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Guideway Snow and Ice Control and Roadside Maintenance

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Contents

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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.

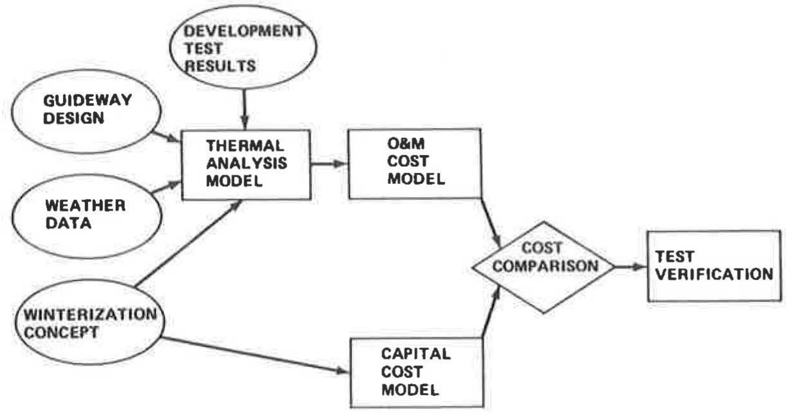
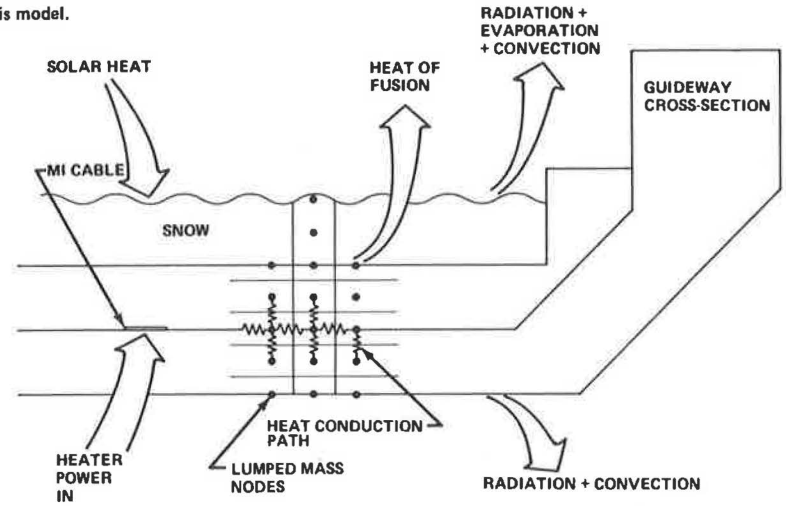


Figure 2. Guideway thermal analysis model.



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.

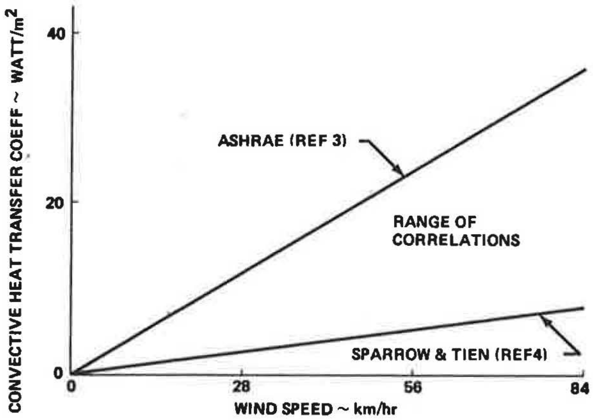
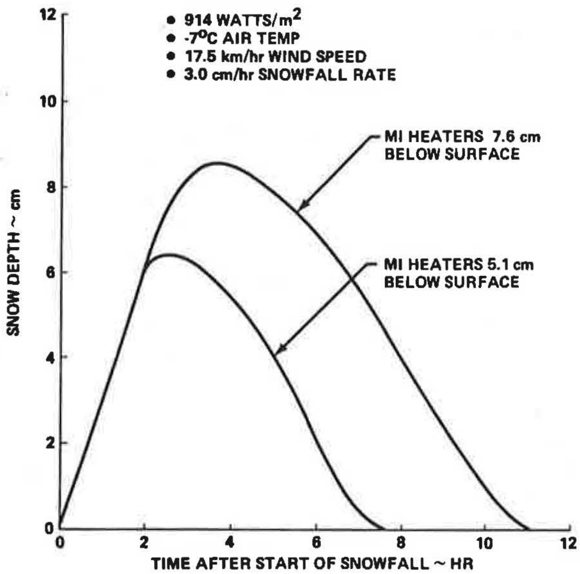


Figure 4. Effect of MI heater depth on snow melting.



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

Figure 5. Effect of insulation on snow melting.

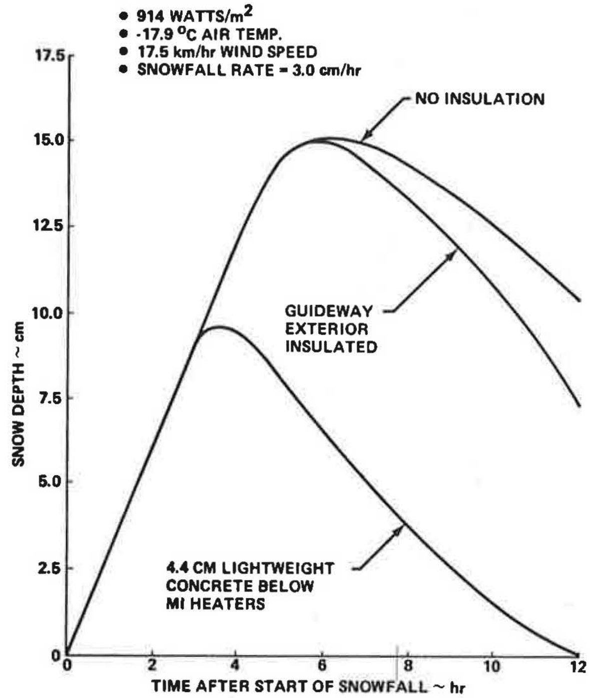
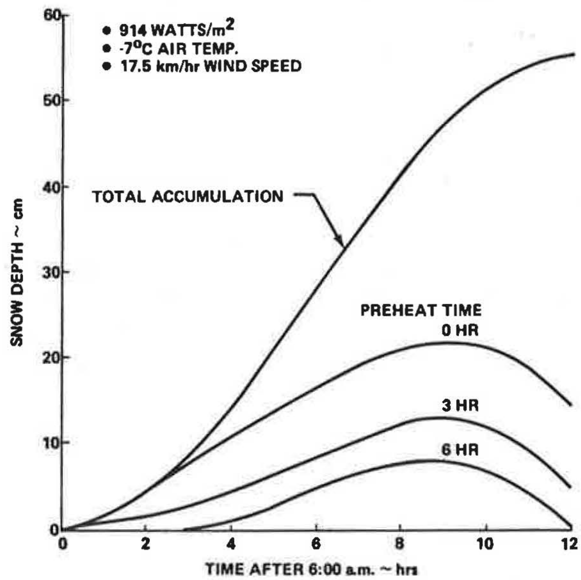
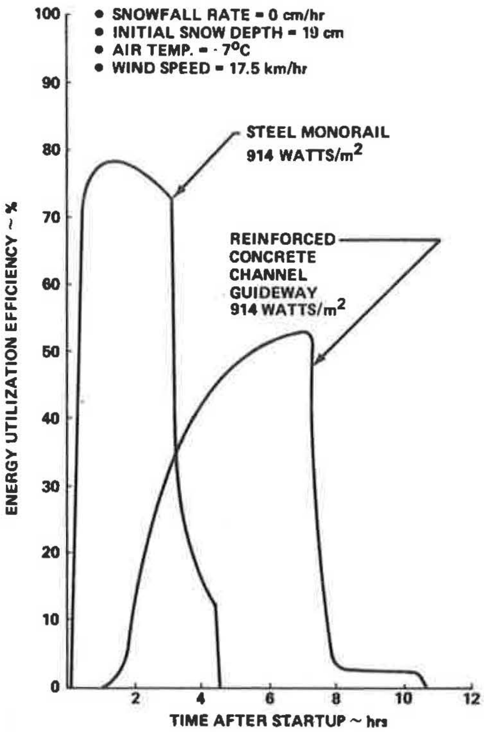


Figure 6. Effect of preheat on snow-melting characteristics.



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 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.

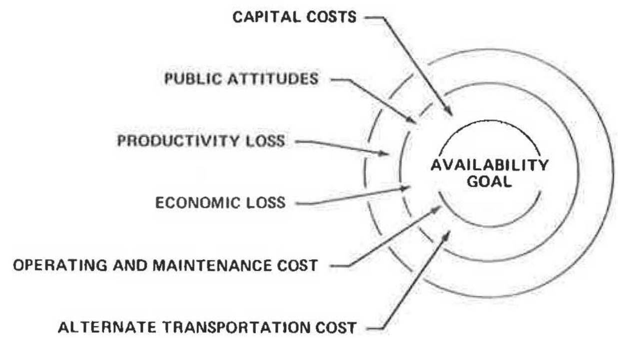
Energy requirements of candidate guideway configurations can be evaluated through thermal analysis modeling. Energy-efficient designs can be identified and potential operating-cost benefits weighed against capital costs. Figure 7 shows a comparison of the energy-use efficiencies of two guideway concepts. 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.

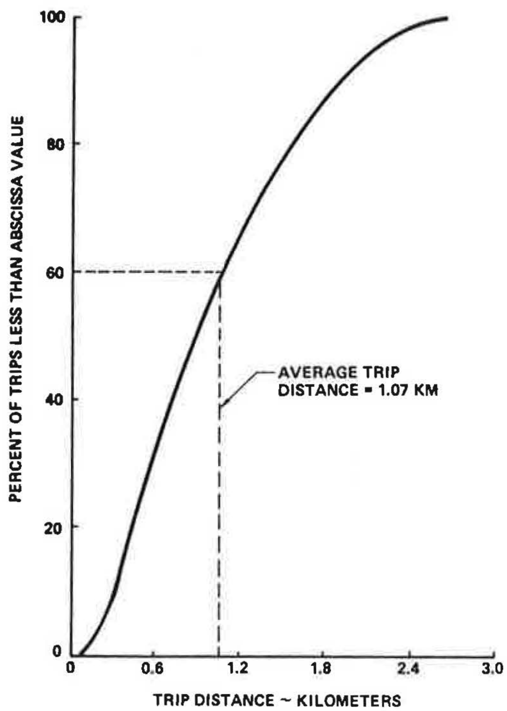
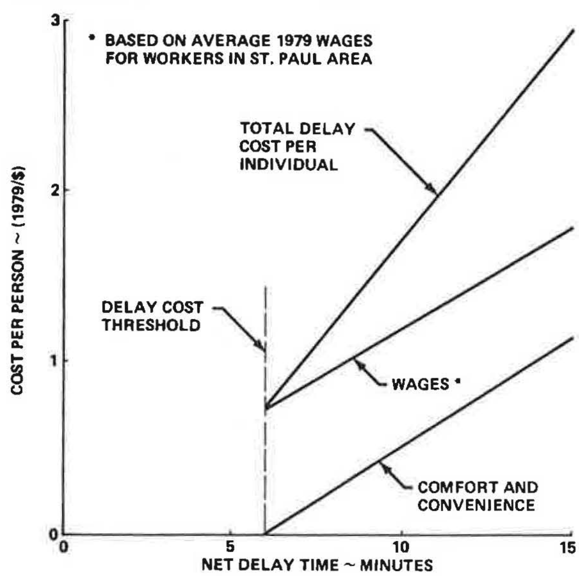


Figure 10. Delay-cost model for DPM user.



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.

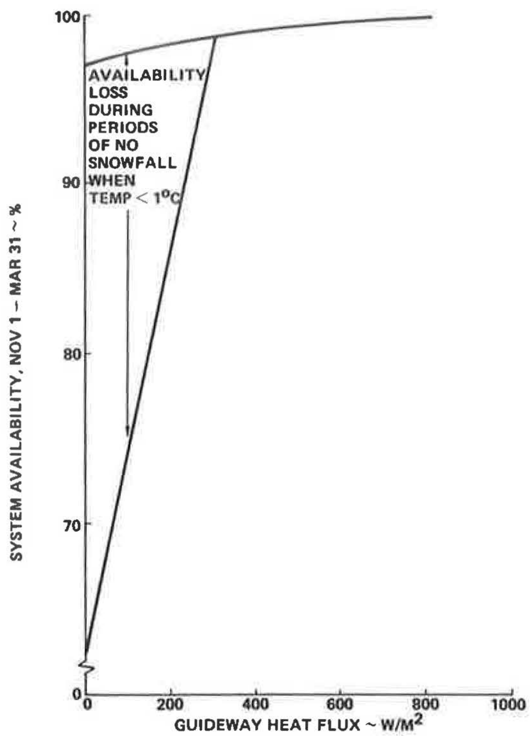
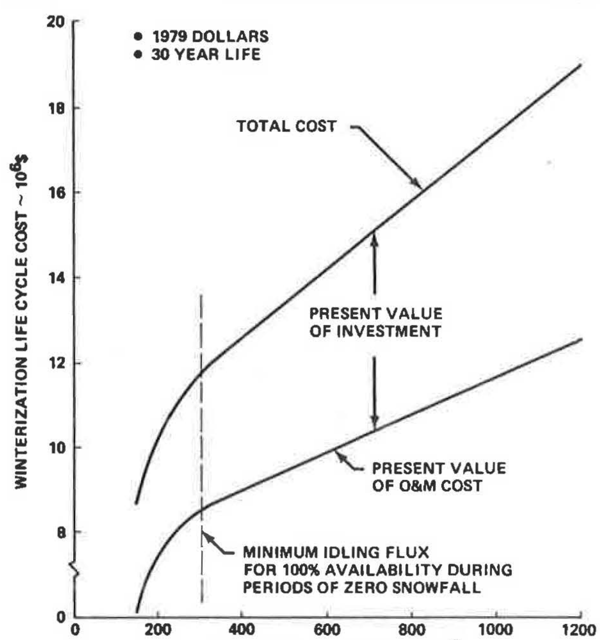


Figure 12. Winterization life-cycle costs for electrically heated guideway.



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/m^2 when the ambient temperature dropped to 0°C or below. If the full-power flux was less than 310 W/m^2, then it was assumed that the idling flux and full-power flux were identical. At flux levels below 310 W/m^2, 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/m^2 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/m^2 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.

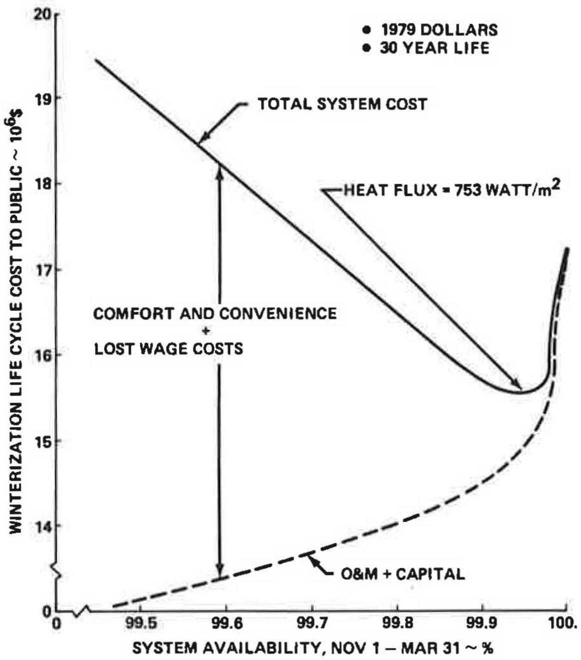
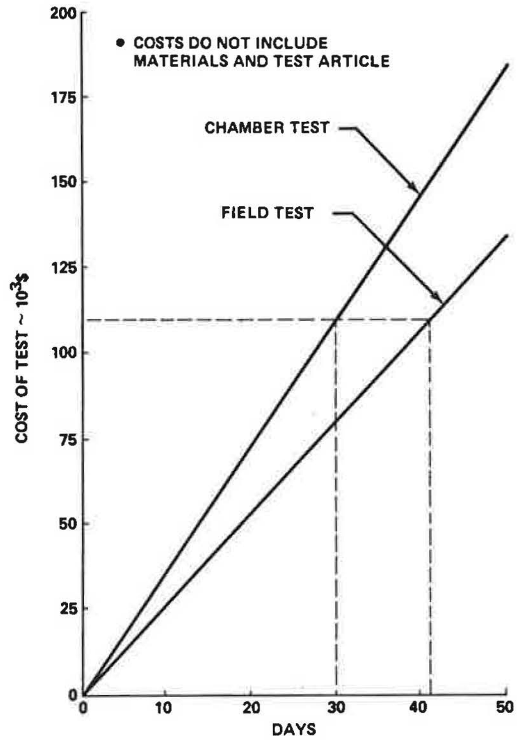


Figure 14. Cost comparison of chamber and field tests.



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. 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.

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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

Figure 1. Effect of variations in backslope on snowdrift accumulation.

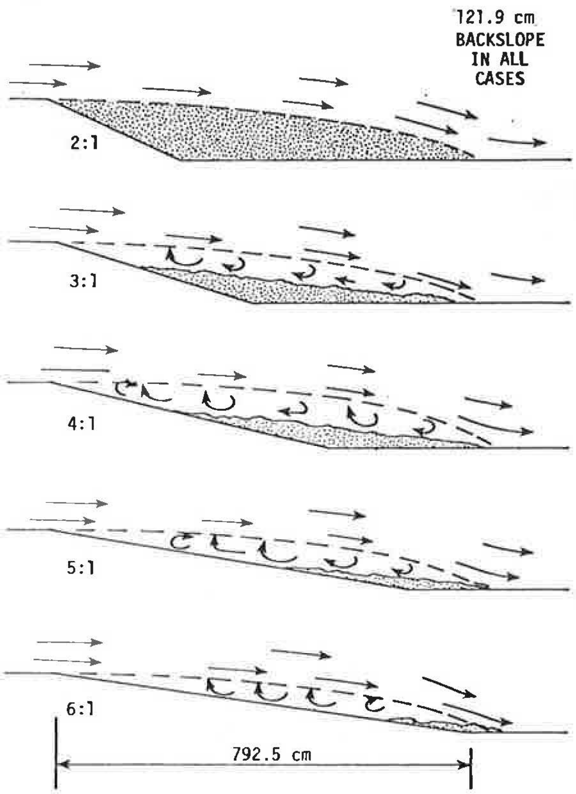


Figure 2. Effect of rounding top and bottom of slope.

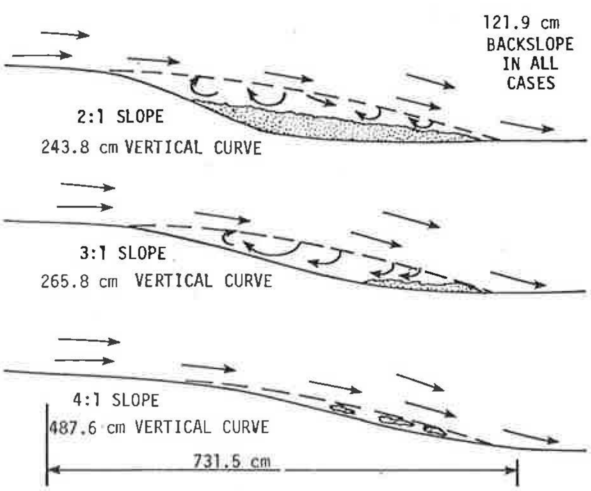
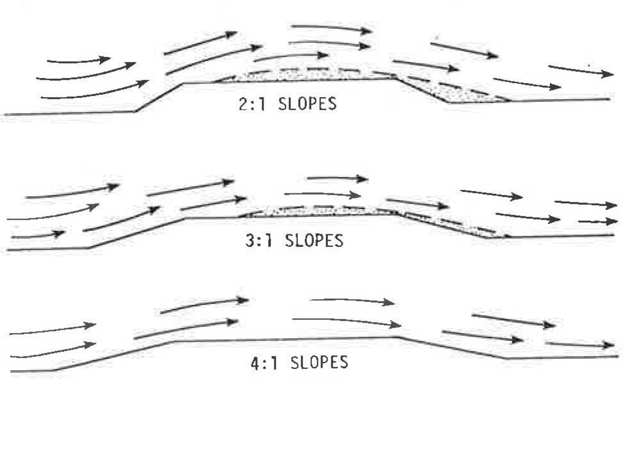


Figure 3. Effect of foreslopes on air flow across roadways.



cause snowdrifts to form. In fact, it is not uncommon for the only snowdrift problems to be in the area under these bridges.

The Iowa DOT contracted with the Engineering Research Institute at Iowa State University to study these snowdrift-prone locations. The research goal was to reproduce the phenomenon of blowing snow in the wind tunnel on an appropriate three-dimensional model and to analyze the effects of strategically placed plantings, or other barriers, in order to make recommendations for the control of snowdrifts.

STATE OF THE ART

The control of drifting snow can be categorized into three general areas:

1. Design of the highway topography to create an aerodynamic cross section that is self-cleaning,
2. Creation of barriers (snow fences or plantings) in order to create wind-pressure changes and cause the snow to accumulate off the pavement, and
3. Removal of improperly located barriers (guardrail, fences, curbs, and weeds) that create snowdrifts on the pavement.

Some of the earliest research into highway design for snowdrift control was by Finney (1-4). Finney's recommendations were based on wind-tunnel experiments and field observations. He noted that the maximum limits of a snowdrift accumulation on the leeward side of a solid barrier (such as a side ditch cut) would always be at a horizontal distance of 6.5 H, where H is the vertical displacement.

Also, Finney's studies clearly illustrated the benefits of flat foreslopes and backslopes and the rounding of slope junctions. Figures 1-3 illustrate this self-cleaning cross-sectional aspect. Finney's recommendations are generally consistent with modern research results and have been the basis for highway designs for decades.

In recent years Tabler (5-10) has made significant contributions to the science of snowdrift control. His 1975 report (7) is representative of the value of his work. Computer programs based on this work have been developed as an analytical tool for the design of the roadway cross section.

Primarily as a result of Tabler's and Finney's work, the highway engineer can usually predict the downwind shape of a snowdrift that accumulates at a barrier. Generally speaking, a solid barrier will create a maximum downwind length of drift equal to 10 times the height of the barrier. (Note that Finney's earlier laboratory results were 6.5 H.) However, a porous type of barrier (optimum snow-fence porosity is approximately 50 percent) may create a drift length as high as 27 H. It should be emphasized that these shapes are for relatively flat topography. Significant variations can occur for rolling topography.

Systematic investigations into the relationship between plants, snow, and wind were started early in this century. Cornish (11), Bates (12), Burton (13), Finney (3), and a number of studies in the 1940s and later have made significant contributions.

It has been shown that combinations of plants and shrubs can achieve a barrier that has varying degrees of porosity. The degree of porosity determines the length of the leeward drift accumulation. In general, a near-solid barrier plant mass will generate a downwind length of drift equal to 7-10 times the height of the solid mass. Also, a mass in the range of 50 percent porosity can achieve a length equal to 27 times the plant heights.

The primary concern is in selecting plants that

Figure 4. View of the bare model before testing.

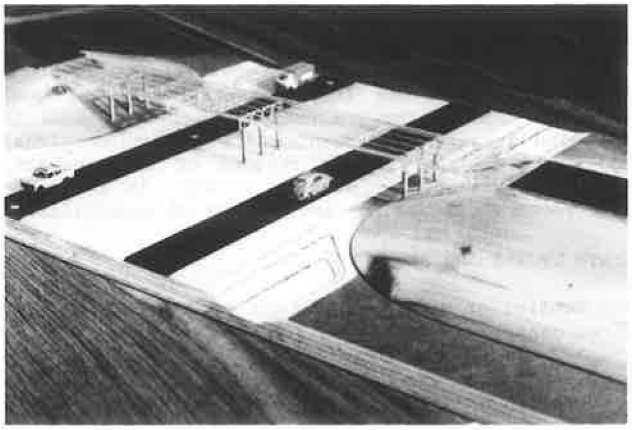
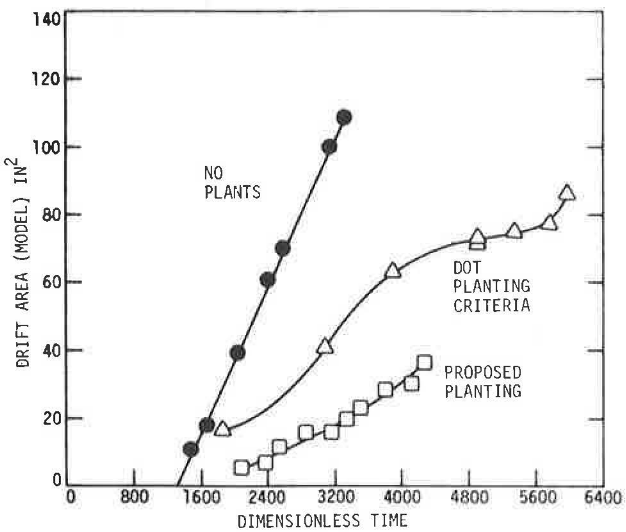


Figure 5. Accumulation of simulated snow as a function of dimensionless time.



are hardy and in predicting the future wintertime porosity. Location of the plants is a function of porosity and height.

It should be emphasized that the capability to predict snowdrift accumulation is influenced by adjacent topography and land features. A grove of trees or farm buildings upwind of the highway may change the quantity of snow available and the wind-pressure level. An upward slope of the topography on the windward side of the barrier will probably increase the volume of snow stored in the drift. A depression on the leeward side of the barrier will also increase the volume of snow accumulated. The final equilibrium profile of the downwind drift probably remains the same, however.

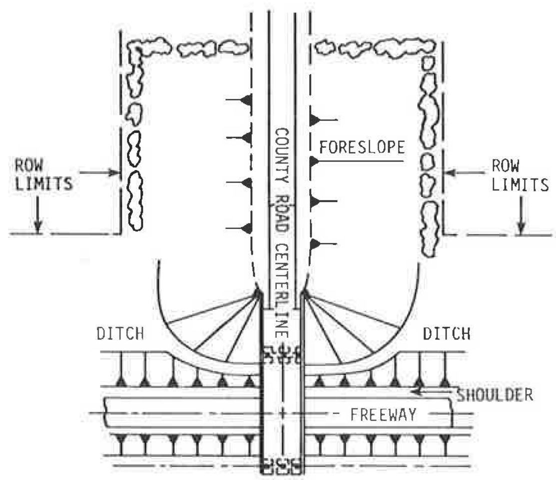
In complex locations, field studies or wind-tunnel modeling may be required to accurately predict snowdrift profiles. Because field studies are time consuming, laboratory modeling is useful if valid predictions can be made from the model results.

DESIGN OF THE WIND-TUNNEL EXPERIMENT

Two three-dimensional models were constructed on a scale of 1:120 in the horizontal [1 cm = 1.2 m (1 in = 10 ft)]. One model had the same 1:120 vertical scale, and the other had a vertical scale of 1:60 [1

Figure 6. Snowdrifting at grade-separation structure.

Figure 7. Snowdrift-control planting where ROW is constrained.



cm = 0.6 m (1 in = 5 ft)]. The purpose of the vertical scale change on the second model was to evaluate the similitude relationships for extrapolation to full scale.

The models represented a typical freeway design and were accurately machined to scale. The embankment and adjacent area were made of cedar wood; the pavement and bridge were of plexiglas. Shoulder areas were covered with fine sandpaper, and the final-model earth areas were covered with a low-nap velour cloth to simulate ground cover. Figure 4 shows the model before application of the cloth ground cover.

A number of different materials were tested in the wind tunnel to represent plant mass. Tests were first conducted on a flat landscape in order to analyze the experimental drifts in terms of known snowdrift characteristics. The final material selected was a commercial packing material of loosely woven fibers that had many air spaces. Its porosity could be varied by means of compression. This material was found to best reproduce plant-mass snowdrifts in the wind tunnel.

A number of wind-tunnel experiments were conducted to select the material to simulate snow. Two different diameters of finely ground walnut shells and two different diameters and densities of glass spheres were tested in relation to their ability to be picked up and transported according to the snow-transport phenomenon (saltation theory).

Glass spheres of 4.0-g/cm³ (249-lb/ft³) density and 49-μm (0.001 93-in) diameter were selected. The material was placed on the bed of the wind tunnel upwind of the model. Wind-tunnel tests were conducted at 4.4-6.6 m/s (10-15 miles/h), at which speeds the glass spheres were picked up and transported as loose particulates according to the saltation phenomenon of snow transport.

A total of 77 separate wind-tunnel experiments were conducted with the two models; 26 were on the bare model (no plantings), and 51 were with experimental plant configurations for snowdrift analysis. The total wind-tunnel experimental time during these 77 runs was 35 h. The models were rotated to achieve varying wind orientations.

ANALYSES

Vertical photographs of the snowdrift accumulation and encroachment on the pavement surfaces were taken at specific time intervals in order to evaluate the effectiveness of each alternative. The time-referenced photographs were subsequently enlarged and the encroachment area calculated.

A plot of dimensionless time versus pavement-encroachment area was then prepared as an evaluation tool. Figure 5 represents a comparison of the time for encroachment to occur for (a) the bare model, (b) the standard planting configuration in use by the Iowa DOT, and (c) the planting configuration to be tested.

As would be expected, the plantings function as a living snow fence and cause the snowdrift to accumulate away from the pavement area. Any encroachment on the pavement is consequently delayed in accordance with the distance from snow fence to pavement and the capacity of the snow barrier.

All snowstorms have a finite quantity of snow to transport at any specific location. In many snowstorms the quantity of snow available to accumulate could be stored off the traveled way. Even the storms that carry large quantities of snow could have a significant delay on the time for snow deposits to reach the pavement, if the drift-creating plantings are located far enough to windward and are of suitable height and porosity.

CONCLUSION

A goal of this research was to determine the suitability of wind-tunnel modeling for reproducing field-observed snowdrifting characteristics through an evaluation of similitude relationships and a direct comparison of modeled drift dimensions with established field-condition drift measurements. The results of the experiments have been shown to correlate well with actual field conditions.

Another goal, based on the testing of various types and configurations of simulated vegetation, was to determine the best design to minimize the deposit of snow on the pavement. The following are recommended:

1. It is important that plantings (or other barriers) be placed some distance away from the freeway. Plantings placed near the bridge may, in fact, cause an increase in snow accumulation on the pavement. Figure 6 illustrates the leeward accumulation on the pavement that results from close barriers.
2. The best planting arrangement in a constrained right-of-way (ROW) situation requires plantings on the minor-road ROW. Figure 7 illustrates this condition.
3. The best planting arrangement in an unconstrained ROW condition provides additional rows of plantings at greater distances from the freeway, as illustrated in Figure 8.
4. Plants selected should generally not exceed 3 m (10 ft) in mature height and should have medium porosity at the lower levels. The type selected depends on soil and moisture characteristics at the

Figure 8. Snowdrift-control planting where ROW is not constrained.

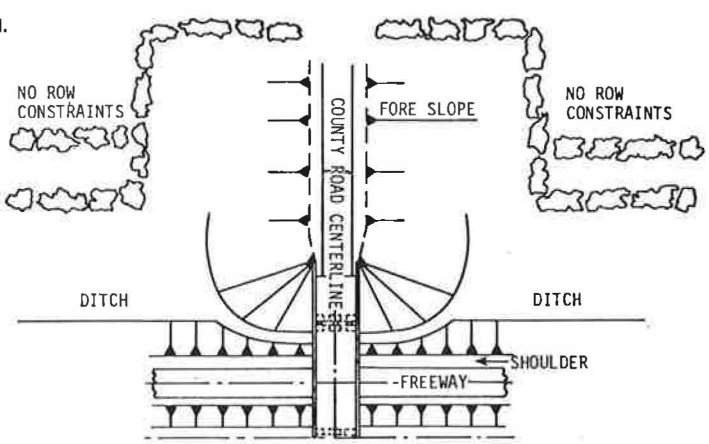


Table 1. Recommended plantings where the ROW is constrained.

Botanical Name	Common Name	Maximum Height at Maturity (cm)	Number of Rows	Distance Between Rows (cm)	Spacing in Rows (cm)
Kolkwitzia ambilis	Beautybush	300	2	150	90
Lonicera xylosteum claveyi	Clavey honeysuckle	150	2	120	90
Lonicera zabeli	Zabel honeysuckle	300	2	150	90
Syringa palibiniana	Dwarf Korean lilac	180	2	120	90
Ligustrum obtusifolium regelianum	Regal border privet	150	2	150	120
Ligustrum vulgare variegated	Cheyenne privet	300	2	150	90
Physocarpus monogynus	Mountain ninebark	120	2	90	60
Rosa rugosa	Rugosa rose	180	2	120	90
Rosa canina	Dog rose	270	2	120	90
Spiraea prunifolia	Bridalwreath spirea	270	2	120	90
Spiraea vanhouttei	Vanhoutte spirea	180	2	120	90

Note: 1 cm = 0.4 in.

Table 2. Recommended plantings where the ROW is not constrained.

Botanical Name	Common Name	Maximum Height at Maturity (cm)	Number of Rows	Distance Between Rows (cm)	Spacing in Rows (cm)
Juniperus virginiana	Eastern red cedar	600+	2	300	150
Rhamnus frangula columnaris	Glossy tallhedge buckthorn	540	2	240	90
Caragana arborescens	Siberian pea tree	540	2	300	150
Viburnum dentatum	Arrow-wood	540	2	300	150
Crataegus cordata or C. phaenopyrum	Washington hawthorn	600	2	300	150
Acer ginnala	Amur maple	600	2	300	300
Elaeagnus angustifolia	Russian olive, oleaster	600	2	300	300
Viburnum lantana	Wayfarer tree	540	2	300	150
Viburnum prunifolium	Blackhaw	540	2	300	150

Note: 1 cm = 0.4 in.

site. For Iowa, Tables 1 and 2 identify suitable plants and their characteristics (honeysuckle is the most practical for normal Iowa conditions).

5. The applicability of guardrail and the type in use should be examined. Moving the guardrail away from the pavement edge improves the potential for snow-free maintenance. Also, the box-beam type may have reduced propensity for creating snowdrifts.

6. A snowdrift-control plan should be implemented at each overhead location at which actual drifting has been observed so that modification of plantings may be made to minimize snowdrifting on the pavement.

ACKNOWLEDGMENT

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Abridgment

Alternatives to Sodium Chloride for Highway Deicing

STANLEY A. DUNN AND ROY U. SCHENK

A search has been made for road deicing chemicals to replace sodium chloride (NaCl). The impetus for this search stems from the numerous drawbacks associated with the current extensive use of NaCl as a road deicer. All classes of chemical compounds were reviewed. Deletions were made on the basis of such pertinent criteria as water solubility and freezing-point lowering, corrosion, toxicity, flammability, relative cost or cost potential, and effect on soils, plants, and water supplies. Low molecular weight and high solubility were primary qualifications. Waste products were considered as possible raw-material sources. Two candidate deicers have been selected that, if used, would result in total costs of about one-half those associated with the use of NaCl. Both materials can be made from waste cellulose. Neither is corrosive. One of them, methanol, reacts almost immediately on contact with snow and ice but is less persistent than the other candidate or than NaCl. The other candidate, calcium magnesium acetate (CMA), acts at about the same rate as NaCl in the temperature range of common activity and shows about the same persistence. In strong contrast to NaCl, CMA is a corrosion inhibitor, is beneficial to most soils, and has no potential to harm drinking supplies.

The well-known corrosive effect of sodium chloride (NaCl) on metals has long begged for replacement of this chemical as a road deicer. It has been demonstrated that this obvious defect is but one of many undesirable results attendant on the use of NaCl for deicing purposes (1-7). Accordingly, the present search for workable alternatives was initiated.

Chemical deicing depends on the general effect of dissolved substances or solutes on the melting point of the material in which they are dissolved, the solvent. The effect is always to lower the melting point. The amount of lowering is almost solely dependent on the number of solute molecules or ions present in solution, roughly proportional to this number, and almost entirely independent of the nature, size, or weight of these solute particles. Thus, low-molecular-weight materials produce the greatest lowering of the freezing point for a given weight dissolved in the solvent. Also, the solubility of the solute determines the degree of lowering it can exert on the melting point of the solvent in which it is dissolved.

If the costs of purchasing and applying alone are considered, there is perhaps no other chemical deicer as cost effective as NaCl. In the long run, the net cost of using NaCl or any other deicer, however, must include the associated damages to the natural and manmade surroundings. It is primarily the cost of these types of damages caused by the use of NaCl that provides the economic justification to search for alternative deicers among possibilities that may be more costly to purchase.

METHOD

It was the rationale of this investigation that the purchase cost of the replacement might exceed that of NaCl, but that the excesses in this cost must be made up by a lessened negative impact on the surroundings. Murray and Ernest (1) estimated that the damages caused by the use of NaCl as a deicer were more than 10 times that of the cost of NaCl. Thus, for an alternative deicer that is free of harmful side effects to the surroundings, there is considerable latitude insofar as the purchase price is concerned.

In this study, all combinations of chemical elements were evaluated as potential chemical deicers. Most elements and compounds were quickly eliminated on the basis of general chemical considerations because they are prohibitively expensive, are extremely toxic and/or are gases or otherwise unsuitable, are not available in reasonable quantities, have low water solubility, are corrosive, or contribute to ecological damage. Nine elements appeared to offer hope to produce effective deicer combinations. These elements are hydrogen, carbon, nitrogen, oxygen, sodium, potassium, magnesium, calcium, and phosphorus. All chemical combinations of these nine elements were evaluated further.

Further rounds of elimination from among the resulting combinations required examination of the pertinent physical and chemical properties in greater depth (8). Values were sought from the open literature and supplemented by laboratory determinations when not available from that source. The process is described more fully in Dunn and Schenk (9).

RESULTS

By this process the field was narrowed to two candidates, methanol and a mixture of calcium and magnesium salts of organic acids, primarily acetic. These two candidate deicers, both of which can be produced from waste cellulose (10-13) were scrutinized from a number of performance and environmental points of view. Both methanol and calcium magnesium acetate (CMA) have compared favorably with NaCl in most of these respects and comparably in most of the remaining ones. The performance of the two candidates is summarized below by using NaCl as the standard of comparison. Whenever documentation is not given in what follows, supporting data are to be found in Dunn and Schenk (9).

Methanol

Methanol exhibits a eutectic with water, -120°C, far below that of NaCl or any other inorganic deicer candidate (14,15). In deicing field tests, methanol works much more rapidly and at far lower temperatures than either CMA or NaCl. Under some conditions, its deicing effect improves with lower temperature. At temperatures above -15°C and over the short term, it performs comparably with CMA and NaCl on an equal osmolar basis. Beyond a few hours, however, more than equal osmolar amounts must be added in order to match the persistence of CMA or NaCl. The methods of handling and dispensing liquids such as methanol, although different, are simpler than those for solids and subject to much finer control.

In only one test series out of six did methanol cause a greater degree of corrosion of a metal than did plain water. In one instance out of the same six, it caused less corrosion than water. By contrast, NaCl caused serious corrosion in five out of the six same test series.

Methanol exhibited no adverse effect on portland cement concrete in a triplicated test series of nine months' duration. It gave one instance of minor attack on asphalt concrete--namely, the partial uncovering of a number of aggregate particles at sample surfaces in the freeze-thaw test series. Investigation of this result is perhaps merited.

Methanol has been used as an antifreeze for gasoline engines but was replaced by the glycols because of its relatively high evaporation rate. At snow and ice temperatures, volatility is much reduced. The remaining volatility, however, serves to minimize the concentration of methanol in the runoff and, correspondingly, its contribution to biochemical oxygen demand (BOD). Spills, of course, are self-removing. Methanol vapor is about 10 percent more dense than air, whereas gasoline by comparison is several hundred percent more dense. Accordingly, methanol vapor is much less prone to collect in low spots and is much more easily dispersed than gasoline vapor is.

The flash point of methanol, 15.6°C, is nearly 16.7°C above the freezing point of water. The flash point of an aqueous methanol solution is, of course, even higher than that of the pure material. Fires can be extinguished with water (as gasoline fires cannot) because methanol and water are miscible in all proportions. Methanol's flammability appears to be limited to the period of storage and application. Once applied to a frozen or a snow-covered road, it appears to be difficult, if not impossible, to ignite.

As with all substances, it has toxic limits. But these limits are relatively high; methanol has been cleared as a food additive (16). No ill effects have been found on prolonged exposure to low concentrations or to short intermittent exposures at high concentrations of its vapors (17). Its label as a toxic substance results from its occasional misuse as a substitute for ethanol and is unwarranted in the context of its use as a road deicer.

Methanol has very few undesirable environmental properties. It is neutral. It contains no nitrogen or phosphorus and thus contributes nothing to eutrophication problems. Although methanol carried into streams and groundwater does create an increase in BOD, its volatility appears substantially to reduce this problem, as already noted. Furthermore, its accumulation from use as a deicer would occur during periods of minimal microbial activity in water that had maximum oxygen capacity. Therefore, harmful BOD effects of methanol would be minimal (18). The vapor gradually oxidizes to water and carbon dioxide.

It would appear that, with reasonable precautions, methanol's use as a deicer should pose no significant operational or ecological problems. In addition, although purchase costs are higher, estimates of total costs, including purchase, application, and environmental, highway, and vehicular damage associated with the use of methanol, are less than half those costs associated with the use of NaCl.

CMA

Late 19th and early 20th century research showed that cellulosic solid waste could be converted to alkaline earth salts of lower carboxylic acids, predominantly acetic, by relatively simple technology and in yields sufficiently large to be interesting (11-13). Most of these salts show sufficient water solubility to function as deicing agents.

The water eutectics of the two primary components, calcium and magnesium acetates, are -15°C and -30°C, respectively, thus bracketing that of NaCl (-21°C). In road and sidewalk deicing tests, CMA performs comparably to NaCl on an equal osmolar basis. On this basis, both salts take effect in about the same time and persist in their effects for similar periods. CMA can be spread with the same equipment used for NaCl.

Braking traction and skidding friction are decreased by both NaCl and CMA when these deicers are applied at dosages insufficient to melt through the ice. By contrast, a sample of unpurified CMA improved both braking traction and skidding friction under the same conditions. To leave the insoluble impurities in the reaction product also reduces production costs.

In repeated tests CMA has shown no significant corrosion of steel, zinc, or aluminum. On the contrary, it has exhibited significant corrosion inhibition effects with respect to A-36 steel and A-3560 cast aluminum. By contrast, both here and in the literature, NaCl has been observed to promote significant corrosion of steel and other metals. Although reinforcing bars embedded in concrete were consistently corroded in the presence of NaCl during nine-month wet-dry tests on reinforced concrete, those bars in the presence of CMA were untouched.

Neither calcium nor magnesium ion presents any more toxicity hazard than sodium ion (19). They are less of a hazard with respect to cardiac patients (20-22). Acetate ion is a food substance, vinegar, and no more hazardous to health than chloride ion. CMA is mildly basic, however, and minimal skin and respiratory protection against dust would be desirable in prolonged exposures during handling.

Environmentally, the more-harmful thing that the calcium and magnesium ions contribute is water hardness. Their acetate salts do not contribute significantly to eutrophication. The acetate is indeed organic, but it is broken down slowly during the cold winter months, which reduces any potential BOD stress. The calcium and magnesium are gradually precipitated as the carbonates and thereby removed from solution where their presence might otherwise influence water density and interfere with the turnover of lakes (23,24).

Soils in the eastern half of the United States, where most deicing is done, are deficient in calcium and magnesium (25,26). Addition of these nutrient elements to the soil in these areas by means of a road deicer could be beneficial. These divalent cations tend to improve the structure of the soil where, by comparison, sodium and to a lesser degree other monovalent cations (e.g., potassium and ammonium) tend to cause the breakdown of soil structure (27-29). Such breakdown results in a decreased permeability for both water and air, often a serious agricultural problem (30).

CMA is essentially nonflammable and generally nontoxic; it retards corrosion of most metals in comparison with NaCl or even water. The one observation of harmful behavior, the superficial scaling of some of the portland cement concrete samples, is probably attributable to the acidification pretreatment given the CMA in these instances rather than to the CMA itself. Rerunning of these tests has been recommended.

Assuming that unacidified CMA will not produce scaling of portland cement concrete, then the total estimated cost of using CMA as a highway deicer, including the cost of all side effects, will be less than half that of using NaCl.

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Deferred Maintenance

MARION F. CREECH

This study investigated deferred maintenance as it concerned roadside vegetation control and drainage. It was also designed to develop the basis for a deferred maintenance program. Field work revealed that vegetation growth control, especially mowing, was being sharply reduced and that most states visited were rewriting their standards to reflect this. Maintenance deferral for drainage facilities, which are less visible, was even more dramatic; maintenance was performed on an as-needed basis, in many cases only when some catastrophic event such as flooding occurred. Major consequences of deferred maintenance were considered in relation to safety, condition of facilities, liability, social and environmental effects, and level of service. A methodology for developing a deferred maintenance program was formulated. This method, which consists of five discrete steps, has the potential to allow selection of maintenance activities to be deferred and determination of the deferment period that has a minimum of risk.

Deferred maintenance is a subject of much interest and concern to many transportation officials. In this time of shrinking revenues, almost runaway inflation, the unknown future energy situation, and environmental restraints, it becomes clear that there will not be enough maintenance dollars to go around. This simply means that some types of maintenance activities performed in the past on a regular basis will have to be deferred or put off completely. Decisions about which activities to defer and the length of deferment are of prime importance. The questions that must always be asked are, If a certain activity is deferred, what are the consequences it will have on the particular element of the highway with which it is associated and what consequences will it have on the overall integrity of the road?

OBJECTIVES OF THE STUDY

This research project was initiated to investigate the feasibility of deferring the maintenance activities of roadside vegetation control and the cleaning and repair of drainage facilities. A second objective was the formulation of a method for developing a deferred maintenance program by using the information uncovered in the investigation.

After such information as was available had been collected and studied, the expectation was that the consequences of deferring maintenance could be determined or predicted in regard to safety effects, integrity of the facility, legality, effects on users, and environment.

PROBLEMS DISCOVERED IN PERFORMING THE STUDY

Several things discovered at the outset of the study made it difficult to quantify the consequences of deferring maintenance. First, the term "deferred maintenance" had never been adequately defined to my knowledge. Accepting the premise that highways, from the time of construction, begin to deteriorate from use and environmental action, then hypothetically maintenance should begin shortly after construction if a road is to be maintained in a manner to meet the American Association of State Highway and Transportation Officials (AASHTO) definition of maintenance. That definition states that highway maintenance is the "act of preserving the roadway, roadside, structures, and other facilities as nearly as possible in their as-built or subsequently improved condition and the operation of the highway facilities and services to provide safe and satisfactory highway transportation for the motoring public."

Since, from a practical standpoint, it is probably not possible to satisfy that definition of maintenance, the question arises as to when maintenance should optimally be performed and when it falls under the definition of deferred maintenance. Deferred maintenance can be defined as the postponement of maintenance beyond the time it would normally have been performed. This definition would fit very nicely if quality standards had been developed for each maintenance activity to indicate when maintenance should be done and had been subsequently adjusted by feedback to optimize the maintenance investment. This, unfortunately, is not the case.

Another very large roadblock in the study of deferred maintenance and its consequences is the record keeping by the states. In the past, maintenance people have been very interested in getting the work done but not so very interested in keeping records of what they did. This problem pointed out the need for a nationwide standardized record-keeping system. I think that initially such a system might not be popular with the rank-and-file maintenance engineer, but it is the foundation in the development of a unified maintenance program in which the levels of maintenance can be realistically set and the consequences of deferring them predicted.

FIELD STUDY

During the field studies, six states were visited (Virginia, Indiana, Louisiana, Minnesota, Wyoming, and California) and several more contacted to collect data and discuss maintenance programs in the areas of roadside vegetation and drainage facilities. Maintenance, legal, traffic, construction, administrative, and research divisions were visited in each of the six states. The actual interview-discussion was divided into two parts. The first had to do with current practice at the time of the visit and the second concerned the consequences of deferring maintenance beyond current practice for certain fixed periods.

Historical cost data were very difficult to obtain because in many cases they did not exist as written records and because in other cases they were broken into separate items such as labor, equipment, and fuel. These costs were kept in different files, which made them almost impossible to collate and combine into one cost figure.

For the deferred-maintenance portion of the interview, the responses, in all but a few instances, were subjective in nature. These opinions were derived from highway engineering experience accumulated over the years by state officials.

FINDINGS ON CURRENT PRACTICES

Deferred maintenance has been and is being practiced on many highway elements throughout the United States. In some cases, officials are not fully aware of potential consequences. Moreover, in several states that have maintenance quality standards, those standards are being rewritten and relaxed without adequate consideration of the outcome. Maintenance deferral is easily understood in light of the shortage of funds.

Roadside vegetation control was one maintenance activity for which but one of the states visited had written performance standards. Vegetation growth is controlled through a combination of mowing and use of chemical herbicides. The number of mowings performed by any one state during a season seemed to be a combination of policy and climatic conditions. The actual number of mowings ranged from a high of six per year in one state to none in another. The state that had no overall system for annual mowing did mow in areas where the restriction of sight distance was potentially hazardous.

Several of the states that had mowing standards were rewriting them in an effort to hold down increasing costs. This was done in two ways: (a) by reducing the areas mowed and (b) by reducing the number of mowings. At least two states visited were contracting part of their mowing to determine whether contracting would be cheaper than using state maintenance resources. Public acceptance of reduced-area mowing standards was good where portions of roadside that did not affect safety or the integrity of the facility were allowed to return to the natural state. Many motorists seem to like a rustic-appearing roadside. Although the acceptance of the reduction in number of mowings where the roadside is apt to take on a ragged appearance was not so positive, there were instances where this too evoked a positive response. One of these was the very positive response by the garden clubs in the Shenandoah Valley of Virginia along I-81. There are a number of early-blooming wild flowers along that route and, because mowing occurred somewhat later than in previous years, the flowers were able to come into full bloom.

Although most states did have mowing programs with fixed mowing standards, this was not the case when it came to maintenance and repair of drainage facilities. Drainage facilities, which included ditches, culverts, drop inlets, and catch basins, are subject to variances in cleaning and repair thoughout the country.

Inspection routines, the key to maintaining proper drainage, varied to some degree in different areas but were characterized as follows:

1. Those elements that can be observed from the road, such as ditches, paved flumes, and certain culverts, are inspected on a continuous basis by the area superintendents on their rounds.
2. All elements are inspected after severe storms or twice annually.
3. Drainage facilities are inspected at fixed times when high levels of runoff can be predicted (for example, in Minnesota, the drainage facilities are inspected each fall before the snow season begins because the drainage facilities must operate at maximum efficiency in spring during the thaws).
4. Large structures, such as box culverts above a certain size [usually 20 ft (6 m)], are inspected at the same time as bridges.

The cleaning and repair of drainage facilities are performed on an as-needed basis and are scheduled as routine maintenance in other than emergency situations. A review of the standards shows that maintenance is necessary for ditches when water is ponding, when there are obstructions, or when the ditches have lost their cross section (emphasis is placed on ditches that have excessive silting and blocked drainage structures) and for other drainage structures whenever drainage is impaired.

Percentages of total maintenance funds allotted to clean and repair drainage facilities ranged from 3 to 14 percent in the states visited; one state (not visited) spent 19 percent of total secondary maintenance funds on drainage maintenance. In some areas, drainage facilities were cleaned only in such emergency situations as flooding, clogged ditches, plugged pipes, or stagnated water.

CONSEQUENCES OF DEFERRED MAINTENANCE

When maintenance is deferred on any highway element, it will affect not only that element but most often other elements as well, since highways are made up of integrated parts. In addition, it may have an effect on safety, both motorist and pedestrian; on the environment; on the level of service of the facility; on individuals who live near the facility (social effect); and on the liability of the administering authority.

The consequences of deferred maintenance in the majority of cases are negative. Since the potential exists that the consequences of deferred maintenance may far outweigh the savings of postponing maintenance, the following previously mentioned major consequences were examined: safety, condition of facilities, liability, social and environmental effects, and level of service.

Safety

Providing safety to the users of transportation facilities should be listed as the number one priority in any consideration of deferring maintenance activities. Dangerous conditions may arise if maintenance is not performed in a reasonable manner. In the case of reduced mowing, regardless of the allowable vegetation height, safe sight distance must be maintained. This is probably more critical now than in the past since cars are decreasing in size and, consequently, are more easily hidden. An actual example of this occurred where crimson clover had been planted in the median strip because it needed no maintenance. It grew to the unexpected height of 3 ft (0.9 m) within the median and caused blocked vision at the intersection that resulted in a collision and a fatality. The highway department of that state was held responsible in judgment for the death.

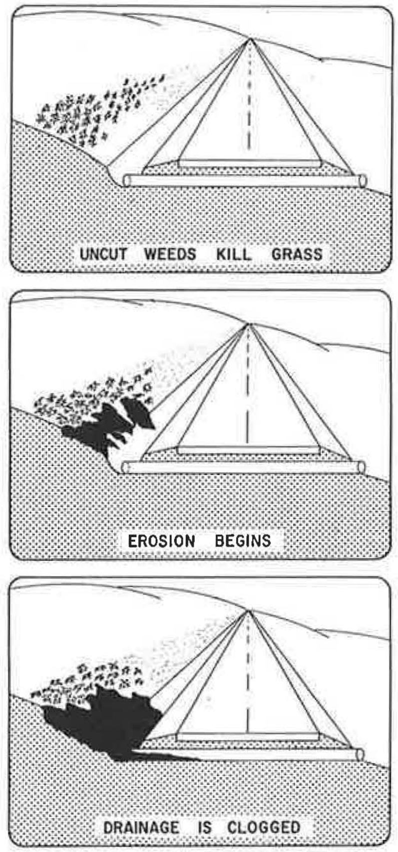
Some of the conditions that result from insufficient levels of maintenance and may produce safety hazards to motorists are reduced mowing, worn-out pavement markings, dirty or faded signs, potholes, fire, flooding, trees lying across the road, landslides, and shoulder drop-off.

Condition of Facilities

A highway begins to deteriorate through use and environmental action as soon as construction is completed. Although maintenance efforts are made to preserve or restore the road on a continuing basis to its original condition, degradation takes place. The level of maintenance to a great extent determines the rate of degradation (1).

Careful planning must be undertaken to protect the large highway investment if deferred maintenance is to be practiced. The Highway Users Federation reports that between 1914 and 1975 approximately $461 billion (excluding expenditures for right-of-way administration and maintenance) was spent by all levels of government on roads and streets. The value of roads remaining in service at the end of 1975 was approximately $262 billion (2).

Figure 1. Reduced vegetation maintenance on a highway that results in its deterioration.



Ill-advised reductions in maintenance programs can speed the deterioration of highway facilities and lead to greater costs in the long run. Figure 1 indicates one way in which maintenance deferral may cause serious roadway problems. A dense weed growth forms that is not mowed; this shades or crowds out the turf; the weeds die in the fall, exposing bare spots; and erosion sets in, which fills the drainage ditch.

In actual maintenance practice, a gradual physical deterioration of the road elements is accepted, and at intervals reconstruction is programmed. However, this is not the type of situation referred to here.

Liability

Closely related to safety are the legal aspects of postponing maintenance activities. In the past, government entities have operated under a doctrine known as sovereign immunity. Briefly, sovereign immunity is that principle that bars suit against the sovereign (here federal, state, or county government) without the sovereign's consent or permission (3). This "immunity" from legal action has been taken away over the years by the courts and legislatures to the point that in 1961 the California Supreme Court held in the case of Muskopf versus Corning Hospital District that "the rule of governmental immunity...must be discarded as both mistaken and unjust" (4).

There is a large backlog of cases pending against state transportation organizations in which sovereign immunity has been abandoned. Courts have taken a hard line on cases, and the burden of proof lies on the plaintiff. Nevertheless, some large judgments have been rendered against transportation agencies. Further, conversations with legal experts throughout the country about reduced maintenance and its legal ramifications indicate that a highway traveler, lawfully using the highway, is entitled to have that highway maintained in a reasonably safe condition.

The ultimate decision on what is reasonable and safe has often been determined by courts of law. However, there are many instances that are obviously unsafe. Some representative examples of potential state liability in case of accident that results from maintenance or lack of it are missing, deteriorated, or improper traffic control devices; blocked critical sight distance (as in the previously cited instance in which crimson clover grew to such a height that it restricted sight distance and a fatal accident resulted); drainage failure that causes flooding on a private citizen's estate; and herbicidal maintenance of highway rights-of-way (states have been found liable for the killing of crops and livestock by herbicide sprayed on the highway right-of-way).

Social Effects

The social effects stemming from highway construction and maintenance can be substantial for populations living near a road. Rough road surfaces, when run over by a car, produce distracting and disturbing noise. Transverse grooves cut into concrete pavements for skid-preventive purposes in earlier times, before random spacings were introduced, created such noise as to seriously disturb nearby dwellers. As a result of the disturbing noise produced by motor vehicles on freeways, many states in urban areas are constructing noise barriers.

In one location where mowing had been reduced and a trash receptacle was present, nearby homeowners complained that rats from the highway right-of-way were infesting the area. This is an example of an environmental consequence of poor maintenance that had negative social effects.

Any act that produces a negative social condition must be carefully considered, since there are a number of conditions that can be an outgrowth of postponing maintenance. For example, if maintenance and repair of drainage facilities is deferred, water may stagnate and produce foul odors, a breeding ground for mosquitoes, and the potential for disease.

Environmental Effects

Highways may contribute significantly to the pollution of the environment. Construction disturbs or destroys ecosystems and disrupts soil equilibrium. An imbalance is then produced that nature tries to correct. Much of the balance may be restored during construction, but this depends on the design and it is seldom complete. For this reason, it becomes a constant struggle to keep the highway facility from becoming a polluter of streams, lakes, etc., as nature seeks its balance.

Aside from the imbalances built into highways, certain maintenance activities, or their lack, may have an effect on the environment. There are many activities having to do with pavements, especially hot plant mixes of aggregates that contain asbestos minerals (serpentite), that are under scrutiny by environmental agencies. More in keeping with this study, however, are those environmental effects that occur when maintenance is deferred.

Level of Service

The level of service, according to the Highway Capacity Manual (5), denotes

> any one of an infinite number of differing combinations of operating conditions that may occur on a given lane or roadway when it is accommodating various traffic volumes. Level of service is a qualitative measure of the effect of a number of factors, which include speed and travel time, traffic interruptions, freedom to maneuver, safety, driving comfort and convenience, and operating costs.

Maintenance may affect the level of service in a number of ways, but anything that tends to restrict lateral clearance, such as trees or brush near the road, will adversely affect the level of service. Shoulder drop-off and surface conditions of the pavement affect the safety, comfort, and convenience of the motorists, as well as their car-operating costs.

Potholes, a pavement-surface condition caused by the failure of the subgrade, affect several level-of-service factors. They severely restrict speed, produce a potential safety hazard, reduce comfort, and cause considerable damage to motorists' vehicles.

DEFERRED MAINTENANCE: THE DECISION PROCESS

Data collected in this study indicate that transportation organizations are searching for methods of conserving funds. Maintenance is a segment of the transportation field in which large sums are expended; therefore, it is an area of potential savings. However, all maintenance activities do not carry equal weight. To lessen or discontinue maintenance on some activities would reduce a facility to the need for reconstruction in a short time, as well as create a multitude of safety hazards and other undesirable consequences; to defer maintenance on others would have lesser consequences. Some organizations are deferring certain maintenance activities (most notably mowing). Others are experimenting with deferring activities, and still others are contemplating completely discontinuing a number of activities. In some cases, the planning and projections of these actions' possible consequences were thorough and in other cases practically nonexistent.

State highway administrators often have to make decisions with a minimum of information and without a clearly defined logic to follow. Sometimes decisions made under these conditions are excellent, but the risk of a wrong decision or one with less than optimum return is great. There are many reasons for deferring maintenance. However, two of the prime reasons are (a) to save resources so they may be applied to other areas and (b) that no funds are available to perform the maintenance activity.

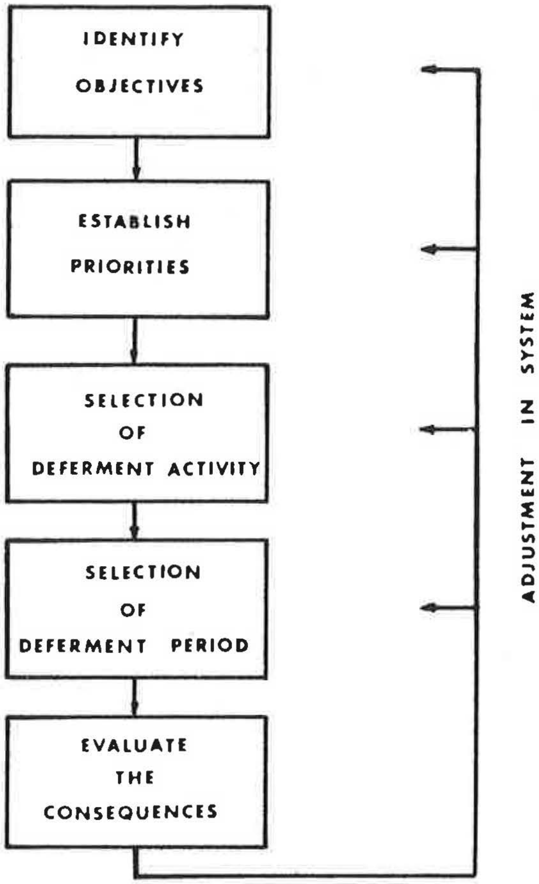
METHOD FOR DEVELOPING DEFERRED MAINTENANCE PROGRAM

The method indicated in Figure 2 was developed with the purpose of aiding maintenance managers and budget and administrative personnel in making decisions concerning deferred maintenance programs.

Step 1: Identify Maintenance Objectives

The first step in the decision process is the identification of maintenance objectives. Maintenance objectives may vary depending on the location of the road, the functional class, the average daily traffic (ADT), climatic conditions, the environment,

Figure 2. Logic in planning a deferred maintenance activity.



etc. In general terms, the maintenance objectives are those previously cited in the AASHTO definition. The validity of those objectives is well established; however, specific objectives must be fitted to the situation. Overall maintenance objectives include

1. Providing safe highway facilities (including structures),
2. Preserving the capital investment,
3. Providing adequate drainage,
4. Providing a road that is aesthetically pleasing both to the traveling public and to the residents of the abutting properties, and
5. Providing adequate levels of service.

For example, on the state level the maintenance objectives of mowing are to provide safe sight distance, provide cover for wildlife breeding, prevent the spread of noxious weeds, and provide an aesthetically pleasing appearance. The objections for cleaning and repair of drainage facilities are to protect investment, provide adequate drainage, prevent water pollution, and preserve a pleasing appearance.

Step 2: Establish Priorities for Maintenance Activities

The second step is to assign priorities to maintenance activities. The AASHTO operating subcommittee on maintenance suggests that maintenance priorities be adopted to direct maintenance activities toward more effective and efficient utilization of our energy resources, materials, personnel, and available funds and that a continued effort be made to provide the consistently high level of service demanded by the traveling public. In light of the objectives cited in step 1, this AASHTO subcommittee listed the following 19 items in order of decreasing priority:

1. Elimination of hazards or other conditions leading to road closure (avalanche danger, mud slides, washouts, heavy snowflow, severe icing conditions, severe bridge damage, pavement blowups, and so on);
2. Hazardous objects in roadway;
3. Repair of damaged or structurally inadequate structure;
4. Hazardous pavement conditions such as bumps, holes, slippery areas, minor heaves and blowups, or snow and ice;
5. Replacement or repair of damaged, obscured, or missing signs, signals, pavement markings, and lighting;
6. Pavement drop-off at shoulder;
7. Repair of damaged guardrail, guiderail, barricades, traffic barriers, impact attenuators, and other off-roadway safety features;
8. Repair of nonhazardous pavement deficiencies, including overlays, to preserve capital investment;
9. Maintenance of drainage features;
10. Minimal landscape maintenance to keep landscaping alive;
11. Maintenance and minor repair of signing and signals;
12. Routine maintenance and minor repair of structures;
13. Safety rest-area maintenance;
14. Mowing to maintain adequate sight distance, prevent erosion, or maintain drainage;
15. Routine maintenance of roadside features (including guardrails, fences, and so on);
16. Motorist aid patrols;
17. Roadside cleanup;
18. Mowing and other work for aesthetic purposes; and
19. Work for other agencies.

This listing makes it possible to assign maintenance activities to the objective groupings previously developed. These objective groupings may vary somewhat according to the needs of the particular organizations that use the process; however, the top two priority groupings in order of importance should be safety and investment.

The California Department of Transportation has also developed a set of priority groupings and subsequently assigned activities to them. These priority groupings in descending order of importance are (a) safety, (b) investment (preservation of capital investment), (c) user service (snow removal, etc.), (d) aesthetic appearance, and (e) miscellaneous (work for other agencies).

Once the groupings are accomplished, it is possible to assign the maintenance items. It is not expected that all transportation organizations will place the same items in similar groups; in fact, some maintenance items fit into more than one group. A sample listing follows:

1. Safety--shoulder drop-off repair, sign maintenance, pothole repair, rock patrol;
2. Capital investment--ditch cleaning, crack and joint maintenance, resurfacing, bridge maintenance;
3. User services--snow removal, repair of bumps, correction of slippery areas; and
4. Aesthetics--mowing, painting, cleaning.

Step 3: Select Activities to Be Deferred

If maintenance objectives are first identified and priorities are then established, the selection of activities to defer is simplified. The selection of items to defer will be based on previously assigned priorities, maintenance policy, and magnitude of savings as determined by a benefit-cost ratio (6).

Step 4: Assign the Deferment Period

If the results of different levels of maintenance were known, it would simplify the task of assigning deferment periods. In many instances, quantitative measures are not available. However, sources of information that can be used in the decision process are historical data, models, engineering judgment, and research.

Historical Data

One of the prime sources of information available for use in determining deferment periods is historical data. Since the advent of maintenance systems and road data banks, large amounts of precise usable information have been stored on such topics as maintenance frequencies, rates of repair, materials used, cost data, road data, skid-resistance of pavements, and pavement serviceability ratings.

In addition, data systems can be programmed to print out selected information that is based on predetermined occurrences. For example, on the subject of resurfacing information, if history indicates that pavements on high-design roads have been resurfaced on an average of every eight years, a computer program may be written in which a list of all sections of pavements that reach this age during a year will be automatically printed out. Files are available in many states for different highway activities. The value of information is greatly increased when it is integrated with other data, such as skid resistance. Not only can the rate of deterioration be observed and decisions on deferments be made, but the causes of deterioration can often be determined also. Pavements sometimes get slick long before they are worn out and this condition requires maintenance to correct. Historical data can indicate the best type of pavement mix to use to avoid this type of situation.

Maintenance Prediction Models

Maintenance models, although not perfected, are valuable tools to determine deferment periods. Two types of models under development in Massachusetts to compute the condition of the accumulated deterioration of inventoried items are

1. Physical models that establish explicit functions between the condition or deterioration and the pertinent physical, environmental, and traffic-induced factors thought to affect life or performance and
2. Frequency models that assume that the underlying physical relationships can be adequately represented by a time-dependent function.

The choice of which model is best for each activity series or group is a matter of judgment and depends on several criteria:

1. The relative importance of the activities modeled (this can be in terms of maintenance costs, as well as in terms of public responsibility, such as safety or legal requirements);
2. The nature by which the demand for maintenance arises, i.e., whether physical factors dominate the time dependencies;
3. The consequences of deferring maintenance to a later date, i.e., whether the maintenance is merely postponed (the level of maintenance effort required does not increase substantially if it is performed later rather than now, e.g., picking up litter), in which case frequency models are most appropriate, or forgone (the opportunity for relatively minor corrective effort exists for only a limited time and if maintenance is deferred beyond this time more expensive actions may be called for, e.g., pavement maintenance), in which case physical models are most appropriate; and
4. The reliability and level of detail of the data available (in general, physical models require more data than do frequency models).

Engineering Judgment

A resource that should not be overlooked is the professional judgment of personnel. Members of select committees given the responsibility for planning deferred maintenance should possess extensive field experience with the activity under consideration.

Research

Much maintenance-activity research, at little or no additional cost, can be blended into regular maintenance performance routines and can offer the additional advantages of providing opportunity for evaluation and comparison with the "normal" schedule by both researchers and field managers. In addition, field maintenance personnel who perform the work have an opportunity to become familiar with the new procedure. One of the more difficult steps in implementing new procedures is to get them carried out as prescribed. Researchers claim that in the implementation of deferred or reduced mowing programs, one major problem was to get the mowing-machine operators not to cut the vegetation until it had reached the new height. If the operators had been mowing vegetation at a height of 8 in (20 cm) for 20 years, they were very apt to continue. Many times, issuing instructions and putting up signs were not sufficient to accomplish the results. With research, to which deferred maintenance appears to lend itself especially well, the training of personnel can be carried on simultaneously. Research has many points to recommend it, but there are two very specific ones:

1. The risk factor is greatly minimized by the controlled conditions and the ability to discontinue on short notice.
2. It is possible to study the interrelationship between activities, i.e., the effects that deferring the repair of scour damage around a culvert might have on the integrity of the shoulder and on drainage or, for that matter, the effect of deferred mowing on pavement deterioration.

Step 5: Evaluate the Consequences of Deferment

The final step in the decision process is to consider the consequences of deferring a maintenance activity. Most of the previously discussed results of deferred maintenance have shown negative aspects. The negative consequences of deferring maintenance activity beyond normal routine do not carry equal weight. For example, a pleasing roadside appearance (aesthetics) will not be ranked equally with a road hazard.

Figure 3. Flowchart for evaluating the consequences of deferred mainenance.

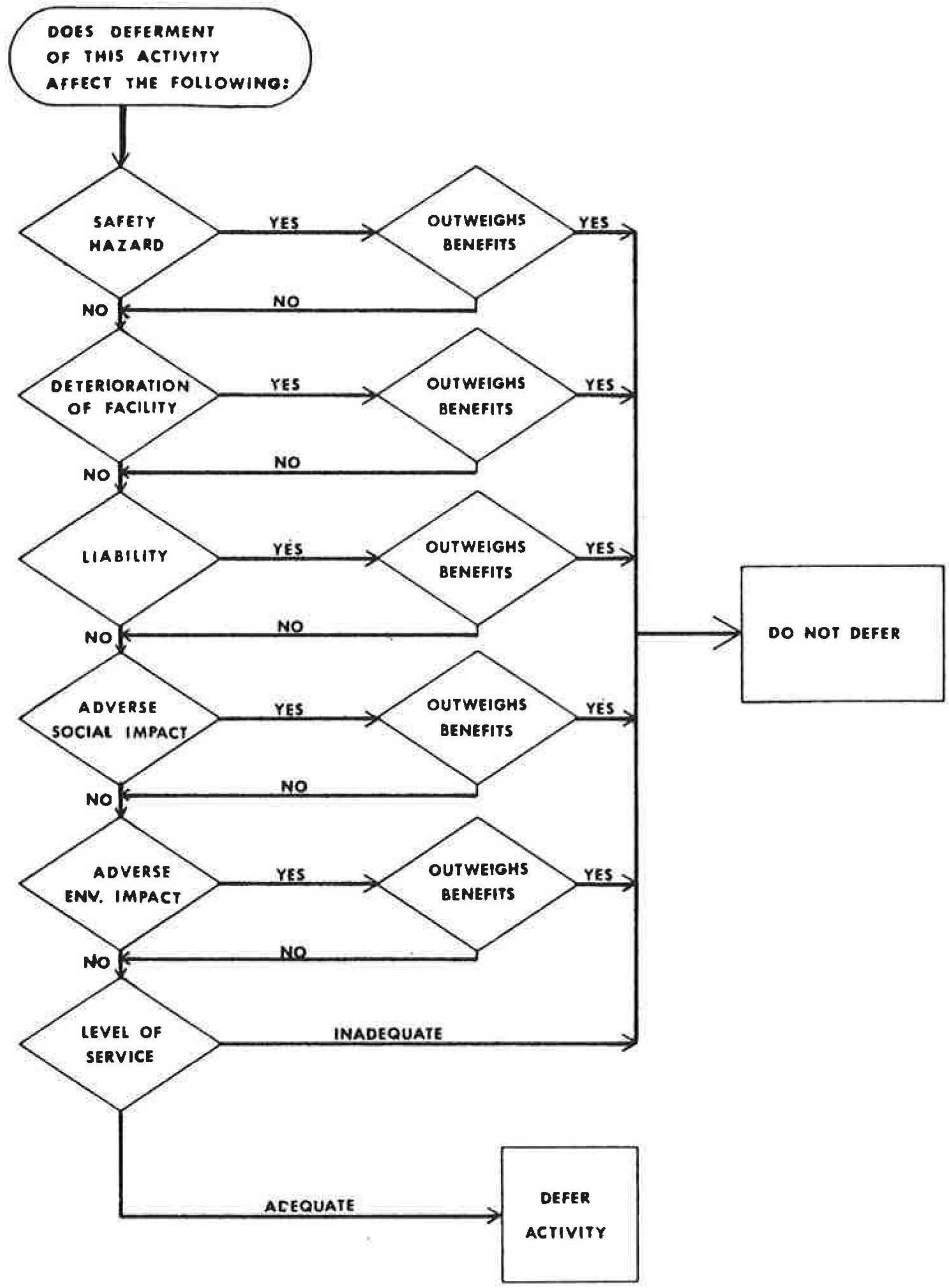


Figure 3 is a flowchart that evaluates the consequences of deferred maintenance. Each deferment activity should be evaluated in terms of these major consequences. This does not imply that every maintenance activity will affect all of the consequences; however, in many cases the results of deferral will show up in more than one of the consequences.

The decision to continue deferment of a maintenance activity will be a summation of the individual analyses of the various consequences shown in Figure 3. For example, in the case of deferred mowing, a ragged appearance may not justify a return to the normal schedule. However, a ragged landscape, insufficient sight distance, and deterioration of the facility would justify such action.

A number of highway measurements and tests may be used to analyze the consequences of maintenance deferment. Examples include sight-distance measurements, pavement serviceability ratings, skid tests, and road roughness tests. In addition, accumulated highway data on accidents, flooding, and citizen complaints are sources to aid in evaluation. Engineering judgment will also be a factor in assessing the consequences of deferring maintenance.

The results of the analysis may be listed in the form of warrants for each activity. An example of this, applied to mowing, might read as follows:

Defer mowing to the point that one or more of the following conditions exist:

1. Sight distances become inadequate (vehicles hidden in crossovers, intersection sight distances blocked, signs hidden, driveways obstructed, etc.),
2. Drainage becomes partly obstructed by vegetation,
3. Noxious weeds become a threat to both the

highway right-of-way and adjacent croplands, and
4. Lack of mowing leads to the deterioration of the roadside.

The analysis and development of warrants for each activity would be based on a comprehensive investigation.

CONCLUSIONS

Deferred maintenance is now widely practiced, sometimes without an in-depth consideration of possible consequences. Since all indicators point toward a simultaneous shrinking of the maintenance dollar and an increase in maintenance requirements that results from the aging and the wearing out of road systems, especially Interstate highways, deferred maintenance will increase in the future. This is a just cause for concern among highway engineers. If the wrong decisions are made, disastrous results could occur and bring harm to the entire highway system. It is hoped that the deferred maintenance logic suggested in this report will aid highway administrators in making as many correct decisions on deferments as possible.

ACKNOWLEDGMENT

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Roadside Management

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The functional requirements of a transportation facility, and its neighbors' needs, dictate roadside management activities as part of the total highway maintenance program. Aesthetic improvement is a no-cost fringe benefit. The roadside is defined as the area between the outside edge of a shoulder and the right-of-way boundary. The median strip on multilane highways and interchange areas are included. The Washington Department of Transportation manages the roadside, either constructed or natural, as a public resource. Four methods of vegetation control are discussed; special emphasis is given to chemical control. Three work zones and separate treatments for each are identified. Planning and timely accomplishments are the keys to effective long-range vegetation management. Roadside maintenance managers must be trained to recognize the roadside as a resource and learn to manage it in the most efficient and effective way. Field-level employees must be well trained before the planned program can be implemented.

The opening paragraph on roadsides in the 1976 American Association of State Highway and Transportation Officials (AASHTO) Maintenance Manual (1) describes the philosophy of the Washington Department of Transportation (WDOT) on roadside management.

> Recent changes in public attitudes have given roadside maintenance new dimensions. As much as any other part of the roadway, the roadside, when properly maintained, presents a new look that recognizes the value of a pleasing and ecologically balanced environment. Roadsides with natural growth present a challenge to the maintenance manager to combine objectives of low cost and effectiveness with elements to improve the roadside environment.

The roadside includes the area between the outside edge of the shoulder and the right-of-way boundary. The median strip and interchange areas within a multilane highway are also part of the roadside. Roadsides can be constructed or be in a natural condition that includes the land remnants adjacent to the construction zone. Constructed roadsides should be maintained to a level that provides a satisfactory contribution to the safety, convenience, appearance, and pleasure of the public and the preservation of the roadway itself. The composite areas, either constructed or natural, need to be managed as a public resource.

Each state or region obviously has its own unique ecosystems within its boundaries, and they must be appropriately controlled and stabilized if the roadside is to function as intended. Special knowledge and treatment are necessary to control the dense brush and tree growth indigenous to the coastal regions of the Pacific Northwest; the juniper, desert grass, and cactus of the Southwest; the mixed hardwoods and brambles of the Northeast; the pine forest, kudzu vines, and aquatic weeds of the Southeast; and the grasslands of the Central States. Washington State's several climatic regions foster many different ecosystems that may be similar to those found in other parts of the nation.

In roadside maintenance, we recognize that our first obligation is to the road user. The traveling public is entitled to use a highway reasonably free from vegetation that reduces visibility, obscures signs, and otherwise introduces safety hazards. We also recognize that a roadside is a resource that can be exploited without detriment to the traveler. For example, it can become a game habitat, a songbird sanctuary, or a source of native fruit. It can also accommodate public utilities, provide trail systems, and produce commercially valuable agricultural crops and still be aesthetically pleasing.

METHODS OF VEGETATION CONTROL

In order to originate a good vegetation management program, we must have a thorough understanding of the effects of human manipulation of natural vegetation patterns. There are four basic methods for controlling vegetation patterns: biological, mechanical, cultural, and chemical.

Biological Control

Biological control consists of the introduction of insects, animals, or specific diseases into an ecosystem. These act as predators on the specific plant species to be controlled. In the Northwest, for example, the cinnabar moth has been introduced. Its larvae are successfully attacking tansy ragwort, a noxious weed. Seed fly and flea beetle species have also been used for biological control of tansy ragwort. The spread of gorse, a plant native to Scotland and imported into the coastal regions of Oregon, has been successfully reduced by the introduction of the gorse seed weevil. The gall midge and gall mite are being studied as possible agents for the control of skeleton weed. Puncturevine is controlled by the puncturevine seed weevil in some areas of the Pacific Northwest. Grazing by farm animals can also be considered as a biological control of dense grass stands. The white amur (a giant carp) and sea cow (or manatee) will control certain types of aquatic vegetation in the tropical climates.

We are not suggesting that biological control is the best method for controlling vegetation on highway roadsides; however, knowledge of existing biological control programs should be a factor during the development of a more practical integrated program for vegetation control. We do not want to introduce other controls that will jeopardize an established program.

Mechanical Control

Mechanical control involves the use of tools and equipment to eliminate a portion of a plant, an entire plant, or all of a plant community. Mowing, cutting, and cultivation are examples of mechanical control. Washington's program of mechanical control requires the use of various types of mowers, including reels, rotaries, flails, and sickle bars. We also use the Bomford and Roanoke machines for mowing heavy vegetation. Other tools used are chainsaws, airsaws, and chippers.

Cultural Control

The third method, cultural control, encourages desirable vegetation to grow, thus enabling it to crowd out the undesirable species. For example, we fertilize and lime grass stands to stimulate strong growth of desirable grasses. This action discourages tree seedlings and weed plants, which are poor competitors at best, from reestablishing themselves.

Chemical Control

A popular method for vegetation control is the use of chemicals. This fourth method is now widely practiced by most states because it is so cost effective. Chemicals, called herbicides, are developed for a variety of uses. Herbicide selection depends on the desired results, since herbicides can be very selective or totally nonselective.

ROADSIDE ZONES

Vegetation management techniques employed in the state of Washington vary. The state's roadsides are divided into three zones.

1. The first, the bare-earth zone, extends from the edge of the pavement or paved shoulder to the centerline of the roadside ditch. The bare-earth zone, on embankment sections, extends beyond the guardrail to the toe of the pavement ballast. All vegetation within this zone is eliminated by the use of nonselective herbicides. The bare earth adjacent to the traveled way ensures proper drainage from the pavement structure, discourages fire starts, and prevents concealment of roadside appurtenances.
2. The second is called the selective vegetation zone. Generally, this zone begins at the outside edge of the bare-earth zone and extends to a point at which the vegetation does not greatly affect the functional requirements of the roadway. Chemical, mechanical, and cultural methods of vegetation control are used to govern the encroachment of plants that will shade pavements and obscure sight lines on curves and to distant views.
3. The third and final zone is known as the transition zone. It extends from the selective vegetation zone to the edge of the right-of-way. As its name implies, this zone functions as a transition between the operating roadway and the lands that abut the transportation corridor. Public relations and aesthetic aspects come into play during the management of this third zone. Sculpturing tree lines, opening views, establishing buffers, and addressing local needs are principal factors to be considered in management of this zone. In areas where a highway changes from an urban to rural environment, special treatment may be necessary to blend a formal landscaped roadside with the natural. Properly controlled native vegetation can be developed as a substitute for ornamental plants wherever a formal landscaped area is desired.

EFFECTIVE ROADSIDE VEGETATION MANAGEMENT

The effectiveness of the four methods of control in any of the three zones will vary. As a general rule, one must consider each vegetation complex and treat it in a prescriptionlike fashion. This prescription may require the use of one or more of the four methods of control.

Planning and timely accomplishments are the keys to effective long-range vegetation management. An example occurred in Washington State recently. Maintenance forces cleared trees and brush from less than an acre of roadside on which vegetation control had been deferred for several years. The cost of removal was in excess of $6500. These same funds, and about one-thirtieth as many employee hours, could have paid for the treatment of more than 150 acres of roadside vegetation if the work had been planned and completed when the trees and brush were seedlings. We are now planning to plant grass as a competitive ground cover to reduce the possibility that the trees and brush seedlings will again dominate the area.

Vegetation control is a continuing program, not just a one-shot clearing and spraying activity. A planned program is less costly in the long run than an intermittent remedial response to a crisis condition. This is why the whole process is appropriately called "vegetation management".

A person involved in planning for roadside maintenance must have a broad general knowledge of the roadside to be managed. This person should have an appreciation of botany in order to know the dynamics of plant replacement in specific vegetation groups or patterns. He or she must have the knowledge of plants' optimum growth conditions, levels of fertility, and moisture, light, and soil pH requirements. Above all, this person must know how the four methods of plant control interact with each other. An understanding of the consequences of any one or a combination of methods and knowing how to compensate for creating adverse conditions is necessary. Since chemical control is the most complicated and sensitive of all methods of vegetation control, a person must have specific knowledge of how each herbicide will work. Finally, he or she must be skilled in public relations and in ways of selling a program to the public and fellow employees.

In our opinion, chemical herbicide control is the most cost-effective and efficient method used in a vegetation management program. There are, however, a variety of cautions to consider if this type of control is planned. Chemicals must be properly used under very controlled conditions. For this reason, employees who apply the herbicide must be thoroughly trained and certified by the U.S. Environmental Protection Agency (EPA) or a state agency that conducts an EPA-recognized certification program.

WDOT has approximately 200 trained and certified herbicide applicators. Only about 75 of these people are involved in herbicide application at any one time. In Washington State, the Department of Agriculture is the EPA-recognized certifying agency and, with its assistance, we train our own employees. Training for employees to use herbicides begins with a 3- to 4-h program, followed by a written examination. Once our employees are licensed, they are given additional training every two years. This training involves 16 classroom hours. The course includes 4 h of instruction on the whys and wherefores of vegetation management, 8 h on specific spray programs, 2 h on the personal safety and legal aspects of herbicide programs, and 2 h for a final discussion by the participants, staff, and representatives from the herbicide industry.

IMPORTANCE OF GOOD PLANNING AND MAINTENANCE

We believe the benefits of a properly executed roadside management plan are many. It is particularly important to maintain clear shoulders and drainage facilities so that water does not collect and damage the shoulder or pavement edge. Any buildup or encroachment of grass or weeds on the shoulder produces a dike that will trap water on or within the roadway structure. We all know that water is the road's worst enemy.

Signs that are obscured by brush cannot perform as intended. Stop signs at intersections that are unseen by a motorist could place the driver in jeopardy. If a driver does not see a sign and runs the intersection, a severe accident may occur.

Fence lines should be kept clear of brush and vegetative growth. Fencing materials deteriorate more rapidly in a microclimate created by dense stands of vegetation. The vegetative cover may also mask a hole or break in the fence.

A properly maintained roadside can improve winter driving conditions. Snow and ice persist on pavements shaded by tall trees or encroaching brush. How often is a driver surprised on a cold, bright, sunny winter day by driving into a shady spot where the pavement is still covered with glare ice? A proper management program will minimize this possibility. In certain localities, a hedge of brush or fencelike row of trees can act as an effective snow fence. In the wrong location, however, these same growths can hamper snowplowing operations by causing snow drifts to form on the roadway and by reducing snow storage areas. Selective thinning of trees and dense brush within the zones adjacent to the bare-earth zone can provide windows, allowing sunlight to fall on the roadway. Selective thinning also creates transition zones between intensely shaded pavements and those in full sunlight.

This type of control is not only necessary from the standpoint of snow and ice control, but it also reduces driver eye stress. This unnatural stress is caused by the rapid adjustment of the eyes to different levels of light. The constant adjustment causes fatigue and short periods of impaired vision--obviously, an undesirable condition.

Roadside management program planning must take into account the effects of the program on the road's neighbors. The results of a vegetation control program must be compatible with the majority of the properties adjoining a highway right-of-way and defensible when challenged by the minority.

Washington state law and local ordinances require citizens to control noxious weeds and, as a state agency, WDOT must provide a model of compliance. Therefore, noxious-weed-control activities are an integral part of the WDOT roadside maintenance management program.

In some areas within Washington State, a grass surface is part of the roadway structure. To perform as expected, these sod surfaces must remain green and active during the summer months when fire dangers are the greatest. One way WDOT has found to maintain this type of shoulder, without irrigation or extensive mowing, is by the use of growth-regulating chemicals. These chemicals reduce grass growth and inhibit seed formation. The stunted grass plants will often survive on natural soil moisture, remaining green several weeks longer than mowed grass. Inhibition of development of the seed head also stops grass plants from maturing and from browning out. Until recently, the use of growth regulants for control in mixed grasses gave erratic results. The modern growth regulants can now be used effectively with many grass species, assuring a reasonably good control in mixed stands. Herbicides used to control broadleafed weeds can be applied in combination with these regulants, thereby eliminating the need for a second application.

CONCLUSION

The need for roadside management is not new. In July 1930, the American Association of State Highway Officials' Committee on Roadside Beautification held its first meeting. They adopted resolutions that described the need for roadside beautification and its various activities to reduce highway maintenance costs caused by erosion, slides, and snow.

Roadside maintenance is an integral part of a state's overall maintenance program, and its importance should not be overlooked. A good roadside maintenance program is cost effective, and it should not be eliminated on the grounds that impacts are for aesthetic purposes only and should not be financed. Improved roadside appearances are actually a measure of a well-maintained roadway and represent the department's concern for the environment through which the roadway passes.

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Abridgment

Minimizing Roadway Salt Problems in Maine

KENNETH M. JACOBS AND RICHARD SCOFIELD

In an effort to reduce the salt problems in Maine that have resulted from winter maintenance operations, a three-phase program was implemented: (a) early detection of salt toxicity to vegetation, (b) reduction in the amount of salt used, and (c) dispersal of sodium ions in the soil. Aerial-photograph interpretation by using color infrared photography was developed for early detection of vegetation damage. Reduction in the amount of salt used was achieved through calibration of salt-spreading equipment and through intensive yearly instructional meetings to inform the operators of the importance of reducing salt use. These two methods allowed the Maine Department of Transportation to reduce the use of salt from 99 000 t (110 000 tons) in the winter of 1967-1968 to 57 600 t (64 000 tons) in the winter of 1978-1979. Sodium-induced stresses on vegetation were further reduced by dispersing sodium ions in the soil through the application of gypsum.

To minimize the effects of salt (NaCl) on the environment and reduce costs, the Maine Department of Transportation (MDOT) developed a method of detecting early damage to vegetation by using color infrared photographs, a program to control the amount of salt applied, and a method for alleviating the sodium toxicity of soil.

Through the use of aerial-photograph interpretations of color infrared photography, it was possible to obtain information on damage that possibly resulted from saline runoff. This method made it possible to determine whether any vegetation damage was visible for the areas adjacent to the roadway and/or salt-storage areas.

Once sodium toxicity to vegetation became evident, it was difficult to correct. However, for some situations it was found desirable to lower sodium levels of the soil in order to reduce the toxicity to vegetation. Thus, research was undertaken to determine whether some means of alleviating this problem was possible. Through this effort, gypsum ($CaSO_4$) was found beneficial in lowering sodium levels in soil.

METHODOLOGY

The first phase was to determine whether vegetation damage existed and whether the damage resulted from saline runoff. This was accomplished by the use of color infrared photography. The second phase, on which the main emphasis was placed, was to reduce the amount of salt used, thus preventing as many salt-related problems as possible. The third phase was the use of gypsum to disperse the sodium ions in the soil.

Detecting Vegetation Damage

It was determined to be feasible to use aerial-photograph interpretation techniques in order to detect possible early vegetation damage that might be salt related. The objectives were to locate and map damaged areas, analyze possible causes, and recommend corrective action.

Color and color infrared 35-mm photographs were used for the study areas; the photographs were taken at various stages of foliage development, from the budding through the coloration period. The aerial photographs were taken from oblique through near vertical angles by means of a hand-held 35-mm camera. It was possible by use of color infrared photography to distinguish healthy vegetation from the damaged vegetation within an area, especially if the area contained the same tree species. Color infrared photography provided the highest image contrast between the healthy and damaged species late in the growing season.

There are other causes for stress, such as blight, insects, plant diseases, herbicides, winter kill, and modification of groundwater level by cuts, embankments, and culverts. However, salt in combination with poor drainage conditions does cause considerable damage. Assistance from forestry personnel may be required to determine the cause of early stress.

Reducing the Salt Application

Various procedures were instituted to keep the use of salt to an absolute minimum and still maintain the desired results. The equipment was calibrated and personnel were trained so that only the desired amount of salt was used. MDOT generally tried to use 113 kg per two-lane kilometer (400 lb per two-lane mile) per application. Although a reapplication was sometimes needed, which required additional work and truck hours, there was still an overall dollar saving.

MDOT reduced the use of salt by attacking the problem in three ways:

1. Old equipment was modified so that it could be calibrated; newer equipment was purchased with calibration in mind.
2. Yearly instructional meetings were held with the operators of all equipment to reinforce MDOT's position on the importance of reducing salt use. These meetings were followed by shorter meetings at the division office level.
3. Supervisors inventoried the salt used in each of the divisions. This information was provided to the division engineers so that they could take corrective action if it appeared that salt use was

Figure 1. Chemical reaction.

$$\frac{\text{Soil}}{\text{Particle}}\begin{matrix}Na^{+}\\Na^{+}\end{matrix} + CaSO_4 \longrightarrow \frac{\text{Soil}}{\text{Particle}}\ Ca^{++} + \underset{\text{(soluble)}}{Na_2SO_4}$$

excessive in any area through errors of either practice or judgment.

In addition to actual control of the amount of salt used, other procedures were implemented as part of a total salt-reduction program. First, plowing operations commenced as soon as snow had accumulated to any appreciable extent. During a winter storm watch, MDOT begins to plow when the snow accumulation reaches 1.27 cm (0.5 in) and it is still snowing. In addition, where positive down pressure could be applied, underbody plows were used. This method partly replaced chemical action with mechanical force, thus requiring less salt. A third method was to use tungsten carbide plow blades without plow shoes. This type of blade rode on the surface and cleaned nearly all the snow from the roadway surface.

Salt Restrictor

One of the more successful pieces of equipment used by MDOT was a restrictor. The restrictor is a simple device employed only on hydraulic tailgate sanders. The tailgate sanders were equipped with an auger shaft that ran the width of the body into a 25-cm (10-in) opening on the left side of the tailgate.

The restrictor, which was adjustable on the shaft, limited free flow and allowed the flow of salt to be regulated. A 1.27-cm (0.5-in) gap between the restrictor and auger opening released the desired application rate at normal speeds. Hard-weld beads on the inside of the restrictor plates aid in grinding the cakes of salt.

Because the auger speed varied between trucks, a chart was developed that related the speed of the auger to the flow of salt for the 1.27-cm gap. A table was developed to convert the flow in pounds per minute to pounds per mile per hour.

Hopper Sander Calibration

Every hopper sander was calibrated at nine individual settings. The discharge gate was set at 2.54-, 5.08-, and 7.62-cm (1-, 2-, and 3-in) openings, and the hydraulic control that regulated the speed of the feed belt was set at three separate settings with each gate change. Calibration took an average of approximately 35 min to complete.

The operator was instructed to race the engine to a working engine speed (1100-1500 RPM for diesel-powered equipment and 2000-2500 RPM for gasoline-powered equipment), put the hopper belt in gear, and discharge salt for 60 s. The weight of the salt discharge was recorded. This process was repeated for each individual setting. For convenience and ease of handling, a 0.03-m^3 (1 ft^3) box was used for weighing. This box was weighed and the net weight recorded. Usually, a setting would contain two to five full boxes plus a partial box that also would be weighed. The calibrations ranged from 23 to 227 kg (50-500 lb) of salt/min. The calibration results were returned to the office and transferred to a calibration chart that was then returned to the operator of the equipment. It was found that no two pieces of equipment calibrated the same, which made it necessary to calibrate all of the hoppers.

Alleviating Sodium Toxicity

A study completed by F.E. Hutchinson in 1965 and 1966 (1) indicated the sodium and chloride levels were a function of the length of time and the amount of salt applied to the highway. He also found that the higher sodium and chloride levels in the soil were near the edge of the highway, within 15 m (50 ft). Soil samples obtained at 0, 9, and 18 m (0, 30, and 60 ft) indicated minimum sodium and chloride levels beyond the longitudinal roadway ditches.

In 1969 Hutchinson initiated a study to determine whether any means was available to remedy the problem of high sodium levels in soils adjacent to highways (2). Later MDOT made a follow-up study (3). Both of these studies focused on dispersal of sodium ions through surface applications of gypsum. These applications were made by using the gypsum both in the dry form and mixed with water to form a slurry. When a slurry was used, three methods of treatment were tried; surface treatment, surface treatment with aeration, and subsurface treatment. When gypsum is applied to a soil that has high sodium levels, the reaction is as shown in Figure 1.

Thus, when the sodium is replaced by calcium in the presence of sulfate ions (SO_4^{--}), a very soluble sodium sulfate is formed and leaches downward through the soil whenever water is available. It should be noted that as the $NaSO_4$ leaches downward it may enter into the groundwater supply and thus raise the sodium levels of the groundwater.

Field Methods of Application

A slurry mixture of 0.5 kg of gypsum per 1 L of water (4 lb/gal) applied with a hydroseeder unit was found to be the most satisfactory method of application; this method of application produced the largest percentage reduction in sodium levels for a one-year period--55 percent for the 0- to 15-cm (0- to 6-in) depth. Use of the hydroseeder eliminated the dust problem, and it was possible to obtain the desired application rate.

RESULTS

Aerial-photograph interpretation, reduction of the salt application, and alleviation of sodium toxicity provided results that minimize roadway salt problems.

Aerial-Photograph Interpretation

Aerial-photograph interpretation techniques provided the means for locating damaged vegetation that was, in some instances, more extensive than first believed. For example, there were cases in which it had been believed that only a few trees had been damaged but, after the photographs had been analyzed, it was found that many thousands of trees showed the early effects of salt toxicity. This finding was verified by field inspections and proved especially true when there had been saline runoff into a bog area. For streams and rivers, sodium and chloride levels were not a problem (4).

The decision to enclose salt-storage areas was based on information obtained from this type of findings, plus other factors such as keeping the salt dry, which allowed better control in application.

Reduction of Salt Application

Early in the program of salt reduction, when the application of salt on the highways was being investigated, it was ascertained that some operators had applied approximately 225-280 kg/km (800-1000 lb/mile) where 85-110 kg/km (300-400 lb/mile) would have been sufficient. At that time the only control over the amount of salt applied to the road was by adjusting the speed of the truck. During 1967-1968, 17.8 t/km (31.5 ton/mile) were applied each year. With only 25 percent of the trucks equipped with restrictors in the winter of 1968-1969, 15.8 t/km (28.0 ton/mile) were applied. In the winter of 1969-1970, after nearly 100 percent of the trucks had been equipped with restrictors, the application was 11.3 t/km (20.0 ton/mile).

During the winter of 1967-1968, MDOT had used more than 99 000 t (110 000 ton) of salt. However, following the policy of keeping salt used to an absolute minimum while maintaining desired results, it was possible to reduce the amount of salt to approximately 57 600 t (64 000 ton) per year in the winter of 1978-1979. The amount of salt used was reduced from 8.53 to 4.61 t/lane-km (15.14 to 8.18 tons/lane mile) although the length of state highways had increased from 11 761 to 12 614 lane-km (7308 to 7838 lane miles).

Alleviation of Sodium Toxicity

Where gypsum was applied, it appeared that the optimum rate of application was 24-34 t/hm^2 (10-15 tons/acre). This rate was based on replications of 0, 22, 34, and 45 t/hm^2 (0, 10, 15, and 20 tons/acre). These applications on a marine clay silt soil resulted in a 55 percent reduction of sodium ions at a depth of 0 and 15 cm (0 and 6 in), 30 percent at 15 and 30 cm (6 and 12 in), and 45 percent at 30 and 46 cm (12 and 18 in). This reduction was obtained over an 11-month period in an area that receives approximately 104 cm (41 in) of rainfall annually. In contrast, sodium levels increased in the control plots.

The application of gypsum is probably limited to urban and/or suburban areas where there is a serious problem of sodium toxicity to vegetation, because gypsum application is a relatively expensive procedure.

CONCLUSIONS

The effort to reduce salt problems that have resulted from highway maintenance operations produced the following results:

1. Aerial-photograph interpretations by using color infrared photography aided in the early detection of salt toxicity to vegetation.
2. Calibration of equipment, keeping the salt dry so that the calibrated equipment functioned properly, and instruction for all the operators so they were aware of the problems that excess salt use causes made possible a reduction in use of salt.
3. Surface application of 22-34 t/hm^2 (10-15 tons/acre) of gypsum lowered the sodium levels 30-55 percent, whereas sodium levels increased 1-24 percent for the untreated plots.

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