vehicle. Rather, vehicles are exposed to many different environments. The location where the vehicle is offered for sale may or may not be the principal environment in which it was driven. Again, this would cause an understatement of the true depreciation brought about by a hostile environment.

The second point made by Belangie and Sy is that other researchers have noted definite correlations between atmospheric pollution and corrosion and between humidity and corrosion. The fact that these variables were not significant in our regressions implies, in their view, that our equations are deficient—and likely to be attributing excessive portions of the total corrosion to deicing salts.

We agree that one would expect to find humidity and air pollution linked to variations in depreciation rates across cities. We did not measure such an effect because, in our view, the relatively crude data we used did not adequately describe the actual humidity and air pollution to which the vehicle had been exposed during its life. Were much more careful research to be done, the true variations in exposure to pollution, humidity, and other causes of increases in depreciation rates should be measurable.

In any case, the fact that air pollution and humidity did not appear as significant determinants of vehicle depreciation rates does not mean that our estimates for the effect of deicing salts would be overstated. Our estimates are overstated only if the use of deicing salts is positively correlated with either humidity or air pollution.

Although others may want to debate this point, we do not believe that the use of deicing salts is in fact positively correlated on a regional basis to either humidity or air pollution levels.

Therefore, we stand by our estimates as accurate allocations of the measured depreciation rates to the separate determinants of vehicle decay.

Finally, Belangie and Sy raise some concerns about our numerical estimates in the regression equation. Their estimates are based on our data for 41 cities. The EPA report was based on essentially the same data, but for 39 cities. Data on the other 2 cities became available only after the EPA report went to press. As noted by Belangie and Sy, the inclusion of the other 2 cities does increase the coefficients of the two salting variables somewhat, thereby raising the total estimated cost of vehicle corrosion attributable to deicing salts by over $200 million to a total of $2.2 billion.

As far as errors are concerned, there was only one. The Multiple R (0.79) on p. 83 of the EPA report was a misprint and should have been 0.89, thus implying that 79 percent, or $(0.89)^2$, of the variation in the dependent variable is explained by the four independent variables. (Belangie and Sy obtain R = 0.90, apparently because of the two additional data points.)

We reiterate our principal finding that our estimate of the cost of vehicle corrosion attributable to deicing salts is most likely biased downward. The true cost probably exceeds our estimates by a significant margin. Because the budget for the EPA study was very limited, we do not feel that our data are the best obtainable. We would encourage others to continue this line of inquiry in order that the true costs of vehicle decay attributable to deicing salts be estimated and used as one of the key inputs in the formulation of government deicing policies.

DISCUSSION BY BRENNER

In response to the discussion by Brenner, the EPA study was restricted to the analysis of the costs of damage to the total environment, man-made as well as natural. Assessment of benefits was not included, and therefore Brenner's statement that we assigned a zero value to the benefits is misleading. Our only role with regard to benefits was to review the research that had been done.

I have never contended that salt has no safety benefits, but I strongly object to the use of erroneous statistics as proof that "salt and safety are synonomous."

Brenner arrives at a significantly lower cost estimate principally by using other data for used automobile prices and no control for regional variation of factors. This method was discarded by most researchers years ago.

With regard to the magnitude of the benefits relative to the costs, the statement that the benefits are far greater than the costs gives no indication that the right amount of salt is being used. In fact, it might be that far too much is used. In order to determine the best amount, one would need to examine the marginal effect of each unit of salt.

Damage to vegetation is not restricted to trees on the shoulder but may extend 20 to 30 m from the edge of the shoulder (or much more if the runoff is directed away from the road). Furthermore, in urban areas, roadside trees that have died from excessive salt are usually replaced.

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Economic Impacts of Snow on Traffic Delays and Safety

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This paper outlines the effects of snow and snow removal on four types of urban and rural highways that were studied in a 4-year project sponsored by 12 "snow" states and the Federal Highway Administration. The project identified and calculated such road-user costs as delay, volume and speed reductions, and fuel consumption; business costs included losses from such things as absenteeism, tardiness, and spoilage.

State and local governments expend considerable manpower and money annually on snow- and ice-control programs (1). These expenditures on road surface conditions consume as much as 33 percent of some state highway maintenance budgets, although the conditions prevail for only 4 to 8 percent of the total time these roads are in use. Expenditures of this magnitude have traditionally been justified as improved road-user benefits, usually as increased safety and decreased traffic delay during storms.

Increasing snow- and ice-control efforts has immediate consequences on delay, traffic congestion, and the public image of the highway department itself. Some of the effects of this effort are temporary in nature, and a return to normal comes relatively soon; other effects, such as bridge deck damage, vehicle corrosion, and environmental impacts (2), however, are more permanent or even irreversible.

It has traditionally been assumed that the economic effects of snow-control practices on non-road users are negligible compared with those on road users. In terms of benefits, this is probably true. A study undertaken by the American Public Works Association (3, p. 67) to formulate a method for controlling snow and ice resulted in an analysis for comparing the relative merits of varying cost levels. Potential benefits to a community were examined before developing the analysis, but, as finally outlined, road users reaped the major benefits. This paper focuses on business and personal economic losses and delays caused by snow.

PURPOSE OF THE PROJECT

The object of this research was to provide decision makers with the necessary tools to formulate snow- and ice-removal policies that use the resources available. It was also designed to help make decision makers aware of the impacts of snow- and ice-removal policies and their effects on the community and individuals.

Savings in vehicle operating costs are provided by higher levels of snow and ice control. For automobiles, such savings generally mean time saved by driving faster (4). Time savings or losses associated with snow and ice should not be handled in the same way as tangible costs or savings. In general, estimates of the value of time are averages, because time has different values to different people and to the same person on different occasions (4). It is also held, and generally acknowledged, that minute time savings are of less unit value than time savings of considerable amount. For a million people to save 1 min of an hour's trip does not produce the same dollar savings as 100 000 people each making a 10-min savings.

DELAY

Normal Traffic Volume

The difference in traffic volumes between normal and snow conditions will influence the evaluation of the costs of total traffic delay; these two volumes were therefore measured. We selected 12 test locations, where normal traffic volumes had been previously recorded by permanent 24-h traffic counters, and then categorized these normal volumes according to hour of day, day of week, and highway type.

Snow Traffic Volume

Snow traffic volumes were obtained hourly as the number of vehicles crossing continuous traffic counters at the same test sites used for measuring normal volumes. The best estimate of snow volumes was statistically determined by using multiple linear regression analysis with the independent variables

1. Normal traffic volume,
2. Hour of day,
3. Day of week,
4. Mean hourly temperature,
5. Maximum hourly temperature,
6. Minimum hourly temperature,
7. Peak hourly snowfall rate,
8. Second peak hourly snowfall rate,
9. Storm duration up to peak hourly snowfall rate,
10. Storm duration after peak hourly snowfall rate,
11. Total storm duration,
12. Snow accumulation up to peak hourly snowfall rate,
13. Snow accumulation after peak hourly snowfall rate,
14. Total storm snow accumulation,
15. Normal traffic volumes for 5 h before beginning of storm,
16. Normal traffic volumes after storm ends,
17. Change in traffic volumes for 5 h before beginning of storm,
18. Changes in traffic volumes for 5 h after end of storm.

Multiple linear regression analysis and a correlation coefficient matrix for the variables were completed. Regressions were determined on an hourly basis, by five time categories during the day, on a storm basis, for urban highways, and for rural highways.

Highway Delay

Vehicle delay measurements were evaluated for four highway classifications: urban Interstate, rural Interstate, urban secondary, and rural secondary. On rural highways (classified as highways where each driver determines his or her own travel speed), normal speeds are generally higher than on urban highways (classified as highways where the traffic flow determines each vehicle's speed). Because we anticipated that average normal and snow-induced speeds will vary depending on traffic density on any particular highway facility, we analyzed these highways separately. A highway segment could be defined as rural or urban at different times depending on the traffic flow characteristics.

Travel Time and Trip Length

Normal travel time for a particular highway segment is defined as the mean travel time on that segment. For the purpose of evaluating the effects of snow and ice control, normal travel times were estimated, as already stated, for each hour of the day and each day of the week.

Snow-induced delay is the additional time, beyond normal travel time, required for a trip over the highway segment being evaluated. The length of this delay for a particular highway segment equals total delay (Equation 1) multiplied by the ratio of highway segment length to average trip length.

Seven test sections were evaluated for delay. Vehicle speeds on them during snow conditions were monitored at various time intervals during the day. In addition to vehicle speeds during storms, we recorded rate of snowfall, total snow accumulation, pavement surface condition, snow control effort, traffic flow characteristics, ambient air temperature, and percentage of trucks.

All categories for traffic delay are functions of the length of time delay. Delay for any one vehicle is given by

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

Speed under snow conditions will vary from vehicle to vehicle, just as it does under normal conditions (dry road). Delay will also vary according to the probability distributions of snow speeds and normal speeds. (Trip length too will vary,' but, because of insufficient data for defining its probability distribution, we assumed it to be constant for given applications.)

Dry road speeds have been observed to generally follow a normal distribution, and we assumed that speeds under snow conditions will follow this same distribution. Accordingly, the probability that the delay D is less than a given value W is

$$F_D(W) = \int_0^{w/t} \frac{1}{2\pi\sigma_S\sigma_N} \int_0^{\infty} \frac{1}{y^2(y+t)^2} \exp\{-0.5[1-\mu_S(y+t)^2]/S^{(y+t)}\} \left(\exp\{-0.5[(1-\mu_N y)/\sigma_N y]^2\}\right) \qquad (2)$$

where

t = average trip length,
σ_s = standard deviation of vehicle speeds for snow conditions,
σ_N = standard deviation of vehicle speeds for normal road conditions,
μ_S = mean value of vehicle speeds for snow conditions,
μ_N = mean value of vehicle speeds for normal road conditions, and
y = dummy variable.

The function $f_D(W)$ is the density function associated with this delay and is given by

$$f_D(W) = (d/dW)F_D(W) \qquad (3)$$

Equation 3 was derived for this study and has been checked by simulation. It enables us to calculate expected comfort, convenience, and lost wage costs, none of which could be done accurately from the single value obtained in Equation 1 by using the mean values for snow and normal speeds.

Mean delay can be computed by

$$\text{Mean delay} = W[f_D(W)dw] \qquad (4)$$

The total delay for all vehicles traveling on a given roadway segment for a given hour can be calculated by multiplying mean delay by the monthly, daily, hourly, and volume reduction from snow factors and by roadway segment length and then dividing by average trip length. Then all hours of the storm are totaled.

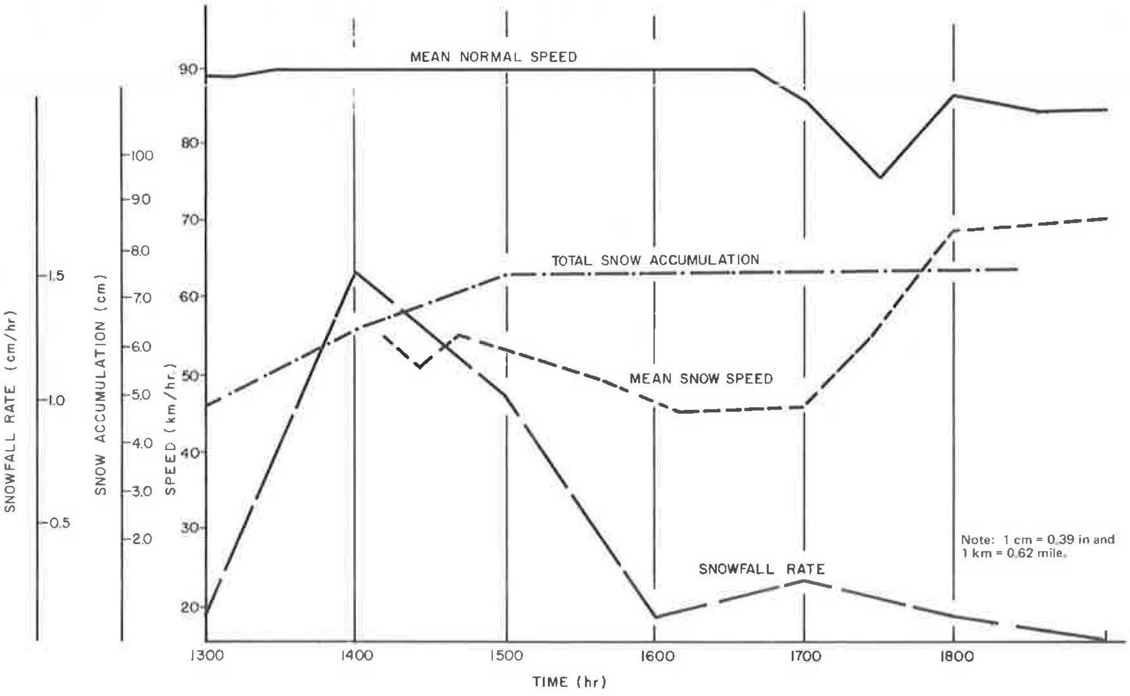
Traffic Speed Reductions

Figure 1 is a typical representation of normal traffic speeds, snow-induced traffic speeds, hourly snowfall rate, and accumulated snow depth according to time of day on an urban Interstate highway. Before snow began to fall, traffic speeds on the high-density highways began to drop, indicating that impending poor pavement conditions affected traffic speeds. The actual amount of snowfall or accumulation did not significantly affect speeds in the range we evaluated. The presence of snow, however, does seem to reduce speeds by approximately 46 percent.

In Table 1 the speed reduction percentages for an Interstate (62 000 average daily traffic) and a secondary highway (18 000 average daily traffic), under varying snow conditions, are given as an example.

It was not possible to vary the level of service on the test sections experimentally. As a level of service indicator, the differences in roadway surface conditions noted for separate highway segments were dry, wet, wet and snowing, wet and slushy, slushy and sticking, snowing and sticking, or snowing and packed. Thus level of service reduced to the best roadway surface the snow removal operators could achieve.

Figure 1. Snowstorm characteristics and normal speed gradients for urban Interstate highway.



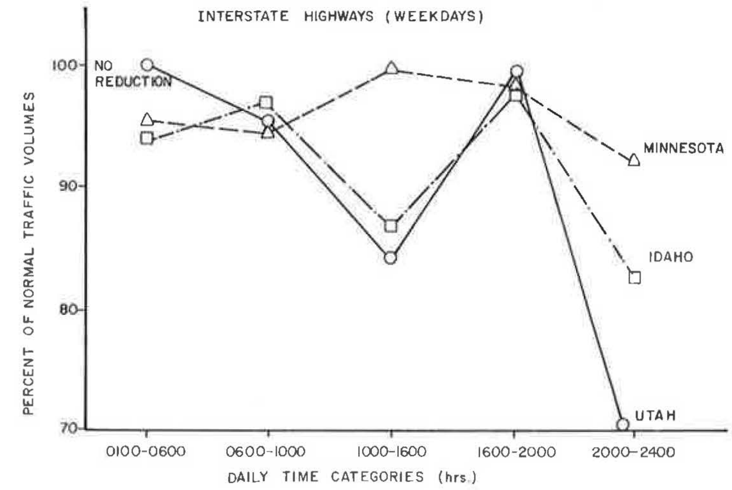
Note: 1 cm = 0.39 in and 1 km = 0.62 mile.

Table 1. Speed reductions and road surface conditions.

	Interstate Highway								
	Uncongested			Congested			Secondary Highway		
Road Surface Condition	No. Cars Observed	Reduction (%)	Standard Deviation	No. Cars Observed	Reduction (%)	Standard Deviation	No. Cars Observed	Reduction (%)	Standard Deviation
Wet only or dry	19 345	0	–	12 300	16	–	13 200	0	–
Wet and snowing	997	13	5.0	398	21	4.5	676	17	5.2
Wet and slushy	3 888	22	5.1	292	36	4.9	2 978	21	5.1
Slushy and sticking	1 548	30	5.1	518	35	4.8	831	26	4.7
Snowing and sticking	2 194	35	5.2	–	–	–		–	–
Snowing and packed[a]	1 696	42	4.2	–	–	–	–	–	–

[a]1 cm (0.039 in) or less.

Figure 2. Snow traffic volumes as a function of normal traffic volumes on Interstate highways.



Traffic Volume Reductions

Total traffic volumes changed during snowstorms, and traffic volume peaked at different times than during normal conditions. Traffic peaks during a snowstorm also tended to be flatter and longer (Figures 2 and 3) than during normal conditions. A typical volume change is summarized in Figure 4. Volume reductions for different road types were calculated by regression analyses. The equations resulting from the analyses and used to calculate hourly snow traffic volume reductions (HSTVR) are summarized in Table 2, where a is the correlation coefficient and b and c are the individual highway segment constants.

ROAD-USER COSTS

Fuel Costs

Economic estimates for vehicle fuel consumption on snow- and ice-covered highways are derived from Claffey (5). Road surface condition is a significant variable affecting average vehicle fuel consumption and is characterized as very slippery hard-packed snow and ice, hard-packed snow on ice with irregular, bumpy, wrinkled surface, 1.27 cm (½ in) of snow on hard-packed snow, 1.9 cm (¾ in) of snow on hard-packed snow, 2.54 cm (1 in) of snow on hard-packed snow, 3.81 cm (1½ in) of snow on hard-packed snow, or 5.08 cm (2 in) of snow on hard-packed snow.

Dividing the average delay for a particular storm on a highway segment or network into the corresponding highway segment length yields the average operating speed required for a given pavement condition. By applying Claffey's charts, the average operating speed is converted to fuel consumption. Excess fuel consumption yields total fuel consumed in excess of normal consumption. This number converts to a dollar figure by multiplying by the fuel cost. Fuel consumption varies with travel speed, which has been accounted for in Claffey's work.

Fuel consumption resulting from travel on snow- and ice-covered pavements is applied to passenger vehicles, light trucks, and vans. Because we assumed that snow-related fuel consumption for large trucks and tractor-trailer combinations depends on the size of load being hauled, not on pavement condition, we used only percentage of automobiles as an input for estimating additional fuel consumption on snow- or ice-covered pavements. The level of service in terms of snow or ice removal, then, influences fuel-consumption rates of automobiles, and the highway policy and modifications or alterations of it affect the economics of fuel consumption by inducing corresponding changes in surface conditions.

Operating Costs

Vehicle operating expenses such as tires, oil, and vehicle maintenance are not included as a function of snow and ice control. How much of these three items individual automobiles require is usually derived from the distance driven, not the time required to do so.

For commercial vehicles such as trucks, the value of a trip is based on operating time, as are some preventive maintenance activities. For these vehicles, operating costs are assumed to be a linear function of excess delay time.

Fixed Costs

Fixed costs here are insurance, depreciation, taxes, drivers' wages, drivers' welfare, workmen's compensation, social security, and registration. Fixed costs are generally a yearly expenditure not directly dependent on distance driven or the time required. For this reason, automobile costs do not include a portion of fixed costs for snow and ice conditions. Commercial vehicles are assumed to have a profit that either is productivity dependent or varies according to the number of trips that can be made per year. Costs for these vehicles are therefore included.

Additional delays for truck and commercial carriers traversing a highway segment under various snow and ice conditions are estimated from values provided elsewhere (6).

Comfort and Convenience Costs

Comfort and convenience costs are not direct, measurable economic costs, but their importance cannot be ignored. These costs are figured as time delay or time of inconvenience for a motorist. We adopted Thomas and Thompson's (7) evaluation approach, which takes these costs as the amount of money people would pay to

Figure 3. Snow traffic volumes as a function of normal traffic volumes on secondary highways.

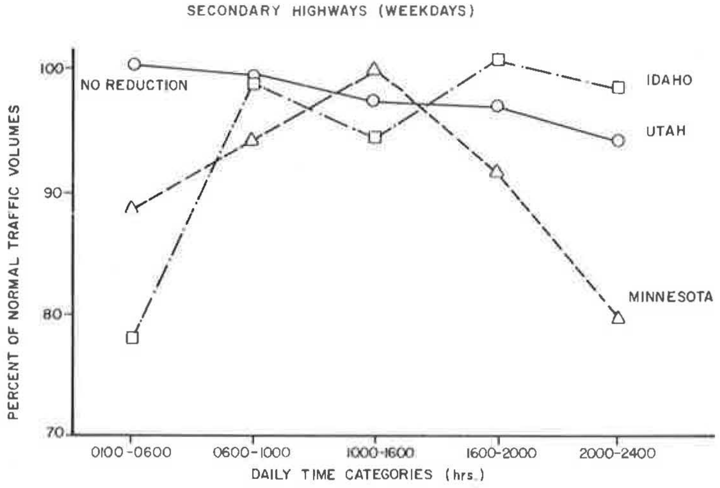


Figure 4. Traffic volume reduction on urban Interstate during a snowstorm.

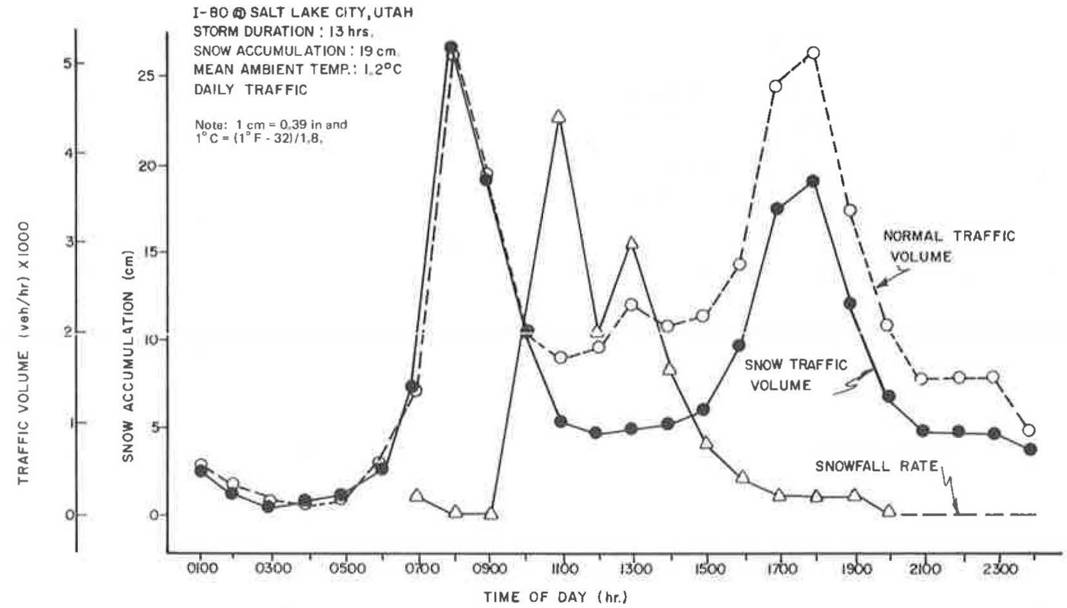


Table 2. Volume reductions from regression equations for various highway types.

Highway Type	State	Average Daily Traffic (1974)	No. Lanes	Weekday HSTVR			Weekend HSTVR		
				a	b	c	a	b	c
Urban interstate	Utah	110 000	6	0.80	712	0.61	0.88	153	0.94
Urban interstate	Utah	122 000	6	0.80	712	0.61	0.88	153	0.94
Rural interstate	Idaho	33 800	4	0.80	143	0.78	0.72	–	0.97
Urban interstate	Minnesota	190 000	8	0.91	-122	1.42	–	–	–
Urban interstate	Minnesota	130 000	6	0.72	-482	1.09	–	–	–
Urban secondary	Utah	40 800	4	0.99	–	0.95	0.98	–	0.97
Urban secondary	Utah	34 000	4	0.99	–	0.95	0.98	–	0.97
Rural secondary	Idaho	7 556	2	0.99	-20	1.12	0.87	24	0.76
Rural secondary	Minnesota	48 000	4	0.65	202	0.77	–	–	–

avoid a given delay. An example of personal delay or discomfort cost as perceived by a driver is given in Figure 5. The slopes, used with the probability density function for delay, derive estimates for comfort and convenience costs.

BUSINESS LOSSES

Interviews were conducted with businesses to estimate their losses resulting from snow and ice conditions. For this, the categories considered include absenteeism, tardiness, production losses, deferred sales, spoilage, and recreational losses.

Business types subject to deferred sales, such as car dealers and clothing stores, were found not to suffer permanent economic losses from highway snow and ice control.

Some companies responding to the questionnaire indicated lost sales, but they were not able to identify the magnitude of these losses.

Absenteeism

Large storms can create significant absenteeism, but industry often compensates for this by using employees' sick leave. It is therefore not clear if snow-caused absenteeism does result in real costs to industry that are not accounted for in production losses.

Tardiness

In order to quantify tardiness induced by snowy highways, we need to know the percentage of traffic comprising work-oriented trips. This percentage is a function of time of day, day of week, and highway characteristics.

Figure 5. Personal discomfort cost as perceived by motorists.

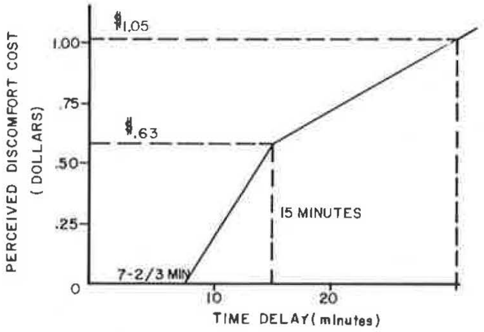
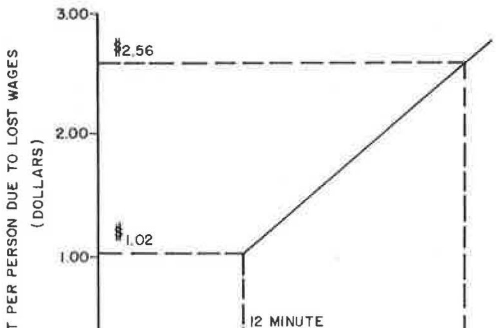


Figure 6. Lost wages per worker as a function of tardiness.



We standardized length of delay and real tardiness times and their corresponding economic impacts by using questionnaires sent to retail sales companies, wholesale manufacturing companies, mining companies, agriculture cooperatives, small businesses, and large supermarkets. This questionnaire solicited information regarding normal tardiness rates, tardiness rates for specific storm days, and the economic impacts of tardiness on both employer and employees.

The cost of snow-caused tardiness per person can be approximated by lost wages. We questioned industrial engineers of a large national company on their general policy for snow-caused tardiness and found that an employee is docked in pay if late beyond a specific time unless he or she is habitually late. In either case, there is some threshold below which no pay would be deducted. Our estimate of the value for lost wages follows Figure 6.

The expected value of lost wages per worker is then given by

$$\text{Lost pay}(K) = [\text{wage}(K)/60]\left(\int_{TH(K)}^{\infty} W f_D(W)\,dw - TH(K)\,\{1 - F_D[TH(K)]\}\right) \qquad (5)$$

where wage (K) is the hourly wage for employees in industry type K and TH(K) is the tardiness threshold in industry type K.

The total value of wages lost by tardiness in industry type K is then given by an expression similar to Equation 5 by using the proportion of workers in industry type K, the proportion of these going to work rather than to other destinations, the amount of tardiness attributable to snow conditions, and the threshold value t, below which tardiness has no economic value.

Production Losses

Very few industries indicated a production loss as a result of inclement weather or snow-covered highways. In the case of assembly-line work, an employee is not allowed to leave the job until his or her replacement has arrived. For non-assembly-line production, weekly or monthly quotas are standard; daily quotas would be more affected by snow- and ice-induced absenteeism. Some industries, however, did report higher overtime expenditures for extended cold periods.

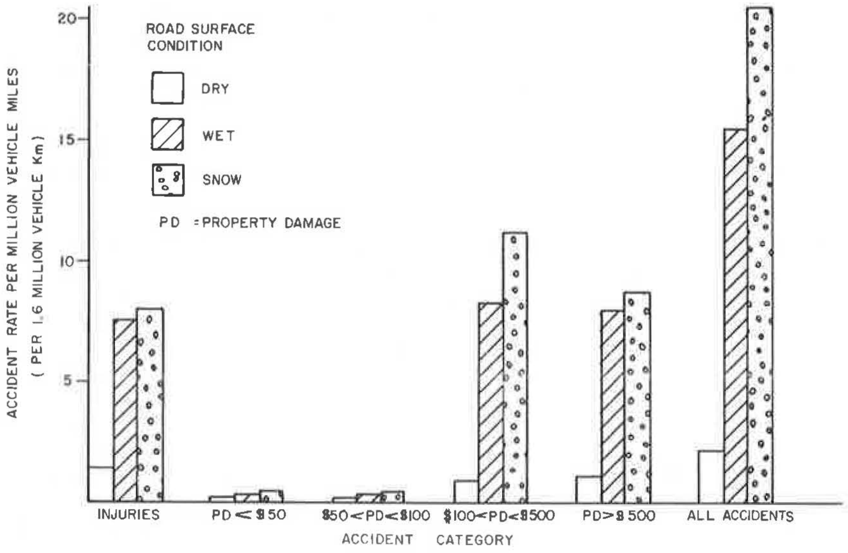
Deferred Sales

Responses from all retail companies indicated an awareness of sales fluctuations on snowy days, but no company gave information or had isolated sales for bad weather conditions. Approximately half of the responses indicated that most sales would be made up on a later date (deferred sales). Thus the quarterly sales index is not significantly reduced. Sales losses resulting from perished goods and impulse buying are not recoverable at a later date, but the magnitude of these losses was not known. Deferred sales, however, comprise the majority of retail expenditures.

Wholesale Sales

Wholesale suppliers of non-perishable goods generally inventory stockpiles on either a quarterly or a demand

Figure 7. 1973 urban accident rates in Utah.



basis. Thus delivery fluctuations on a daily scale as a result of snow do not seem to alter quarterly sales. The majority of wholesale sales losses also fall into the deferred sales category.

Spoilage Costs

Highways that serve as supply routes for perishable products can cause economic losses as a result of snow- and ice-caused closures. Especially susceptible are products delivered daily such as eggs or milk. The dairy industries who returned questionnaires indicated that spoilage was not a major problem and that only on rare occasions did farmers have to dump their milk because of shipping delays. Present snow removal practices have essentially eliminated losses associated with snowstorms, and any losses are associated only with extreme storm conditions.

Wholesalers of perishable goods reported that produce may freeze on trucks during bad weather conditions. They did not distinguish between highway conditions or the cold weather as causing these losses, nor did they indicate the amount of these losses.

Recreational Losses

All recreation industries polled, such as restaurants, theaters, and sporting events, with the exception of sporting franchises with seasonal ticket sellouts, reported a definite decline in business on stormy days. Estimates ranged from 20 to 50 percent reductions on bad days. It was not clear whether the decline was the result of bad weather or anticipated roadway surface conditions.

ACCIDENT ANALYSIS

We selected 21 test sections and compared accident rates under dry road conditions with those under snowstorm or wet and slippery conditions. For each section, traffic volume under normal conditions was estimated by multiplying the average annual daily traffic (AADT) by the monthly volume factor and the number of days in that month. Traffic volumes accumulated during snow and wet conditions were then subtracted, which left the traffic volumes for dry pavement conditions.

Where records indicated that 1.37 cm or more snow had fallen on a given day, the hours during which snow had been falling were determined. Traffic volumes accumulated during these snow hours were then estimated by multiplying the AADT, monthly factor, and the hourly factor and totaling these over the hours of the storm. These volume estimates were then reduced by regression-derived factors relating snow traffic volumes to normal traffic volumes.

Before analyzing accident severity and frequency, one must identify roadway segment length and number of accidents. All highway segments chosen had no major interchanges, weaving areas, or other geometric configurations that would add variables affecting accident rates. In the control segments, of a total of 539 accidents, 248 were on dry roads, 128 on wet roads, and 163 on snow-covered roads.

The severity or type of accident was thought to relate to pavement condition. Therefore, from the accident reports filled out by the investigating officer at the accident site, the estimated severity was classified as property damage less than $50, more than $50 but less than $100, more than $100 but less than $500, or more than $500, and as personal injury (total number per accident), and as a fatality (total number per accident).

Accident rates were determined separately for property damage accidents and for those involving injuries or fatalities. This allowed us to use the same accident twice, because accidents involving injuries or fatalities inevitably involved property damage as well.

Figure 7 illustrates the 1973 urban accident rates in Utah on dry, wet, and snow-covered pavements. Distinctions among property damage, injuries, and fatalities are also shown.

For the economic analysis of this study, estimates of fatalities and injuries were made with no attempt to derive their economic consequences. It was intended that the safety aspect of snow and ice control would be understood on its own merit. Safety together with economics serve to moderate the administrators' decision processes through more complete awareness. The relative importance of the two must be evaluated separately for each application.

CONCLUSIONS

The influence of snowstorms on traffic and traffic patterns was noted to be more pronounced during the first third of a storm. Traffic disruptions seemed to taper off as the storm progressed. This may not hold true for storms of abnormally long duration.

The safety aspect of snow and ice control becomes a minor economic effect for short highway segments or highways without extremely high traffic volumes. Many vehicle-kilometers must be traveled during and shortly after a storm for the small difference in accident rates for various road surface conditions to have a measurable effect.

User savings as a result of snow- and ice-control activities should be made by means of a comprehensive economic analysis that includes the costs of providing higher levels of service. The most extreme service for snow and ice control will still result in user costs. It is not anticipated that for every dollar saved in user costs, a dollar's expenditure is justified to control snow- and ice-covered highways. An incremental benefit-cost analysis is required to determine the point of diminishing returns. Even in this case, the costs summarized should be used as a tool to tender responsible administrative decisions.

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Impact of Highway Deicing Salts on Rural Stream Water Quality

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This study examines chloride concentrations in small rural streams receiving runoff from highways treated with deicing salts. Sampling points were established near Jamesville, New York, on Butternut Creek and some of its smaller tributaries. Higher mean chloride levels were found downstream of the highway than upstream. Downstream dilution reduced mean chloride levels in approximately inverse proportion to the additional watershed area; the higher variability was still evident. The chloride level in highway runoff was correlated by linear regression with the level in the receiving stream. Other relations were developed by investigating downstream dilution, stream confluence, temperature, and recent salt applications. Precipitation and temperature seem to act as controls on the release of salts from the highway area into natural drainage systems. There are also indications that much salt can be temporarily stored in the roadway vicinity until it rains. Intensive sampling showed that chloride concentrations can vary significantly in a matter of hours. And, when salt infiltrates the soil, stream chloride levels vary long after the season of salt applications.

The purpose of this study is to provide quantitative, preliminary data for assessing the impact of highway deicing salts on rural stream water quality. Published data of this type are currently rather limited.

Samples taken from rural streams both upstream and downstream of a salted highway were checked for differences in chloride levels attributable to highway runoff. Also investigated were chloride levels in the highway runoff. Also investigated were chloride levels in the highway runoff itself, the effects of dilution as watershed area increases downstream of the highway, and environmental factors affecting salt delivery to the streams.

STUDY AREA DESCRIPTION

The study area is in the Butternut Creek watershed, just east of Jamesville, New York. I investigated Butternut Creek, which has a drainage area of 48.2 km^2 (18.6 $miles^2$) at the sampling sites, and two small tributaries, stream I, which has a watershed of 1.8 km^2 (0.7 $mile^2$), and stream II, which drains 1.8 km^2 (0.7 $mile^2$). These tributaries were further subdivided into basins Ia and Ib, and IIa and IIb in Figure 1, where the sampling sites are the lettered circles.

Butternut Creek in this area runs through a glacial valley on the northern fringe of the Allegheny Plateau. Butternut Valley has a local slope of about 1 percent; the tributaries sampled slope from 5 to 10 percent diagonally down the valley side. All the streams studied receive deicing salt from US-20, which traverses the area in an east-west direction.

Land use is primarily agricultural, but there are woods and permanent pastures, where slope or soil or both precludes efficient cultivation. The area is free of high-density land uses, and residential development is confined to scattered one-family dwellings.

Stream I's watershed includes 0.8 km (0.5 mile) of US-20 and 1.1 km (0.7 mile) of unpaved town road. Stream II's watershed has 1.3 km (0.8 mile) of US-20, 1.7 km (0.8 mile) of paved county road, and 0.8 km (0.5 mile) of unpaved town road. Deicing salt effects from the town and county roads near the upper watershed boundaries are considered minimal.