978 and the System was to become completely operational in the Summer of 1979. The initial Tourister Train (No. 1) arrived on site near the end of the 1978-79 Winter season and was operated on guideway sections that were restricted to a total of over 1,000 feet in length due to construction limitations imposed by an extremely harsh winter.

This primary test area for the 1978-79 Winter Program extended northerly along the main guideway from a point 100 feet south of the maintenance switch spur for a distance of 540 feet to a point north of the maintenance facility. The trains could also operate over the maintenance spur and into the maintenance building. Consequently, 1978-79 Winter activities were limited to guideway and subsystem level testing; 1979-80 Winter activities were performed over the entire guideway with many specific tests conducted in the above-described 540 feet long primary test area.

1.4 DOCUMENTATION

The on-site conditions, demonstrations and tests were documented by using 20 different data forms that were prepared or adapted by UMI. Appendix A contains samples of Data Forms No. 17, 18 and 19 as well as texts for video cassette commentaries for the 1978-79 and 1979-80 Winters.

Appendix B contains all weather-related references. Included in these references are:

(1) Data Forms No. 6 through 10 -- samples of on-site weather conditions

(2) Data Form No. 11 -- National Weather Service tabulations of local (Minneapolis International Airport) weather conditions for 1978-79 and 1979-80 Winters

(3) Data Forms No. 12, 13 and 14 -- samples of hard copy produced by nearby back-up weather station

(4) Graphical summaries of 1978-79 and 1979-80 temperature and precipitation data contained on Data Form No. 11

(5) Listing of instrumentation used by UMI at the on-site weather station

(6) Letter from consulting meteorologist discussing 1978-79 Winter

Appendix C contains samples of Data Forms No. 1 through 5, 15, 16 and 20. The first five of these data forms were applied to nearly all of both the specific and system-level tests. Data Forms No. 15, 16 and 20 were, respectively, for more restricted uses to: measure System energy consumption; monitor performance of an optional power and/or control rail heating system; and survey revenue passenger comments on System winter operations. Appendix C also contains twelve monthly Operability Charts for UNIMOBIL System performance in either the automatic or manual modes at MZG from November 1, 1979 through April 30, 1980.

2. DESCRIPTION OF THE TEST FACILITY

The MZG Test Facility used during the 1979-80 Winter is a revenue service system which was designed, manufactured and constructed for operations on every day of the year. The vehicles are completely enclosed and each of them has an individual heating and air conditioning unit. The vehicles are connected as three 6-car UNIMOBIL trains, with seating capacities of 96 to 120 passengers per train. The trains operate over a single-lane loop guideway that is approximately 1.25 miles in length. The average Tourister train speed is 3 to 4 miles per hour; normal maximum service speeds are 5 to 6 miles per hour and the maximum operating speed is 7.5 miles per hour. Figure 2 presents a UNIMOBIL Train that has departed from the main MZG station through an opening in the solar panels.

FIGURE 2. TRAIN NO. 3 WITH SNOW MODULE READY FOR USE

The UNIMOBIL System is normally operated in the automatic mode by MZG. After initiating start up from the station, the automatic mode requires no further involvement by the on-board guide/narrator until after the train completes a trip around the loop and is ready to discharge its passengers. In the automatic mode, the guide/narrator can control the train speed from the maximum allowable value down to a full stop to optimize the train position when an interesting situation occurs in any of the exhibit areas. A following train, also in the automatic mode, will maintain a preset separation based on the speeds of both trains; the analog autopilot on the following train adjusts its speed to conform, if affected, to the requirements established by the leading train. A typical example of this automatic spacing, during revenue service, is shown as Figure 3. This same relationship is extended to all three MZG trains if they should become proximal. Such a bunching situation should practically never occur since the trains are dispatched on a scheduled basis.

FIGURE 3. AUTOMATIC SPACING OF TWO TRAINS APPROACHING THE MAIN STATION

The existing MZG System has one operating station and provisions for a second which will be constructed when the exhibits in that area become developed. The main station provides separate platforms, on opposite sides of the guideway, for train ingress and egress. When the passenger volumes are low, the trains board and deboard to the same platform; boarding passengers are held inside the station until the train to be entered is empty. A station operator controls the station doors and provides supplemental monitoring, using both direct line-of-sight and strategically-placed mirrors, of station and platform conditions; the station operator has radio communications with each train's guide/narrator as well as with the maintenance facility. The station mirrors are placed so the guide/narrator has full view of both platforms.

During the 1978-79 Winter activity period, over 1,000 feet of guideway was available for testing and operations; this available guideway 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, the transfer beam, outside storage facilities and the weather measurement/recording instruments were all available for both Winters.

The maintenance building contains two roller beds, one with an overhead crane and a full-length service pit, as well as office, shop and storage rooms. The roller beds are fixed steel structures that align and support a complete 6-car train on wheels connected to the car side framing; this arrangement allows for complete and unobstructed servicing of the UNIMOBIL system bogies, power and control pickup equipment, environmental control units, propulsion and braking assemblies, door operators and controls, and nearly all of the hardware required for operations. There are also two roller beds outside the maintenance building and a stub section of regular guideway for storing support equipment.

2.1 TEST TRACK

The test track consists of: (1) a single-lane main loop that is 6,628 feet in length; (2) a 358 foot long maintenance spur; and (3) the guideway switch that connects the main guideway with the spur to the maintenance building and its outside facilities. The guideway has approximately 730 feet, including the maintenance transfer beam, of the total 6,986 feet at grade; the remaining nearly 6,260 feet of guideway is elevated on steel columns.

2.1.1 Slimline Guideway

A primary element of the UNIMOBIL System is the Slimline Guideway; it is fabricated of COR-TEN steel at MZG. Painted COR-TEN provides a particularly durable structure in corrosive atmosphere environments; MZG elected to have the more conventional application whereby normal oxidation produces the exposed surface coating that is aesthetically-pleasing and maintenance-free.

The guideway is a welded box beam fabricated of COR-TEN plates, tubes and angles as shown on Figure 4. The top of the guideway is the flat primary traction surface that is 40 inches wide. The primary traction surface extends four 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 three power rails are extruded aluminum conductors with stainless steel contact surfaces while the control rail is an extruded aluminum conductor with a copper contact surface. All four rails are encased in PVC and, except for one of the power rails, are electrically isolated from the guideway; the remaining power rail is grounded to the guideway.

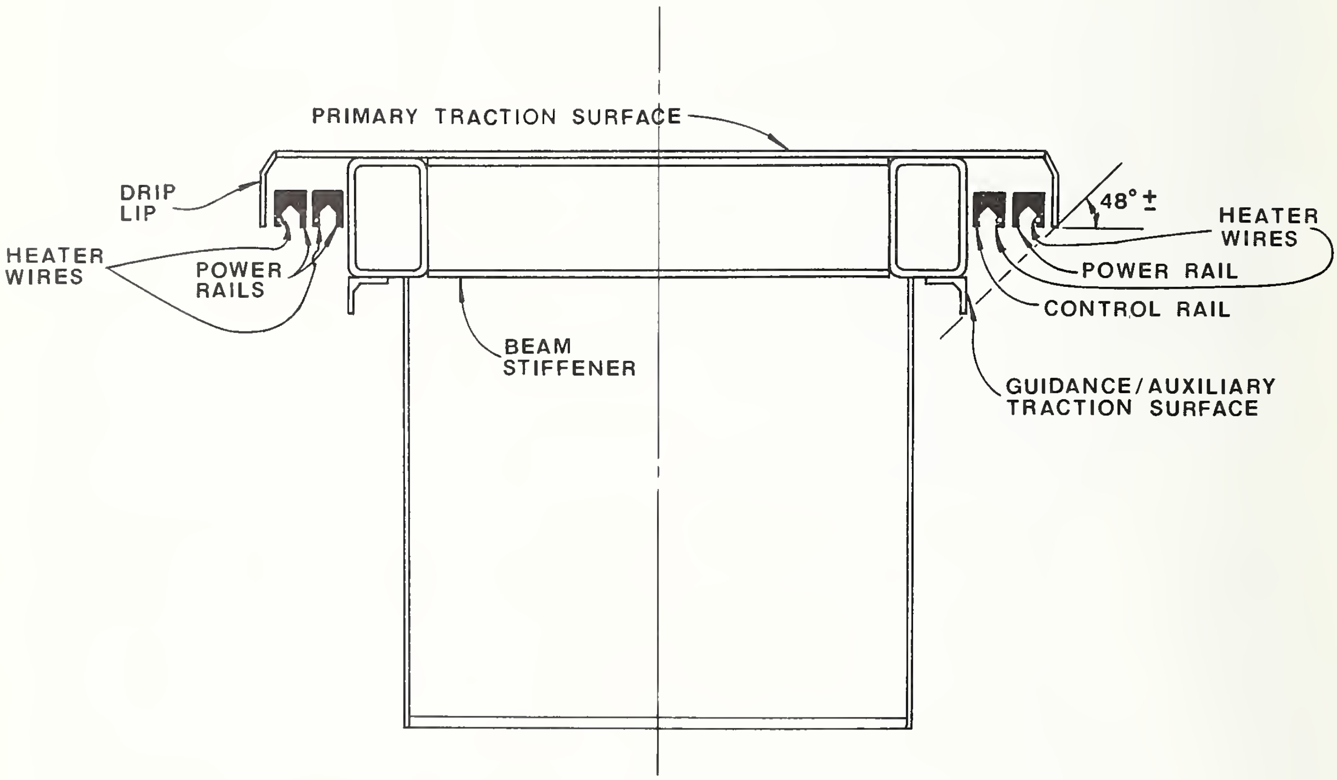

FIGURE 4. GUIDEWAY CROSS SECTION

station provides separate platforms, on opposite sides of the guideway, for train ingress and egress. When the passenger volumes are low, the trains board and deboard to the same platform; boarding passengers are held inside the station until the train to be entered is empty. A station operator controls the station doors and provides supplemental monitoring, using both direct line-of-sight and strategically-placed mirrors, of station and platform conditions; the station operator has radio communications with each train's guide/narrator as well as with the maintenance facility. The station mirrors are placed so the guide/narrator has full view of both platforms.

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The test track consists of: (1) a single-lane main loop that is 6,628 feet in length; (2) a 358 foot long maintenance spur; and (3) the guideway switch that connects the main guideway with the spur to the maintenance building and its outside facilities. The guideway has approximately 730 feet, including the maintenance transfer beam, of the total 6,986 feet at grade; the remaining nearly 6,260 feet of guideway is elevated on steel columns.

2.1.1 Slimline Guideway

A primary element of the UNIMOBIL System is the Slimline Guideway; it is fabricated of COR-TEN steel at MZG. Painted COR-TEN provides a particularly durable structure in corrosive atmosphere environments; MZG elected to have the more conventional application whereby normal oxidation produces the exposed surface coating that is aesthetically-pleasing and maintenance-free.

The guideway is a welded box beam fabricated of COR-TEN plates, tubes and angles as shown on Figure 4. The top of the guideway is the flat primary traction surface that is 40 inches wide. The primary traction surface extends four 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 three power rails are extruded aluminum conductors with stainless steel contact surfaces while the control rail is an extruded aluminum conductor with a copper contact surface. All four rails are encased in PVC and, except for one of the power rails, are electrically isolated from the guideway; the remaining power rail is grounded to the guideway.

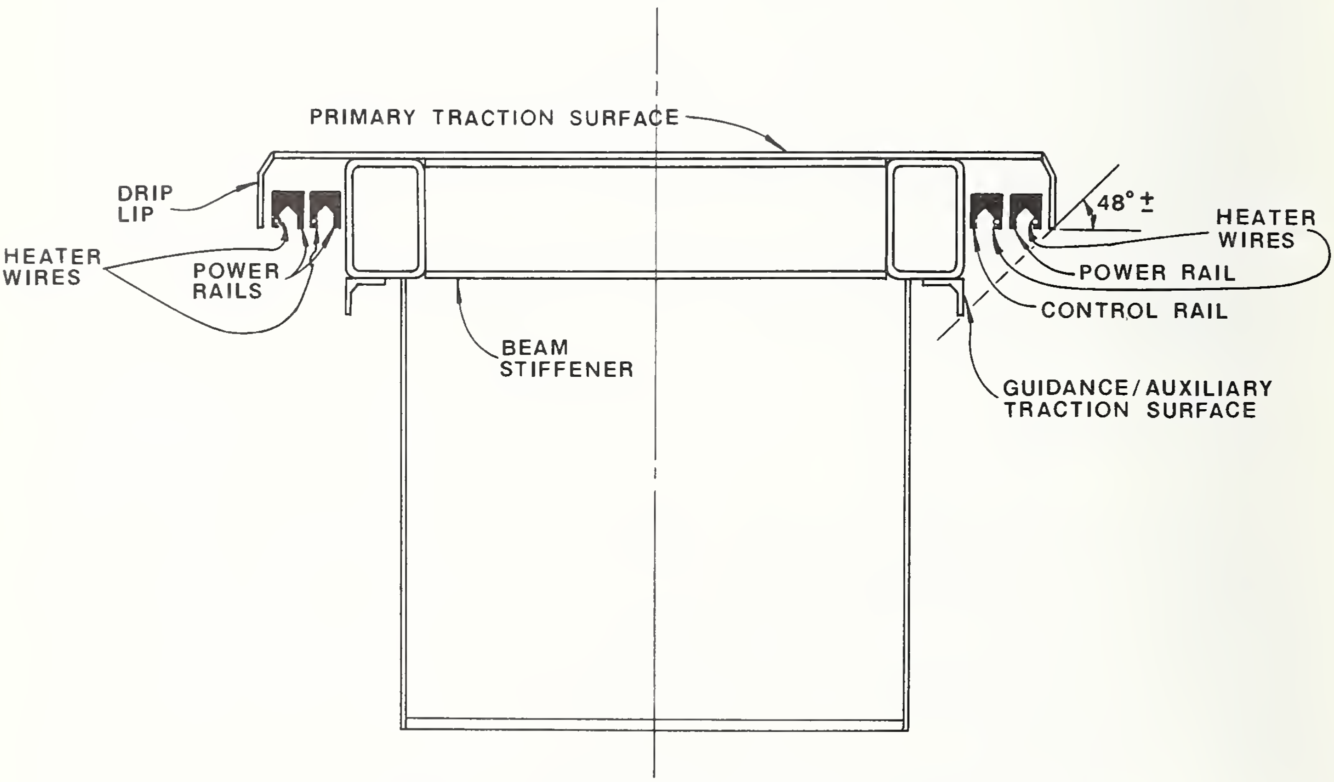


FIGURE 4. GUIDEWAY CROSS SECTION

The guideway is supported on concrete foundations at grade and 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).

2.1.2 Cold Guideway Concept

UMI's Cold Guideway Concept (CGC) is a fundamental and logical application of the benefits derived from the Slimline Guideway. The CGC was developed in order to provide an energy-efficient guideway for DPM locations where operations during extreme Winter conditions are a major factor.

The CGC functions in two related, but distinct, ways. The first is that by being cold and free of any geometric features which can trap snow or rain, surface accumulations are comparable to, or usually less than, amounts that would collect on open ground as shown on Figure 5. The small snow deposits result from power and control rail brackets which alter the guideway's airfoil characteristics with the wind.

FIGURE 5. WIND FREQUENTLY CLEARS SNOW FROM GUIDEWAY

Figure 6, shows the second functional advantage -- the ease of removing accumulations from the primary traction surface. Only dense, relatively warm snows or freezing rain normally cause any guideway primary traction surface accumulations. Warm snow is easily snowplow/brush removable (Figures 6 and 7), while in freezing rain, operations can continue during removal actions utilizing the snow module and solar radiation.

The geometry and materials used in UMI's Slimline Guideway at MZG induce melting of snow and ice without requiring any artificial heat sources. The solar heat absorbed, even on overcast days, has been demonstrated as sufficient to melt and vaporize the minimal snow or ice accumulations -- including the extremely small residues from snow and/or ice clearing operations.

A representation of the Slimline Guideway in the Cold Guideway Concept configuration is shown as Figure 4. Attached to both sides of the primary traction surface are "Drip Lips." The Drip Lip provides three basic functions: (1) extending the power and control rails' protection afforded by the primary traction surface against all snow and ice accumulations induced by severe ambient wind vortices' actions; (2) offering shelter against most accumulations which can develop on the guidance/auxiliary traction surface; and (3) furnishing an enclosed environment to reduce or preclude the heat-loss effects of deep-space radiation. This type heat loss exceeds that attributable to normal convection; it is a major factor in promoting frost accumulations on exposed metal surfaces such as power or control rails.

2.1.3 Guideway Switch

The guideway switch (Figure 8) is used to route trains/vehicles between the main guideway and the maintenance facility. Both switch segments (spur and main guideway) are structurally-connected and are moved together by a hydraulically-powered chain drive. The controls, hydraulic pumps, reservoirs, primary drive motors and switchgear are located inside a concrete building under the guideway switch. During the Winter, the hydraulics are maintained at a $60^{o}F$ temperature by both a reservoir heater and a space heater in the pump

FIGURE 6. PLOW BLADE ELEVATED FOR BRUSH (ONLY) SNOW REMOVAL

FIGURE 7. CLEAR GUIDEWAY AFTER SINGLE BRUSHING OF OVERNIGHT SNOWFALL

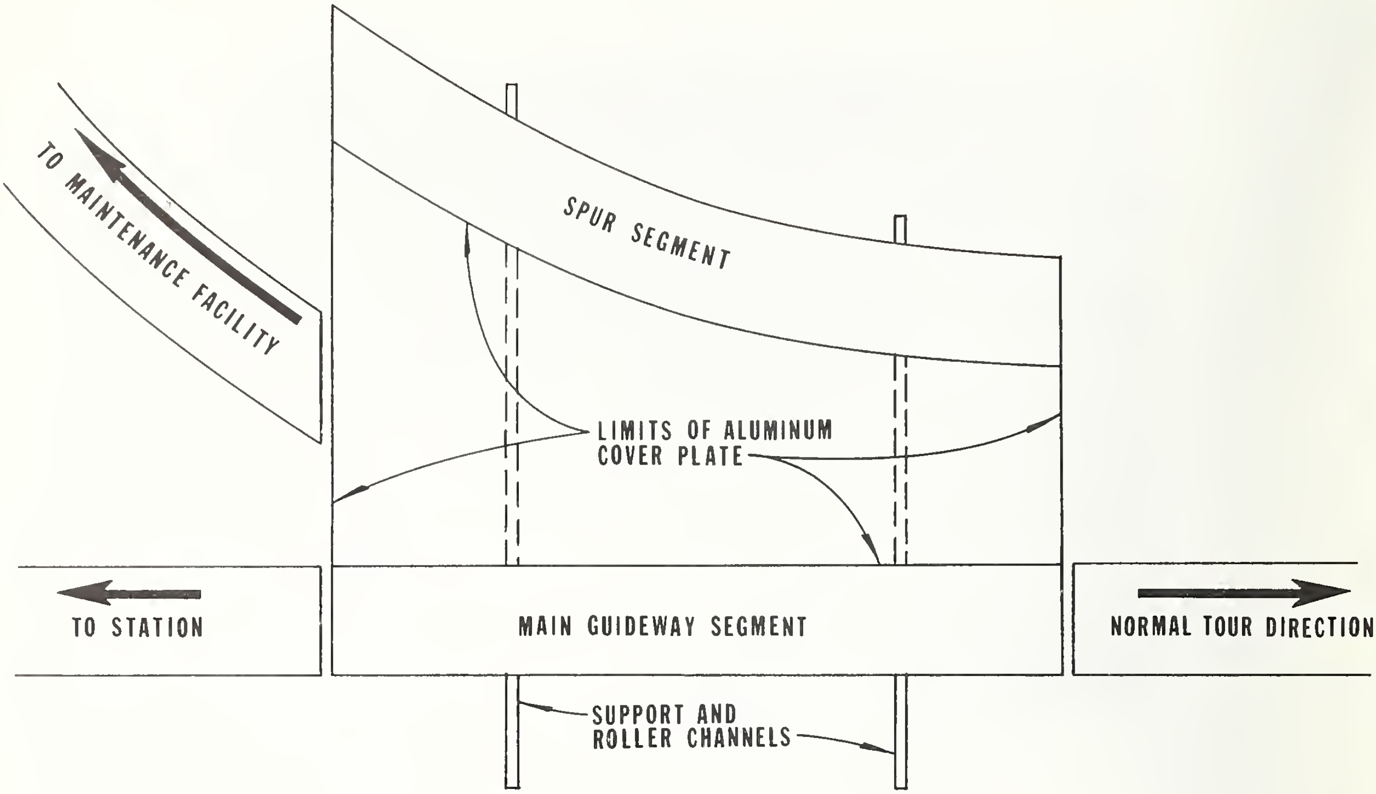


FIGURE 8. GUIDEWAY SWITCH DIAGRAM

room. The hydraulic drive motors and lines, chain drive mechanisms, locking pins, and remote control panel are located outside and above the building in sheltered areas at the guideway switch operating level.

2.2 TEST VEHICLES

The test vehicles which UMI used at MZG were three UNIMOBIL Tourister Trains. As previously mentioned, each train consists of six cars or vehicles supported by seven bogies as shown on Figure 9. The lead and last two trailing bogies are idlers, while the remaining four bogies are electrically-powered. The lead bogie has smaller, high-pressure bias ply tires while two radial-tire wheels are mounted on the remaining six bogies. Two of the trains had pneumatic tires and one had foam-filled tires.

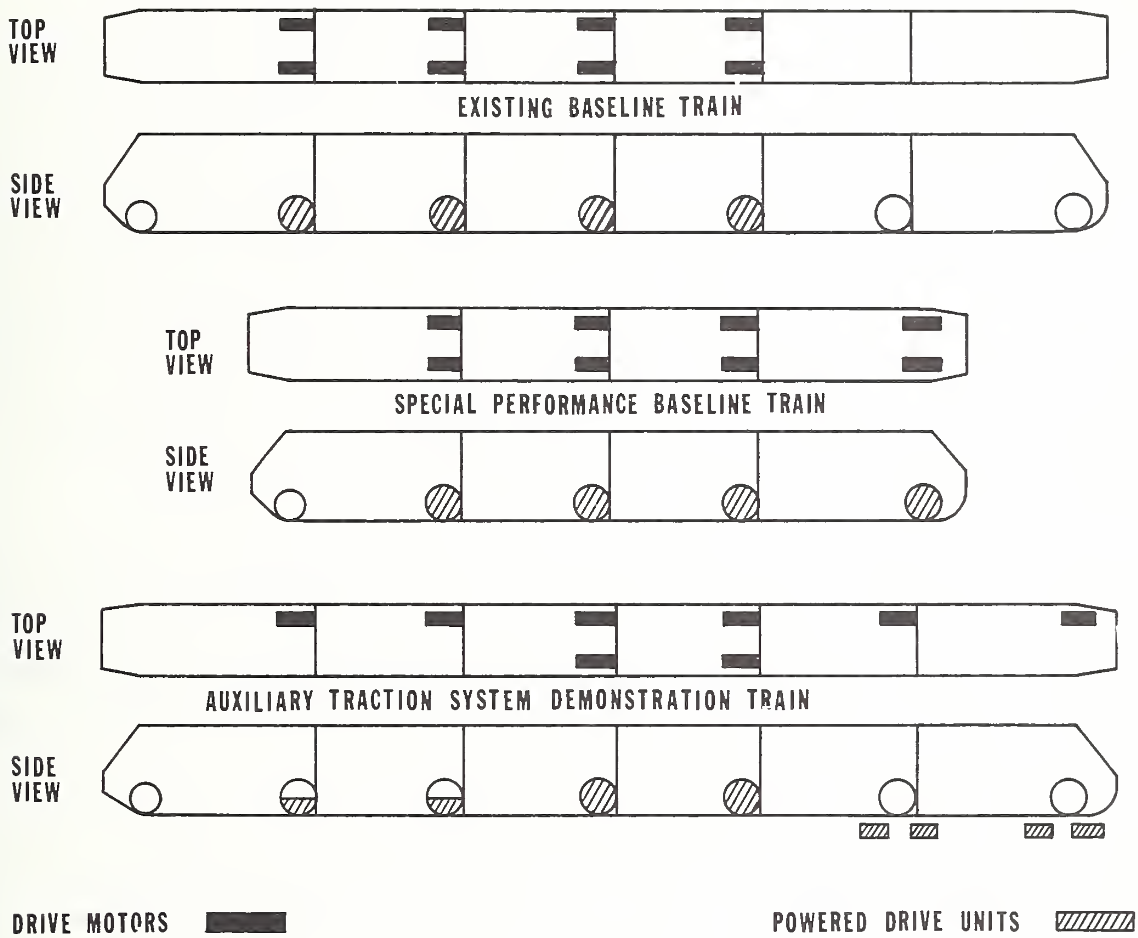


FIGURE 9. VARIOUS TRAIN CONFIGURATIONS OF MINNESOTA ZOOLOGICAL GARDEN VEHICLES

The propulsion system utilizes planetary gear-driven bogies with two 7.5 HPDC electric traction motors for each powered bogie. The primary power is three-phase, 60 cycle 480 VAC 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.

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 vehicles. The center bench seats in each vehicle are mounted back-to-back and a heating/air conditioning unit is mounted under them; the return air grilles are placed between the seat and floor to provide direct return air flow into each heating/air conditioning unit. Heated or cooled air is discharged from ceiling grilles which are integral with the interior lighting fixtures.

The lead vehicle in each train has communications links with MZG maintenance and security offices as well as the station. Intra-train communications are also provided for: normal tour narrations; discussions with the passengers; or emergency purposes. In the event of a primary power outage or loss, communications can be maintained using on-board batteries.

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 both for train separation and speed control as well as for checking the diode networks that provide the guideway condition (or occupancy) responses.

The vehicles are steered by the support bogies as shown on Figure 9; these are, in turn, guided by mechanisms attached to each bogie. These mechanisms consist of four hard-tire, vertical-axis guidewheels that are mounted in sets of two to engage the guidance surfaces located on either side of the guideway (Figure 4). 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 (maximum preload force of 50 pounds per guidewheel) against the guidance surfaces; these wheels are contained by housings that are pivot-connected to frames attached to the bogie structure. The housings and guidewheels have limited travel in the horizontal direction.

Each intermediate bogie is involved in steering two vehicles; the car that leads the bogie is connected by a vertical hinge and the car that trails the bogie is supported by a spherical bearing. This arrangement allows response to deflections introduced by horizontal or vertical curves as well as any combinations. The hinge and bearing arrangement also compensates for the minimal roll requirements associated with the primary suspension (pneumatic tires) system. The lead bogie pivots about a center point, while the trailing bogie is configured similar to, but without the spherical bearing of, the intermediate bogies.

The trains used during the 1979-80 Winter are each designated by numbers (1, 2 and 3). Train No. 1 was available in its entirety during the 1978-79 Winter while only the last two cars of Train No. 3, and none of Train No. 2, were available during this period. Trains No. 1 and No. 2 are baseline trains while Train No. 3 can be configured as a baseline train or, when desired or necessary, can be traction-augmented by an Auxiliary Traction Subsystem (ATSS); both of these configurations are shown on Figure 9.

2.3 SNOWMAKING EQUIPMENT

Artificial snow and ice accumulations were applied to the guideway and/or the vehicles for specific tests when natural conditions were not satisfactory. The most elementary techniques used were to pile snow on the guideway using a snow thrower and to flow water (laminarly) on the guideway to produce smooth ice. Snowfalls of various densities as well as rime ice and pebbly ice were produced using professional snowmaking equipment.

The snowmaking equipment consisted of three snowguns, an air compressor, a compressed air aftercooler and various hoses and fittings. One of the snowguns, a Snow Giant II, was mounted above a truck bed so it could be maneuvered along the primary test section across the guideway from the maintenance facility; this arrangement was used to take advantage of winds which prevail from the northwest. The other two snowguns, Snow Launchers, were sled-mounted; one was usually located on the ground near the maintenance facility while the other was placed near the end of the maintenance support vehicle with its flow aimed down the center of the guideway.

A full range of winter precipitation stresses, from dry or dense snow to rime ice and freezing rain, could be produced with various arrangements and adjustments of the three above-described snowguns. This was made possible by leasing a 600 cfm, diesel-powered industrial air compressor and modifying the maintenance building water lines to provide an outside, high-flow water tap in close proximity with the primary test area.

Nearly all of the artificial winter precipitation stress conditions were created between sunset and sunrise. This approach was necessary to utilize the lower temperatures and lesser winds that generally occur at night. In addition, the solar heat attained by the guideway heat had to be dissipated by night convection and radiation to prevent melting the artificial snow or ice.

Figure 10 and 11 are representative of the normal sequencing for producing artificial snow or ice accumulations. At about 8:00 to 10:00 p.m., snowmaking activities were initiated. The average snow accumulation rate was in the range of two inches per hour; the maximum depth usually occurred after 8 to 12 hours -- usually about sunrise. This allowed the actual tests or demonstrations to be performed entirely, or in part, during daylight hours. For recording and observation purposes, the early morning tests were desirable during the 1978-79 Winter Program; they were absolutely necessary throughout the 1979-80 Program when MZG required the guideway every day for revenue service between 10:00 a.m. and 4:00 p.m.

FIGURE 10. INITIAL STAGES OF LIGHT DENSITY SNOW PRODUCED BY THREE SNOW GUNS

FIGURE 11. READY FOR A TEST AFTER MAKING SNOW ALL NIGHT

2.4 METEOROLOGICAL INSTRUMENTATION

The on-site meterological instrumentation was assembled to accurately report eight basic meteorological parameters which describe weather conditions that can affect the performance of DPM Systems. These eight parameters include: barometric pressure; temperature; precipitation; wind speed; wind direction; solar radiation; dew point; and relative humidity.

2.4.1 Continuously Recording Instrumentation

The on-site weather station was located approximately 40 feet southerly of the MZG main guideway on a ridge at the average elevation of the entire guideway. This location was convenient to the primary (main guideway) test area as well as the guideway switch, transfer beam and maintenance building. The instrumentation and associated recording devices were installed in accordance with the applicable National Weather Service Bulletins. Figure 12 shows the on-site weather station as viewed from the easterly side.

FIGURE 12. VIEW OF ON-SITE WEATHER STATION ADJACENT TO PRIMARY TEST AREA

All of the eight basic meteorological parameters' data acquired at the on-site station were continuously-recorded on instruments inside the maintenance building; a listing of these meteorological and recording instruments is presented in Appendix B. Appendix B also contains samples of six data forms used for recording the eight parameters.

An agreement was established with a commercial off-site weather station about four miles south of MZG to provide data for both the 1978-79 and 1979-80 Winter Programs. The benefits of this agreement were many and include: (1) close proximity data available in the event of a power outage or instrumentation failure at the on-site station; (2) proximal information available to verify the validity of on-site records; and (3) continuous data-processed hard copy available in tabular and graphical forms from the commercial station. This last feature was particularly time and cost effective because it provided easily-recognized orientation for detecting the times or values of the most useful or illustrative on-site data. The on-site data was only available in a continuous graphical format which was somewhat cumbersome to use; this was especially true when making comparisons (e.g., ambient temperature vs. dewpoint temperature).

2.4.2 Other Instrumentation

In addition to the continuously-recording meteorological instrumentation, the on-site station also had other instruments available. This other instrument grouping could best be defined as manual devices; these manual devices are also listed in Appendix B. The manual devices were used as references for the continuously-recording instrumentation as well as for providing specific and discrete data during tests peformed at, near or away from the primary test area. This latter use included both tabulated data accumulation and visual recording (e.g., photograph of thermometer during switch operation test).

3. TEST ENVIRONMENT

The MZG test environment was appropriate to the DPM Winterization Program for several reasons: (1) the winter weather exposure is consistent with the extremes expected to be encountered in northern DPM candidate cities; (2) the UNIMOBIL System was in daily revenue service throughout the 1979-80 Winter; and (3) MZG employees performed normal operations and maintenance activities required for revenue service during the Winter as well as the rest of the year. In particular, the peak winter weather conditions that occur during December, January and February have temperatures which average from lows of near $0^{o}F$ to highs in the 20's^{o}F; these temperatures are accompanied by an average of 27 $\pm$ inches of snowfall. The discrete daily temperatures frequently have highs of near $0^{o}F$ and lows in the range of $-10^{o}F$ to $-20^{o}F$. When November and March are included, there are normal expecations of frequent subfreezing weather, with accompanying frost conditions, and about 17 more inches of accumulated snowfalls; October and April can also produce some frost conditions and minimal snowfall accumulations. It is not unusual for seasonal snow accumulations to exceed 50 inches.

The 1979-80 Winter activities at MZG were unique to DPM Winterization Demonstrations in that MZG employees were responsible for normal maintenance activities. UMI employees were available, however, in those instances where assistance was required when test conditions or equipment associated with specific Winterization tests exceeded the requirements of normal MZG operations. Examples for each of these instances include creating ice to a one-half inch thickness on the maintenance spur switch just before the regular morning revenue service starting time; and transfer of the foam-filled tires from a baseline train (No. 1) to the specially equipped winterization train (No. 3). As will be described later in this report, the two baseline trains, No. 1 and No. 2, and Train No. 3 in its baseline configuration, were more than adequate to perform in the naturally-occuring conditions encountered at MZG during the 1979-80 Winter.

A total of 131,827 passengers were carried by the UNIMOBIL Trains at MZG from November 1, 1979 to April 30, 1980; this volume was accomplished by using, as passenger densities required, one, two or three trains operating at one time over the 1.25 ± mile guideway route. The service provided produced almost 3,000 miles of revenue travel and nearly 164,000 seated revenue passenger-miles and about 300,000 available seated passenger-miles.

3.1 DESIRED CLIMATOLOGICAL EXTREMES

The northern DPM candidate cities presently include Detroit, Michigan and St. Paul, Minnesota. Both of these cities have climates which will require DPM systems to perform during periods with temperatures near and below 0^{o}F for prolonged periods; both cities are also exposed to snowfalls which can deposit accumulations in excess of 6 inches during an operating day. In addition to occassional sleet and freezing rain incidents, Detroit and St. Paul are subjected to conditions which can produce significant frost accumulations on any unheated power and/or control rails -- even when such rails are sheltered. St. Paul, in particular, has climatological extremes which are nearly identical to those encountered at MZG.

3.2 CLIMATOLOGY OF TEST LOCATION

The MZG is located in an area nominally described as the middle latitudes of the Continental Moist Region. The winter weather at this location is strongly influenced by the winds which orient along a northwesterly-southwesterly axis; the dominant cold and relatively dry air flows from the high plains (direction of 290^{o} to 360^{o}) with some moderation by warmer and more moist Mississippi Valley (direction of 120^{o} to 180^{o}) air. The geographic location, when modified by these principal wind flows and the presence of the nearby rivers and many moderately-large interior lakes, produces a winter climate that, during December, January and February, has daily temperatures that consistently reach below-freezing levels and monthly snowfall accumulations of 8 to 10 inches.

The guideway is generally exposed and elevated over a rolling terrain, prehistoric glacial area. Some sections of the guideway traverse ponds, small lakes and both paved and unpaved roadways as well as congregational areas, walkways and building roofs; about 2,000 feet of the main guideway is in lightly- to heavily-forested areas. These characteristics tend to modify locally the influence of frost accumulations which are normally expected from September 30 through May 5 of each winter season -- particularly from mid-November to mid-April.

3.2.1 Historic Weather Data

Historic weather data for the MZG site was obtained from the National Weather Service (NWS) station at the Minneapolis International Airport; this NWS station is located about nine miles northerly of the MZG site at Apple Valley. Graphical presentations, based on NWS historical temperature and precipitation data, are included in Appendix B. These historical data graphs are used as reference bases for the plots of the 1978-79 and 1979-80 Winter Test Periods' daily temperature and monthly precipitation data which were obtained from NWS.

The Minneapolis-St. Paul temperature and precipitation records extend over a more than 125-year period. Initial Twin Cities' temperature values were recorded during 1819 at Fort Snelling, just east of the present Minneapolis International Airport, and unadjusted precipitation records started at the same site in 1836; snowfall records were started in 1859 at St. Paul. Since April of 1937, precipitation, including snowfall, measurements have been made and recorded at the present NWS station. Temperature values are adjusted (reduced) to compensate for the metropolitan heat island effect by correlations with values measured at Farmington, Minnesota -- a Minneapolis-St. Paul suburb about five miles south of the MZG site at Apple Valley.

From the foregoing, it can be seen that the historic (NWS) weather data should be quite comparable to site-specific MZG data.

3.2.2 Climatological Conditions 1978-79

The 1978-79 Winter was the most severe since weather records have been kept for the Minneapolis area. A copy of a letter from a consulting meteorologist in the Minneapolis-St. Paul area, elaborating on that winter, is contained in Appendix B. Snow and temperature information, obtained from NWS, for this period is shown as Figure 13 on the following page. Monthly NWS weather summaries as well as samples of on-site weather data summaries are presented in Appendix B.

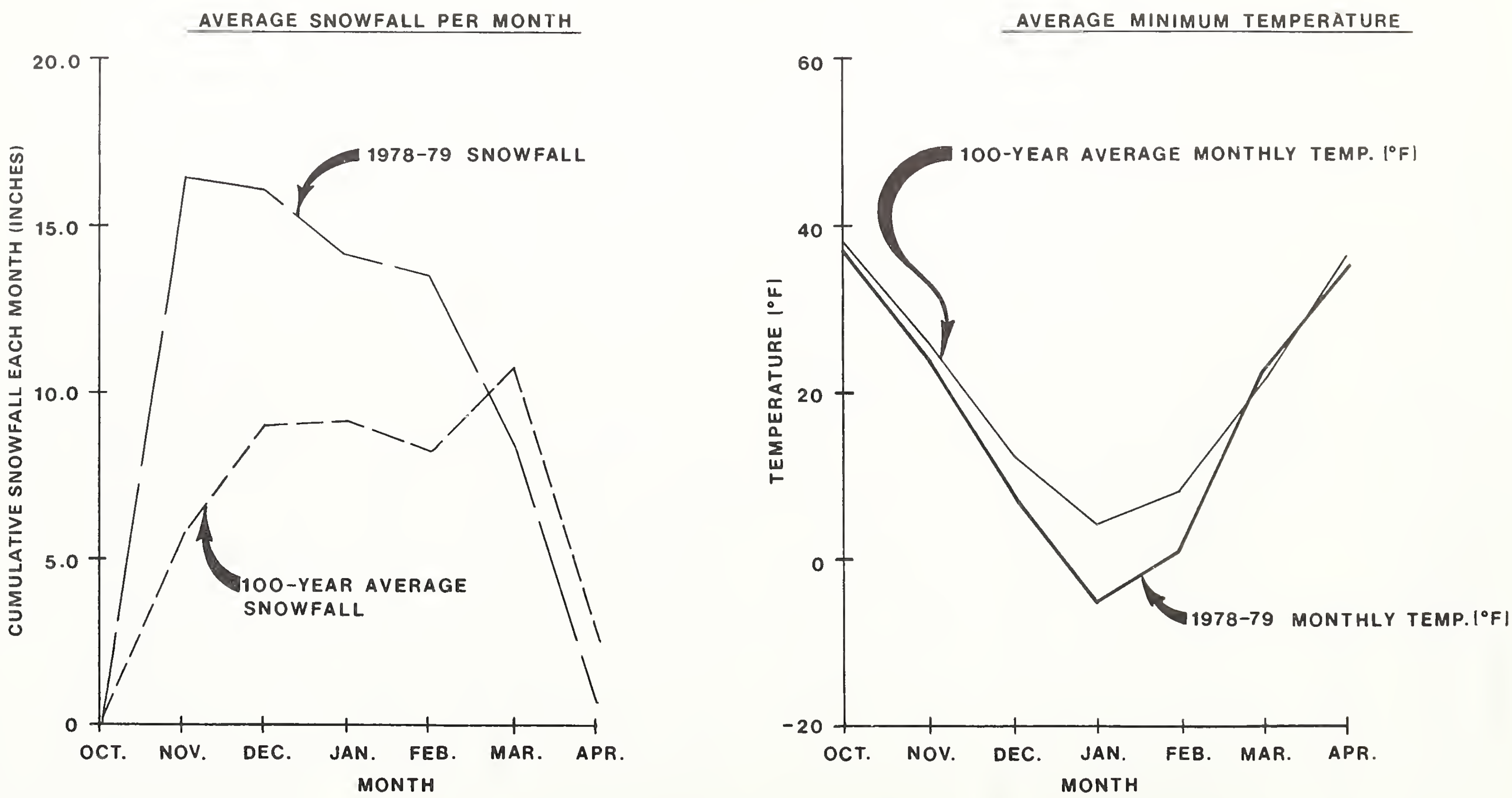


FIGURE 13. RELATIVE INTENSITY OF 1978-79 WINTER

3.2.3 Climatological Conditions 1979-80

As a season, the 1979-80 Winter was milder than normal. According to NWS records, the period from November 1, 1979 through April 30, 1980 had a daily temperature average 2.0°F above normal and the precipitation, expressed in water equivalence, totaled 2.51 inches below the normal accumulated during this six months period. This reduction in water equivalence, if it had all occurred as snow, resulted in, depending upon density, from 13 to 47 inches less snowfall than normal.

Figure 14 shows a comparison of the snowfalls and temperatures that, according to NWS, occurred between the November 1979 and April 1980, and average values for that period. Samples of daily weather data from the on-site weather station, backup weather station and NWS monthly summaries, for the above-described demonstration period, are presented in Appendix B.

3.3 SUPPLEMENTAL MEASURES

Supplemental measures were of two types: (1) augmenting weather conditions -- either artificially-created snow or ice accumulations; and (2) recording data using instruments other than those associated with the continuously-recording on-site weather station operations.

Examples of supplemental weather conditions were the use of snow throwers and snowmaking equipment to create artificial snow, sleet or rime ice on the guideway for various tests such as snow removal and operability continuance. Figures 15 and 16, on page 3-7, show, respectively, thrown snow piled for snow removal tests and simulated blizzard conditions that included snow, rime ice and icicles. Glazed ice to thicknesses of about 1/2 inch was made to test the capability of the guideway switch to function under such a stress.

Supplemental temperature data was accumulated during the Demonstration Periods for specific tests; this supplementary data was often recorded using the manual meteorological instruments. An example of such a measure is a large face thermometer which was photographed during the low temperature guideway switch performance tests. An example of a supplementary temperature record is shown as Figure 17 on page 3-8.

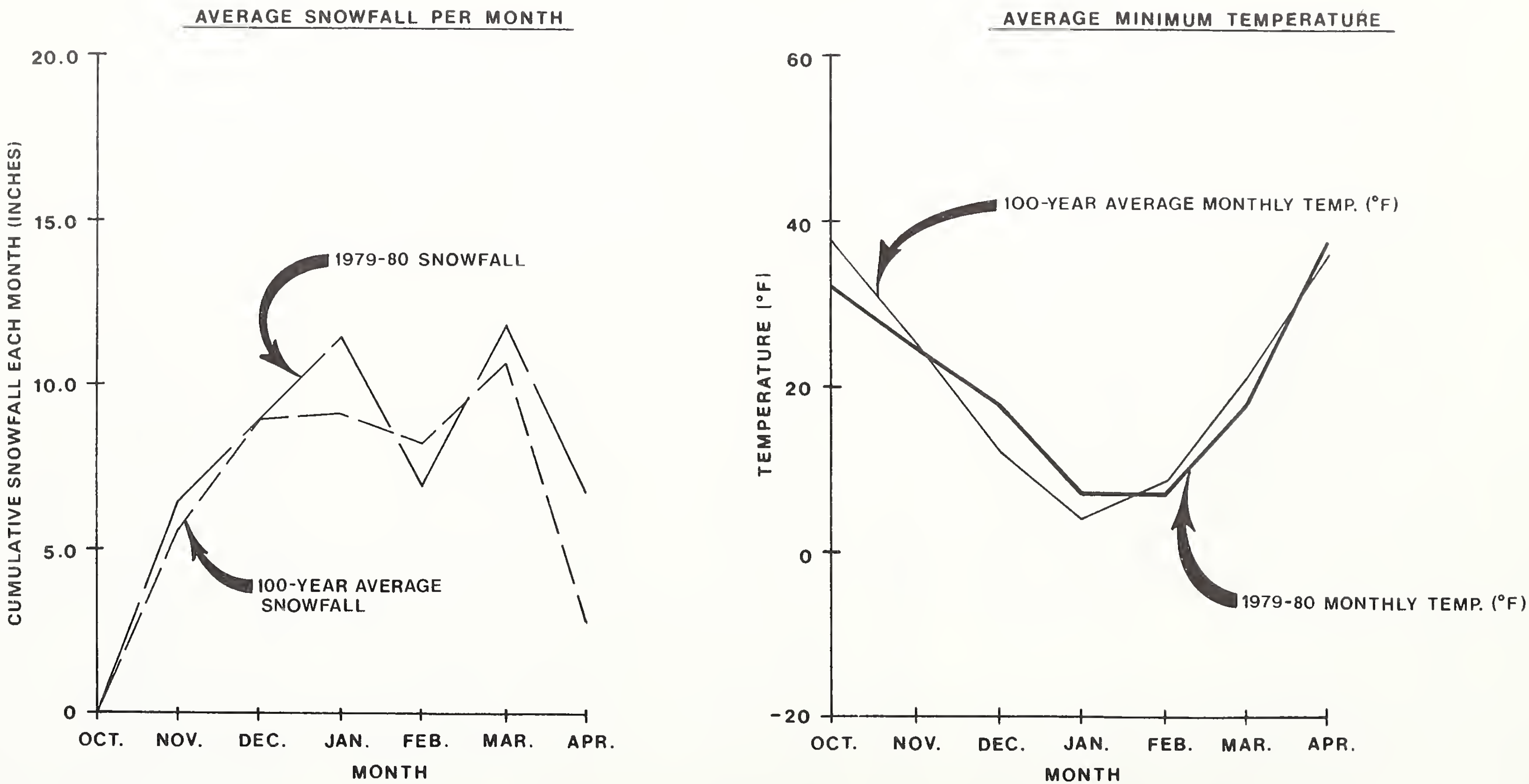


FIGURE 14. RELATIVE INTENSITY OF 1979-80 WINTER

FIGURE 15. REMOVING SNOW, OVER 20 INCHES DEEP, THAT HAD BEEN PLACED BY A SNOWTHROWER

FIGURE 16. RUNNING OVER A GUIDEWAY SECTION WITH SIMULATED BLIZZARD RESULTS

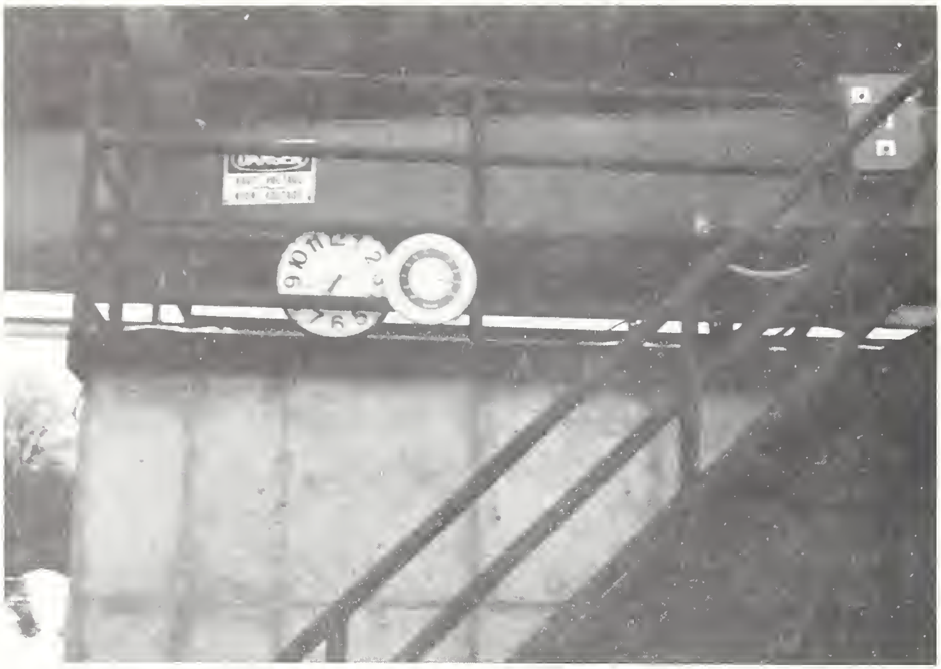


FIGURE 17. THERMOMETER INDICATING -23°F DURING EXTREME COLD GUIDEWAY SWITCH OPERABILITY TESTS

4. DEVELOPMENT OF DETAILED TEST PLAN

The 1979-80 Winter Demonstrations were primarily associated with the routine operability of the UNIMOBIL System during scheduled revenue service. There were, however, specific tests, such as snow removal and guideway switch operations, which required artificially-created conditions to augment the natural circumstances which were insufficient to demonstrate either the limits of UMI equipment or representative Northern Cities' extreme conditions. The 1978-79 Winter Demonstrations, though performed at the subsystem and specific component levels, were sufficient to identify the areas where the greatest emphasis was to be placed during the 1979-80 Program.

4.1 IDENTIFICATION OF CRITICAL SUBSYSTEMS

During the 1978-79 Winter Demonstrations, all of the subsystems were tested except: automatic stopping for the main station; train separation; air conditioning; and on-train (hardwire) communications. At that time, it was determined that certain of the subsystems, such as the guidance and radio communications, were essentially unaffected by weather conditions. With other subsystems, the weather extremes either had limited effects or easily identified and corrected impacts; therefore, extensive specific tests were not conducted during the 1979-80 Winter. Subsystems, and solutions, for this latter category were:

- Doors -- Rigorous cold soak and exposure to icing tests were performed using both primary power and battery power for the doors during the 1978-79 Winter. No special operating procedures were required for any test conditions and it was determined that the 1979-80 Program would be limited to door operations associated with normal revenue service. When the situation was appropriate, artificial icing from the snowmaking equipment was applied to the cars of revenue service trains to verify that the door subsystems in normal operations were not constrained by cold, snow or ice conditions.

- Environmental Control Unit -- Passenger comfort is necessary for user acceptance of DPM Systems exposed to extreme weather conditions. Limited heating-related observations were made during the 1978-79 Winter and the Environmental Control Unit (ECU) appeared to perform satisfactorily. The ECU's cooling function was used during revenue service in September, October and November 1979, as well as March and April of

1980; its heating function was used in every month from October 1979 to April 1980. Because the MZG trains take about 18 to 24 minutes, between door closings/openings, to complete their tours, the ECU's were not particularly stressed -- even on the coldest days (-14°F at 3:00 p.m. on January 8, 1980) of revenue service. Records were kept for interior heat level recoveries after the doors were held open for as much as five minutes during revenue passenger deboardings/boardings at the main station.

Maintenance Transfer Beam -- Any DPM System will require routine, and probably curative, maintenance and servicing of vehicles in its operating fleet. It is reasonable to expect some transfer medium will be necessary to position vehicles or trains to access the appropriate maintenance building stalls for the required level of service. While there are a number of methods which can be used for positioning the vehicles, UMI selected the transfer beam, shown as Figure 18, as the least costly, most compact and simple device for effecting these maneuvers.

FIGURE 18. TRAIN EXITING MAINTENANCE BUILDING WHILE REMOVING SNOW FROM THE TRANSFER BEAM

Large snow or ice accumulations on the apron where the transfer beam is located can possibly restrict or stop the transverse motion of the beam. The normal MZG maintenance procedure during the 1979-80 Winter was to plow the apron before a stopping condition developed; the transfer beam did operate in unplowed snow depths of about five inches.

Because the propulsion is developed by hydraulically-driven drums acting on fixed cables, icing did not inhibit the transfer beam operations. The major requirements were to use winter viscosity hydraulic fluid and to provide heat to the hydraulic reservoir.

- Vehicle Motion Control -- Except for the collector mechanisms and brushes, the train-carried hardware for the vehicle motion control subsystem (VMCSS), or autopilot, is completely enclosed and does not exhibit any temperature-related tendencies. The collector mechanisms and brushes, as well as the control and ground rails required by the VMCSS, are susceptible to winter environment limitations; these will be discussed in greater detail later in this report.

The remaining subsystems or equipment, therefore, could be considered as being critical for operations in winter environments. These critical items, and a brief commentary on each, are in the following list:

- Vehicle Primary Traction -- Fundamental to a DPM System are its abilities to move and to make either scheduled or unscheduled stops. These abilities are affected by both the interface between the vehicle propulsion system and the guideway traction surface and gradients over which the vehicles operate. Both available tractive forces and interface friction coefficients were examined in detail and will be discussed at length in this report.

- Guideway-Mounted Power Distribution -- The power (and control) rails must remain free of snow, ice and frost to provide a continuous contact for conducting power (and control signals) from the guideway to the vehicles. The effectiveness of this conduction is a function of weather conditions, rail materials and configurations, and guideway geometry.

- Vehicle-Mounted Power Collection -- The vehicle counterpart of the power and control rails are the collectors. The collectors include the brushes which contact the rails and the mechanisms which align and hold these brushes against the rails.

- Snow Module -- The snow module is necessary for plowing or brushing snow from the primary traction surface as well as plowing and brushing under extreme conditions. The plow blade can also be used for removing ice under some conditions.

- Maintenance Support Vehicle -- Because of the potential adverse winter effects on either the guideway (and guideway-mounted hardware) or the vehicles, a reliable maintenance support vehicle (MSV) must be able to perform in any weather conditions. In addition to the normal MZG maintenance functions, the MSV can also move an unpowered train or propel a snow module. The predecessor of the current MSV had integral snow removal capabilities.

- Guideway Switch -- A guideway switch must operate reliably and within close margins of its design speeds under all conditions to assure the maintenance of DPM System schedules during the very demanding winter operations.

4.2 DEVELOPMENT OF POTENTIAL SOLUTIONS

With the exception of minor procedural changes and the addition of a covering for the guideway switch mechanism, the UNIMOBIL System provided to MZG satisfied the requirements of winter season revenue service for this installation. However, the demands on DPM Systems operated in harsh winter environments require considerably higher performance levels than MZG. The two most significant deviations for DPM applications are expected to be steeper guideway gradients and longer hours of operation. The resultant impacts could be, in the case of the former deviation, a need for greater, or augmented, primary traction and, for the latter deviation, a highly reliable and economic means for assuring the transfer of control signals and power from the rails to the vehicles.

UMI has two proprietary products which appear to resolve the above-described impacts; one is an auxiliary traction subsystem (ATSS) to overcome degraded accelerations and decelerations that result from steep guideway gradients with slick (low friction) traction surfaces, and the other is a power rail feedback control system (PRFCS) which can assure totally and continuously operable power and control rail contact surfaces at extremely low (electric) power consumption costs. Neither the ATSS nor the PRFCS were a part of the baseline UNIMOBIL System configuration provided to MZG and were, therefore, only tested as time and conditions allowed. The testing limitations on the PRFCS and, more particularly, the ATSS were the result of higher priorites assigned to baseline system tests for UMTA -- and MZG's revenue service requirements.

The primary thrust of UMI's 1978-79 and 1979-80 Winter Program activities were to identify equipment and weather situations which would inhibit DPM operations in extremely adverse winter service and to identify procedures or service limitations which would be necessarily imposed. As indicated in the first paragraph of this subsection, the solutions developed were primarily procedural. As such, the developed procedures, and their success, are most applicable to UNIMOBIL Systems, but many, e.g. remove snow before it can produce either a glazed traction surface or geometric distortions in the vehicle/guideway interface, are applicable to nearly any competitive DPM System.

4.3 PRIORITIZATION OF TEST ACTIVITIES

The test activities fell into two basic areas: (1) those associated, or consistent, with MZG's normal revenue service; and (2) those which had to be performed when MZG was not in revenue operation. The highest priorities assigned to those "tests" associated with normal revenue service were primary traction surface clearing (of snow and/or ice) and constraints associated with the power and control rails (and the vehicle-carried brushes). The highest priorities assigned to non-revenue service tests were for determining the primary traction friction coefficients and the characteristics of guideway switch operations. These four categories were assigned the highest priorities because: (1) without power DPM vehicles can't move under any circumstances; (2) without adequate traction DPM schedules can't be maintained -- and safe stopping will probably be impossible; (3) without the guideway/vehicle automatic control interface, the raison d'être of a DPM System is obviated; and (4) a guideway switch must be functional for maintenance and, possibly, operational strategy purposes.

The guideway switch function, while not operationally inherent to a DPM System without crossovers or off-line stations, is nevertheless required for all DPM Systems to provide maintenance and/or emergency routings. Such routings will probably be in greatest demand during adverse weather when supplementary mobile snow and ice removal equipment may be needed and when the incidence of on-line vehicle failures and/or performance degradations will increase. The latter situation could require: a means for a support vehicle to access the guideway to push or pull a disabled or degraded-performance DPM vehicle; an off-line stall for temporarily storing the affected DPM vehicle; or both.

4.4. TEST PLAN AND PROCEDURES

The 1979-80 Winterization Test Program Schedule, presented as Figure 1 on page 1-3 of this report, identified the UNIMOBIL subsystems to be tested or retested (to verify or adjust 1978-79 Winter results). The subsystem tests were scheduled to make maximum use of Minnesota's seasonal weather extremes. The expected, and actual, lowest temperatures occurred in January and the specific testing of the most temperature-sensitive subsystems were so-scheduled. The most demanding precipitation-related tests were scheduled for February; this approach allowed for both a distribution of specific precipitation-related tests between February and March and a March fallback position for any of these type tests not performed in February. Since most of the key specific subsystem tests had been performed at least once during the 1978-79 Winter (see Section 4.1), continuous monitoring of revenue service operations during the 1978-79 Winter was considered as a reasonable method for obtaining subsystem data; this would be particularly necessary if the 1979-80 Winter was milder than normal -- which it was.

The frost-related testing was more difficult to schedule since the greatest frost accumulations usually occur on clear, calm nights that follow relatively warm days. This combination provides both sufficient atmospheric moisture and the low structural temperatures necessary for frost to accumulate in noticeable and performance-degrading quantities. The clear night skies increase the radiational cooling of the power and control rails beyond the normal convective and conductive heat losses. This results in the rails becoming colder than the ambient air temperature; the presence of snow cover or other light (colored), reflective materials on the surfaces below the guideway accentuates this phenomenon.

Most of the specific subsystem tests were performed at night to maximize the low temperature effects and, during the 1979-80 Winter Program, to preclude conflicts with MZG's revenue service operations. In addition, the heat absorption properties of UMI's Slimline Guideway essentially prohibited testing the effects of precipitation or temperature between sunrise and sunset.

5. GUIDEWAY - RELATED TESTING

The basic simplicity of the Slimline Guideway provides many advantages for the installation/construction, operation and maintenance of a DPM System. The Cold Guideway Concept (CGC), discussed on pages 2-5, 6, and 7, describes characteristics and techniques available to northern DPM System candidate cities for establishing low-cost, reliable operations during snow, freezing rain, extreme cold and frost-producing conditions. The CGC is a systems approach for overcoming extreme winter weather conditions for DPM operations and is dependent on the interrelationships of both vehicle and guideway components. Thus, to conform with the organization of this report (which accommodates the system characteristics of all three Winterization Contractors -- including Otis and Westinghouse), some items, e.g. power and control rails, which are directly or indirectly related to the guideway and the CGC are found in Sections 6, 7, and 8.

5.1 GUIDEWAY CHARACTERISTICS

For purposes of this discussion, the guideway will be considered as the structural members which span between either the columns or the concrete at-grade foundations. The guideway provides vehicle support and guidance as well as the structure on which to fasten the power and control rails. In addition, the guideway provides the primary and auxiliary traction surfaces.

The Slimline Guideway is a continuously-welded structure of prefabricated units with field-welded splices made when the spans were erected in the field. The prefabricated units, nominally in spans of 70 feet, are lightweight box beams built-up of plates and rolled sections; the complete MZG cross section is shown on page 2-4. The continuous welding provides a smooth, flat riding support primary traction surface which also allows easy removal of snow and most ice accumulations. The dark coloration of the naturally-oxidized COR-TEN top and side surfaces produces a heat-gain capability that results in a daytime guideway structure temperature that can be over 50^{O}F above the ambient temperature.

Because the guideway is prefabricated, it is relatively easy to maintain the 1/4 to 1/2-inch clearances required to interface with other guideway elements. Examples of these other guideway elements are the guideway switch, transfer beam, and the roller beds and storage stub located at the maintenance facility.

5.2 PRIMARY TRACTION SURFACE

The primary traction surface, as previously described, and shown on Figure 4, does not easily accumulate snow or ice. This significant advantage for System operations caused considerable difficulties in performing the various tests where snow or ice was required. Because the guideway absorbs so much solar energy, it was usually necessary to delay the manufacture of snow until after sunset when the guideway became cold. Furthermore, the nights had to be extremely cold (below $10^{\circ}F$) with little or no wind blowing to produce snow of conventional characteristics. If there was any wind, very dense (but usually not deep) snow or freezing rain was made; precipitation produced during $10^{\circ}F$ to $20^{\circ}F$ temperatures usually resulted in slush or freezing rain. On extremely cold nights, light snow, analogous to natural types, could be manufactured; but even light winds would prevent its remaining atop the guideway (see Figure 5).

Except for the general observations presented above, the primary traction surface was not tested as an independent element. Rather, its winter characteristics were reflected in tests of the vehicle/train primary traction subsystem and the snow removal module.

The Vehicle Primary Traction Subsystem consists of four powered bogies as previously described and as shown on Figure 9. Two 7.5 HPDC motors are belt-connected to a hypoid pinion assembly for driving each two-wheeled bogie through a planetary gear set. Tachometer units on the second and third bogies are used to generate signals that must match the value provided for the velocity selected by the autopilot during automatic mode operations.

Service braking is applied to the powered bogies by motor resistance induced by reversing polarity on the generator (dynamic braking). Emergency braking is provided by multiple friction discs on each motor armature; these brakes are held off electro-magnetically and they are spring-applied. There are also hydraulically-operated, manually-applied, drum brakes on the second and third bogies; they normally function as parking brakes but can also supplement emergency braking.

The dynamic testing was performed in the subject areas of friction coefficients and drawbar pull. Friction coefficient values were developed from tests on a variety of primary traction surface conditions; most of these conditions were artificially induced. The results of the tests are graphically summarized on Figure 19. The friction coefficient tests are based on emergency brake applications on selected bogies since both acceleration and service decelerations are too moderated, by design, to be applicable in the relatively short test section. Test values were determined using both a 5g accelerometer furnished by a subcontracted testing service and distance-time velocity plots derived from an on-board fifth wheel tachometer running on a (protected) guidance surface. Correlations of the results of these two different methods for evaluation are shown on Figure 20. It is recognized that the indicated maximum (baseline) friction coefficients for rubber on steel are low, but their development was based on the specific setting for emergency braking deceleration.

The friction coefficients were determined from the basic physics relationship of $\underline{\mu = F/N}$, where: $\underline{F = M}$ (M = W/g, W = measured weight of train) $\underline{x\ a}$ (train deceleration); and N = measured weight on selected bogies. The decelerations recorded on the accelerometer were verified by developing values from the distance - time velocity plots. These developed values were based on $\underline{a = 2S/t^2}$, where: S = measured vehicle stopping distance; and t = time duration for stopping.

These tests were performed sequentially for each of the temperature and traction surface conditions identified on Figure 19. In this sequencing, a train would be accelerated to a velocity of about 11 feet/second and then braked; after completely stopping, the process would be repeated in the opposite direction. The results indicate that the minimum friction coefficient for all moisture conditions in the well below freezing range (in this case $-1^{o}F$ to $-5^{o}F$) would approach 0.092. This value is indicative of the ice surface being polished by train wheel action; although visual observations indicated that compacted/reworked snow produced the same results, no precise records were made of this situation.

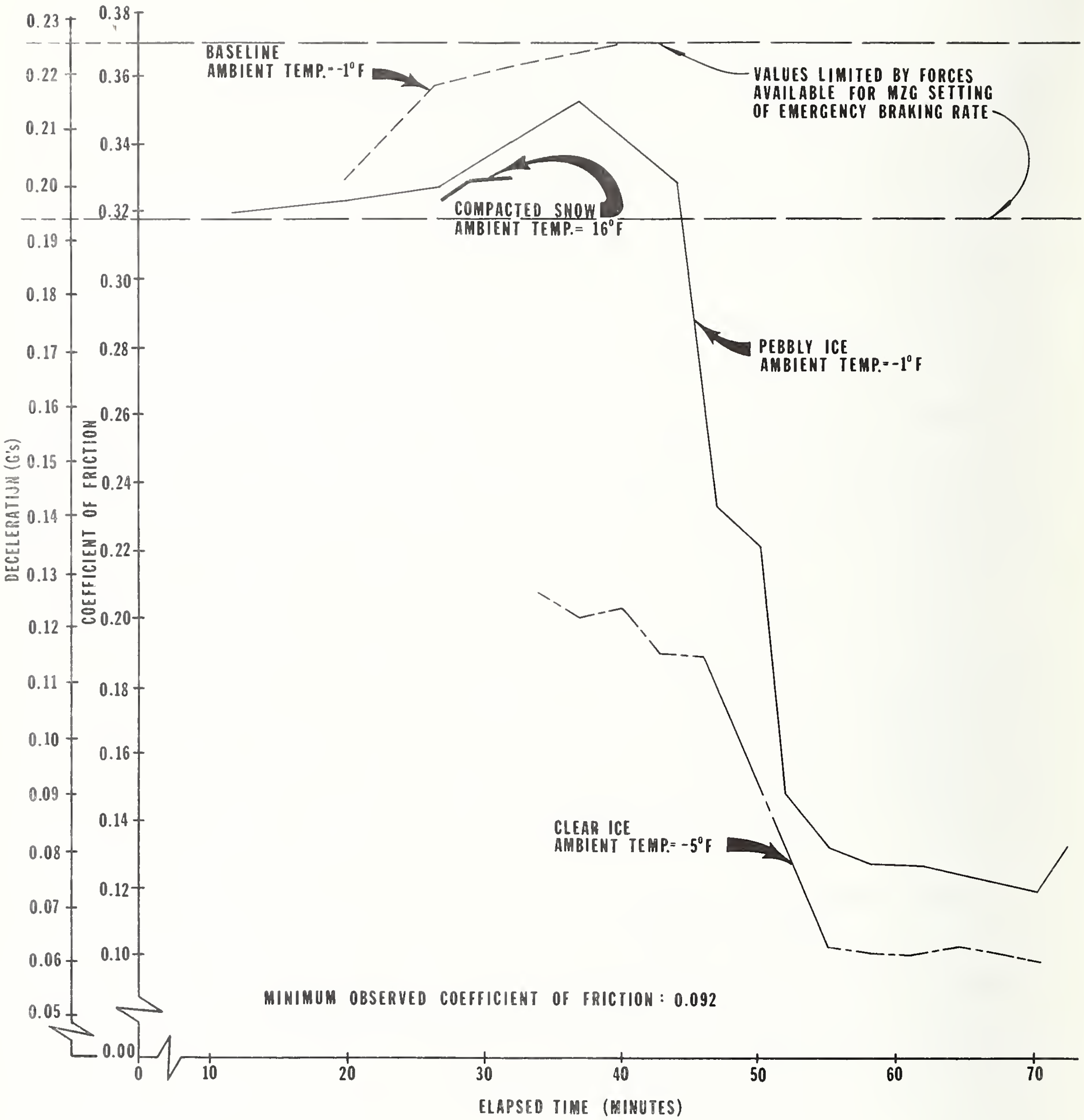


FIGURE 19. PRIMARY TRACTION SYSTEM EMERGENCY BRAKE PERFORMANCE

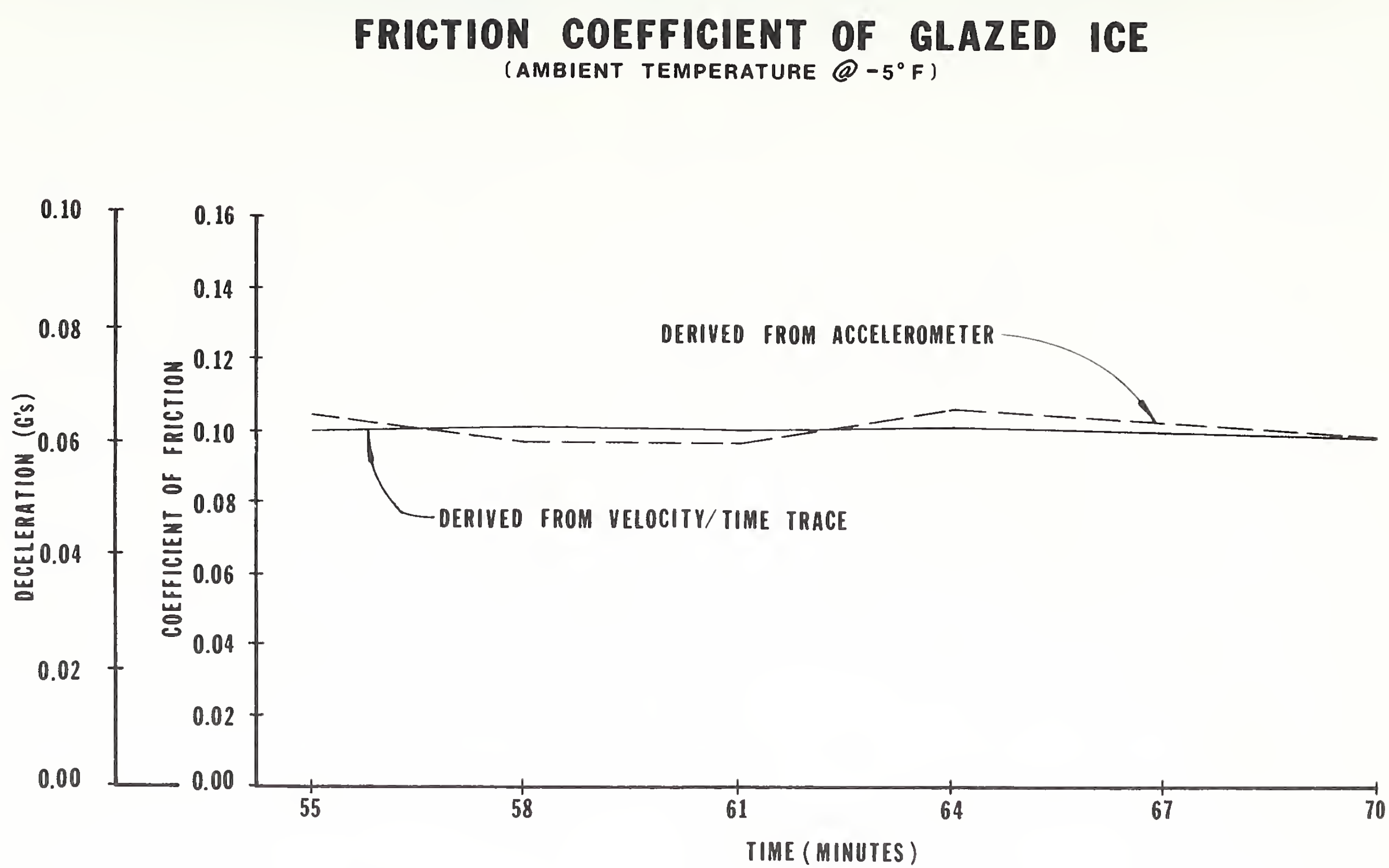


FIGURE 20. COMPARISON OF VALUES DERIVED USING ACCELEROMETER VS. TIME-DISTANCE MEASUREMENTS

Static and dynamic drawbar pull tests were performed to develop the available tractive effort of the baseline system as indicated on Figure 9. The static tests were performed by pulling against a cable connected to the guideway under a variety of primary traction surface conditions. A load cell was placed in-line with the guideway connection and drawbar pull values recorded as train tractive effort was increased. The maximum recorded static drawbar pull value was 6,000 pounds with power applied to all four drive bogies. This value was repeatable; it was developed on dry glare ice at low (near and below zero) temperatures. During the static drawbar pull tests, the drive wheels did not slip; this indicates that the available traction drive power, rather than adhesion, was the limiting factor on static tractive effort for extremely cold conditions.

Dynamic drawbar pull tests were also conducted during the 1978-79 Winter; these were not particularly informative since the only available dynamic resistance, or loading, was the maintenance vehicle. The maintenance vehicle was too light to provide satisfactory resistance. However, during the 1979-80 Winter additional dynamic drawbar pull tests were performed with rather variable results; the range of unbraked (train) resistances was from 1,000 to 2,000 pounds.

The coefficient of friction values presented on Figure 19 are for cold, dry-surfaced ice. When iced traction surfaces have a thin film of water present, these friction values will decrease. Such a thin film can result from: increasing ambient temperatures (near and above freezing); direct solar energy; or spinning or sliding wheels creating friction heat. This latter condition developed about 11:00 a.m. on January 25, 1980 when a train was operated over an area which had been covered with white, opaque ice to a depth of ± 1/2 inch for an earlier switch operability test. Previous train operations over this area, which has both level and +0.706% grades, resulted in no problems when the temperatures were well below freezing. However, as both ambient temperatures and solar energy levels increased, a thin film of surface water became visible in this area. This resultant condition was unusual in that previous artificial and natural ice accumulations during both the 1978-79 and 1979-80 winters were both thinner and much more translucent. Such accumulations either totally melted or were rather easily removed rather than remaining and acquiring the problem-causing surface film.

The baseline train in this January 25 situation could start and accelerate on the level gradient, but it could not climb the +0.706% gradient. Based on a vehicle weight of 62,000 pounds, including passengers, with a relatively low estimated horizontal rolling resistance of nearly 1,300 pounds (due to ambient temperatures and active operating state), approximately 1,700 pounds of thrust was required to climb the grade. This experience suggests a minimum value for the friction coefficient of a rubber-tired UNIMOBIL System train on water-filmed ice is 0.034 to 0.047.

5.3 GUIDEWAY SWITCH

The guideway switch was described, including a diagram, on Pages 2-7 and 2-8. The guideway switch at MZG was tested for two situations: (1) locked-to-locked switch times at extremely low tempertures; and (2) the ability to overcome a major ice accumulation that extended beyond the switch extremities when it was initially lined for through movements on the main guideway.

5.3.1 Locked-to-Locked Operations at Extremely Low Temperatures

The only two guideway switch modifications related to this Program were the addition of the aluminum cover plate and replacing the hydraulic fluid with Mobil Aero HFA (MIL-H-5606). A series of guideway switch operation tests were performed on January 11, 1979 when the ambient temperature was -23°F; the results of these tests are presented as Figure 21. These results suggest that, before the hydraulic fluid was chilled while passing through the exposed hydraulic lines and after the lines are warmed by the hydraulic fluid distribution of the reservoir/pump room heat, a complete switch operation time of 30-35 seconds can be expected for ambient temperatures in the -20°F range. The consistently longer guideway to spur movement time was the result of a hydraulic flow valve which required readjustment. At warmer, but below freezing, temperatures, casual observations indicate complete guideway switch operating times of 20 to 30 seconds can be expected.

5.3.2 Icing Effects on Operations

During the night preceeding the morning of January 25, 1980, water was carefully flowed over a section of the main guideway to form the ice cover used to

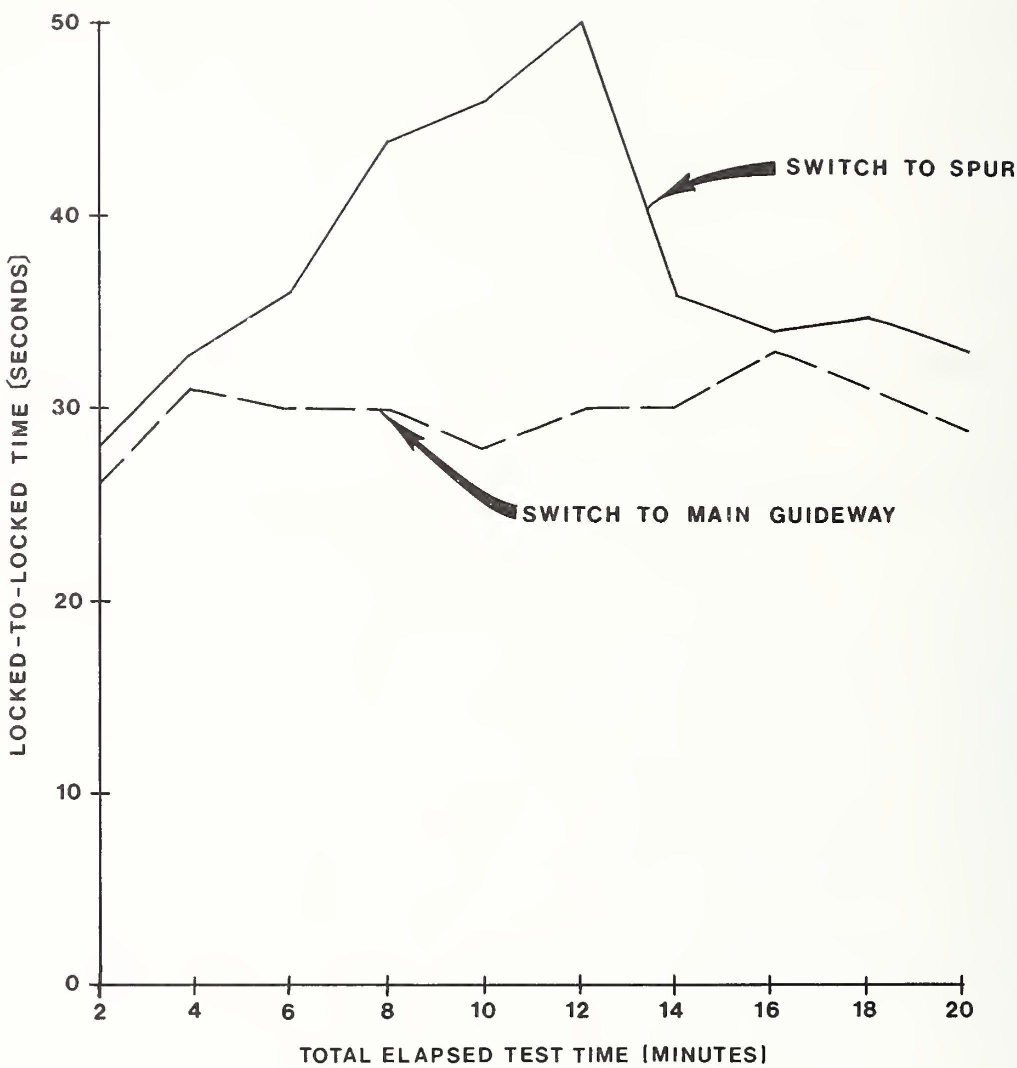


FIGURE 21. GUIDEWAY SWITCH TEST PERFORMED AT -23°F

demonstrate the guideway switch's capability. The guideway switch is located with its closest edge 471 feet from the centerline of the main station; the iced main guideway section started about 450 feet from the station centerline and extended for 340+ feet in the direction of normal travel. The 100-foot iced section closest to the station was on a level gradient and the remaining 240-foot section was on a + 0.706% grade.

The ice was white opaque and was formed in layers to a thickness of at least 1/2 inch in the switch area and a nominal 1/2 inch for the remainder of the section; both ends of the iced section were sloped to intersect the non-iced guideway. The 1/2 inch thickness of ice was extended all the way across the cover plate and onto the switch segment which provides the divergent routing to the maintenance spur.

The temperature was 6^{o} to 13^{o}F during the preceeding night and pre-dawn hours when the ice was being made; it was 7^{o}F at 5:30 a.m. when the request was initiated for the guideway switch to reposition from the through alignment for the main guideway to the diverging alignment to the maintenance spur. The switch responded in a totally satisfactory fashion; the locked-to-locked times for this and subsequent operations, were in the range of 30 seconds. No special preparations had been made and the last lubrication of moving parts had been made about 10 months before this test.

Because the ice was opaque and so thick, it took more than six hours after sunrise for the guideway to be completely cleared. The clearing was accomplished by using sand, hand chopping, snow plow blading and, as the top surface became exposed, the sun's heat. The combination of the ice thickness and the uphill grade caused one significant problem subsequent to MZG's normal revenue service starting at 10:00 a.m. After a train stopped on the uphill gradient about 11:00 a.m., it lost forward traction and was backed downhill to the station; it completed its tour after sand was applied to the top surface of the iced uphill section. It should be noted that the train that lost traction was a baseline unit without ATSS. It should also be noted that with a daytime temperature in the low to middle teens, the sun could only melt the upper surface of the white opaque ice to form a thin layer of water on the traction surface for the drive bogies.

5.3.3. Cover Plate

The cover plate, indicated on Figure 8, essentially precludes any snow or ice accumulations in the transfer mechanism by sheltering the mechanism area from direct snow or rain. Guideway runoffs which might collect and freeze in the mechanism are also directed away by the cover plate. The need for this plate was determined during the 1978-79 Winter test period.

5.3.4. Additional Comments

Additional comments on the guideway switch are as follows:

- The design and installation were such that structural and operating continuity was maintained in spite of temperatures that varied over a range of 90°F during the testing periods.

- No analysis was made of the effects on pump life resulting from using a low viscosity hydraulic fluid.

5.4 MAINTENANCE TRANSFER BEAM

The maintenance transfer beam is effectively a complete guideway section 120 feet long supported by eight fixed notched-tread steel wheels aligned for movements transverse to the beam. The wheels are mounted in four sets, one wheel on each side of the beam; the most extreme sets roll over steel plates placed on concrete sleepers while the two interior sets provide guidance from their notches engaging steel angles that have their outer edges anchored in the concrete sleepers and their common edge pointing upwards.

The beam positioning is provided by two hydraulic motors that drive cable drums located over the center wheel sets. The cables are fixed at the ends of the middle two concrete sleepers and they are wrapped around the drums. The transfer beam can stop anywhere within its extreme position limits, but its power rails only function when it is aligned, and pin-locked, with one of the four roller bed or the stub section positions.

5.4.1 Normal Operations

The transfer beam was used almost daily throughout the 1979-80 Winter Program. On the days that it was used, the transfer beam was positioned at least twice and more probably three or four times. On days when snow fell or there were overnight snow accumulations, it was operated at least twice each day between its extreme positions to move either the snow module or the MSV from the stub section to the maintenance spur access position. This situation also occured when tests were made involving artificially-created snow. The transfer beam's maintenance spur acccess position also aligns with Roller Bed No. 1 inside the maintenance building; its remaining positions sequentially serve Roller Bed No. 2 (also in the building), Roller Bed No. 3, Roller Bed No. 4 and the stub section.

The transfer beam was used infrequently during the 1978-79 Winter Program because only one complete train was available and the maintenance facilities were incomplete. Furthermore, except for UMI's testing purposes, the requirements for the transfer beam's use during that winter did not compare with the following year when there were usually three trains, with at least one in daily use, available for MZG revenue service.

5.4.2 Testing

The real test of the transfer beam was its routine ability to move trains as well as the maintenance support vehicle and snow module into position whenever it was required; Figure 18 shows it in use before MZG opening on April 9, 1980. However, on February 29, 1980, a series of ten (five sets of extreme position movements) transfer beam operations were performed from 8:30 a.m. to 9:15 a.m. under carefully monitored conditions; the temperature ranged from -8°F to -5°F while the tests were performed. The range of motion times were 1 minute: 34.7 seconds to 1 minute: 40.0 seconds; eliminating the fastest and slowest times, the average stop-to-stop (outside of both Roller Bed No. 1 and Stub Section positions) time was 1 minute: 36.8 seconds.

5.4.3 Additional Comments

The following additional comments are applicable to the transfer beam:

- The nominal pavement clearance of ten inches along the beam's length would require snow removal actions for snowfalls or drifting depths greater than ten inches.

- While the hydraulic reservoir heaters were adequate for the motor functions, the 60 foot hose lengths to the locking pins at each end of the beam caused slow pin retractions/extension during extremely cold weather. This problem can be overcome by procedures (eg. circulating the hydraulic fluid until it becomes warm and repositioning the bleed valves, lower viscosity hydraulic fluid, etc.) or modifications (eg. heat tracing the long hydraulic hoses, repositioning the bleeder valves for easier access, etc.); the second procedure was applied.

5.5 GUIDANCE/AUXILIARY TRACTION SURFACES

The primary function of the guidance/auxiliary traction surfaces are to provide the contact surfaces for interaction with the UNIMOBIL train/vehicle guidance wheels. Because these contact surfaces are vertical, freezing rain or snow almost always runs off or drops off. Two additional factors contribute to this result: (1) the combination of the primary traction surface overhang and the Drip Lip creates a situation which nearly precludes any natural accumulations on the guidance/auxiliary traction surfaces (precipitation angles of incidence must exceed $48^{o}\pm$ -- see Figure 4); and (2) storms cause snow or freezing rain to impinge on only one side of a vertical structure. The net result is that, with normal extreme winter precipitation conditions, these surfaces remain clear and, even under artificially-induced adverse conditions, at least one of the guidance/auxiliary traction surfaces will remain in service.

While MZG's Winter season operating requirements are satisfied using the UNIMOBIL System's conventional primary traction capabilities, UMI has developed an Auxiliary Traction Subsystem (ATSS) for alignments that would include vertical gradients in excess of those encountered at MZG (2.36% uphill and 2.44% downhill).

Two methods of enhancing the auxiliary traction surface performance were installed during the initial testing season: (1) a grit surface was applied on both sides of the guideway for the entire test section of 857 feet; and (2) electric resistance heating tapes rated at 24 watts per foot were placed behind a section, 240 feet in length, on both sides of the guideway.

As previously noted, natural accumulations of snow or ice would be infrequently expected to collect on the guidance/auxiliary traction surfaces. However, artificially-induced ice and snow was caused to impinge upon these surfaces and the efficacy of the heating tape is quite apparent in an April 6, 1979 picture (Figure 16). The heated, and clear section of the auxiliary traction surface is in the left foreground while snow and ice cover on the unheated section of this surface is visible in the area to the center and right.

The auxiliary traction surface heater tape was activated in March, 1979 and was operated for about 200 hours during the remainder of that test period. The tapes were removed and returned to the vendor who certified their satisfactory condition and availability for continued use. This heating was not required to support system operations for any natural precipitation condition that occurred during either the 1978-79 or 1979-80 Winters.

None of the freezing rain, rime ice and frost accumulations on the guidance/auxiliary traction surfaces had any effects on the train/vehicle guidance. Some preliminary observations, which primarily relate to the ATSS, can be made with regard to these surfaces:

- grit-covered surfaces provide little or no traction benefits without supplementary heating when snow or ice was induced on them;

- when snow or ice coverings were induced, the 24 watt/foot heater strips easily melted these coverings even when temperatures were below $0^{o}F$; and

- the grit surfaces accelerated wearing of the guidewheel/ATSS tire material.

Further discussions on the ATSS will be presented in Section 8.3. While there were limited winter weather demonstrations of the ATSS during the 1979-80 Winter, tests were restricted until after the inception of warmer weather by other tests and activities with higher priorities.

6. VEHICLE - RELATED TESTING

The bulk of the testing conducted during both the 1978-79 and 1979-80 Winters was oriented towards vehicles or trains. Many of these tests, however, involved other components of the UNIMOBIL System such as the guideway. In addition to the specific subsystem tests performed during both Winter Programs, a large part of the data gathered by UMI was based on MZG's revenue service operations.

6.1 STEERING AND GUIDANCE

Both the bogie connections and the guidance mechanisms were investigated for winter-induced problems. The bogies' hinge and spherical bearing connections were examined only for cold-related variations since their location is high and they are sufficiently sheltered to preclude any moisture-related problems originating from the guideway as well as from rainfall or snowfall. The same effort, estimated at 10 to 15 foot-pounds, was required to rotate the bogie at $-10^{o}F$ and at $60^{o}F$. The guidance mechanisms are protected from direct snow or rain impingement by the vehicle skirts; the CGC essentially precludes subjecting these mechanisms to refreezing free moisture.

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; these fragments were from small icicles that only occurred when snow on the primary traction surface was allowed to melt (with subsequent refreeze) rather than being removed. No difference in steering forces was noted over a range of winter and early spring temperatures.

The only other steering-related observation made was that an extremely slight possibility exists for heavy ice to form on the vehicle ends or the shields between connecting cars. In such an unlikely event, procedural actions would be required to prevent fiberglass damage during cornering for curves and to prevent large, heavy pieces of ice that could fall from the vehicles.

6.2 PRIMARY TRACTION SUBSYSTEM

The baseline train (empty) weight is carried by the bogies, identified as front-to-rear (left-to-right in Figure 9), as follows: No. 1 - 10,450 pounds; No. 2, 3, 4 and 5 - 8,100 pounds; No. 6 - 7,300 pounds; and No. 7 - 4,600 pounds.

Passenger loads of 96 seated passengers of 150 pounds each add a nominal 1,200 pounds to bogies No. 1 and No. 7, and 2,400 pounds to each of the five remaining bogies. Therefore, the corresponding loaded weights are 11,650 pounds on the lead bogie and 10,500 pounds on the next four powered bogies; the last two idler bogies carry, when loaded, 9,700 pounds and 5,800 pounds. This arrangement makes effective use of available weight for traction effort when four bogies are driven.

In addition to supporting the train, the vehicle primary traction subsystem (VPTSS) provides both propulsion and braking capabilities when it interacts with the primary traction surface (top) of the guideway. The influences of dry, snow-covered, or icy, guideway surfaces on traction (friction coefficient) are shown on Figure 19. Because the friction coefficient of ice and compacted snow degrades with increasing traffic or ambient conditions which produce smooth or thin film water surfaces, any accumulation should be subjected to remedial measures.

During the day, the remedial measure would be snow or ice removal; in cold weather (below 20°F) the guideway cleared of snow will be essentially dry, while in warmer weather snow removal leaves a wet residue which rapidly evaporates from the absorbed solar energy and prevents ice accumulations. However, freezing rain that occurs, or snow removal residue that remains, after sundown when temperatures are dropping from an initial 32°F to 20°F range can cause a thin film of ice to form. Such ice formations, which initially develop when the temperatures are in the range of near-0°F and lower, do not significantly inhibit the stopping and acceleration characteristics of the UNIMOBIL System at MZG.

As shown on Figure 19, repeated operations, in this case emergency braking at three minute intervals, can reduce the effective primary traction system thrust to about 30 percent of the baseline value; otherwise a value in the range of 50 percent, or more, of the baseline value can be expected. While the testing conditions were somewhat artificial, certain observations can be realistically made if snow or ice is allowed to accumulate on the primary traction surface:

(1) readily-available additional traction effort to increase traction and reduce stopping distances must be provided to compensate for resistances associated with steep gradients, long pulling distances and curves;

(2) procedural changes, such as greater headways, must be applied to offset the greater stopping and accelerating distances that would result from reduced effective friction coefficients; and/or

(3) support actions such as heated primary traction surfaces, deicing agents (or activities) or friction enhancers (eg. hot sand) must be used.

Numerous investigations have been made on the efficacy of the support actions; above (3) the principal disadvantages of such actions are sufficiency, economics, and environmental impacts. Sufficiency disadvantages include both the necessity of maintaining, or having access to, a large complement of support services (eg. hand labor, backhoes, dump trucks, etc.) and an inability to overcome extremely large snowfalls without system shutdowns. Economic disadvantages encompass high investment, operating and maintenance costs -- especially when support services are required. The environmental disadvantages can affect such diverse interests as: water runoff quantity and quality; nearby pedestrians, buildings and facilities; and possible deleterious (ice or chemical) actions on the vehicles, power rails and control rails.

The procedural changes above (2) have limited applicability in that they are neither safe nor useful if consistently safe (excess) headways can't be maintained. Examples of this inability would be if pushing assistance is required or if two trains, or vehicles, would require stopping on the same downgrade. Some additional procedures could compensate for these exceptions, but the procedures and operations would become increasingly complex as additional problems arise when any standard operating procedure for the system is modified.

Readily available traction effort, item (1) is the most promising from UMI's perspective. To accomplish such a condition, the ATSS has been devised for installation on the baseline system. The characteristics of such a subsystem, which depends on propulsion and braking efforts applied to the guidance/auxiliary traction surfaces, will be described in Section 8.3.

6.3 ENVIRONMENTAL CONTROL UNIT

An environmental control unit (ECU) that provides heating/air conditioning is mounted under the back-to-back bench seats in the middle of each vehicle. In addition to providing passenger comfort, the ECU supplies bleed air to warm the door operator mechanism cabinet in cold weather.

6.3.1 1978-79 Winter Activities

A 24-hour hygro-thermograph was obtained to measure ECU performance, but, because of weather-related construction conflicts which often precluded electric power availability and higher priorities of other demonstration activities, very little testing of the ECU was accomplished. However, casual and subjective observations, made during other test activities, indicated satisfactory comfort levels inside the train when ambient temperatures were $-10^{\circ}F$. It should be noted that these observations were made while wearing heavy outdoor clothing and physical activity was intense due to the performance of outside-related testing (i.e. it was good to get in and out of the wind and cold). A further, somewhat-related observation was the ability to melt glare ice covering the train at a thickness of about 1/8 inch in approximately one hour with an ambient temperature of $28^{\circ}F$ on February 12, 1979; this was ECU-related since the glossy white train bodies tend to reflect, rather than absorb, solar heat.

6.3.2 1979-80 Winter Activities

During the 1979-80 Winter Demonstration period, all three MZG trains were rotated for revenue service which could, depending on passenger demands, require one, two or all three trains in operation. Between December 23, 1979 and February 3, 1980, specific attention was devoted to temperatures and passenger comfort inside the trains. Data was accumulated from instrumentation, limited UMI passenger surveys and unsolicited passenger comments.

The subjective data, passenger surveys and comments, indicated a satisfactory level of comfort; it should be recognized that the passengers were appropriately clothed for both outside winter walking as well as inside (the MZG complex) exhibit viewing and educational activities. Based on Figure 22, shown on the following page, the ECU can be expected to provide temperature of 30^{o}F above ambient temperatures with comparatively empty cars and a non-corrected (excluding moving trains' relative winds) wind speed of approximately 5 miles/hour. These values are based on hygro-thermograph values recorded in the lead car of a train; intermediate cars with lesser interior volumes and both ends protected (by connecting cars) could be expected to improve the recorded values by, perhaps, 25 percent.

Other comments can also be made about the Figure 22 data. The indicated passenger compartment temperature rise rates of 0.2$^{o}\pm$F/minute were taken in cars with greater exposed window and exterior wall space areas than the intermediate cars; better temperature rise performance could be expected in the interior cars. In addition, DPM cars could be expected to have more and larger (MZG passenger ratios are heavily weighted towards small children) passengers both to displace interior air volumes and to generate body and exhaled heat.

6.4 DOORS

The MZG trains have a total of 24 sliding doors on a six-car consist; two doors are located on each side of every vehicle. These doors automatically open at the station stop and can be automatically-sequenced (side-to-side) to open for a boarding/deboarding pattern on opposite sides of the train(s). Normal winter operations are for boarding/deboarding from the platform on the station side of the train. Door closing is performed by the on-board guide/narrator as a part of the start-up procedure in automatic operation. The 27.5 inch wide door openings should allow 108 passengers to deboard within 15 seconds.

Each door is supported at the top and bottom by a ball bearing track treated with a low-temperature grease. The doors are operated by a mechanism housed in a sealed compartment that is heated by bleed air from the ECU; this bleed air for the housing is vented through the door threshold to aid in preventing

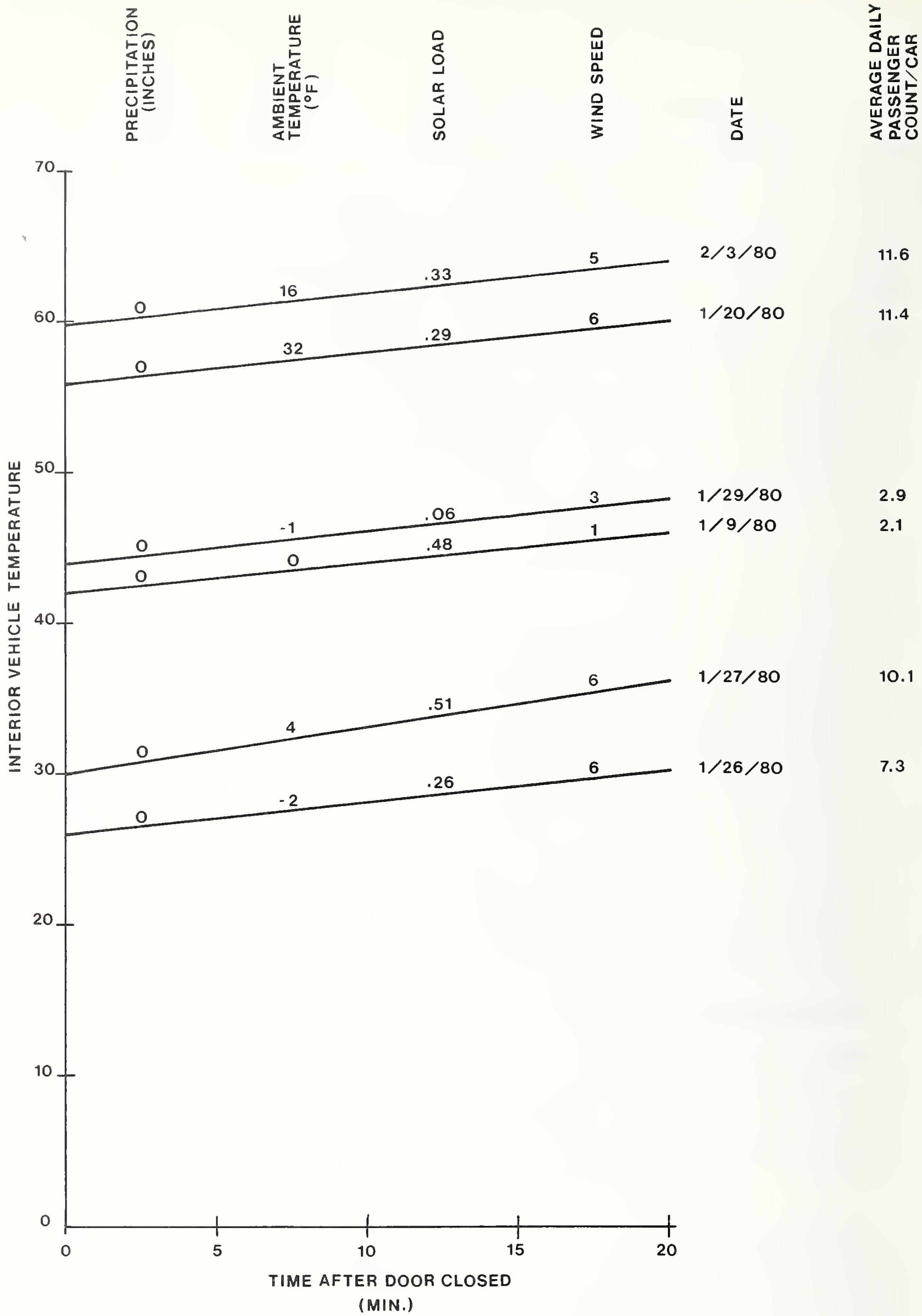


FIGURE 22. TEMPERATURE INSIDE TRAIN LEAD CAR UNDER A VARIETY OF CONDITIONS

ice accumulations. Each door has a rubber mating-edge door guard which is pressure sensitive by means of an air chamber. This chamber extends over the entire vertical dimension of every door to preclude injuries or damage from door closings against obstructions.

6.4.1 1978-79 Winter Tests

Due to constraints imposed by weather and construction conditions, only one series of door opening/closing tests were run. One February 22, 1979, these tests were initiated using battery power, and no ECU heat because electrician's work procedures precluded the availability of line power. The ambient air temperature was $-10^{o}F$ and the train had been exposed overnight to temperatures in the $-15^{o}F$ range. The doors on the left side were opened/closed 3 times at five-minute intervals, and, with the exception of limited openings (70%), could be considered as a successful operation. The limited openings were later corrected to provide full openings by adjusting the door cushioning controls.

The doors on the right side were covered by clear ice 1/8 to 1/4 inch thick. The ice-covered doors could not be opened by either battery or line power; various fuses and overload trips disrupted the door opening/closing circuit whether the attempt was made for opening one pair of doors or all six pairs. Each pair of doors are linked by a single actuator on that pair's side of the vehicle. About four hours after the start of the February 22 tests, line power was made available. The ECU was turned on and, within an hour, the vehicles were ice-free and the door cycle testing, using a five-minute set timer, was reinitiated. The opening/closing cycles were recorded by both time-lapse photography and an on-board hygro-thermograph. The hygro-thermograph was placed against the rubber door edges to verify the five-minute cycles by indicating a discontinuity in the recorded temperature trace due to the mechanical shock of the closing door.

After removal of the ice coating on the left-hand side of the car, the ECU was not operated. As a consequence, the warm bleed air was not available to the actuators and both the rate and extent of the door openings degraded as the temperature dropped towards $-10^{o}F$.

A preliminary conclusion from this brief test is that the ECU must be operating, and the doors must be properly adjusted, to provide door openings at a satisfactory speed and to the desired opening width. No tests were performed during severe precipitation or while subjected to degraded threshold conditions by pedestrian traffic.

6.4.2 1979-80 Winter Tests

The majority of the 1979-80 Winter Tests were performed during revenue service. There were no instances when any of the doors failed to open or close due to weather-related conditions; in all cases, the doors completely opened and closed. Pedestrian traffic had no adverse effects on the door threshold conditions.

Recognizing that the 1979-80 Winter was mild by most standards, natural precipitation conditions were enhanced by applications of artificial snow and ice when the revenue service trains passed over the UMI primary test area. This procedure was applied on February 14, 1980 when the temperatures ranged from $7^{o}F$ to $20^{o}F$; these artificially-induced conditions had no adverse effects on the door operations. This demonstration was recorded by a TSC subcontractor who was on site to record, on film, representative operations and specific test activities.

7. POWER AND SIGNAL SUBSYSTEMS TESTING

The power and signal subsystems for any DPM system are dependent on the continuity of functional contact between the collectors and the fixed power and control sources. This continuity is more critical to control subsystems since any signal interruption in a fail-safe logic network will cause the system to revert to its safest condition -- unnecessary interruptions will result in nuisance slowing or stopping. The inertial characteristics of rotating electric motors and/or generators are such that minimal continuity interruptions produce little, if any, traction motor disruptions. However, such power interruptions can cause power rail deterioration due to the resultant arcing between the brushes and the rails.

The demonstrations and tests that were performed, particularly during the 1979-80 Winter Program, provided strong indications that, while snow and ice can adversely affect some power and control rail configurations, frost affects the performance of all unheated rails. Operability records for the UNIMOBIL System during the 1979-80 Winter Program at MZG are contained in Appendix C; later discussions in this section will analyze the conditions which caused the recorded system performance.

7.1 POWER DISTRIBUTION

The power distribution portion of the power subsystem essentially consists of the primary (commercial) power supply, the secondary power supplies, and the guideway-mounted power rails that supply the three-phase, 60 cycle, 480 VAC power to the UNIMOBIL trains. Because there is nothing unusual about the configurations or functions of the primary and secondary power supplies, UMI's power distribution testing and demonstrations were limited to the power rail functions and their interrelationships with the car-carried collectors. The 1978-79 Winter activities were basically of a specific testing nature while the 1979-80 Winter activities were primarily observing and recording performance data.

7.1.1 1978-79 Winter Activities

Because the guidance/auxiliary traction surfaces were completely available only on the maintenance spur and in the vicinity of the test area during the 1978-79 Winter, tests associated with vehicle motion were somewhat limited. Due to their orientation and location, as well as the additional shelter afforded by the Drip Lip (see Figure 4), the interactions of the power and control rails with the collectors proved to be satisfactory for all naturally-occurring precipitation. The only naturally-occurring condition which interfered with this interaction was frost. Moderate to heavy frost caused arcing of increased severity as the power rail accumulations (and collector brush buildups) grew; light to moderate frost reduced the effectiveness of all power rails and, more particularly, the control rail. While there is a reasonable expectation for reduced rail and brush lives from frost-induced arcing, no assessment was made due to the shortage of time and the limited sample size of collector brush and rail data.

The application of heating wire to selected sections of the power and control rails provided 100% availability of these sections when heat, which could be provided at the maximum rate of 13 watts per foot using the 480 VAC power supply, was applied at the required rate for an appropriate duration. This status was maintained throughout all natural weather conditions as well as artificially-induced blizzard conditions. The heater wire was installed on one side of each of the operating rails (Figure 4) as well as on one side of the non-operating, side-mounted arrangement (Figure 23); the side-mounted rails are representative of typical arrangements used by other systems. The heater wire runs were 240 feet (between expansion joints) and 180 feet (between the guideway switch and the column with the heater control contactor) on the UMI System operating rails. The heater wire was installed in lengths of 240 feet so that the four 60 foot sections of the non-operating, side-mounted rails were also heated, for comparative purposes, at the same heating rate.

Figure 23 shows icing conditions created on March 27, 1979; it can be seen that ice is clear of the inside area above the guidance/auxiliary traction surface while the side-mounted power rails remain ice covered. The side-mounted rails remained inoperable for 120 hrs after this condition was induced even though they were heated

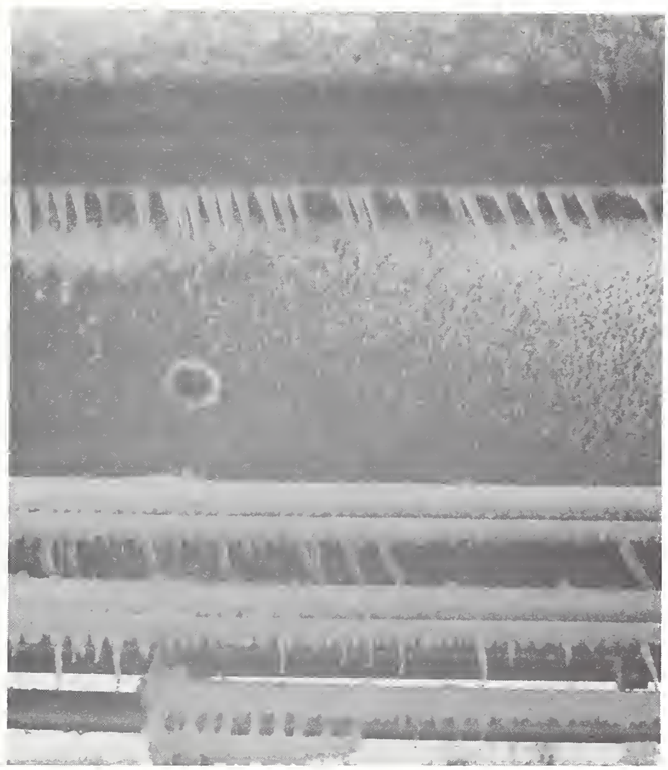


FIGURE 23. COMPARISON BETWEEN CLEAR INVERTED POWER RAILS AND ICE-COVERED SIDE-MOUNTED RAILS -- ALL IDENTICALLY HEATED

in an identical manner to UMI's inverted and sheltered rails throughout the test period. Temperature and humidity conditions caused a refreezing of the ice that had formed on the side-mounted rails' contact surfaces so that, while the contact surfaces were ice-free, external ice accumulations on the insulation were extended to form a crust over the contact surface openings thereby causing this configuration to remain inoperable.

igure 24 graphically depicts the results of blizzard conditions created on April 6, 1979. These conditions rendered the conventional side-mounted power rails inoperable within 15 minutes of the start of the demonstration while the UMI rails remain clear of any adverse accumulations. It should also be noted that the warmth provided by the auxiliary traction surface heating tapes was sufficient to melt the snow visible above this surface so that it fell to the ground after 20 minutes of heating.

FIGURE 24. INSPECTING CLEAR INVERTED POWER RAILS AND GUIDANCE/AUXILIARY TRACTION SURFACE OF HEATED SECTION, WHILE SNOW AND ICE REMAINS ON SIDE-MOUNTED SECTION TO THE RIGHT

The rail heating arrangement used was adequate to keep the inverted and sheltered power and control rails free of frost or ice. The only problem encountered was the result of mechanical stresses to the heater wire where it was unconfined across air gaps in the control rail; these gaps are required for automatic train operation. A heater wire break occurred at one of these gaps; it was repaired and operation continued with no further problems.

Additional potential problem areas observed were related to the mechanical aspects of the power and control rails. Unless otherwise indicated, the following were the result of installation during extremely cold weather:

- Design power continuity was unsatisfactory at about five percent of the mechanical splices placed at nominal intervals of 30 feet around the guideway. The faying surface grease at these splices was too stiff to get proper splice/rail compression (and conductivity) for the specified torques on the bolts which held the splices to the rail. When identified, the bolts were retorqued in warmer weather to obtain design conditions.

- Adequate care must be taken during expansion joint installation or replacement to assure that positioning is based on rail temperature and not ambient temperature. Of a total 112 expansion joints, 5 were improperly installed and failed.

- Rail anchor points were satisfactory for all normal thermal expansion/contraction situations. However, some anchors also failed when the improperly installed expansion joints failed.

7.1.2 1979-80 Winter Activities

The 1979-80 Winter activities, as previously mentioned, were basically demonstrations of routine operations under winter stress conditions; these stress conditions included extreme cold, snow, ice, and frost. As often indicated throughout this report, the only winter stress condition which affected the power rails' functioning was frost.

Figure 25, on the following page, is an operability history for February, 1980; this history is for manual (i.e. non-automatic) operating capabilities of at least one train in daily revenue service. February, 1980 had the greatest frost incidence, in terms of both frequency and intensity, of any month in the 1979-80 Winter Program; 18 of the month's 29 days had frost accumulations. Subjective observations were used to determine that, of the 18 days when frost occurred, 7 days had moderate frost and 9 days had heavy frost; these observations were nominally verified by dewpoint and

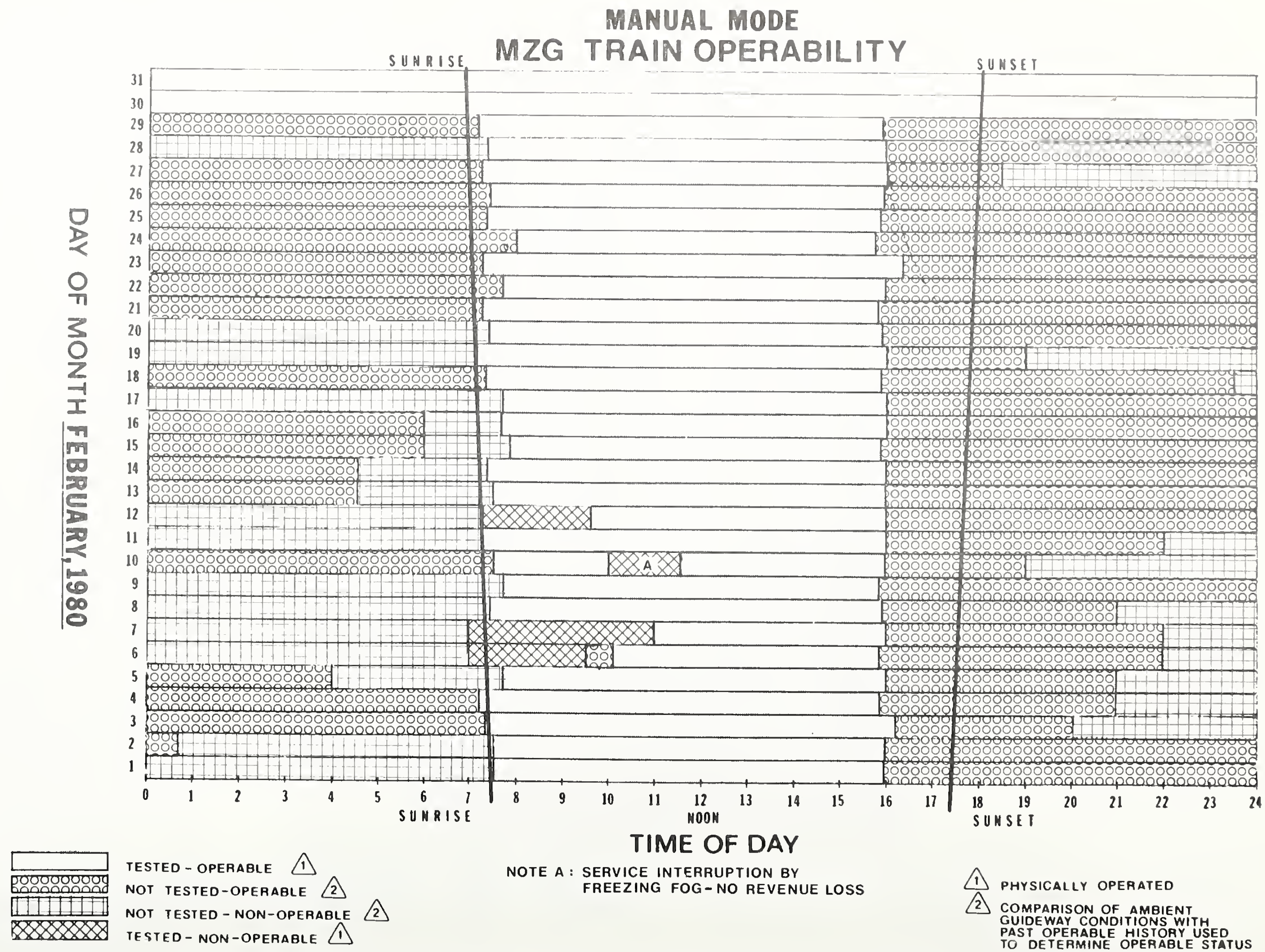


FIGURE 25. FEBRUARY 1980 MANUAL MODE TRAIN OPERABILITY AT MINNESOTA ZOOLOGICAL GARDEN

structural temperature data recorded at the on-site weather station. It should be noted the UNIMOBIL System was available for manual operations by 10:00 a.m. every morning except February 7; on that day fog prevented either the guideway structure from becoming sufficiently warm, or the ambient air from having properties necessary, to dissipate the frost until 11:00 a.m.

7.2 POWER COLLECTION

Power collection and control signals interface between the vehicles and the power and control rails are accomplished by means of 6-inch copper alloy brushes set on Insul-8 pantographs mounted on bogie frames. There are two pantographs (and brushes) for each of the three power phases serially separated by 16 inches at the front of the lead (idler) bogie; a similar arrangement is used for the control signal brushes.

The three basic areas of concern relative to the functioning of brushes and pantographs in winter operations are:

- 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.

7.2.1 1978-79 Winter Activities

The same general comments can be made regarding susceptibility to ice affecting the pantograph motions as were made for the steering mechanisms. Their location (inside the train skirts) and the Cold Guideway Concept generally preclude the collection of moisture accumulations originating on the guideway surfaces. However, condensation can collect, and ultimately freeze, inside the sealed rubber boot that protects the collector wrist motion assembly, positioned directly under the brushes, from the environment. To minimize this eventuality, a fitting, for periodic lubrications, was added to the collector housing below the boot and a vent hole was made in the boot. The resulting lubrications serve two purposes: (1) lubrication enhancement of the stainless steel (wrist) shaft sliding in an oil-impregnated bearing; and (2) a means for collecting moisture (in the lubricant) so it can be periodically displaced through the vent under pressure of adding new grease. The cold weather greasing was performed at 14-day intervals and no collector freezing problems were observed.

Ice and frost impact on the brush/rail interface in two distinct ways: (1) reduction or elimination of current flow through pure frost, ice or snow (non-conducting materials); and (2) increased potential for power brush/rail arcing due to intermittent current flow. The former is partially limited by the 16-inch separation between the serially-mounted pantographs; the latter remains a problem as long as any frost, ice or snow accumulations exist on the power rails. 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 the brushes is greater because of reduced rail/brush lubrication and other mechanical actions. The rail/brush lubrication is reduced because the frequent frost accumulation/melting process prevents a satisfactory buildup of the brush alloy lubricating fraction deposited on the rail contact surfaces. The installation of the power and control rails occurred with temperatures in the near $-0^{o}F$ range and often when it was below $0^{o}F$. As a result, the installation crews did not (or would not) chamfer the leading edges of the power and control rails at continuity breaks for (long and short) expansion joints, control gaps and physical interruptions for the guideway switch. The sharp edges of these non-chamfered joints increased brush wearing rates. Less significant, but still identifiable, brush-wear problems resulted from substandard rail alignments at the expansion joints and due to the inability to obtain proper clamp-up at those points where the faying surface grease between the rails and splices was too stiff when applied. In warmer weather, these problems were corrected by reworking them to acceptable standards.

In summary, the power and control mechanisms, including the brushes, did function -- but at less than optimal levels. The less-than-optimal function was essentially reflected in accelerated brush wear. Due to the short duration of the test period as well as the obvious corrective areas (rail alignment and chamfering) representative data was not accumulated.

7.2.2 1979-80 Winter Activities

The 1979-80 Winter Program activities related to power collection were primarily oriented towards monitoring the operability, as discussed under Section 7.1.2, and the collector/rail interface. There were three basic collector/rail interface areas which were closely scrutinized: (1) the continuity through expansion joints; (2) brush life; and (3) potential advantages of heated brushes interacting with frost-covered power rails.

After properly aligning, chamfering and fastening the expansion joints during the Spring and Summer of 1979, the brush life and contact characteristics were practically unaffected by the presence of these joints. With ambient temperatures that ranged over $110^{\circ}F$, from a high of $96^{\circ}F$ on August 6, 1979 to a low of $-15^{\circ}F$ on January 9, 1980, the power rails and the expansion joints maintained their alignments and successful interfaces with the collectors through the end of the winter season. This is notable because the extruded aluminum power rails have a thermal coefficient of expansion that is approximately three times that of steel; the range of structural temperatures probably exceeded $170^{\circ}F$ between the 1979 summer high and the 1980 winter low.

The winter season copper/graphite brush life was considerably lower than might have been anticipated; with single train service on new rails and high frost incidents, brush life was on the order of 150 hours. With two train service and less severe frost conditions, the life of a set of brushes might extend to 250 hours; life in the range of 300 hours for copper/graphite brushes can be expected if three train service is continuously provided by MZG during the frost seasons. Any moisture (dew or frost) accumulations on the brush contact surfaces of the power rails tended to wash away the lubricating fraction that the brushes deposited on the rails. The frost accumulations seemed to accelerate this washing action by lifting the lubricant during the freeze portion of the freeze/thaw cycle which occurred due to frost on 75 of 152 days between November 1, 1979 and March 31, 1980. When the frost melted, the heavier droplets with the lubricant would fall before the evaporation process removed the remaining water.

Brush heating, at the rate of 12.6 watts/brush, was tried for several days with less than spectacular results during February, 1980. In theory, the heat should melt the frost, or frost-induced ice, from the brush/rail contact surface. However, even at speeds in the range of 5 feet/second, the frost/ice buildup between the brush and the rails exceeded the melting rate of the brush heaters. When this happened, the train stopped, or was controlled to stop, until the heaters melted the frost/ice on the brushes and the frost on the power rail surfaces; this process was repeated in short intervals until the passive (solar energy) removal of the frost was complete. A much more effective and probably, in total, less expensive solution to the rail frost problem is rail heating; one heating alternative, UMI's power rail feedback control system, is discussed in Section 8.4.

7.3 CONTROL RAILS

The control rails are the fixed component of the vehicle motion control subsystem (VMCSS). The VMCSS maintains a safe separation between trains/vehicles and between a train/vehicle and a decision source such as a station or an (open) guideway switch. Insofar as the VMCSS is concerned, a decision source is interpreted the same as a guideway occupancy by a train that is approaching -- the approaching train/vehicle is first slowed and then (possibly) stopped if a guideway condition precludes continued safe travel at the selected autopilot-controlled speed.

The control rails actually consist of two rails; one is the guideway-grounded power rail and the other is the rail with the copper contact surface. The ground rail, while electrically necessary for the VMCSS to function, is more properly considered as a part of the power subsystem. Therefore, throughout this report, all references to a control rail will only apply to the copper contact surface rail.

The control rail is basically the intelligence rail; it has gaps every 15 feet which can be used for train vehicle separation and control. Because there are at most three trains simultaneously operating at MZG, and those operate at relatively low speeds, it was determined that anticipated service requirements could be easily satisfied by "jumpering" alternate control rail gaps to provide control increments that are 30 feet long. Diode networks are placed at the "non-jumpered" gaps to provide train separation and guideway status data.

The train-carried autopilot is set to begin response to a decision source approximately 690 to 720 feet before the decision source is encountered. The autopilot is also adjusted to smoothly reduce the observing train's preset velocity until it reaches a point where a 1/8g service stop is applied; the service stop is presently initiated 300 feet (10 increments at 30 feet/increment) before the location of a decision source.

7.3.1 1978-79 Winter Activities

On April 6, 1979 a series of VMCSS tests were performed using Train No. 1 (in motion) and the trailing cars of Train No. 3 (stopped). Figure 26, on page 7-12, is a representation of the oscillograph data recorded for three different initial cruising speeds (11 FPS, 8 FPS and 4 FPS) selected for Train No. 1. The April 6, 1979 operating conditions were temperatures in the upper 20^{o}'s F with sunshine and a snow cover on the ground.

7.3.2 1979-80 Winter Activities

The 1979-80 Winter control rail activities were nearly all related to normal revenue service operations. Figure 27, on page 7-13, is a summary of the automatic operability records for February, 1980. All restrictions on automatic operations were the result of frost accumulations on the control rail. When the automatic mode operable availability of Figure 27 is compared to the manual mode operable availability shown on Figure 25, it is clear that frost inhibits control rail functions more than those of the power rails. Two identifiable, but not proven during this

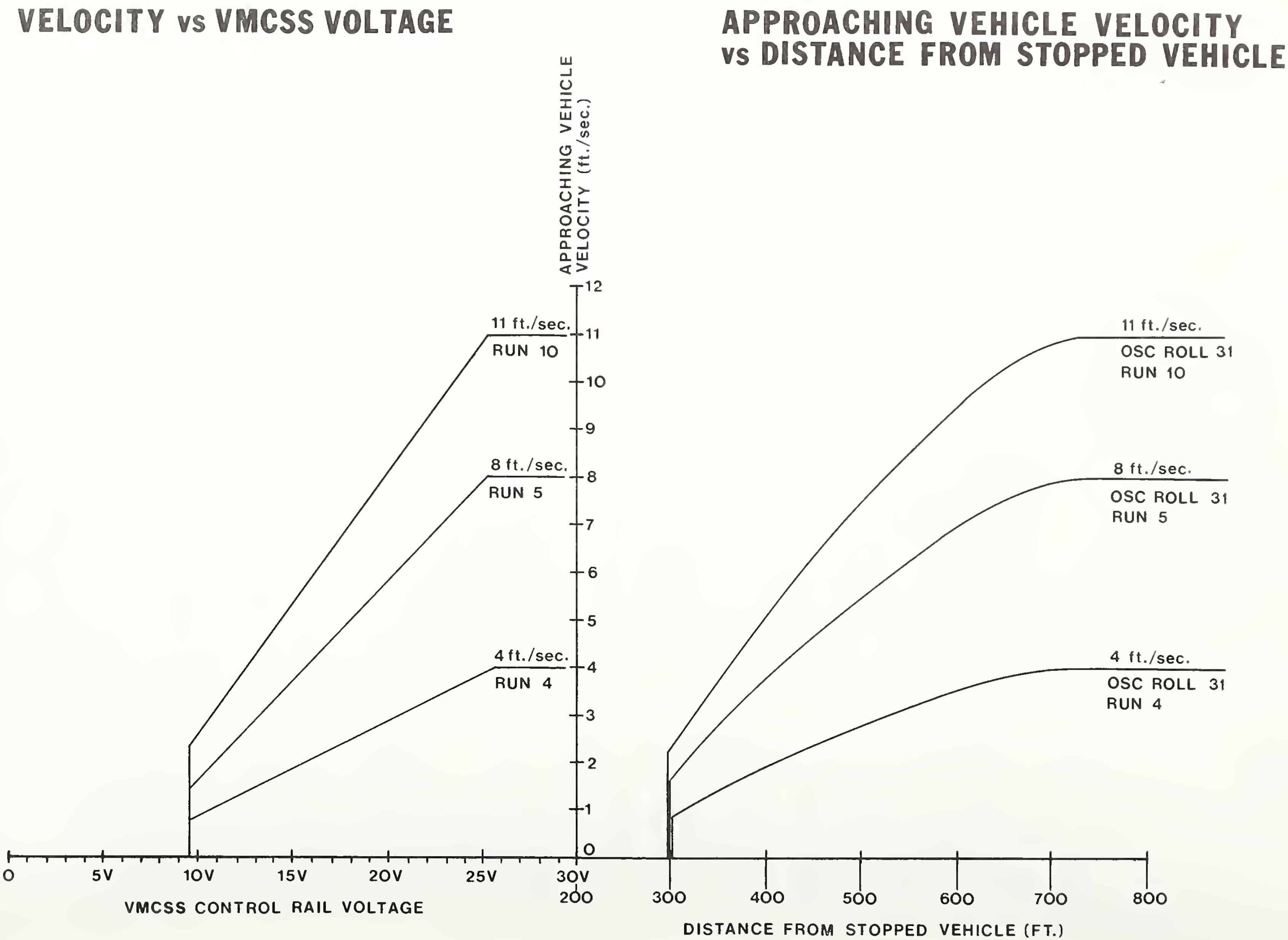


FIGURE 26. VEHICLE MOTION CONTROL SUBSYSTEM TEST PERFORMED ON MARCH 16, 1979

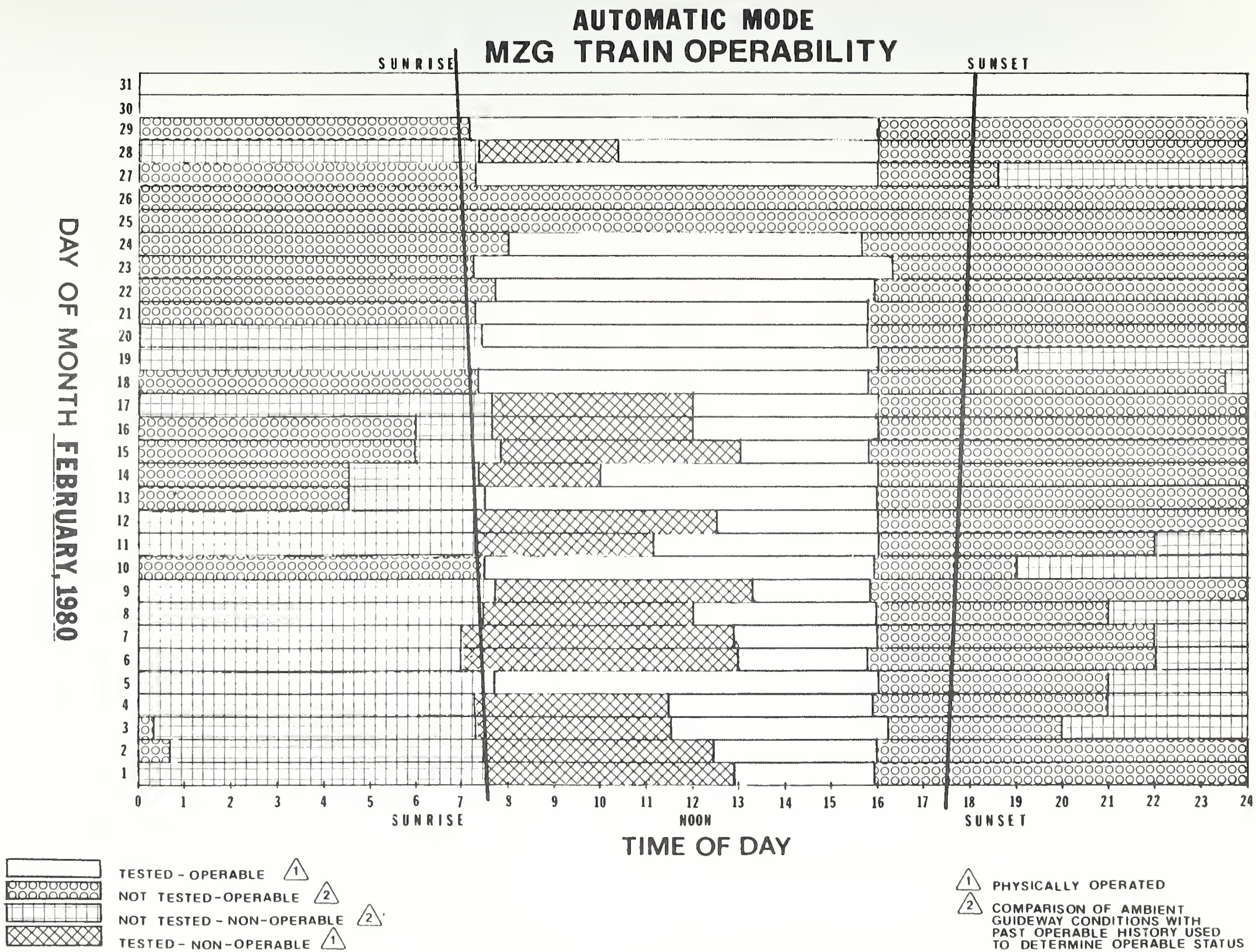


FIGURE 27. FEBRUARY 1980 AUTOMATIC MODE TRAIN OPERABILITY AT MINNESOTA ZOOLOGICAL GARDEN

demonstration, possible differences are: (1) the stainless steel power rail contact surfaces are less susceptible to frost accumulations than the copper contact surface of the control rail; and (2) the higher voltages and currents associated with the power rails can overcome some frost conditions that the low voltages and currents of the VMCSS can't overcome.

Visual observations seemed to indicate frost accumulated on the control rail, relative to some of the power rails, with greater frequency, more depth and for longer durations. However, these observations were not consistent in that they varied by guideway location -- both side-to-side and longitudinally. The arcing marks on the power rails did indicate that the greater available power tended to neutralize some of the insulating properties of frost.

7.4 VEHICLE-CARRIED CONTROLS

The principal vehicle-carried components at the VMCSS are the collectors and the autopilot. By virtue of its location within the train as well as experience gained at MZG and other installations, the autopilot is not susceptible to winter weather conditions.

At the front of each train, the control signal brushes are mounted on the same collector mechanisms as the power collection brushes described in Section 7.2 and, therefore, comments on the mechanisms are common to both the power and control functions. In addition to the two serially-mounted brushes at the front of the trains, four (two signal and two ground) VMCSS brushes are mounted in pairs on the last two bogies of each train.

7.4.1 1978-79 Winter Activities

With the exception of the tests described in Section 7.3.1, very little testing or demonstrations were performed on the VMCSS during the 1978-79 Winter Program. The expectation of problems associated with frost interference on the brush/rail interface was verified. That, along with the demonstrated ice and snow problems of exposed brush/rail interfaces, i.e. side-mounted rail configurations, suggested that some investigation of collector brush heating should be made.

7.4.2 1979-80 Winter Activities

The 1979-80 Winter Activities were almost entirely oriented towards the MZG revenue service demonstrations. The degraded performance due to winter season frost was conclusively established and recorded on a 24-hours/day basis; the results of frost-induced performance degradation can be determined by comparing Figures 25 and 27. The more striking comparison is that automatic operations were possible about 84 hours less during the month of February, 1980 than were manual operations; this reduction in automatic operations was entirely due to frost accumulations on the rails. Frost either could, or did, cause a loss of approximately 146 hours for manual mode operations and a total loss of 230 hours in the automatic mode during this month; no other precipitation or temperature condition caused any type of service degradation. It should be noted that a combination of circumstances, including UMI auxiliary traction subsystem work on one train (No. 3), made it impossible to have any of the trains available for automatic mode operations on February 25 or 26.

As discussed in the above paragraph, the control brush/rail interface appears more susceptible to frost degradation than the power brush/rail interfaces. For this reason, greater effort was expended in the observation of benefits derived from heating the control brushes than the power collection brushes. The February operability data does indicate that the control brush/rail interface would probably benefit more from heating than would the power brush/rail interfaces. However, the material presented under Section 7.2.2, on page 7-9, suggests that there are better alternative solutions to this problem than brush heating.

8. OTHER SUBSYSTEM TESTING

Several other UNIMOBIL System features and Subsystems were tested or demonstrated during the 1978-79 and 1979-80 Winter Programs. These items, most of which were superseded during the second year, are discussed in this section and they include: maintenance support vehicle; snow removal; auxiliary traction subsystem; and power rail feedback control system. The latter two items were optional efforts and were not a part of the baseline system that UMI supplied to MZG.

8.1 MAINTENANCE SUPPORT VEHICLE

On April 18, 1980, the maintenance support vehicle (MSV) first used at MZG was replaced by the unit specifically designed and manufactured for this installation. There were considerable differences in the capabilities of the original and replacement MSV's; these differences will be presented in Sections 8.1.1 and 8.1.2.

8.1.1 Interim Maintenance Support Vehicle

The MSV used in the 1978-79 Winter Program was designed specifically for construction of the MZG guideway. The interim MSV was powered by a 60 horsepower gasoline engine which drove a (1,000 psi) variable-volume, vane hydraulic pump; Mobil Areo hydraulic fluid (MIL-H-5606) was used for this extreme cold weather application. Propulsion was provided to the two support bogies, located near each end, by hydraulically-actuated screw drives. The bogies were center-pivoted with guidance mechanisms of the same general configuration as those used on the trains.

This MSV had powered bench lifts on each side for easy reach to the power and control rails for inspection and any necessary servicing; it could also be used for guideway structural inspections. The bench lifts retracted so the MSV could operate on both elevated and at-grade guideway sections without limitations or adjustments. The MSV functioned in all winter applications -- primarily assistance in power and control rail installation as well as Drip Lip and guidance/auxiliary traction surface welding activities.

The principal problem areas were related to the hydraulics. Prior to the change to low-temperature fluid, subsystem response and vehicle speed both began to slow at 10°F; after the change the degrading was delayed until temperatures fell below -10°F. The pump seal also developed leakage as temperatures dropped below -10°F; it would reseal in about 5 minutes of operation at that temperature. As the temperatures continued to decline the resealing time increased; by the time -20°F was reached, resealing was seldom accomplished. A 1,200 watt electric heater added to the hydraulic fluid reservoir essentially eliminated the leakage problem and lowered to -15°F the temperature when there was a noticeable degrading of vehicle speed and subsystem response.

In addition to its inspection, construction and maintenance functions, the MSV served as a platform for the snow removal equipment; this application is described in more detail in Section 8.2.1.

8.1.2 Permanent MZG Maintenance Support Vehicle

The most significant difference between the interim and permanent MSV is the latter's capability to move a train on the guideway. After the close of MZG's revenue service on May 16, 1980, the MSV moved an entire train over the complete 1.25 mile main guideway route. This movement was over a guideway that is about 56.3% on tangent alignment with the remaining 43.7% having horizontal curves with radii as short as 80 feet. Vertical gradients encountered in the normally clockwise train operations ranged from +2.361% to -2.447% -- frequently combined with the horizontal curves.

The permanent MSV is powered by a 60 horsepower gasoline engine which drives a 2,500 psi variable stroke piston pump. The piston pump is directly-connected to hydraulic motors for each of the eight drive/guidewheels; this arrangement provides both propulsion, with limited positraction capabilities, and braking. The rubber-tire guidewheels are configured and in contact with the guidance/auxiliary traction surface in essentially the same manner as the train guidewheels.

The MSV platform can accomodate 20 passengers, having average weights of 150 pounds, within an area totally enclosed with pipe railings. The MSV was operated with sixty bags that each contained 53 pounds of sand along with three people weighing a total of 600 pounds; it was so certified by a local testing company. The lifting benches on both sides, each with a design capacity of 400 pounds, were similarly certified with 530 pound loads; the MSV was operated over an approximately 0.65 mile section of guideway with 1,060 pounds on the two benches.

The MSV is equipped with a 110/220 VAC, 12 VDC gasoline powered motor-generator that can be used for operating tools and appliances as well as providing heat for the hydraulics during winter cold. This MSV is not presently equipped for either snow removal or to propel the snow module although minor modifications would allow either alternative.

8.2 SNOW REMOVAL

During the 1978-79 Winter, and during a part of the 1979-80 Winter, snow was removed from the guideway by using the plow and/or brushes on the interim MSV; snow removal, using this MSV, was accomplished by running it independently or by pushing it with a train. The snow module arrived at MZG on January 7, 1980 and, to date, is limited for use with Train No. 3. After January 25, 1980, either the snow module or the interim MSV were used for snow removal.

8.2.1 1978-79 Winter Activities

Snow removal during the 1978-79 Winter was accomplished by means of a snowplow with two trailing brushes mounted at one end of the interim MSV. The plow was a V-shaped splitter, 48 inches in width; the two 24-inch diameter counter-rotating nylon brushes had vertical axes. The brushes were driven by hydraulic motors which provided sufficient force to clear the guideway of slushy snow one inch deep at an estimated brush tangential speed of 20 feet/second and an MSV travel rate of 12 feet/second.

The brushes and the snowplow can be used separately or together; the brush pressure and the blade clearance are both directly adjustable. The brushes are adequate to remove snow with a density of 6.25 pounds/cubic foot up to a depth of 2 inches; their upper performance limit is to remove snow weighing 8.32 pounds/lineal foot of guideway at the MSV travel rate of appoximately 2 feet/second.

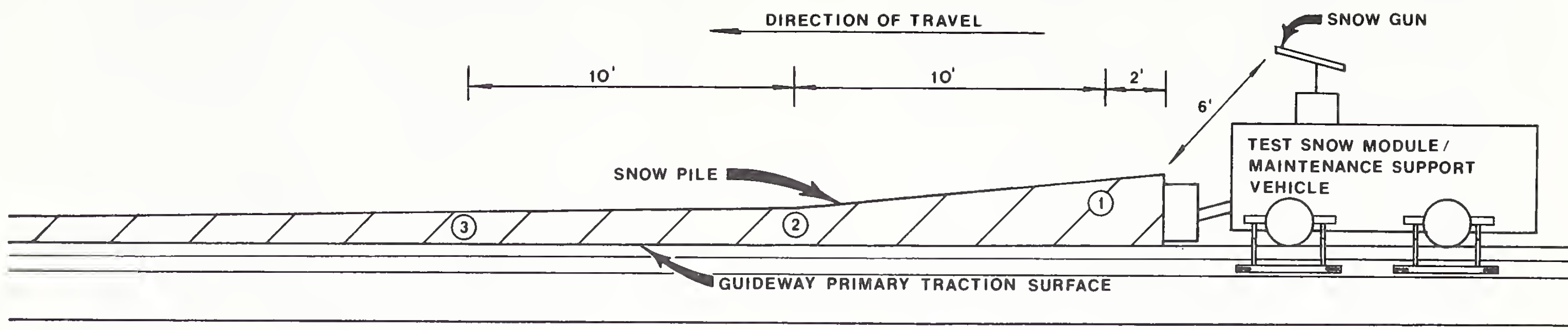
The snowplow is used when accumulations of ice, slush or snow exceed the capabilities of the brushes. Figure 28 depicts a snowplow test performed on March 27, 1979 with the interim MSV and the snow removal equipment positioned as Figure 29 shows on page 8-6. Without exception, using only the snowplow and brush combination or the brushes only, the primary traction surface was maintained free of snow throughout the 1978-79 Winter. It should be noted that while the entire guideway was not available for train operations, the MSV could traverse the complete main guideway route.

The snowplow also removed glare ice when guideway structural temperatures were at or above 32°F. Due to the COR-TEN steel characteristics, the guideway temperatures often exceed ambient temperatures by 20°F to 50°F between sunrise and sunset. It was also possible to remove pebbly ice at higher (near freezing and above) ambient temperatures. Glare ice allows the direct passage of solar heat to the guideway surface while pebbly or milky ice inhibit such transmissions. In these latter instances, however, the guideway did gain solar heat accumulated along its sidewalls. It was also indicated that the colder the guideway, the greater was the difficulty in removing the ice.

Nearly all of the ice encountered was artificially created. Most of the remainder was the result of snow accumulations left on the primary traction surface (for study purposes); these snow accumulations melted from solar heat gained on the guideway sidewalls and then refroze. Other minimal scattered and patchy amounts were the result of slush or post-snow-removal surface moisture that froze before the solar heat vaporized it.

8.2.2 1979-80 Winter Activities

The natural snowfalls during the 1979-80 Winter Program did not produce accumulations or conditions requiring use of blade removal. However, to allow maximum snow removal (travel) rates in the range of 10 feet/second when the snow module was placed in front of a train in revenue service, the blade was used, with 3/8 inch clearance, in conjunction with the brushes -- regardless of accumulated snow depths.



TIME: 6:20 A.M.
AMBIENT TEMPERATURE: 11.5°F
WIND SPEED: 1 M.P.H. FROM NORTHWEST
SNOWPLOW TRAVEL RATE: 2 ft./sec.

SNOW CHARACTERISTICS
AVERAGE SNOW TEMPERATURE: 31.5°F
AVERAGE SNOW DENSITY: 20.41 lbs./cu.ft.
AVERAGE SNOW HARDNESS: 6.05 P.S.I. @ PENETRATION
AVERAGE SNOW DEPTH AT INDICATED LOCATIONS: (1) 26.5"
(2) 15.3"
(3) 11.5"

FIGURE 28. SNOWPLOW PERFORMANCE TEST ON MARCH 27, 1979

FIGURE 29. SNOW REMOVAL USING INTERIM MAINTENANCE SUPPORT VEHICLE CAPABILITIES

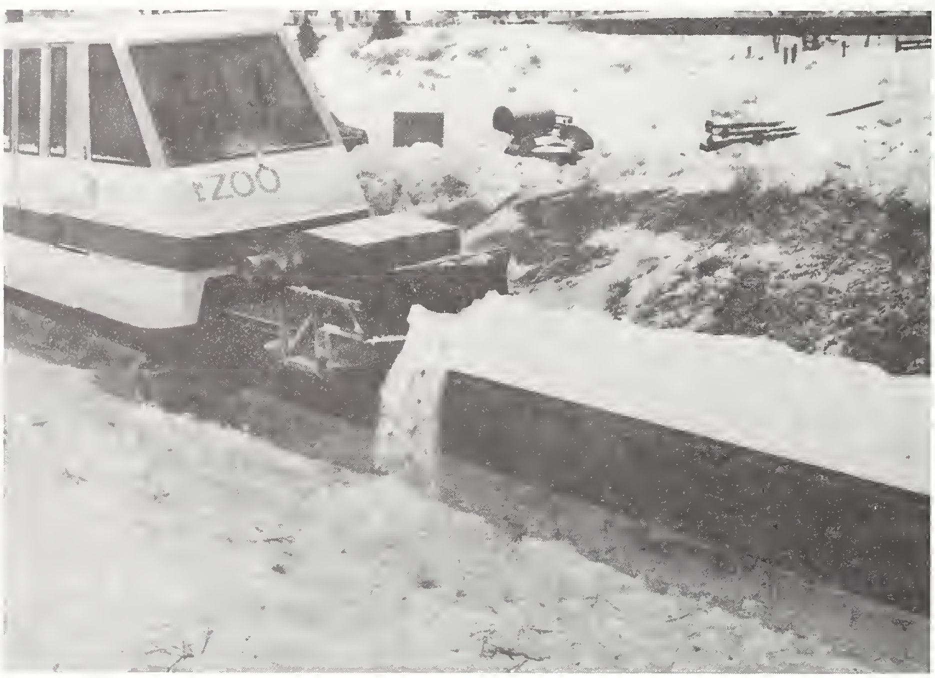


FIGURE 30. SNOW MODULE OPERATION ON MAINTENANCE SPUR -- ACCUMULATION THROWN FROM HILL IN BACKGROUND

The snow module brush and blade operations can be controlled from either inside the train lead car or preset from outside. The module has two 24-inch diameter counter-rotating nylon brushes with vertical axes; the brushes are driven by a 7.5 HP, all-weather enclosed AC electric motor. The module blade is a V-shaped steel splitter that is 48 inches wide. Demonstrations were performed for Raytheon, a TSC film subcontractor, on February 14, 15 and 16, 1980, using artificially-created snow accumulations; Figure 30 shows the snow module being used to remove an accumulation averaging over 20 inches (maximum depth of 22 inches) produced with the aid of a snowthrower.

The MSV was most often used because of its compatability with Train Nos. 1 and 2 (snow module controls were only in Train No. 3). When the MSV was used for snow removal, only brushing action was applied.

8.3 AUXILIARY TRACTION SUBSYSTEM

An auxiliary traction subsystem (ATSS) is a readily-apparent extension of the inherent properties of the UNIMOBIL System baseline train and the Slimline Guideway. As previously-presented discussions described, at least one of the two guidance surfaces shown on Figure 4 remains essentially free of snow and/or ice accumulations in nearly any circumstance. This positive condition was further enhanced by the addition of heater tapes behind these surfaces in the testing area. The guidewheels and the guidance mechanisms also tend to remain free of such accumulations. Therefore, it is only reasonable to incorporate these advantageous elements into the ATSS.

8.3.1 1978-79 Winter Activities

The ATSS, as first tested at MZG near the end of the 1978-79 Winter, was based on providing tractive effort to modified guidewheels on the two trailing (previously idler) bogies of a partial train (Cars 5 and 6 of Train No. 3). All four guidewheels on each of these two bogies had individual hydraulic motors that were driven by hydraulic power pack modules located in available space above these bogies.

Primary power for each of the hydraulic power packs was provided by switching the line feed from a 7.5 horsepower powered bogie electric traction motor to an electrically-equivalent motor in the power pack (Figure 9 shows one possible arrangement). Because this was a temporary, test-only configuration, the lead bogie of Car 5 was modified to provide guidance for the partial train. For the same reason, primary power for partial Train No. 3 was provided by a manually-switched power line which diverted energy from two traction motors on Train No. 1. This procedure was used since the primary power collection for Train No. 3 must be on the lead vehicle and complete assembly of Train No. 3 was not possible at that time.

The ATSS was designed to overcome a train rolling resistance of 2,000 pounds; this value was derived from observing deceleration characteristics of a rolling UNIMOBIL System 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 2,000 pounds, combined with the availability of eight guidewheels from the two trailing idler bogies, was the basis for selecting the ATSS configuration. The guidance mechanism thrusts against the guidance/auxiliary traction surface were adequate for the desired forces along the guideway; the space above the idler bogies was sufficient for the electric motors and hydraulic pumps (ATSS power packs).

The available starting and continuous energy from the 7.5 hp electric traction motors was the limiting factor for selecting the maximum train speed associated with the required 2,000 pound force. The design curves for each of the two ATSS modules are presented as Figure 31. Prior to installation at MZG, the ATSS modules were performance tested, and adjudged satisfactory, on February 12, 1979.

On June 3, 1979, the ATSS demonstrated its capability to pull a complete train. This demonstration was performed with temperatures in the range of well over 70°F. This demonstration, although optional, was, in part, delayed to that date because of the press of other MZG activities. In addition, after April 6 there was no significant winter weather to provide better data for this demonstration. It should be noted that, besides providing propulsion, the ATSS can provide supplementary braking (approximately 0.08g at MZG) to whatever baseline system value is available over the range of primary traction surface friction coefficients.

2220 MOTOR RPM = 134 GUIDEWHEEL RPM = 4.78 MPH = 7.01 FPS. THIS VALUE REPRESENTS 65% OF THE MAXIMUM BASELINE CONFIGURATION VELOCITY [11 FPS]

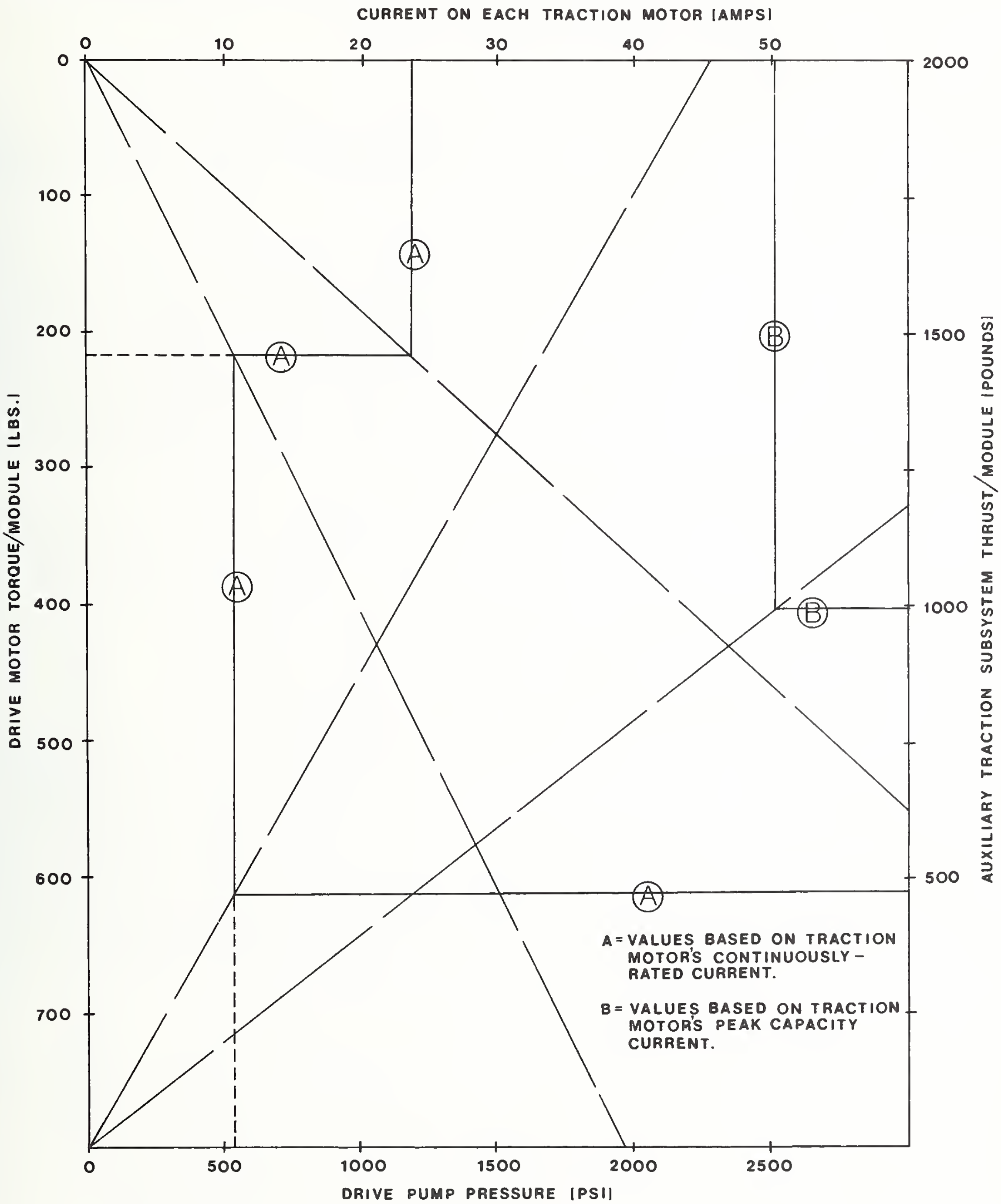


FIGURE 31. DESIGN CURVES FOR EACH AUXILIARY TRACTION SUBSYSTEM MODULE

Figure 32 presents the advantages of propulsion and braking available with the ATSS augmentation to the MZG baseline configuration. These variations in propulsion and braking result from:

- The effective gain in hydraulic (propulsion and braking) thrusts for given traction motor currents are due to lower maximum velocity limits as established by the lower "gearing" and, thus, greater power in the hydraulic motors.

- The propulsion energy utilized by the ATSS is limited to 25 percent of the available primary traction energy because two of the eight traction motors are used by the ATSS. It should be noted that below $\mu = 0.0875$, the primary tractive force of only four motors can be applied (any additional force would be lost in slippage); therefore below $\mu = 0.0875$, the full benefits of the ATSS augmentation are available. Above $\mu = 0.0875$, available generator currents, combined with primary traction surface friction coefficients, limit the total propulsive forces of the primary traction subsystem augmented by ATSS.

- The train emergency braking capability includes all of the friction values available from the eight traction motors (even though power is only supplied to six) plus the 2,000 pounds (less slippages) of hydraulic effort that would be statically available from the closed-loop ATSS in the shutdown mode.

8.3.2 1979-80 Winter Activities

During the 1979-80 Winter Program, ATSS modifications were made to allow greater operating flexibility. These modifications were basically the addition of clutches for the hydraulic motors and, consequently, exchanging the 1978-79 Program hydraulic motors for vertically shorter motors to maintain guideway clearances; the new clutches consumed five inches of the available clearances. In addition, control features were added, at TSC's request, to allow any ATSS applications by the guide/narrator from the lead train vehicle.

The very limited 1978-79 Winter Program testing showed that clutches were necessary because the ATSS-equipped train was restricted to a maximum speed of 5.5 feet/second -- about 50% of the revenue service top speed. Because the motors used in the 1979-80 Winter Demonstrations were appreciably smaller in size, they provided less torque for given motor loads than did the previous year's. The available ATSS propulsion thrust is now limited, by allowable traction motor currents and heating, to 2,000 pounds for short-term applications and 1,000 pounds for long-term operations. Short-term applications or operations are in the range of five minutes -- with some variation due to temperature and other conditions.

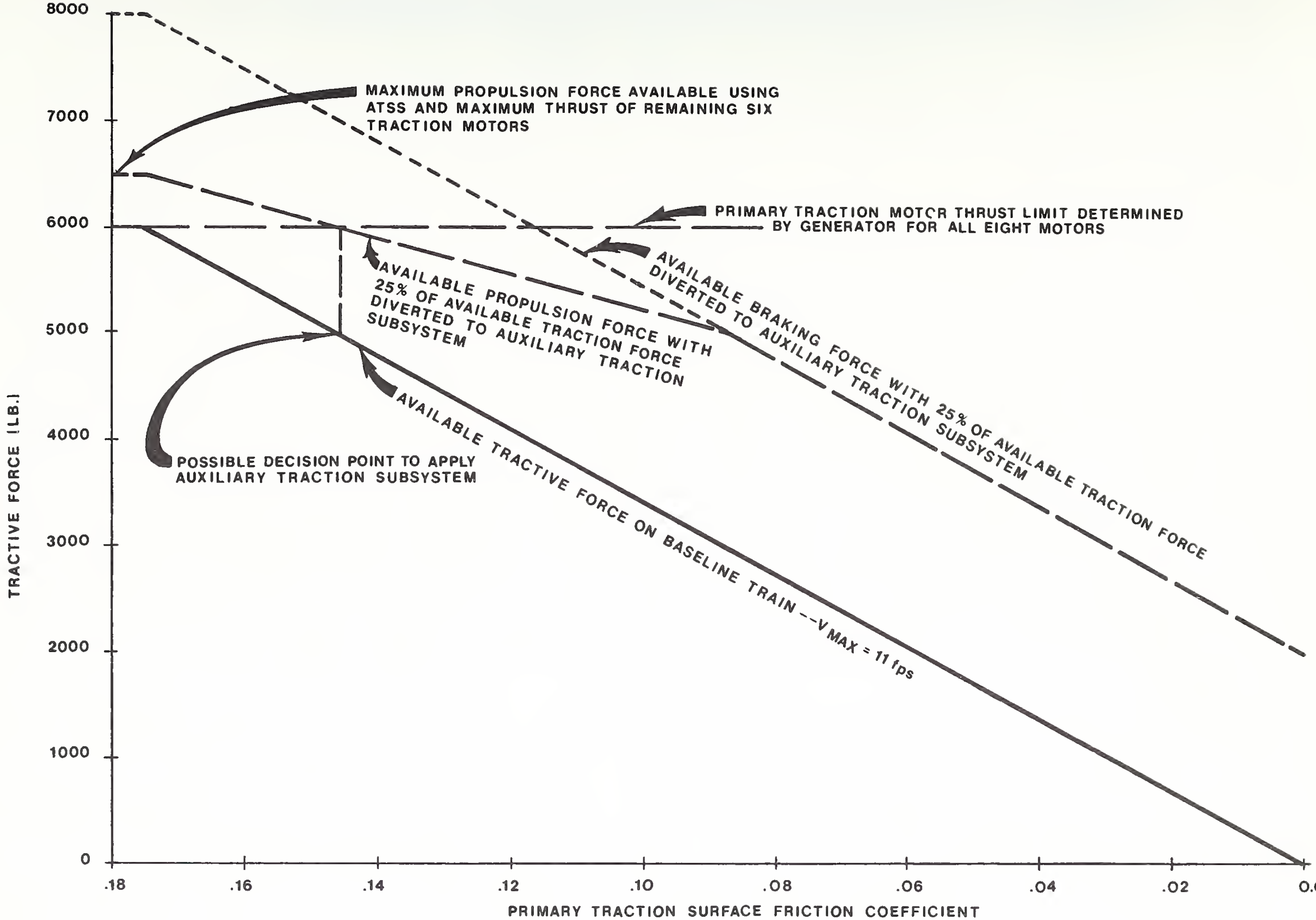


FIGURE 32. MZG SYSTEM TRAIN PERFORMANCE DESIGN CURVES

8.4 POWER RAIL FEEDBACK CONTROL SYSTEM

The power rail feedback control system (PRFCS) is a UMI proprietary development which maintains power and control rails clear of any frost or ice accumulations at an extremely low energy cost. UMI's recognition of the need for, and the initial steps toward development of, a PRFCS predates the contract award for this demonstration program. The success of the PRFCS rail clearing capabilities is evident from Figures 23 and 24; these pictures were taken during the 1978-79 Winter.

8.4.1 1978-79 Winter Activities

Benefits of a power or control rail heating system include improved operational certainty due to elimination of frost problems and increased collector brush life because of reduced icing and improved retention of lubricants on the rails. However, the really significant potential benefit of the PRFCS is its energy conservation characteristics. Figure 33 shows the relationship between power rail temperatures based on two different heat selection criteria used on March 12, 1979: (1) from 2:09 a.m. to 3:48 a.m. heating was applied because the ambient temperature was below 32^{o} and there was no solar energy source; and (2) from 3:48 a.m. until 7:18 a.m. the PRFCS was in operation. While the first criterion is not a suggested technical or policy procedure, it is representative of an approach for reducing energy consumption to maintain power and control rails free of ice, snow and frost.

A comparison between the ambient dewpoint temperature and the temperature of the power rail under the direct influence of the PRFCS is shown as Figure 34 on page 8-14. This comparison is for a two-day test period in April 1979. The criterion for applying heat in this instance was to maintain a $+4^{o}$F differential between the dew point and power rail temperatures for frost prevention. While instrumentation to indicate heating "on-off" time data was not yet available, reduced electrical energy requirements, as detemined by the feedback controls, can be easily inferred from the daytime rail temperature increases which do not relate to the ambient temperatures. During this period, the ambient air temperatures ranged from 26^{o}F to 43^{o}F; both the rail temperature gain and duration were the result of guideway-absorbed solar energy which was radiated (primarily) and conducted to the test rail.

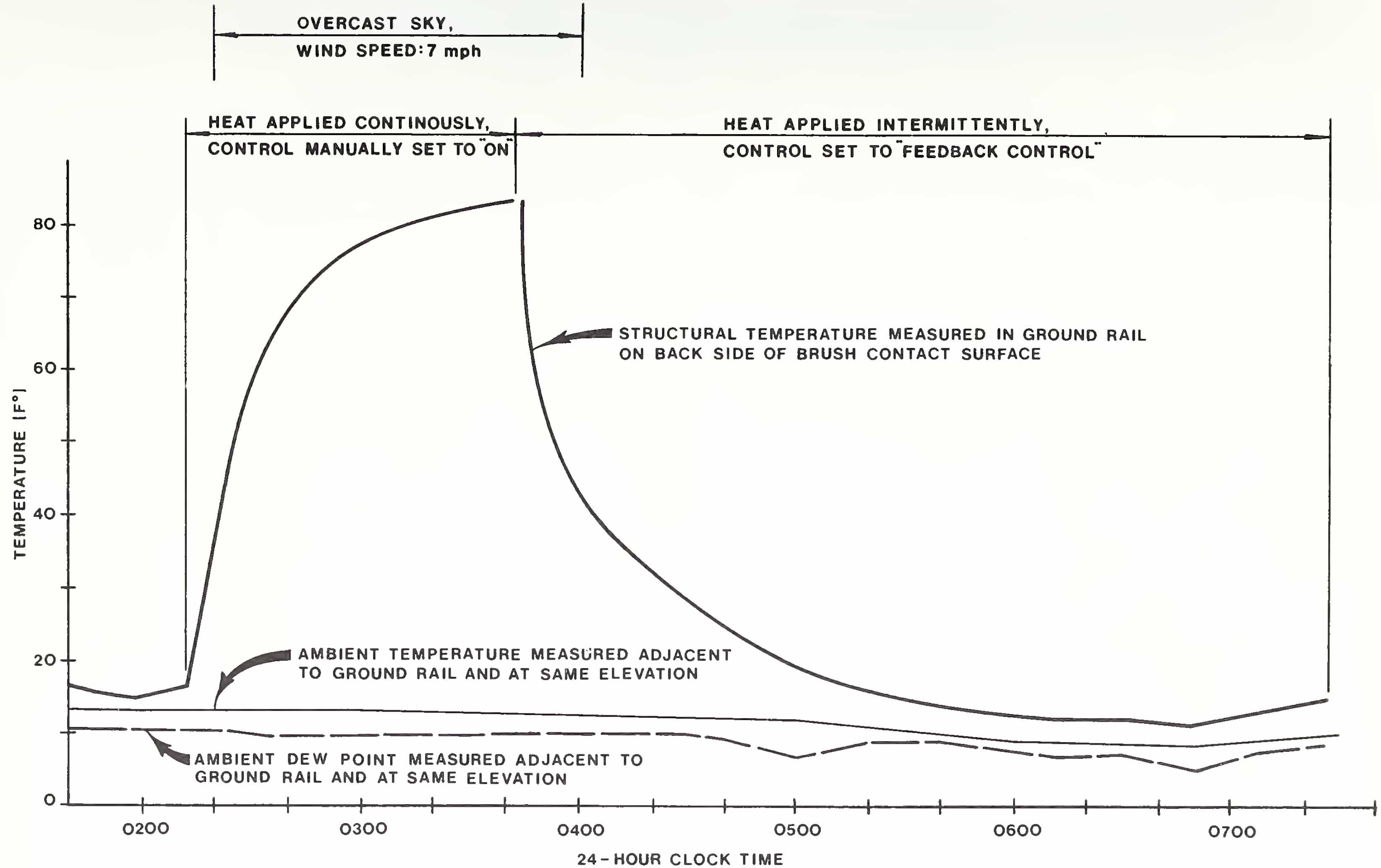


FIGURE 33. POWER (GROUND) RAIL TEMPERATURE COMPARISONS (MANUAL VS. FEEDBACK MODES) DURING MARCH 12, 1979 TESTS

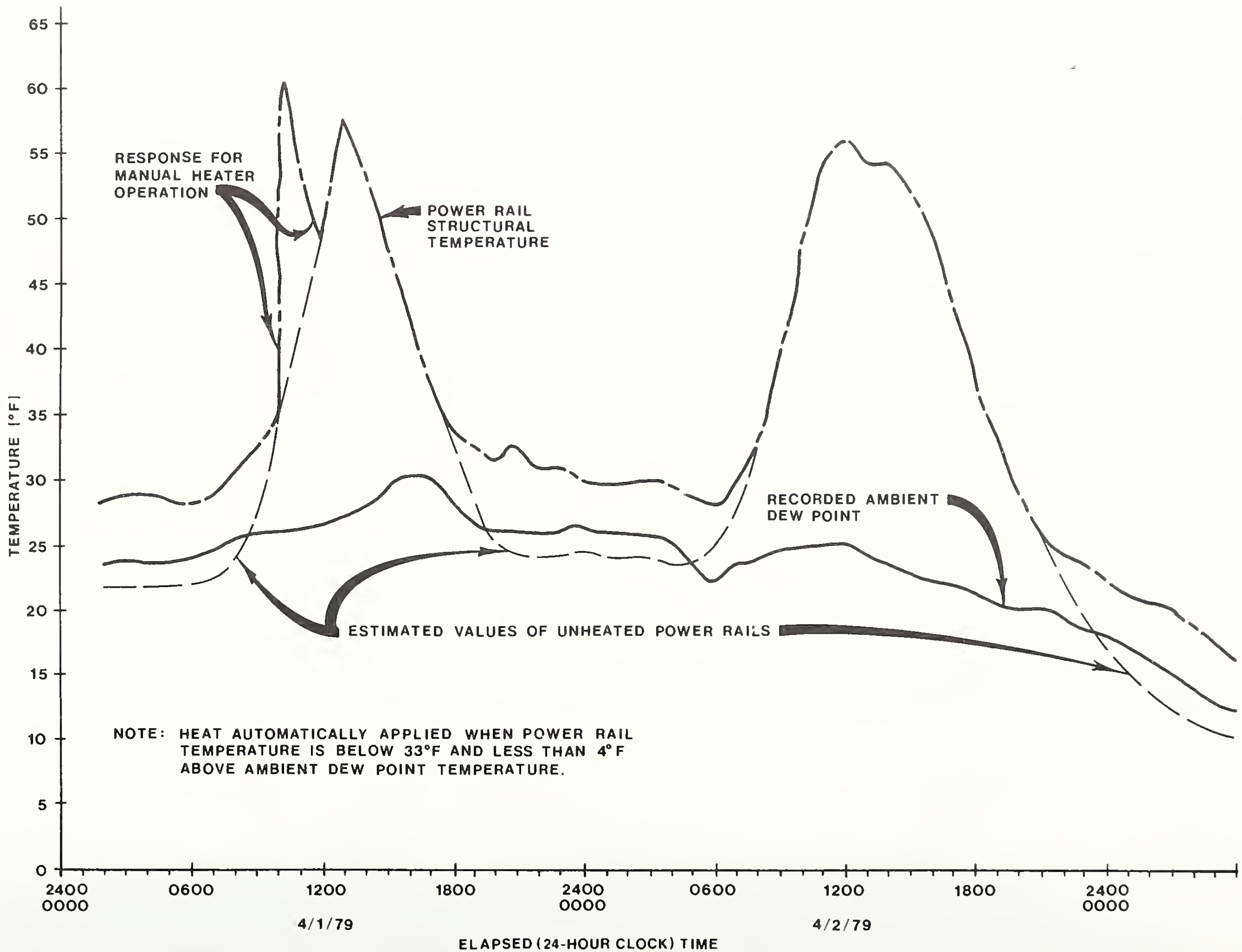


FIGURE 34. COMPARISON OF POWER RAIL AND AMBIENT DEW POINT TEMPERATURES

Figure 35, on the following page, is a comparison of estimated cumulative rail heating hours for different heat application criteria required by MZG ambient conditions from November 1, 1978 to April 30, 1979, based on appropriate 1978-79 data. It is obvious from this figure that the PRFCS provides at least an order of magnitude energy savings over any of the other presented criteria.

8.4.2 1979-80 Winter Activities

The complete PRFCS was in continuous operation from February 8, 1980 through May 31, 1980; the only interruptions in its functions were due to unrelated power failures. This over 16 weeks of continous service provided achievements beyond the signal benefit of 100% freedom from frost, ice, or snow; there were neither electrical nor mechanical failures at the system, subsystem or component levels. A problem of this and other similar systems, mechanical fatigue of the heater wires at expansion, control and/or construction joints, had been resolved. Several approaches for preventing this problem had been tested during the 1978-79 Winter Demonstrations; the most promising approach from these tests was selected and proved to be successful.

During the period of continuous operations, energy was applied to the heaters for a total of 9.07 hours out of nearly 2,000 in-service hours from February 8 through April 30, 1980. From the operability data, there are indications that during this same period frost accumulations developed for nearly 268 hours; of this 268 hour total, about 35 hours had light to moderate frost accumulations and the remaining 233 hours had moderate to heavy accumulations. The accumulated applied heat time was recorded on a meter which read to the nearest hundredth of an hour; the accumulated frost data was based on the interpretation of on-site weather data, visual observations and actual System tests.

Based on the above information, the total cost for maintaining a three mile long guideway with four power and control rails continuously free of frost from November 1, 1979 to April 30, 1980 is $940. This amount is developed from a total of over 673 hours of frost accumulations for this six-month period and electricity at a rate of $0.05/kilowatt-hour for 18,800 kilowatt-hours.

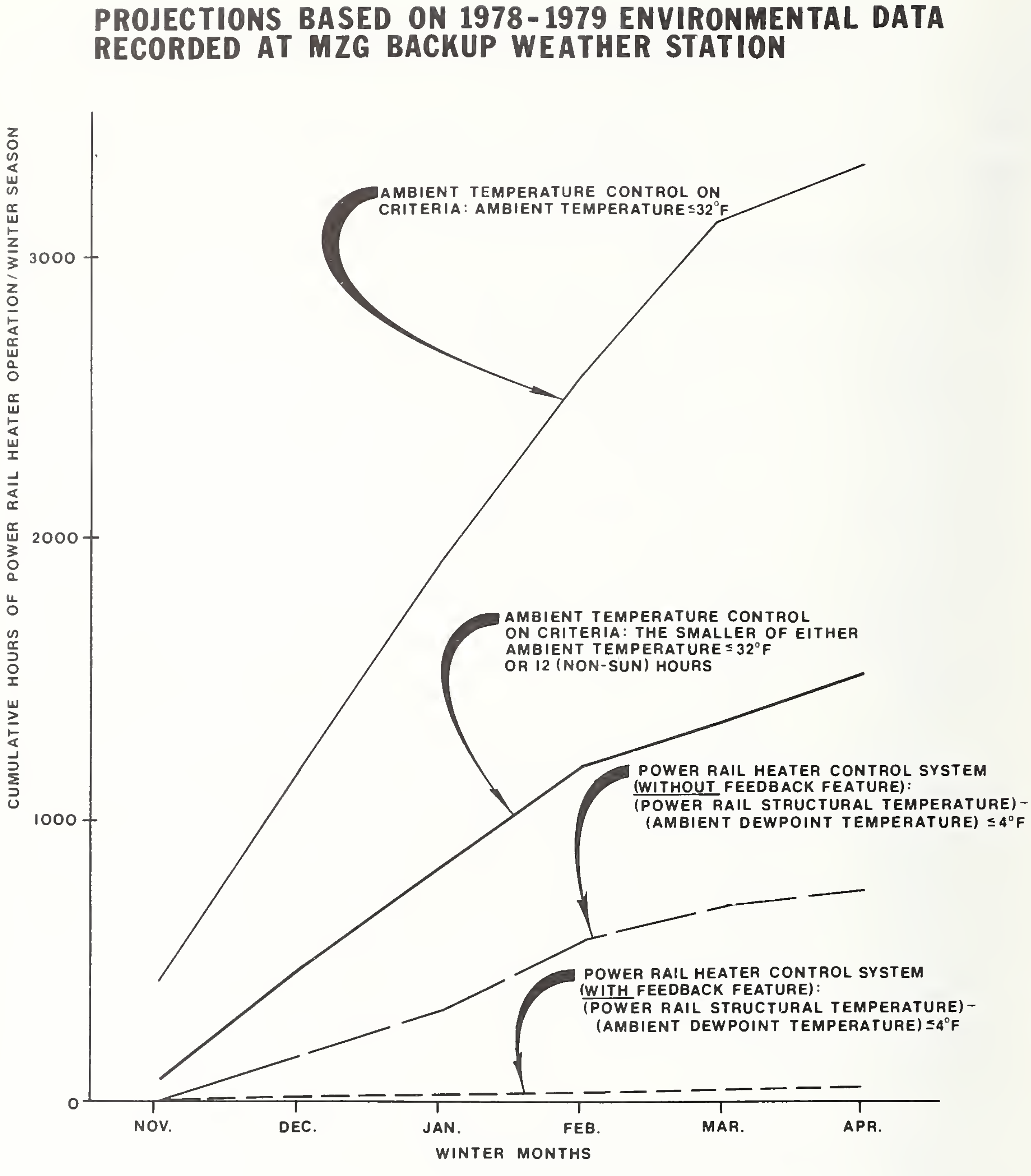


FIGURE 35. ESTIMATED CUMULATIVE HOURS OF POWER/CONTROL RAIL HEATER OPERATION DURING WINTER BASED ON VARIOUS CONTROL CRITERIA

9. SYSTEM LEVEL TESTS

System level testing encompassed the bulk of the UMI 1979-80 Winter activities. This complemented the devotion to subsystem and component level testing which had been necessary during the 1978-79 Winter. The desired characteristics of DPM Systems, with particular orientation towards responses to extreme winter weather stresses, were the bases for determining the tests that were performed as well as for interpretting their results. These desired characteristics include operability, safety, economy, aesthetics and comfort.

9.1 OPERABILITY

Operability can be considered as the ability of a DPM System to function under predetermined conditions. However, this ability must further be defined by acceptable levels of operation and applicable procedures to reach these levels. Such levels and procedures must be incorporated into all aspects of the DPM System including, but not limited to, maintenance facilities and equipment, support equipment and station facilities.

9.1.1 Levels of Operability

Twelve (six manual mode and six automatic mode) operability charts, covering the period from November 1, 1979 to April 30, 1980, for the UNIMOBIL System demonstrated at MZG are contained in Appendix C. These charts contain the following summarized information for the 182 day operating period they represent:

1 - on 182 days the System was manually operable by 12:00 p.m. (noon);
2 - on 182 days, the System was automatically operable by 2:15 p.m.;
3 - on 180 days, the System was manually operable by 10:00 a.m.;
4 - on 147 days, the System was manually operable by 7:00 a.m.;
5 - on 152 days, the System was automatically operable by 10:00 a.m.; and
6 - on 133 days, the System was automatically operable by 7:00 a.m.;

The preceding summarized figures were developed by interpreting the chart data to less than fifteen minute intervals. This was considered to be reasonable since, except when the trains were actually run, the acceptable level of operability data was interpretted from recorded on-site weather records. There are several comments appropriate to the operability data:

- the only condition which prevented either automatic or manual operations was frost;
- frost dissipates to a level that will sustain manual operations earlier in the day than for automatic operations; and
- while inductive control systems may not require rail or contactor heating, the power rails still require some heat source to allow frost-free rail/contactor interface.

All of the above-described frost conditions were continuously overcome from February 8, 1980 through April 30, 1980 in the power and control rail test section served by the PRFCS. The PRFCS is described in detail under Section 8.4.

Other than frost, no naturally-occuring 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 to the range of $-20^{O}F$ had only limited impacts on any parts of the System; these impacts were on the various hydraulic drives and were essentially compensated 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 at any time they were not in revenue service.

9.1.2 Operabaility Procedures

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 period 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 up to 1/2 inch. On the following page, Figure 36 shows the actual snow module use at MZG compared to the number of hours the NWS recorded at least a trace of snowfall during the 1979-80 Winter. Because 1979-80 was a rather mild winter, the greater 1978-79 Winter snowfall data from NWS is also shown for reference pruposes.

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-0^{o}F 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-tracing lines).

9.2 SAFETY

The operational safety of the UNIMOBIL System demonstrated during the 1979-80 Winter testing and revenue service at MZG is representative of similar existing systems' performance which have produced well over 300 million revenue-passenger-miles of service in North America without serious damage or injuries. The System characteristics, including guideway geometry and on-board control configurations, limited the impacts of all winter stresses. Only frost, which could have been eliminated by a System-wide PRFCS, prevented continuous automatic mode operations in revenue service.

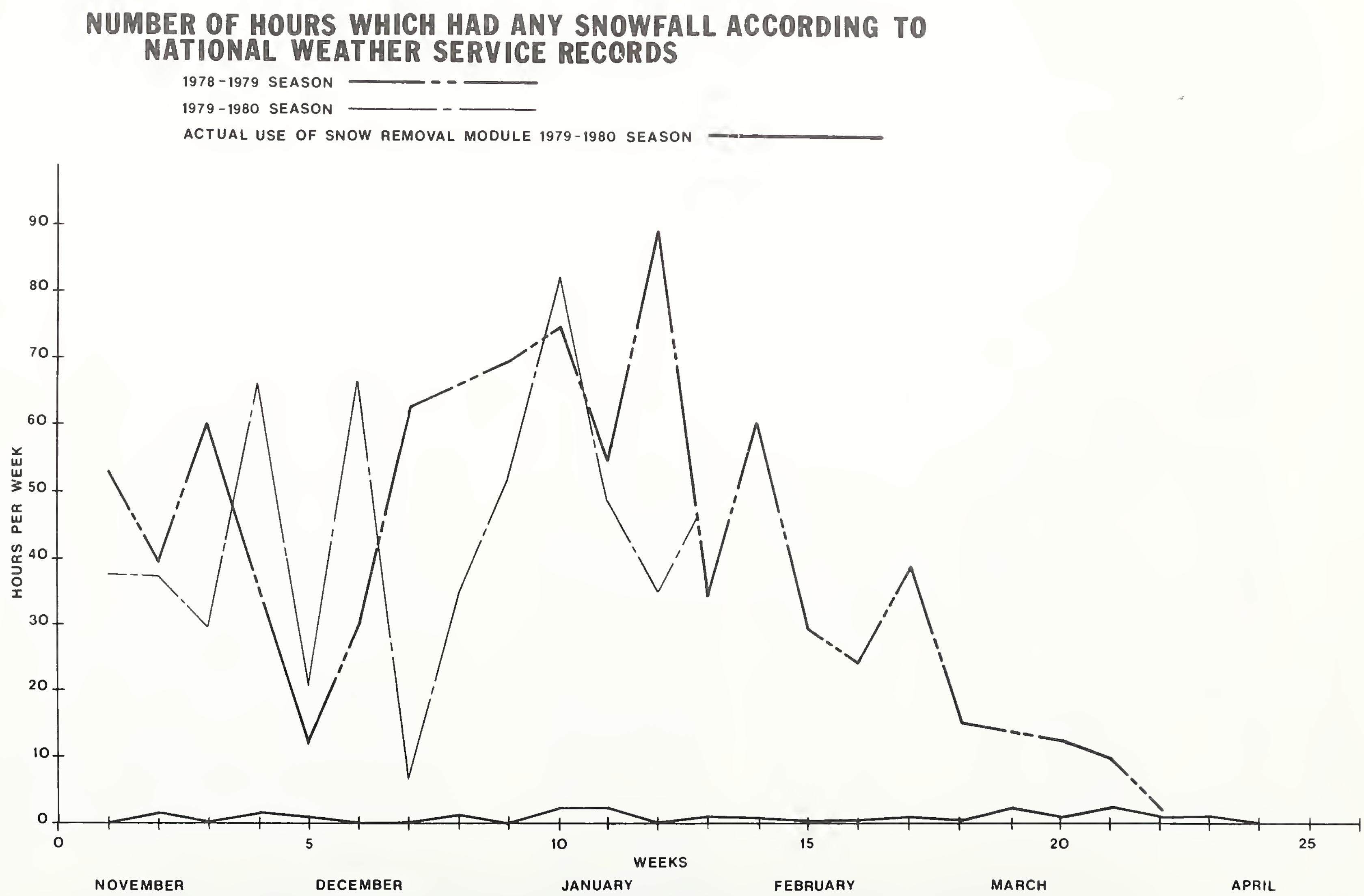


FIGURE 36. ACTUAL SNOW MODULE USE COMPARED TO SNOWFALL FREQUENCIES

The System at MZG was operable in the automatic mode every day, except for two days -- February 25 and 26, 1980, from the September 20, 1979 start of revenue service until beyond April 30; on those two days, a combination of UMI Winterization Team and MZG Maintenance Force activities precluded the availability of a train functional in the automatic mode. The manual and automatic mode operability charts contained in Appendix C express the reliability, and, therefore, the safety inherent in the UNIMOBIL System controls.

The VMCSS, including the on-board autopilot, functioned per design with one, two or three trains in simultaneous operations. It should be mentioned that every MZG train has manual override capabilities to enable the on-board guide/narrators to run the trains when frost conditions precluded automatic mode operations. This capability, which allowed revenue service for all but 3 of the scheduled 1092 (plus extensions for passenger demand) revenue service hours, may or may not be a DPM consideration.

9.3 ECONOMY

The operating and maintenance costs for any DPM System should be consistent where there are similarities such as number of operating vehicles or trains, and daily vehicle-miles or train-miles. However in locations where extreme cold, snow or ice are identifiable and quantifiable considerations, significant savings can accrue as the result of System design characteristics. The three UMI System design characteristics which are most beneficial to reduce operating and maintenance costs in a winter environment are: (1) the Slimline Guideway; (2) the inverted and sheltered power and control rails; and (3) the power rail feedback control system (PRFCS).

The Slimline Guideway, which is the basis for the Cold Guideway Concept, provides many proven advantages developed during the 1978-79 Winter Tests and the 1979-80 Winter Demonstrations:

- the simple cross-sectional geometry precludes nearly all snow or ice accumulations on the primary traction surface (Figures 4 and 5);
- the guideway geometry provides a surface that clears easily with uncomplicated equipment (Figures 7 and 28);

- the guideway geometry limits high-velocity wind-blown accumulations to, at most, one guidance/auxiliary traction surface which is easily cleared with limited heating (Figures 4, 16 and 24); and
- passive (solar) heating of primary traction surface and sidewalls reduces daytime snow removal requirements and limits guideway icing (Figure 3).

The inverted power and control rails are sheltered by the primary traction surface overhang as indicated on Figure 4; this same figure shows the additional protective benefits of the optional Drip Lip. This positioning somewhat lowers convective and radiational heat losses, thereby reducing some frost accumulation problems; the Drip Lip also enchances this benefit.

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 three 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 $1,000. If the weather conditions were twice as demanding and the DPM System had dual lane guideways over a five mile route, the direct annual costs, based on $0.05/kilowatt-hour, would still only be in the range of $6,000 for a winter of continously 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.

9.4 AESTHETICS

Aesthetics have a limited place in this report. However, there are certain factors associated with aesthetics that can be identified in a technical study; these factors are visual intrusion and functionality. With regard to the former, there are numerous photos, provided as figures, throughout this report which show the guideway and vehicles do not detract from their environment. Furthermore, there have been only positive comments on this subject by MZG, System passengers and other MZG patrons. In addition, there have been no adverse comments regarding the COR-TEN as it aged and acquired its oxidized surface.

With regard to functionality, frequent comments in technical publications indicate that engineering projects or products which respond to their function in a balanced scale while providing their expected level of performance are functionally attractive. In the past this standard has been applied, among other things, to buildings, bridges, boats, ships, airplanes and trains. To date, the UNIMOBIL System at MZG has enjoyed this type of public response.

9.5 COMFORT

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. A common example of this situation was evident during the video recording of revenue service operations; these recordings included normal levels of passenger conversations in the background on the test conductor's audio reporting track.

In addition to the technical evaluation of the ECU in Section 6.3, limited UMI questionnaires (sample contained in Appendix C) were distributed to System passengers. The responses to these questionnaires were almost unanimously positive; MZG had similar results with their own surveys.

10. FINDINGS AND CONCLUSIONS

The tests and demonstrations performed by UMI during the 1978-79 and 1979-80 Winter Programs at MZG confirmed that simple DPM Systems can satisfactorily function in harsh winter climates. It was, however, found that proper procedures must be applied as demanded by various situations. Furthermore, the physical properties of the Systems must either accommodate, or be capable of quickly responding to, the encountered winter situations.

10.1 FINDINGS

The UNIMOBIL System, as delivered to MZG, can perform satisfactorily in the harsh winter environment that is representative of the Minneapolis-St. Paul, Minnesota area. The environment of this area has extreme winter parameters where temperatures average, in January, between daily lows near $0^{\circ}F$ and daily highs in the low $20's^{\circ}F$, and where the average annual snowfall is about 47 inches. During the winter, it is not unusual for overnight low temperatures to reach $-20^{\circ}F$ and daily high temperatures to be below $0^{\circ}F$; annual snowfalls in excess of 50 inches are not uncommon.

It should be recognized that satisfactory UNIMOBIL System performance at MZG does not suggest that the same level of performance would be satisfactory for a DPM System. Rather, the results of the UMI tests and demonstrations at MZG suggest that a UNIMOBIL System with one or, possibly, two options could satisfactorily perform under the demanding winter weather conditions associated with, for example, a St. Paul DPM System. The necessary option would be the power rail feedback control system (PRFCS), or a performance equivalent, and the possible option would be the auxiliary traction subsystem (ATSS); these two options are respectively described in detail under Sections 8.4 and 8.3.

10.1.1 Hardware

The baseline UNIMOBIL System hardware which UMI supplied to MZG satisfactorily performed in daily revenue service during the 1979-80 Winter. While the 1979-80 Winter was somewhat mild when compared to average Minneapolis-St. Paul winter conditions, and very mild when compared to the 1978-79 Winter, nothing in the tests or demonstrations suggest that the UNIMOBIL System would have performed less than satisfactory under more adverse weather conditions.

Frost was the only winter condition encountered, during either the 1978-79 or 1979-80 Winters, which presented a notable problem to the baseline UNIMOBIL system. Frost caused power and signal interruptions when it accumulated on the rails in sufficient amounts to produce significant frost or ice buildups on the collector brushes. In addition to the consequent power and control signal interruptions or losses, frost can contribute to conditions which may cause accelerated collector brush wear. Because frost apparently removes at least some of the lubricating fraction deposited by the brushes on the brush/rail contact surfaces, this lubricating loss probably reduces collector brush life due to higher brush/rail interface friction.

The optional PRFCS, described in Section 8.4, was in continuous operation from February 8, 1980 through May 31, 1980; it maintained the power and control rails, that it served, free of frost throughout this period. Extrapolation of the February 8 through April 30 on-site MZG weather data indicated that the total cost to provide continuous frost-free conditions on four power and control rails for a 5-mile long, dual-guideway (10 miles of guideway and appurtenances) system would be about $6,000/year in a Minneapolis-St. Paul environment. This annual cost is based on electricity purchased at $0.05/kilowatt-hour and a conservative power consumption estimate that is twice the requirements for MZG during the 1979-80 Winter Program. In addition to the low energy costs, PRFCS maintenance costs should be low since it experienced no deterioration during the more than 16 weeks that it was in operation. While the PRFCS was not used to melt ice from any of the UNIMOBIL System rails, it is possible to incorporate a control option that allows sufficiently high rail temperatures to provide a melting function for any system where the rails are properly sheltered and/or oriented.

The remainder of the baseline UNIMOBIL System provided to MZG performed essentially as expected during both natural and simulated extreme winter conditions. Limited amounts of natural snow, and practically no natural ice accumulated on the primary traction surfaces; these accumulations were easily removed by the actions of either the snow module or the passive solar heat absorbing capabilities of the Slimline

Guideway. On the following page, Figure 37 shows the cumulative operating hours and energy costs, based on electricity purchased at $0.05/kilowatt-hour, for snow module requirements at MZG; extrapolated values for a dual-lane DPM System with a route 5 miles in length (10 miles of guideway) are also shown. Except when excessive ice was created for a switch operability test (Section 5.3.2), the trains at MZG accommodated the natural and artificial snow and ice conditions without incident. Traction was the only problem in that instance; sanding the ice surface remedied that problem.

From Figure 37, it can be seen that annual snow removal energy costs for a 5-mile, dual-lane DPM System, in an environment similar to Minneapolis-St. Paul during the 1979-80 Winter, would be less than $50. Using the same doubling factor applied to the PRFCS costs to account for much worse winter conditions, the annual snow removal costs would still be less than $100. Therefore, if electricity costs $0.05/kilowatt-hour, the total annual energy costs to maintain a dual-lane, 5-mile long DPM System continuously free of snow and frost accumulations, throughout a much worse than average Minneapolis-St. Paul winter, would be considerably less than $7,000.

Because the primary traction surface remained essentially clear of snow and ice and uphill gradients were less than 2.4%, the baseline UNIMOBIL System performed adequately at MZG. However, should snow or ice accumulations develop on a DPM System primary traction surface and should uphill grades exceed 2.4% (a quite probable DPM System requirement), a supplementary braking/propulsion traction source might be necessary to assure safe, reliable scheduled service. The UMI guideway provides a guidance surface (Figure 4) which is easily adaptable for an auxiliary traction surface; similar capabilities exist in other DPM Systems. The ATSS, as described in Section 8.3, redirects UNIMOBIL System primary traction motor energy to power modified guidewheels which are driven by hydraulic motors. This arrangement augments the baseline propulsion and braking capabilities.

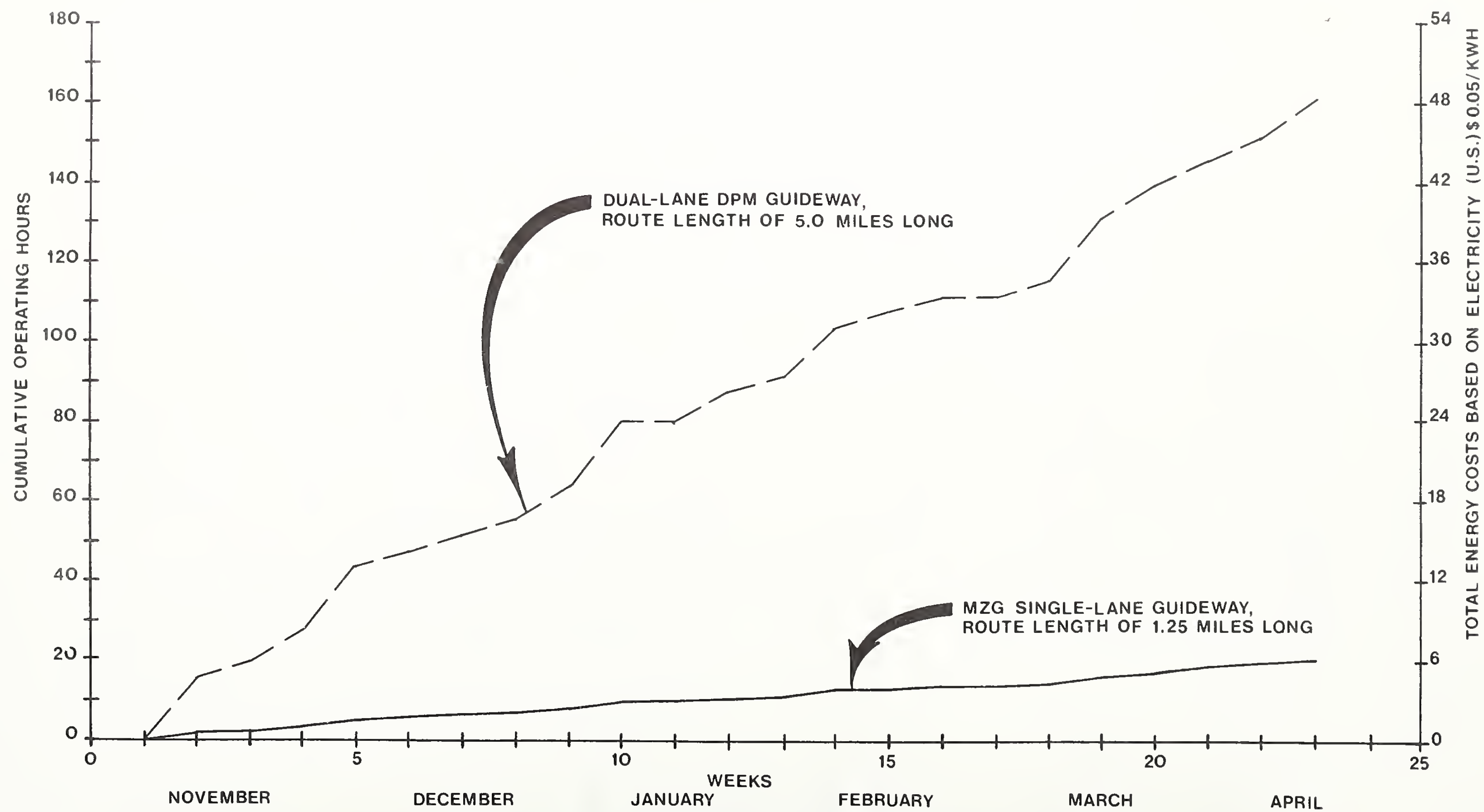


FIGURE 37. CUMULATIVE SNOW MODULE HOURS AND ENERGY COSTS FOR 1979-80 WINTER

Passenger comfort at MZG was little affected by winter temperature or precipitation conditions; this was so indicated by system riders' written and oral comments. While the car interior temperatures did occasionally range down to freezing levels, they were generally $30^{o}F$, or more, above the outside temperatures. MZG passengers, and DPM patrons, are expected to be dressed for outside weather conditions and not attired for inside the home or office, so such temperature levels appear to be acceptable. Door operations were essentially unaffected by winter temperature or weather conditions since bleed air from the ECU warmed the door operators and thresholds. The UNIMOBIL System door design and operation also precluded snow or ice accumulation problems.

The train controls, except for frost actions, were not affected by the winter environment at MZG. The on-board equipment, excluding the collector brushes, are in sheltered train locations not subject to ice or snow intrusions; extreme cold did not affect any of this equipment. Cold had no impact on the collection system although power and control rail frost did cause power and signal interruptions; such interruptions cause unscheduled System stopping which is a safe, but inconvenient, state.

While snow and ice had little affect on the various other subsystems or equipment, extreme cold did; items in this category include the guideway switch, transfer beam and maintenance support vehicle. The common characteristic of these items is their hydraulic units; all require reservoir heating, winter viscosity fluids and a recognition of slower operations during extreme cold weather.

10.1.2 Procedures

The UNIMOBIL System at MZG required very little in the way of special procedures to accommodate the extreme weather conditions encountered. In addition to the normal fair weather inspection and maintenance procedures, there were four basic special procedures required:

(1) turn on the ECU's so sufficient heat is available for passenger comfort and door operations;

(2) select automatic or manual operating mode since frost can often stop or degrade System performance in the mornings; sometimes, temperature and humidity conditions sustain frost accumulations until much later in the day;

(3) maintain the guideway clear of snow prior to and during revenue service; and

(4) expect hydraulic systems to slow down as the temperatures fall -- especially in the -20°F range.

The above four special procedures are ordered in their frequency of application. Because the trains were stored outside, heat for the passenger modules was required nearly every operating day between November 1 and April 30.

Frost, to some extent, accumulated on 77 days during this period; the applicable procedure was to wait until either ambient conditions or the heat absorbed by the guideway dissipated the frost. Manual operations were possible sooner on these days due to higher power subsystem currents and voltages, compared to automatic control levels, passing between the rails and brushes; there is a possibility that less frost accumulates on the stainless steel contact surfaces of the power rails than on the copper-surfaced control rails. Automatic operations were precluded until the copper contact surface of the control rail was free of frost.

Since only 420 feet of the total route of 1.25 miles was protected by the PRFCS, its benefits, while recognizable, were not available to MZG. Had the entire route been so protected, no special frost-related procedure would have been necessary -- and automatic operations would have been continuously possible.

The special procedure for clearing snow was somewhat subjective. A decision had to be made as to whether the use of the snow module would be necessary before either ambient conditions or guideway temperatures would clear the accumulations prior to the start of revenue service. It was also a matter of judgement whether such passive removal would occur at all. Similar judgements were made if the snowfalls occurred during the day -- especially near the end of revenue service.

The usual criteria for implementing snow removal procedures was ride quality and not performance constraints. If safety or reliability were to be at all affected, the extent of the existing or anticipated snowfall combined with the ambient conditions clearly indicated that snow removal was necessary. Once a decision was made to implement snow removal procedures, the snow module remained on the guideway and functioning until it was no longer needed. Because of this approach, snow removal, except for testing and some of the unusual 1978-79 Winter conditions, was accomplished by only brushing. Brushing snow has less impact on people or objects in the vicinity of the guideway than plowing; continuous brushing results in lesser quantities being removed in each time-distance interval thereby still further reducing the snow removal impact.

Recognition that extreme cold reduces the speed of hydraulic systems which function on a non-continuous or intermittent basis is nominally identified as a procedure. MZG has no need for rapid hydraulic system responses (e.g., the guideway switch is for access to the maintenance facility), because advance notices for use of hydraulically-powered equipment are measured at least in minutes -- and often in hours. Such advance notices would be to: add or remove a train for scheduled service; place snow removal equipment in service or in storage; and position MSV for guideway inspections prior to scheduled start of System revenue service.

10.2 CONCLUSIONS

There are three basic conclusions to be drawn from the results of UMI's participation in the 1978-79 and 1979-80 Winterization Tests and Demonstrations: (1) the baseline UNIMOBIL System at MZG can provide safe, reliable operations under all winter conditions except frost; (2) reliable, low-cost and easily-maintained methods are available to overcome the effects of the snow, ice and frost which will occur at harsh winter climate DPM System sites; and (3) proper design of DPM System vehicles, equipment and facilities will preclude the need for unneeded, redundant and costly System operating requirements as well as similar requirements for storing and maintaining the vehicles and equipment. An associated, but more subjective, conclusion is that it is unnecessary to apply undue measures to maintain interior DPM vehicle temperatures at more than 30°F above ambient temperatures.

10.2.1 The Baseline UNIMOBIL System

The baseline UNIMOBIL System overcame every winter condition encountered except frost. While the total operating time lost to weather conditions, only 3 hours of a scheduled 1,092 MGZ revenue service hours, is impressive, it is not conclusive; this high level of performance was attained in the manual mode. DPM System must operate automatically, for all practical purposes, at all times. Furthermore, DPM Systems must be operating at 7:00 a.m. or 8:00 a.m., or, possibly, even 5:00 or 6:00 a.m. in the morning -- well before MZG's usually sun-warmed 10:00 a.m. start of revenue service. Therefore, a power and/or control rail heating system, such as the PRFCS, must be available to prevent any frost-related constraints.

Snow and ice had no real impacts on the baseline System at MZG. That snow which accumulated was removed, and routine brushing prevented significant accumulations. This approach, of allowing minimal accumulations, reduced both the impact of snow removal on nearby people and facilities and essentially precluded the formation of ice on the guideways (and spray-originated ice on the vehicles or any fixed objects). The COR-TEN Slimline Guideway also absorbed solar energy to passively aid snow and ice removal. There was insufficient exposure to naturally-occuring sleet or freezing rain to measure System-wide adverse effects; primary test area demonstrations indicated practically no impacts.

While extreme cold lowered car interior temperatures and lowered the response speeds of hydraulic devices, neither situation was of real consequence. There were practically no negative comments from patrons, who were in the trains from 18 to 25, or more, minutes with the doors open in the station and closed while in motion. Additional measures are available to improve hydraulic system performances, but, to date, there has been no indicated need for such measures.

10.2.2 Overcoming the Effects of Snow, Ice and Frost

The least impactive, and apparently least costly, means for overcoming the effects of snow, ice or frost are to keep these effects continuously at a minimal level. Snow and ice were not problems during the Demonstration and Testing Program because they were removed before they became a problem -- in terms of either quantity to be removed or impacts on operations. Frost was a problem since, except in the area protected by the PRFCS, it could not be prevented from accumulating.

From the above comments, it follows that prevention of significant snow, ice or frost accumulations are necessary to minimize their impacts. Therefore, the guideway geometry should allow that it be easily cleaned and its alignment should be such that direct and on-the-spot removal should have minimal adverse affects on nearby people or facilities. Power and/or control rail frost should be prevented by a heating system such as the PRFCS.

It is possible that freezing rain, or in a downtown environment, runoffs from adjacent structures can cause ice to form on a DPM System guideway. This is rather probable because DPM Systems will be in shadowed locations and, possibly, contiguous to buildings. Since UMI's experience to date is somewhat limited for either the situation (downtown) or condition (guideway icing), it is only possible to offer a solution without precise cost considerations. The ATSS, described in Section 8.3, provides a means for train/vehicle braking and propulsion when the primary traction surface friction degrades below that which will provide safe and acceptable performance levels.

Since the UNIMOBIL System vehicle/guideway interface is readily adaptable to an ATSS configuration, this would be a reliable, apparently low-cost solution to the problem of slipperiness associated with ice or compacted snow on the primary traction surface. An ATSS can be considered as low cost because it would only be applied as needed and it would overcome any ice or similar accumulations by mechanical use of energy and not by expensive heating (and melting). Heating methods have proven to be expensive in operation because of the caloric requirements for melting (and keeping melted) ice as well as the conductive (to the guideway and appurtenances) and convective losses. Additional snow or ice heating/melting problems, with accompanying curative costs, include assuring positive drainage of melted materials and corrective measures associated with resulting spray on vehicles, facilities or people.

10.2.3 Effects of Extreme Cold

Extreme cold should have minimal, or no, adverse effects on DPM Systems selected for harsh winter climate cities. Except for limited degradation of infrequently-used hydraulic systems at temperatures near and below $0^{o}F$, the UNIMOBIL System at MZG was unaffected by cold. There are numerous procedures cited in Sections 2, 5, 8, 9 and, this Section, 10, to overcome, if necessary, such problems; hardware adaptations, if necessary, are also cited in these sections.

The train doors were the only other electrical or mechanical components of the UNIMOBIL System at MZG which were at all cold-sensitive. However, since DPM cars would require passenger module heating during normal cold weather service, the warm bleed air from the ECU would also be available to allow routine and complete door operations. The experience at MZG during the 1978-79 and 1979-80 Winters indicated this approach to be totally satisfactory for a DPM System in an extremely cold climate.

The UNIMOBIL System trains were stored outside from the close of revenue service at 4:00 p.m. until the 10:00 a.m. start of the next day's service. Other than starting the ECU's to warm the vehicle interiors and the interior air, there was no special cold-related procedure for putting trains in service. It can, therefore, be concluded that if the vehicles, guideways and supporting equipment and facilities are properly designed and constructed, the only inside facilities required would be for vehicle and equipment servicing and repairs -- not storage.

11. RECOMMENDATIONS FOR WINTER OPERATIONS

Based on the experience and results gained during the 1978-79 and 1979-80 Downtown People Movers (DPM) Winterization Test Demonstrations, UMI has three general types of recommendations:

(1) DPM System specifications should be established that integrally reflect the inherent nature of winter-related requirements rather than treating winter responses and characteristics as being supplementary or deviant in nature;

(2) effective and timely operating, or maintenance, responses should be made to any conditions (e.g., snow, ice or frost) which can increase their adverse effects as they grow in frequency or quantity; and

(3) additional specific investigations should be made of technical, economic, and institutional matters that are often interrelated.

11.1 DPM SYSTEM SPECIFICATIONS

The only consistently difficult operating condition that occured at MZG was the accumulation of frost. While the adverse effects of frost increased in frequency and duration as the winter deepened, frost accumulations can be reasonably expected for about 6 months of every year in northern climate cities. Furthermore snow and ice accumulations occur for an approximate 5-month period. This commentary is provided to emphasize that winter-related responses should be considered as a normal part of operations for DPM Systems located in northern U.S. cities.

Recognizing that the DPM System must routinely respond to conditions that produce frost, snow or ice accumulations, it is incumbent upon the boards, agencies, commissions, consultants and other involved parties in decision-making positions to properly weigh this aspect in every stage of the System development process. It is reasonable to expect that DPM Systems will sustain their greatest peak usage during the worst weather conditions. Therefore the selected System should be the one which is most reliable, safe and attractive during adverse weather conditions.

Since these Systems will receive both general taxpayer and farebox support, the annual, daily and trip costs must be as low as possible for any selected service level. The costs and availability of energy are now major factors in public transportation, they can only be expected to become more significant. Both the general public and the DPM System users will be concerned about the energy costs to sustain System operations since they, the public and users, will pay these costs.

The point of the preceding paragraphs in this Section 11.1 is that DPM System design characteristics can have a significant impact on the System's reliability, safety, costs and, hence, attractiveness to the public and users. Therefore, the DPM System design characteristics should minimize both the effects of, and costs of responding to, frost, snow and ice conditions.

Simple guideway structure geometry, such as that of the UMI Slimline Guideway, is a means by which snow and ice accumulations are both minimized and easily removed. Unless freezing rain, sleet or runoffs from nearby thawing surfaces are a consideration, iced primary traction surfaces will probably not be a major concern. If this becomes a major concern, especially when combined with gradients steeper than, say, three or four percent, primary traction augmentation, e.g. UMI's auxiliary traction subsystem (ATSS), may be necessary.

The effects of frost, frequently mentioned throughout this report, can be reduced by the proper orientation and location of power and control rails. These effects can be eliminated by using a rail heating system similar to UMI's power rail feedback control system (PRFCS).

11.2 OPERATING RESPONSES TO SNOW, ICE AND FROST

Snow and ice accumulations were not significant problems during the demonstrations at MZG. Naturally-occuring ice was practically non-existent because the usually cold guideway could be completely brushed dry and there was no melting and refreezing of residual moisture. When the sun heated the guideway while the snow accumulated, nearly all moisture that remained after the brushing evaporated. Either the brushed or evaporated dry guideway conditions were the result of timely responses to any snow which accumulated on the guideway. Because of this response, snow was seldom, if ever, compacted by the bogies on the primary traction surface. If such had occurred, with its potential for converting to ice, the snowplow capability would have been used.

The incidence of freezing rain and sleet was practically non-existent. Had this been a problem, an immediate brushing and, possibly, plowing response would have been initiated. If the primary traction surface performance had deteriorated because of the resulting icing condition, the ATSS would have been used.

Except in the area protected by the PRFCS, the UNIMOBIL System at MZG depended on ambient conditions or solar heat to dissipate frost accumulations. While the location and position of the power and control rails reduced the adverse effects of frost, it is obvious that an additional remedy is required. The PRFCS provides a function that is similar in effect to the rapid response for snow removal, i.e. frost prevention is activated and maintained when conditions are appropriate -- rather than waiting to remove small or large accumulations.

11.3 ADDITIONAL SPECIFIC INVESTIGATIONS

While performing the tests and demonstrations, and as a result of discussions with various UMTA representatives, there developed an awareness that additional guidelines or background, relative to winter operations, are needed for DPM Systems. While some of these additions are technical in nature, they are most often interrelated with economic and institutional considerations.

11.3.1 Effective Train Resistances

While it is reasonable to expect that the individual DPM System suppliers are knowledgeable of the effective resistances of the trains or vehicles that they provide, it may be necessary to develop this data in a uniform and convenient way for applications by others such as consultants. This data would be especially useful in developing gradient/horizontal curvature impacts on acceleration/deceleration performances; this becomes particularly important at low temperatures when nearly every subsystem is applying for maximum energy and train/vehicle rolling resistance is highest.

11.3.2 System Energy Consumption

DPM Systems will be situated in existing downtown areas which are serviced by existing utility networks. These Systems will concentrate their facilities and energy demands into relatively small geographic areas and time frames. A major electrical energy consumer, especially if rail and/or, more particularly, guideway heating is a consideration, could seriously impact an existing utility's power distribution network. Alternative potential System solutions should be evaluated on their total energy impacts and costs -- particularly at their peak demand times.

11.3.3 Energy Generation/Distribution

The various System guideways have primary traction/support surfaces that are long, essentially-flat plates that range in width from narrow to relatively wide. It is possible that these surfaces, properly prepared and oriented, could serve as solar collectors to satisfy, at least partially, their winter heating needs. They could also carry heating conduits for either their own needs or for distribution from central heat/steam generation stations.

11.3.4 Utility Conduits

Since many central city areas are as congested below ground as above, it might be possible to carry new or existing electric or telephone lines within the guideway structure. This may be particularly important where guideway foundations interfere with existing or proposed underground utility locations. An additional advantage of this arrangement is that current and valid documentation for such lines would then exist -- central city utility location records are often less than accurate.

11.3.5 Public Tolerance of System Characteristics

This is a catchall area that includes two general concerns -- guideway intrusiveness and snow/ice removal. There seems to be generally accepted views that pedestrians and adjacent property owners oppose the presence of guideway structures over the sidewalks in front of buildings and insist that snow or ice accumulations or residues must be totally collected and conducted to storm sewers. Building owners elect to have marquees, decorative entries, awnings, etc. which often collect snow and rain with accompanying top and side surface runoffs; people walk under these as well as pedestrian walkways, bridges, elaborate street lights, etc. Therefore, these two concerns, guideway's intrusiveness and runoffs, must be relative rather than absolute. It seems reasonable that relative values should be established as measures of these concerns so they can be rationally and economically approached.

11.3.6 Frost

The impacts of snow and ice are often major, but erratic, concerns because of their expected impacts on DPM Systems. UMI's experience at MZG indicates that frost accumulations are a more frequent and consistent disruptive influence on any System which utilizes power and/or control rails. More site-specific data is needed for the DPM System candidate cities in potentially frost-impacted locations to determine the extent of this problem -- and the most cost/service effective solution(s).

11.3.7 Primary Traction Surface

Since nearly every DPM System utilizes a horizontal surface for propulsion and/or braking, and central city environments may be conducive for icing on this surface, generic alternatives to this surface should be investigated. Such investigations should include, but not be limited to, operating costs, reliability and maintainability.

11.3.8 Vehicle Interior Temperatures

During the warmest and coldest seasons, concern for Transit vehicle interior temperatures are often expressed by patrons. Since the sizing of an environmental control unit, for vehicle heating/cooling, is a relatively flexible technical matter, temperature values, by interior location, would be a useful design standard for DPM System suppliers. UMI's experience at MZG suggests that temperatures related to exterior ambient values, rather than establishing absolute interior values or ranges, could be acceptable. Such a standard would also result in effective energy consumption during the peak heating and cooling periods.

APPENDIX A

PHOTOGRAPHIC AND VIDEO DOCUMENTATION, INCLUDING SAMPLE DATA FORMS

STILL PHOTOGRAPH RECORDS

FRAME NO.	DATE EXPOSED	SUBJECT	NOTES	FILE NO.
1	2/14/80	SNOW MEASUREMENT	TEMPERATURE	4381
2	"	"	DEPTH	"
3	"	"	HARDNESS	"
4	"	"	DENSITY	"
5	"	SNOW MEASUREMENT	DENSITY	"
6	2/14/80	GUIDEWAY SNOW ACCUM.	24" ACCUMULATION	4381
7	"	"	MEASURING SNOW PROF.	"
8	"	"	"	"
9	"	"	MEASURING LENGTH OF SNOW REMOVAL TEST	"
10	"	GUIDEWAY SNOW ACCUM.	"	"
11	2/14/80	SNOW MODULE OPERATION	START OF SNOWPLOWING	4381
12	"	"	SNOWPLOWING ACTION	"
13	"	"	"	"
14	"	"	"	"
15	"	"	"	"
16	2/14/80	SNOW MODULE OPERATION	SNOWPLOWING ACTION	4381
17	"	"	CLOSE-UP OF SNOWPLOW OPERATION	"
18	"	"	"	"
19	"	"	CLOSE-UP OF SNOWPLOW OPERATION	"
20	"	SNOW MODULE OPERATION	DEMONSTRATION OF SNOWPLOW DISCHARGE	"
21	2/14/80	GUIDEWAY SURF. CONDITION	PRIMARY TRACTION SURFACE AFTER SNOW REMOVAL	4381
22	"	"	"	"
23	"	"	PRIMARY TRACTION SURFACE AFTER SNOW REMOVAL	"
24	2/14/80	GUIDEWAY SURFACE COND.	DETAIL OF PLOWED PRIM. TRACTION SURFACE	4381
25				

FORM NO. 17

MOTION PICTURE PHOTOGRAPHIC RECORDS

REEL NO.	DATE EXPOSED	SUBJECT	NOTES	FILE NO.
1	11/17/78	SNOW MODULE	SELF-PROPELLED INTERIM UNIT--11" NATURAL SNOW	18
2	JAN, 1979	SNOW MODULE	SELF-PROPELLED INTERIM UNIT--2" NATURAL SNOW	"
3	JAN, 1979	GUIDEWAY HEATING	50,000 BTU. PROPANE TORCH MELTING G'WAY SURF. SNOW	"
4	DEC, 1978	AUXILIARY TRACTION SUBSYSTEM	TIME-LAPSE OF GUIDEWAY CONTACT SURFACE HEATING	"
5	JAN, 1979	GUIDEWAY ICE REMOVAL	MANUAL METHODS	13
6	FEB, 1979	SOLAR HEATING GUIDEWAY	TIME-LAPSE OF SOLAR ENERGY REMOVING SNOW ACCUM.	"
7	JAN, 1979	GUIDEWAY SWITCH OPERATION	-23°F TO -27°F	"
8	FEB, 1979	POWER RAIL INSTALLATION	ELEC. SUBCONTRACTOR WORKING IN HEAVY SNOWFALL	"
9	MAR, 1979	"	SOLAR ECLIPSE	13
10	JAN, 1979	TRAIN UNLOADING	CARS 5 & 6 OF TRAIN NO. 3 -57°F WIND CHILL FACTOR	"
11	FEB, 1979	TRAIN DOOR OPERATIONS	TIME-LAPSE AFTER COLD SOAK	"
12	MAR, 1979	SNOW MODULE	TRAIN-PROPELLED INTERIM UNIT ON HEAVY, WET SNOW	"
13	MAR, 1979	DRIP LIP	PROTECTION FROM FREEZING RAIN & SLUSHY SNOW ACCUM.	13
14	MAR, 1979	SNOWMAKING OPERATIONS	RIME ICE & SNOW ACCUMULATIONS ON G'WAY & SIDE-MTD. PWR. RAILS	"
15	MAR, 1979	EMERGENCY BRAKING PERFORM.	GLARE ICE COVERING PRIMARY TRACTION SURFACE	13
16				
17				
18				
19				
20				
21				
22				
23				
24				

FORM NO. 18

TELEVISION RECORDS
CARTRIDGE NO. 2

COUNTER NO.	DATE RECORDED	SUBJECT	NOTES	FILE NO.
0	4/6/79	SNOW MODULE	TRAIN-PROP. INT. UNIT -- ARTIFICIAL 12" SNOW & RIME ICE	19
53	11/17/78	"	SELF-PROPELLED INT. UNIT -- VAR. DEPTHS, HVY. WET SNOW*	19
71	JAN, 1979	"	SELF-PROPELLED INTERIM UNIT -- LIGHT, DRY SNOW*	19
101	11/17/78	SNOW MODULE	SELF-PROPELLED INTERIM UNIT -- HEAVY, WET SNOW	19
112	DEC, 1978	AUXILIARY TRACTION SUBSYST.	TIME-LAPSE OF VARIOUS HEATING RATES ON TRAC. SURF	19
246	11/17/78	SNOW MODULE	SELF-PROP. INTERIM UNIT -- HEAVY, WET SNOW*	19
289	DEC, 1978	AUX. TRACTION SUBSYSTEM	TIME-LAPSE OF VARIOUS HTG. RATES ON TRACTION SURFACE	19
316	JAN, 1979	TRAIN UNLOADING	OFF-LOADING CARS 5 & 6 OF TR. NO. 3 (WIND CHILL -57°F)	19
348	"	SNOW MODULE	SELF-PROPELED OPERATION OF INTERIM UNIT	19
367	"	"	SELF-PROP. INTERIM UNIT REM. LIGHT, DRY SNOW*	19
385	JAN, 1979	POWER RAIL INSTALLATION	UNION ELECTRICIANS WORKING WHILE SNOWING*	19
433	DEC, 1978	AUXILIARY TRACTION SUBSYSTEM	TIME LAPSE OF VAR. HEATING RATES APPL. TO TRAC. SURF.	19
480	"	GUIDEWAY SWITCH	OPERATION-INT. SNOW MOD. ACTIV. - WIND EROSION*	19
525	DEC, 1978	AUXILIARY TRACTION SUBSYSTEM	TIME-LAPSE OF VAR. HTG. RATES APPL. TO TRAC. SURF.	19
535	FEB, 1979	SNOW MODULE	GEO. ANAGNOSTOPOULOS (UMTA) OBS. SELF-PROP. INTERIM OP.*	19
566	JAN, 1979	GUIDEWAY HEATING	50,000 BTU PROPANE TORCH USED FOR SNOW REMOVAL*	19
595	"	GUIDEWAY SWITCH OPERATION	AMBIENT (SUB 0°F) TEMP AFTER O'NIGHT COLD SOAK	19
602	JAN, 1979	TRAIN DOOR OPERATIONS	TIME-LAPSE OF REPEATED OPENINGS/CLOSINGS	19
630	2/26/79	POWER RAIL INSTALLATION	TIME-LAPSE OF UN. ELEC. ACTIV. DURING SOL. ECLIPSE	19
679	3/27/79	SNOWMAKING	PORTABLE EQ'T. USED FOR SNOW, FRZG RAIN, ICE, ETC.	19
695	MAR, 1979	SNOW MODULE	SELF-PROPELLED INTERIM UNIT, REMOVING SNOW	19
723	4/5/79	SNOWMAKING	ARTIFICIAL BLIZZARD DURING 47 MPH WINDS	19
740	4/1/79	SNOW ACCUMULATION	TIME-LAPSE OF SNOW* ACCUM. ON GUIDEWAY	19
774	4/5/79	SNOWMAKING	ARTIFICIAL BLIZZARD DURING 47 MPH WINDS	19
808	MAR, 1979	SNOWMAKING	REPRESENTATIVE NIGHT OPERATION	19

*NATURAL PRECIPITATION

FORM NO. 19

CARTRIDGE NO. 1

Counter Location	Contents/Comments
0	Vehicle/snow module operation, using support vehicle as mockup snow module. It is quite effective and is the basis for design of proposed snow module.
17	Snow impacted against front of snow module brushes when it was pushed into snow mass without brushes operating. After the snow was removed the guideway remained snow-free from available solar energy (late March). Rain gauge not effective for measuring snow depths, the heater vaporizes some fallen snow. The snow module was not required; the surface remained clear from solar energy. In the background is more conventional means of snow removal.
80	During this test, vehicle was operated every hour to demonstrate it was operable during this heavy snowfall.
98	Although snowfall continues, the guideway surface is clear and wet.
127	Continued operation demonstration during snowfall, the snow module brushes are capable of removing approximately two inches of very wet slushy snow without use of the plow.

Counter Location	Contents/Comments
157	Time lapse of snow accumulation; it eventually reached 29 inches. We had to shovel snow to maintain a clear trajectory for snow gun. The snow guns malfunctioned two times and dumped water on the snow for several minutes before we could clear problem and again make snow. Most of our accumulation occurred late in the morning when the wind stilled; used technique of directing two snow guns together to form a vortex and drop more dense snow on guideway. Note the swirling action of the wind created significant accumulations on the side-mounted power rails; they were inoperable. Snow density measurements were recorded to determine effectiveness of equipment for various weights and densities of snow; this snow was heavier than naturally occuring snow because of the water. Note the protected configuration of the power rail and auxiliary traction system as opposed to unprotected side-mounted power rail.
220	Support car was removed and connected to train for use as mockup snow module.
223	Shown to give you a feeling of the density of snow accumulation; it was not the typical light fluffy dry snow which accumulates in Minnesota. Snow removal is quick -- 29-inch deep snow accumulation removed in a single pass.

Counter Location	Contents/Comments
250	After initial contact with snow mass, train was accelerated to 11 feet per second. We would not expect that much accumulation on the guideway under normal conditions. Construction worker on board to watch pressure gauge.
280	The guideway is 100 percent operational; side-mounted power rails remained inoperable for the remainder of the day.
289	The side-mounted rails were equipped with heaters identical to the inverted rails. Ice and snow would have prevented brush contact with the side-mounted power rail surfaces.
295	Very good illustration of the inverted power rail being completely ice-free on November 17, 1978. This was the result of 8 to 11 inches of natural snow on some segments of the guideway; it was the deepest and heaviest naturally-occurring snowfall of the winter. We were successful in removing this snow accumulation in a single pass. Brushes were defective as a result of being improperly stored all Summer. Two views - one is a heavy, wet snow and the other is a more dry snow typical of Minnesota winters; heavy snow occurred during the months of November and March.

Counter Location	Contents/Comments
335	Wind erosion removes snow from local guideway areas that are protected by hills and trees; accumulation is typically less than half of that on the ground in adjacent areas.
355	Guideway surface heating was employed to remove light accumulations of precipitation to illustrate effectiveness of the Cold Guideway Concept.
372	Time-lapse photography shows effectiveness of sample segment of the Auxiliary Traction Subsystem heater on cold days. It is extremely difficult to separate ice from the guideway surface without solar energy (3/8 inch snow accumulation rapidly melts and evaporates before 10 A.M.) What appears to be steam is actually reflections of clouds moving in stiff wind.
420	Guideway switch operation at -22°F; the temperature recorded at our weather station was -25°F at guideway height and was -27°F at the National Weather Service. Switch operations were slightly slow but acceptable -- 38 seconds instead of 30. No special provisions were required to accomplish switch operations in these temperatures. Successful switch operations have since been demonstrated on a daily

Counter Location	Contents/Comments
	basis; however, this was the lowest temperature encountered in the 78-79 Test Program. Switch operation has also been demonstrated with up to 1/2 inch accumulated ice cover.
450	Second shot in sequence of power rail assembly. Notice the typical snowfall; the snowfall for this winter was 1.95 times the 100 year average. The connection at a guideway bus bar splice; these occur every 30 feet.
464	Time-lapse photography of power rail assembly and solar eclipse; power rail assembly occurred during the solar eclipse. There was not a total eclipse in this area but was still very evident. Off-loading the center vehicles of Train No. 3 occurred during very cold conditions. During testing, the doors only partially opened in the cold weather because the electrical cushions had not been properly adjusted and motor current was removed at the halfway (open) point.
490	Effectiveness of the Drip Lip in preventing moisture accumulations on the power rail. George Anagnostopoulos viewing demonstration of snow removal of extremely wet snow; it was only necessary to plow once and the remainder of the day solar energy melted remaining snowfall. This position of the switch was not plowed and as the sun rose icicles were formed on the shaded side of the guideway.

Counter Location	Contents/Comments
521	Snowplow operation removing snow in two passes. The plow can be used with brushes removing remaining snow; the plow can be lifted and at slower speeds the brushes remove all of the snow from the surface. Instead of dropping large clumps (with the plow), the brushes disperse the snow and throw it further. Nighttime snow-making; it is very difficult to get snow to remain on the guideway surface. By impinging the snow guns against the sides of the guideway we can get significant accumulations on these surfaces. The snow module is being propelled by the train. The side-mounted power rails are completely inoperable; the auxiliary traction surface is completely free of ice and snow because of: (1) it's sheltered position; and (2) it is heated at this time.
560	Emergency brake stopping tests on glare ice surface; hoses were used to ice up the primary traction surface. Repeated stops glazed the ice surface to produce a coefficient of friction of .097 for cold glazed ice. Snow had been plowed from the surface and sun was starting to warm the guideway structure; we were able to plow the ice from the guideway early on the morning of April 5, 1979.
583	The train is operational during this severe weather. Power rail heating was required to keep it ice-free under these artificially-

CARTRIDGE NO. 1 (Cont.)

Counter Location	Contents/Comments
	induced conditions. Power rail heating has not been required for any naturally-occurring winter conditions other than frost. Extreme icing conditions; vehicle operation was stopped to accumulate a worst case condition. Snow equipment was moved along guideway to accomplish maximum accumulation over extended length of the guideway.

CARTRIDGE NO. 2

Counter Location	Contents/Comments
0	Snow plow operation April 6, 1979.
10	Side-mounted power rails; rime ice obscured power rail for two days. Snow module cleared icicles.
24	Auxiliary traction surface clear to the point where heater stops.
40	Power collector operation on heated power rail.
47	Same shot with a different camera.
50	Electricians operating support car with snowplow attachment; heavy wet snowfall in November, 1978.

CARTRIDGE NO. 2 (Cont.)

Counter Location	Contents/Comments
66	Contract personnel used our winterization equipment to help construction activities.
70	Different snowfall -- very dry light snow.
95	Snow plow in elevated position -- only the brushes are being used.
100	Taken from on top of support car as snow module was being operated.
110	Continuation of electrical contractors operating support car snow module around guideway.
113	Time-lapse photography showing snow accumulation on heated plates.
150	Time-lapse photography was useful for evaluating materials of different thermal capacities.
170	Time-lapse photography.
183	New reel of time-lapse photography.

CARTRIDGE NO. 2 (Cont.)

Counter Location	Contents/Comments
233	Time-lapse photography.
240	Conclusion -- this film is very poor and should be excluded.
260	New film -- additional footage of contractors using support vehicle; each morning they cleared guideway.
263	Dense wet snowfall.
270	Work platforms used by electricians to install power rail.
280	Snow module example of operating a vehicle without clearing snow.
290	Alternate snow removal method; not much energy is required to displace snow 20 inches laterally.
300	Time-lapse photography of a more severe snowfall.
317	Off-loading aft portion of Train No. 3 in extreme cold; the chill factor was -57°F. The activities of all operations were severely reduced by cold temperatures.

CARTRIDGE NO. 2 (Cont.)

Counter Location	Contents/Comments
347	Snow plow operation in future station; it is adjacent to hill and subject to drifting snow. Through the oak trees, the snow accumulation is the greatest because of restricted wind erosion action.
364	Good impression of snow removal rate.
374	Close-up view of snow brush in operation on support car; another method of removing snow from guideway.
380	Final segments of power rail installation, almost the entire power rail installation was accomplished during extremely severe weather.
410	It (power rail installation) was all accomplished from support equipment suspended from the guideway (no scaffolding).
418	Electricians are installing the intermittently located ground straps.
430	Grounding bus bar to the guideway structure.
434	Time-lapse.

Counter Location	Contents/Comments
440	Time-lapse photography was used to verify proper heating rate (watts per foot) had been selected for the auxiliary traction subsystem.
470	Auxiliary traction subsystem heater was intended for rapid response; it would accumulate snow only under extreme wind-driven conditions.
481	Support vehicle being used to clear guideway; this was the most severe winter in recorded history -- in terms of both cold and snowfall.
490	Demonstration of guideway switch.
500	How the guideway switch works.
510	This is another support vehicle that was used for guideway construction. At this time the elements of the guideway switch were not covered and snow and ice would accumulate on switch drive mechanisms to impede both switch operation and engaging of the locking pins.
518	Trigger on camera froze on while being carried. Typical wind erosion of snow accumulation.

Counter Location	Contents/Comments
539	Support vehicle being used to remove guideway snow accumulation; George Anagnostopoulos of TSC was present at this demonstration. Bus bar being carried on right side of support vehicle; this is a typical means of transporting materials from one site to another (overland travel was too difficult).
560	Very little snow accumulation on wind-swept areas.
570	Guideway surface heating (using a large propane weed burner rated at 50,000 Btu's) was employed in localized areas to demonstrate or simulate the response of a heated guideway to snow accumulations.
580	Leaving guideway cold and brushing the snow off. Using a torch, water will immediately refreeze and icicles will form due to low thermal capacity of guideway surface plate.
604	Time-lapse photography of vehicle door operations on timer, as temperature dropped, door would open and permit snow to get in car. It was also noted that during the coldest part of the night, the doors did not open to their fullest extent; this was corrected.
624	Time-lapse photography of door operations.

Counter Location	Contents/Comments
631	Time-lapse photography of solar eclipse; the weather station recorded significant reductions (eclipse-related) in solar energy.
654	Time-lapse photography of different power settings on auxiliary traction system heaters.
680	Artificial snow accumulation testing on March 27, 1979 -- Super-8 film is also available of this test.
690	Attempting to show comparison of inverted power rail and side-mounted power rail.
700	Cold temperatures -- the camera would stick in the "on" position when released (close-up of Keith Tarver).
710	Snow covered guideway surface taken from the support vehicle, after the support vehicle had passed over the surface. Typical wind erosion.
720	Snow accumulations resulting from wind vorteces created by power rail support hangers. Support vehicle cleared icicles; it is rare for icicles to accumulate on cold guideway.

CARTRIDGE NO. 2 (Cont.)

Counter Location	Contents/Comments
723	View of rime ice on April 6, 1979. Very high winds, with gusts to 47 mph; snowmaking equipment made dense white rime ice.
730	Time-lapse photography of snow accumulation on side of guideway.
740	April 1, 1979.
750	Time-lapse photography of snow falling on sun heated guideway.
780	Early part of April 6, 1979 blizzard; the temperature dropped sharply. Snowmaking equipment installed beside guideway during average 25-30 mph winds (gusts to 47 mph). At this point it is too warm to make snow; however, the temperature dropped rapidly. One of our most impressive system demonstrations; the guideway is being sheeted with water -- forming rime ice during high winds.
808	Prevailing northwesterly winds; it was difficult to accumulate snow on the guideway. We had to move snow guns too close and accumulated rime ice.

CARTRIDGE NO. 2 (Cont.)

Counter Location	Contents/Comments
841	Later on April 6, there was a severe wind storm and snow. The wind was a significant factor in ice and snow accumulations, temperature dropped and water we sprayed was turning to ice and accumulating on guideway. On the following morning (April 7) there was severe icing along the guideway; side-mounted power rails were obliterated. Two days before ice melted off, heated section of auxiliary traction system remained ice free -- even with icicles. The protected position of the auxiliary traction subsystem, and the inverted power rails provided 100 percent operability in spite of very severe icing from an artificially-induced snow storm. Very severe icing conditions with ice was nearly 5 inches thick; recorded by MZG using their video equipment. They recorded our snow equipment removing snow; the support vehicle was propelled by the baseline train.

CARTRIDGE NO. 3

0	April 6, 1979 - additional film of April 6, 1979 storm. Early in testing, when the train was still operated on a one hour basis before we made the decision to cease operation and go for recovery from maximum accumulation, portable snowmaking equipment was used to take advantage of wind direction to apply ice and snow in test area. Temperatures were $33^{o}F$ and by the next morning they had dropped

Counter Location	Contents/Comments
	to the single digits. System recovery after an all night snow storm; the film washed out in the bright morning light. Several rolls of film were exposed on this day. Sequence of icing which occurred early in the test.
135	Power rail heating was required to keep bus bar ice-free; bus heater was energized because ice was accumulating on brush face of power rail under these severe conditions. Nighttime snowmaking during a different test sequence. Side-mounted power rails are one of the first things to ice up. This is film very light.
210	Support vehicle removing heavy snow and ice from guideway surface; this film washed out.
221	Vehicle power collector operation showing guidewheels on heated guidance/auxiliary traction surface.
252	Static drawbar-pull testing was used to determine capability of baseline train on dry and ice covered surfaces.
261	FILM WASHED OUT

Counter Location	Contents/Comments
285	Vehicle operation in the area of the switch, electro-magnets located under the guidewheels can be used to communicate with the guideway switch.
321	Routine vehicle operation, the next morning after March 27 testing; the system completely operational while the side-mounted power rails are iced up. Removing ice that has been loosened by solar energy from the surface; the guideway surface is warm. This film is washed out.
349	Heavy surface ice is produced artificially. Because temperatures are generally high during freezing rain, large accumulations of ice did not occur naturally on the guideway surface. Early in the April 6, 1979 test sequence, we wanted to be sure that we had adequate film coverage. Drip Lip and non-Drip Lip guideway sections; the Drip Lip protects the bus bar from ice and snow accumulations.
375	Support car plowing wet, naturally-occuring snow accumulations. The 1978-79 Winter had the greatest snowfall in Minnesota recorded history; November, 1978 had more than twice the 100-year average. Snowplow effectively removes nearly all of the snow accumulation with the brushes clearing the remainder. The brushes were not

Counter Location	Contents/Comments
	100 percent effective because of damage which occurred in summer storage. As an option to using the snowplow blade, it is possible to raise the blade and use only the brushes. The 1979-80 module will have improved brushing capability. When snow is removed in this manner (brushing), it is dispersed in smaller more natural particles.
429	Time-lapse photography, from night to day, shows typical wind erosion of snow accumulation on guideway surface. More snow accumulates on the vehicle window than on the guideway surface. The effects of solar radiation on the guideway can be seen.
474	Nighttime snowmaking activities; although, we have six 1500 watt lights, there is not adequate illumination.
509	Demonstration of naturally-occurring freezing rain on guideway surface (Keith sliding on surface) shows function of Drip Lip in protecting auxiliary traction surface from naturally-occurring snowfalls. The Drip Lip protection does not successfully extend down to side-mounted power rails. The Drip Lip has been successful in protecting inverted power rails from all naturally occurring ice accumulations -- with the exception of frost. The inverted power rail configuration has been 100 percent operational during the 1978-79 Winter.

CARTRIDGE NO. 3 (Cont.)

Counter Location	Contents/Comments
553	Time-lapse photography of door operations on a cold night. Test of guideway switch operation for ambient conditions in the -25°F to -27°F range; the switch was successfully demonstrated in these temperatures. This shows manual removal of ice from COR-TEN surface; it has been loosened by solar action.
608	Ice, which has started to melt and separate is easy to remove. It is nearly impossible to remove ice which has not separated from the COR-TEN surface.
636	Guideway snow removal in the future station area. Another shot of switch testing on a day when temperatures reached -25°F. Apparently these are the scrap footage of films which have been spliced back together after a master film was made for an earlier presentation.
659	This film has been put on these video tapes twice.
688	Guideway power rail installation (duplicate).
701	Manually-applied guideway heating to demonstrate effectiveness of the Cold Guideway Concept (duplicate).

Counter Location	Contents/Comments
719	Plowed snow from the guideway early in the morning of March 27, 1979. The snow module was not required for the remainder of the day even though it continued to snow; this indicated the effectiveness of the Drip Lip protection and the inverted power rail configuration.
741	The Drip Lip protects all but the lower half of guideway from wind blown snow accumulations; side-mounted power rail and Phase 1B Morgantown configurations were available for relative comparisons.
755	Time-lapse photography of guideway during snowfall -- this is unclear - not useful. George Anagnostopoulos viewing early morning snow removal operations during continuing snowfall in March of 1979.
827	Snow gun startup for nightime snowmaking operations; such activities were conducted in preparation for guideway snow removal testing. A peak of 29 inches of snow was artificially-placed in this test area. Dense snow with a heavy rime ice base was accumulated due to improper snow gun operation. Swirling snow and ice had obliterated the side-mounted power rails; the same amount of heat was applied to the inverted power rails which remained operable throughout the test. Guideway snow removal in the Winterization Test area. The remainder is blank.

CARTRIDGE NO. 4

Counter Location	Contents/Comments
0	The main passenger station platform is shown with Train No. 3 leaving the station.
50	The guideway surface is only wet after a single pass of the snow module removed surface accumulations.
102	This is a typical primary traction surface accumulation after a heavy, wet snow. It should be noted that the power and control rails as well as the auxiliary traction surfaces are clear.
235	A static view of the primary winterization test area is shown.
236	The snow module is being used in a plow-down configuration. Propulsion is provided by a train that is being operated by Minnesota Zoological Garden Monorail Maintenance personnel.
272	The "Drip Lip" protects the power and control rails from snow module discharges during snow removal in the guideway switch area.
288	It can be seen that the auxiliary traction subsystem drive unit under the train has adequate clearance through the guideway switch area.

Counter Location	Contents/Comments
303	The "Drip Lip" provides both clearance and shelter when the snow module is used.
321	The primary traction surface is cleared with a single pass of the snow module.
385	These are views of continued snow module operation.
430	Snow module operations are viewed through the windshield of the lead car of the train that is pushing the module. The camera is located in the guide/narrator's compartment and aimed out the front windows.
459	Approximately one inch of wet snow is melting on the guideway.
473	Wind erosion of the snow on the guideway is very evident.
495	The train rocking motion results from the deterioration of the train's foam-filled tires; the performance of these tires was being compared with that of conventional pneumatic tires.

Counter Location	Contents/Comments
513	Solar energy collection and transfer through the guideway structure is evident from the pattern of the melting snow.
541	Wind erosion of the snow on the guideway is influenced by the surrounding terrain.
570	The train's rocking motion is most noticeable when the flat spots on the support wheels' foam-filled tires reach a critical relationship with each other. It should be noted that one train was completely equipped with foam-filled tires; all of these tires were replaced with conventional pneumatic tires by March, 1980.
612	Even with the low morning sun angle, the convective and conductive heat transfer of solar energy within the guideway is evident. This causes the guideway structural temperatures to rise significantly above ambient temperatures.
663	It can be observed that wind erosion continues even with wet, melting snow.
723	(This is an interruption in the recorded material.)

Counter Location	Contents/Comments
739	Snow is being removed from the guideway using the snow module function of the interim maintenance support vehicle.
756	Pedestrian tracks are visible in the snow cover on the guideway. Maintenance personnel can walk in reasonable safety on the guideway during most conditions. Specific exceptions to this type activity include when the guideway is slick from glare ice cover or when high winds and/or lightning are present.
797	The snow module is being pushed into the main passenger station on the first, and only, snow removal run of the day.
830	A trip around the guideway is made to demonstrate the clear primary traction surface after a single pass of the snow module.
854	Train No. 3 and the snow module are being removed from the guideway.

CARTRIDGE NO. 5

Counter Location	Contents/Comments
0	The transfer beam is being used to move the snow module from Roller Bed No. 3 to alignment with Roller Bed No. 2. Upon alignment with Roller Bed No. 2, the snow module is attached to Train No. 3; this train will propel the module for guideway clearing.
270	Guideway clearing operations start as the train equipped with the snow module is driven from the maintenance building.
302	The train with the attached snow module easily fits on the transfer beam.
315	The transfer beam moves the train and attached snow module from alignment with Roller Bed No. 2 to alignment with Roller Bed No. 1; alignment with Roller Bed No. 1 allows access to the guideway spur. There are approximately two inches of accumulated snow on the transfer beam tracks at grade; this does not hinder the transfer beam motion.
354	A train equipped with the snow module leaves the transfer beam and moves over the guideway spur towards the guideway switch and main guideway.

Counter Location	Contents/Comments
507	The cover plate is visible at the guideway switch; this cover plate protects the operating mechanism and the switch guidance rails from snow and ice accumulations.
527	Although moderate-to-heavy snowfall continues, there are no accumulations on either the power rail contact surfaces or the auxiliary traction subsystem operating surfaces.
542	The snow module, using only the brushes, performs its function on the maintenance spur and guideway switch.
570	The train's operation was intended to compact snow in the primary (winterization) test area.
589	The "Drip Lip" and the auxiliary traction subsystem geometry provide effective shelter for the rails and guidance/auxiliary traction contact surfaces.
651	The guideway switch cover plate is covered with 8 to 10 inches of snow accumulation. The clearances between this cover plate and the mechanisms and wheels of the guidance/auxiliary traction subsystem should be noted.

CARTRIDGE NO. 5 (Cont.)

Counter Location	Contents/Comments
673	Snow is compacted on the guideway primary traction surface while routine train operations continue.
683	This sequence shows the relationships between the snow module and both the "Drip Lip" and the guidance/auxiliary traction surface.
702	Snow is compacted on the guideway primary traction surface while operations continue.
776	As the snow cover on the primary traction surface is compacted into ice, train speeds may be increased without displacing this snow cover. This snow compacting and surface glazing operation was performed in preparation for the auxiliary traction subsystem dynamic drawbar pull tests.

CARTRIDGE NO. 6

Counter Location	Contents/Comments
0	The guideway surfaces are viewed from the lead car.
175	While snow is falling, operation of the snow module connected to the train ahead is observed from the following train. It should be noted that the primary traction surface cover is only water.

Counter Location	Contents/Comments
266	The snow module clears 1/2 inch of slushy snow, standing on ice, from the guideway surface. After the module has passed, the guideway is approximately 20% ice-covered; this remaining ice cover will quickly melt from absorbed solar energy.
313	The snow module is operated at a track speed of approximately 10 feet per second; the brushes only configuration is used for these conditions.
360	The train is stopped at the future Mid-Trek Station.
396	Train travel is resumed and snow module operations are continued.
488	(This is an interruption in the recorded materials.)
550	The snow module removes 1/2 inch of slushy snow while the module is being propelled at 11 feet per second.
582	The guideway surface is viewed from the lead car window of Train No. 2 as it follows Train No. 3 (with snow module attached) into the main passenger station.

Counter Location	Contents/Comments
597	The train has the snow module operating as it enters the main passenger station.
611	(This is an interruption in the recorded materials.)
693	As observed from Train No. 2, Train No. 3 is leaving the main passenger station; the guideway surface, while wet, is clear of snow and nearly all of the ice. Train No. 3 continues to be viewed from the following Train No. 2; the snow module discharge is much lighter on the second trip as little additional snow has accumulated and the remaining surface ice has begun to melt from the guideway.
821	The guideway surface is wet but clear of ice and snow. The left side of the guideway has an oil stain caused by a hydraulic leak from a construction cart. The wet guideway surface will rapidly dry from absorbed solar energy (approximate drying time is 30 minutes).
864	Train No. 3 is leaving the main passenger station with passengers. The snow module operation has been discontinued; however, the inactive module will remain connected to Train No. 3 should it be required for later use.

CARTRIDGE NO. 7

Counter Location	Contents/Comments
0	Train No. 3, with the snow module attached, is backing into the main passenger station. An overnight snowfall has accumulated and snowfall continues at a moderate rate.
110	Train No. 3 is leaving the main passenger station with the snow module in operation.
160	Train No. 3, with the snow module attached, is crossing the guideway switch. It should be noted that the snow module blade is in the "up" position.
185	Approximately 1/2 inch of light snow remains on the guideway primary traction surface. Compacted snow and ice, from previous test activities, remains on the top surface of the guideway in the primary winterization test area.
236	The auxiliary traction subsystem drive units on the last two bogies of Train No. 3 can be seen.
273	Approximately six inches (total accumulation) of snow is on the guideway switch cover plate.

Counter Location	Contents/Comments
275	The inverted power rails and the guidance/auxiliary traction surface are completely free of snow and ice after a recent snowfall.
309	Conventional snow removal procedures are used on the road surface beneath the guideway.
326	As viewed from the boarding platform, Train No. 3 is backing into the main passenger station.
359	One of the auxiliary traction subsystem drive units can be seen above the last bogie of Train No. 3; the rear window of the train had been previously removed.
365	Train No. 3 is leaving the main passenger station.
437	Even with the auxiliary traction subsystem units in place, the capability for emergency exit from the train is maintained.
517	The snow module is in operation during passenger service.

Counter Location	Contents/Comments
569	Conventional snow removal operations remove approximately four inches of dense snow accumulated on the ground and roadways while the snow module is used to remove lesser amounts from the guideway.
624	Wind erosion produced guideway primary traction surface snow accumulations of approximately 1/2 to 1/4 of that found on the adjacent ground surfaces. No auxiliary traction surface accumulations resulted from this snowfall.
659	Train No. 3 is making the first passenger trip of the day; it approaches the main passenger station with the snow module operating.
697	This is a characteristic discharge of the snow module, using only its brushes, on approximately 1/2 inch of dense snow.
712	Train passengers appear unaware of the snow module operation.

Counter Location	Contents/Comments
717	The snow module is operating over a pedestrian plaza; the characteristic discharge of the snow module can be observed.
729	A revenue service trip is being completed at the main passenger station.
768	The second revenue service trip of the day consists mostly of children under the age of 10.
791	A revenue service train exits the main passenger station. Snow removal from the platforms is not the responsibility of Minnesota Zoological Garden (MZG) Monorail Maintenance; it is the responsibility of another MZG department.
813	Train No. 3 is approaching the main passenger station at end of its second revenue service trip; snow is still falling and the snow module continues in operation.
841	The slow train speed is required for passenger viewing.

CARTRIDGE NO. 7 (Cont.)

Counter Location	Contents/Comments
856	The snowfall rate is approximately 1/2 inch per hour; the snow is melting to standing slush as it falls. Snow compacted from earlier (pre-snow module) train operations is easily removed because of the absorbed solar energy.
877	Passengers are deboarding at the main passenger station.
885	A passenger falls on a snow-covered station platform which has not yet been cleared.

CARTRIDGE NO. 8

0	Door functions are tested after extended (overnight) cold soak and snow accumulation. While the doors are coated with freezing rain and wind-driven wet snow, their operation is normal. It should be noted that no heater or battery chargers were operated prior to the initial door test.
75	Interior heat provided for passenger comfort is starting to clear frozen snow from the train windows.

Counter Location	Contents/Comments
113	Although a moderate rate of snowfall continues, wind erosion keeps the guideway nearly clear of accumulations.
173	Snow module operations begin.
221	The effects of wind erosion on guideway snow accumulations are evident.
270	Wind vortexes, resulting from power rail hangers under the guideway's top surface overhang, produce small mounds of snow where the "Drip Lips" are not installed.
334	Wind erosion of snow accumulations on the guideway's top surface is influenced by adjacent terrain.
412	Heavy snow can accumulate adjacent to at-grade sections of the guideway because of terrain-induced drifting.
444	This is a close-up view of the snow module brush actions.

CARTRIDGE NO. 8 (Cont.)

Counter Location	Contents/Comments
453	The transfer beam is operated during a snowfall; its operation is unaffected by snow accumulations of less than 10 inches.
505	The transfer beam is operated over its maximum limits between Roller Bed No. 1 and Roller Bed No. 5; the reverse movement to alignment with Roller Bed No. 1 follows. The demonstrated translation rates are typical.
559	The transfer beam translation between Roller Bed No. 1 and Roller Bed No. 5 is repeated.
566	The guideway switch operation is demonstrated after cold soaking and snow accumulation; approximately five inches of snow has accumulated on the cover plate. Guideway switch operations are not affected by snow accumulations. The guideway switch actuation and translation times are typical.
674	In addition to the cover plate which provides the guideway switch with large area shelter against the elements, smaller covers extend over the ends of the translation rails and provide similar shelter.

CARTRIDGE NO. 8 (Cont.)

Counter Location	Contents/Comments
682	This view shows the relationship between the "Drip Lip" on and near the guideway switch and the remainder of the guideway switch structure.
697	Snow can be cleared from the guideway switch cover plate by lowering the work benches on the maintenance support vehicle as it traverses this area. This same technique is applicable for removing accumulations which can develop along at-grade guideway sections.
771	(No further materials are recorded on this cartridge.)

CARTRIDGE NO. 9

0	This is a view of the main passenger station from the front of an entering train.
25	Revenue passengers are boarding the train for a narrated tour of about 20 minutes duration.

Counter Location	Contents/Comments
66	This is the first revenue operation on a New Year's holiday. The camera is set up adjacent to the guide/narrator's position in the lead car of the train; the view through the windshield shows a clear guideway.
300	Extremely heavy fog is visible as the train approaches the site of the future Mid-Trek Station.
496	The first tour is complete and its passengers deboard the train before the passengers for the second tour board the train.
524	The second tour of the day is made with the camera mounted in the front of the lead car and directed into the passenger compartment. The outside temperature during this second tour is about 20°F and the passengers are dressed accordingly; it should be noted that the guide/narrator's clothing is representative of a person prepared to work in the comfort of, perhaps, an office.
611	Heavy frost or frozen fog accumulations are visible on tree limbs adjacent to the guideway.

Counter Location	Contents/Comments
751	This scene is representative of winter season station activities at the conclusion of the second revenue service tour and the preparation for the third tour of the day.
885	This cartridge terminates as the third tour approaches the area of the proposed Mid-Trek Station.

CARTRIDGE NO. 10

Counter Location	Contents/Comments
0	In preparation for drawbar pull tests, Train No. 3 is stopped in the primary winterization test area with Car 6 (the trailing car) on the guideway switch.
115	(Discussions on the static and dynamic drawbar pull testing are presented.)
125	The second train (No. 2) is approaching the primary test area; it will provide the resistance for Train No. 3 during the drawbar pull tests.
183	After Train No. 2 is positioned behind Train No. 3, the trains are connected for the drawbar pull tests.

Counter Location	Contents/Comments
416	The train doors are closed and the testing is initiated; this dynamic drawbar pull test is being performed on compacted rime ice and snow.
445	Forward motion of the connected trains stops.
540	This dynamic drawbar pull test was performed on one inch of compacted ice and snow.
551	The auxiliary traction subsystem relief valve is being adjusted.
590	The lead train (No. 3) is moved backwards to provide the slack required to disconnect the load cell used in the drawbar pull tests.
605	Train No. 3 door operations (opening and closing) are demonstrated.
660	The snow module is operated in the "brush-only" configuration to remove snow from the guideway; under the snow cover, thick accumulations of previously-compacted ice are evident.

Counter Location	Contents/Comments
692	The power module for the trailing vehicle of Train No. 3's auxiliary traction subsystem is visible through the opening for the (removed) rear window.
700	Extensive data is recorded to describe guideway surface conditions.
716	The ride comfort is noticeably affected when the baseline train is operated on a guideway covered with one inch of compacted snow and ice.
749	Guideway snow accumulations are beginning to be eroded by the wind.
762	Train No. 1 is backing over compacted snow and rime ice.
789	While Train No. 1 is being backed into maintenance area, it appears that surface conditions have been a probable cause for an automobile accident in the parking area.
804	Train No. 3 is moved backward, and then forward, in the primary winterization test area.

CARTRIDGE NO. 10 (Cont.)

Counter Location	Contents/Comments
831	The guideway switch is repositioned from the "spur" to the "through" alignment.
843	Train No. 3 is backed into the main passenger station for revenue service.

CARTRIDGE NO. 11

0	This is a view of the 1978-79 configuration of the power rail feedback control system. It is then tested for temperature (32°F) response and the dead band for signal stability (eliminating electrical noise) is adjusted.
75	The on-site weather instrumentation is being calibrated.
88	A clock connected to the power supply recorded the actual minutes of accumulative power rail heater operation.
99	These probes are used to measure the power rail temperatures.

Counter Location	Contents/Comments
107	The "Drip Lip" is an addition to the guideway structure which provides passive protection to the inverted power and control rails as well as the guidance/auxiliary traction surfaces.
115	Conventional side-mounted power rails, with heating identical to UMI's inverted power rails, are used as a reference for the effectiveness of UMI's approach.
131	Portable snowmaking equipment was used to produce a wide range of snow and ice conditions. The "Drip Lip" shelters critical guideway components during natural and artificial snow storms.
161	Guideway surfaces are examined before and after the snow module removed the accumulations from the guideway.
168	The interim snow module can be operated in a self-propelled configuration.
181	After this snow removal operation, ice remained on the guideway.
187	The interim snow module can also receive its propulsion from a train.

CARTRIDGE NO. 11 (Cont.)

Counter Location	Contents/Comments
199	The snow module usually removes snow by brushing, its plow is normally limited in use, when possible, for ice removal.
224	The interim snow module is operating in the self-propelled configuration; the brushes alone are quite effective.
267	During the 1978-79 Winter, a temporary barricade was used to permit winterization testing during guideway construction activities.
286	The interim maintenance support vehicle served as a mock-up for the deliverable snow module. This interim arrangement was quite effective and provided assurances for the satisfactory performance of the deliverable snow module.
317	Snow impacted against the snow module brushes' leading surfaces when it was pushed into a snow mass without the brushes operating.
324	After the snow was removed from the guideway, it remained snow-free from available solar energy during this late March demonstration.

Counter Location	Contents/Comments
331	The rain gauge was not particularly accurate in measuring snow accumulations; the gauge's heater vaporized some of the fallen snow.
346	The snow module was not required to clear this accumulation; the surface remained clear from solar energy. In the background is a more conventional means of snow removal.
373	During this test, the train was shuttled over the guideway once per hour to demonstrate that it was operable during this heavy snowfall. The snow module was used initially for snow removal; this was eventually unnecessary since solar energy kept the guideway clear.
397	Although the snowfall continues, the guideway surface remains wet and clear of snow.
420	The snow module was continued in peration during this snowfall; its brushes are capable of removing approximately two inches of very wet, slushy snow without use of the plow.

Counter Location	Contents/Comments
440	This is a time-lapse photographic record of an artificial snow accumulation; it eventually became 29 inches at its deepest. Most of the artificial snow accumulated late in the morning when the wind stilled. A snowmaking technique, which proved satisfactory, consisted of directing two snowguns to a point where a vortex was formed to cause more dense snow to fall on the guideway. To maintain a clear trajectory for the snowgun, it was necessary to shovel a path in front of the snowgun. The snowguns malfunctioned two times and sprayed water on the accumulated snow for several minutes before the problem was corrected and snowmaking was resumed; because of the water spray, this snow was heavier than natural snow. Snow density measurements were recorded to determine the snow removal equipment's effectiveness for various snow weights and densities. The swirling action of the wind had created significant snow accumulations on the side-mounted power rails; this rendered them inoperable. The configuration and location of the UNIMOBIL System's power and control rails and its guidance/auxiliary traction surfaces afforded much more protection than was available to the side-mounted rails.

Counter Location	Contents/Comments
508	The snowmaking equipment was removed from the maintenance support vehicle; this vehicle was then connected to the train for use as the snow module.
517	The snow produced for this test was very dense; it was not the typical light, fluffy and dry snow which accumulates in Minnesota. However, the snow removal operation is quick and effective -- a 29-inch deep snow accumulation was removed in a single pass.
528	After initial contact with the snow mass, the train and snow module accelerated to 11 feet per second. A natural snow accumulation on the guideway is not expected to reach this great magnitude.
553	A construction worker is on the maintenance support vehicle to observe the pressure gauge which indicates the thrust and resistance values for the snow removal operation.
569	Inspite of artificially-induced crystalline snow/freezing rain and rime ice accumulations, all of the components of the UNIMOBIL guideway are 100% operational; the side-mounted rails remained inoperable for the balance of the day.

Counter Location	Contents/Comments
575	Even though the side-mounted rails were equipped with heaters identical to the inverted rails, ice and snow would have prevented the power collection brushes from contacting the side-mounted power rail surfaces.
584	The deepest and heaviest natural snowfall of the 1978-79 Winter occurred on November 17, 1978; it resulted in 8 to 11 inches of cover on some segments of the guideway. This snow accumulation was removed in a single pass even though the brushes were defective as a result of being improperly stored all Summer. In spite of this extreme weather condition, the inverted power and control rails remained completely ice-free.
609	This shows a contrast in the types of snows encountered in Minnesota. Heavy, wet snows often occur during the months of November and March, while the dryer snow is more typical of the colder Minnesota winter months.
619	Wind erosion removes a large percentage of the snow from the guideway in open areas; wind erosion also removes some snow from local guideway areas that are protected by hills and trees. The accumulations on the guideway are typically less than half of that on the ground in adjacent areas.

Counter Location	Contents/Comments
639	To illustrate the effectiveness of the Cold Guideway Concept, guideway surface heating, using a propane torch rated at 50,000 Btu's, was employed to remove light accumulations of precipitation. (Snow is easily removed from a cold guideway, while solar energy is more effective than artificial heat sources for removing ice and snow.)
654	Time-lapse photography of a test section shows the effectiveness of the auxiliary traction subsystem heater on cold days.
667	While it is rather easy to remove ice from a relatively warm guideway, it is extremely difficult to separate ice from the guideway surface without the assistance from solar energy.
676	A snow accumulation of 3/8 inch rapidly melts and evaporates before 10 a.m. The apparent vapors rising from the guideway surface are actually reflections of clouds moving in a brisk wind.
705	This guideway switch operation is taking place at -23°F on January 11, 1979. The temperature recorded at UMI's on-site weather station was -25°F at guideway height; it was -27°F at the National Weather Service Station at Minneapolis International Airport. Switch operating times were acceptable, although slightly

Counter Location	Contents/Comments
705 (Cont.)	slow; locked-to-locked motions required an average of about 38 seconds instead of the normal time of less than 30 seconds. No special provisions were required to accomplish switch operations in these temperatures. Successful switch operations have since been demonstrated on a daily basis; however, this was the lowest temperature encountered in either the 1978-79 or 1979-80 Winters.
725	Switch operations have also been demonstrated with up to 1/2 inch of accumulated ice cover.
728	This is a view of the power rail assembly sequence during a typical 1978-79 Winter snowfall; the snowfall for this winter was 1.95 times the 100-year average. The connection is made at a guideway bus bar (rail) splice; these splices occur every 30 feet along the power rail.
746	Time-lapse photography of the power rail assembly and a solar eclipse; the power rail assembly continued during the solar eclipse. Although this was not a total eclipse in the Twin Cities area, it was still quite recognizable.
757	Off-loading the center vehicles of Train No. 3 occurred during very cold conditions.

Counter Location	Contents/Comments
766	During testing, the vehicle doors only partially opened in the extremely cold weather because the electrical cushions had not been properly adjusted; motor current was removed at the halfway (open) point.
773	The effectiveness of the "Drip Lip" in preventing moisture accumulations on the power rails is evident during this incident of heavy, slushy snow.
779	George Anagnostopoulos, the UMTA Coordinator, is viewing a demonstration of removing extremely wet snow; after plowing in the morning, solar energy melted the remainder of the day's snowfall without allowing an accumulation.
792	The spur diversion segment of the guideway switch was not plowed. As the sun rose, the surface accumulation melted and icicles were formed on the shaded side of the guideway; the side in the direct sun became clear.

Counter Location	Contents/Comments
799	The snowplow operation is removing snow in two passes. The plow can be used with brushes removing the remaining snow; the plow can be lifted and, at slower speeds, the brushes can be used to remove all of the snow from the surface. Instead of dropping large clumps (with the plow), the brushes disperse the snow and throw it a considerable distance from the guideway. Even making snow at night, it is sometimes very difficult to get snow to remain on the guideway surface.
814	By impinging the snowguns against the sides of the guideway, it is possible to produce significant accumulations on these side surfaces.
834	The snow module can be propelled by the train because the inverted rails are clear; however, it is evident that the side-mounted rails are totally inoperable.
839	The auxiliary traction surface is completely free of ice and snow because: (1) of its sheltered position; and (2) it is heated at this time.

Counter Location	Contents/Comments
840	Emergency brake stopping tests were performed on a glare ice surface; hoses were used to flow the water that produced the ice on this section of the primary traction surface. Repeated stops glazed the ice surface to produce a minimum coefficient of friction of .092 for glazed ice in the range of $0^{\circ}F$.
860	Snow had been plowed from the surface and the sun was starting to warm the guideway structure; it was possible to plow the remaining ice from the guideway surface.
863	The train is operational during this severe weather; heating was required to keep the power and control rails ice-free under these artificially-induced conditions.
874	With the exception of frost, power rail heating has not been required for any naturally-occurring winter weather conditions.
885	Extreme icing conditions were created using the snowguns on April 6, 1979; the train was stopped to accumulate a worst case condition. The snowmaking equipment had been moved adjacent to the guideway for producing a maximum accumulation over an extended length of the guideway.

CARTRIDGE NO. 12

Counter Location	Contents/Comments
4	This is a typical mid-winter scene in Minnesota, with snow on the ground, as a revenue service train departs the station. The thermal expansion slide plates, which support the guideway at selected columns, are displaced as a result of the extremely low winter temperatures.
33	This is a good-sized, mid-winter crowd at the Minnesota Zoological Garden (MZG), the passenger loading is nearly 100% for one train. Cross-country skiing at MZG provides an additional attraction to gain Zoo patronage.
47	Routine passenger boarding and deboarding takes place at the main passenger station.
53	This is an interior view of train passenger compartments and shows the sights as seen from the train passenger compartments.
65	The guide/narrator's compartment provides a view of the deliverable snow module in operation.
75	The train and snow module operate very quietly with essentially no impact on the surrounding areas. Animal activities adjacent to the guideway are not disturbed by the passing trains.

CARTRIDGE NO. 12 (Cont.)

Counter Location	Contents/Comments
97	Winter passenger boardings and deboardings are restricted by the use of the platform on only one side of the guideway; MZG decided to not remove snow or ice from the ramps on the (normal) exit side of the guideway.
112	System performance is demonstrated under simulated freezing rain conditions. This type of activity can be conducted during revenue service hours because previous similar tests have had no impact on revenue operations.
130	The "Drip Lip's" effectiveness is readily apparent in an area indicating representative winter precipitation conditions.
137	A revenue service train is passing through the primary winterization test area while the snowguns are operating.
165	A typical train configuration provides winter day revenue service.
170	The snow module performance is being tested on a specially-prepared section of snow-covered guideway that is 300 feet long; the snow depths range from 14 to 22 inches and averaged 20 inches deep.

CARTRIDGE NO. 12 (Cont.)

Counter Location	Contents/Comments
187	Snowplow operation of the deliverable snow module is demonstrated on an artificial "worst-case accumulation".
200	Snow characteristic measurements are made during the snowplow tests.
215	The snowplow is being operated at a train speed of 6 feet per second; this artificial snow accumulation is 15 inches.
235	The snowplow operation is complete and the guideway surface is 100% clear.
240	This demonstration is a representative of making snow at night.
260	This test was designed to compare the performance of the UNIMOBIL System's inverted rails sheltered by the "Drip Lip" with conventional side-mounted rails exposed to artificial freezing rain and rime ice.
265	The snow module is removing artificial snow accumulations in a test area.

CARTRIDGE NO. 12 (Cont.)

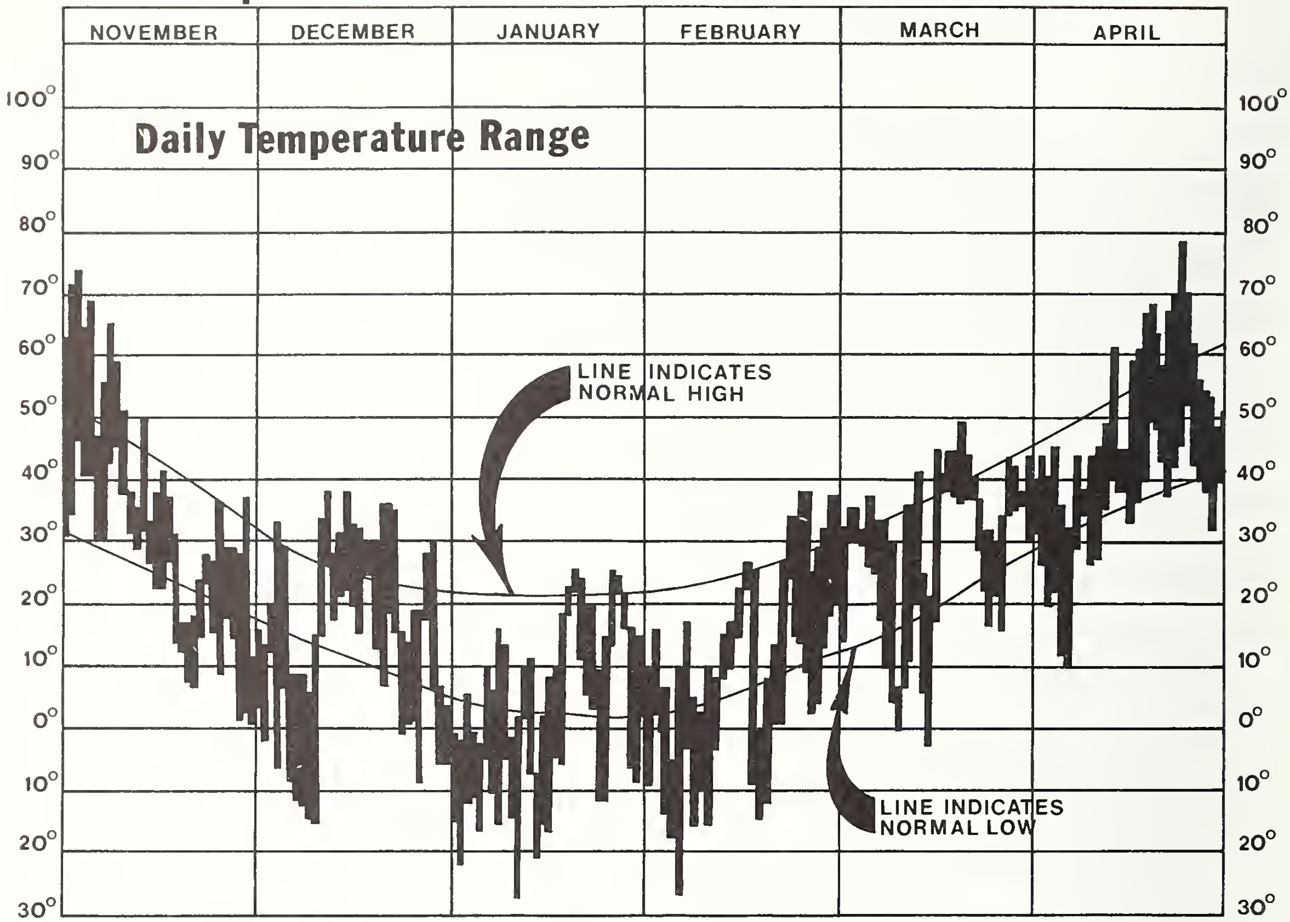
Counter Location	Contents/Comments
275	A train-to-train pull test is performed on one inch of compacted natural snow.
285	The conditions of the auxiliary traction surface and drive wheels can be observed during a naturally-occurring snowfall.
295	The vehicle pull test is complete.
300	This train-to-train push test is performed on one inch of compacted natural snow.
331	This is a view of the control module and data recording equipment for the power rail feedback control system (PRFCS). The data being evaluated is characteristic of the PRFCS performance; the PRFCS remained continuously on line, and without interruption, from February 8, 1980 until April 30, 1980 (the end of the testing period.) The PRFCS successfully maintained the power and control rails frost-free on a 24-hour per day basis; this was accomplished with the minimum energy consumption that is characteristic of the feedback nature of this system.

Counter Location	Contents/Comments
365	The power and control rails are being performance-tested under severe winter conditions. The total inoperability of the side-mounted power rails can be compared to the completely-operable inverted rails with "Drip Lip" protection. It should be noted that, while the inverted rail configuration remained 100% operational without further rail heating, the side-mounted rail reference configuration remained totally inoperable for the next six days.
370	The snow module is train-operated in a section of the primary winterization test area served by the PRFCS. Since the train received its power from the guideway, the UNIMOBIL System rails were verified as being 100% operational by this test.
379	Routine snow module operations are performed prior to revenue service; train speeds are 11 feet per second for this demonstration.
393	The snow module is operated in a heavy accumulation area and then over a pedestrian plaza.
400	A train equipped with a snow module is boarding passengers at the main passenger station.
410	(No further materials are recorded on this cartridge.)

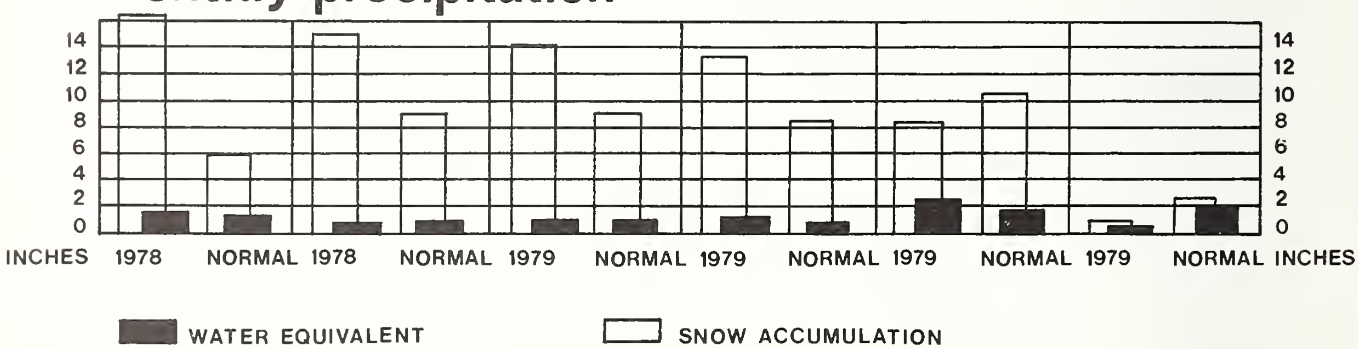
APPENDIX B

METEOROLOGICAL DATA, INCLUDING SAMPLE DATA FORMS

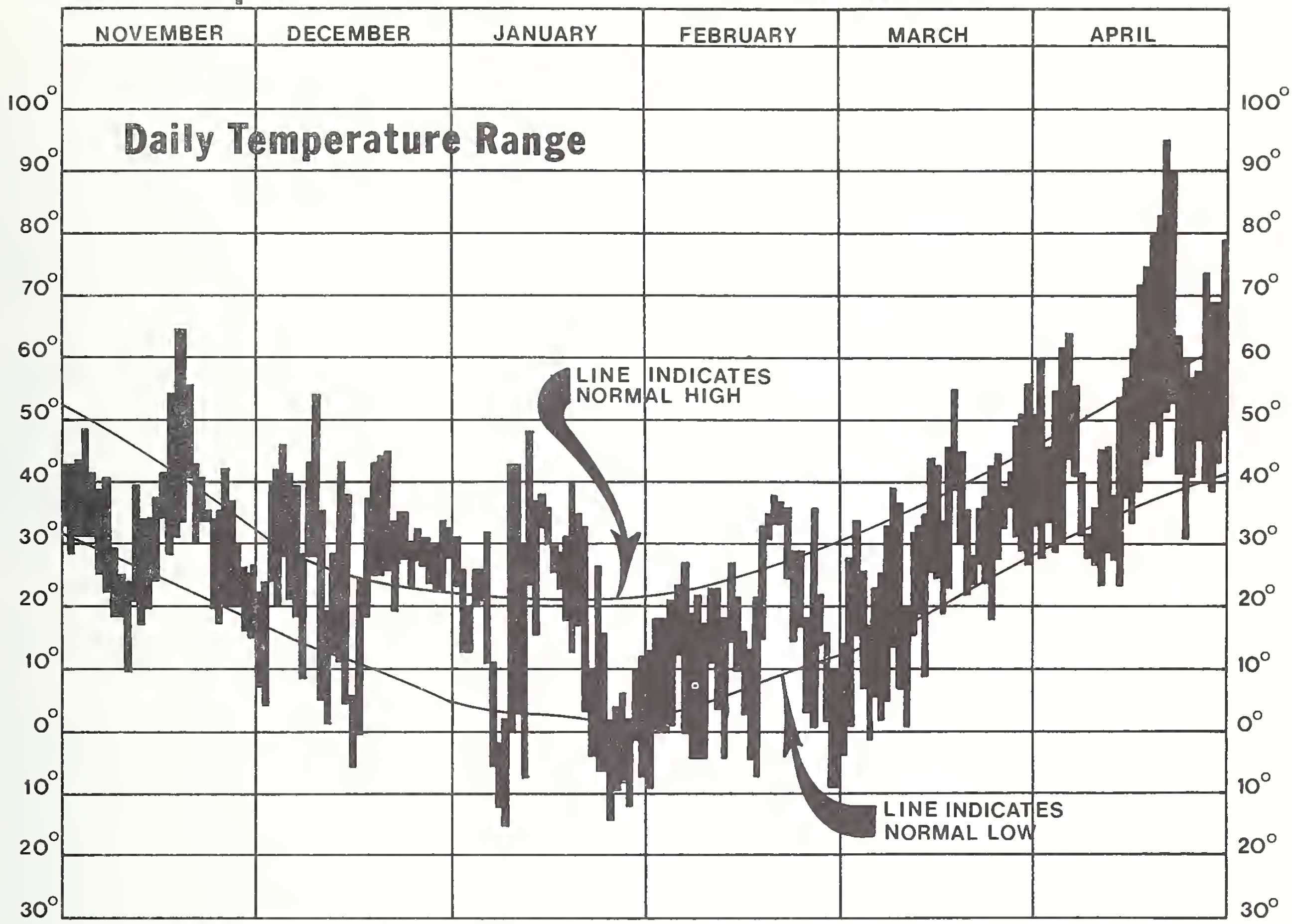
Minneapolis weather for 1978–79 winter



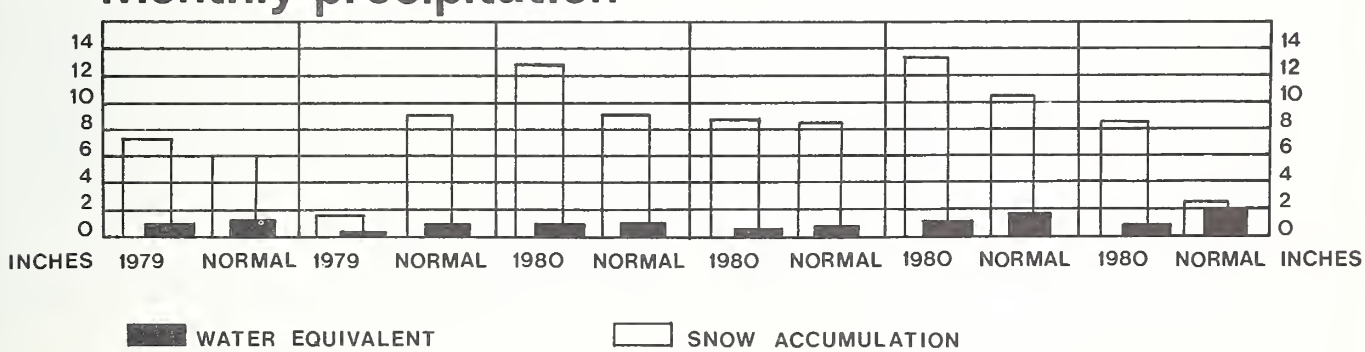
Monthly precipitation



Minneapolis weather for 1979–80 winter



Monthly precipitation



BRUCE F. WATSON
CONSULTING METEOROLOGIST
2511 BRENNER STREET
ROSEVILLE, MINNESOTA 55113
PHONE 612-633-3496

November 20, 1979

Universal Mobility, Inc.
712 Rushmore Drive
Burnsville, Minnesota

Attn: Don Sullivan

Dear Mr. Sullivan:

The winter of 1978-1979 was one of the very bitterest in comparison with others dating back to the time continuous records began locally in 1819. It may have been the bitterest ever.

The bitterness of the temperature over this winter of 1978-1979 can be seen from the record of a continuously-recording thermometer that I maintain at the Federal cooperative weather observing station in Farmington, Dakota County, Minnesota for my detailed, high-precision climatic work. Every month from October 1978 to May 1979, inclusive, was below the 1941-1970 normal in temperature. January was 13.0 degrees below normal, February 7.4 below normal, December 6.9 below normal, and November 3.2 below normal. Temperature alone competes with the bitterest of cold winters, experienced in the 1880's.

However, the addition of the snow factor makes the past winter most severe. I have day-by-day snow records dating back to 1926. Never, since that time, has a snow cover that began so early stayed around so late in the spring. The surface was covered continuously from November 17th to March 22nd. In addition, a total of near 70 inches fell -- it exceeded that at my weather station. At the NWS (National Weather Service) station at Minneapolis-St. Paul International Airport, 68.4 inches was recorded. The long-term normal since 1859 is 42.5 inches. One must go back to 1882-1883 to find a bitter winter with as much snow -- and even that winter did not have as much snow as I recorded.

The cold was not only great in absolute terms in 1978-1979, but it was chronic. Even at the NWS Airport station, affected by heat from the city, the temperature was below freezing from December 24th to February 20th, and no warmer than 38 from November 17th to March 13th. Even in the winter of 1882-1883, February brought some relief with a temperature of 46 in St. Paul.

The temperature did not reach 50 degrees in 1979 until April 12th, and then just for a day. A break then took place on April 15th, after which temperatures in the daytime reached 50 almost every day.

It would take a considerable amount of research to judge if 1978-1979 or 1882-1883 were the worst winter ever since some aspects of each are the more severe. However, the 1978-1979 winter was, at least, the worst in 96 years, and could be judged, in some aspects, to be the worst ever. The heavy snow, with the enduring bitter cold was most remarkable.

Yours truly,

Bruce F. Watson

Bruce F. Watson
Consulting Meteorologist

LISTING OF METEOROLOGICAL EQUIPMENT

Cotton Region Instrument Shelter with Steel Legs - U.S. Weather Bureau Model 5-970A

Bendix Hygrothermograph - Model 5-594

Belfort Hygrothermograph - Catalog No. 5-594

Bendix Micro-Barograph - Model 5-800A, Catalog No. 792

Belfort Heated Tipping Rain and Snow Gauge -Catalog No. 5-405HA

Wind Screen for Rain and Snow Gauge

Texas Electronics Strip Chart Read-Out - Model R2-1014

Belfort U.S. Weather Bureau Max/Min Thermometer - Catalog No. 5-484, with Townsend Support - Model 5-484

Belfort Solar Radiation Recorder - Catalog No. 5-3850A

Robert E. White 5-inch Aneroid Barometer

Environmental Tectronics Battery-Powered Psychrometer - Model CP-147

Standard U.S. Weather Bureau Thermometer

Belfort Wind Speed and Wind Direction Recorder - Catalog No. 1250B-1275B (Figure 3-2A)

Custom-Fabricated Dew Point and Structural Temperature Recorder; components supplied by Yellow Springs Instrument Company

MICRO-BAROGRAPH

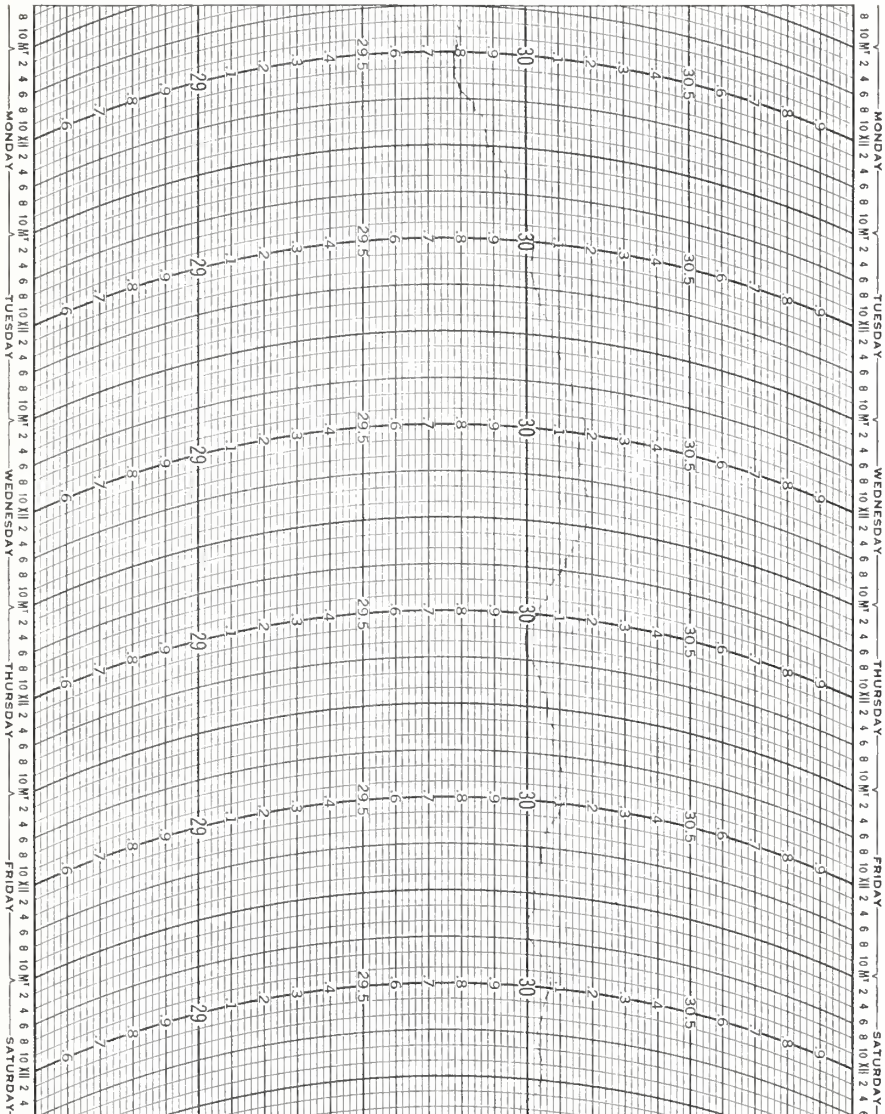
CHART NO. 5-1071

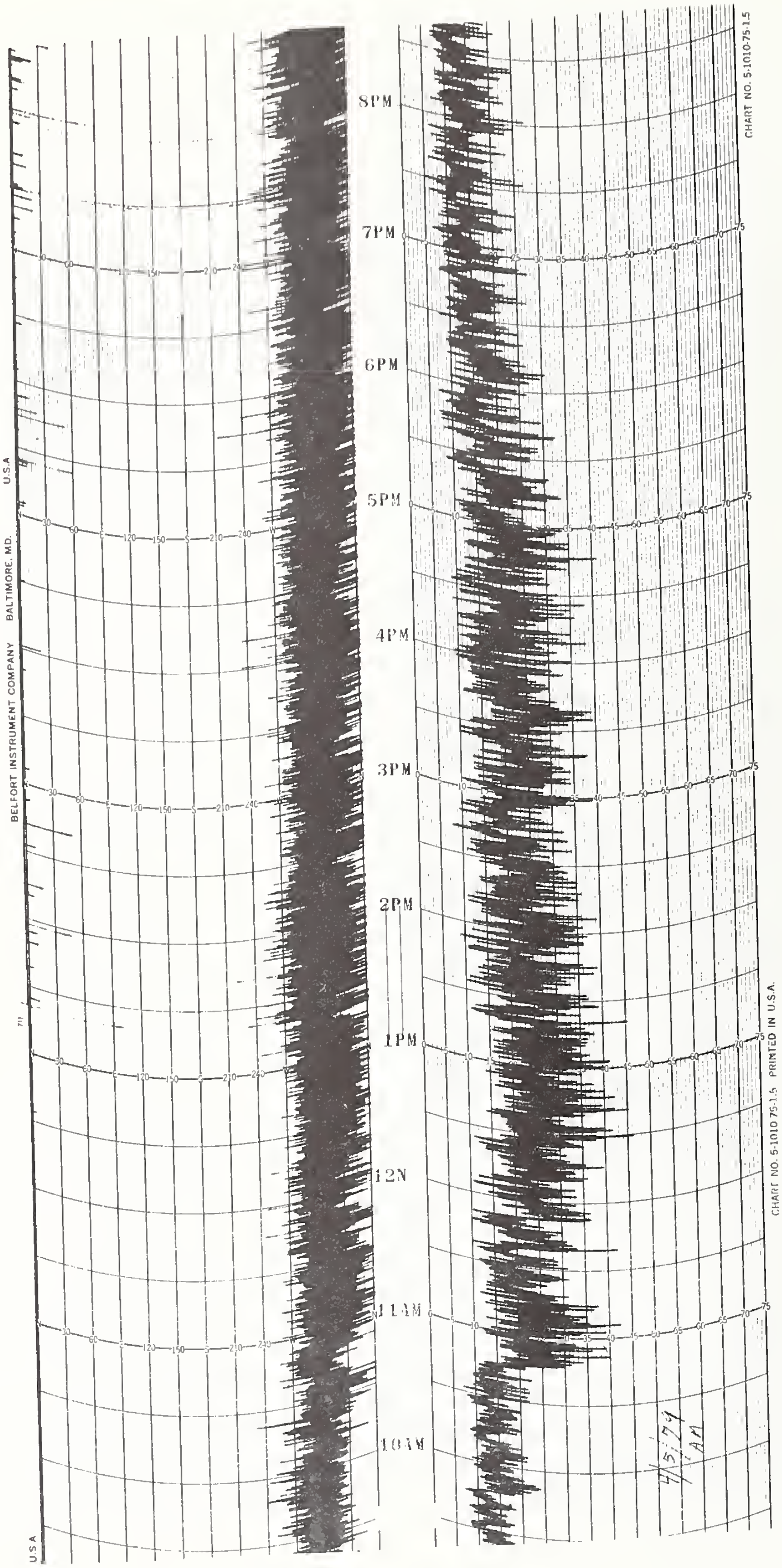
BELFORT INSTRUMENT COMPANY

BALTIMORE MARYLAND, U.S.A.

INSTRUMENT NO. 410 DATE 3/3 - 3/10/80 STATION UMI-MZG

REMARKS. DOT-TSC 1585




8PM
7PM
6PM
5PM
4PM
3PM
2PM
1PM
12N
11AM
10AM
BELFORT INSTRUMENT COMPANY BALTIMORE, MD. U.S.A
CHART NO. 5-1010-75-1.5
CHART NO. 5-1010 75-1.5 PRINTED IN U.S.A.
4/5/79 AM

PRINTED IN U.S.A.

HYGRO-THERMOGRAPH

CHART NO. 5-209-W

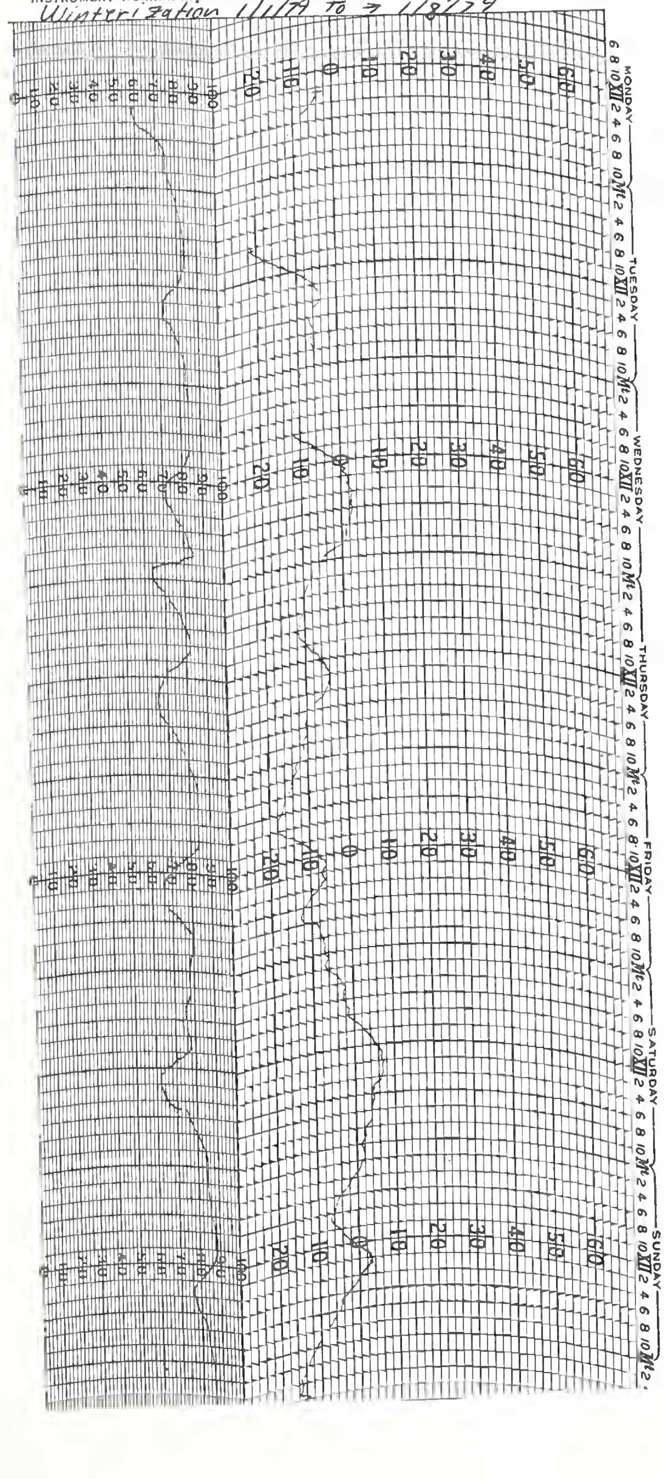
BELFORT INSTRUMENT COMPANY

BALTIMORE MARYLAND, U.S.A.

STATION UMI (MZG) DOT-TSC -1585

INSTRUMENT NO. .... DATE 1/1/79

Winterization 1/1/79 TO → 1/8/79



PRINTED IN U.S.A.

RECORDING PYRHELIOMETER

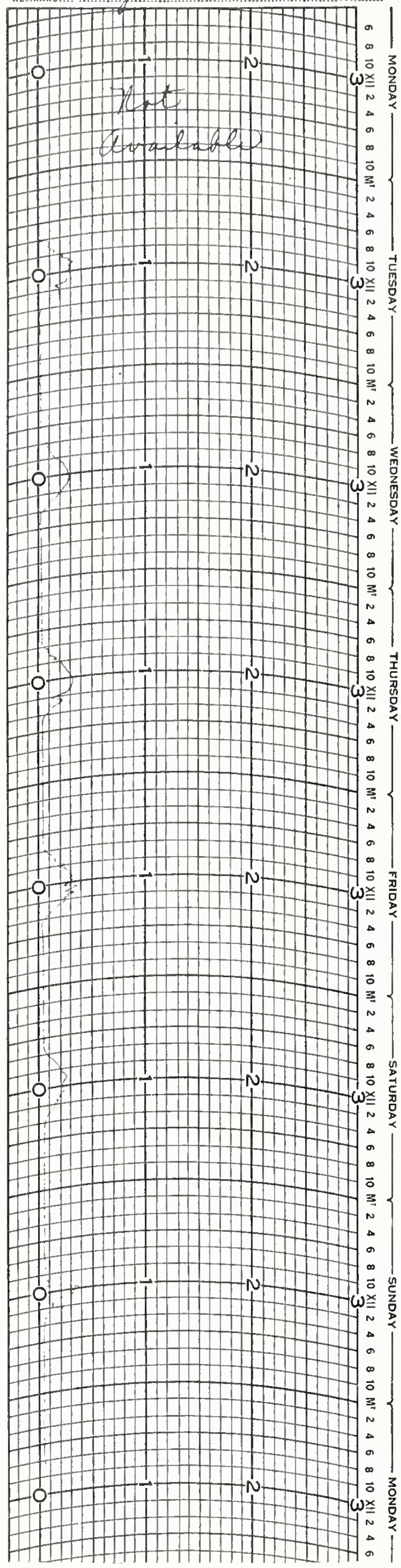
CHART NO. 5-1050-AW (Note - 12/17 Data missing)

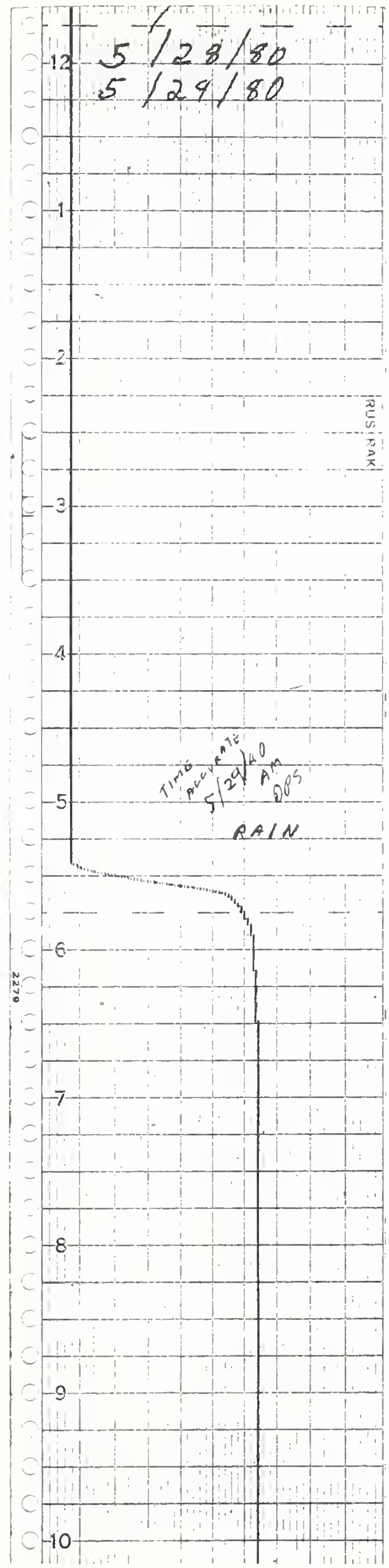
BELFORT INSTRUMENT COMPANY

BALTIMORE MARYLAND, U.S.A.

STATION UMI-MZ6 12/18 - 12/24/79

REMARKS Weatherized DOT-TSC-1585 19




5/28/80
5/29/80
12
1
2
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9
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TIME ACCURATE
AM
RAIN
RUS RAK
2279

JANUARY 1980
MINNEAPOLIS-ST.PAUL, MINNESOTA
NAT WEATHER SERVICE FCST OFC
INTERNATIONAL AIRPORT

Local Climatological Data

MONTHLY SUMMARY

LATITUDE 44°53'N LONGITUDE 93°13'W ELEVATION (GROUND) 834 FT. STANDARD TIME USED: CENTRAL WBAN #14922

DATE	TEMPERATURE °F: MAXIMUM	MINIMUM	AVERAGE	DEPARTURE FROM NORMAL	AVERAGE DEW POINT	DEGREE DAYS BASE 65°: HEATING (SEASON BEGINS WITH JULY)	COOLING (SEASON BEGINS WITH JAN.)	WEATHER TYPES ON DATES OF OCCURRENCE (1 FOG, 2 HEAVY FOG, 3 THUNDERSTORM, 4 ICE PELLETS, 5 HAIL, 6 GLAZE, 7 DUSTSTORM, 8 SMOKE, HAZE, 9 BLOWING SNOW)	SNOW, ICE PELLETS OR ICE ON GROUND AT 06AM IN.	PRECIPITATION: WATER EQUIVALENT IN	SNOW, ICE PELLETS IN.	AVG. STATION PRESSURE IN. ELEV. 838 FEET M.S.L.	WIND: RESULTANT DIR.	RESULTANT SPEED M.P.H.	AVERAGE SPEED M.P.H.	FASTEST MILE: SPEED M.P.H.	DIRECTION	SUNSHINE: MINUTES	PERCENT OF POSSIBLE	SKY COVER TENTHS: SUNRISE TO SUNSET	MIDNIGHT TO MIDNIGHT	DATE
1	2	3	4	5	6	7A	7B	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
1	31	24	28	14	24	37	0	1 6	T	T	T	29.11	30	5.3	6.9	9	36	0	0	10	10	1
2	26	13	20	7	16	45	0	1 6	T	T	T	29.30	01	10.5	10.6	14	01	315	59	7	6	2
3	20	13	17	4	11	48	0		T	.06	1.4	29.43	10	2.4	6.0	10	02	0	0	9	9	3
4	26	20	23	10	18	42	0		T	.06	1.1	29.22	13	11.0	11.4	16	13	116	22	10	10	4
5	26	21	24	11	17	41	0	8	1	T	T	29.22	12	11.3	11.9	15	11	76	14	10	10	5
6	32	11	22	9	20	43	0	1 6 89	3	.31	4.1	28.55	20	11.1	19.0	29	30	0	0	10	10	6
7	11	-5	3	-9	-5	62	0	9	5	.01	.1	28.87	29	19.6	19.8	30	30	447	83	5	4	7
8	-2	-12	-7	-19	-15	72	0		5	0	0	29.39	29	10.9	11.2	17	30	469	87	4	4	8
9	2	-15*	-7	-19	-21	72	0		5	0	0	29.49	22	3.0	8.1	15	13	400	74	4	5	9
10	43	1	22	10	11	43	0	1 6	5	T	0	28.76	14	14.6	15.1	23	12	0	0	10	9	10
11	43	0	22	10	1	43	0	9	5	.05	1.1	28.77	29	22.3	23.3	31	29	187	34	10	9	11
12	30	-7	12	0	-1	53	0	9	5	T	T	29.26	17	7.9	13.5	23	17	0	0	9	7	12
13	48*	24	36	24	25	29	0	4 6	4	.06	.2	28.74	21	7.7	15.5	18	18	434	79	6	5	13
14	37	16	27	15	19	38	0		2	0	0	29.14	10	4.5	9.6	22	13	359	66	8	7	14
15	38	33	36*	24	32	29	0	1	1	.11	0	29.07	10	6.7	8.8	13	11	0	0	10	10	15
16	36	30	33	21	32	32	0	1	1	.06	.3	29.00	01	13.7	13.8	21	36	0	0	10	10	16
17	30	26	28	16	23	37	0		1	T	T	29.09	33	11.2	11.5	15	34	0	0	10	10	17
18	29	23	26	15	21	39	0		T	T	T	29.29	27	4.3	5.8	12	31	226	41	10	10	18
19	31	18	25	14	15	40	0	1	T	T	T	29.56	32	9.3	10.2	14	35	510	92	1	3	19
20	40	13	27	15	12	38	0		T	0	0	29.49	24	7.5	7.8	16	24	558	100	2	1	20
21	35	17	26	14	17	39	0		T	T	T	29.02	22	10.3	10.6	16	20	434	77	9	7	21
22	33	4	19	7	11	46	0	9	T	T	T	28.94	32	17.1	17.3	25	32	505	90	3	4	22
23	10	-4	3	-9	-7	62	0		T	.06	1.2	28.99	29	2.4	8.5	14	13	486	86	3	4	23
24	26	9	18	6	13	47	0	1 6	3	.14	2.7	28.49	07	5.9	8.8	15	02	226	40	10	10	24
25	16	-6	5	-7	0	60	0		4	T	T	29.01	34	11.3	11.7	17	32	494	87	5	4	25
26	-1	-14	-8*	-20	-19	73	0		4	0	0	29.42	31	12.1	12.2	16	32	462	81	9	5	26
27	4	-9	-3	-15	-13	68	0		4	0	0	29.37	30	8.3	8.5	16	26	509	89	2	4	27
28	6	-8	-1	-13	-13	66	0	1	4	T	.2	29.41	30	8.2	8.3	13	32	446	77	7	5	28
29	2	-12	-5	-17	-17	70	0		4	0	0	29.56	33	5.0	6.6	10	32	553	95	2	4	29
30	10	-1	5	-8	-7	60	0	8	4	.02	.5	29.60	34	3.1	5.2	9	31	415	71	10	9	30
31	12	-7	3	-10	-8	62	0		4	0	0	29.67	29	4.9	5.5	8	25	584	100	3	1	31
	SUM	SUM				TOTAL	TOTAL			TOTAL	TOTAL	FOR THE MONTH:						TOTAL	%	SUM	SUM	
	730	216				1536	0	NUMBER OF DAYS		.94	12.9	29.17	30	3.3	11.1	31	29	9211	FOR	218	206	
	AVG.	AVG.	AVG.	DEP.	AVG.	DEP.	DEP.	PRECIPITATION		DEP.						DATE: 11		POSSIBLE	MONTH	AVG.	AVG.	
	23.5	7.0	15.3	3.1	7	-101	0	≥ .01 INCH	11	0.21								17157	54	7.0	6.6	
						SEASON TO DATE		SNOW, ICE PELLETS														
	NUMBER OF DAYS					TOTAL	TOTAL	≥ 1.0 INCH	6	GREATEST IN 24 HOURS AND DATES						GREATEST DEPTH ON GROUND OF SNOW, ICE PELLETS OR ICE AND DATE						
	MAXIMUM TEMP.		MINIMUM TEMP.			4426	0	THUNDERSTORMS	0	PRECIPITATION		SNOW, ICE PELLETS										
	≥ 90°	≤ 32°	≤ 32°	≤ 0°		DEP.	DEP.	HEAVY FOG	0	.31	6	4.1	6			5	12+					
	0	22	30	13		-304	0	CLEAR 7	PARTLY CLOUDY 7	CLOUDY 17												

* EXTREME FOR THE MONTH - LAST OCCURRENCE IF MORE THAN ONE.
T TRACE AMOUNT
\+ ALSO ON AN EARLIER DATE, OR DATES.
HEAVY FOG: - VISIBILITY 1/4 MILE OR LESS.
FIGURES FOR WIND DIRECTIONS ARE TENS OF DEGREES CLOCKWISE FROM TRUE NORTH. 00 = CALM.
DATA IN COLS. 6 AND 12-15 ARE BASED ON 7 OR MORE OBSERVATIONS PER DAY AT 3-HOUR INTERVALS.
FASTEST MILE WIND SPEEDS ARE FASTEST OBSERVED ONE-MINUTE VALUES WHEN DIRECTIONS ARE IN TENS OF DEGREES. THE / WITH THE DIRECTION INDICATES PEAK GUST SPEED.
ANY ERRORS DETECTED WILL BE CORRECTED AND CHANGES IN SUMMARY DATA WILL BE ANNOTATED IN THE ANNUAL SUMMARY

STATION CONVERTED FROM FASTEST MILE WINDS TO FASTEST OBSERVED ONE-MINUTE WINDS ON JAN. 1ST.

SUMMARY BY HOURS

HOUR LOCAL TIME	AVERAGES: SKY COVER TENTHS	STATION PRESSURE IN.	TEMPERATURE: AIR °F	WET BULB °F	DEW PT. °F	RELATIVE HUMIDITY %	WIND SPEED M.P.H.	RESULTANT WIND: DIRECTION	SPEED M.P.H
00	6	29.16	15	14	8	73	10.8	30	4.3
03	7	29.17	13	12	6	74	10.6	31	3.5
06	7	29.17	11	10	5	75	10.1	32	3.1
09	7	29.20	13	12	5	72	10.9	30	3.0
12	7	29.19	17	15	8	69	11.6	29	2.8
15	7	29.15	18	16	8	65	11.9	29	4.0
18	7	29.15	17	15	8	68	11.0	29	3.0
21	7	29.16	15	14	8	72	11.5	29	3.2

HOURLY PRECIPITATION (WATER EQUIVALENT IN INCHES)

DATE	A.M. HOUR ENDING AT 1	2	3	4	5	6	7	8	9	10	11	12	P.M. HOUR ENDING AT 1	2	3	4	5	6	7	8	9	10	11	12	DATE
1	T	T	T	T	T	T	T	T	T	T	T		T				T	T	T	T	T	T	T		1
2	T	T	T	T	T	T	T	T	T	T	T	T	T	T											2
3		T	T	T	T	T	.01	.01	.02	.01	T	T	T	T	T	T	.01	T	T	T	T	T	T	T	3
4	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	.01	.01	.01	T	.01	.01	.01	4
5	T	T								T	T	T	T	T	T										5
6	.02	.04	.03	.02	.05	.03	.03	.01	T	T	T	T	.02	T	T	T	.01	T	.01	T	.01	.02	.01	T	6
7	.01	T																							7
8																									8
9																									9
10												T	T	T	T	T	T	T	T						10
11		T	.01	.01	.02	.01			T	T	T		T	T	T										11
12															T	T			T	T	T				12
13				.03	T	.01	.02	T																	13
14																									14
15			T	.04	.03	.03	.01	T	T	T	T	T													15
16								T	T	.01	T	.01	.02	.02	T	T									16
17									T	T	T	T	T	T	T						T	T			17
18										T	T	T	T												18
19	T	T	T	T	T	T																			19
20																									20
21																							T	T	21
22	T	T	T	T	T	T	T				T	T													22
23																				T	.01	.01	.02	.02	23
24	.04	.04	.01	.01	T	T	T	T	T	T	.01	T	T		T	.02	.01	T	T	T	T	T	T		24
25									T	T															25
26																									26
27																									27
28										T	T	T	T	T	T	T	T								28
29																									29
30							T	T	T	.01	.01	T	T				T	T	T	T	T	T			30
31																									31

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I CERTIFY THAT THIS IS AN OFFICIAL PUBLICATION OF THE NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION, AND IS COMPILED FROM RECORDS ON FILE AT THE NATIONAL CLIMATIC CENTER, ASHEVILLE, NORTH CAROLINA 28801.

noaa NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION / ENVIRONMENTAL DATA AND INFORMATION SERVICE

Daniel B. Mitchell
DIRECTOR, NATIONAL CLIMATIC CENTER

USCOMM--NOAA--ASHEVILLE 02/29/80 1050

OBSERVATIONS AT 3-HOUR INTERVALS

HOUR	SKY COVER TENTHS	CEILING HNDS. OF FT.	VISIBILITY WHOLE MILES	VISIBILITY 16THS MILE	WEATHER	AIR °F	WET BULB °F	DEW PT. °F	REL. HUM. %	WIND DIR	WIND SPEED KNOTS
DAY 01											
00	10	3	2		F	28	28	26	92	33	6
03	10	4	2	8	ZLF	27	26	24	88	29	4
06	10	4	2	8	ZLF	27	26	24	88	26	5
09	10	3	1		SGF	26	25	23	88	25	8
12	10	4	2		F	27	26	24	88	30	6
15	10	3	2	8	F	27	26	24	88	26	6
18	10	5	4		SF	25	24	22	88	33	5
21	10	6	4		SF	25	24	22	88	36	8
DAY 02											
00	10	8	4		ZLF	26	25	22	85	35	6
03	10	10	7		ZL	24	23	20	85	01	10
06	10	12	15		S	24	23	19	81	01	11
09	10	12	6		S	21	20	16	81	01	12
12	10	13	12		S	23	21	16	74	01	11
15	2	UNL	20			25	22	12	58	01	10
18	0	UNL	25			21	18	10	62	02	9
21	0	UNL	25			17	16	10	74	35	5
DAY 03											
00	0	UNL	25			13	12	08	80	36	7
03	10	15	15		S	15	14	11	84	01	6
06	10	13	3		S	17	16	12	81	04	4
09	9	21	2		S	19	18	13	77	14	5
12	10	19	4		S	20	18	12	71	17	5
15	9	20	12		S	20	18	11	68	17	4
18	10	22	8		S	19	17	11	71	15	4
21	10	22	6		S	18	17	13	81	12	7
DAY 04											
00	10	25	7		S	20	19	14	77	14	5
03	10	33	15		S	21	20	15	78	14	10
06	10	31	15		S	21	20	16	81	13	8
09	10	34	5		S	22	21	16	78	15	9
12	9	14	5		S	24	22	17	75	13	12
15	10	14	2	8	S	26	25	21	81	13	11
18	10	12	2		S	26	25	21	81	12	12
21	10	12	2		S	25	24	20	81	10	12
DAY 05											
00	10	20	2		S	24	23	19	81	10	11
03	10	33	7			23	22	18	81	12	12
06	10	42	7			22	21	16	78	09	9
09	10	14	8			22	21	16	78	12	9
12	10	42	5		S	24	23	18	78	12	11
15	10	34	9			25	23	16	69	14	10
18	10	20	5		H	25	23	17	72	14	9
21	10	16	6		H	25	23	18	75	15	12
DAY 06											
00	10	16	6		H	26	24	19	75	14	12
03	10	1	0	8	S	24	23	21	88	13	14
06	10	12	2	8	S	26	25	22	85	14	15
09	10	11	2	8	S	29	28	25	85	16	10
12	10	9	1		SF	32	31	28	85	17	18
15	10	17	4		S	24	23	18	78	24	17
18	10	16	2	8	SBS	24	23	18	78	25	24
21	10	6	0	12	SBS	13	12	09	84	27	22
DAY 07											
00	10	15	1	8	SBS	11	10	06	80	30	25
03	7	UNL	10			05	04	-04	66	30	21
06	2	UNL	3		BS	01	00	-07	69	30	20
09	7	250	4		BS	00	00	-06	75	30	18
12	5	UNL	7			04	03	-03	72	28	16
15	5	UNL	7			05	03	-07	57	28	16
18	0	UNL	7			00	00	-06	75	29	10
21	0	UNL	10			-03	-03	-10	71	28	12
DAY 08											
00	0	UNL	15			-04	-04	-12	68	29	9
03	0	UNL	25			-06	-06	-13	71	27	9
06	0	UNL	25			-08	-08	-14	74	29	12
09	0	UNL	25			-08	-08	-16	67	28	10
12	0	UNL	25			-05	-05	-18	53	29	11
15	10	UNL	25			-14	-14	-16	90	32	11
18	6	UNL	25			-07	-07	-17	61	28	6
21	10	220	25			-09	-09	-16	70	29	10
DAY 09											
00	7	UNL	25			-12	-12	-21	63	29	10
03	7	UNL	15			-14	-14	-21	70	29	8
06	0	UNL	15			-15	-15	-21	74	28	5
09	2	UNL	15			-12	-12	-28	44	23	5
12	1	UNL	20			-05	-06	-22	43	06	3
15	10	70	15			-01	-02	-19	41	20	7
18	10	65	15			00	00	-14	51	13	8
21	10	65	15			02	00	-19	36	15	10
DAY 10											
00	0	UNL	20			01	00	-12	54	14	12
03	7	UNL	25			02	01	-09	59	12	10
06	10	50	20			08	07	00	70	13	13
09	10	250	10			13	12	07	76	12	16
12	10	16	4		ZLF	19	18	14	81	13	14
15	10	11	3		ZLF	26	25	23	88	14	13
18	10	6	2		ZLF	32	30	28	85	15	16
21	10	12	6		F	40	38	38	93	17	11
DAY 11											
00	1	UNL	10			43	40	36	76	24	14
03	10	20	6		S	25	23	19	78	29	25
06	10	60	8			07	05	-07	52	30	17
09	10	14	2		SBS	02	01	-07	66	28	22
12	9	17	4		BS	01	-01	-11	56	28	23
15	10	16	2	8	BS	02	01	-05	72	29	27
18	10	18	2	8	BS	02	01	-07	66	29	18
21	10	16	6		BS	03	02	-08	60	31	16
DAY 12											
00	3	UNL	10			01	00	-09	62	28	11
03	0	UNL	25			-01	-02	-08	72	30	8
06	0	UNL	25			-04	-05	-13	65	25	4
09	9	130	12			-03	-04	-10	71	16	7
12	10	100	15			07	06	-01	69	13	13
15	10	70	12		S	15	13	09	77	13	18
18	10	90	7			22	19	08	55	17	14
21	10	100	6		BS	25	23	17	72	18	19
DAY 13											
00	8	150	12			30	25	13	49	17	16
03	10	90	12			31	27	20	64	17	16
06	10	70	7			33	29	21	61	17	15
09	10	70	15			35	32	26	70	18	11
12	8	250	20			39	36	32	76	22	12
15	1	UNL	25			47	41	34	61	29	15
18	0	UNL	15			40	36	31	70	30	10
21	0	UNL	15			29	27	21	72	33	13
DAY 14											
00	0	UNL	15			24	22	17	75	31	9
03	0	UNL	20			20	18	16	84	33	6
06	4	UNL	20			18	17	15	88	36	4
09	2	UNL	20			20	19	16	84	08	6
12	10	UNL	15			27	24	18	69	13	6
15	10	90	15			30	27	21	69	12	10
18	10	75	15			32	28	21	64	12	12
21	10	100	15			35	32	28	76	13	14
DAY 15											
00	10	90	15			36	32	25	64	18	5
03	10	90	8		R	36	33	28	73	12	10
06	10	27	5		RF	35	34	32	89	12	9
09	10	70	2		RF	35	34	33	92	11	9
12	10	75	2	8	RF	36	35	35	96	10	9
15	10	60	2		F	37	35	33	85	10	7
18	10	7	2		F	35	34	34	96	05	6
21	10	7	2	8	F	35	35	34	96	36	6
DAY 16											
00	10	3	1	8	F	35	34	34	96	01	6
03	10	1	1		F	34	34	34	100	36	8
06	10	3	2		F	34	34	34	100	01	10
09	10	4	1	12	RSF	35	34	32	89	02	12
12	10	6	5		SF	36	34	32	85	01	14
15	10	12	6		S	35	34	31	85	36	12
18	10	12	10			35	33	30	82	36	18
21	10	11	10			33	31	29	85	36	16
DAY 17											
00	10	11	10			30	27	21	69	34	14
03	10	8	10			29	28	26	89	34	12
06	10	9	15			27	26	24	88	33	12
09	10	10	8		S	28	27	24	85	33	12
12	10	13	10		S	28	26	22	78	32	9
15	10	14	10			28	26	22	78	32	9
18	10	34	12			28	26	21	75	31	6
21	10	25	10		S	26	25	22	85	30	6
DAY 18											
00	10	25	12			27	25	22	81	27	4
03	10	18	15			27	25	18	69	29	5
06	10	15	12			26	24	19	75	29	4
09	10	12	15			26	24	20	78	21	4
12	10	9	7		S	28	27	23	82	20	7
15	10	13	12			28	26	21	75	24	4
18	10	13	10			27	25	21	78	32	7
21	10	10	8			26	24	20	78	29	5
DAY 19											
00	10	8	8			23	22	20	88	31	10
03	10	10	7		S	24	23	20	85	32	7
06	9	16	12			23	22	17	78	34	12
09	3	UNL	20			19	17	12	74	34	10
12	1	UNL	20			25	23	16	69	33	10
15	1	UNL	25			31	25	13	47	32	10
18	0	UNL	25			25	21	09	50	28	6
21	0	UNL	25			22	19	11	62	26	6
DAY 20											
00	0	UNL	25			20	18	11	68	24	4
03	0	UNL	25			17	16	11	77	24	4
06	1	UNL	25			13	12	09	84	22	6
09	7	210	20			19	17	11	71	23	8
12	2	UNL	20			28	24	13	53	23	8
15	0	UNL	20			38	29	12	34	26	11
18	0	UNL	25			31	25	13	47	24	7
21	0	UNL	25			21	19	13	71	21	6
DAY 21											
00	7	UNL	25			26	22	13	58	24	9
03	1	UNL	25			23	20	12	63	23	9
06	0	UNL	25			17	15	08	68	22	8
09	6	UNL	20			24	21	14	66	22	9
12	10	250	20			32	28	19	59	23	10
15	10	150	20			32	30	26	79	20	14
18	10	80	15			30	28	23	75	21	9
21	10	27	15			31	28	23	72	25	6
DAY 22											
00	10	12	8		S	31	30	27	85	31	10
03	10	22	6		S	29	26	20	69	32	14
06	10	22	6		SBS	21	20	16	81	33	16
09	4	UNL	15			16	14	08	71	32	17
12	3	UNL	15			16	14	06	64	33	19
15	0	UNL	15			12	10	03	67	33	17
18	0	UNL	20			12	11	04	70	32	13
21	0	UNL	20			09	08	02	73	32	14
DAY 23											
00	0	UNL	20			05	04	-01	76	33	10
03	0	UNL	25			01	00	-07	69	34	8
06	0	UNL	25			-02	-02	-10	68	35	5
09	0	UNL	15			-01	-02	-12	59	36	6
12	1	UNL	20			05	03	-12	45	30	4
15	7	80	20			10	07	-08	43	24	6
18	10	180	15			10	08	-04	53	19	9
21	10	70	4		S	09	08	01	70	16	11
DAY 24											
00	10	15	1	8	S	10	09	04	76	13	12
03	10	18	2	8	S	13	13	10	88	13	8
06	10	7	8		ZL	13	13	10	88	10	7
09	10	4	1	8	S	15	15	12	88	05	5
12	10	9	3		SF	20	19	15	81	08	3
15	10	5	2	8	F	24	23	18	78	10	3
18	10	13	7		S	22	21	18	85	02	10
21	10	26	8		S	18	17	14	84	02	13
DAY 25											
00	8	50	12			11	10	06	80	36	8
03	5	UNL	20			08	08	05	87	35	6
06	1	UNL	25			08	08	04	84	36	7
09	10	46	6		S	14	13	08	77	34	12
12	4	UNL	25			12	09	-03	51	33	13
15	1	UNL	25			10	08	-05	50	34	10
18	5	UNL	25			04	03	-05	66	32	10
21	2	UNL	25			01	00	-11	56	32	15
DAY 26											
00	0	UNL	25			-06	-06	-17	58	32	15
03	2	UNL	25			-11	-11	-22	57	31	10
06	6	UNL	25			-13	-13	-27	48	32	13
09	10	200	15			-11	-11	-26	46	31	12
12	10	200	20			-06	-06	-11	78	32	8
15	10	200	20			-02	-03	-10	68	30	10
18	2	UNL	20			-04	-06	-15	58	31	7
21	1	UNL	15			-05	-06	-20	47	32	10
DAY 27											
00	1	UNL	15			-08	-08	-15	71	31	7
03	10	UNL	25			-09	-10	-28	38	30	6
06	10	UNL	25			-08	-09	-18	61	31	6
09	2	UNL	25			-03	-04	-15	56	29	7
12	2	UNL	25			02	01	-08	62	29	11
15	1	UNL	25			04	03	-07	60	32	11
18	0	UNL	20			01	00	-05	76	30	6
21	0	UNL	20			-01	-02	-06	79	31	5
DAY 28											
00	3	UNL	20			-04	-05	-08	83	30	6
03	8	UNL	20			-06	-07	-13	71	29	7
06	10	200	15			-05	-06	-19	50	30	4
09	10	60	10			-02	-02	-12	62	30	8
12	10	30	4		S	02	02	-05	72	30	9
15	4	UNL	15		S	06	03	-16	35	31	10
18	0	UNL	20			00	00	-14	51	32	7
21	0	UNL	20			-01	-02	-13	56	31	7
DAY 29											
00	0	UNL	15			-05	-05	-16	58	31	9
03	0	UNL	15			-09	-09	-20	58	31	5
06	0	UNL	15			-10	-10	-19	64	30	4
09	0	UNL	15			-08	-08	-17	64	31	6
12	0	UNL	20			-02	-03	-16	51	32	8
15	2	UNL	20			01	00	-15	46	01	7
18	10	UNL	25			-03	-04	-17	50	03	4
21	10	UNL	25			-03	-04	-16	53	12	3
DAY 30											
00	10	UNL	25			-01	-02	-13	56	03	4
03	10	80	15			-01	-02	-13	56	05	6
06	10	49	15			00	00	-13	54	34	3
09	10	15	1	8	S	01	00	-09	62	31	5
12	10	UNL	3		SW	06	05	-03	66	[illegible]	3
15	10	UNL	12			09	07	-03	58	00	0
18	10	15	3		S	09	08	00	67	30	8
21	10	80	8		S	07	06	02	80	31	7
DAY 31											
00	0	UNL	20			02	02	-01	87	31	6
03	0	UNL	15			-02	-02	-06	83	30	3
06	1	UNL	15			-04	-04	-08	83	30	3
09	7	UNL	8			-02	-03	-12	62	30	4
12	4	UNL	12			09	07	-06	50	29	6
15	0	UNL	20			12	09	-07	42	32	6
18	0	UNL	25			06	04	-10	47	26	6
21	0	UNL	25			01	00	-11	56	23	4

NOTES

CEILING

UNL INDICATES UNLIMITED

WEATHER

- T TORNADO
- T THUNDERSTORM
- Q SQUALL
- R RAIN
- RW RAIN SHOWERS
- ZR FREEZING RAIN
- L DRIZZLE
- ZL FREEZING DRIZZLE
- S SNOW
- SP SNOW PELLETS
- IC ICE CRYSTALS
- SW SNOW SHOWERS
- SG SNOW GRAINS
- IP ICE PELLETS
- A HAIL
- F FOG
- IF ICE FOG
- GF GROUND FOG
- BD BLOWING DUST
- BN BLOWING SAND
- BS BLOWING SNOW
- BY BLOWING SPRAY
- K SMOKE
- H HAZE
- D DUST

WIND

DIRECTIONS ARE THOSE FROM WHICH THE WIND BLOWS, INDICATED IN TENS OF DEGREES FROM TRUE NORTH: I.E., 09 FOR EAST, 18 FOR SOUTH, 27 FOR WEST. ENTRY OF 00 IN THE DIRECTION COLUMN INDICATES CALM.

SPEED IS EXPRESSED IN KNOTS; MULTIPLY BY 1.15 TO CONVERT TO MILES PER HOUR.

STATION: MINNEAPOLIS MINN

YEAR & MONTH: 80 01

U.S. DEPARTMENT OF COMMERCE
NATIONAL CLIMATIC CENTER
FEDERAL BUILDING
ASHEVILLE, N.C. 28801

AN EQUAL OPPORTUNITY EMPLOYER

POSTAGE AND FEES PAID
U.S. DEPARTMENT OF COMMERCE
COM-210

U.S. MAIL

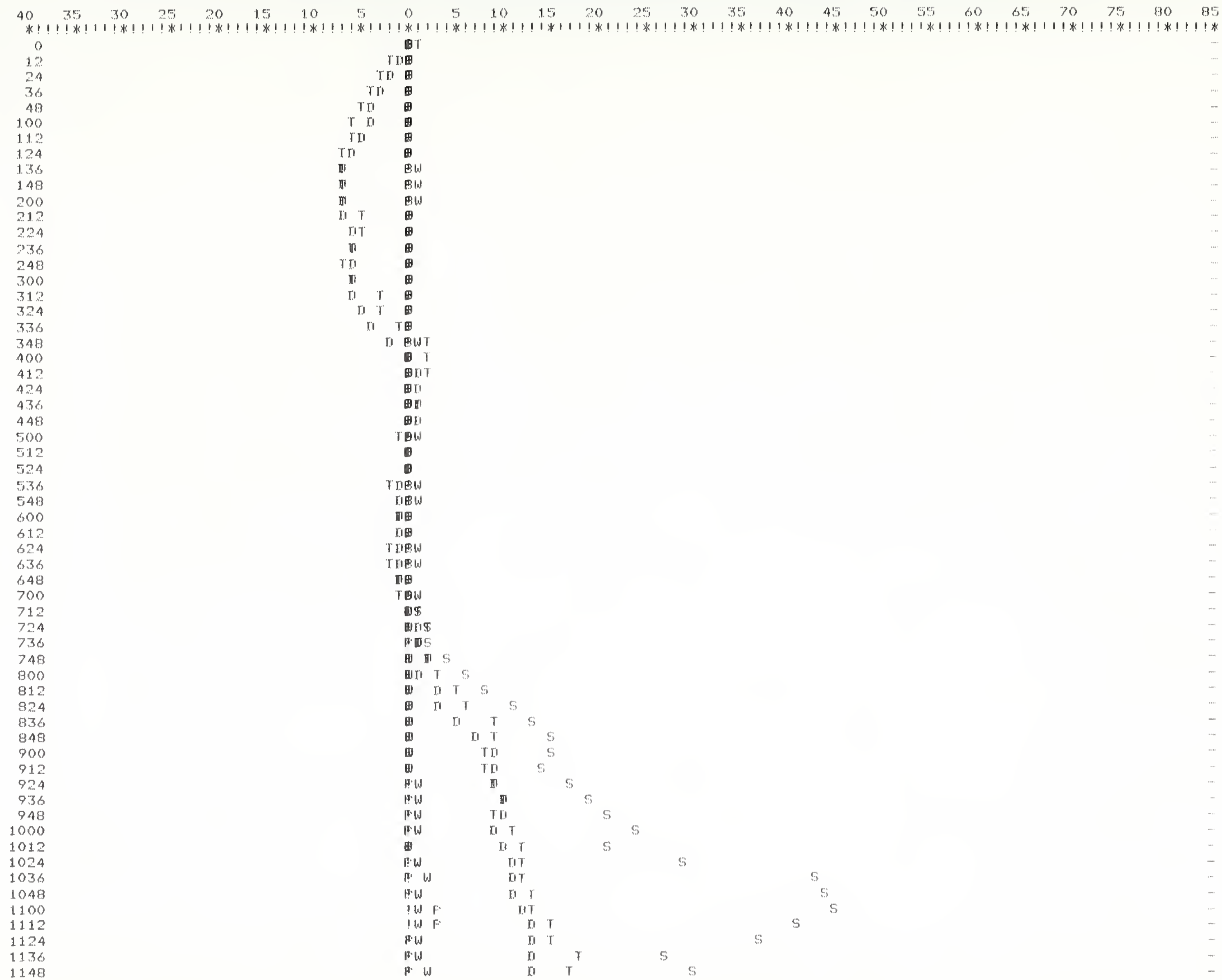
FIRST CLASS

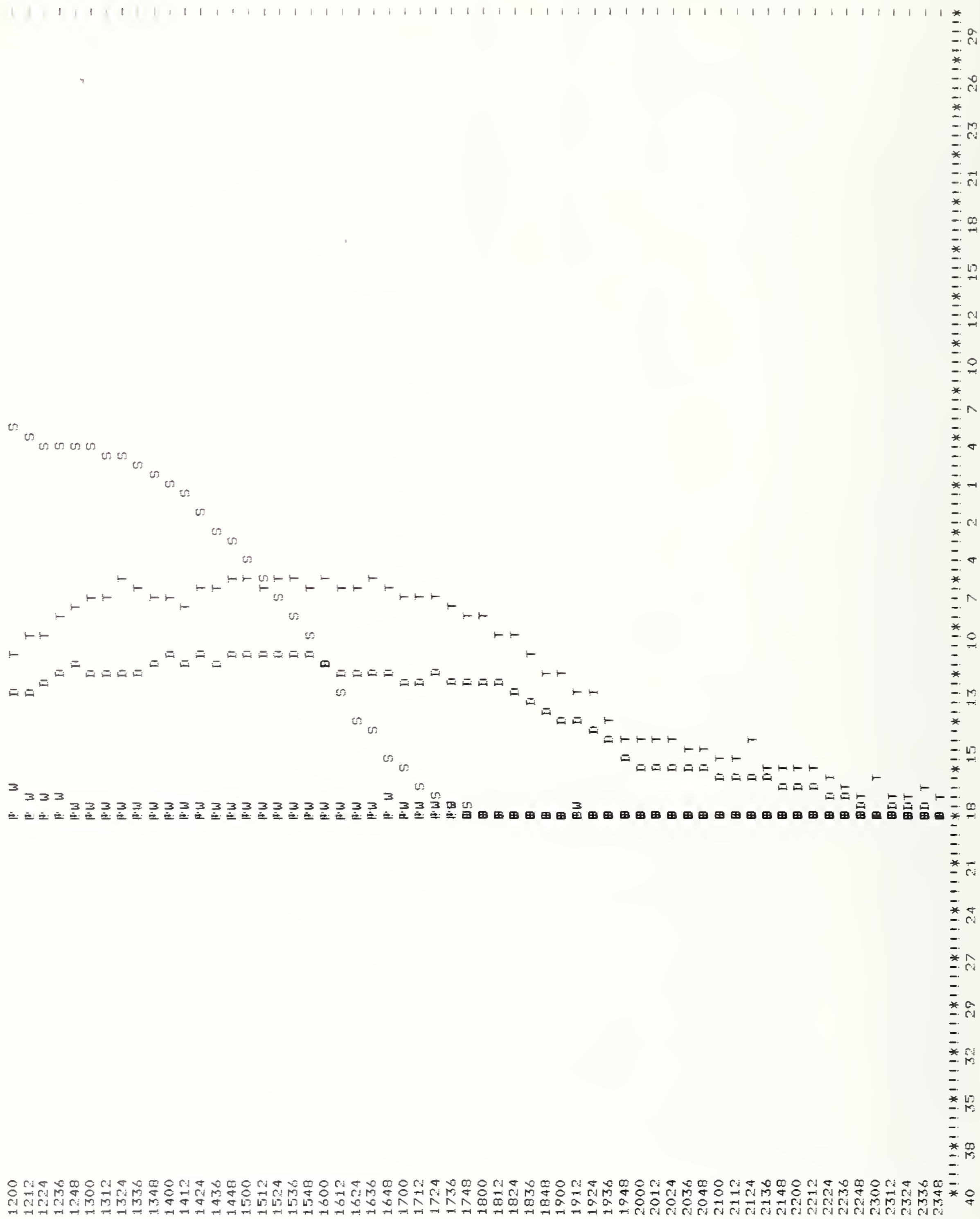
SPECIFIC TIME DATA FOR 3/7/80

TIME	PRESS	TEMP	HUMID	PRECIP	W SPD	W DIR	SOLRAD	DEWPT
0	29.91	+1.5	75.7	0.00	0.0	--	0.00	+0.5
6	29.94	-1.8	72.2	0.00	0.0	--	0.00	+0.4
12	29.98	-1.9	72.2	0.00	0.0	--	0.00	-0.8
18	29.98	-2.2	71.8	0.00	0.0	--	0.00	-1.5
24	29.92	-2.7	71.5	0.00	0.0	--	0.00	-1.8
30	30.01	-4.1	71.0	0.00	0.0	--	0.00	-2.3
36	29.97	-3.5	71.2	0.00	0.0	--	0.00	-2.4
42	29.97	-3.8	70.7	0.00	0.0	--	0.00	-2.7
48	29.99	-4.3	70.2	0.00	0.0	--	0.00	-3.1
54	29.99	-4.7	69.8	0.00	0.0	--	0.00	-3.6
100	30.00	-5.0	69.5	0.00	0.0	--	0.00	-3.8
106	29.97	-6.1	69.1	0.00	0.0	--	0.00	-4.0
112	29.99	-5.6	69.1	0.00	0.0	--	0.00	-4.8
118	29.95	-7.6	68.2	0.00	0.0	--	0.00	-5.5
124	30.02	-6.7	68.4	0.00	0.0	--	0.00	-5.4
130	29.99	-7.3	68.2	0.00	1.4	NW	0.00	-6.0
136	29.98	-6.1	68.6	0.00	1.1	S	0.00	-6.5
142	29.97	-6.3	68.6	0.00	1.0	NW	0.00	-6.9
148	30.01	-6.3	68.6	0.00	1.0	NW	0.00	-6.6
154	29.99	-4.4	69.7	0.00	1.0	NW	0.00	-6.5
200	29.99	-6.2	68.9	0.00	1.0	NW	0.00	-6.7
206	30.01	-5.5	69.3	0.00	0.0	--	0.00	-6.5
212	29.94	-5.0	69.7	0.00	0.0	--	0.00	-6.2
218	30.00	-4.8	70.0	0.00	1.0	NW	0.00	-5.9
224	30.02	-4.5	70.1	0.00	0.0	--	0.00	-5.7
230	29.99	-4.4	70.1	0.00	0.0	--	0.00	-5.9
236	30.01	-5.8	69.5	0.00	0.0	--	0.00	-5.4
242	30.00	-4.3	70.1	0.00	0.0	--	0.00	-5.7
248	29.98	-6.0	69.4	0.00	0.0	--	0.00	-5.3
254	30.00	-5.6	69.5	0.00	0.0	--	0.00	-5.5
300	29.99	-5.7	69.4	0.00	0.0	--	0.00	-5.5
306	29.97	-5.2	69.7	0.00	0.0	--	0.00	-5.4
312	30.02	-2.7	71.4	0.00	0.0	--	0.00	-5.4
318	30.00	-2.3	71.8	0.00	0.0	--	0.00	-4.6
324	29.99	-2.0	72.2	0.00	0.0	--	0.00	-4.2
330	30.04	-1.1	72.7	0.00	0.0	--	0.00	-3.7
336	29.97	-0.5	73.2	0.00	0.0	--	0.00	-3.2
342	29.96	+1.3	73.8	0.00	1.0	SE	0.00	-2.3
348	29.95	+2.4	74.3	0.00	1.0	NW	0.00	-1.3
354	29.97	+2.7	74.4	0.00	1.0	NW	0.00	-0.3
400	29.94	+3.0	75.9	0.00	0.0	--	0.00	+0.3
406	29.95	+3.4	76.0	0.00	0.0	--	0.00	+0.6
412	29.97	+2.5	76.6	0.00	0.0	--	0.00	+1.3
418	29.99	+1.6	76.0	0.00	0.0	--	0.00	+1.6
424	29.94	+0.7	75.3	0.00	0.0	--	0.00	+1.7
430	29.99	+1.7	75.4	0.00	0.0	--	0.00	+1.8
436	30.01	+1.9	74.8	0.00	0.0	--	0.00	+1.7
442	30.02	+2.5	74.6	0.00	0.0	--	0.00	+1.3
448	30.00	+0.7	73.6	0.00	0.0	--	0.00	+1.2
454	30.00	-0.4	73.0	0.00	1.0	NW	0.00	+1.0
500	29.97	-0.4	72.9	0.00	1.0	NW	0.00	+0.8
506	30.03	+0.4	73.6	0.00	1.0	NW	0.00	+0.5
512	30.01	+0.9	74.5	0.00	0.0	--	0.00	+0.2
518	29.98	+0.9	74.2	0.00	0.0	--	0.00	+0.8
524	30.06	+0.7	73.7	0.00	0.0	--	0.00	+0.7
530	30.00	-1.1	72.8	0.00	1.0	NW	0.00	+0.4
536	29.98	-1.5	72.4	0.00	1.8	NW	0.00	-0.3
542	29.98	+0.5	73.1	0.00	2.0	NW	0.00	-0.5
548	30.00	+0.5	73.1	0.00	1.2	NW	0.00	-0.2
554	29.97	-0.3	73.5	0.00	0.0	--	0.00	-0.4
600	29.98	-0.9	72.9	0.00	0.0	--	0.00	-0.1
606	30.02	-1.3	73.2	0.00	0.0	--	0.00	-0.4

X-Y PLOT FOR 3/7/80

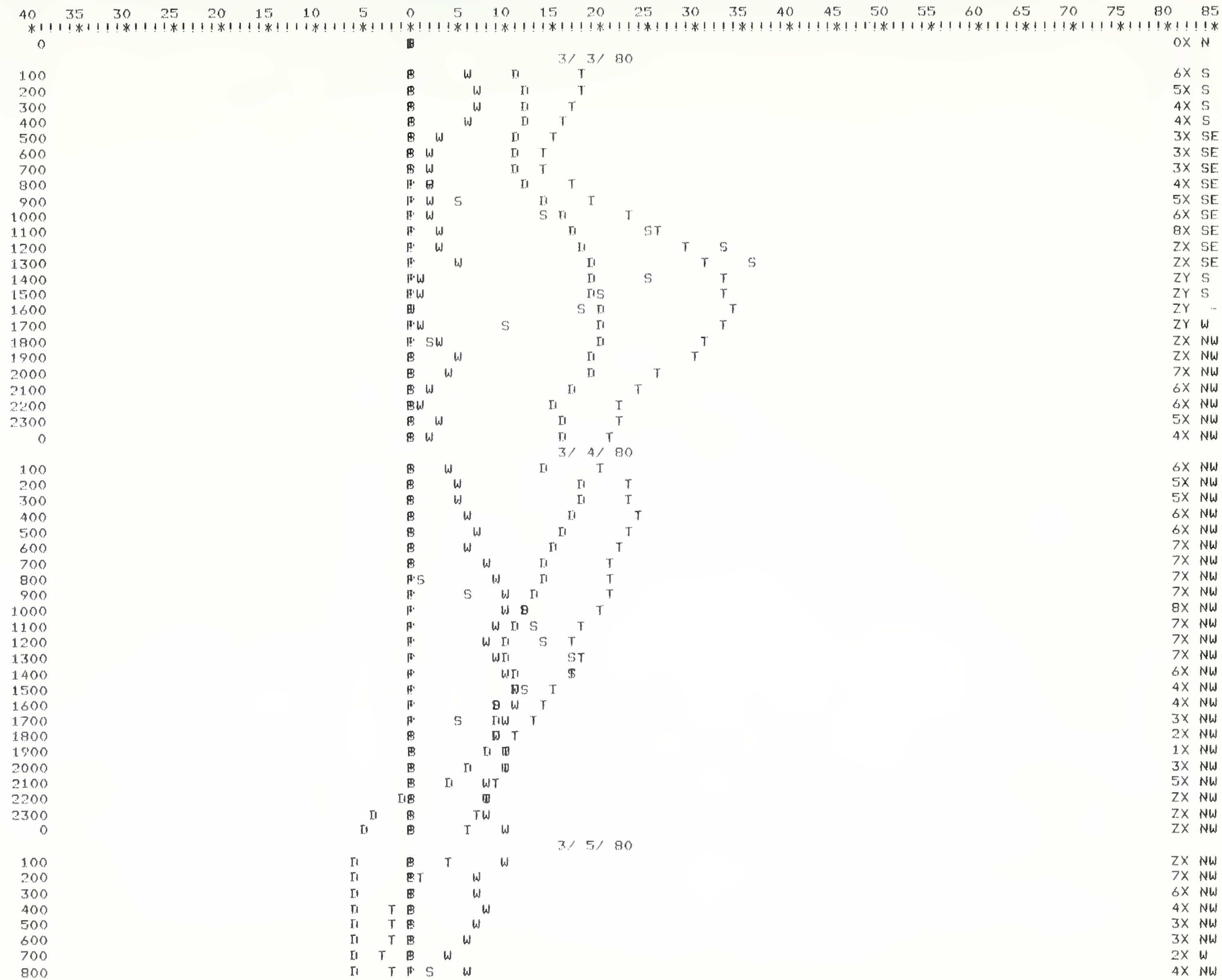
KEY: T=TEMP(F/C) W=W SPD(MPH) D=DEWPT(F/C) P=PRECIP(IN.) S=SOLRAD(CAL/CM*CM/MIN), EACH ! EQUALS 1

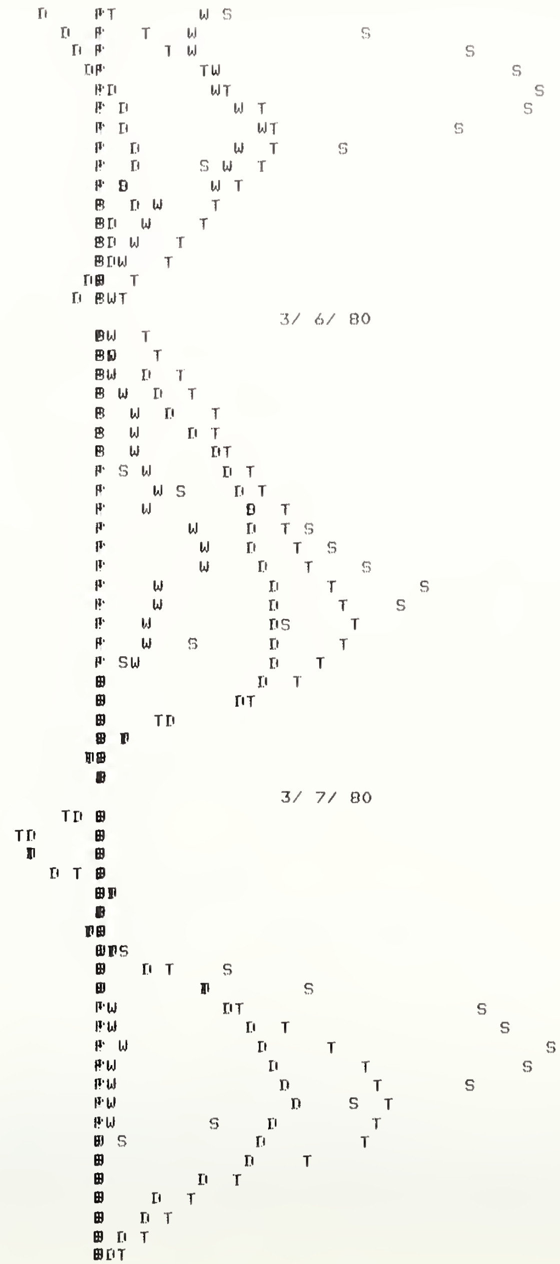




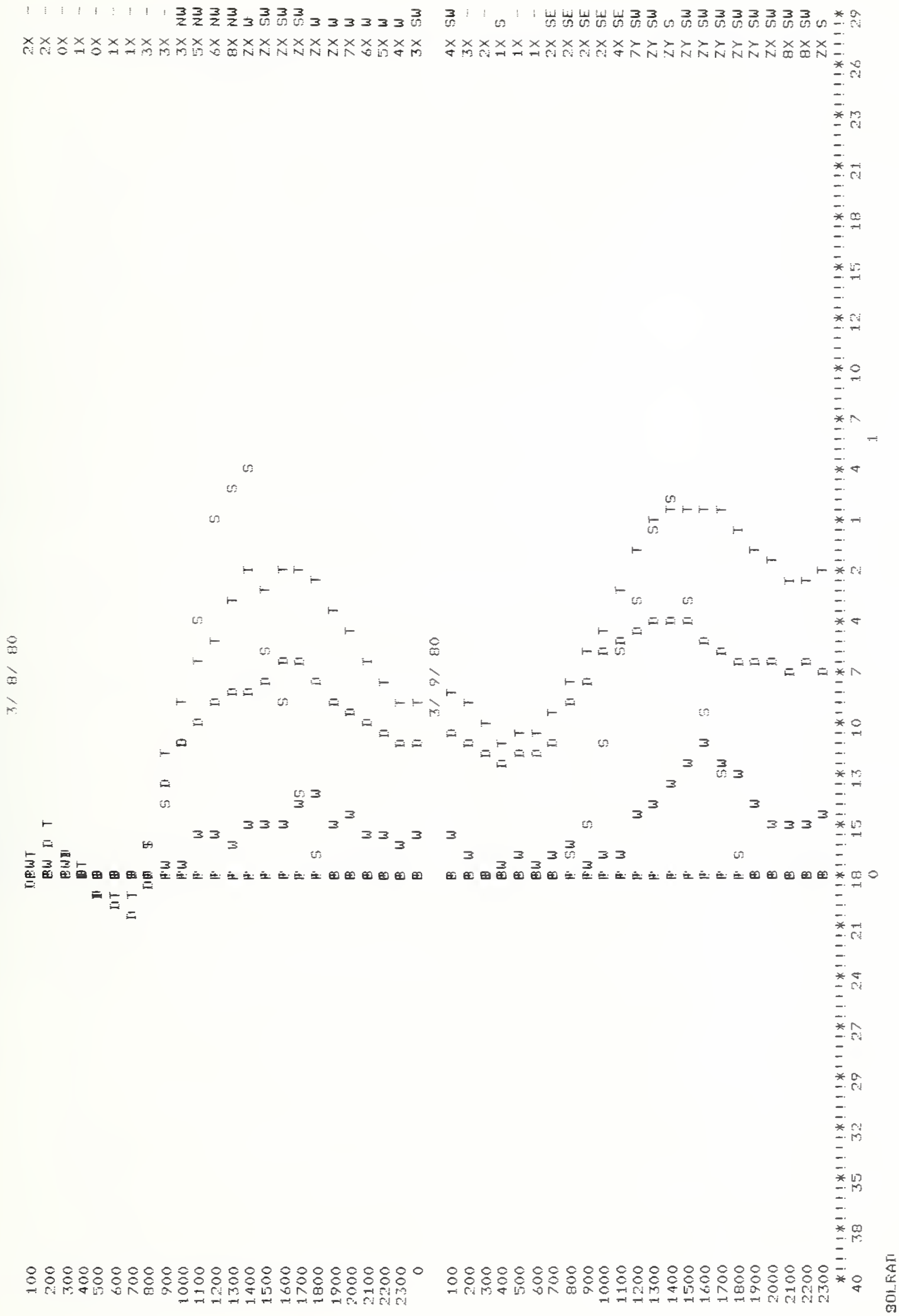
X-Y PLOT FROM 3/3/80 COVERING 7 DAYS

KEY: T=TEMP(F/C) W=W SPD(MPH) D=DEWPT(F/C) P=PRECIP(IN.) S=SOLRAD(CAL/CM*CM/MIN). EACH ! EQUALS 1



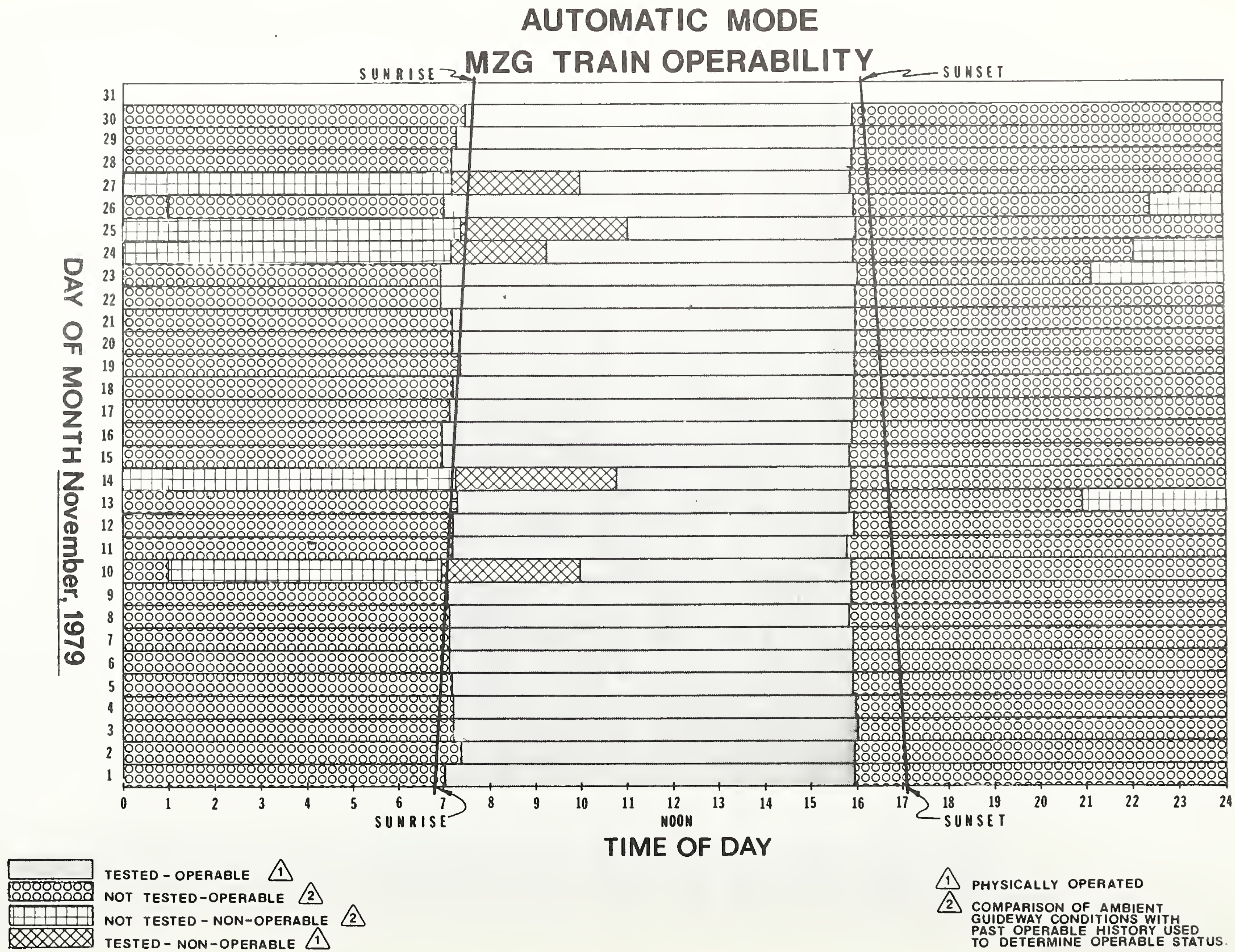


Time	Wind
900	5X NW
1000	6X NW
1100	8X NW
1200	ZX NW
1300	ZX NW
1400	ZX NW
1500	ZX NW
1600	ZX NW
1700	ZX NW
1800	ZX NW
1900	7X NW
2000	7X NW
2100	6X NW
2200	4X NW
2300	4X -
0	4X -
3/ 6/ 80	
100	3X -
200	3X -
300	2X S
400	3X S
500	4X S
600	2X S
700	1X SE
800	1X SE
900	1X SE
1000	2X SE
1100	2X SE
1200	3X S
1300	3X S
1400	4X S
1500	6X S
1600	6X S
1700	5X SW
1800	4X SW
1900	3X -
2000	1X -
2100	0X -
2200	0X -
2300	0X -
0	0X -
3/ 7/ 80	
100	0X -
200	0X -
300	0X -
400	2X -
500	0X -
600	0X -
700	0X -
800	0X -
900	2X -
1000	0X -
1100	1X -
1200	3X E
1300	6X E
1400	8X E
1500	7X E
1600	7X SE
1700	8X NW
1800	8X -
1900	4X -
2000	2X -
2100	3X -
2200	2X -
2300	1X -
0	1X -

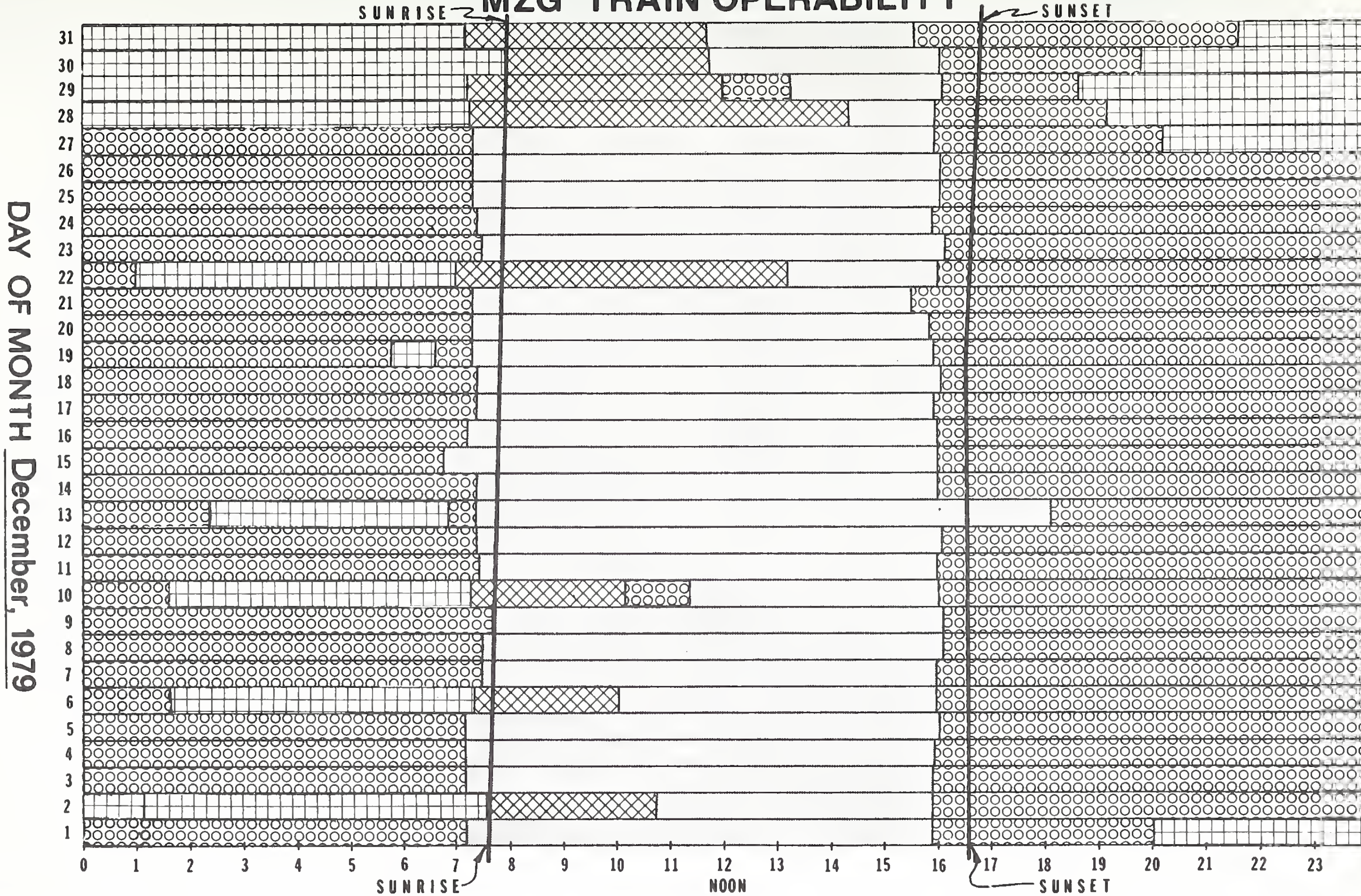

3/ 8/ 80
3/ 9/ 80
SOLRAD

APPENDIX C

OPERABILITY CHARTS AND SAMPLE DATA FORMS FOR SPECIFIC TESTS, SYSTEM PERFORMANCE, ENERGY CONSUMPTION AND PASSENGER COMMENTS


AUTOMATIC MODE
MZG TRAIN OPERABILITY
SUNRISE
SUNSET
31
30
29
28
27
26
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
DAY OF MONTH November, 1979
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
NOON
TIME OF DAY
TESTED - OPERABLE 1
NOT TESTED-OPERABLE 2
NOT TESTED - NON-OPERABLE 2
TESTED - NON-OPERABLE 1
1 PHYSICALLY OPERATED
2 COMPARISON OF AMBIENT GUIDEWAY CONDITIONS WITH PAST OPERABLE HISTORY USED TO DETERMINE OPERABLE STATUS.

AUTOMATIC MODE
MZG TRAIN OPERABILITY



TESTED - OPERABLE 1

NOT TESTED - OPERABLE 2

NOT TESTED - NON-OPERABLE 2

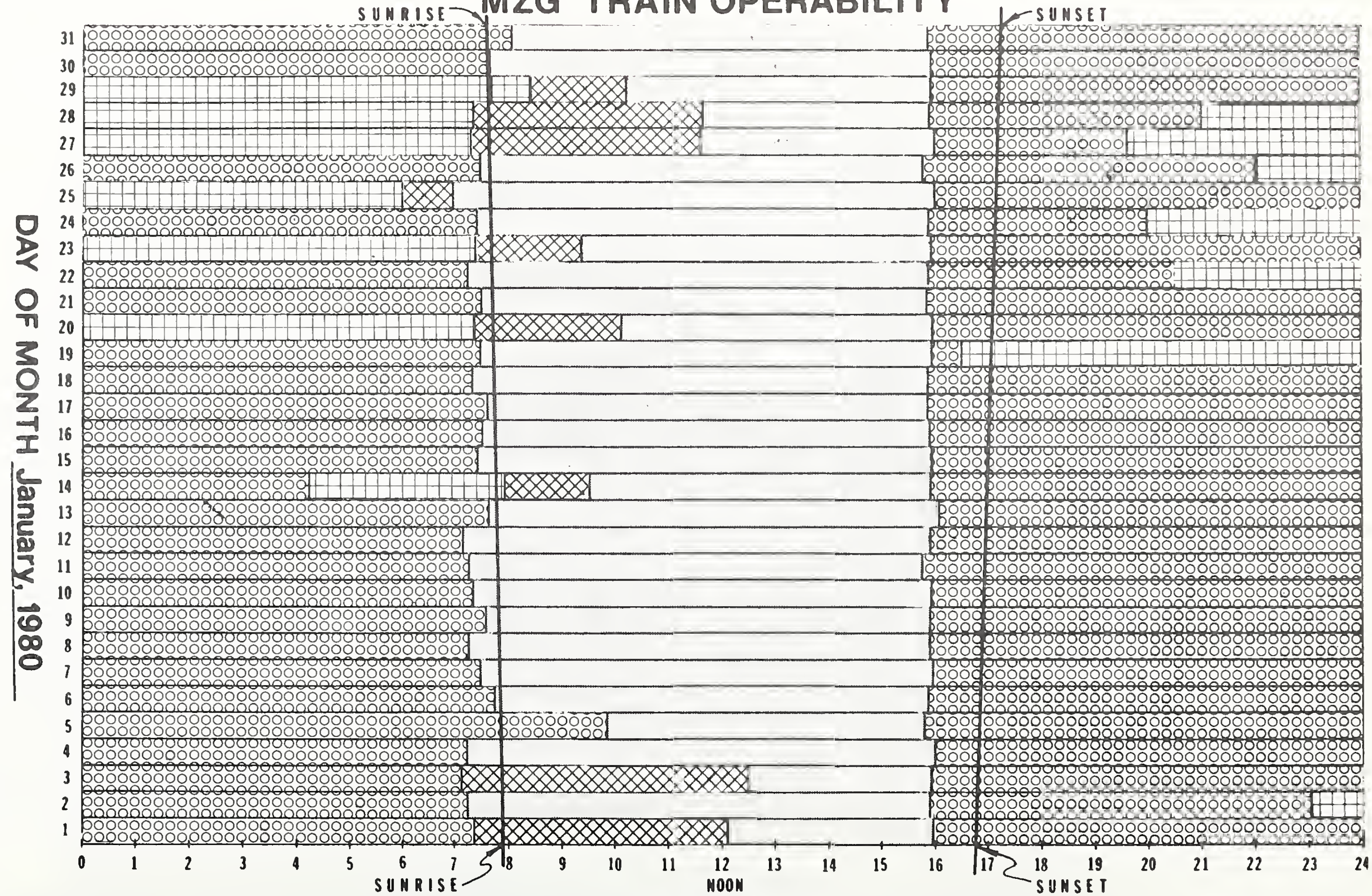
TESTED - NON-OPERABLE 1

NOTE: Dec. 28 thru 31 Automatic operation was limited by a heavy freezing fog. Photographic data obtained for inclusion in final report.

1 PHYSICALLY OPERATED

2 COMPARISON OF AMBIENT GUIDEWAY CONDITIONS WITH PAST OPERABLE HISTORY USED TO DETERMINE OPERABLE STATUS.

AUTOMATIC MODE
MZG TRAIN OPERABILITY



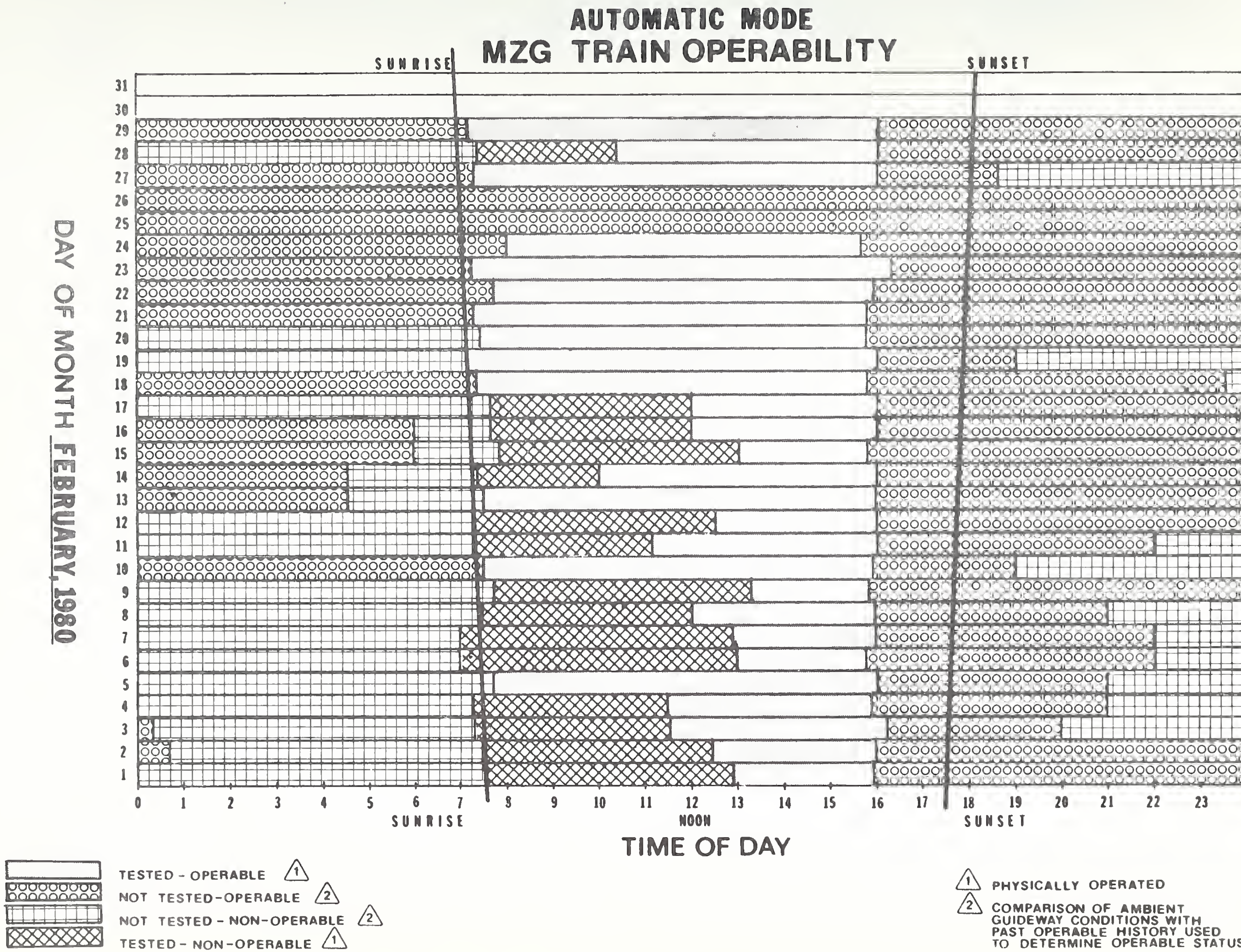
TIME OF DAY

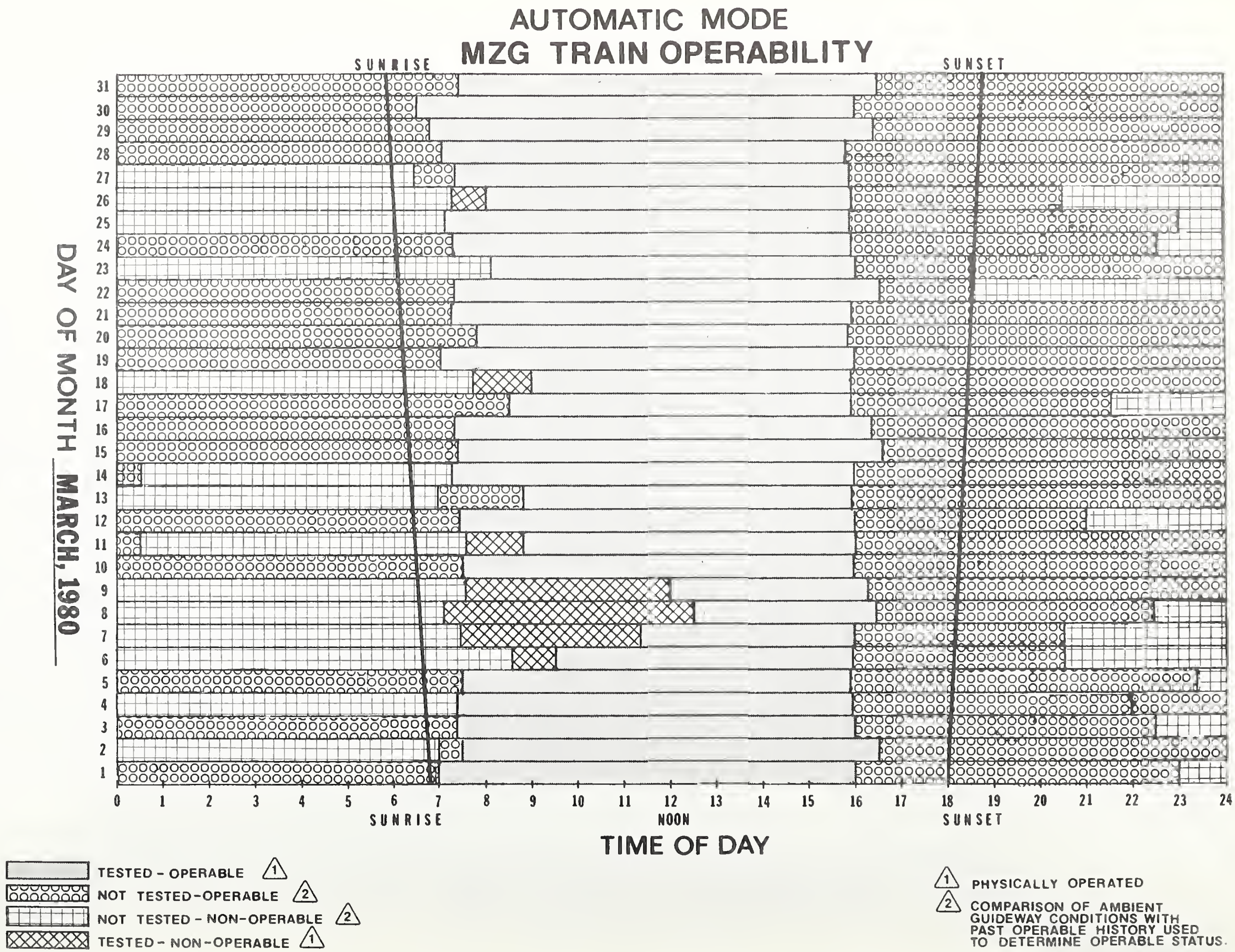
- TESTED - OPERABLE (1)
- NOT TESTED - OPERABLE (2)
- NOT TESTED - NON-OPERABLE (2)
- TESTED - NON-OPERABLE (1)

NOTE: Where indicated as Not Tested, Non-Operable, the evaluation is based on expected frost accumulations on power and control rails.

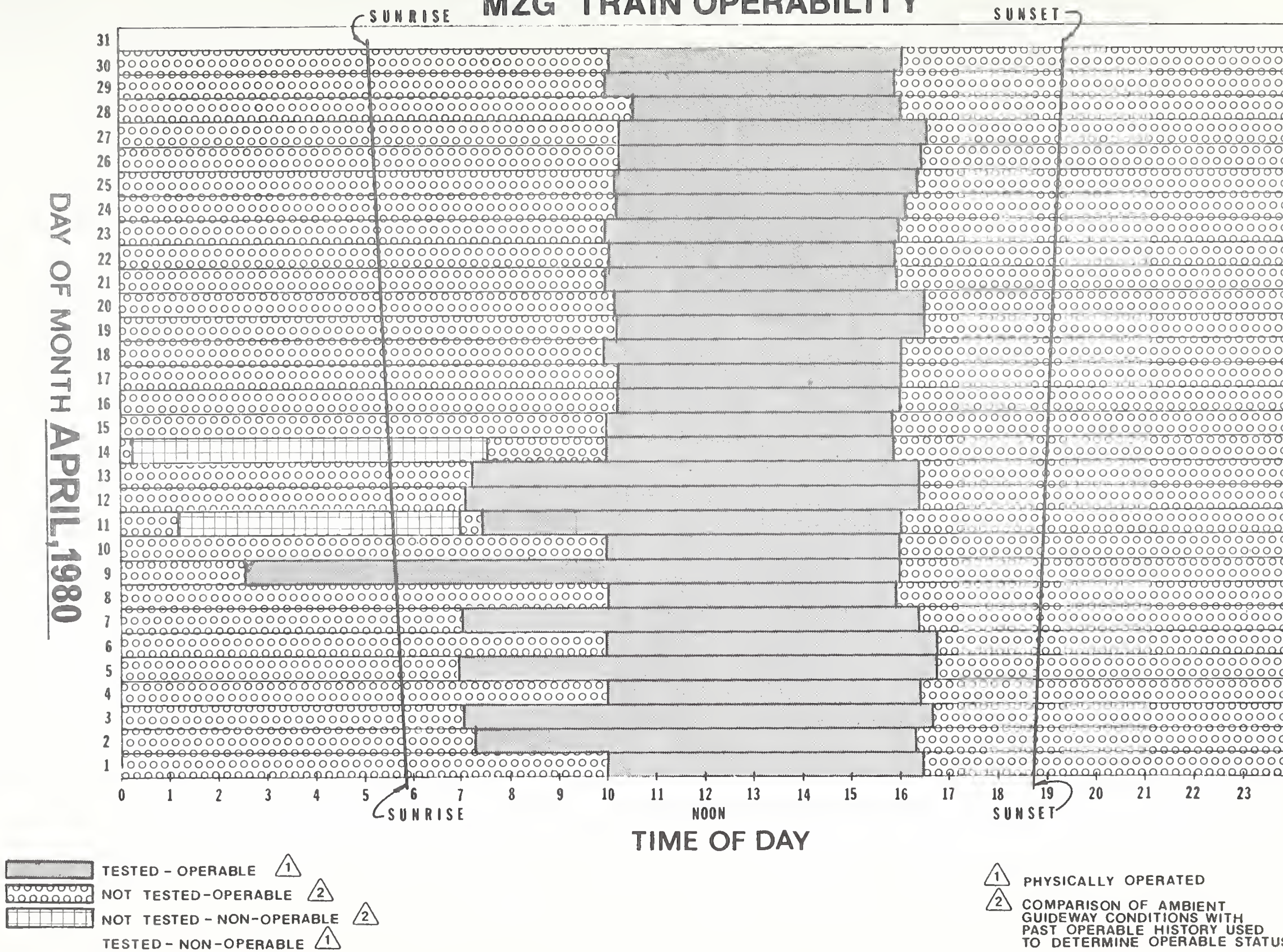
(1) PHYSICALLY OPERATED

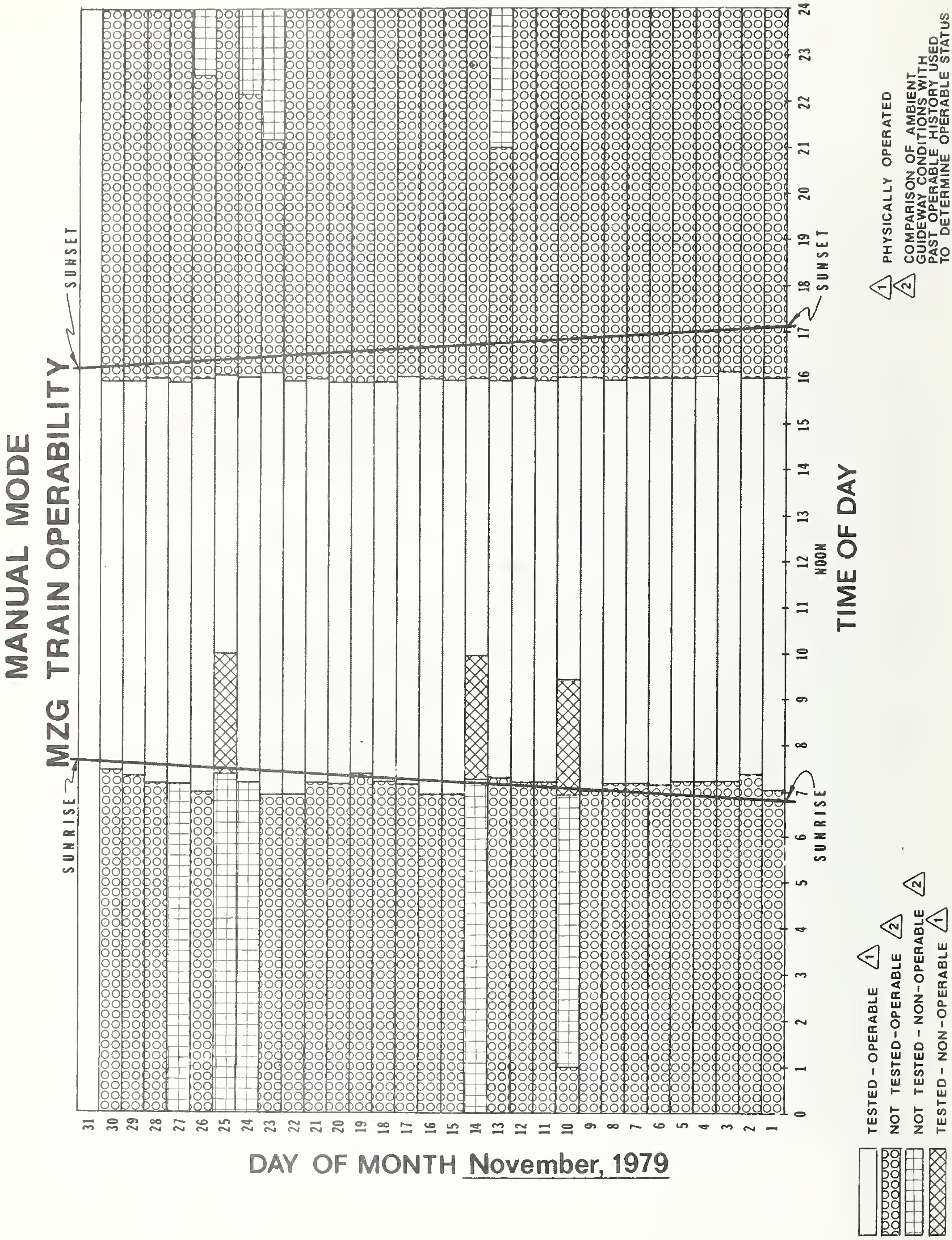
(2) COMPARISON OF AMBIENT GUIDEWAY CONDITIONS WITH PAST OPERABLE HISTORY USED TO DETERMINE OPERABLE STATUS


AUTOMATIC MODE
MZG TRAIN OPERABILITY
SUNRISE
SUNSET
DAY OF MONTH FEBRUARY, 1980
31
30
29
28
27
26
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
SUNRISE
NOON
SUNSET
TIME OF DAY
TESTED - OPERABLE 1
NOT TESTED-OPERABLE 2
NOT TESTED - NON-OPERABLE 2
TESTED - NON-OPERABLE 1
1 PHYSICALLY OPERATED
2 COMPARISON OF AMBIENT GUIDEWAY CONDITIONS WITH PAST OPERABLE HISTORY USED TO DETERMINE OPERABLE STATUS

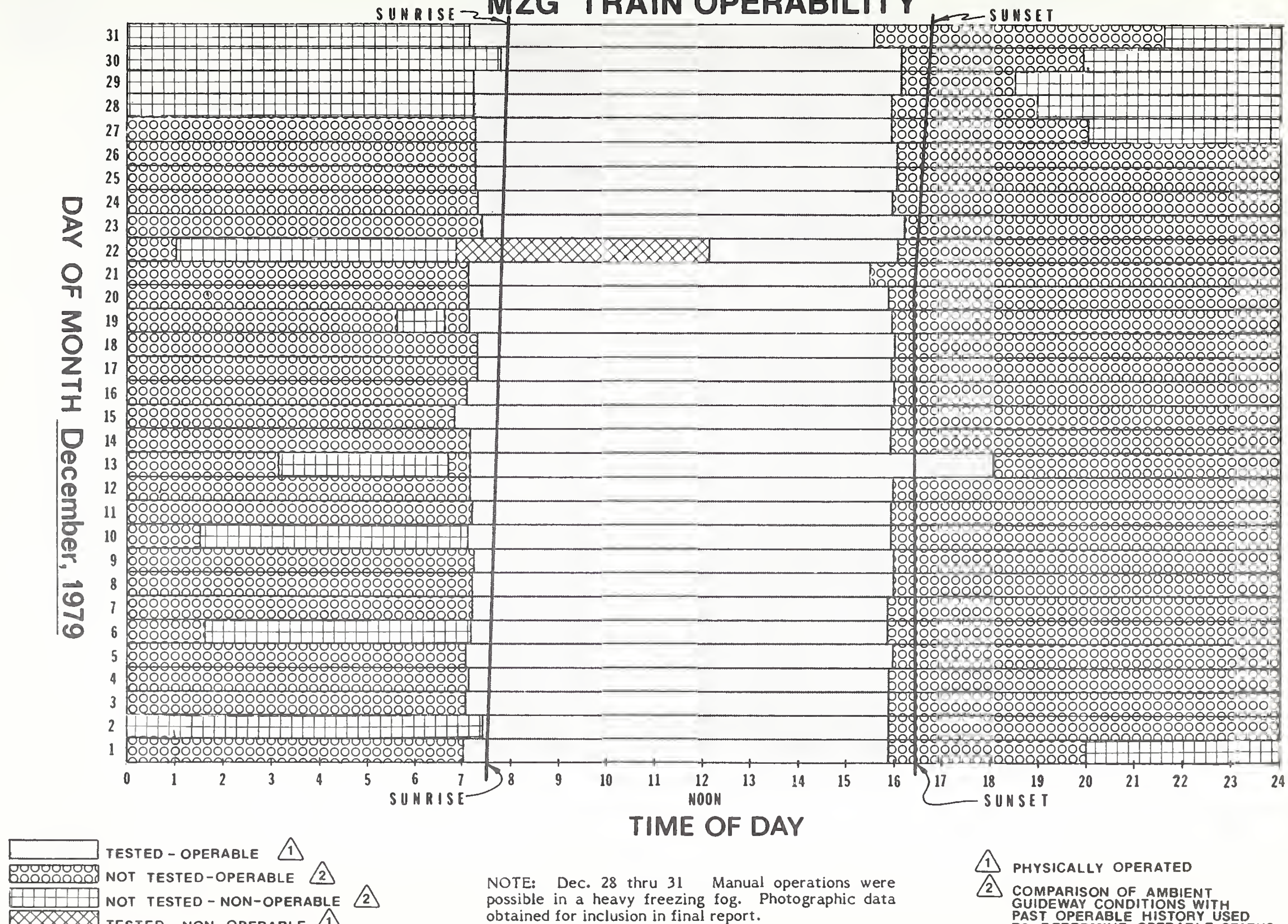

AUTOMATIC MODE
MZG TRAIN OPERABILITY
SUNRISE
SUNSET
DAY OF MONTH MARCH, 1980
31 30 29 28 27 26 25 24 23 22 21 20 19 18 17 16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
SUNRISE
NOON
SUNSET
TIME OF DAY
TESTED - OPERABLE 1
NOT TESTED-OPERABLE 2
NOT TESTED - NON-OPERABLE 2
TESTED - NON-OPERABLE 1
1 PHYSICALLY OPERATED
2 COMPARISON OF AMBIENT GUIDEWAY CONDITIONS WITH PAST OPERABLE HISTORY USED TO DETERMINE OPERABLE STATUS.

AUTOMATIC MODE
MZG TRAIN OPERABILITY




MANUAL MODE
MZG TRAIN OPERABILITY
TIME OF DAY
DAY OF MONTH November, 1979
SUNRISE
SUNSET
NOON
TESTED - OPERABLE 1
NOT TESTED - OPERABLE 2
NOT TESTED - NON-OPERABLE 2
TESTED - NON-OPERABLE 1
1 PHYSICALLY OPERATED
2 COMPARISON OF AMBIENT GUIDEWAY CONDITIONS WITH PAST OPERABLE HISTORY USED TO DETERMINE OPERABLE STATUS.

MANUAL MODE
MZG TRAIN OPERABILITY

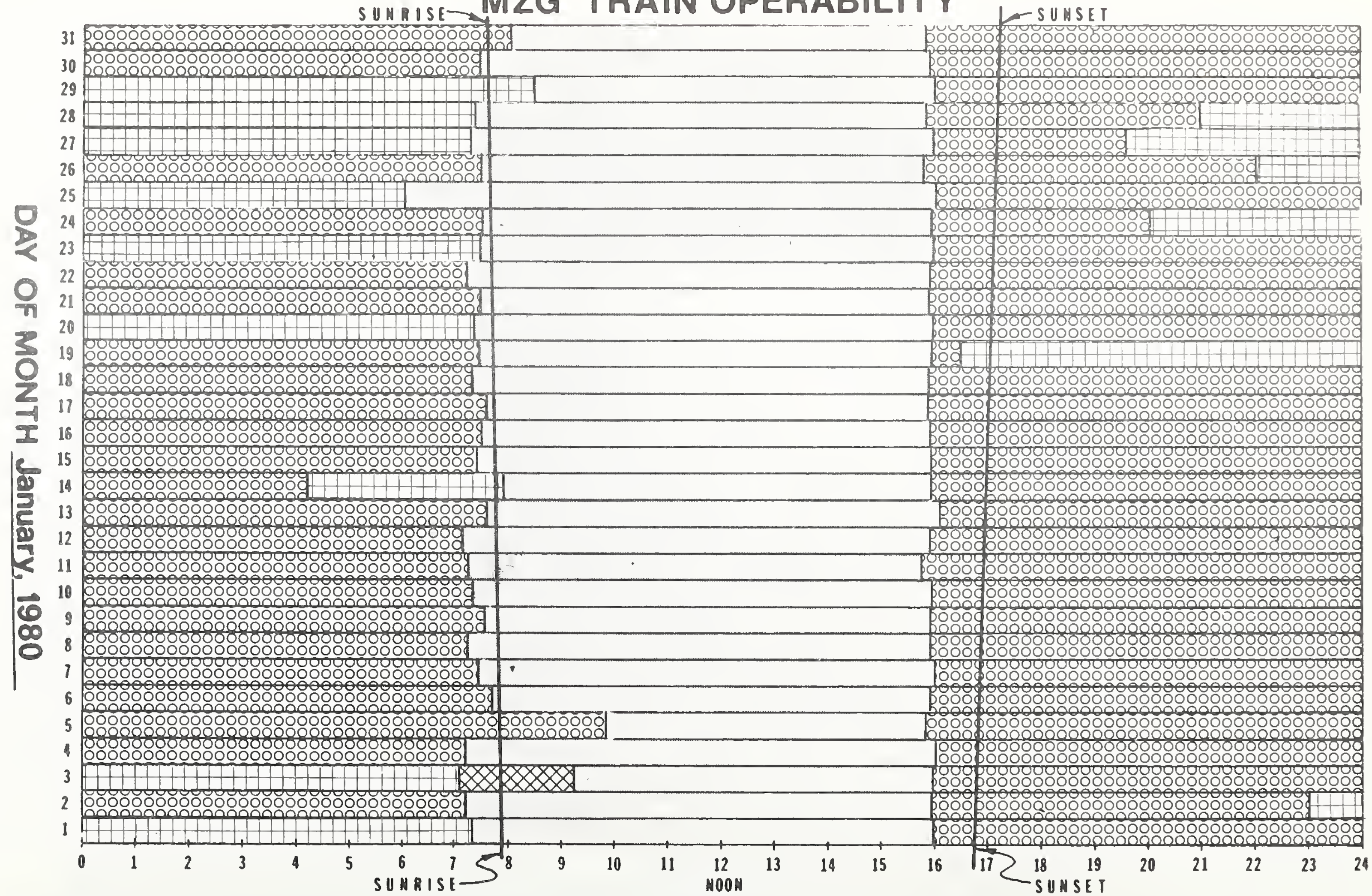


NOTE: Dec. 28 thru 31 Manual operations were possible in a heavy freezing fog. Photographic data obtained for inclusion in final report.

1 PHYSICALLY OPERATED

2 COMPARISON OF AMBIENT GUIDEWAY CONDITIONS WITH PAST OPERABLE HISTORY USED TO DETERMINE OPERABLE STATUS.

MANUAL MODE
MZG TRAIN OPERABILITY



TESTED - OPERABLE ⚠1

NOT TESTED-OPERABLE ⚠2

NOT TESTED - NON-OPERABLE ⚠2

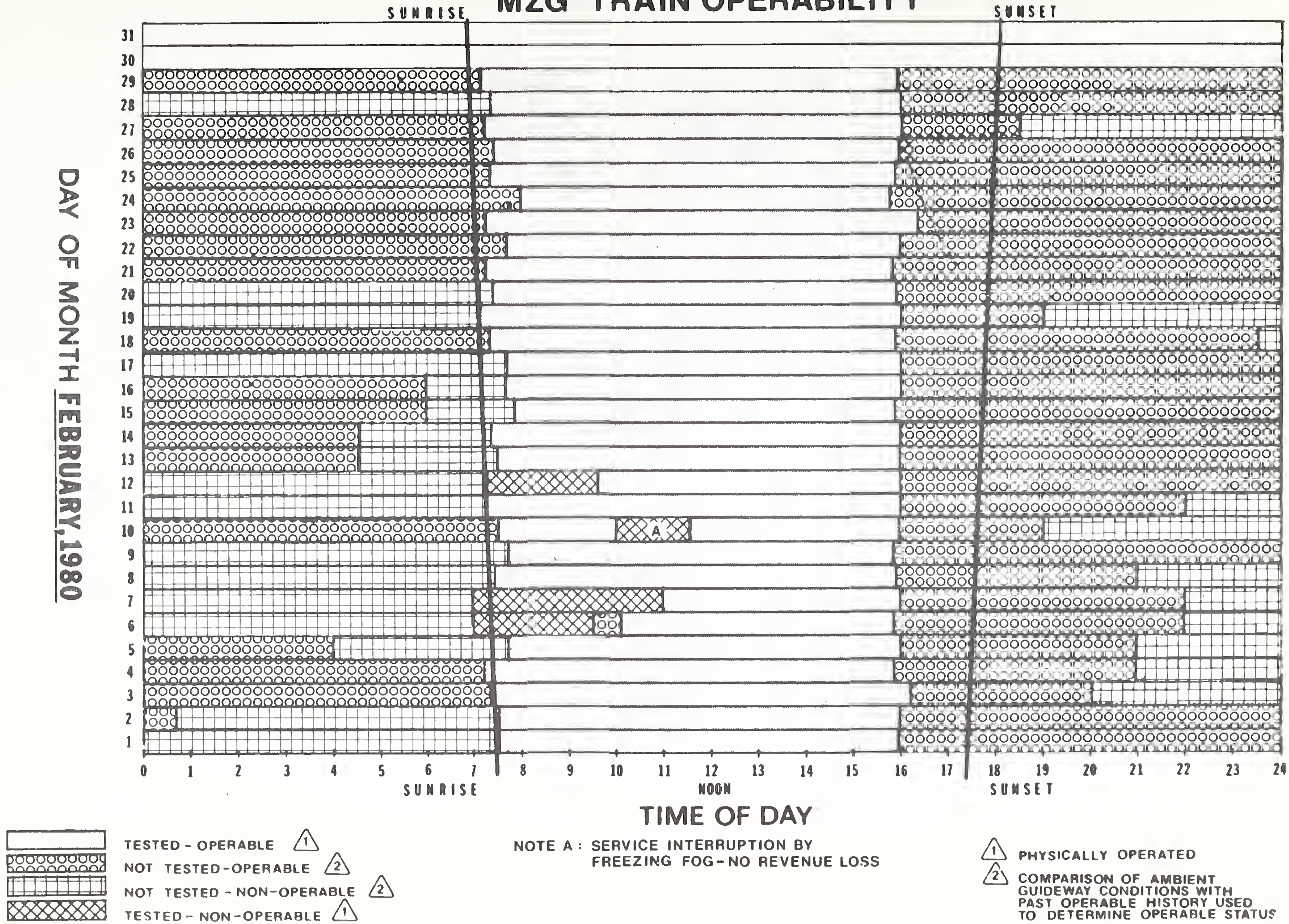
TESTED - NON-OPERABLE ⚠1

NOTE: Where indicated as Not Tested, Non-Operable, the evaluation is based on expected frost accumulations on power and control rails.

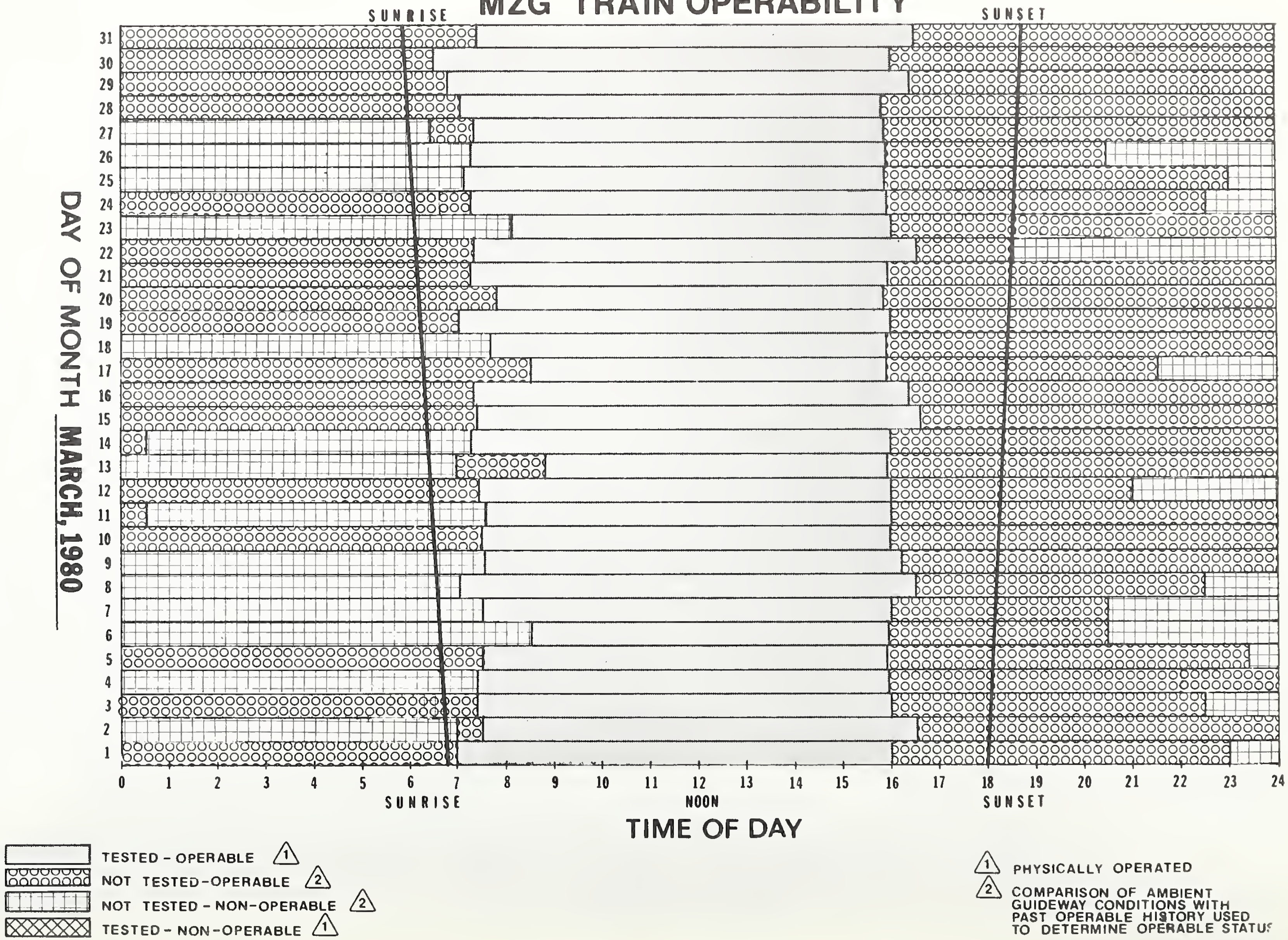
⚠1 PHYSICALLY OPERATED

⚠2 COMPARISON OF AMBIENT GUIDEWAY CONDITIONS WITH PAST OPERABLE HISTORY USED TO DETERMINE OPERABLE STATUS

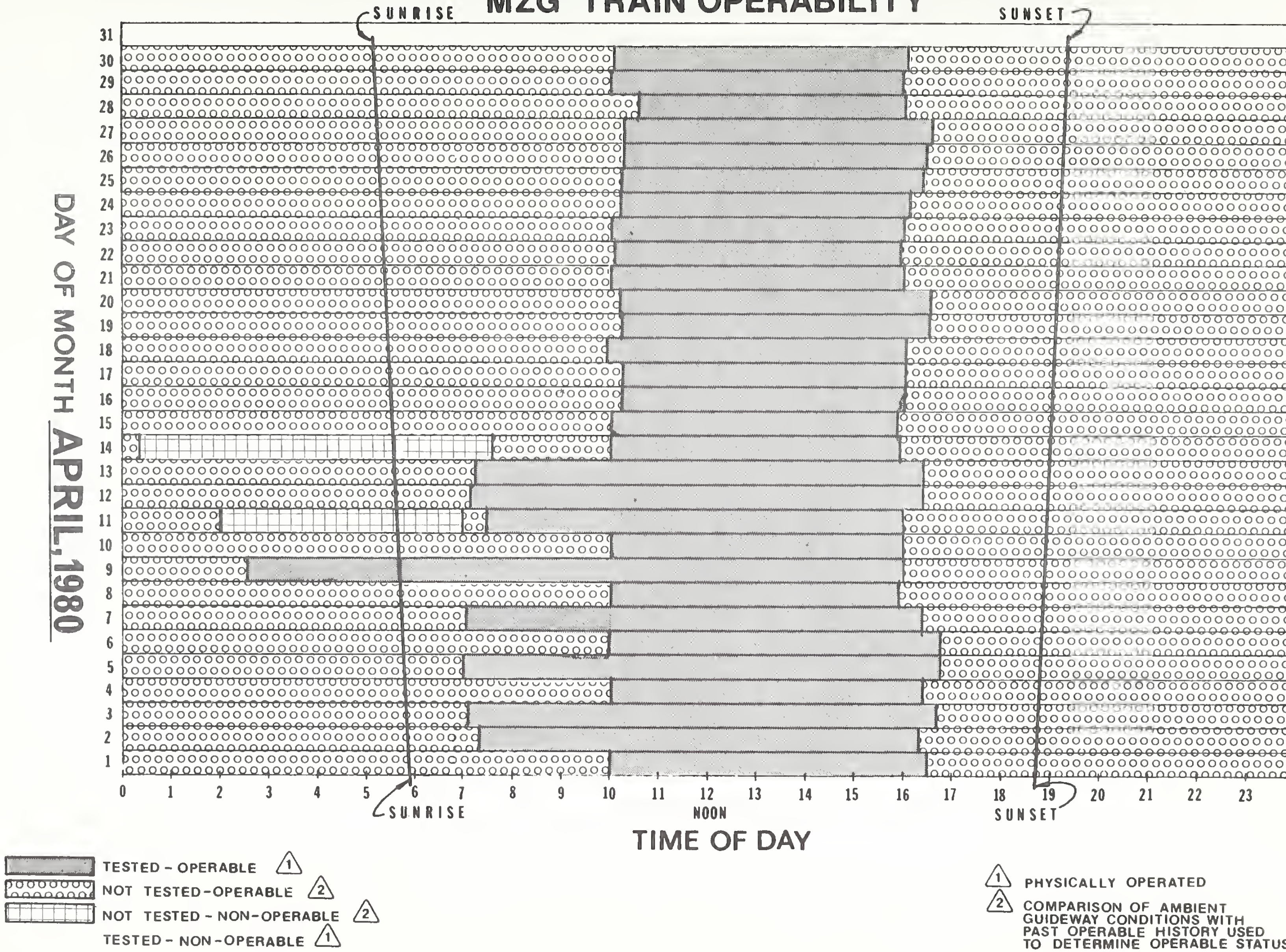
MANUAL MODE
MZG TRAIN OPERABILITY



MANUAL MODE
MZG TRAIN OPERABILITY



MANUAL MODE
MZG TRAIN OPERABILITY



DATE 1-24-80

SPECIFIC TEST CONDITIONS AND CORRESPONDING SUBJECTIVE EVALUATION OF SYSTEM PERFORMANCE

ITEM UNDER TEST Snow Module - Train 3

TEST CONDUCTOR R. T.

AMBIENT CONDITIONS

Duration of Operation in Hours	Ambient Dew Point Temp. (°F)	Wind Velocity (MPH)	Ambient Temperature (°F)	Guideway Snow Depth in Inches	Guideway Ice Accumulation in Inches	Rain or Snow Rate (IWH)	Snow Rate (Inches Accumulation/Hour)	Snow Density (% Water Content)
Cont	-50	75	-50	40	.90	3.0	9	100
22	-45	70	-45	35	.85	2.0	8	95
20	-40	65	-40	30	.80	1.0	7	90
18	-35	60	-35	25	.75	.9	6	85
16	-30	55	-30	20	.70	.8	5	80
14	-25	50	-25	15	.65	.7	4	75
12	-20	45	-20	10	.60	.6	3	70
10	-15	40	-15	9	.55	.5	2	65
9	-10	35	-10	8	.50	.4	1	60
8	-5	30	-5	7	.45	.3	.9	55
7	0	25	0	6	.40	.2	.8	50
6	+5	20	+5	5	.35	.15	.7	45
5	+10	15	+10	4	.30	.10	.6	40
4	+15	10	+15	3	.25	.05	.5	35
3	+20	8	+20	2	.20	.04	.4	30
2	+25	6	+25	1	.15	.03	.3	25
1	+30	4	+30	.5	.10	.02	.2	20
.5	+35	3	+35	.25	.05	.01	.1	15
.25	+40	2	+40	T	T	T	T	10
<.25	+45	<2	+45	0	0	0	0	5

CATEGORIES OF SYSTEM OPERATION

MAINTAINING SYSTEM AVAILABILITY	ACCOMPLISHING SYSTEM STARTUP
o No winterization activity required 100% availability	o No winterization activity required on schedule start
o Winterization procedures only required 100% availability	o Winterization procedures only required on schedule start
o Winterization procedures and specific equipment required 100% availability	o Winterization procedures and special equipment required on schedule start
o Winterization procedures and special equipment required 100% available at a reduced performance level	o Winterization procedures and special equipment required startup accomplished on a delayed schedule
o Above the threshold of winter problems which can be overcome. Operation limited to shutdown or emergency evacuation.	o Above the threshold of winter problems which can be overcome. Start up delayed indefinitely

Notes:

7:00 AM

.10" melted water shown in rain gauge - approx 1½-2" of snow fell overnight

Approx. 5% of track was covered with approx ½-¾" of snow; rest blown clear

(Note: 1 area of spur track - 1½" cover)

▭ Conditions verified operational by test
XXX Conditions considered operational because of reduced weather stress
/// Conditions considered operational by data extrapolation

FORM NO. 1

1-25-80

SPECIFIC TEST CONDITIONS AND CORRESPONDING SYSTEM PERFORMANCE AT SCHEDULED 7 A.M. STARTUP

EXISTING AMBIENT CONDITIONS Time [illegible]

Platform temp. 4°F Sunrise 7:41 Sky Cover [illegible]
Raining – Snowing – Ground Cover [illegible]
Notes:

Weather Station Readings

Time	[illegible]	[illegible]	
Temperature	6°F	8°F	
Relative Humidity	100%	100%	
Dew Point	* 5°F	* 7°F	
Barometric Pressure	29.88	29.90	
Wind Speed (average)	3-5	3-5	
Gusts to:	–	–	
Wind Direction	NW 330°	NW 330°	
Solar Energy Reading	0	0	

Previous Ambient Conditions (Last 24 hours):
High 24°F Low 6°F Precipitation [illegible] Ground Cover [illegible]
Notes:
* Weatherama

TRACK SURFACE INITIAL CONDITIONS Time [illegible]

Dry
Leaves
Wet
Frost

Snow: Surface
New crystals
Depth
Density
Hardness Index

Notes: Test section iced overnight (1/2" acc. glaze ice)

INITIAL TRAIN CONDITIONS Time [illegible]

Train # [illegible] Operator [illegible]

Train Condition:
Outside storage
Inside storage
Track power on [illegible] am
Charger on
Battery heaters on
ECU's on
First motion at

Doors:
Initial operation OK
Subsequent operation OK
Cab temperature:
Before test run
After test run
Notes:

TEST RUN CONDITIONS

Start Time	[illegible]	[illegible]	[illegible] am
Manual Operation Time	[illegible]		
Automatic Operations Time		[illegible] *	[illegible] am
Snow Module not Installed			
Snow Module Installed			
Snow Module Plow Up			
Snow Module Plow Down			
Snow Module Brushes Up			
Snow Module Brushes Down			
Stop Time	6:35	7:05	[illegible]

Notes:

* [illegible]
[illegible]
See Form #16, 1-25-80

FORM NO. 2

TRAIN LOG

TRAIN # 1
DATE 12-10-79

TRAIN HOURS: 263.0 / 266.1 Total: 3.1
Start End

MAINTENANCE RELEASE:

Restrictions: 6ft/SEC. don't run in automatic untill frost is clear.

MB
Signature Time

OPERATOR CHECK:

Battery Voltage (front panel) 28
Battery Voltage (side panel) (charger off) 29
Track Voltage (Phase A) 470
Track Voltage (Phase B) 480

Signal Voltage 21
Reserve Brake Pressure 460
Security Radio (turned off) ____
Security Beeper (turned on) ____

M.L. Martin 7:12 AM
Signature Time

AMBIENT AND TRACK SURFACE CONDITIONS:

	Sky Cover	Temp.	Track Surface	Precip.	Initial
7:00	Mostly Clear	28°	Heavy frost	—	MLM
10:00	MOSTLY CLEAR	34°	FROST MELTING	—	DH
1:00	Partly Cloudy	48°!	Clear - Few wet spots	—	KH
4:00	PARTLY CLOUDY	47°	CLEAR	—	DR

SNOW MODULE USE:

Trip Start Time	Module Attached Yes/No	Brushes Up/Down	Plow Up/Down

OPERATOR COMMENTS: (Log time and initial all entries)

2-12-80

Sent

STATION OPERATORS' LOG OF SPECIFIC OPERATING CONDITIONS AND SYSTEM PERFORMANCE

TRAIN #	SNOW ~~MODULE~~ ATTACHED - YES/NO	TIME STARTED	TIME ENDED	CIRCUITS	TOTAL HOURS
2	no	10:39	4:02	9	5 1/2

ZOO ADMISSIONS 373 MONORAIL ADMISSIONS 161 43 %

Previous Ambient Conditions (Last 24 hours):
High ______ Low ______ Precipitation ______ Ground Cover ______
Notes:

Time	Sky Cover	Temp.	Track Surface	Precipitation	Initial
7:00	Clear	-2°F	Heavy frost	None	[illegible]
10:00	Clear	6°	[illegible]	—	[illegible]
1:00	light clouds	10°	dry	none	[illegible]
5:00 / 4:00	[illegible]	12°F	Dry	None	[illegible]

Notes: (Log time and initial all entries)

Winterization testing: 7:16 AM: Phase A + B Volts dropped 10-15 V. Due to possibility of frost accumulating on brushes (Train 2 doesn't have brush heaters), testing suspended for the present. (Note: Auto. and Manual both fully operable in heated test area). [illegible]
Manual tested operable at 9:30. [illegible]
Auto 12:37

2-11-80

TEST CONDUCTORS LOG

Universal Mobility Inc. Winterization Test/Demonstration
Contract DOT-TSC-1585, Mod 2

Train 2 Operator: M. L. Martin

Platform temp: 7:10 AM: 2°F

Track surface: Mod. frost, trace of snow

Precip. last 24 hrs: Trace of snow

Sky cover: P. Cloudy

Ground cover: 100% Snow-Covered

Trip time: 7:15 - 7:55 (Manual)

7:15 - Auto. operable in heated test section

11:07 - Auto. operable on entire guideway

REGISTER ANY INQUIRY OR COMPLAINT AT:

DAKOTA ELECTRIC ASSOCIATION
FARMINGTON, MINNESOTA 55024
PHONE 612—463-7134

CUSTOMER INFORMATION BOOKLET AVAILABLE ON REQUEST AT:

RECEIVED DEC 1 3 1979

TEAR OR FOLD HERE

30987-00.2
MINN ZOOLOGICAL GARDENS
2 EAST SIDE MONORAIL
12101 JOHNNY CAKE RIDGE RD
APPLE VALLEY MN 55124

ACCOUNT NO.	30987-00.2
AMOUNT DUE NOW	100.19
AFTER THIS DATE	12/26/79
PLEASE PAY	110.21
BILLING DATE	12/11/79

TEAR OFF HERE AND MAIL WITH CHECK —— PLEASE BRING THIS STUB WHEN MAKING PAYMENT

REGISTER ANY INQUIRY OR COMPLAINT AT

DAKOTA ELECTRIC ASSOCIATION
FARMINGTON, MN. 55024 • PHONE 612-463-7134

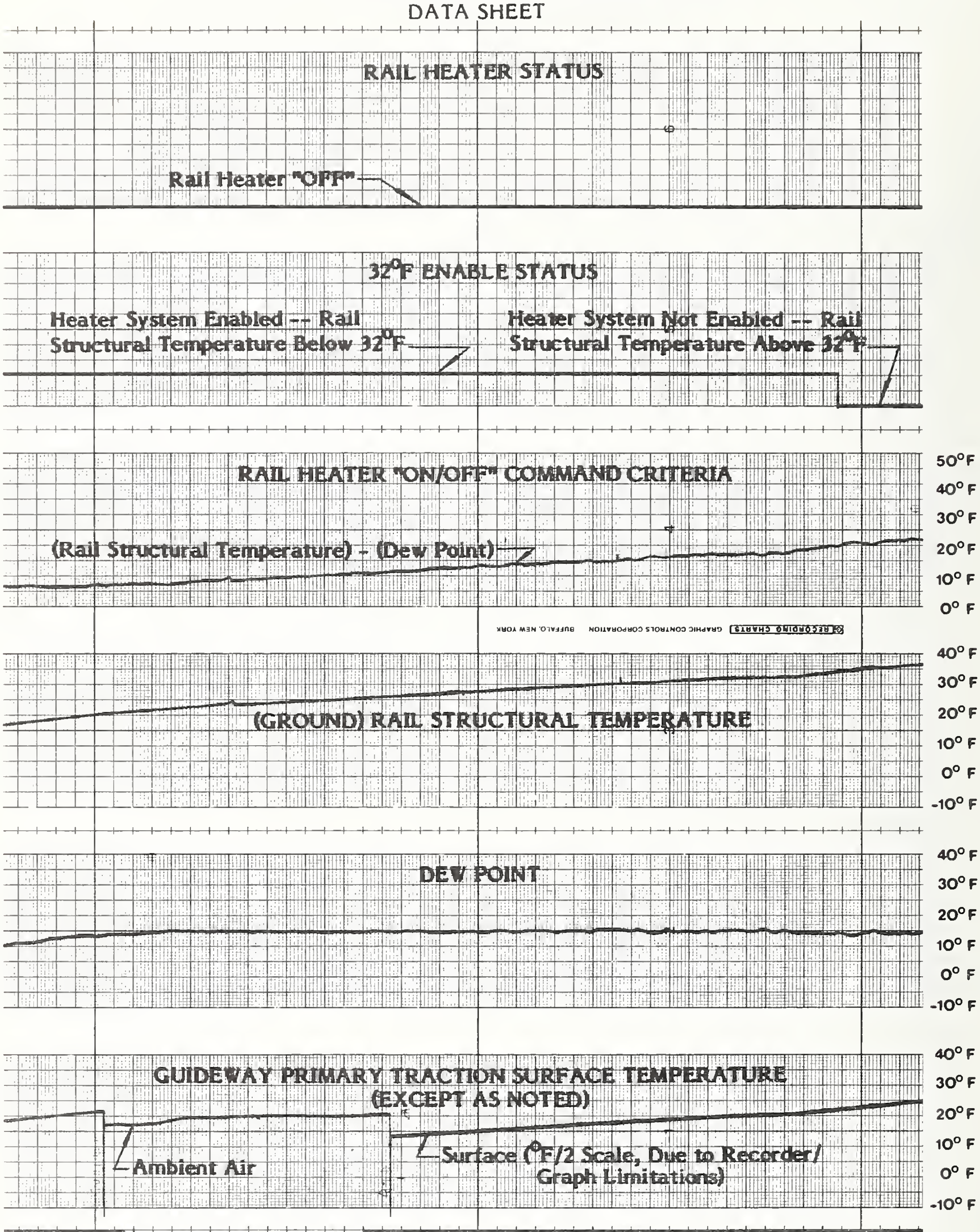
CUSTOMER INFORMATION BOOKLET AVAILABLE ON REQUEST AT:

READING DATES FROM 10/30/79 TO 11/28/79 COMMERCIAL LARGE

KW DEMAND	PREV READING	PRES. READING	KWH CONSUMPTION	CONSTANT		AMOUNT OF CHARGES
44.80	5	6	160	160		
			FIXED CHARGE			5.00
			ENERGY	160 KWH	.039	6.24
			DEMAND CHARGE			87.00
			POWER COST ADJ		.0122	1.95

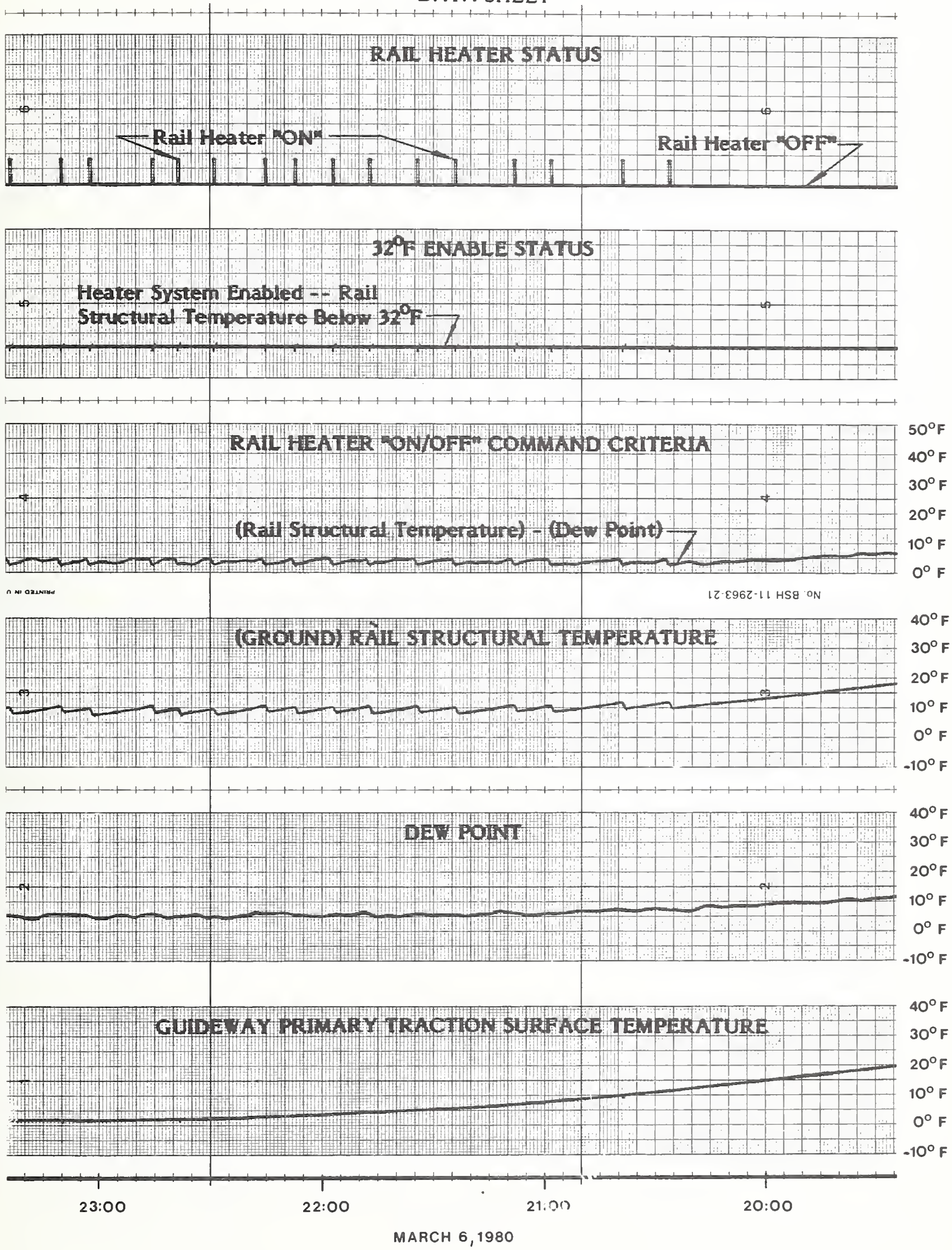
LAST PAYMENT 148.08 DATE 12/05/79
ACCOUNT NO. 30987-00.2 82-15-40-15-00-00 AMOUNT DUE NOW ➡ 100.19
NAME MINN ZOOLOGICAL GARDENS 2 EAST SIDE MONORAIL
BILLING DATE 12/11/79 AFTER 12/26/79 PAY THIS ➡ 110.21

DATA FORM 16 -- HCS
(POWER RAIL HEATER FEEDBACK CONTROL SYSTEM)
DATA SHEET

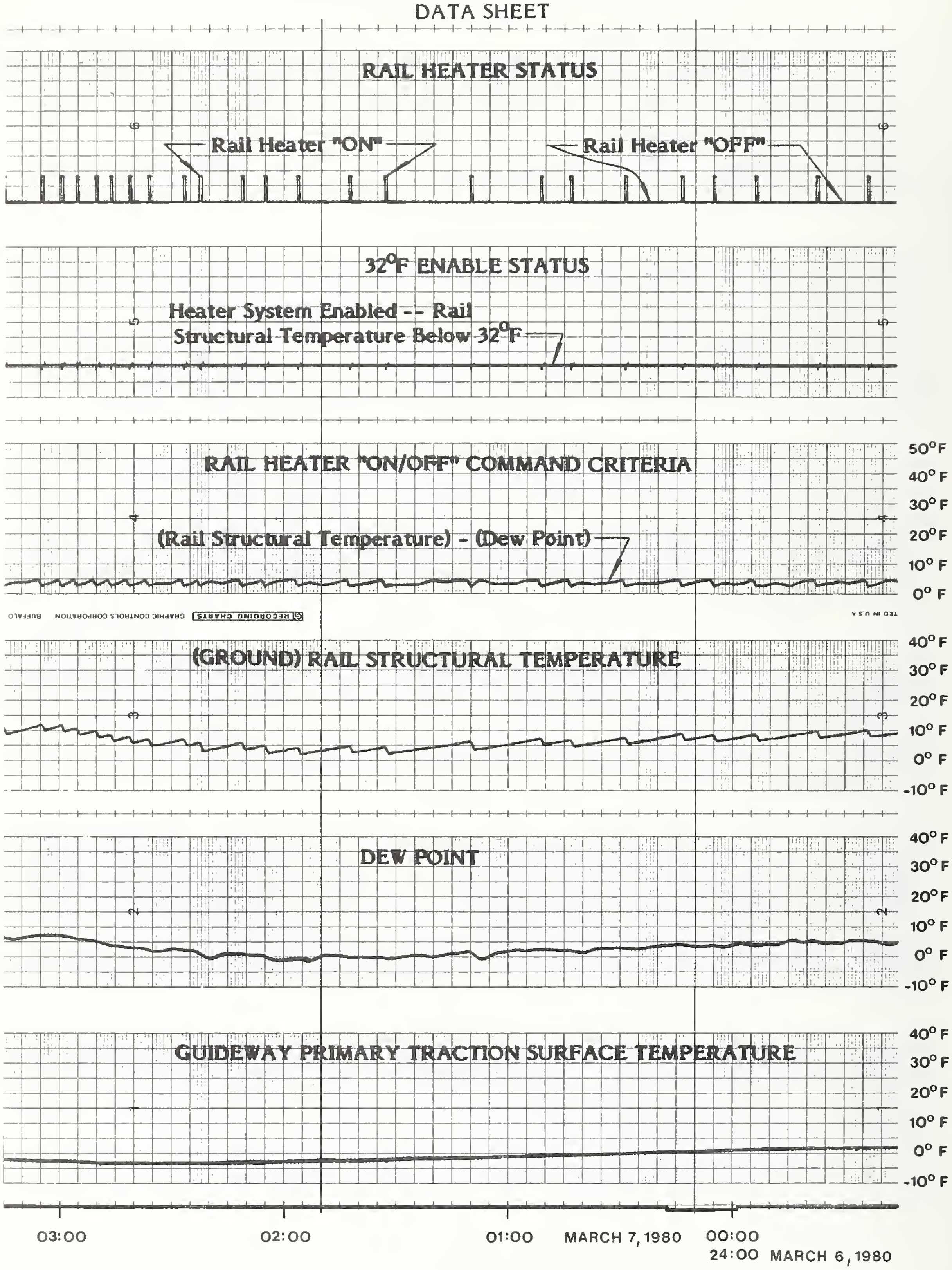


MARCH 6, 1980

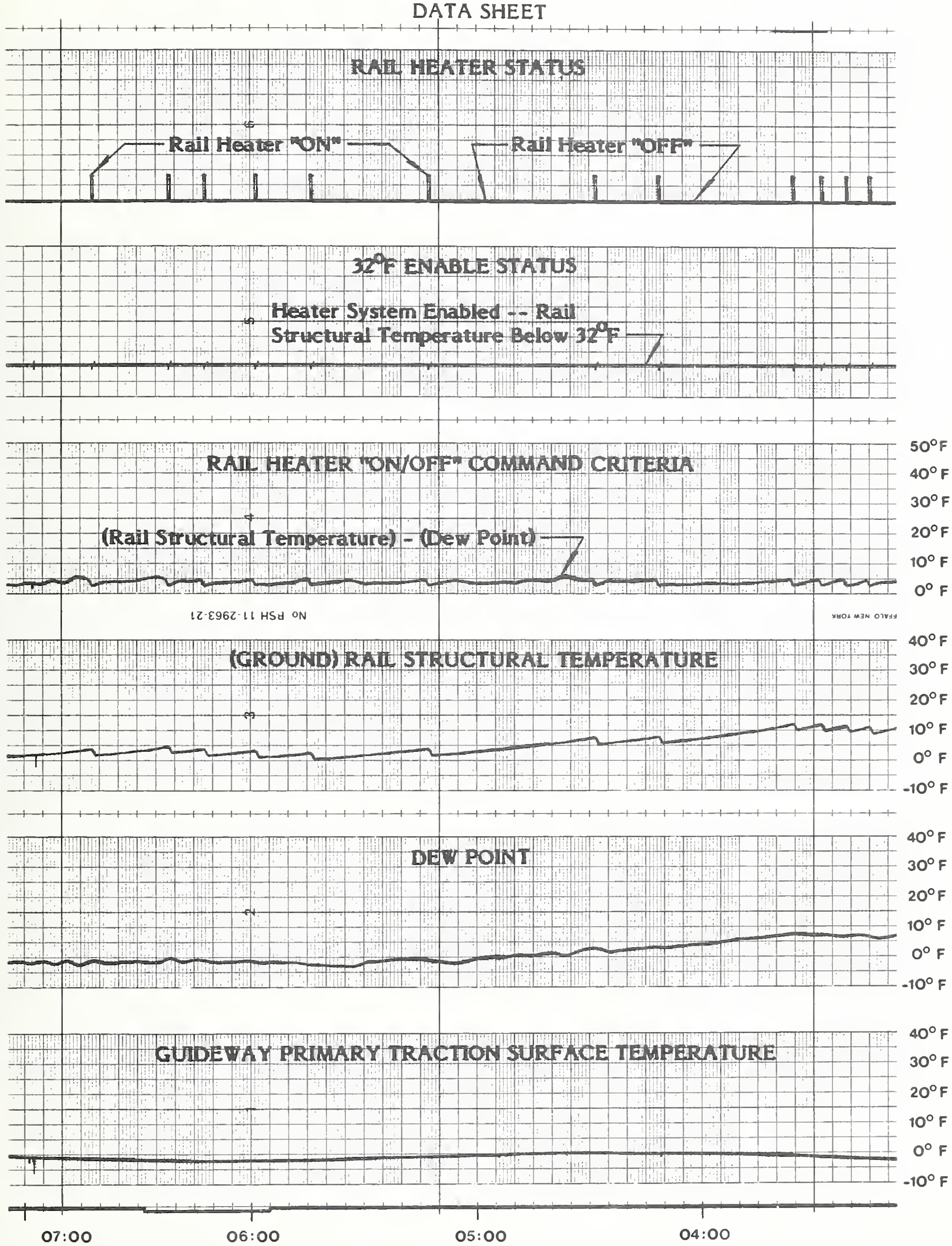
DATA FORM 16 -- HCS
(POWER RAIL HEATER FEEDBACK CONTROL SYSTEM)
DATA SHEET



DATA FORM 16 -- HCS
(POWER RAIL HEATER FEEDBACK CONTROL SYSTEM)
DATA SHEET

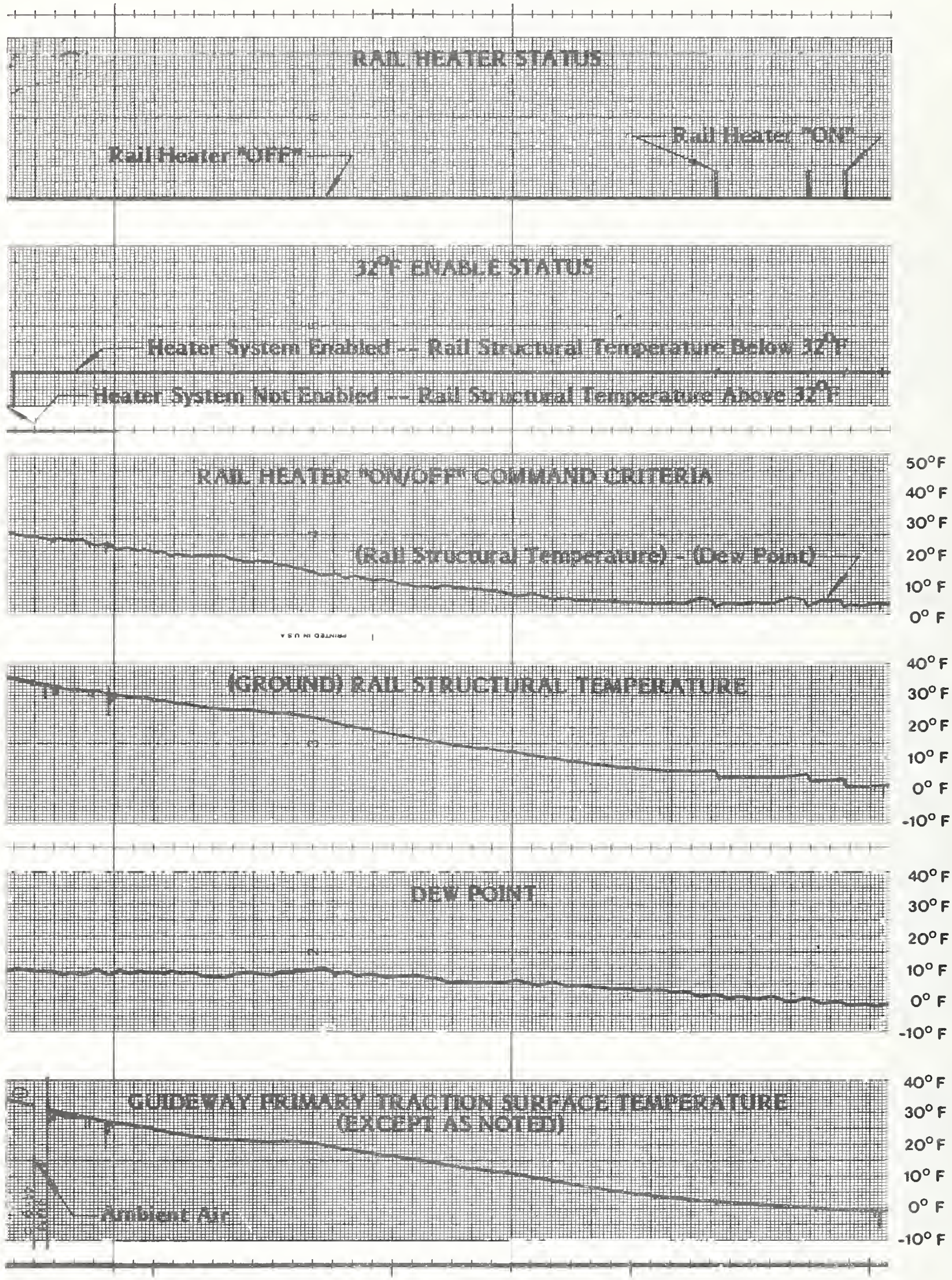


DATA FORM 16 -- HCS
(POWER RAIL HEATER FEEDBACK CONTROL SYSTEM)
DATA SHEET



MARCH 7, 1980

DATA FORM 16 -- HCS
(POWER RAIL HEATER FEEDBACK CONTROL SYSTEM)
DATA SHEET



MARCH 7, 1980

4/10/86

UNIVERSAL MOBILITY INC./MINNESOTA ZOOLOGICAL GARDEN SURVEY

1. Did you come to the zoo specifically because the monorail is now open?

   Circle one: YES (NO)

2. Did the monorail ride experience meet your expectations?

   Circle one: YES NO

3. How did you arrive at the zoo?

   Circle one: (Private car)
   Public transit
   Charter bus
   Other____________

4. Did you expect the monorail to be operational in this weather?

   Circle one: (YES) NO

5. Were you comfortable during your trip?

   Circle one: (YES) NO

6. Did you have any problems entering or exiting the monorail?

   Circle one: YES (NO)

7. Did you know this system operates for almost the same cost summer and winter?

   Circle one: YES (NO)

8. Additional comments:

Good way to stay out of weather, And take those who get tired walking fast, such as children & elderly adults

Thank you

APPENDIX D

REPORT OF NEW TECHNOLOGY

Universal Mobility, Inc. (UMI) has filed patent applications for various aspects of its AGT System which have been independently developed by UMI. Specifically, UMI has filed patent applications covering its power rail feedback control system (PRFCS), an auxiliary drive traction system and certain design aspects of the monorail guideway assembly. The PRFCS is designed to prevent the formation of frost or dew on the power and control rails by controlling a heating element in response to the detected bus bar structural temperature and the detected ambient dew point temperature. The auxiliary traction system provides a secondary drive system for an AGT vehicle that may be driven independently of the AGT vehicle's main drive system, thus enhancing operability of the AGT vehicle during severe weather conditions. The monorail guideway assembly developed by UMI and which is also the subject of various patent applications is specifically designed to discourage the collection of ice or snow upon exterior running surfaces and power and control rails.

The equipment, winterization techniques and operating strategies developed by UMI will be useful at AGT sites exposed to severe winter climates. UMI's winterization technology has been designed to provide reliable AGT system performance at the lowest reasonable cost.

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