Design Approach for Thermal Removal of Snow and Ice on Automated-Transportation-System Guideways

TED J. KRAMER

A computer simulation technique is described for modeling dynamic heat-transfer processes that influence the snow and ice removal performance of guideway heating systems. A concrete-channel guideway section is modeled, and the analysis results are presented to demonstrate the potential of this technique as a design tool for evaluating and screening snow-removal concepts. A cost model of guideway heating systems is developed. The model includes delay costs incurred by riders when the transportation system is unavailable as a result of snow or ice accumulation on the running surface. This cost is added to the capital, operating, and maintenance costs, and an optimum cost-design point is identified for an electrically heated concrete guideway. A comparison of the costs of field testing with those of environmental chamber testing is also presented. It is recommended that design verification tests be conducted under extreme operating conditions to identify potential inadequacies missed in computer modeling. This strategy favors the use of chamber testing, where extreme conditions can be simulated on demand.

Snow removal and ice control are familiar problems to the highway engineer. State and local governments spend hundreds of millions of dollars annually to clear roads during the winter months. In some extremely northern states, over half of the highway operating and maintenance budget may be allocated directly and indirectly to the snow-removal problem.

Snow and ice removal on automated-transportation-system guideways will be a problem of even greater magnitude. As it does for conventional rubber-tired vehicles, the presence of snow or ice on the guideway significantly reduces traction and, therefore, greatly increases stopping distances. Since the cars in an automated system are computer controlled, there is no human judgment available to adjust driving technique to the changes in traction brought about by snow and ice. Consequently, rider safety can be adversely affected. In systems such as the one in Morgantown, West Virginia, loss of traction makes it impossible to maintain sufficient side force to hold power pickups against the power rail; therefore, any snow or ice accumulation on the guideway running surface is sufficient to shut down the system in certain instances. Since snow and ice have a much greater potential impact on automated transportation systems than on highways, eliminating any accumulation may be a necessity rather than a goal.

This paper investigates guideway heating as a method of eliminating snow and ice on running surfaces and presents an approach for identifying the optimum design for a particular application. The approach employs thermal analysis modeling as a design tool to evaluate heating system performance and to identify energy-efficient designs. An economic model that includes the cost of discontinuing service as well as capital, operating, and maintenance costs is presented. This model allows the engineer to select the guideway heat flux that optimizes the total cost to the public.

The results of a study of guideway winterization for a downtown people-mover (DPM) system for St. Paul, Minnesota, are presented to demonstrate the usefulness of the approach.

DESIGN APPROACH

The design approach that is taken in high-technology industry relies heavily on analysis. This situation is based on economic factors that have changed drastically since the advent of high-speed computers. The large, complex computer programs that are now available to the engineer allow accurate simulation of physical phenomena that once had to be produced by testing. At the present, computers are used to rapidly analyze and screen design concepts at only a fraction of the flow time and cost that would be required for a comparable test evaluation. Testing still plays an important role in the development process, but its scope is limited to final verification of the selected design and to supplying necessary information to the analysis models.

Figure 1 shows the analytical approach that would be taken in the development of a winterization design for a DPM system. The thermal analysis model serves as a tool for predicting the performance of winterization concepts. Inputs to the model include the guideway design, weather statistics for the DPM construction site, and the running-surface heater design. Development test results are incorporated into the thermal model when existing information and correlations are found to be inadequate. Typical development tests might include thermal conductivity measurements on reinforced concrete sections or measurement of convective heat-transfer coefficients for unique guideway geometries.

The thermal analysis model performs the following tasks:

1. Evaluates performance over a range of conditions,
2. Identifies major sources of inefficiency,
3. Analyzes design improvements,
4. Develops operating strategies, and
5. Determines energy requirements.

Winterization concepts are screened on the basis of predicted ability to meet performance goals under design operating conditions. The candidate concepts that pass the thermal analysis screening are evaluated on an economic basis. Models for operating and maintenance (O&M) costs and capital costs are used to identify the most cost-effective winterization design. O&M costs are based on energy requirements and on operating strategies developed from predictions of the thermal analysis model.

Verification testing of the selected optimum design is best performed in the controlled environment of a test chamber. Test results are used to improve the accuracy of the thermal analysis model and to verify predicted system performance.

THERMAL ANALYSIS MODELING

A number of computerized thermal analysis programs have been developed by the aerospace industry. The Systems Improved Numerical Differencing Analyses (SINDA) (1) and Boeing Engineering Thermal Analyses (BETA) (2) programs use essentially identical solution techniques: The object to be modeled is divided into a number of small volumes. The mass and thermal capacity of each volume are assumed to be lumped at a central point, or node. The nodes are connected by conduction heat-flow paths. Boundary nodes are placed at the physical boundaries

Figure 1. Winterization design approach.

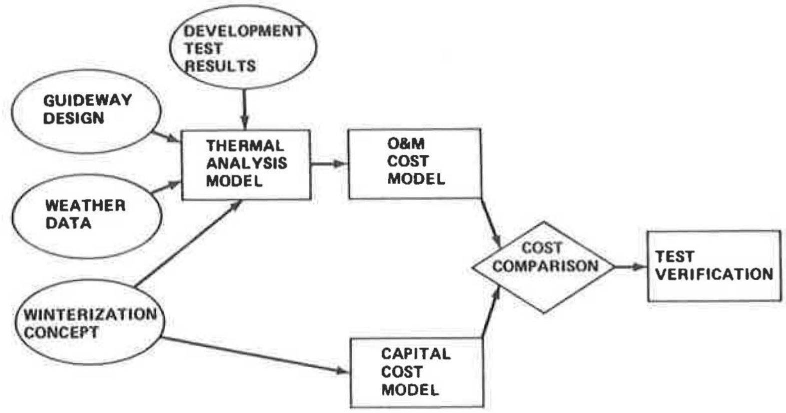
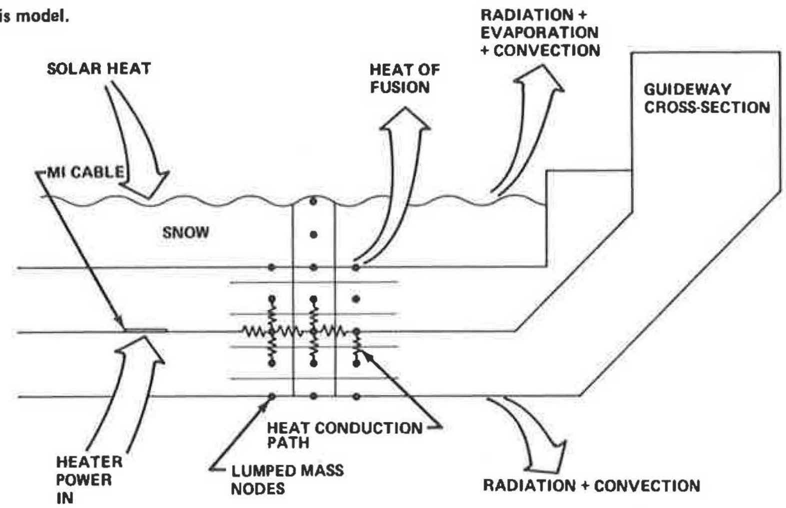


Figure 2. Guideway thermal analysis model.



of the object and are connected to the environment by radiation and convection heat-flow paths.

The modeling technique as applied to a reinforced-concrete guideway design is depicted in Figure 2. The guideway and snow are divided into small volumes. Nodes placed at the center of each volume are interconnected by conduction heat-flow paths. Heating by mineral-insulated (MI) cables and solar radiation can be incorporated in the model, as can heat loss by radiation, convection, and evaporation. Heat of fusion absorbed by the melting snow is calculated by holding the snow-concrete interface at 0°C and by calculating the difference between the heat conducted to the interface through the concrete and the heat conducted away through the snow.

Convective heat losses are dependent on wind velocity and the temperatures of the air, concrete, and snow. Configuration and orientation of the object that exchanges heat with the ambient air also play an important role in the convective process and are, to a large extent, responsible for the scatter encountered in published correlations of measured test data. Figure 3 demonstrates this point by showing the wide range of heat-transfer coefficients that are predicted by numerous wind-speed correlation equations (3, 4). At a wind speed of 56 km/h, predicted heat-transfer coefficients could range from 5.5 to 24 W/m^2, depending on the correlation selected. In instances such as this, development tests are necessary to provide accurate relationships between model variables and heat-transfer parameters.

To demonstrate the utility of thermal-analysis modeling as a design tool, a detailed thermal model of a reinforced-concrete-channel guideway was developed. The guideway cross section was similar in configuration to the shape shown in Figure 2. The guideway had an overall width of 3.66 m, a depth of 0.97 m, and a running-surface width of 2.44 m. A 7.6-cm-thick running-surface infill of concrete was placed over the 14.6-cm-thick floor of the precast section. Snow melting was achieved by means of an MI cable embedded in the infill.

Figure 4 compares the predicted snow-melting performance for heating elements embedded at two depths below the guideway running surface. A 4-h decrease in snow clearing time is achieved when the heating elements are raised from a depth of 7.6 cm up to a depth of 5.1 cm below the surface. This design improvement could reduce power costs by 36 percent; however, the potential power-savings cost would have to be evaluated against possible increased maintenance problems that could result from infill cracking.

Other potential design improvements (such as the use of insulation to minimize heat loss) can be evaluated by thermal analysis. Figure 5 compares the performance of two insulation schemes with the snow-melting characteristics of an uninsulated guideway. In one case, the bottom and sides of the elevated guideway were covered with 5 cm of rigid foam insulation. In the second case, the MI cables were assumed to be placed over a 4.4-cm-thick layer of lightweight concrete with a 5-cm layer of standard 2400-kg/m^3 concrete poured over the

Figure 3. Convective heat-transfer coefficient correlations.

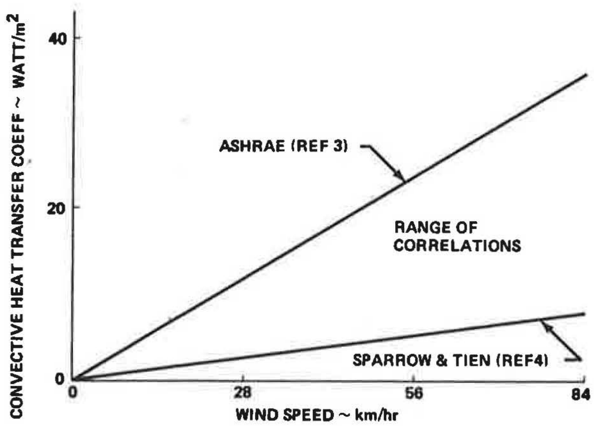
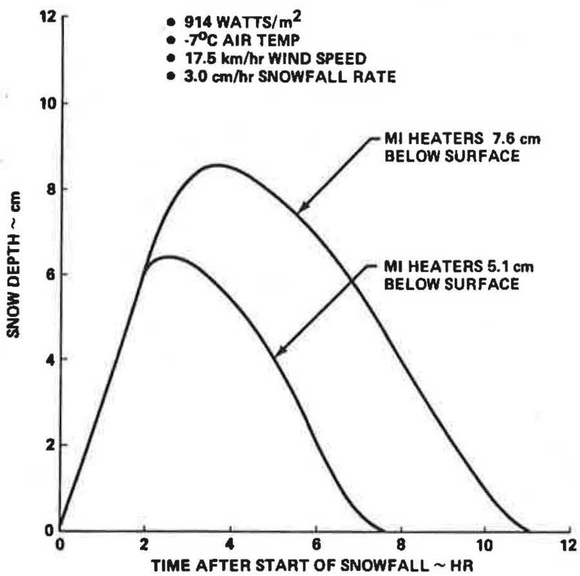


Figure 4. Effect of MI heater depth on snow melting.



cables. The thermal conductivity of the lightweight concrete (1280 kg/m³) was assumed to be 20 percent (0.52 W/m·°C) that of the standard concrete (5).

The addition of exterior insulation had a relatively small effect on system performance. It significantly reduced radiation and convective heat losses from exposed concrete surfaces but did nothing to reduce the wastage from heating the concrete below the MI cables and in the curb and channel sidewalls. Placement of the insulation concrete layer directly below the heating elements greatly reduced both convective and conductive losses, as well as heat-absorption losses, by effectively blocking heat flow to the structural portion of the guideway. This design improvement was found to decrease the energy requirement for snow melting and idling during freezing weather by 40 percent.

In addition to evaluation of performance and design improvements, thermal analysis can be used to develop strategies for heating-system operation. Figure 6 shows the effect of preheat on snow-melting characteristics for a particularly severe storm during which 56 cm of snow falls in a 12-h period. Although the heating system in this particular instance cannot keep up with the snowfall at the height of the storm, a 6-h preheat period allows 3 h of snow-free operation at the beginning of the storm and clears the guideway in 12 h. Accurate weather forecasting and thermal analysis modeling can be combined to optimize both the use of heater energy and transportation-system availability. The requirement for accurate weather forecasting has already been established by winter operation of the Boeing-developed Morgantown people-mover system. It was found that significant energy savings could be achieved by not heating the guideway during freezing weather if the running surface was bare and dry (6). Both independent and federal weather forecasting services were employed to monitor the approach of potential snowstorms, and the heating plants were activated well in advance of snowfall.

Figure 5. Effect of insulation on snow melting.

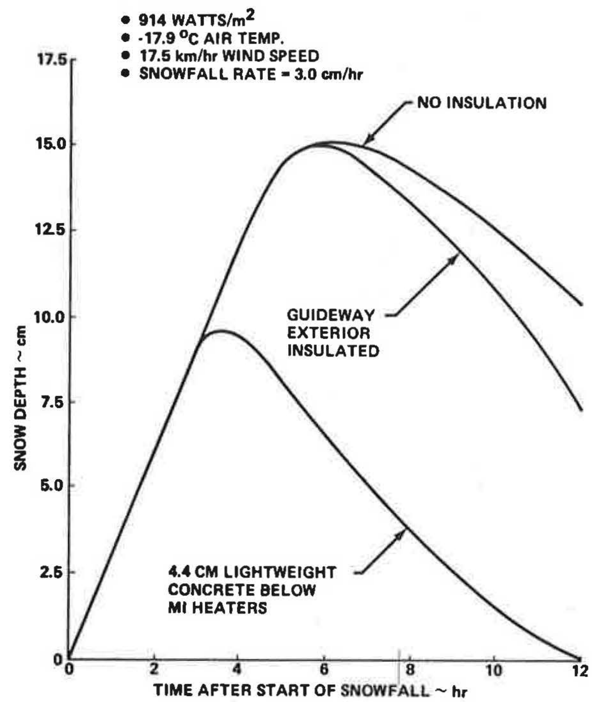


Figure 6. Effect of preheat on snow-melting characteristics.

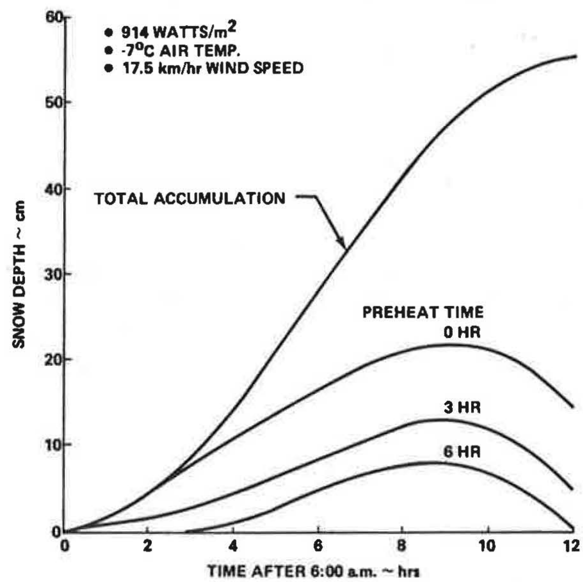
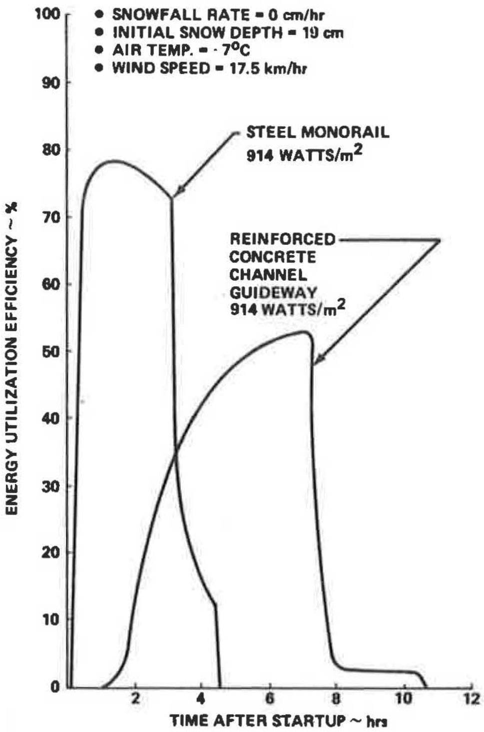


Figure 7. Effect of guideway design on snow-melting efficiency.



Preheat time was selected by rule of thumb. Use of thermal analysis modeling would allow the preheat time to be based on prevailing environmental conditions and predicted severity of the approaching storm, thereby reducing wasted energy and the possibility of discontinuation of operations as a result of snow accumulation on the guideway.

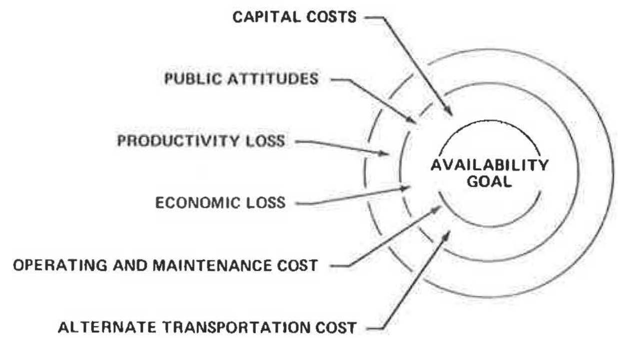
Energy requirements of candidate guideway configurations can be evaluated through thermal analysis modeling. Energy-efficient designs can be identified and potential operating-cost benefits weighed against capital costs. Figure 7 shows a comparison of the energy-use efficiencies of two guideway concepts. Energy-use efficiency is defined as the fraction of the total heater power that is used to melt the snow on the running surface. Heat applied to the steel monorail is seen to be used more efficiently than in the concrete-channel guideway and, owing to the much smaller thermal mass of the steel monorail, the snow is melted in less than 5 h rather than in almost 11 h. The small plateau in the energy use of the concrete-channel guideway is caused by the fact that snow remains next to the curb even though most of the running surface is cleared after 8 h.

The preceding examples of thermal analysis predictions for a typical DPM guideway section demonstrate some of the potential applications of a detailed analytical approach to winterization design. The main advantage of this approach is that a large number of design options can be evaluated quickly and economically with sufficient accuracy to allow major design decisions to be made.

ECONOMIC MODELING

The economic evaluation of candidate guideway winterization concepts includes estimates of capital and O&M costs. The cost-model base must also include the economic impact of loss of system availability due to snow and ice formation on guideway

Figure 8. Factors that influence system availability.



surfaces. In the case of Morgantown-type systems that use rubber-tired automatically controlled vehicles, it is essential that the guideway running surface be kept free of frost, snow, and ice. If the heating system cannot keep the running surface clear and if the safety of the public is impaired, then the DPM system must be shut down.

The availability goal for a public transportation system (the fraction of the time the system is available for use by the public) is determined by a number of factors, as shown in Figure 8. The most significant factor is the economic impact on the public when loss of the system causes delays in transit time or complete cancellation of trips. A survey of availability requirements for conventional publicly operated transportation systems, such as highways, revealed that uniform requirements do not exist. The guidelines that are followed are created by individual states or local governments and can be modified in the field. The major determinants are safety, public demand, hidden losses (such as accident costs), and capital and O&M costs.

Economic impact on the public consists of wage and convenience costs that arise from delays caused by reduced vehicle speeds. If the system is shut down, the riding public must bear the expense of finding alternate transportation or, more likely, the delay costs that result from walking to destinations.

Since availability affects both the capital and O&M costs of the winterization system as well as the cost to the public, it can be used as the prime independent variable for optimizing the cost of candidate winterization concepts. Increased availability reduces wage and convenience losses borne directly by the public but increases capital and O&M costs that are passed on to the public in the form of increased taxes or fares. Since the public ultimately bears all costs of the system, the approach to be taken is to minimize total cost for each winterization concept and then compare concepts on the basis of minimum cost. This approach was taken in the analysis of airport snow removal and ice control performed in 1971 for the Federal Aviation Administration (7). That is, the following expression is to be minimized:

$$C_{om}(A) + C_c(A) + C_d(A) = \text{total cost} \quad (1)$$

where

C_{om} = O&M costs,
C_c = capital costs,
C_d = delay costs, and
A = availability.

To demonstrate the approach that would be taken and to show the role of thermal analysis in economic

Table 1. DPM system route model.

From	To	Distance (m)	Dwell Plus Transit Time (s)
Route 1			
A	B	586	109
B	C	248	62
C	D	132	51
D	E	452	103
E	F	241	81
F	G	326	78
G	H	340	82
H	I	436	108
Route 2			
W	X	459	136
X	Y	426	100
Y	Z	397	102

evaluation of winterization systems, the results of a study of a hypothetical DPM system are presented. The DPM system chosen was based on the system proposed for St. Paul, Minnesota. The system consisted of two separate routes, one having nine stations and the other four. Distance between stations and average trip times are summarized in Table 1. If it is assumed that all stations and routes experience equal traffic density, then the average trip distance and average trip time can be calculated from the expressions

$$\text{average trip distance} = [2 D_i(n - i) i (n - 1)!]/n! \quad (2)$$

$$\text{average trip time} = [2(T_t + T_d) i (n - i) i (n - 1)!]/n! \quad (3)$$

where

n = number of stations,
i = route segment counting from one end of system (e.g., the segment between stations B and C would be the second segment),
D_i = distance of the ith segment,
T_d = dwell time, and
T_t = transit time.

For the route model in question, the average trip distance was found to be 1.07 km, and the average trip time was 4.4 min. A histogram of the distribution of trip distance (Figure 9) shows that 60 percent of all trips were less than the average distance.

Delay costs were based on a model discussed by Kennedy and Austin (8) and by Welch and others (9). This model contained the results of a Stanford Research Institute Study (10) of the expense that people were willing to accept in order to avoid delays on highways. The model divided the delay cost into two elements, a comfort-convenience cost and a cost arising from lost wages. The model, as it was adopted for this study, is shown in Figure 10. It assumes that riders are willing to accept delays up to a threshold of 6 min before they will pay to avoid further delay. Similarly there is a 6-min threshold before the average worker loses wages or feels compelled to make up his or her time. The sum of comfort-convenience costs and wages costs determines the total delay cost to the average individual.

If the DPM system becomes unavailable to users, they will be forced to resort to alternative modes of transportation. Since other forms of public transportation, such as buses, will probably be limited to promote DPM ridership, most users will have to walk when the system fails, especially if

Figure 9. Distribution of trip distances.

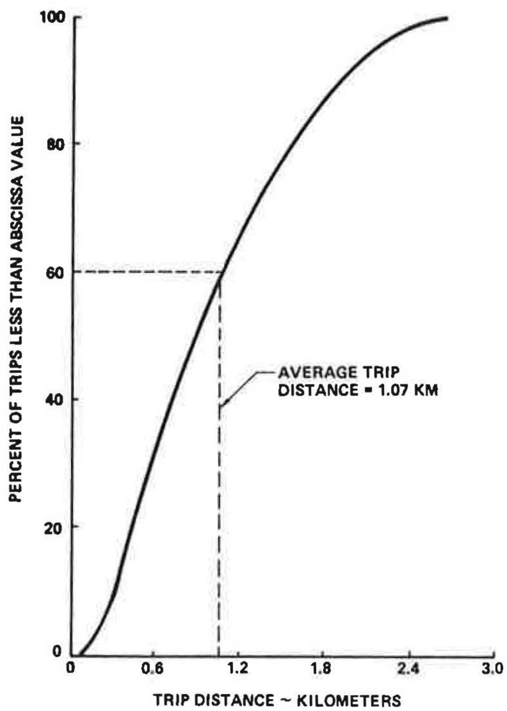
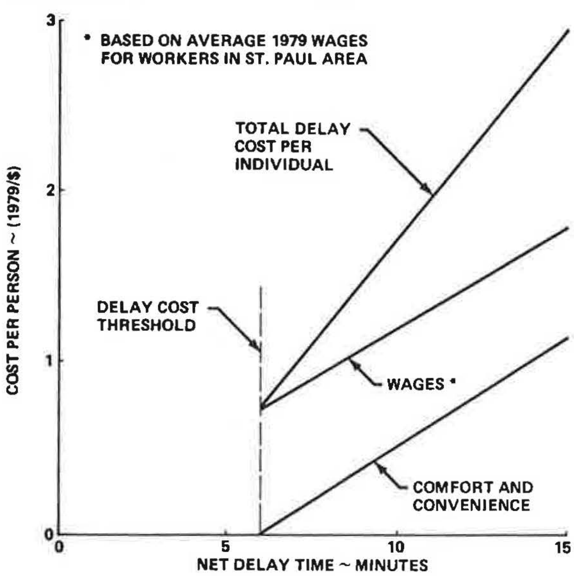


Figure 10. Delay-cost model for DPM user.



failure is weather related. The resulting average delay time can be calculated as the difference between the time required to walk the average trip distance and the time required to ride it on the DPM. At an average walking speed of 3.33 km/h, the average walking time is 19.4 min between stations. When the average trip time is subtracted, this produces a net average delay of 15 min/trip, which has a cost value of \$2.95. For an average traffic density of 3133 passengers/h, the delay cost to the public is \$9243.33 for each hour that the DPM is unavailable for use.

The relationship between availability loss and guideway heat flux can be established by a

Figure 11. Effect of guideway heat-flux selection on DPM availability.

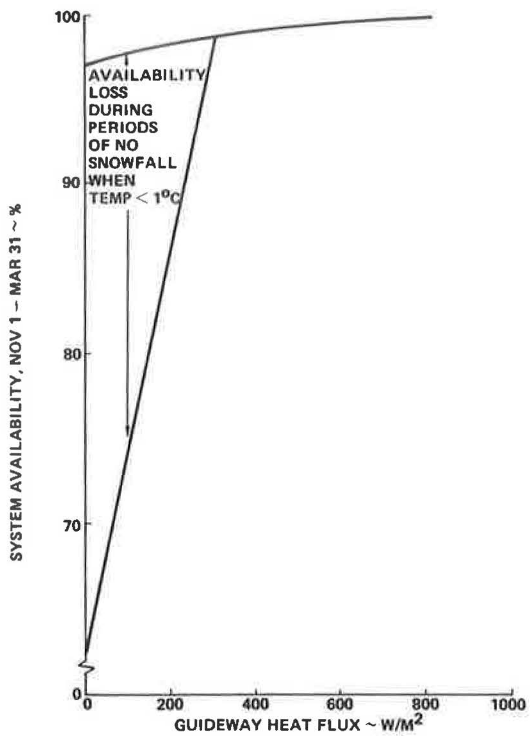
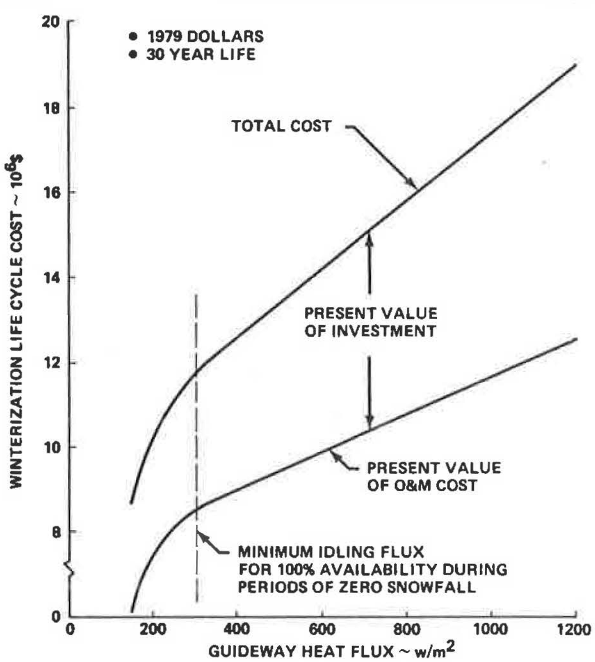


Figure 12. Winterization life-cycle costs for electrically heated guideway.



combination of thermal analysis modeling and weather statistics. A statistically significant sample of measured weather conditions that occur during periods of snowfall must be obtained. The required information includes snowfall rate, air temperature, wind velocity, and relative humidity. Thermal analysis modeling is then employed to predict the minimum guideway heat flux required to maintain a bare, wet running surface. The heat flux values are then grouped into ranges, and a frequency distribution is determined. This frequency distribution, coupled with the average hours of snowfall per year, allows the engineer to predict the number of hours per year that the system will be unavailable because of the inability of the heating system to prevent snow buildup.

An example of the relationship between system availability and guideway heat flux is shown in Figure 11. The upper line represents availability loss due to snowfall only. Note that availability is based on 12-h days and the period between November 1 and March 31. Weather statistics are for the Minneapolis-St. Paul area, and a simplified thermal model (3) was used. For elevated guideway sections, a more detailed model of the type discussed in the previous section should be used to accurately account for radiative and convective losses off the back of the guideway. During periods of no snowfall, it was assumed that the guideway heating system was activated at an idling level of 310 W/m² when the ambient temperature dropped to 0°C or below. If the full-power flux was less than 310 W/m², then it was assumed that the idling flux and full-power flux were identical. At flux levels below 310 W/m², availability dropped off significantly because the heating system could not maintain running-surface temperatures above 0°C under all weather conditions that occur for zero snowfall.

Cost models for estimating capital cost and O&M costs as a function of heat flux were developed. Models were based on an expected 30-year life and 1979 dollar costs for materials and energy. Figure 12 shows the predicted life-cycle costs for an electrically heated guideway as a function of guideway heat flux. An annual inflation rate of 11 percent was assumed in calculating the present value of capital investment and the 30-year O&M costs. The rapid drop-off in O&M costs at heat fluxes below 310 W/m² is caused by reduced energy costs for idling operation.

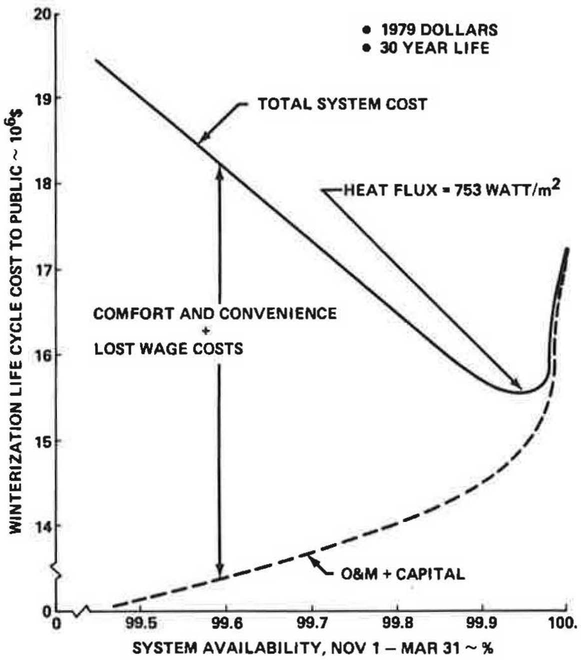
By combining the investment and O&M cost data in Figure 12 with the relationship between availability and guideway heat flux shown in Figure 11, and by employing a delay cost of $9243/h of lost availability, it was possible to determine winterization life-cycle costs to the public. The results of this calculation are presented in Figure 13, which shows total winterization life-cycle cost (the present value of the sum of O&M, capital, and delay costs) of an electrically heated DPM system as a function of availability. The cost optimum occurs at an availability of 0.9995, based on 12 h/day of scheduled operation during the period extending from November 1 to March 31. This availability level corresponds to a heat flux of 753 W/m² and occurs at the point at which the sum of O&M and capital costs begins to increase rapidly as availability increases.

Similar cost optimums could be developed for other candidate winterization concepts. Minimum costs would then be compared to identify the optimum concept. Additional factors such as aesthetic consideration, environmental impact, and local codes would play a role in the final decision process.

VERIFICATION TESTING

Verification testing, usually performed under controlled conditions, is employed in the aerospace industry as a check on the validity of the selected design. Testing is performed before the commitment of large amounts of resources for full-scale production. Verification tests demonstrate system performance under the most severe operating conditions that will be encountered. Test results are also

Figure 13. Winterization cost optimum.



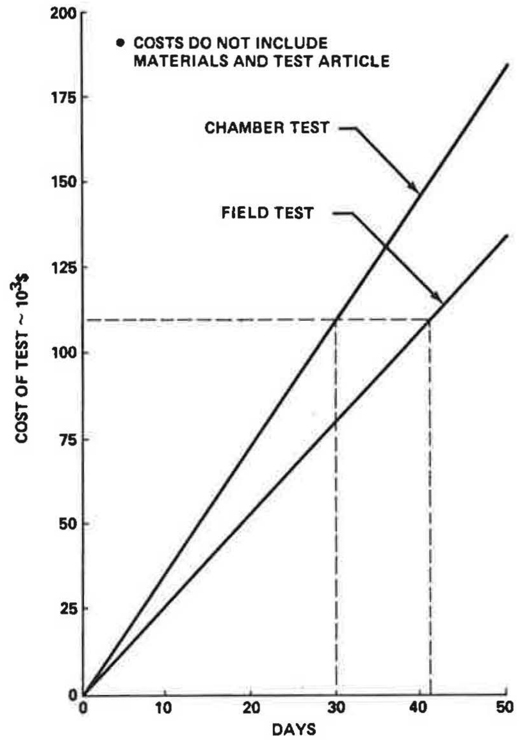
used to improve the accuracy of the analysis models.

It should be stressed that, as a minimum, testing is conducted for the most extreme operating conditions for which satisfactory performance is required. This strategy ensures that performance is proved for the most demanding conditions and that any design inadequacies overlooked in the analysis modeling are exposed.

Testing under controllable conditions ensures that the desired test environment is available on demand. Field testing, on the other hand, involves a degree of chance. If testing is to be performed under conditions that have a low probability of occurrence, a great deal of time and money can be expended in waiting for the right conditions to occur. In the case of verification testing of a guideway heating system, several months, or even several years, may pass before the desired combination of snowfall rate, wind speed, air temperature, and relative humidity occurs. If the testing is performed under the controllable conditions of an environmental chamber, the allocation and use of resources can be planned and implemented with low risk and minimum waste of time and money.

A comparison of field testing cost with the cost of testing in Boeing's 3.626 Environmental Chamber was made. This chamber has a test volume 12 m wide, 12 m high, and 24 m long and it could easily accommodate a full-scale DPM guideway section. Temperatures as low as -50°C can be achieved within 5 h of start-up, and wind and snow can be simulated. This chamber has been used to perform cold-weather tests on the Morgantown people-mover car, on an 18-m-long section of 747 fuselage, and on a mobile-home design developed under a contract with the U.S. Department of Housing and Urban Development. It was assumed that a field test crew would consist of two test engineers, two instrumentation engineers, and two technicians. Testing was assumed to be conducted on a two-shift-per-day basis; crew were assumed to be rotated back to Seattle every two weeks. Costs of airline tickets, lodging, automobile rental, and living expenses were estimated.

Figure 14. Cost comparison of chamber and field tests.



A similar test schedule was assumed for the chamber tests. An additional engineer was required for each shift to operate the chamber, and a chamber occupancy fee of $600/day was added. The costs of materials and fabrication of the test article were not included. Figure 14 shows the results of the cost calculations. The cost of chamber testing is greater than the cost of field testing for a given test period. However, the hourly cost differential is not great enough to outweigh the probability that a much greater amount of time will be required in the field to achieve the desired test conditions. According to the chart, $110 000 will purchase 30 days of chamber time and 41 days of field time. It is unlikely that these additional 11 days would significantly affect the probability of the desired test conditions occurring at the test site.

SUMMARY

An approach to the design and development of guideway heating systems for snow and ice removal has been described. It was patterned after procedures and methods employed in the aerospace industry and relies heavily on computer modeling simulation to provide information for front-end decisions made early in the design process. Thermal modeling was shown to be an effective tool for evaluation of guideway heating concepts and prediction of performance in the field. Thermal analysis modeling was also a key element in the economic evaluation of guideway heating concepts; it provided information on the relationship between heat flux and system availability and on energy requirements for each design.

A cost model that included delay costs borne directly by the public as well as capital and O&M costs was demonstrated. For a hypothetical DPM system located in St. Paul, Minnesota, it was found that the optimum heat flux for an electrically heated concrete guideway is 753 W/m².

Verification testing of the concept selected for full-scale development and eventual production was recommended. The test should demonstrate system performance under extreme operating conditions. Full-scale testing in an environmental chamber was suggested as a low-risk and potentially low-cost alternative to field testing.

ACKNOWLEDGMENT

I wish to thank D.T. Huang, currently with North American Rockwell, for his role in the development of the thermal analysis models and P.H. O'Callaghan for her assistance in exercising the models and developing background information for this paper.

REFERENCES

1. Users Manual: Systems Improved Numerical Differencing Analyzer (SINDA). TRW Systems Group, Redondo Beach, CA, Rept. 14690-H001-RO-00, April 1971.
2. J.J. Brossard and others. Boeing Engineering Thermal Analyzer Program (AS1917). Boeing Aerospace Company, Seattle, WA, Rept. D180-10016-1, Aug. 1970.
3. ASHRAE Handbook and Product Directory of 1976 Systems. American Society of Heating, Refrigerating, and Air-Conditioning Engineers, New York, 1976, pp. 38.1--38.16.
4. E.M. Sparrow and K.K. Tien. Forced Convection Heat Transfer at an Inclined and Yawed Square Plate: Application to Solar Collectors. ASME Journal of Heat Transfer, Vol. 99, 1977, pp. 507-512.
5. A.M. Neville. Properties of Concrete, 2nd ed. Pitman Publishing Corp., New York, 1973, pp. 428-431.
6. T.C. Barker and others. Personal Rapid Transit System Reports: 1976-1977 Winter Operation. College of Engineering, West Virginia Univ., Morgantown, 1977.
7. D.J. Tighe and others. An Analysis of Airport Snow Removal and Ice Control. Federal Aviation Administration, Rept. FAA-RD-71-20, March 1971.
8. W.J. Kennedy and J.A. Austin, Jr. A Model for Traffic Delay and Its Convenience and Wage Costs. In Snow Removal and Ice Control Research, TRB, Special Rept. 185, 1979, pp. 57-60.
9. B.H. Welch and others. Economic Impact of Snow and Ice Control. Utah Department of Transportation, Salt Lake City, Rept. FHWA/RD-77-20, 1976.
10. C. Thomas and G.I. Thompson. The Value of Time Saved by Trip Purpose. Stanford Research Institute, Menlo Park, CA, Project MSU-7362, Oct. 1970.

Publication of this paper sponsored by Committee on Winter Maintenance.

Wind-Tunnel Analysis of the Effect of Plantings on Snowdrift Control

STANLEY L. RING

Modern highway design practices have, in general, created an aerodynamic highway cross section that is relatively snowdrift free. However, adjacent topographic features or obstructions may create localized snowdrift-prone locations. One such situation is the grade-separation structure over a freeway. Landscape and maintenance specialists have sought planting arrangements to reduce the problem. To study snowdrift patterns in the field is time consuming and demanding, since control of weather conditions is not possible. The objective of this research was to reproduce the phenomenon of blowing snow in the laboratory wind tunnel, on an appropriate freeway grade-separation three-dimensional model, and to analyze the effect of various plant configurations in minimizing snowdrift accumulations on the pavement. Seventy-seven separate experiments were conducted in the wind tunnel by using 49-μm (0.001 93-in) glass spheres as the particulates to represent snow. Comparisons of snowdrift accumulations versus time were subsequently made to evaluate the effectiveness of various plantings. Similitude relationships were evaluated for relating the model results to known full-scale field conditions. Specific recommendations about plant types, densities, and spatial arrangements are presented for Iowa conditions.

Blowing and drifting snow has been a problem for the highway engineer virtually since the inception of the automobile. In the early days, highway engineers were limited in their capabilities to design and construct drift-free roadway cross sections, and the driving public tolerated the delays associated with snow storms.

Modern technology, however, has long since provided the design expertise, financial resources, and construction capability to create relatively snowdrift-free highways, and drivers today have come to expect a high-design highway facility that is free of snowdrifts; if drifts develop, drivers expect highway maintenance crews to open the highway within a short time. Highway administrators have responded to this charge for better control of snowdrifting. Modern highway designs in general provide an aerodynamic cross section that inhibits the deposit of snow on the roadway insofar as it is economically feasible to do so.

Maintenance operation policies have called for immediate removal of snowdrifts and have provided the necessary resources. The commitment of snow-removal equipment and personnel for immediate action has, in fact, reduced the concern for natural control of snowdrifting (as through the use of snow fences and the strategic placing of plantings).

Financial limitations and reduced energy availability, however, are now causing administrators to review maintenance policies. Thus, if equipment for rapid snow removal will not be as promptly or readily available in the future as in the past, there will be a renewed interest in the control of snowdrifting by natural means wherever possible.

The Iowa Department of Transportation (DOT) has been concerned with a specific snowdrift-prone location. At certain minor-road grade-separation structures over a freeway in rural areas, when the snow is blown from the same general direction as the minor-road embankment, pressure changes occur and