All-Weather Protection for AGT Guideways and Stations

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This paper presents a synopsis of the state-of-the-art review of winter weather protection for existing AGT (automated guideway transit) systems conducted as part of the U.S. Department of Transportation UMTA sponsored AGT Guideway and Station Technology Project. The objective of this paper is to identify the problems, experiences, and techniques associated with winter weather operation of AGT systems. The information presented was compiled through a literature search and from information provided by system and equipment operators and manufacturers. Bottom-supported, rubber-tired AGT vehicle systems are the focus of the paper as they are the only type of AGT system with significant winter operational experience. These systems include Bendix at Toronto Zoo, Boeing at Morgantown, Ford at Fairlane, Vought at Airtrans, and the Westinghouse test tracks at South Park and West Mifflin. Three AGT guideway-related areas are identified as being most susceptible to the adverse effects of winter weather--power and signal collection, maintenance of traction, and switching. The problems experienced and countermeasures currently employed in each of these areas are presented. The countermeasures include mechanical, thermal, chemical, abrasive, manual, and other approaches. The paper also identifies techniques which warrant further investigation to improve AGT all-weather operation.

All transportation systems, including rail, bus, automobile, and aircraft, suffer deterioration in service, performance, and safety during adverse weather conditions. For automated guideway transit (AGT) systems, operating without the judgment provided by a driver or on-board attendant, the problems inherent in operation during severe weather are especially important. Achievement of the high productivity potential of fully automated operation will depend in large measure upon a satisfactory resolution of the issues associated with safe and reliable all-weather operation.

AGT systems, such as those shown in Figure 1, have been carrying passengers in completely unattended vehicles since 1965, when Westinghouse, under a $5 million contract from the U.S. Department of Housing and Urban Development, installed a 3.2 km (2 mi) loop demonstration system at South Park, a suburb of Pittsburgh. It carried nearly 41,000 passengers during the 1965 Allegheny County Fair. Since then numerous AGT systems have been installed in airports, universities, and other activity centers.' A total of 23 domestic installations comprising over 64 km (40 mi) of guideway and almost 700 vehicles have carried in excess of 200 million passengers over the past 13 years. They range in size from systems with approximately 360 m (1200 ft) of guideway and a few vehicles to those with guideways of over 21 km (13 mi) and more than 50 vehicles. Despite this accumulated experience, information on AGT all-weather operations is fairly limited. The great majority of AGT applications have been located in regions with mild climates, have been in amusement parks which do not operate during the winter, or have the option of not operating under severe weather conditions.

To further the development of AGT systems, the U.S. Department of Transportation Urban Mass Transportation Administration has established the Automated Guideway Transit Technology Program. The objective of this AGT program is to address among others the technological, operational, environmental, and cost aspects of AGT systems and to identify solutions to problems which have been identified. The program includes three generic types of AGT systems. These are shuttle-loop transit (SLT), group rapid transit (GRT), and personal rapid transit (PRT).

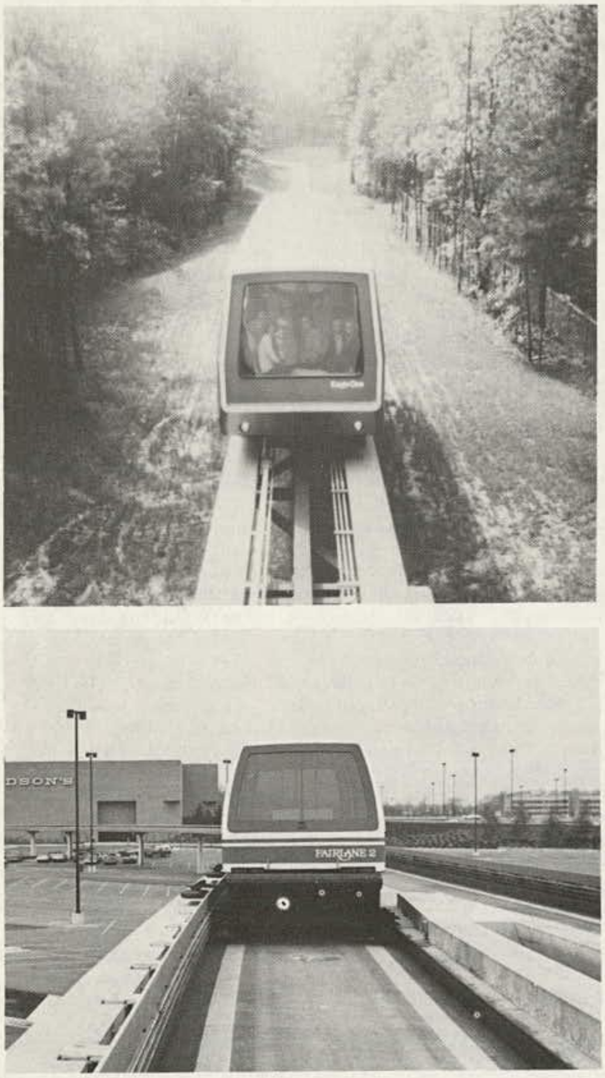
The AGT program includes a number of projects. One of these--the AGT Guideway and Station Technology Project--has as its primary objective the establishment of guideway, weather protection, and station concepts which will result in lower cost AGT installations. The work related to the weather protection area currently under way in this project is the basis for this paper.

In the weather protection area, the work involves a review of existing weather protection problems and techniques used in both AGT and other related transportation systems, the development and analysis of weather protection concepts, and the testing of weather protection concepts. To date the review portion of this work has been completed. The focus of this review was on bottom-supported, rubber-tired, operating AGT systems and the difficulties associated with winter weather operation.

The review of existing AGT winter weather-related operating experiences included the Ford Fairlane system and Cherry Hill test track, the Boeing Morgantown system, the Westinghouse South Park and West Mifflin test tracks, the Vought Airtrans system, and the Bendix Metropolitan Toronto Zoo system. Though the latter is not an automated system, its design and operating characteristics are similar to those of an AGT system, and it provides operating experience in a severe winter environment.

The most severe winter operational requirements are faced by the Morgantown system at the University of West Virginia. This system is required to provide normal service during the winter months in a region with significant ice and snow accumulation. The terrain is rugged, with guideway grades of up to 10 percent.

Figure 1. Typical operating AGT systems. (Top) Westinghouse at Busch Gardens in Williamsburg, Virginia. (Bottom) Ford at Fairlane Shopping Center in Dearborn, Michigan.



A more severe winter environment is faced by the rubber-tired people mover system at the Toronto Zoo. However, this system, being under manual control, has a degree of flexibility in coping with weather conditions not available to unmanned fully automated systems.

Ford AGT systems have also accumulated appreciable experience with ice and snow operation, both at the Ford test track in Cherry Hill, Michigan, and at the two-vehicle shuttle system at the Fairlane Shopping center in Dearborn, Michigan.

Although Westinghouse has installed a number of AGT systems, none of their commercial installations has required operations under conditions of ice and snow. Westinghouse does have, however, a considerable body of data accumulated from test programs involving operations in ice and snow. This includes tests conducted on the South Park demonstration system and more recently at their test facility in West Mifflin, Pennsylvania.

Finally, the Vought Airtrans system at the Dallas-Fort Worth Airport has had limited experience operating in ice and snow. While the Dallas-Fort Worth climate is relatively mild, there is sufficient ice and snow to require countermeasures for coping with winter weather.

Through this review, three guideway-related areas were identified which offer potential for winter-weather problems: (1) icing of signal and power rails; (2) loss of traction due to ice, snow, sleet, or freezing rain; and (3) freezing and jamming of guideway switches. Table 1 summarizes the winter weather provisions found in these three areas at the AGT systems examined. A discussion of the problems associated with and the countermeasures employed in each of these areas follows.

Power Rails

Icing of signal and power rails was found to be the most critical AGT guideway-related winter weather operational problem. Icing of rails may occur even without precipitation; with precipitation, the problem may be compounded. Signal and power flow to the vehicle can be interrupted by even a thin frost formation on the rails. Such an interruption typically results in automatic stopping of vehicles and possibly a system shutdown.

The rail icing problem can be combatted in a variety of ways including rail orientation, application of anti-icing or deicing chemicals, electric heating, and manual ice removal.

Figure 2 illustrates some of the power/signal rail arrangements employed by current AGT systems. Only the Toronto Zoo system, which incorporates stainless steel-clad aluminum rails with the contact surface facing downward, has experienced no rail icing problems. Among non-AGT transportation systems, only the Southeastern Pennsylvania Transit Authority's Market-Frankford line, with an underriding power rail configuration, reports similar ice free experience. Westinghouse's South Park test track did experience winter icing difficulties with a downward facing configuration, but that system's center guidebeam arrangement subjected the power/signal rails to water splashed by the vehicle guide wheels.

The most common rail icing countermeasure employed to date is chemical spraying of the rails. At both Airtrans and Morgantown the rails are sprayed with a heated ethylene glycol solution as an anti-icing measure. At Fairlane, the rails are sprayed with methyl alcohol (methanol) as a deicing measure. Chemical spraying as an anti-icing measure requires anticipation of frost, sleet, or freezing rain conditions sufficiently in advance to allow time for system application. A deicing strategy, however, allows ice or frost to form and possible system operation interruption before clearing of the rails is initiated.

At Airtrans, a converted automated cargo vehicle which incorporates spray nozzles, chemical storage drums, pumping equipment, and a spray operator booth, shown in Figure 3, is used to spray the power rails. Another similarly configured vehicle is used to apply the ethylene glycol to the power rail by a sponge wiper arrangement. Morgantown has several portable spray rigs for use with standard automated vehicles which spray the ethylene glycol on the rails and a towed service vehicle which incorporates spray nozzles and a bristled brush for clearing and cleaning the rails.

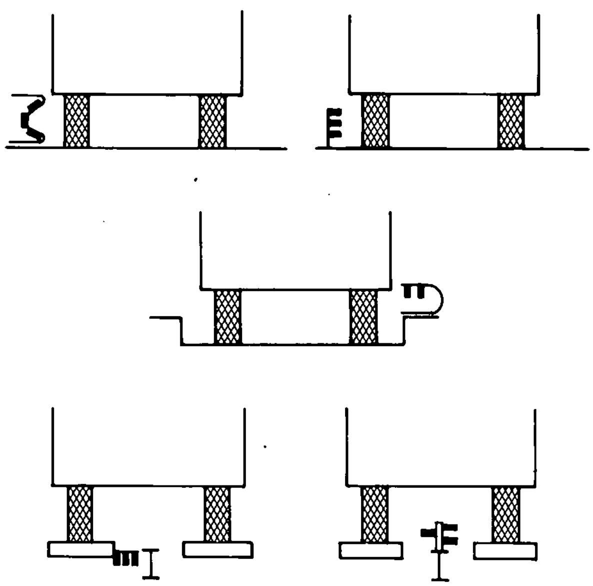
One of the disadvantages of ethylene glycol in this application is the residue it leaves on the rails. This residue must be cleaned off periodically, as it can result in electrical leakage between phases and can trap contaminants which may accelerate power collector wear.

At Fairlane, an internal combustion engine utility vehicle is employed for spraying the rails. This vehicle contains a storage tank and a compressor which supplies methanol through a reeled hose. A maintenance person walks behind this vehicle while using the spray nozzle to manually spray the rails. Fairlane also tried spraying with ethylene glycol and UCAR, a proprietary urea and ethylene glycol deicing agent. At Fairlane, both of these chemicals

Table 1. Summary of AGT systems winter weather provisions.

	Traction Surface				Power Rails			Switching
System	Primary	Backup	Snow Tolerance	Prediction	Primary	Backup	Collectors	Primary
Airtrans	Ethylene glycol spray	Snow blower	2.5 cm.	Monitor forecasts	Ethylene glycol spray/ wipe	-	-	-
Fairlane	Embedded electric	Snow blower	2.5 cm	Monitor forecasts	Methanol spray	Manual scrape	-	-
Morgantown	Embedded pipe	Snow blower	None	Weather service	Heated ethylene glycol spray	Manual scrape	Heated	On board heated
South Park	Selective embedded electric	-	4.6 cm	Detector	Electric heat	-	-	-
Toronto Zoo	Sand/urea pellets	Snow blower	2.5 cm.	Monitor forecasts	-	Broom underneath	-	Switch pit heated

Figure 2. Typical AGT power rail arrangements and their relationship to guideways and vehicles. (Top left to bottom right) Morgantown, Airtrans and Fairlane, Toronto Zoo, South Park, and West Mifflin.



were considered unsatisfactory due to the residue problem.

Whenever the towed vehicle is in use at Morgantown and the self-propelled utility vehicle is in use at Fairlane for spraying the rails, all power to the rails is shut off.

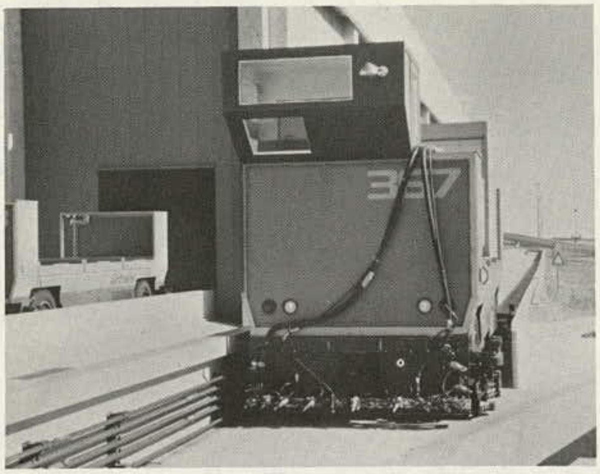
At Morgantown, the power rail system initially had several fires caused by the salt used for snow removal on station platforms and on an adjacent highway. The saline runoff from the platforms and the splashing of highway slush onto the power rails created conductive paths between rails and in combination with the ABS plastic carrier and glycol resulted in fires. As a result of these problems, use of salt on station platforms has been prohibited and a splash guard has been erected between the at-grade guideway and the highway.

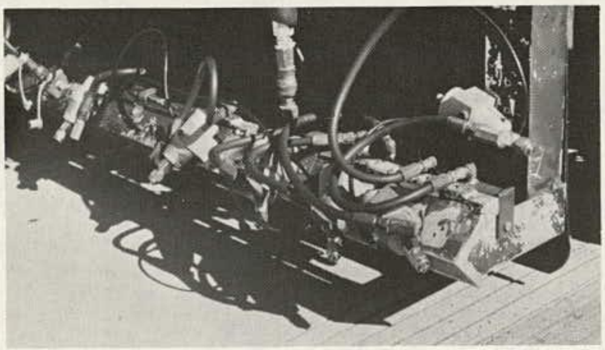
A similar review of the use of chemicals for anti-icing or deicing of power rails on electrified rail transit systems was made. This review concluded that rail transit usage of chemical methods of rail icing control has met with very limited success. For example, the Long Island Railroad has been testing anti-icing agents for power rail application since 1973. To date, the products tested have not been successful in reducing power rail ice adhesion for more than a few days without leaving an unacceptable residue on the rail.

Electrical heating of AGT power rails has only been employed at test track installations. These include Ford's Cherry Hill test track and Westinghouse's South Park and West Mifflin test tracks. The Ford AGT system installation at Bradley Airport in Hartford, Connecticut included electric power rail heating, but the system has not been operated. Electric heating of the power rails is scheduled for installation at Morgantown as part of the current Phase II system expansion and retrofitting. Typically, electric power rail heating is provided by an electrical resistance heating wire, rated at 49.2 W/m (15 W/ft), which is installed in each power rail. Since most of the AGT systems employ an average of four rails, the total amount of energy used is 196.8 W/m (60 W/ft) of guideway. Activation of the installed rail heating systems is accomplished manually in response to weather forecasts or after rail icing occurs.

Manual ice removal from AGT power and signal rails is a backup method used once ice has adhered to the rail and service has been disrupted. Manual frost and ice removal methods are not only laborious and crude, but extend system downtime. Two of the AGT systems employ in-house manufactured ice scrapers. Fairlane uses a modified metal bracket at the end of a common fiberglass bicycle safety flag and Morgantown employs a plexiglass scraper blade at either end of a polyvinyl chloride pipe. While vehicle-mounted scrapers have been tested, results to date have not been satisfactory. The only success with a vehicle-mounted scraper was achieved in a test chamber experiment conducted by Vought. It was successful, however, only when the ice was first sprayed with ethylene glycol and the scraper heated to keep its flukes clear.

Figure 3. Airtrans spray vehicle and close-up of spray nozzles.





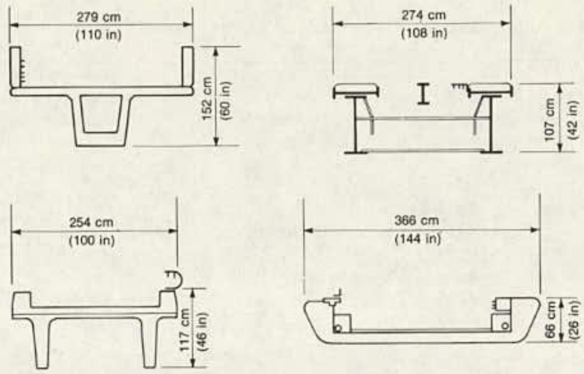
Traction

Maintaining traction between AGT vehicle tires and the guideway is a second operational problem and the most critical one from a safety standpoint. All presently operating AGT systems require traction for emergency braking. This includes AGT systems with linear induction motor (LIM) powered vehicles. Mechanically guided rubber-tired vehicles also require traction for propulsion, service braking, and station stopping. Laterally unconstrained rubber-tired vehicles, such as at Morgantown, require traction for steering control as well. Typical AGT guideway shapes and their associated traction surfaces are shown in Figure 4.

Though traction is a function of pavement aggregate characteristics, surface texture, tire material properties, tread pattern, and vehicle speed, the most significant factor affecting available traction is the presence of rain, snow, or ice on the pavement surface. The friction factor on snow and ice is considerably less than on bare pavement surfaces. Unlike wet and dry pavement traction, traction on ice and snow is not heavily dependent upon speed. Traction on ice--which exhibits the lowest friction factor--does not exhibit any speed dependency. Similarly, the available friction on ice is not particularly sensitive to wheel slip.

Two significant factors affecting friction on ice are temperature and tire pressure. Wet ice at or near a temperature of 0°C (32°F) has the lowest friction factor; as temperature decreases, the friction factor increases, typically doubling at -18°C (0°F). The direct relationship between friction factor and stopping distance is critical to the safety of the system and headway control. Properly inflated, higher pressure tires tend to have a lower friction

Figure 4. Typical AGT guideway configurations showing arrangements of traction and guidance surfaces. (Top left to bottom right) Airtrans, South Park, Toronto Zoo, and Fairlane.



factor than properly inflated, lower pressure tires. Thus, buses, trucks, and AGT vehicles have lower skid numbers than automobiles. This is significant in that the wealth of literature relating to automobile stopping tests and experience must be used with caution when applied to AGT systems.

The braking traction available in snow depends primarily upon the condition of the snow--dry, wet, loose, or compacted. The skid number on ice is roughly half that on snow. The use of traction aids, such as abrasives, snow tires, studs, or chains enhances traction on snow in that order. Studs and chains enhance traction on ice. Abrasives are more effective on wet ice than dry ice.

Current AGT systems employ a variety of methods to maintain traction in snow and ice conditions. These include embedded pavement heating, abrasives, chemicals, snow blowers, and an assortment of manual measures.

Embedded pavement heating is provided by both electric resistance wire and piped systems. The entire 0.9 km (0.6 mi) Fairlane system includes electric resistance wires spaced 20 cm (8 in) apart, 2.5 cm (1 in) below the concrete running surface. The heating system is divided into 31 zones which can be activated simultaneously or alternately (every other zone). The entire 8.8 km (5.5 mi) Morgantown system includes 2.5 cm (1 in) diameter pipes, spaced 30 cm (12 in) apart, 5.1 cm (2 in) below the concrete running surface. The heating system is divided into three zones through which a propylene glycol solution, heated by ten gas-fired boilers, is circulated. Both systems are designed for a heat output at the surface of 646 W/m^2 (60 W/ft^2).

The alternating section scheme installed at Fairlane to allow lower average heat output and energy consumption as weather conditions permit, has not been successful as it creates a washboard effect from alternating sections of accumulating and melting snow/ice. The systemwide activation approach as installed at Morgantown, though capable of heat modulation, is not sufficiently segregated to heat only those sections experiencing icing. Consequently, during cold conditions when earth heat is sufficient to keep grade level sections of the guideway free of ice, the entire heating system must be operated to clear ice on elevated sections.

Pavement heating has proven to be an effective, though costly, method of ensuring guideway traction. In addition to large initial capital costs, guideway heating incurs ongoing operating and maintenance costs. Embedded pipe system energy costs are dramatically overshadowed by the high power demand charges imposed upon embedded electric systems.

During the 1977-78 winter, the Ford Fairlane heating system operating policy was changed to avoid over-

reacting to weather problems and to reduce energy consumption and costs. This new policy did not require anticipation of bad weather and also terminated use of pavement heating. The system successfully operated with up to 2.5 cm (1 in) of packed snow on the guideway. (The allowable depth of packed snow is constrained by the vertical tolerance of the power collector assembly.) Loose and packed snow was mechanically removed from the guideway by a small front-end loader and walk-behind snow blowers with the system shut down. Less system downtime was reported from undrained refrozen melt water and the cost of guideway heating was eliminated. At the relatively short and level Fairlane system, this unheated guideway approach to winter weather operations is now preferred.

In addition to adequate drainage of melted snow/ice and capital and operating costs, several other considerations in the employment of guideway heating are relevant. To ensure timely heating system activation sufficiently in advance of precipitation, accurate weather forecasting is essential. The relatively long lead time required to bring pavement temperature up to melting temperatures, one to four hours, also makes false activations a significant energy/cost factor. Further, splashing of melted snow from vehicle tires may result not only in power rail icing, but in ice accumulation on the underside of the vehicle. This underbody icing may interfere with the operation of mechanical components and even lead to steering malfunctions on unconstrained systems.

At South Park, Westinghouse experimented with a load sharing concept which interlocked the vehicle power supply to the electric pavement heating power supply. This approach, while reducing the effective heat density, offers a potential to reduce electric power demand charges.

Only the Toronto Zoo system successfully employs abrasives, in the form of sand, to provide traction on ice or snow. The Toronto Zoo guideway does not incorporate embedded heating. Sand was also tried at Airtrans and Fairlane, but rejected due to ingestion into vehicle intakes, fouling of bearings and joints, accelerated power collection system wear, and clean up problems.

Chemicals are employed at Airtrans and the Toronto Zoo system to remove snow and ice on the traction surface. Airtrans employs a heated ethylene glycol solution, sprayed from the previously described modified cargo vehicle. Toronto employs aero-prill urea pellets spread from a self-propelled tractor. Ford developed a vehicle for spraying UCAR, a proprietary solution of urea and ethylene glycol, on the guideway traction surface, but has not used it on an operating system. The tendency of ethylene glycol to create a slippery surface on clear pavement is counteracted at Airtrans by a pavement overlay of carborundum grit embedded in an epoxy coating.

All winter-operating AGT systems use snow blowers to clear accumulations of snow on the guideway. Fairlane and Toronto Zoo both originally used large, vehicle-mounted units, but now all systems prefer and use small garden variety snow blowers. With the larger units, difficulties were experienced with proper visibility of casting areas below the guideway and with discharge chute clogging problems. Plows are not employed by any AGT system primarily, it appears, because of disposal problems and guideway structural interferences. During the 1977-78 winter, Fairlane used a front-end loader to clear the guideway of snow accumulations and snow pack, dumping it over the guidewall onto parking spaces below the guideway.

At one time or another, all of the surveyed systems have had to resort to manual snow shoveling and/or ice chipping. Vought experimented with a hot air blower. Though it melted the snow and ice, the speed of about 0.05 km/h (0.03 mi/h) proved too slow for guideway use. Further, refreezing of melted snow after passage of the hot-air blower resulted in a more serious ice condition. Studded tires were also tried at Airtrans. These tires wore the guideway pavement at an excessive rate.

Switching

Switching--negotiating merge/diverge sections of the guideway--has not been a serious problem for existing AGT systems during winter weather operation. This is due primarily to the design of the switch systems in use, which are either inherently winter tolerant or provided with appropriate heaters.

Only the Morgantown system has experienced any difficulties in switching. These difficulties, which occurred during the first year of operation in tight radius guideway turnout areas, were primarily due to freezing of vehicle-mounted switching components. Correction of these malfunctions has been affected by the installation of heating elements and the application of non-water soluble lubricants on the vehicle switching/steering mechanisms.

Though traction is essential in switch areas to enable vehicles to stop before entering a blocked switch area, only the Morgantown system is unconstrained and steered by lateral tire traction forces. Consequently, adequate traction is a necessity at Morgantown not only for braking, but also for steering. This traction is assured by a bare pavement policy which is achieved by utilizing the embedded pipe heating system.

The Airtrans system employs an active guideway mounted switch rail and a passive vehicle switch wheel. The electromechanical switch mechanism, adapted from a conventional railroad application, is installed under the guideway, protected from weather. The Fairlane system employs a passive guideway rail and an active vehicle-mounted switch wheel system, depicted in Figure 5. The Morgantown switching system also employs a passive guideway and active vehicle arrangement, but is not captured by the guideway. The Toronto Zoo system employs an active guideway switch arrangement, shown in Figure 6, as does the Westinghouse test tracks. Neither Airtrans nor Fairlane incorporate any heating devices as part of their switch. Toronto utilizes a 15 kW space heater in the switch pit below the guideway and Westinghouse uses a combination of heaters and shields to protect against winter weather.

Conclusions and Recommendations

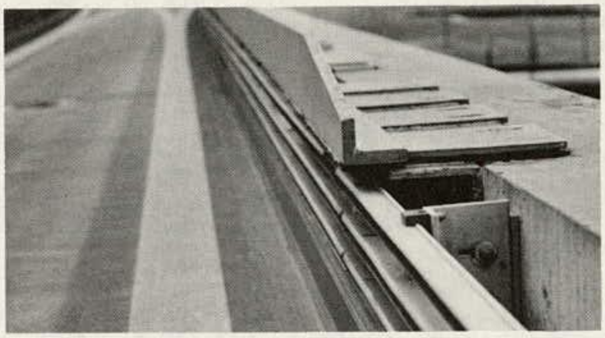
The review of existing AGT winter weather operational experience and provisions identified three problem areas--power and signal rail icing, maintenance of traction, and switching. While switching was identified as a potential winter weather related problem area, operating experience indicates that it is not currently an area of concern. The conclusions reached and the recommended topics for further investigations to improve AGT all-weather operation in the two remaining problem areas follow.

Power rail icing is the most serious operational problem experienced to date. Icing of power and/or signal rails occurs more frequently, and often before, loss of traction due to winter weather. Without rail icing countermeasures, loss of traction often is not experienced as rail icing interrupts service before traction degradation impacts the system.

Electric heating of rails appears to offer a workable solution. Engineering development of power load sharing and application techniques offer short-term potential for reducing heating-associated energy consumption costs. Inductive coupling methods of power collection may provide a long-term alternative to contact power collection and its associated weather-related problems. Susceptibility to icing appears to be minimized or eliminated by using a downward facing power rail mounting orientation. This approach, however, would require changes which may not be compatible with certain of the existing AGT vehicle/guideway/switching configurations.

While wiping or spraying of power rails with chemical solutions has been demonstrated as feasible,

Figure 5. On-board vehicle switch as employed by Ford at Fairlane. (Top) Passive switch rail mounted on the guidewall. (Bottom) Vehicle mounted switch arm/wheel engaged with switch rail.



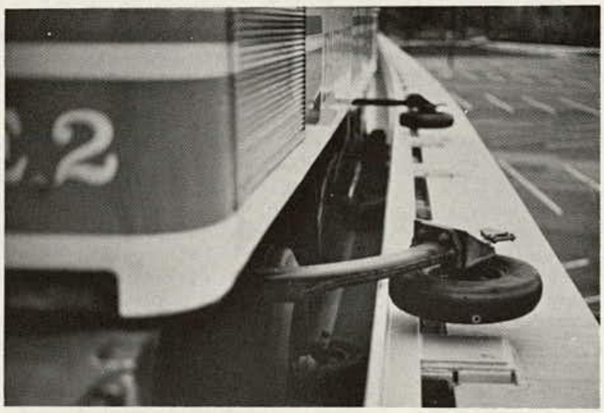
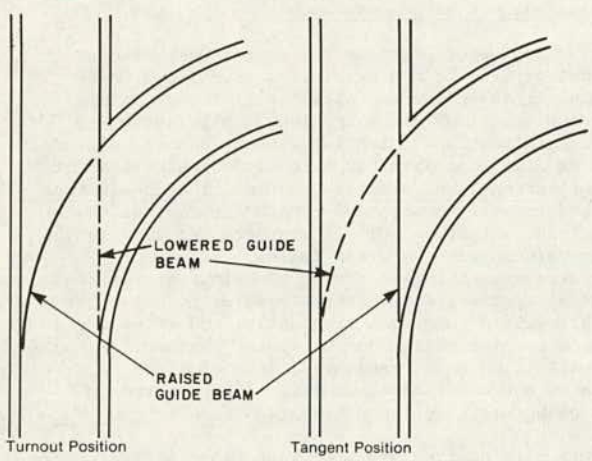


Figure 6. Active guideway/passive vehicle switch as employed by Bendix at Toronto Zoo.



a longer lasting, non-residue producing anti-icing agent is desirable. The effectiveness of chemicals in a deicing role is very limited. The goal of ice control on AGT power rails remains the maintenance of uninterrupted system operation.

Mechanical methods of power rail ice control appear ineffective in allowing uninterrupted system operation. As an ice removal method, scraping is time-consuming, relatively ineffective, and useful only as a last resort.

Traction becomes increasingly important as the power rail problem is controlled, but is not as readily resolved. The capital and operating costs of embedded pavement heating systems prompts a search for more cost-effective and lower energy consuming approaches. Provisions for maintaining traction are affected by the operating policy options established for each AGT system. Operating policies which allow an orderly shutdown of the system as an acceptable option in inclement weather, as at all the current amusement park, shopping center, and outdoor airport AGT system installations, will not necessarily be the case in future urban installations. Such urban systems may tolerate degraded service, such as increased headway or reduced speeds, but a high priority is expected to be placed on maintaining uninterrupted service in winter weather.

Techniques for reducing the lead time necessary for heating system activation and energy consumption/cost reductions are important. Reducing the area of the guideway to be heated, guideway designs to minimize snow accumulation, insulation of heat loss from the guideway, automated mechanical snow removal techniques, and modified operating strategies all offer areas of higher efficiencies. Simple snow/ice sensor activation of embedded systems, to reduce dependency upon weather forecasts and the human element, is handicapped by relatively long lead times required to bring the guideway traction surface up to melting temperature. Keeping the heating system activated at a lower output level to reduce this time lag appears prohibitive in terms of energy consumption/costs.

The adaptability of the guideway design to mechanical snow removal techniques warrants investigation not solely to replace heating methods but to augment them. Reducing the volume of snow to be melted would not only reduce the thermal energy required but possibly permit reducing the lead time of system activation before precipitation. Such a scheme would not only reduce heating system on-time, but would minimize energy wasted due to inaccurate forecasts. Disposal of snow mechanically removed from the traction surface creates problems of still another type.

Finally, there is a need for AGT vehicle stopping distance data on snow and ice. The bulk of transportation system data currently available in this area is for automobiles. Such data would strongly influence decisions on operating strategies, the need for systemwide pavement heating, and the effectiveness of mechanical snow removal.