The revised policy that was recommended and adopted goes some way in the direction of the trunk roads policy and will enable some economies to be made in rural areas.

The present policy of close cutting is to be continued on all county roads in urban areas.

On main roads in rural areas the revised policy is a one-swath width adjacent to the carriageway on both sides of the road cut regularly, and the full width of the roadside verge cut regularly at the inside of bends together with splays at junctions and entrances.

Full width cutting will be carried out at the end of every third growing season to prevent the establishment of scrub and to deter other nuisances.

On minor roads in rural areas the assistance of the adjoining landowner should be enlisted, and if necessary severe obstructions should be modified to encourage adjoining landowners to cut the grass. Where the adjoining landowner declines to cut the grass, then those verges will be cut overall every third year to prevent the establishment of scrub.

The future expenditure on roadside maintenance will be carefully monitored to confirm the significance of any savings in real terms in order that the policy may be reconsidered and amended as necessary.

REVISED POLICIES OF ROADSIDE MAINTENANCE

The summer of 1976 was the driest ever recorded throughout England, and consequently grass growth was at an all-time minimum.

It would therefore be inappropriate to draw any comparisons between the roadside maintenance costs of 1976 and other years. However, the long-standing dry grass on trunk road verges presented a considerable fire risk. There were many instances of roadside fires, some of which spread to adjoining property. All presented a traffic hazard by reducing visibility.

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Economic Analysis of the Environmental Impact of Highway Deicing Salts

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This paper reports on an analysis of the cost of damages that result from sodium chloride used to melt snow and ice on highways. An extensive literature search and several surveys were made to determine the types and extent of damages that have occurred. The major cost sectors examined were water supplies and health, vegetation, highway structures, vehicles, and utilities. A conservative cost estimate was developed for each sector. The total annual national cost of salt-related damage approaches $3 billion, about 15 times the annual national cost of the salt and its application. The highest direct costs result from damage to vehicles, but the most serious damage appears to be the pollution of water supplies and the attendant degradation of health. It is difficult to assign costs to this, and therefore the estimate may substantially understate actual indirect costs to society. These findings indicate that some areas should, on the basis of local conditions, reduce the amount of salt used.

Extensive use of the salts sodium chloride (NaCl) and calcium chloride ($CaCl_2$) for removing snow began during the early 1960s. Before that time, highway maintenance departments depended primarily on abrasives, such as sand and cinders, combined with plowing, to clear snow and ice from highways; salt was generally added to the abrasives to prevent freezing. However, maintenance departments gradually began to appreciate salt's accelerated melting effect.

Through experimentation, maintenance engineers learned that direct application of salt before, during, and after a snowstorm greatly facilitated their snow removal operations, in terms of both time and money. Since that discovery, the use of salt for snow and ice removal has grown rapidly, in some cases by as much as 900 percent in the past 15 years (1). This extensive use of salt, however, has now been associated with a significant amount of damage.

There is no question that salt is an excellent tool for removing snow. There also is no question that, in terms of time and budget constraints for snow removal operations alone, salt used in large quantities with plowing is essential.

Highway departments trying to create the safest driving conditions believe that providing most bare pavement in least time is best achieved by extensive use of salt—given budget constraints. However, some highway departments, in their eagerness to perform well and meet these goals, have inadvertently used salt inefficiently. The education and understanding fostered by the Salt Institute, the Environmental Protection Agency (EPA) (2, 3), the Massachusetts Special Commission on Salt Contamination (4), and many others have corrected some of this misuse. The result has been a more effective use of salt with no essential reduction in level of usage.

Total salt use for snow and ice removal in this country now stands at approximately 9 million Mg (10 million tons) each year. Many highway departments apply as much as 37 Mg/lane·km (25 tons/lane·mile) in one season. On a four-lane highway, this amounts to 56 kg of salt in the runoff for every meter of the highway (38 lb/ft). As we build more highways, we can expect salt use to increase, if we continue with our present policy (and if no alternative method for snow and ice removal is found).

The concept of June travel in January, better known as the "bare pavement policy," has led highway departments and the public to the situation in which we currently find ourselves. And over the past 10 years, and especially the past 4 to 5 years, the number of reports of damage to water supplies, vegetation, and the very vehicles and highways that originally served as the only focus of attention has grown.

The reports of salt-related damage are extensive and well documented. There have been several excellent works summarizing these reports (2, 3, 4, 5, 6) and many excellent in-depth studies on certain areas of damage. On careful examination of all these studies and the other literature, one can only conclude that this very serious problem requires careful assessment as do the current guidelines for snow-removal procedures.

It is in this context that the idea for the EPA study was formulated. Previous studies, as thorough as they were, did not assess the entire problem of damage in terms that included economic analysis. Logically, except in extreme cases, no amount of damage claims without the necessary economics could allow a rational salting policy to be formulated. Without such an economic analysis, no alternative to salt, whether it be more snow left on the highways or a more expensive replacement for salt, could ever be economically justified.

Consequently, although this analysis of damage from road salt was undertaken with a view to quantifying the problem, the lack of cost data in some instances prohibited it.

I was impressed not only with the extensive damage reports and the costs of that damage but with the extensive amount of damage in one sector. Rusted vehicles and bridges, although costly, can be replaced. Damaged vegetation can be ignored by those who do not incur the costs. But pollution of our water supplies is a serious matter. This is not to say that all road salting leads to water pollution, but it has in many instances.

The medical implications of salt in drinking water must not be taken lightly. Because of many unknowns, the economic analysis of the damage to water does not demonstrate how potentially serious the problem may be. Each of us must become aware of the facts on road salt damage in our environment. It is to be hoped that in this way a rational solution will be found and serious damage to our environment be prevented.

The fact that salt damage has reached this magnitude should come as no surprise to anyone who understands the way our current policy evolved. Highway maintenance departments' primary goal is to provide maximum highway safety and convenience. Although current practices may be near the optimum in terms of department goals (and highway budget constraints), in many locations these practices are far from the optimum in terms of the whole environment, man-made and natural. This has occurred primarily because those who determine present maintenance policies are largely unaffected by the adverse environmental conditions. Legal liability in some instances may have forced highway departments to attend only to accident prevention, and there have been no outside forces to regulate a department's activities.

Determining the precise levels or combinations of winter maintenance policies that maximize social well-being within certain constraints is the crux of the problem. Theoretically, at least, this should be accomplished by assigning prices to the various social and environmental values and then choosing those that maximize total net value. However, it is not possible to assign exact costs to all items, because their values are often subjective. This is especially difficult in cases where irreversible, permanent damage to health and vegetation occurs.

The concept of "public pressure for bare pavement" may actually have evolved simply because the public was unaware of environmental damage and thought that more bare pavement resulted only in a small increase in the maintenance budget. This attitude seems to be rapidly changing as the public becomes more aware of the need for a sound environment, and citizens of many cities and towns are working with state and local departments of public works to develop reduced salting and better water. The public information programs that have increased public awareness seem to have paved the way for policy changes to be favorably received. There is every reason to believe that a rational salting policy would be welcomed by every community.

METHOD

During the course of the EPA study, a complete review of the literature on snow and ice removal, salt use, and salt damage was made, and the most relevant documents—over 450 in number—were obtained. Each one of these documents was carefully screened for validity and relevance; over 300 were retained in a bibliography at the end of the EPA report.

The second portion of the research involved mailing several hundred questionnaires and letters to universities, public works departments, public health departments, and water suppliers. There were over 100 respondents who indicated that they had incurred damage or knew of damage in their areas or who provided us with documents or contacts pertaining to salt-related damage. Follow-up was done in many cases to clarify responses or obtain further information.

Nearly 200 personal contacts from the literature and surveys were made by either letter or phone. Almost all of these people provided information on salt-related damage. But, as in the case of the literature and the surveys, "hard" data on damage costs were few.

The study was essentially restricted to readily available data, either as publications or as accessible records. Unfortunately, most of the research on the potential damages of deicing salts has been in the nature of case studies. This orientation has led to interesting but often irrelevant findings useless for decision making at the local or state level.

Deicing salts are foreign substances that change characteristics of natural or man-made resources directly or indirectly in a way that reduces usefulness. These reductions can be related, at least at a conceptual level, to dollar costs that describe the damages in terms of a common denominator. These costs (estimated or imputed) are an expression of the value of the "lost usefulness" of the respective resource, or the cost of restoring that resource to its full usefulness.

The main problem of applying this framework to actually estimating costs is the nature of the relations between damages and salt application. These damages in the environment result from complex processes.

Generally, numerous factors other than salt must be taken into consideration in analyzing salt use and any suspected damages from it, but present knowledge of the interaction among factors is limited. In addition, the processes also depend on such phenomena as precipitation patterns and on the amount of salt applied. All of this produces considerable uncertainty in the known relations between damages and salt use, which impedes the development of a microanalytical model that translates relations into functional and quantifiable expressions.

Consequently, the EPA cost analysis was based on a general model expressing the expected (or average) annual cost in a particular damage category as the product of the expected magnitude of total damages (which in turn is the product of the probability of occurrence times the damage per occurrence) and the cost per unit of damage.

This general cost model provided the basis for examining the literature and other materials accumulated during the study. Considerable effort was given to adapting the available information to fill the data needs. However, in most cases, because the estimation procedures used to quantify parameters of the cost function were too broad, costs were estimated on an ad hoc basis, for example by a weighted extrapolation of detailed cost data for a particular state or region.

The analysis works best with damages to automobiles. Multivariate analysis is used to determine the incidence of salt-related damage; motor vehicle registrations provide reliable data on the total population at risk; and automobile prices can be used to determine the unit cost of salt-related damage. It is interesting that this method yielded the highest cost estimate of all categories examined.

RESULTS

Damage to natural components of the environment from road salt has been mentioned frequently in the literature. There is an abundance of information on how damage occurs and numerous reports of specific damage cases and, in some instances, what the cost incurred was. Nevertheless, the proponents of salt use have continually denied the significance of such findings, dismissing them with such comments as "the value of a tree does not compare to the value of human life." Damage to vegetation, although extensive and costly, is not the major component of damage; contamination of water supplies and and the impact on human life are.

In general, salt damage to natural resources is usually irreversible, too costly or difficult to reverse, or remedied only by the passage of time. Irreversibility means a significant risk, because the true meaning of the damage may only emerge in the future, when it is too late.

Assessing damage to natural resources from road salt has always been difficult. Not all the processes by which damage occurs are known, nor is the exact relation between salt use and damage. The effects of salt in nature are also often cumulative and therefore require lengthy studies for complete understanding. Finally, because irreversibility is so poorly understood, frequent disagreement over the extent of damage makes it difficult to assign costs.

Our cost analysis of damage to natural resources was conservative. The figures developed provide a lower bound, but actual costs may far exceed these numbers.

Man-made goods are also substantially damaged by road salt. Vehicles passing over the salt solution on the highway are sprayed with a highly concentrated solution, and salt deposits on metal surfaces accelerate corrosion. Salt splash from vehicles and direct runoff can coat highway structures and those nearby and make them more vulnerable to corrosion. Salt seepage through pavement will eventually damage the roadway. Runoff and percolation will also allow the salt solution to eventually attack underground wires and pipes.

Damage to Drinking Water Supplies and Health

The contamination of water supplies is possibly the most serious damage that results from the use of road salt. Salt percolating down through the soil can enter groundwater supplies. It can also enter surface supplies as direct runoff from highways. Processing water to remove salt is an extremely expensive and complicated task rarely done. Although not always possible, the safest means of preventing the salt from reaching water supplies is to catch the highway runoff and direct it to a high-flow stream or river that eventually reaches the ocean without entering another water supply. Although new highways may provide for runoff, the cost must be considered. This has not been incorporated into most existing roadways, and to do so now would be either very costly or impossible.

The details of salt contamination in various parts of the country have been extensively recorded. Some of the first cases of serious salt infiltration were caused by improper storage facilities, but most salt pollution is now caused by runoff from streets and highways. The following examples should help to illustrate the extent of the problem.

Before 1940, all Massachusetts data indicated chloride content of public water supplies was less than 10 mg/L (implying a sodium content less than 3 to 6 mg/L). Recent data (1976) indicate that at least 117 communities (over 260 suppliers) have one or more of their public water supplies containing sodium above 20 mg/L. Two towns experienced such severe contamination of public wells that new wells had to be dug at a cost of approximately $150 000 for each town.

These data do not include private water supplies, for which few data exist. After several residents detected bad tasting, corrosive water, the town of Goshen, Massachusetts, discovered that many private wells were above 250 mg/L sodium and the school well was 390 mg/L. Residents and the school were forced to purchase bottled water.

Water supplies in Connecticut have been showing similar salt intrusion. Recently a few supplies appear to have leveled off, possibly in response to the one-third cut in the state's use of salt, a measure initiated because of salt infiltration.

Since 1964 the state of New Hampshire's budget has included funds for replacing wells contaminated by salt. Originally set at $100 000 a year, the budget was increased to $200 000 in 1974, when 50 wells were replaced.

These damage figures and the replacement costs for New Hampshire—along with the salting intensities of all the snowbelt states and the relative importance of well supplies in other states as compared to New Hampshire—imply that the direct costs of replacement alone for the nation are close to $50 million annually. These costs cover the replacement only of seriously polluted wells, those with over 250 mg/L chloride (162 mg/L sodium), a guideline set by the Public Health Service in 1962.

Measuring the cost of health degradation from elevated sodium levels in drinking water is virtually impossible. For years now medical research has established that intake of sodium chloride is a critical factor in many conditions such as hypertension, cardiovascular diseases, renal and liver diseases, and metabolic disorders (7). Intake of salt also endangers many pregnant women.

Recent research has further strengthened the link between salt and hypertension and between salt and the other diseases and problems mentioned above (8, 9, 10, 11, 12, 13). Freis cites "epidemiological studies in unacculturated peoples showing that the prevalence of hypertension is inversely correlated with the degree of salt intake . . . " (13) and concludes that

On the basis of present knowledge, it would seem wise for individuals with a family history of essential hypertension to accustom themselves to a truly salt-free diet (less than 1 gm of salt or 15 mEq of sodium per day) and to prevent their children from acquiring the habit of eating salted foods.

The American Heart Association, backed by many leading medical researchers and physicians, has recommended a limit of 20 mg/L sodium in drinking water for patients whose diets are restricted to less than 1 g of sodium per day (7).

According to recent estimates, approximately 23 million Americans are suffering from hypertension and should restrict their sodium intake (14). This group, together with others who should restrict their sodium intake to 20 mg/L, represent 20 to 25 percent of the population; some researchers claim the percentage is as high as 40 percent (9). Unfortunately, many of those who should restrict their salt intake are not aware that their lives are at risk. For one person, water containing more than 20 mg/L sodium may not be a significant danger, while such water is potentially very harmful to people who are or should be on low sodium diets (approximately 4 to 5 percent).

In addition, education of the public will undoubtedly result in greater awareness of hypertension, and more people will restrict their salt intake. Complete reversal of the trends that increase sodium presence might take years once action is taken, and endanger many more people than just those currently on salt-restricted diets.

Several years ago, the state of Connecticut adopted a 20 mg/L standard, and Massachusetts is now in the process of doing so. A Massachusetts advisory committee of 16 medical authorities has overwhelmingly—one dissented because he felt the evidence inadequate—recommended this standard (15).

An indication of the cost of salt-contaminated drinking water in terms of effects can be obtained by estimating the expenditures required to remove the hazard. Total costs can be roughly obtained by assuming that all hypertensive people would purchase bottled drinking water once their water supplies exceeded a 20 mg/L sodium concentration. For the normal adult, an average daily drinking water consumption of 2.2 L has been estimated, and 3.8 L (1 gallon) of bottled water sells for about 50¢, so the average person would spend approximately $106 (2.2/3.8 × 365 d × 50¢) a year.

The number of people on low sodium diets exposed to drinking water above 20 mg/L sodium attributable to road salt is extremely difficult to estimate. Massachusetts' experience indicates that approximately 27 percent of the water supplies (not necessarily the population) are affected by high sodium concentrations from road salting. As a broad estimate, roughly 25 percent of the population under conditions similar to those in Massachusetts are affected, and 4 percent have been estimated to be on low sodium diets.

By using salting intensity as a weight to make other states in the snowbelt comparable to Massachusetts, we estimate a total cost for the nation of $105 million. Massachusetts relies more heavily on groundwater than the nation as a whole (23 percent versus 21 percent), so the estimate should be somewhat lower, $96 million for bottled water to people on low sodium diets.

In summary, the annual direct and indirect costs of water supply contamination may add up to almost $150 million nationwide. This figure is meant to convey an impression of the magnitude of the damage, not to describe actual costs. Note that we have not included any costs to industry of special processed water requirements.

Damage to Vegetation

Experiments and empirical studies have clearly demonstrated that many trees used for roadside planting in the snowbelt are sensitive to increased sodium concentrations in the soil and that there is a direct link between the deterioration or death of roadside vegetation and salt application.

Salt directly interferes with the chemical processes by which plants absorb nutrition and affects the osmotic balance, thus inhibiting the water intake of plants. It may replace vital nutrients.

In addition to these direct effects, sodium in the soil may also result in a rapid deterioration of the soil itself. Westing (16) has said that "when sodium comes to occupy more than about 15 percent of the total cation exchange capacity of the soil, soil structure begins to deteriorate ... permeability and water-holding capacity decrease markedly." The soil becomes low in nutrients, and little, if any, vegetation can grow in it. In some cases this in turn has led to severe erosion and the eventual clogging of drain sewers. Continued application of road salt has been shown to have a cumulative effect on the soil.

Although drainage conditions are important in determining how far from the edge of the highway vegetation is affected, most damage occurs within 9 to 12 m (30 to 50 ft). Other factors such as drought, low soil fertility, low soil permeability, pollution from vehicle exhaust, and mechanical injury to roots also contribute to the damage.

However, comprehensive studies have shown that salt is often the prime factor leading to death of vegetation (17, 18, 19). These studies were based on soil samples and analyses of sodium and chloride contents in leaf and twig samples. One study clearly demonstrated the effect of salt by comparing tree damage on salted and unsalted roads in the same towns (20).

The usual sequence of events in salt damage in plants is increasing sodium and chloride concentration in plant tissue, reduced growth, falling leaves, dropping twigs, dying limbs, and death. Clinton E. Carlson found in controlled experiments that "once foliar symptoms of salt were noticed, it was not possible to prevent further damage—the trees always died even though they were taken off the salt solution and given only pure water."

Heavy salt use and the resulting damage to vegetation can lead not only to personal property damage and possibly crop damage but also to the creation of unsightly highways, reduced property values, and failed highway beautification programs. There are also real costs involved in terms of increased highway maintenance for removal and replanting.

Although the botanical and chemical evidence is sufficient to document widespread deterioration of roadside vegetation in areas characterized by the heavy use of deicing salts, the empirical support is somewhat meager. Apart from studies of specific stretches of highway and vegetation, the data base relating to deicing salts and vegetation damage on a macroscale is limited to reports of specific instances.

Rich (20) reports that in 1957 the New Hampshire Highway Department removed 13 997 dead trees along 6000 km (3700 miles) of highway. The estimated cost of removal was $1 million, or more than $70 per tree. According to other reports, Winchester, Massachusetts, which has applied as much as 31 Mg/km (55 tons/mile), has lost an average of 56 trees a year since 1963 (6). Similarly, Newton, Massachusetts, which also applied amounts of salt far above the average for towns and cities in the state, is reported to have lost about 500 trees a year between 1965 and 1970.

The problem with evaluating these reports is that they tend to ascribe all tree deaths to salt application. Because there are no national statistics on the number of trees dying each year, it is impossible statistically to establish the net effects of deicing salts in terms of damages to roadside trees. Similarly, data on the risk—roadside trees possibly exposed to deicing salt runoff—that would be useful in applying microanalytical findings to a macrolevel framework are unavailable. As a result, accurate national damage estimates simply cannot be generated.

Direct costs are maintenance and removal in the case of death; indirect costs involve losses to individual property owners resulting from the death (or deterioration) of a fully grown shade tree that may or may not be replaced by a small young tree. Evaluating indirect costs is of course the most difficult task. Fortunately, a number of studies have been made of the monetary value of shade trees.

The International Shade Tree Conference (21) base the monetary value of a shade or ornamental tree on three basic factors, the size, kind, and condition of the tree, and in August 1973 they adopted \$1.55/cm^2 (\$10.00/in^2) of trunk cross section as the value of a perfect shade tree specimen. This figure would add \$10 milmion in indirect costs to direct costs [using a fairly conservative average of 25.4-cm (10-in) diameter for the 13 997 trees removed].

The measures established by the International Shade Tree Conference may be somewhat arbitrary and, more importantly, may apply primarily to urban trees, but they provide an indication of the potential magnitude of the problem. If only 6 percent of all tree deaths in the New Hampshire example were attributed to deicing salts, the total annual direct and indirect costs would be \$660 000, an amount comparable to the cost computed for the water contamination damages. Extrapolating from this figure to a national level by using salting intensity by state produces a total annual figure of about \$45 million. This is a representative cost figure. If dollar amounts could be determined for damage to privately owned vegetation and roadside vegetation other than trees, the total damage costs would be far higher.

Damage to Highways and Highway Structures

A thorough search of the literature and a survey of all snowbelt state highway departments and approximately 100 large city highway departments have disclosed that there has been extensive salt-related damage to bridge decks. By far the most devastating damage is the general deterioration of the West Side Highway in New York City.

On December 15, 1973, the northbound roadway between Little West 12th Street and Gansevoort Street collapsed. The city transportation administration contracted consulting engineers to conduct a complete examination (22). The analysis, conducted from July 9 to November 14, 1974, comprised four substantive volumes, the last dated May 30, 1975. The following is taken from the most recent report (22, p. 21).

> The deterioration of the West Side Highway has been a continuous problem. As early as the mid-fifties, public officials had anticipated its early demise. The use of salt to remove ice, combined with heavy traffic, has caused disintegration of large sections of the roadway.

"The deterioration," they continue, "is a direct result of water and waterborne salt leaking through the expansion joints and the concrete deck." They conclude, not surprisingly, that in part the "Use of salt for deicing should be minimized. Other methods and materials for maintaining traffic during ice and snow conditions should be considered." The report also concludes that, although restoration of the highway is feasible, the cost of the work, estimated at \$58 to \$88 million, is almost prohibitive.

Although the cost of the repairs to the West Side Highway may not be representative of typical bridge damage, there are other examples of costly salt-induced deterioration. It was recently reported that four Washington, D.C., bridges had become dangerous to traffic because salt had caused extensive corrosion of the reinforcing steel. The cost of the repairs is \$11.7 million (23).

The actual cost outlay by state highway departments for the repair of bridge decks was estimated to be \$40 million in 1971; total outlays, including repairs that would halt the deterioration in quality, were estimated between \$80 and \$120 million.

Evidence from individual states, particularly West Virginia, provides a check on these figures. The cost of maintaining West Virginia's 6000 bridges in good condition was recently said to be approximately \$12 million, or about \$2000 per bridge. Assuming that bridges are distributed throughout the state in the same proportion as the population, that 100 percent of the bridges located in severe deterioration regions require periodic maintenance and repair of salt-induced damages, and that only 20 percent of the bridges in moderate regions require such maintenance, we conclude that nearly 100 000 bridges are adversely affected.

If the West Virginia estimates are representative of other severe deterioration regions, a yearly cost of \$200 million for the nation's bridges is estimated. Similar procedures estimate the cost of special construction techniques to prevent rapid deterioration of new bridges at about \$10 million annually. Direct costs of salt damage to bridge decks will be in the range of \$200 to \$250 million annually. In addition, the relevant direct costs should also include necessary repairs of structural damages. Although these damages are insufficiently documented for the nation as a whole, specific instances such as the West Side Highway can be cited to indicate the potential magnitude of the problem.

The direct cost estimates include only (a) expenditures by highway agencies for special design features on new bridges and (b) repair of existing structures to counter the adverse effects of road salting. Full social costs would include delays to motorists during repair, repair costs for damages to ball joints and front end alignment from travel on uneven bridge surfaces, and the cost of accidents caused by rough bridge deck surfaces. Some of these, although potentially important, would be exceedingly difficult to measure accurately.

On the basis of a recent discussion of vehicle behavior at sites of traffic obstructions (24), the cost of lost commuter time during bridge repair has been estimated. The conservative figure comes close to \$250 million annually. In summary, the total annual costs of bridge deck damages related to salt use can be said to exceed \$500 million.

Corrosion of Motor Vehicles

It is likely that people have directly observed vehicle corrosion more than any other form of salt-related damage. The link between the application of salt on highways and the corrosion of automobiles is well documented. Previous studies have concluded that road salting causes a doubling of the normal corrosion rate (25). Although it accepted these figures, the Environmental Protection Agency report has distinguished four major cost categories:

1. Costs of protective measures both by manufacturers and by owners,
2. Costs of repairs required to maintain the ability of the automobile to function at the same level as without salt-induced corrosion,
3. Losses in economic value of the automobile as a result of salt-induced corrosion, and
4. Costs of accidents attributable to automobile malfunctioning associated with salt-induced corrosion.

The third category is the most amenable to analysis, because we can attribute depreciation rates to the influence of salt. A regression model for depreciation rates was built on an economic model of used automobile prices and data on used automobile prices (30 on the average) for three makes of automobile in each of 44 metropolitan regions. The interim models included temperature, humidity and rainfall, proximity to ocean, sanding intensity, air pollution (SO_2 levels), income per capita, and vehicles per capita, all of which were found to be unimportant and were therefore removed from the analysis. The final model predicted depreciation rates on the basis of state salt use, city salt use, snowfall, and kilometers driven.

The cost of incremental depreciation from salt was estimated by evaluating the stocks of automobiles in various environments and multiplying by the incremental depreciation attributable to salt use. On this basis, the total annual national cost of automobile depreciation caused by road salt was $1.4 billion. Extrapolating from the above model and from known estimates of costs of damage and maintenance for trucks and buses, an additional cost of $690 million was estimated. Thus, the total annual cost to owners of motor vehicles is in excess of $2 billion.

Other Damages

Damages attributed to the use of deicing salts have been noted in areas other than those discussed in the preceding sections, but available evidence, of course, is limited to a few reports. A brief review of this evidence suggests, for example, that on a national scale the potential effects of deicing salts on underground cables and electric utility lines may be substantial.

One of the best-documented instances of salt-related damage to underground power transmission lines is the case of Consolidated Edison's (ConEd's) facilities in New York City. This company maintains the largest system of underground electric facilities in the world. The winters of 1972 to 1973 and 1973 to 1974 contrasted strikingly in terms of salt applications and resulting damages to this underground cable system. After extensive analysis of the damage, ConEd, in an in-house memo in 1974, stated that "Altogether, it is safe to estimate that the salt spread on the streets of New York City resulted in additional expenditures by ConEd in excess of $5 million during the winter of 1973 to 1974."

No estimate of the cost to consumers as a result of power outages has been made, but data suggest that several hundred power outages during the severe winter months can be attributed to salt use. The costs of such extensive power losses are very significant in terms of inconvenience, lost production time, and lost personal time.

It is likely that the costs incurred by ConEd are far higher than those incurred by any other municipal electric company. Many other instances of such damage that have not been so well documented and analyzed will probably be found to be salt related. The analysis will ideally pave the way for other large utility suppliers (and users) to thoroughly document and investigate their own reports of salt-related damage.

BENEFITS OF ROAD SALTING

Salt is beneficial insofar as it increases safety and saves time. The relations between salt use and these two factors are complex, especially with regard to safety. However, it is appropriate to report briefly on the work that has been done in these areas.

How much alternative winter maintenance policies affect highway safety cannot be established by directly comparing accident rates and maintenance policies—unless driver behavior is included. Although one would expect considerable research to have been directed toward understanding situations that involve the risk of injury and death, surprisingly little is actually known. Human behavior under conditions of financial uncertainty has a rich theoretical and applied literature, but such models are largely inappropriate for the analysis of accident risk, and attempts to model human behavior in situations involving the risk of life or limb have not been very successful. The existing evidence for a connection between safety and alternative winter maintenance policies is both meager and inconsistent. Deicing salts are often assumed to improve driving conditions. There is no question that salt can increase friction between the tire and road. Courts, in assigning liability for single-vehicle winter accidents have on occasion found highway department officials negligent for not applying enough salt to provide an acceptable level of safety to motorists. Also, the assumed causal relations between deicing salts and highway safety are a major rationale offered by highway department officials for the twenty-fold increase in the annual use of deicing salts since 1950.

Three studies that contain information supporting the contention that deicing salts reduce highway accident rates are all flawed by serious design and analytic errors and omissions that make the results meaningless.

The key issue is really driver behavior. Some researchers have reported that salting may create a false sense of security in many drivers (26). This statement remains unproved, but other researchers have noted that improvements in safety can bring increases in speed that cancel out the impact of the improvements on accident rates (27, 28).

Under hazardous winter conditions, drivers do slow down, but probably only enough to make their perceived risk of injury the same as under normal conditions. Whether perceived risk is the same as actual risk is unknown, although an Ottawa consulting firm found that accidents on icy roads generally involve property damage, while accidents on bare (dry or wet) pavement in winter are more likely to involve personal injury (29).

Substantial research into the relations between salt and safety is a necessity. Salt used properly does increase friction, but this is not the only factor that determines accident rates. Continuity of conditions along a roadway, speed, and, above all, driver behavior must be considered. Such research will be extremely difficult, because determining what constitutes taking a risk under varying driving conditions is a difficult (if not impossible) task. Until such research is performed, we cannot assume that salt and safety are synonymous.

In fact, it is quite possible that the level of salt is not a fixed factor in determining safety. If the amount of salt were reduced and alternative measures were not taken to retain the same level of bare pavement, then presumably the public could be forewarned satisfactorily so that greater care and fewer trips could be taken during snowstorms. If highway speed were reduced, then the level of safety would remain the same. The only advantage of heavy salt use then would be time savings. This is certainly a very important factor; time savings must be maximized whenever possible.

Anyone who has driven under snow and ice conditions knows that progress is slowed, especially during rush hour. There have been scattered estimates of the cost of lost time but no major effort to assess the true value of lost time. The costs may be high, but a certain amount of care must be taken in developing the figures.

For example, it is false to suggest that a 1-h delay for all people in a city will result in a loss of one-eighth of the economic activity for that day. There may be losses to workers paid on an hourly basis, to industries that must shut down from staff shortages, and in rare instances to food stores because of spoilage. However, delay has little effect on the income or productivity (in the long run) of salaried workers, and there is probably little if any loss in terms of shopping expenditures, because shoppers will simply defer their errands to a later time.

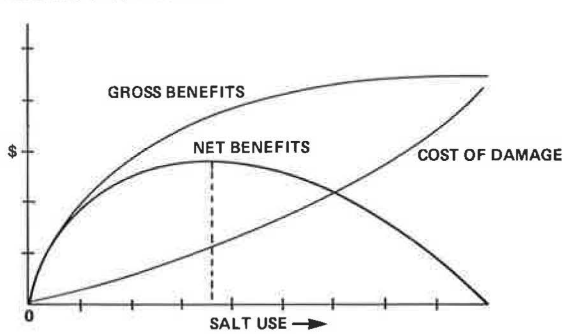
Better planning for the possibility of hazardous snowstorms would probably help reduce business losses. Nevertheless, the question of actual costs of lost time from snowstorms is still a problem open to research.

A recent study sponsored by the Salt Institute (30) attempted to establish the economic benefits lost if salt were eliminated. (No one, including the EPA, has suggested that salt be eliminated, just that it be reduced in environmentally sensitive areas.) Unfortunately the estimates, based on the assumption that 10 percent of the workers would be absent and all the rest would be 2 h late throughout all the snowbelt states for 20 days appear inflated. In addition, the researchers double-counted benefits by including both loss in wages and loss in value of goods produced.

A major point is that we should certainly expect the benefits to be substantially greater than the costs. Units have not been assigned to the axes in Figure 1 because little is known about the exact relation between level of salt use and actual costs and benefits. Nevertheless, it can be shown that the gross benefits and cost of damage curves are of the shape shown in this figure. The exact shape for a region or locality varies according to local conditions.

Net benefits are maximized at a level of salt use for which the gross benefits and cost of damage curves have identical slopes. Explained in another way, salt use is optimized at a level for which the marginal benefits equal the marginal costs. The gross benefits could be many times the costs at this point, and if the benefits were not significantly greater than the costs, one might suspect that salt is overused. There is no simple way to determine the best level of salt use, and the only way an agency could begin to do so would be to experiment with level and frequency of application. This is exactly what many agencies have done and are currently doing.

Figure 1. Costs, gross benefits, and net benefits of salt as a function of salt use level.



CONCLUSIONS

The costs of actual salt damage to water supplies and health, vegetation, vehicles, bridges, and utilities are immense. Annual damage costs, at a very lower bound, approach $3 billion. This hidden cost is almost 15 times the annual national budget for the purchase and application of road salt and about 6 times the entire annual national budget for snow and ice removal.

Furthermore, heavy salt use in many instances upsets the natural ecological balance and results in damages that cannot be assigned a dollar value. This is one of the many reasons why the above amounts must be considered as lower bounds. The potentially most serious of all these damages are the irreversible ones, such as the risk of increased hypertension that results from the heightened levels of sodium in water supplies. As much as 5 percent of the population drinking water contaminated by road salt may be adversely affected.

The implications are clear. The costs of damage to bridge decks and vehicles are high but reversible; the damage to health may not be reversible. We can no longer afford to ignore the fact that we are depositing large quantities of salt into the water on which we are dependent every moment of our lives.

The most advanced medical research indicates that water with more than 20 mg/L of sodium is unhealthy and detrimental to a substantial portion of the population. The American Heart Association supports this fact. Disregard for the quality of drinking water in this and any instance is extreme negligence, and we must face the issue squarely. Road salt may be only one of the many serious pollutants in our environment, but that is no excuse to allow the present situation to continue. In order to avoid further damage and high costs, salt use for winter maintenance must be reduced.

It is public information programs that have given carefully designed reduced salting policies public acceptance. The most notable case is the state of Connecticut, where state salt use was reduced by 33 percent because of rising sodium content in water supplies. This reduction was apparently made with little change in level of service or accidents and with a resulting cost savings. Also, a 50 percent reduction in salt use was made in one area of Madison, Wisconsin, during the winter of 1974 to 1975.

A public opinion survey (with an 84 percent response rate) was used to determine the public's reaction to the cutback (31).

> Survey results indicate that Madison residents strongly support the limited salt program. More than 90 percent of the respondents believed that the program is a worthwhile experiment and should be continued, while 85 percent supported a reduced salt program on a city wide basis.

There is every reason to believe that the residents of individual cities and towns or other states would accept reduced salting if salt-related damages were made known to them.

RECOMMENDATIONS

In order to maintain the public's right to clean water, the level of salting in many areas should be reduced according to local conditions such as the effect of salt-laden runoff on water supplies, the level of public demand for bare pavement, and the size of the winter maintenance budget. Greater emphasis should be placed on nonchemical methods of snow and ice control (such as increased plowing and sanding).

Setting the level of bare pavement is a burden that need not be the sole responsibility of highway maintenance departments, who should seek advice from all interested groups and the public at large. Through public affairs programs, the public should be made aware of the trade-offs and alternatives. A city or town may want to form a special committee or hold a voter referendum to ensure the best solution. Changes in winter road policies should have public support and should be publicly announced before they are effected.

There should be a greater emphasis on training drivers in the skills of snow and ice driving and less emphasis on the concept of guaranteed June travel in January. Moreover, an operating policy to encourage motorists to stay off the roads during and immediately after storms would facilitate snow and ice removal.

Snowbelt states should test public and private water supplies and provide funds for replacing wells (as has been done in New Hampshire). State legislation should be passed allowing individuals to sue for damages when water supplies show an abnormal or hazardous increase in sodium content and placing the burden of proof on the highway departments that the cause was not road salt. If road salt is found to be the source of contamination, then corrective action, such as the installation of drainage systems or a reduction in salt use, must be taken to restore the damaged water supplies. Until an acceptable sodium level is reached, it would appear proper for the local governing body or the highway maintenance department responsible for the damage to provide bottled water to those using the contaminated supply.

Reasonable levels should be established on the basis of the sodium standard in the Safe Drinking Water Act and on the basis of natural background levels of sodium in the water supplies. Finally, the states should consider instituting a requirement that all salt users file an environmental assessment.

Although these measures may seem burdensome, they are necessary in order to ensure that we maintain our high quality of water and that large costs are not incurred as a result of winter highway policies.

ACKNOWLEDGMENTS

Many people across the nation and from several foreign countries contributed to this paper. I have been impressed by and greatly appreciative of the concern on the part of hundreds of individuals and agencies who provided valuable information. Sincere thanks go to all those who have helped make the original Environmental Protection Agency report and this paper possible. The support of the original effort by the Wastewater Research Division of Edison, New Jersey, of the USEPA Municipal Environmental Research Laboratory, of Cincinnati, Ohio, and especially of Mr. Hugh E. Masters for his guidance, suggestions, and inputs and thorough manuscript review is acknowledged with gratitude. Copies of the complete report (EPA-600/2-76-105) may be obtained by writing to Storm and Combined Sewer Section, Wastewater Research Division, Municipal Environmental Research Laboratory, Edison, NJ 08817.

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Discussion

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This discussion is concerned only with the adequacy of the assumptions and the technical discrepancies in the vehicle corrosion portion of the original EPA document (32) from which Murray's paper was derived.

Murray assigns two-thirds of the $3 billion in annual damage, reported due to deicing chlorides, to vehicle corrosion damage. He represents this annual damage cost as the "very lower bound" of the total costs attributable to deicing chlorides, but it is important to recognize that his approach overstates the vehicle corrosion costs attributable to deicing salts.

The Ackerman approach (32, pp. 75-76) appears to be a reasonable method for determining differences in the depreciation rate. Whether the Anderson-Murray approach and the resulting regression equation are a valid distributor of the additional depreciation, developed as Ackerman does, is the principal point in question.

Before writing this discussion, a copy of the original data (33) from which the regression equation was developed was obtained. These data did not include mean January temperatures but otherwise corresponded with those described in the reports (32). Mean January temperatures were obtained (34, 35), and the data were then subjected to regression analysis by using BMD-02R program—stepwise regression—Rev 6/11/74. (This analysis was written in U.S. customary units.) The results of that regression analysis are as follows: depreciation rate equals 15.9418 plus 0.0469 state salt plus 0.0258 snow plus 0.1531 miles plus 0.0204 city salt. The multiple R for this equation is R = 0.9033, and the coefficient of determination is 0.816. Estimated standard error for state salt is 0.0156, for snow is 0.0068, for miles is 0.153, and for city salt is 0.0059. Other results follow.

Snow Versus Collinearity Correlation	
State salt	R = 0.64
City salt	R = 0.59

Depreciation Rate Versus Individual Correlation	
Snow	R = 0.81
State salt	R = 0.75
City salt	R = 0.75

Importance of four independent variables in contributing to the multiple R of R = 0.9033 follows (1 mile = 1.6 km).

Variable	R	R^2	Increase in R^2
Snow	0.812	0.659	0.659
City salt	0.877	0.770	0.110
State salt	0.898	0.807	0.037
Miles	0.903	0.816	0.009

The most obvious comment about these results is that if the assumptions on which the equation is based are valid, the authors had somewhat better data than they portrayed. According to these results state salt costs are increased by $167 million and city salt costs by $36 million.

The multiple R (0.79) is probably in error. In any case a multiple correlation coefficient of 0.79 does not imply that 79 percent of the variation in the dependent variable has been explained by the four independent variables used in their equation. It explains 62 percent, or 0.79^2. Note that in our cross check of the Murray-Anderson (regression analysis) data, a multiple correlation coefficient R = 0.90 was obtained.

In the regression analysis "the unit of observation is the city" (32, p. 77). Application of city regression estimators (depreciation rates versus city salt) to the state as a whole may be untenable, and the authors' justification for it is not obvious.

Regardless, the amounts used (32, Table 8, pp. 85-86) may well overstate the damages. For instance, in California, over 90 percent of the population is concentrated where deicing salts are not used. The 0.567 Mg/lane·km (1 ton/lane·mile) annual state salt and city salt figures seem a bit excessive.

The EPA document discusses 44 cities, 41 of which were incorporated in the regression analyses. According to the original paper, which was retained essentially intact in the EPA report, the 2 cities "Houston and New Orleans were deleted because of high rates of decay attributable to humidity and proximity to the ocean." Rainfall was substituted for humidity "because humidity rates proved difficult to obtain" (32, p. 81).

Which humidity data did the authors use to justify the deletion of these two cities? High depreciation rates in the absence of deicing salts are not a valid basis for their deletion. And if humidity is the basis for deletion, on which criteria were Tampa, Florida, and Charleston, South Carolina, retained? Both are in close proximity to the ocean and have high humidity rates, Tampa somewhat higher than either Houston or New Orleans, Charleston somewhat lower (35).

In citing others (36, 37, 38) and referencing Chance (39, 40) in the original study, the authors developed a skeletal technical perspective against which the validity of the regression equation assumptions could be evaluated. The technical data indicate that deicing salt and air pollution contribute about equally to corrosion damage and that a humid, air-polluted environment can produce four times the corrosion damage sustained in a dry, non-air-polluted environment. Note that even in a dry, non-air-polluted environment with no deicing salts there is still corrosion damage (36). The proxy variables, mean ambient January temperature, rainfall, and average annual sulfur dioxide concentration selected to represent the natural environment and air pollution did not contribute to the equation, but the technical data indicate that they should have. The variables selected, then, are probably inadequate.

Until this discrepancy is reconciled, the credibility of the regression equation and the costs derived from it are at best questionable. A more detailed study is required before costs can be ascertained by this approach.

The amount of corrosion sustained by a vehicle is not only a function of the corrosiveness of the environment in which the vehicle is operated, but also the amount of corrosion resistance built into the vehicle.

What the EPA report does not take into account is that, if in the process of being modified a product becomes less able to withstand the environment, is it valid to charge the losses resulting from this change to the environment and more specifically to one particular aspect of the environment? Furthermore, nowhere in the study do the authors deal with the long-term effects of the reduction in sheet steel thickness that accompanied the adoption of unibody construction by the American automobile industry. This construction was adopted on a wide scale in 1955. At that time the automotive industry's anticorrosion capability was low, and its relatively high anticorrosion capability achieved only recently. Whether the premature corrosion perforation of 1955 through early 1970 models is due largely to reduced metal thickness combined with inadequate anticorrosion technology is arguable (41).

No substantial basis for the $690 million in annual truck damage was developed. The arbitrary assignment of $30/truck based on the opinions of truck fleet managers is at best qualitative.

In summary, the approach the authors used has a great deal of potential. The correlations between salt and depreciation cannot be lightly dismissed. But the technical work cited indicates that correlations between air pollution and corrosion in the same range are also to be expected. Furthermore, no study to date has adequately dealt with the amount of corrosiveness attributable to the unpolluted base environment. The four to one corrosion ratio between a dry, non-air-polluted environment and a humid, air-polluted one indicates that the base environment does have a significant effect. The adoption of unibody construction has, to our knowledge, only recently been considered in this frame of reference and then only as a logical argument that does not assign costs. In our opinion, the costs developed in this section are excessive.

Although we have been extremely critical of the regression equation and the dollar costs developed therefrom, this was more in response to the unqualified use of the $2 billion figure in the conclusions than the method of approach. It is our belief that those responsible for the allocation of research efforts and funding, as well as others, rarely have the time or the desire to read qualifications buried in the text. As a result, unqualified, unchallenged conclusions, such as those appearing in the EPA-sponsored report, result in a distortion of effort. If, in fact, the EPA or some other group desires to determine and allocate the costs of vehicle corrosion, we would strongly recommend that consideration be given to the method developed by the authors, providing that the points stated in the discussion are adequately dealt with.

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My colleague Jack Moshman and I recently published a paper on the benefits and costs in the use of salt to deice highways. In it, we examined the principal findings of the work by Murray in the original EPA study. We then developed our own model of the problem.

Murray deals only with the costs of the adverse effects of salt; he does not seek to estimate the economic value of the benefits associated with rapid deicing of highways. Clearly, the costs of adverse effects should be compared with the economic benefits, and community decision making on road salting should relate to the net difference.

I question the $2.91 billion estimate as the annual economic cost to snowbelt states resulting from the use of road salt. By changing some of the underlying assumptions and using different constants, we come up with something around a third of this estimate. But even if the higher figure is used, the benefits still far exceed the costs by a factor of six. In short, regardless of which assumptions are taken in numerical exercises such as Murray's or ours, the benefits of rapidly deicing roads are far greater than the costs. The complete comparative picture is unmistakable.

The fact that Murray assigns dollar values only to the adverse effects of road salting and a zero dollar value to the benefits is a transparent weakness. More disturbing than this, however, is the unclear safety logic, as expressed in this statement on safety that appeared in the presentation draft. "The use of salt for winter maintenance generally results in better traction on the highways, but because of a number of confounding factors, especially driver behavior, the link between salt and safety has not been proved." Improved traction, whether produced by better quality tires or by regrooving the pavement or by resurfacing sections with low coefficients of friction, means safer travel. Improved traction produced by salt means safer travel. Thus, the statement that salt improves traction but its link with safety is unproved is obviously self-contradictory.

He continues, saying that "While several studies have reported that salt reduces accidents the methods of data collection and analysis have been found to be mathematically unsound.

During the 30 years I have been associated with highway safety, the field has been crippled by statements to the effect that some obviously important safety (accident-preventing or injury-reducing) measure has not been proved to the satisfaction of some statistical purist. One can readily substitute "good brakes" or "properly trained drivers" for "salt": "While several studies have reported that good brakes reduce accidents, the methods of data collection and analysis have been found to be mathematically unsound." The absence of statistical proof of the link between good brakes and safety would hardly convince any rational person to venture onto a high-speed freeway in a vehicle whose brakes do not work.

Safety is the absence of hazards; hazard is the absence of safety. The hazard of iced-over highways is a fact, but, if statistical proof is required, it is a simple enough matter to examine hospital emergency room records or vital statistics records to determine what goes on when highways are iced over.

If salt is the fastest and cheapest way known today to reduce the duration of time over which highways are iced, then it also must be the fastest and cheapest way to reduce the hazard. There simply cannot fail to be a link between salt and safety, if in fact salt is the best way known today to accelerate deicing. Statements about the absence of statistical proof linking salt and safety are, along with similar statements on brakes and safety, empty.

Along with the statistical argument, Murray invokes the equally time-worn argument of driver behavior. For ages this has been dragged into accident analyses, even when the direct cause was some glaring engineering deficiency in the highway or the vehicle. But let us assume that driver inadequacy or error is a significant factor. We nevertheless must recognize that, in the highway field, we design to be forgiving of driver error. We do not pass off hazardous conditions by saying the driver should learn how to cope with them. We do not design roads with poor sight distance and leave it to the driver to adjust to the danger. We place guardrails in front of abutments or other exposed rigid objects to protect occupants in out-of-control vehicles, regardless of which factors might precipitate the loss of control—driver error, inadequacies of the vehicle's brakes or suspension, or inadequate skid resistance of the pavement.

Safety is apparently not Murray's primary concern in his classical statistical and driver error arguments, which have historically been used to attack some initiatives to reduce the highway death and injury tolls. Another illustration of his perspective may be seen in the $50 million estimate of annual salt-caused damage to roadside trees, which, in my view of safety, do not belong on road shoulders in the first place. Basic policy of the U.S. Department of Transportation and Federal Highway Administration calls for installation of yielding or breakaway sign supports precisely to eliminate the type of hazard the tree on the shoulder presents to occupants of the out-of-control vehicle. We design the highway environment to be forgiving of driver error, not punishing.

Notwithstanding the fact that there are many species of tree that are not harmed by salt runoff, the decision seems to me to be one of killing people or trees.

There are also highway planning flaws in Murray's work, illustrated by his $500 million estimate of the cost of highway bridge deck corrosion. Half of this is the value of the time motorists waste while bridge decks are being repaired. Not included in this particular entry in his bookkeeping is the value of delay motorists would incur in safely negotiating iced-over bridges. I know of few budget requests—federal, state, or local—for highway capital improvements that do not enter expected benefits in the budget request.

Finally, there is the $2.91 billion as an indicator of the total cost of the environmental impact of highway deicing. Vehicle corrosion accounts for about 74 percent, or $2 billion, of this amount. I question the accuracy of this estimate, but let us assume it is correct. If we add to this the $500 million for bridge deck damage and to the $200 million for the cost of salt and its application, we get about $2.7 billion as the nonecological salt damage, leaving a remainder of $200 million as the cost of ecological damage. This puts the ecological damage from road salting of $2.91 billion off by a factor of about 14.

Few ecologists, I suspect, would consider the automobile and the highways on which they operate as essential to the environment. It is interesting that the automobile seems to have new stature in the environmental protection community.

In summary, the Murray work seeks to assess the costs to society of road salting. I question both the accuracy of the figures and the underlying assumptions of the model, which contains other fundamental peculiarities. However, whether his costs are correct or not is not of great consequence. What is important is that whatever these costs might be, they must be considered in relation to road salting benefits, particularly as no better method for controlling iced-over highways is known today.

Author's Closure

This closure was written in part by Robert Anderson, who was chiefly responsible for the development of the regression analysis.

DISCUSSION BY BELANGIE AND SY

Belangie and Sy have focused their three contentions solely on the method used to estimate vehicle corrosion costs. First, total vehicle corrosion costs can also be derived from an analysis of regional variation in used vehicle prices. Second, the analysis we used to determine the relative contribution of the separate factors leading to vehicle corrosion is incomplete and as such may attribute excessive costs to deicing chemicals. Third, the regression results reported in the EPA report may have contained an error (or errors).

In response to the first point, we observe that the regional variations in used vehicle prices are at best a lower limit on the true losses in economic value. Many used vehicles driven in environments hostile to them (deicing salts, humidity, sunshine, salt spray near oceans) are retired prematurely and never offered for resale simply because the value of the vehicle does not warrant it. Scrapping the vehicle is economically more attractive.

When looking at used automobile prices in a region, one should try to incorporate the near zero value of all prematurely scrapped vehicles. Our approach of looking at advertised asking prices understates the true depreciation of vehicles in these hostile environments.

We also note that most vehicles are not owned and operated in a single city or state for the entire life of the 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.