currently unfenced sections of four-lane highways where fences are about to be installed. In view of the findings in this report, additional advantages are that gaps under the fence would not occur as frequently on the more level ground near the highway, and there would be a far less severe problem with falling trees.

ACKNOWLEDGMENTS

This work was supported by the Pennsylvania Department of Transportation and the Federal Highway Administration, U.S. Department of Transportation. We thank Richard Shaffer of the Pennsylvania Department of Transportation for his interest and aid. We thank personnel of the Institute for Research on Land and Water Resources for aid in the fieldwork, especially Terry Bashore, Leonard Corin, Noel Falk, and Michael Kress. Blair Carbaugh of Lock Haven State College provided invaluable help and suggestions. We acknowledge the help of Lowell Snyder, game protector, in obtaining data on deer mortality. We appreciate the cooperation of Troop S of the Pennsylvania State Police, Milesburg, Pennsylvania.

REFERENCES

1. M. J. Puglisi. Pennsylvania Conducts Study of Vehicle-Deer Collisions. Traffic Safety, Vol. 74A No. 4, 1974, p. 25.
2. E. D. Bellis and H. B. Graves. Deer Mortality on a Pennsylvania Interstate Highway. Journal of Wildlife Management, Vol. 35, No. 2, 1971, pp. 232-237.
3. B. T. Carbaugh, J.P. Vaughan, E. D. Bellis, and H. B. Graves. Distribution and Activity of White-Tailed Deer Along an Interstate Highway. Journal of Wildlife Management, Vol. 39, No. 3, 1975, pp. 570-581.
4. N. W. Falk. Fencing as a Deterrent to Deer Movement Along Highways. Pennsylvania State Univ., DEd thesis, 1975, 45 pp.
5. D. M. Tubbs. Ecology and Behavior of White-Tailed Deer (Odocoileus virginianus) Along a Fenced Section of a Pennsylvania Interstate Highway. Pennsylvania State Univ., DEd thesis, 1972, 51 pp.
6. P. J. Bobak. A Comparative Study of Activity and Behavior of White-Tailed Deer (Odocoileus virginianus) Along Two Sectors of Interstate Highway. Institute for Research on Land and Water Resources, Pennsylvania State Univ., 1975, 56 pp.
7. F. Peek and E. D. Bellis. Deer Movements and Behavior Along an Interstate Highway. Highway Research News, No. 36, 1969, pp. 36-42.

Publication of this paper sponsored by Committee on Roadside Maintenance.

Economic Impact of Highway Snow and Ice Control

Joseph C. McBride, Utah Department of Transportation

An overview of a national study of highway snow and ice control that involved the Federal Highway Administration and eleven state highway agencies is presented. A method of establishing level of service for winter maintenance based on an economic analysis is discussed. A winter maintenance questionnaire was distributed to Idaho, Illinois, Minnesota, and Utah to determine the public's attitude toward the maintenance effort being made in each state. The study also examined the user costs that occur during winter maintenance. Accident rates, user delay, traffic volumes, and vehicle speeds during snow and ice storms were evaluated. A telephone survey was made to businesses to determine losses caused by poor traveling conditions. Environmental damage to wells, plants, and lakes was investigated as well as deterioration of roadway, structures, and vehicles that can be associated with winter maintenance. The ESIC economic computer model developed through the study yields costs for maintenance and traffic and safety by storm and level of service, written warning of possible environmental damage, and annual costs for structural deterioration and vehicle corrosion.

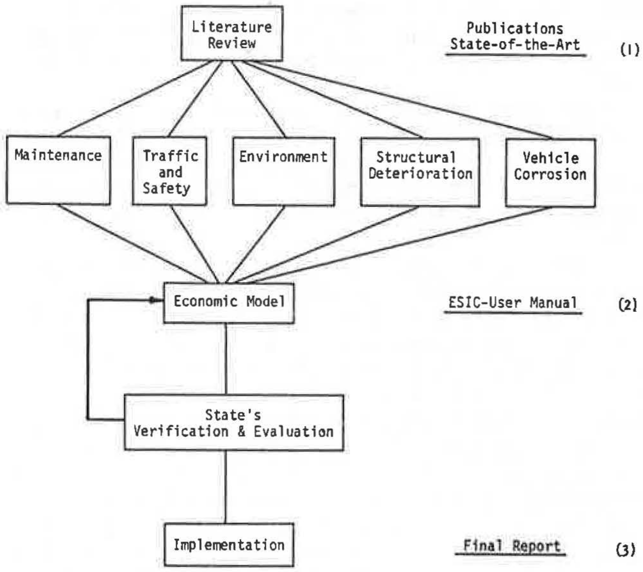
The impact of snow and ice storms has long been a concern to the traveling public. Before the development of the automobile, travel during winter weather was somewhat limited. With the advent of the motor vehicle, a demand for better all-weather roadway conditions required the development of better snow and ice removal techniques. Since that time, considerable effort has been expended by various highway and research agencies to quantify the effects of winter maintenance programs on highway facilities, the environment, highway users, and the levels of service provided.

In an effort to combine and consolidate the available information and add to weaker areas, a national pooled fund study was undertaken. Participating in the study were the Federal Highway Administration and the state highway agencies of Idaho, Illinois, Maryland, Michigan, Minnesota, Montana, New Hampshire, South Dakota, Virginia, and Washington with Utah's as the lead agency. The objective of the research project was to develop a rational method for determining the costs and benefits accrued through snow and ice control on highways. This method included the development of an economic computer model (ESIC) and a user's manual or guide on how to implement the model, verification of the model on a small scale, and a report on the state of the art of snow and ice removal.

RESEARCH APPROACH

An illustration of the research approach to the study is shown in Figure 1. The first phase of the study included a literature review of the different aspects that make up an economic analysis of snow and ice removal policies.

Figure 1. Research approach.



As a result of the review, it was determined that there were many areas that influence snow removal policy that did not lend themselves to a user economic analysis, i.e., special interest groups, legislative policies, political pressures, and past or traditional maintenance policies. To accomplish the economic analysis, it was decided to limit the specific areas to the following costs: maintenance; traffic and safety; environmental, structural, or roadway damage; and vehicle corrosion.

The results of the literature search were published separately in a state-of-the-art report (1). Only a limited amount of background information is given in this paper, and the reader is referred to the full report to gain a background for the material used. The state-of-the-art report contains a summary of conditions in the snow-belt states and snow removal policies and also a chart that covers the salt tolerances for trees and shrubs. The report has over 400 references and a word index.

In the second phase of the study, a computer model was developed by using the information obtained through the literature search and data collection. The ESIC model contains five modules: maintenance, traffic and safety, environment, structural deterioration, and vehicle corrosion. A complete explanation of the workings and use of ESIC has been published in the user's manual (2). Maintenance and traffic and safety modules produce costs on a "per storm" and level-of-service basis. The term level of service (LOS), as defined in the study, was used to describe the goal of a specified condition of the travel way. The level of effort to attain this goal would vary depending on the highway facility and its own particular characteristics. The environmental module provides written statements on potential environmental damage. Actual costs were not included because sufficient information is not available to itemize environmental costs as a function of winter maintenance activities. Structural deterioration and vehicle corrosion modules yield an annual cost. Because of the limited state of the art, these costs are only estimated.

The final phase of the study involved evaluation and implementation of the model by various participating states. This phase allowed an actual interface between the researcher and maintenance personnel that is lacking in many such studies. Since the conclusion of the study, the model has been evaluated for practicality and usefulness by each of the participating states.

A project panel made up of representatives from the participating pooled fund agencies met three times during the course of the study: at the beginning, to refine the project work plan and identify implementable study goals; at midstream, to evaluate progress and provide direction for the field verification; and at the conclusion of the study, to evaluate the final project documents to ensure optimum use of the findings.

As a result of this study, the highway decision maker will have an additional tool to aid in the selection of snow and ice control priorities.

To aid in the implementation of the study results, a 16-mm motion picture and a slide-tape presentation were prepared from the study findings.

FINDINGS

In the maintenance portion of the study, emphasis was placed on reviewing available information concerning snow removal and incorporating this information into an economic model.

The maintenance module of the computer program contains three parts: (a) the LOS, or goal, to be achieved in the study area; (b) the available equipment, material, and personnel; and (c) the required equipment, materials, and manpower required to achieve the LOS. These requirements are used as inputs in the module for cost analysis. After further investigation, it was found that each agency had its own procedure for allocating snow removal resources. Therefore, the optimization procedure has been left to the user, who selects the one best suited to his or her individual needs.

At the beginning of the study, the problem of establishing maintenance priority levels, or levels of service for snow and ice control, was apparent. To help solve this problem, questionnaires were sent to each snow-belt state to request information on established levels of service for their highways. Traffic volume and highway type were the two parameters used most in determining level of service.

For the purposes of the economic analysis, traffic volume and highway type alone were not enough. Information about snow accumulation and results of snow and ice control should be included. The stated levels of service to be used in the maintenance model were written by combining policies of several states. These five levels of service range from an effort to maintain a bare pavement to allowing seasonal closing of a highway. These levels of service specify when overtime hours can be used, maximum allowable snow accumulation, and frequency of plowing. Through the specification of each of these parameters, it becomes an easy process to optimize the equipment to maintain a section of roadway at a specified level of service.

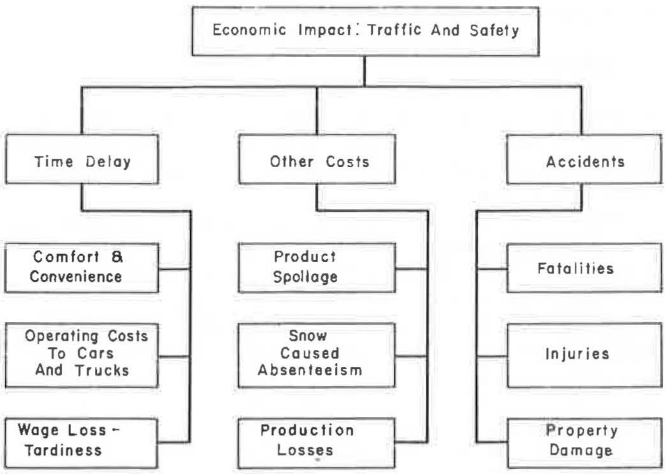
To determine drivers' opinions of maintenance practices, a questionnaire was distributed to drivers in four participating states: Idaho, Illinois, Minnesota, and Utah. These states were selected to represent different maintenance policies, weather conditions, industrial areas, and types of routes. Over 5000 questionnaires were distributed. The results of the survey indicated that motorists were satisfied with the current maintenance effort on freeways and highways but were dissatisfied with the current effort on city streets. Plowing, sanding, and salting policies also received high ratings.

A summary of the categories evaluated as having a significant effect on the economics of snow-induced traffic delay or safety is shown in Figure 2. All categories of value for traffic delay are a function of the magnitude of time delay. The magnitude of the delay for any one vehicle is given by

$$\text{Delay} = \text{trip length} \times [(1/\text{snow speed}) - (1/\text{normal speed})] \qquad (1)$$

The speed under snow conditions will vary from vehicle to vehicle as will the speed under normal (dry road) conditions. Delay will also vary, and the way it varies will depend on the probability distributions of snow speeds and normal speeds. (Trip length will also vary, but sufficient data were not available to define its probability distribution and it was thus assumed to be constant.) Dry-road speeds have generally been observed to follow a normal distribution, and it was assumed that speeds under snow conditions would follow this same distribution.

Figure 2. Economic loss caused by roadway snow and ice.



With these assumptions, a probability delay function was developed to determine the mean delay for a volume of traffic. The mean delay was converted to cost by using comfort and convenience, operating costs to cars and trucks, and wages lost through tardiness and absenteeism.

Reductions in speed and volume resulting from snow and ice on the highway are given in Tables 1 and 2.

Costs related to comfort and convenience are not direct, measurable economic costs, but their importance cannot be ignored by anyone who must answer to the public. It is difficult to evaluate these costs. The method used in this study was that of Thomas and Thompson (4) whose approach was to determine the amount of money people would pay to avoid a given delay. Results showed that the delay cost, as perceived by drivers, was similar to the cost shown in Figure 3, where the slopes and threshold values are determined by the level of personal income. This figure is for yearly incomes between $10 960 and $13 700. These curves were used together with the probability density function for delay given earlier to derive estimates of the comfort and convenience cost.

Fuel consumption was the only operating expense included in the economic analysis. Other operating costs, such as tires, oil, and insurance, are based on distance driven and not time required to drive the distance, so delay would not affect costs. Gasoline consumption on snow- and ice-covered highways was derived from Claf-

Table 1. Speed reductions by condition of roadway surface.

	Interstate[a]								
	Uncongested			Congested			Non-Interstate[b]		
Condition of Road Surface	Automobiles Observed	Reduction (%)	Standard Deviation	Automobiles Observed	Reduction (%)	Standard Deviation	Automobiles Observed	Reduction (%)	Standard Deviation
Dry		0			16		-	-	-
Wet		0			16		-	-	-
Wet and snowing	997	13	5.0	398	21	4.5	676	17	5.2
Wet and slushy	3888	22	5.1	292	36	4.9	2978	21	5.1
Slushy and sticking snow	1548	30	5.1	518	35	4.8	831	26	4.7
Snowing and sticking snow	2194	35	5.2	-	-	-	-	-	-
Snowing and ≤1 cm packed snow	1696	42	4.2	-	-	-	-	-	-

Note: 1 cm = 0.39 in.
[a]ADT of 61 607, six lanes, concrete pavement, no access. [b]ADT of 18 059, four lanes, asphalt pavement, limited access.

Table 2. Regression equations for various types of highways.

						Average Snow Traffic			
						Weekday		Weekend	
Type of Road	State	1974 ADT	Lanes	Pavement	Roadway Characteristic	Equation	Correlation Coefficient	Equation	Correlation Coefficient
Interstate	Utah	50 500	6	Concrete	Urban commuter	712 + 0.61 (AVNT)	0.80	153 + 0.94 (AVNT)	0.88
	Utah	61 100	6	Concrete	Urban commuter				
	Idaho	16 900	4	Concrete	Rural commuter	143 + 0.78 (AVNT)	0.80	-8 + 0.97 (AVNT)	0.72
	Minnesota	95 000	8	Concrete	Urban commuter	-122 + 1.42 (AVNT)	0.91		
	Minnesota	65 000	6	Concrete	Urban commuter	-482 + 1.09 (AVNT)	0.72		
	Illinois	41 260	6	Concrete	Urban commuter	29 + 0.77 (AVNT)	0.92		
	Illinois	106 000 (1973)	12	Concrete	Urban commuter	22 + 0.84 (AVNT)	0.93		
Non-Interstate	Utah	20 400	4	Bituminous	Urban commuter	1 + 0.95 (AVNT)	0.99	-8 + 0.97 (AVNT)	0.98
	Utah	17 000	4	Bituminous	Urban commuter				
	Idaho	3 778	2	Bituminous	Rural commuter	-20 + 1.12 (AVNT)	0.99	24 + 0.76 (AVNT)	0.87
	Minnesota	24 000	4	Two concrete, two bituminous	Rural commuter	202 + 0.77 (AVNT)	0.65		

Note: AVNT = average normal traffic.

fey's work (5). (Those calculations were formulated in U.S. customary units of measurement, and therefore no SI equivalents are given.) The excess fuel consumption per mile multiplied by the highway length yielded total gallons of gasoline consumed in excess of normal consumption. This number was converted into a dollar figure by multiplying the cost per gallon of gasoline by total gallons of gasoline consumed.

For tardiness caused by snow, the value of tardiness losses per person was approximated by the cost in lost wages. Industrial engineers at a Utah plant of a large national company were questioned on the general company policy toward snow-caused tardiness. One engineer explained that the union contract called for a person to be docked in pay if he or she were more than 6 min late. Another engineer said that the shop practice was to dock people only if they were more than 15 min late except in the case of persons who were habitually tardy. In either case, there was some threshold below which no pay would be deducted. The value for lost wages for industries was thus assumed to follow the form shown in Figure 4. The threshold value T varies from place to place and industry to industry; it is therefore an input to the computer program.

A questionnaire was distributed to businesses to evaluate economic losses resulting from highway snow and ice control. Nondeferred sales, perishable items, and recreation were the areas where costs were evident.

Accident rates for test locations in Utah, Idaho, and Illinois were studied. The study indicated that accident rates on wet pavements were almost as high as rates during snow conditions. An attempt to link accident rates with level of service failed because of insufficient data. For this reason, accident costs were not included in the economic analysis but can be added when sufficient data are available.

The environmental investigation consisted of the following:

1. Over 300 questionnaires were mailed out to universities, environmental groups, state and local highway agencies, the U.S. Environmental Protection Agency, and special interest groups.
2. An extensive literature review was undertaken. Over 100 periodicals and publications were critically evaluated in order to summarize the state of the art with respect to the environmental aspect of highway salting.
3. On-site inspection of damaged areas and interviews with those responsible for monitoring and rectifying any damage done from the use of deicing chemicals were conducted.

Figure 3. Cost of personal discomfort perceived by motorists.

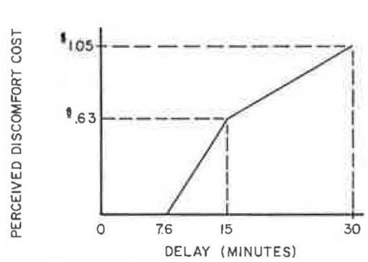
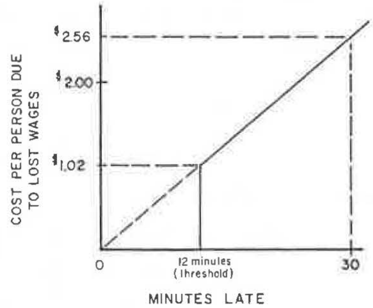


Figure 4. Lost wages versus tardiness.



The environmental program is designed as a predictive tool based on past experiences of environmental damage, other research, and some understanding of nature and physics. The model is divided into two major areas: damage from storage and damage from road application of sodium chloride. These sources of damage are applied to potential damage to wells, plants, and lakes. The model has been designed to accept other chemicals when more information becomes available about the impacts that can be expected.

The vehicle corrosion portion of the study investigated three available types of information on corrosion—corrosivity of the environment, changes in automobile manufacturing, and deicing salt—as well as advances in anticorrosion methods.

The effects of the atmosphere and its pollutants on corrosion rates are substantial. The atmosphere is both the source and the principal moderator of the corrosion process. It supplies two of the three constituents that are required before corrosion can occur: water and oxygen.

Studies by Fromm (6) in Canada indicated that corrosion rates were four times higher in air-polluted, humid environments than in dry, nonpolluted climates. His data also showed an additional doubling of corrosion rates when deicing chlorides were used. It should be noted that Fromm's most severe conditions are probably more or less typical of the northeastern United States and those states bordering the southeastern shores of the Great Lakes. This severely corrosive area can be characterized as having high air pollution and high relative humidities and in addition using large quantities of deicing chlorides.

Another contributor to the rusting problem that began in the mid-1950s was the use of lighter gauge, formed, sheet-steel members in vehicle bodies without anticorrosion measures.

Deicing salt undoubtedly contributes to vehicle corrosion. But a principal reason for premature rustouts could be the method of manufacture adopted by the American automotive industry in the period beginning in 1955.

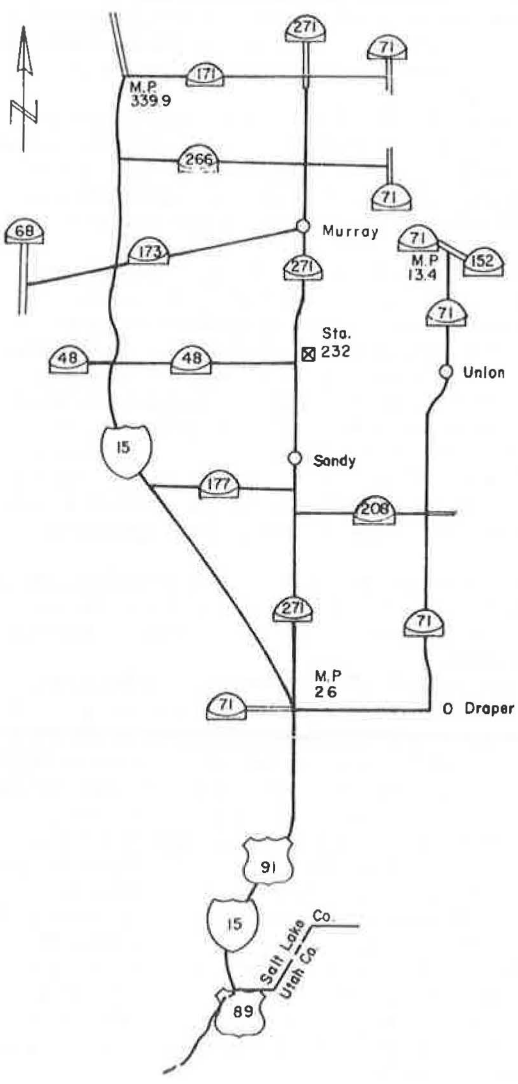
Perhaps the best argument against implicating deicing salt as the principal cause of premature corrosion perforation results from reviewing areas that do not use deicing salts, such as the Gulf Coast of the United States, which have equally severe corrosive environments. In semitropical and tropical climates, the upper portion of the vehicle body is more subject to corrosion than the lower portion; in areas that use deicing salts, the lower portion is affected more than the upper (7, 8, 9). If deicing salt was the principal cause of the increase in corrosion, the vehicles should have fared better in the Gulf Coast region. They did not.

The vehicle corrosion module of the economic analysis is a regional model based on a conservative estimate of the corrosive environment. The module also assumes that all excess depreciation is due to corrosion damage. Thus, the module is a worst case model, and the costs developed by the model may be considered to approach the upper costs reasonably assignable to deicing salts for the region under consideration. The present state of the art in vehicle corrosion is such that any use of the module to develop costs for specific segments is discouraged.

Structural deterioration is a result of a multiplicity of causal factors. But where structural deterioration is a result of corrosion of reinforcing steel, deicing or environmental salts are the cause element and the time of visible damage is moderated by design, construction, and environmental factors. Discontinuing the use of deicing salts is rarely effective because the chloride-contaminated concrete has no substantive, inherent chemical or mechanical mechanisms by which the chloride ion is automatically bound or removed. Once the chloride ion concentration exceeds the level required to depacify the reinforcing steel, the process is established and becomes an ongoing one.

In those cases where the structure has not been salted, the decision to salt should be weighed carefully.

Figure 5. Utah maintenance station 232 (Murray).



Past findings (1, 10) make it clear that the depacification threshold is reached after a very limited number of applications.

The ESIC module BRIDGE is the procedure developed for including structural deterioration costs in the economic model. The BRIDGE module is an inventory model. Initially, it was felt that a multifactor predictor model would be desirable. As the study progressed, it became apparent that, although time to onset of visible damage is moderated by a variety of factors, the corrosion reaction itself is a threshold "go/no-go" reaction and there is very little identifiable change in corrosion reaction rate caused by change in chloride concentration. It also became apparent that, although bridge inspections were being made, the type of inspection required to implement a prediction model was not being made on a basis that was general enough to warrant development of such a model. Nevertheless, an input median for estimated or potential costs was necessary. The inventory model was selected.

EXAMPLE OF USE OF THE MODEL

As explained previously, ESIC, the economic model, has five modules that cover maintenance, traffic and safety, environment, structural deterioration, and vehicle corrosion. Each of the modules may be used separately or in combination depending on the requirements of the user.

The costs generated from the maintenance and traffic and safety modules are calculated for a specific level of service and storm. The environment, structural deterioration, and vehicle corrosion modules produce warnings and annual costs.

Methods of analyzing the costs generated by the model are discussed in the state-of-the-art report (1). In the example cited here, cost comparisons are based on an incremental benefit/cost ratio. In this method of analysis, the additional benefits and costs that result from changing from one level of service to another are compared.

To understand how the entire model can be used in determining the economic impact of snow and ice control, a sample problem given in the user's manual (2) is reviewed. The sample problem analyzed Murray Station 232 in Utah for four levels of service. The Murray Station area is in the southeast section of the Salt Lake Valley. This station maintains 389 lane-km (242 lane-miles) or 79 center-lane-km (49 center-lane-miles) (Figure 5). The storm cited in the analysis occurred on February 5, 1974. It began at 7:00 a.m., lasted 11 h, and dropped 12.7 cm (5 in) of snow on the ground. The area receives an average of 25 storms/year. The maintenance area contains three main roads: I-15, which has an average annual daily traffic (AADT) of 31 983; UT-271, which has an AADT of 19 211; and UT-71, which has an AADT of 15 173.

The environmental module does not determine the cost of damage to the environment, but it gives warnings of possible damage to wells, lakes, and plants. The in-

Table 3. Cost breakdown for 11-h snowstorm from maintenance and traffic and safety modules.

Level of Service	Cost ($)							
	Maintenance				Traffic and Safety			
	Equipment	Materials	Personnel	Total	I-15	Utah-271	Utah-71	Total
L1	1527	325	128	1980	1 753	1 900	1 227	4 880
L2	956	185	157	1298	3 115	2 534	1 651	7 300
L3	603	108	115	826	5 820	5 824	3 927	15 571
L5	0	0	0	0	82 880	57 841	43 967	184 688

vestigators did not feel that the state of the art was sufficient to be able to assign environmental damage cost per storm and by level of service. To avoid giving any misleading information, only a verbal evaluation of possible damage is given. The structural deterioration and vehicle corrosion modules yield estimated costs on an annual basis. However, rust deterioration is a continuous process and may be meaningless for evaluating costs per storm. Only the maintenance and traffic and safety modules can yield costs per storm.

For this sample problem, the maintenance effort for level-of-service 1 (L1) required nine snowplows; L2 required five snowplows; and L3 required three snowplows. L5 is the no-maintenance condition.

The cost breakdown that results from the maintenance and traffic and safety modules for the 11-h storm is given in Table 3.

The incremental benefit/cost ratio for each level of service is given below:

Level of Service	Costs ($)	Benefits ($)	B/C Ratio
L3 over L5	826	169 117	204
L2 over L3	472	8 271	17
L1 over L2	682	2 420	3

The ratios in the incremental benefit/cost ratio analysis indicate that L1 is economically sound. That is, if $682 in additional maintenance money were spent, an additional benefit of $2420 could be obtained.

The sensitivity in the selection of a level of service depends on the relation between the cost for the maintenance, environment, structure, deterioration, and vehicle corrosion modules and the user benefit from the traffic and safety module. The following additional costs can be accrued before the level of service is considered economically unjustifiable:

Level of Service	Costs ($)	Benefits($)	Additional Costs ($)
L3 over L5	826	169 117	168 291
L2 over L3	472	8 271	7 799
L1 over L2	681	2 420	1 738

As the level of service increases, the sensitivity between the benefits and costs becomes more critical. Therefore, when selection of a high level of service appears warranted, the effects of environmental damage, structural deterioration, and vehicle corrosion should be closely evaluated.

CONCLUSIONS

The study produced, among other things, two major contributions in the area of snow and ice control. The first was a comprehensive state-of-the-art report. This report includes maintenance practices, equipment descriptions, policies, and many other factors pertaining to snow and ice removal. It also covers the effect of snow removal on traffic, the environment, vehicle corrosion, and structural deteriorations. The second contribution was the economic computer model ESIC. In this model, the user has a tool by which he or she can examine the economic effects of different aspects of snow and ice control in a program. By doing this, the user is made aware of what the consequences of decisions may be from more than just a maintenance viewpoint.

REFERENCES

1. B. H. Welch. Economic Impact of Highway Snow and Ice Control—State-of-the-Art. Federal Highway Administration, National Pooled Fund Study, FHWA-RD-77-20, Sept. 1976.
2. J. C. McBride and others. Economic Impact of Highway Snow and Ice Control: ESIC—User's Manual. Federal Highway Administration, National Pooled Fund Study, FHWA-RD-77-96, Aug. 1977.
3. J. C. McBride and others. Economic Impact of Highway Snow and Ice Control. Federal Highway Administration, FHWA-RD-77-95, Final Rept., Aug. 1977.
4. C. Thomas and G. Thompson. The Value of Time by Trip Purpose. Stanford Research Institute, Menlo Park, CA, Project MSU-7362, Oct. 1970.
5. P. J. Claffey. Running Costs of Motor Vehicles as Affected by Road Design and Traffic. NCHRP, Rept. 111, 1971.
6. H. J. Fromm. Corrosion of Auto-Body Steel and the Effects of Inhibited De-Icing Salts. TRB, Transportation Research Record 227, 1968, pp. 1-47.
7. R. F. Waindel. Automotive Body Rusting: Causes and Cures. SAE, Rept. 680145, Jan. 1968.
8. R. L. Chance. Corrosion, Deicing Salts, and the Environment. Materials Protection and Performance, Oct. 1974.
9. Motor Vehicle Corrosion and the Influence of De-icing Chemicals: Road Research. Organization for Economic Cooperation and Development, Paris, 1969.
10. J. M. Dale. Development of Formed-in-Place Wet Reflective Pavement Markers. NCHRP, Rept. 85, 1970.

Publication of this paper sponsored by Committee on Winter Maintenance.