Costs and Benefits on Road Salting

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The use of salt on highways has increased eighteen fold in the past twenty years, principally because it is perceived as an inexpensive and efficient means of clearing snowy highways to bare pavement. The assumed connection between bare pavement policies and highway safety has frequently been offered as a justification for the increased use of salt. Others have argued that the use of salt has several external diseconomies, or costs that are not borne by the user directly. Among the costs cited are those associated with the corrosion of automobiles, damage to highways and highway structures, damage to roadside vegetation, pollution of water supplies and damage to wildlife. None of the above mentioned factors has been the subject of careful scrutiny on economic grounds. It is the purpose of this paper to bring together, where possible, the results of other studies, to supplement them with our own research, and to produce an evaluation of the gains and losses to society from each of these factors. We conclude it is quite likely that the social costs from salting far exceed the social benefits and that the use of salt for highway de-icing should be sharply reduced.

I. Highway Safety and Gains from De-icing Policies

It has been widely assumed that the use of salt for highway de-icing lowers accident rates and saves travel time. Evidence of a reduction in accident rates attributable to the use of salt is inconclusive. For example, Arvai, in an analysis of individual accidents in selected Michigan counties and cities, found that as the use of salt increased the percentage of accidents occurring under icy conditions decreased. This is to be expected since salt reduces the frequency of exposure to icy conditions. He also noted an increase in the total number of winter accidents with increased usage of salt. Unfortun-
ately, he was unable to measure the total mileage under varying conditions and compute accident rates per mile driven. We will show that an increased number of winter accidents following the use of salt should not be surprising.

We may view the consumer's decision to motor as a two stage process. First, the price of motoring is determined in terms of its cost per mile. The consumer then allocates his income between motoring and all other goods so as to maximize his utility. The consumer faces two sets of costs that both depend upon his speed of travel. Accident costs will increase with speed, and operating costs, including the value of the driver's time, will decrease with speed.\(^1\) For given highway conditions costs will be minimized by choosing that speed for which the marginal increase in accident costs resulting from a one mile per hour increase in speed is just matched by the marginal decline in total operating costs.\(^6\) Frequently, the optimal or cost minimizing speed will be in excess of the speed limit; for these cases the least cost solution is to simply drive at the speed limit. Winter driving situations are quite different, and the cost minimizing speed may be substantially below the enforced speed limit.

We wish to investigate the effect of an improvement in highway conditions, perhaps due to salting, on three variables: speed, accident rates and cost per mile. It can be shown that speed will increase as conditions improve.\(^6\) It can also be shown that costs per mile traveled will decrease with improving conditions. The impact on accident rates is ambiguous; the direct effect of improved conditions is to lower accident rates, but with improved conditions people drive faster, which tends to raise accident rates. The net effect cannot be determined theoretically. We did attempt to empirically evaluate this latter factor in an analysis of variation in accident rates as a function of snowfall and de-icing policies. The state to state variation in fatality rates did not correlate to our measures of conditions or de-icing policies, and it is interesting to note that a study by the National Safety Council produced evidence that fatality rates are actually lower in the winter (See Table I). Lower winter fatality rates might be due to slower speeds insofar as the accident rates for personal injury and property damage may increase with worsening roadway conditions, but the accidents are less serious. An evaluation of property damage accidents was impossible to make due to: (1) variation from state to state in the minimum loss limit above which accidents should be reported; and, (2) differences in compliance with the reporting law because of difficulties in filing such
TABLE I
Fatality Rates 1971
(fatalities per 100 million vehicle miles)

<table>
<thead>
<tr>
<th>Month</th>
<th>Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>4.5</td>
</tr>
<tr>
<td>February</td>
<td>4.3</td>
</tr>
<tr>
<td>March</td>
<td>4.5</td>
</tr>
<tr>
<td>April</td>
<td>4.7</td>
</tr>
<tr>
<td>May</td>
<td>5.1</td>
</tr>
<tr>
<td>June</td>
<td>4.8</td>
</tr>
<tr>
<td>July</td>
<td>5.1</td>
</tr>
<tr>
<td>August</td>
<td>5.3</td>
</tr>
<tr>
<td>September</td>
<td>5.1</td>
</tr>
<tr>
<td>October</td>
<td>5.5</td>
</tr>
<tr>
<td>November</td>
<td>5.0</td>
</tr>
<tr>
<td>December</td>
<td>5.0</td>
</tr>
</tbody>
</table>

(Source: Accident Facts, 1972 edition, at 51.)

reports. We did obtain figures for personal injury accidents for a number of states which hopefully employ uniform standards of reporting. Fitting state personal injury accident rates to variables that represent altered condition of highway surfaces (snowfall, salt and sand) by ordinary least squares, we obtained the following (t statistics in parentheses):

\[
\text{PIR} = 1.72 + 0.038 \text{Snow} - 0.054 \text{Salt} + 0.0066 \text{Sand} - 0.044 \% \text{Int.}
\]

\[
R^2 = 0.81
\]

\[
F = 8.0 \text{ with 4 and 7 degrees of freedom}
\]

where:
- PIR is the 1971 state personal injury rate per million miles of travel.
- Snow is the snowfall in inches for 1971 for the state.
- Salt is tons of salt per lane mile on state highways 1970-71.
- Sand is tons of sand per lane mile on state highways 1970-71.
- % Int. is the ratio of interstate highway mileage to all state highway mileage.

The regression itself and the snowfall and salting variables are significant at the .95 level, indicating that for data chosen at random there is less than one chance in twenty the coefficients would be as large as they are in relation to their inherent errors of measurement. The coefficient of the salting variable indicates that a one ton per lane mile increase in the use of salt is associated with a reduction in the personal injury rate of .054. Salt usage on state highways varied from near zero to over forty tons per lane mile, and the personal injury rate ranged from 1.2 to 3.1 per million vehicle miles. It is somewhat surprising that sand has a positive coefficient,
though it is not statistically significant and is small compared to the coefficient of salt. The ratio of interstate highway mileage to all state highway mileage was included as a control on variations in highway quality between states, but the difference was not significant, either.

![Figure I](image)

It would be improper to use this estimated equation to attempt a direct evaluation of the benefits to consumers as a result of the use of salt, because operating costs and the number of miles driven are not being held constant. Rather, we must estimate the impact of de-icing policies on the cost per mile driven. We have shown elsewhere that salting reduces the average cost per mile driven during the winter from 2 to 1.5 cents depending upon snowfall and the intensity of salting. The gain to consumers is the difference between the amount he would have been willing to pay for travel without salt and the lesser amount he pays for that same travel now that conditions have been improved. This consumer's surplus is the shaded area under the demand curve between the old price per mile \( P_1 \) and the new price per mile \( P_2 \) (See Figure 1). The more inelastic is the demand for motoring, the more nearly the change in consumer's surplus is represented by \( Q_2 \Delta P \), where \( \Delta P = P_1 - P_2 \). We might characterize three components of demand. First, there is the demand for business travel in conjunction with employment. Since most of this type of travel is fairly urgent, we characterize its demand as inelastic. The second demand component is the journey to work. This also is an inelastic demand because it is not easily postponed, but to the extent that there are close substitutes (e.g., public transportation), the demand may be more elastic. The third type of demand is for leisure usage and similar reasons for motoring. Since trips in the latter category are more easily postponed during adverse driving conditions, this demand is probably highly elastic. A rela-
tively small increase in cost per mile may sharply curtail such travel. As elasticity in overall demand increases, $Q_1$, $\Delta P$ increasingly becomes an overstatement of the area under the demand curve. $Q_2$, the present mileage in winter, is approximately 80 billion miles. Using a figure of one cent per mile we estimate that the gain to consumers due to salting is less than an $800$ million reduction in the cost of winter motoring. This could vary, though, if significant externalities are involved. If the presence of additional cars slows other traffic before, but not after, snow removal, the gains will be larger; and if additional cars slow traffic only after snow removal, the gains will be less. The actual winter situation probably involves externalities both before and after snow removal.

II. Damage to Automobiles

It has long been recognized by consumers, automobile manufacturers, and the salt industry that the use of salt for de-icing roads causes damage to metallic surfaces on an automobile. Estimates of the cost to the consumer vary widely. If there are two means of measuring the impact of de-icing policies on the cost of operating a vehicle. One is to conduct a controlled experiment subjecting automobiles to various conditions of humidity, temperature, and salt for a prolonged period of time. The second is to use data on used car prices realized following uncontrolled experiments by drivers in different environments. The former method requires a substantial period of time and does not directly provide a dollar estimate of damage done. The latter method, which this article adopts, will be subject to error if automobiles are driven in more than one environment; if regional prices reflect differences in tastes and preferences for used automobiles; and if maintenance expenditures are dependent on the amount of salt in the immediate environment. There is reason to believe that the use of salt may accelerate the deterioration of various metallic surfaces in an automobile. Rusting is essentially an oxidation process involving the transfer of electrons; the presence of electrolytes such as salt, fertilizers, and the soluble products of atmospheric pollution facilitate this electron movement.

The temporal depreciation of automobiles has not been analyzed in the context of a market for new and used automobiles. Rather, depreciation rates have simply been computed from asking prices for automobiles of different vintages. Cramer (1958) and Chow (1957) found that a constant rate of depreciation producing expo-
ponential decay in value provided a good fit to the existing data for both U.S. and British used car prices. They did observe a considerable variation in the depreciation rate, both over time and from one make to another. We used the basic assumption of exponential decay to compute the relative depreciation rates for 45 major metropolitan regions in the U.S. (see Table II) and then attempted to explain variations in the depreciation rate with factors involved in the chemical process of rusting.

Table II

<table>
<thead>
<tr>
<th>City</th>
<th>State</th>
<th>Composite attributed to Salting</th>
<th>X&lt;sub&gt;1&lt;/sub&gt;</th>
<th>X&lt;sub&gt;2&lt;/sub&gt;</th>
<th>Y Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Albuquerque</td>
<td>N.M.</td>
<td></td>
<td>.3</td>
<td>0</td>
<td>16.8</td>
</tr>
<tr>
<td>Baltimore</td>
<td>Md.</td>
<td></td>
<td>30.8</td>
<td>33</td>
<td>20.7</td>
</tr>
<tr>
<td>Boston</td>
<td>Mass.</td>
<td></td>
<td>35.0</td>
<td>40</td>
<td>21.5</td>
</tr>
<tr>
<td>Burlington</td>
<td>Vt.</td>
<td></td>
<td>44.0</td>
<td>36</td>
<td>24.0</td>
</tr>
<tr>
<td>Cheyenne</td>
<td>Wyo.</td>
<td></td>
<td>.2</td>
<td>8</td>
<td>20.0</td>
</tr>
<tr>
<td>Chicago</td>
<td>Ill.</td>
<td></td>
<td>19.0</td>
<td>75</td>
<td>21.6</td>
</tr>
<tr>
<td>Cincinnati</td>
<td>Ohio</td>
<td></td>
<td>25.5</td>
<td>51</td>
<td>19.5</td>
</tr>
<tr>
<td>Cleveland</td>
<td>Ohio</td>
<td></td>
<td>25.5</td>
<td>46</td>
<td>20.8</td>
</tr>
<tr>
<td>Concord</td>
<td>N.H.</td>
<td></td>
<td>39.0</td>
<td>125</td>
<td>24.3</td>
</tr>
<tr>
<td>Denver</td>
<td>Colo.</td>
<td></td>
<td>1.5</td>
<td>1</td>
<td>18.9</td>
</tr>
<tr>
<td>Des Moines</td>
<td>Iowa</td>
<td></td>
<td>8.8</td>
<td>6</td>
<td>18.6</td>
</tr>
<tr>
<td>Detroit</td>
<td>Mich.</td>
<td></td>
<td>29.0</td>
<td>135</td>
<td>22.5</td>
</tr>
<tr>
<td>*District of Columbia</td>
<td></td>
<td></td>
<td>28.0</td>
<td>135</td>
<td>21.1</td>
</tr>
<tr>
<td>Great Falls</td>
<td>Mont.</td>
<td></td>
<td>33.0</td>
<td>40</td>
<td>20.9</td>
</tr>
<tr>
<td>Hartford</td>
<td>Conn.</td>
<td></td>
<td>12.0</td>
<td>22</td>
<td>19.5</td>
</tr>
<tr>
<td>Indianapolis</td>
<td>Ind.</td>
<td></td>
<td>14.0</td>
<td>21</td>
<td>19.2</td>
</tr>
<tr>
<td>Kansas City</td>
<td>Mo.</td>
<td></td>
<td>12.0</td>
<td>6</td>
<td>20.3</td>
</tr>
<tr>
<td>Louisville</td>
<td>Ky.</td>
<td></td>
<td>4.0</td>
<td>0</td>
<td>17.7</td>
</tr>
<tr>
<td>Memphis</td>
<td>Tenn.</td>
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<td>15.2</td>
<td>50</td>
<td>20.1</td>
</tr>
<tr>
<td>Milwaukee</td>
<td>Wis.</td>
<td></td>
<td>11.0</td>
<td>64</td>
<td>22.6</td>
</tr>
<tr>
<td>Minneapolis</td>
<td>Minn.</td>
<td></td>
<td>6.0</td>
<td>24</td>
<td>19.2</td>
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<tr>
<td>Newark</td>
<td>N.J.</td>
<td></td>
<td>1.4</td>
<td>13</td>
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<tr>
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<td></td>
<td>34.0</td>
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<td>20.3</td>
</tr>
<tr>
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<td>Pa.</td>
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<td>41</td>
<td>22.9</td>
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<tr>
<td>Pittsburgh</td>
<td>Pa.</td>
<td></td>
<td>1.0</td>
<td>0</td>
<td>16.9</td>
</tr>
<tr>
<td>Providence</td>
<td>R.I.</td>
<td></td>
<td>35.0</td>
<td>25</td>
<td>21.0</td>
</tr>
<tr>
<td>Richmond</td>
<td>Va.</td>
<td></td>
<td>10.0</td>
<td>20</td>
<td>18.9</td>
</tr>
<tr>
<td>St. Louis</td>
<td>Mo.</td>
<td></td>
<td>14.0</td>
<td>15</td>
<td>19.4</td>
</tr>
<tr>
<td>Salt Lake City</td>
<td>Utah</td>
<td></td>
<td>39.0</td>
<td>8</td>
<td>20.4</td>
</tr>
<tr>
<td>Seattle</td>
<td>Wash.</td>
<td></td>
<td>1.6</td>
<td>0</td>
<td>18.8</td>
</tr>
<tr>
<td>Springfield</td>
<td>Mass.</td>
<td></td>
<td>35.0</td>
<td>68</td>
<td>20.9</td>
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<tr>
<td>Syracuse</td>
<td>N.Y.</td>
<td></td>
<td>18.7</td>
<td>100</td>
<td>23.5</td>
</tr>
<tr>
<td>Wilmington</td>
<td>Del.</td>
<td></td>
<td>12.0</td>
<td>25</td>
<td>19.5</td>
</tr>
</tbody>
</table>

* For this observation the state figure is a composite of Virginia and Maryland.
Asking prices for used cars were obtained from newspaper advertisements during December of 1972 for three makes: Volkswagen, Chevrolet Bel Air and Chevrolet Impala. These makes were chosen because they were among the most frequently offered for sale and, with the exception of the Impala, typically contained little optional equipment. Only vehicles manufactured between 1958 and 1970 were included. Pre-1958 Chevrolets frequently had been modified and were offered at prices substantially in excess of newer models. Post 1970 vehicles were excluded because depreciation rates, though based upon best estimates of actual retail sales prices when new, were quite sensitive to mileage and optional equipment. These additional factors were frequently not specified in the advertisements. A composite depreciation rate (Y) equal to the mean of the rates for these three makes was calculated for each metropolitan area.  

The composite depreciation rate was fitted by ordinary least squares to the factors thought to be responsible for spatial variation in depreciation. The regression specification was linear and additive as suggested by the work of Fromm (1968). A more complicated model is not suggested by first order effects of salt in the concentrations typically encountered on highway pavement. The salting variables included tons of salt per lane mile of pavement during the winter of 1969-1971 in the state (X₁) and city (X₂), respectively. Snowfall in inches for this same winter, normal annual rainfall, and tons of sand per lane mile in 1969-70 were also included in various formulations. Average mileage per vehicle per year in each state was obtained from Automobile Facts and Figures and included in the equation to adjust for regional variation in automotive usage. In every specification tested, snowfall and the salting variable were significant, but in no case were sand or rainfall significant. The following equation was selected as the best estimate of the hypothesized model with R² of .84 (t statistics in parentheses):

\[
Y = 17.0 + 0.042 X_1 + 0.019 X_2 + 0.071 X_3 + 0.025 X_4
\]

where:

- \(Y\) composite depreciation rate.
- \(X_1\) salt in tons per bare pavement lane mile on state highways.
- \(X_2\) salt in tons per bare pavement lane mile on city highways.
- \(X_3\) miles per vehicle in thousands.
- \(X_4\) snowfall in inches for the winter 1969-70.
All variables have the expected signs and all except vehicles' mileage are significant at the .99 level. Although the chemical mechanism of rusting strongly suggested that humidity would play a significant role, especially in the presence of salt water, this particular hypothesis was not thoroughly tested due to difficulty in obtaining data. As a result, data on two cities, Houston and New Orleans, were never included despite high depreciation rates consistent with our prior expectations.

Since the rate of chemical reaction is temperature dependent, a subset of 30 cities which salt their roads was analyzed for the separate influence of temperature. Mean January temperature was added as an explanatory variable in the composite depreciation rate equation. It had the incorrect sign and was not significantly different from zero at the .50 level. This might be explained if significant rusting occurs when body components are relatively warm — such as occurs during the normal operation of a vehicle. In this case, differences in ambient temperature may not be a significant factor.

Table II summarizes the actual salting policies, depreciation rates and the incremental depreciation attributed to salting for 34 of the observations where vehicles had some exposure to salt. The variables are the same as in the composite depreciation rate equation except that the component of the depreciation rate attributed to salting is now included.

This rate indicates that a $2000 car in Boston, for example, will depreciate by $44 more per year under the current policy than if the entire state (including the city of Boston) were to switch to a sand-only policy.¹⁶

Two qualifications must accompany these reported depreciation rates. One concerns the statistical errors associated with this sampling procedure. Five samples spaced over one week intervals were taken for Boston, Detroit and Los Angeles. The sample variances ranged from .044 for Boston to .095 for Detroit. A 95% confidence interval for the reported rate for Detroit would be 22.5 ± .85. These errors, though, are small compared with the overall variation in the depreciation rates. The second qualification is that these figures should not be interpreted as the best possible estimates of such rates. Ideally, one would estimate the value of the stock of vintage i in period t, V_it, and the value of this same stock in period t + 1 and compute the depreciation rate for the year as V_it - V_it + 1/V_it. Since our estimates do not include survival probabilities, they would be biased downward. Also, the inclusion of Volkswagen low-
ers the overall rate by about 2% from the domestic model rate alone.17

In a study of this nature it might be argued that the observed regional differences in depreciation rates are due to geographical differences in tastes and preferences. In an attempt to test this alternative hypothesis we included two variables which might be adequate proxies for model preference in a re-estimation of the composite depreciation rate equation: per capita income in 1970; and car ownership per capita for each state in 1970. It was expected that higher per capita income might lead to a relative preference for new automobiles and that with greater per capita ownership might come a lessening of the prestige associated with ownership of a new car. When depreciation rates were regressed on these variables, both were significant and had the expected signs. When the two additional variables were included in the composite depreciation rate equation, neither was significant, and the original coefficients were unchanged to three decimal places. This indicates that the taste factors in themselves do not account for the observed differences in depreciation, but they are probably correlated geographically with the snow and salting variables.

An additional source of error in the estimates could arise from collinearity among the independent variables. If snowfall is highly correlated with the usage of salt, we might attribute to salt what really is due to snowfall. Given that the simple pairwise correlations were all below .64, and that the t statistics are relatively large, collinearity was not judged to be a serious problem.

One may use the figures for the incremental depreciation attributed to salt in each city times the value of the automobile stock in that region to arrive at a total annual salting cost nationally. It must be recognized that this figure will be conservative if automotive maintenance expenditures are also related to salting policies of highway departments. Using stock figures reported in 1972 Automobile Facts and Figures and used car prices reported in the 1972 NADA Used Car Guides, we estimated an approximate annual salting cost of $1.1 billion. This compares with the direct cost of salt of about $100 million in 1970.18

III. DAMAGE TO HIGHWAYS AND HIGHWAY STRUCTURES

There is no evidence of any extensive damage to asphalt highways as a result of salting. Although no definite correlation has been established between salting applications and the deterioration of concrete bridge decks, these structures appear to deteriorate se-
verely when exposed to prolonged de-icing applications. Callahan examined bridge structures in twenty states and found a correlation between salting and bridge deterioration.19

Scaling and spalling are two processes which affect concrete bridges and are aggravated by salting. Salt’s role in scaling is non-chemical. Fairly shallow peeling and chipping are caused by hydraulic pressure due to the expansion and contraction of freezing brine, and the resulting interior pressure can lead to destructive scaling. Cumulative applications of salt tend to increase the number of these cycles and thereby accelerate scaling damage.

Spalling constitutes a more serious chipping of the bridge surface which is actually due to corrosion of the concrete covered steel reinforcing bars. Brine penetrates to the bars through hairline cracks in the concrete overlay and the corroding steel expands—creating internal pressure and further cracks in the concrete overlay. The rate of spalling is dependent upon traffic density and the depth of the concrete cover as well as the salting rate.

These two deleterious processes can be prevented through proper design specifications and proper mixing, as well as by protective coatings.20 Yet, these preventive measures must be accounted for in terms of added construction costs. In addition, those structures not built to withstand salt will continue to deteriorate faster than if salt were not used. We shall not attempt to estimate these costs, but suspect that they are substantial, since national expenditures on highways exceed ten billion dollars annually. If only one-tenth of one percent of our highway capital stock is ruined each year due to salt the cost might be $150 million.

IV. Pollution of Groundwater Supplies

The connection between the use of salt for de-icing and the pollution of public water supplies has only recently become a subject of concern. The Massachusetts State Legislature commissioned a report on this topic following the closure of public water supplies in the towns of Burlington, Weston, Goshen, and Auburn when their chloride ion content exceeded the maximum standard for potability of 250 ppm established by the Department of Public Health.21 Although a direct causal relationship has not been proven, there is persuasive evidence that salt for highway de-icing was responsible for most of the increased chloride contamination of wells in these cities. For example, following a marked increase in the chloride ion content in the Burlington water supply, the town built an improved salt storage facility in 1968 and banned salt from 1970 to 1972. Two
years later the chloride content had dropped from 283 ppm to 85 ppm.

If public water supplies were a free good, there would be no cause for concern over contamination of some wells or reservoirs with salt. However, at the current price it appears that in several states, including New York and Massachusetts, the demand for water very nearly equals all that is available. The loss of part of the water supply will have one of two effects. First, it could cause rationing such as occurred in New York City during periods of drought. Second, it could result in a higher price being charged for water. In either case, this represents a loss to consumers. Moreover, even moderate salt contamination imposes costs on some individuals, especially those who, because of medical advice, must maintain low sodium diets.

The extent of the contamination of water supplies with salt is not well known nationally, though one source does mention studies showing large chloride increases in Lake Erie, Lake Wingra in Wisconsin, First Sister Lake in Michigan and Irondequoit Bay in Rochester, New York. Owing to the lack of adequate national statistics on the extent of the problem, this article only attempts to present the costs of a hypothetical situation. National water consumption is about 25 trillion gallons per year. We shall assume that the price currently charged by the Metropolitan District Commission in Massachusetts, $120 per million gallons, is representative of prices elsewhere. Turnovsky has estimated the price elasticities of domestic and industrial demand to be -.3 and -.5. Figure II depicts the demand and supply for water under the assumption that current reserves (unused supply) are near zero.
From the estimated demand elasticity we can calculate that if salt contaminated 10% of the national water supply, the price would rise about 25%, to $150 per million gallons, before demand would be equated to supply. This would represent an outside limit on such costs because a greater increase in price might make it economically more feasible to augment the supply from more distant sources or to reprocess waste water. In the extreme situation presented above, the loss in consumer surplus would be about $700 million. However, it should be noted that at the present time there is little evidence of higher prices being paid for water due to the salt contamination of water supplies.

From the experience of Burlington, Massachusetts, it would appear that the salt contamination of underground water supplies is reduced fairly rapidly when salting is curtailed, because a water system will purify itself over time if the water flowing into the underground aquifers is free of contamination.

V. Vegetation

Under natural conditions sodium and calcium chloride do not damage plants. In fact, calcium is essential to their growth, and most vegetation requires small amounts of chloride. Too much salinity, however, interferes with the osmotic process by which water enters the plant root by making it difficult for the plant to absorb water. The result is similar to that exhibited during drought conditions. High concentrations of chloride have been shown to result in leaf burn and shoot tip die-back. Under aggravated conditions sodium accumulation causes the tips or margins of many plant leaves to die and fall from their stems sooner than normal. Unhealthy trees, especially those suffering from too much salinity, can frequently be detected at the onset of the fall foliage season because their leaves are the first to turn.

Although injury to roadside vegetation can result from saline contamination of water supplies to the vegetation, it apparently can also result from direct contact of the plant surfaces with salt spray from passing vehicles. Hofstra and Hull have concluded that this spray can affect trees up to 120 meters away from a highway. In another study, Lacasse and Rich examined 550 roadside maples in New Hampshire and found that severe injury was limited to those trees immediately adjacent to the road and its drainage areas. Kothiemer also examined roadside maples in New Hampshire and reached similar conclusions. Button and Peaslee studied roadside
sugar maples in Connecticut and found that they contained unusually high levels of sodium and chloride ions, lower than normal levels of other essential nutrients and exhibited low overall vigor.\textsuperscript{31}

Unfortunately, it is easier to establish a correlation between the use of salt and declining tree vigor than it is to make any monetary estimate of the losses involved. For one thing, trees may not die immediately. Salt may merely make a tree more susceptible to disease and insect attack, and the latter may be the instruments of death. The other problem is that trees are not normally consumed directly, but rather are part of neighborhood aesthetics. The International Shade Tree Conference has developed a formula used in conjunction with insurance and damage appraisals. Under this formula, well situated trees in perfect condition are valued at $9 per square inch at four and one-half feet above ground.\textsuperscript{32} Thus, a 24 inch diameter tree would be worth $4,072, but it would be hazardous to attempt to use this formula to establish a cost figure nationwide. A very rough idea of the possible magnitude of the loss can be obtained by examining tree statistics for the town of Winchester, Massachusetts. During the period 1962-70 it was estimated that over 100 maple deaths could be attributed to saline conditions exacerbated by a drought.\textsuperscript{33} These trees were valued at approximately $250,000. It is not possible to estimate how many more will die as a consequence of salt that has been applied during past years, although properly this cost should also be included. National losses could conceivably run as high as several hundred million dollars annually. Clearly, this is an area where further research is necessary.

VI. CONCLUSION

We have shown that at the current levels of salt usage for highway de-icing, the gains to society appear to be far less than the costs. In a study of this nature one should examine the time profile of benefits and costs; benefits or costs that will accrue in the future are worth less than the same items today. In this study we found that most if not all of the benefits are immediate, while costs such as the pollution of water supplies and damage to vegetation and highway structures may accrue over relatively long periods of time. Since good estimates of the time profile of these costs have not been made, no attempt was made to discount them to present values. Rather, we included in our cost estimate only a rough approximation of the current costs and omitted any future costs.

Although it was shown that the cost in terms of automobile depreciation alone exceeds the benefits due to reduced travel costs, this
does not necessarily imply that all salting should be discontinued. Rather, one is interested in applying salt until the gains from the last ton applied are just balanced by the additional costs incurred. Presumably at some level less than current application rates this relationship might hold. It is impossible, given the quality of the available data, to determine how much salt would then be used.

One final question is worth asking: given that the gains to society appear to be far less than the costs, why has the use of salt continued to increase? There are a number of answers. First, the direct cost of salt to highway departments is no more than that of sand (including sweeping sand off the pavement in the spring). At best, highway departments would be indifferent to a choice between salting and sanding policies. Some find salting much cheaper. An area with little snow for example, could dispense with plowing entirely if an aggressive salting policy were followed. Second, the gains and losses are not distributed uniformly. Motorists gain from the reduction in the cost of travel while damages to vegetation and water supplies are costs borne by nearly everyone when salt is heavily used. Motorists might continue to advocate salting even if society as a whole receives a net loss. Third, public safety officials and highway departments may have an incorrect perception of the weak connection between highway conditions and safety. Finally, many individuals are unaware of the costs, although increased publicity is correcting this problem.

Given the findings in this study, it appears that the use of salt for de-icing should be curtailed. The extent of the reduction can be determined only through a more detailed and comprehensive analysis of the various benefits and costs.

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**FOOTNOTES**

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1Salt Institute, _The Case for Road Salt_, (1972).
3Arvai, E.S., _The Effect of Salt on the Number of Winter Accidents_, (Highway Safety Research Institute, U. of Michigan, January 1971).
We assume the consumer values these expected gains and losses symmetrically; that is, a $1,000 accident with probability of .00001 per mile and a cost savings per mile of (.00001) (1000) = $.01 would be offsetting. To the extent motorists are risk averse, they will value the loss in utility from the uncertain accident as more than the gain in utility from cost savings. Risk averse behavior is typically associated with the use of insurance. Including the effect of insurance, the costs of accidents to consumers will be lowered and our original assumption appears more reasonable.

Formally, we take the derivative of the function total costs per mile, set it equal to zero and solve for the cost minimizing speed. The second order conditions require that the second derivation be positive.

For a mathematical derivation of this and other results cited below, see Anderson, R.C., The Effect of Road Salting on Highway Accidents and the Demand for Motoring, (unpublished, April, 1973).

Personal injury statistics are reported in Traffic Safety each month.

See Anderson, supra n. 6.

About 40 million cars are driven some 600 miles per month for three and one half months of winter in the snow belt, producing a figure of 80 billion miles. Total yearly mileage in the whole country is 1,100 higher as reported in Highway Statistics, 1971.

Hopt, R. L., COMPLETE SALTING SANDING ECONOMIC STUDY, (Idaho Department of Highways, 1971). This study used the cost of undercoating amortized over a seven year period to arrive at the figure of $5 per year. A $100 figure has been used by the Society of Automotive Engineers.

The American Public Works Association has conducted such experiments for periods of three to four years and found evidence of internal, but not external, damage attributed to salt. In our view such a period may be too short to adequately examine situations of structural weakening due to the effect of salt. In Corrosion of Auto Body Steel and The Effects of Inhibited De-icing Saltes, (Highway Research Record, 227, 1968), Fromm found that de-icing salts approximately doubled the natural corrosion of auto body steel.

Although both suppliers and users have frequently suggested that exhaust systems suffer corrosion due to salt and moisture, it was not possible to test this hypothesis due to (1) the absence of any regional figures on such expenditures, and (2) the lack of uniformity among states in enforcing statutes prohibiting leaking exhaust systems.
Chevrolet rates were based on factory list price less 10% plus destination and preparation charges. The average sample size for each was 84 observations — approximately 30 for each make.

Though salt requires moisture to transport electrons we simply treated its effect as additive because moisture nearly always is present when salt is applied.

A lane mile is defined as the equivalent of a two way, one mile stretch of highway with one lane in each direction. The Salt Institute has made a survey of usage for two recent winters; 1966-67 and 1969-70.

It should be noted that about one half of the incremental depreciation is attributed to natural factors (as measured by snowfall). For an area with an 80 inch snowfall (typical New England, Great Lakes region and Montana) the incremental depreciation due to snowfall would be 2.0%. This result is consistent with findings in Fromm (1968).

An additional problem may occur if prices in newspaper advertisements are lower than average retail prices due to misleading advertising practices. Our prices for the whole sample averaged 3.4% below NADA prices which may mean our depreciation rates are biased upward due to this factor.


Habitat, Inc., supra n. 2, at 19.

In [U.S. Department of the Interior], THE COST OF CLEAN WATER, Vol. 1, Summary Report, (G.P.O. Washington, D.C. 1968), waste water volume was estimated at 18.4 trillion gallons for 1963. We have projected a 3% growth per year in demand and included the demand of some 70 million households not currently served by sewers to arrive at our figure of 25 trillion gallons.

Turnovsky, S., The Demand for Water: Some Empirical Evi-

25Since ground water supplies only 20% of the nation's fresh water, this assumes one half of groundwater supplies are lost due to salt contamination.

26A notable exception is the small town of Goshen, Massachusetts, which has been forced to haul water by truck. Historical records indicate a background level of 5ppm chloride ion, but water from wells located near highway 9 have concentrations ranging from 300 to over 2500 ppm.


33Southworth, A. et. al., WINCHESTER CITIZEN'S REPORT ON DE- ICING SALTS, (March, 1971).