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Publication of this paper sponsored by Committee on Coatings, Signing, and Marking Materials.

Vehicle Corrosion in Perspective

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Early perforation corrosion of American manufactured vehicles was a limited localized phenomenon before the mid-1950s, but a short time after the introduction of unibody construction and sculptured styling in 1955, its occurrence became common throughout most of the United States. The use of deicing salts, which had approximately doubled between 1953 and 1956, was cited in some of the literature of the period as the probable cause. There was little mention of the reduction in sheet-metal thickness that accompanied the change to unibody construction. Anticorrosion measures were nominal in the period immediately following the adoption of unibody construction. The period before the mid-1960s was not typified by major advances in anticorrosion technology, but was a period of trial and error with much of the emphasis being placed on improved anticorrosion design practice. It is doubtful that the improvements made in this period (1958 to 1965) could have counteracted the effect of the sevenfold increase in deicing salt use during 1953 to 1965 if deicing salts were the principal cause. Although it appears that the changes in manufacturing practice were the principle cause of widespread corrosion, the modifications in that practice since the change are producing significantly more corrosion-resistant vehicles. Low-priced, 1955 and 1956 vintage automobiles having unibody construction began to perforate within 6 months in severely corrosive environments. In late 1976, one motor company of Canada began warranting its cars for 36 months against perforation.

It is pertinent to the following discussion to remember the prejudicial character of the deicing salt versus corrosion controversy and that fixed in the minds of many persons in this country is the conviction that deicing salt is the principal cause of automobiles rusting.

The questions addressed here are these. First, Is the opinion that deicing salts are the principal cause of vehicle corrosion damage legitimate? And second, If it is not legitimate, how much of the depreciation in the value of the average automobile can be assessed to deicing salts? These questions are not casual. In January, 1975, the research section of the Utah Department of Transportation became the lead agency in an 11-state pooled-fund study that included Idaho, Illinois, Maryland, Michigan, Minnesota, Montana, New Hampshire, South Dakota, Utah, Virginia, and Washington and the Federal Highway Administration. The purpose of this study was to develop an economic model for snow and ice control activities (1). However, the funding was insufficient to allow the type of economic analysis of vehicle corrosion that would be necessary to effectively determine the portion of increased automotive depreciation costs that can be attributed to deicing salt. As an alternative, an in-depth review of the literature was made. More than 200 publications on vehicle corrosion were collected: Of this number, more than 80 percent were technical, as opposed to economic or summation, documents. Of the technical documents, many came

from the Society of Automotive Engineers and the National Association of Corrosion Engineers. The essence of this collection is summarized in an unpublished draft, *Vehicle Corrosion, a Synthesis* (2).

In developing this synthesis, it became apparent that the document collection could be divided into two sections: those documents or portions of documents dealing with the corrosivity of the environment and those dealing with the ability of the vehicle to resist corrosion. The differentiation is important in evaluating and assigning relative economic costs because it accentuates the fact that both the ability of the average vehicle to resist corrosion and the corrosivity of the environment have varied over time. This makes the assessment of costs due to corrosion considerably more complex than would be indicated by recent economic studies.

An understanding of the market place may be adequate to determine the additional depreciation of the average automobile of a given vintage due to corrosion. However, it is not sufficient to determine the assessment of costs against one environmental factor. To make this assessment, a basic understanding of the variability of the corrosive environment as well as of the changing technology of the average automobile is mandatory.

CORROSIVE ENVIRONMENT

What factors then must be considered if one wishes to assess the cost of a specific corrosion-causing environmental factor, in this case, deicing salts? The size and extent of the corrosive environment is probably a reasonable starting point.

Figure 1 indicates that vehicle corrosion is a worldwide phenomenon. The map shows the noncommunist areas having the potential for a substantial degree of corrosion. Blackened areas indicate the probable use of deicing salts; slashed portions show those areas that do not use salt. Unshaded areas are not exempt from corrosion, but in these areas, it is likely to occur so late in the economic lifetime of the average vehicle as to have relatively little effect on its resale value.

Of the 282 million vehicles registered in noncommunist countries in 1973 (3), approximately 55 percent were in corrosive environments in which deicing salts were apt to be used (blackened areas). Twenty-five percent were in equally corrosive environments in which no deicing salts were used (slashed areas). And 20 percent were in environments where corrosion occurs, but is generally not considered a substantial problem.

Of the 102 million automobiles registered in the United States in 1973 (3), between 46 million and 74

million were in corrosive environments in which deicing salts are used. The lower of these estimates (46 million) was derived from Figure 2 (4, 5) and represents a conservative estimate of the corrosive environment in the continental United States. The larger was derived from Figure 3 (6) and represents a more generous view of the corrosive environment in the United States.

Figure 1. Noncommunist areas having potential for substantial vehicle corrosion.

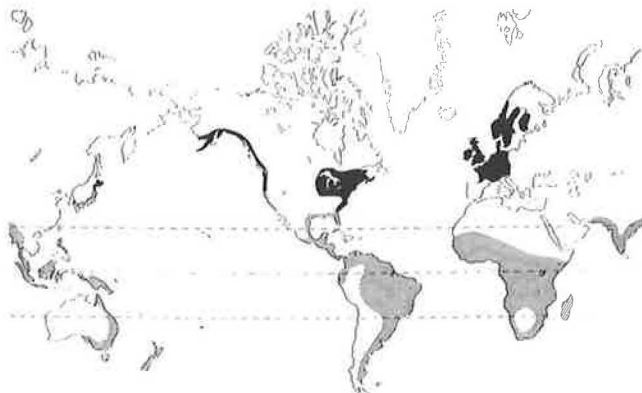


Figure 2. Conservative estimate of corrosion environment in the United States.

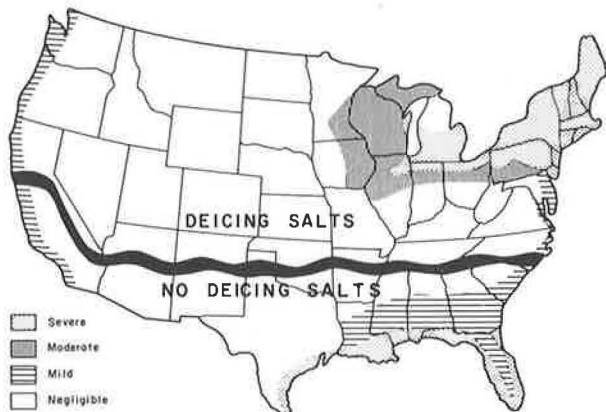
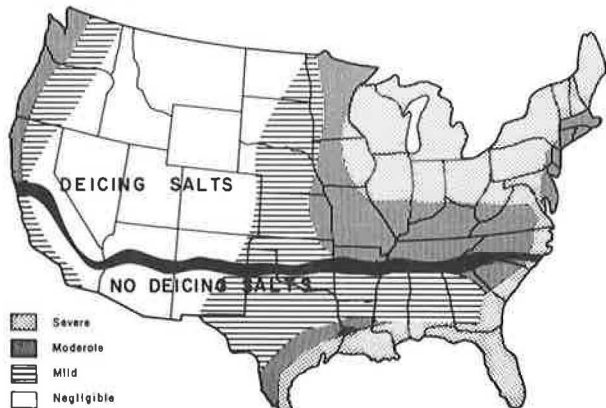


Figure 3. Generous estimate of corrosion environment in the United States.



CORROSIVITY OF THE ENVIRONMENT

If this is the extent of the corrosive environment, then what determines the corrosivity of the environment?

The effects of the atmosphere and its pollutants on the corrosion rate are substantial. The atmosphere is both the source and the principal moderator of the corrosion process. It supplies two of the three constituents—water and oxygen—required before corrosion can occur (metal is the third constituent). [Corrosion mechanisms affecting vehicles have been summarized elsewhere (5, 6, 7)].

Fromm's studies (8) in Canada indicated that corrosion rates were four times higher in humid air-polluted environments than in dry nonpolluted climates. His data also showed that deicing salts and air pollution contributed about equally to corrosion damage in the Toronto area. The most severe conditions studied (Toronto and Halifax) are probably more or less typical of the northeastern United States and those states bordering the southeastern shores of the Great Lakes. These severely corrosive areas can be characterized as having high air pollution, high relative humidities, and high uses of deicing salts.

Air pollutants are absorbed into particulates that adhere to surfaces and form point sources of corrosion. Most of the common air pollutants, as well as the deicing salts, are anhydrous and act as moisture reservoirs, allowing corrosive processes on even apparently dry surfaces. Dissolved air pollutants and deicing salts form electrolytes that lower solution freezing points and increase electrochemical activity. Both processes increase corrosion rates. As a paper published by the National Association of Corrosion Engineers (9) states,

Contaminants from the air occur in such minute quantities that their effect would seem trivial; however, the corrosive rate is at its maximum in dilute acid solutions. Therefore, small quantities of contaminants are the most harmful.

Relative humidity, the presence of dissolved oxygen, and the temperature are some of the principal factors affecting corrosion processes. The effects of these factors have been described by Chance (5):

... it is not necessary to have 100 percent relative humidity to produce condensation on metal surfaces. Hygroscopic impurities in the atmosphere or on the metal surface will cause condensation at much lower values. For certain metals, there is such a thing as a critical relative humidity above which corrosion will proceed at an accelerated rate. For such metals as iron, copper, nickel, and zinc, the critical relative humidity generally falls between 50 and 70 percent. As an example, the corrosion behavior of iron in a 0.01 percent SO_2 atmosphere at various relative humidities is shown in Figure 8 [Figure 4 (10, p. 147)]. Note the dramatic increase in corrosion rate beginning at 60 percent relative humidity.

Dissolved oxygen in solutions has a very definite effect on corrosion rates. In nearly neutral solutions, as in many natural waters, the concentration of dissolved oxygen is the controlling factor that determines corrosion rates. This fact is demonstrated in Figure 7 [Figure 5 (10, p. 81)], which shows the effect of dissolved oxygen concentration on the corrosion of mild steel in slowly moving water containing 165 ppm CaCl_2 .

An old axiom in reaction kinetics states that reaction rates increase by a factor of two for every 10°C rise in temperature, and it is also generally true that corrosion rates increase with temperature. However, there are other considerations. For example, the dependence of the solubility of oxygen in water on temperature is shown in Figure 6 [(11)]; as the temperature rises, the solubility of oxygen decreases. Diffusion rates increase somewhat to compensate for the loss of oxygen, but the effect on corrosion rates could still be significant.

Our affluent society and the low energy costs of the past have had a direct influence on vehicle corrosion,

Figure 4. Corrosion of iron in air containing 0.01 percent SO_2 : effect of critical relative humidity.

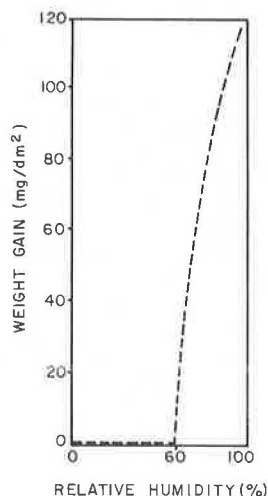


Figure 5. Effect of oxygen concentration on corrosion of mild steel.

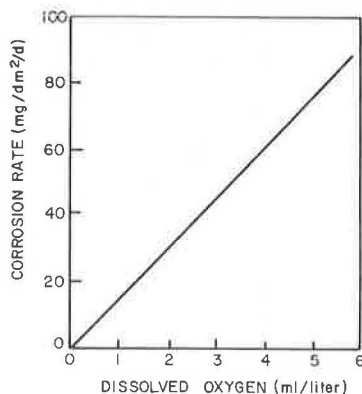
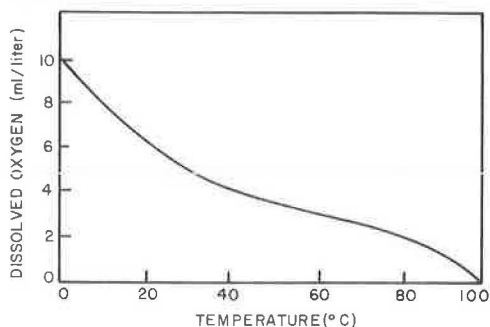


Figure 6. Dependence of solubility of oxygen in water on temperature.

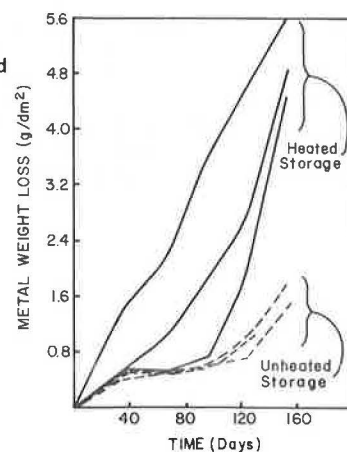


in the form of enclosed and heated garages. The effect on the corrosion rate, as shown in Figure 7 (12), is substantial. The lower lines represent corrosion rates in open unheated storage. The upper lines represent corrosion rates in closed heated garages.

AUTOMOBILE MANUFACTURING (CHANGING TECHNOLOGY)

The question that has generally been either avoided or ignored in assessing vehicle corrosion in economic studies is this: If a product is modified and in the process becomes less able to withstand the environment, is it valid to assess the loss against the environment, or more particularly against one particular aspect of the environment?

Figure 7. Corrosion rates of crevice specimens attached to vehicles in heated and unheated garages.



Before the mid-1950s, automotive corrosion was apparently a relatively isolated problem. However, in 1955 the appearance of automobiles changed. Sculptured styling became common and, with it there was a reduction in sheet-metal thickness. Accompanying these changes in body geometry were the beginnings of modification in support structures. Cross-member construction was replaced by unibody construction characterized by relatively light-gauge, formed, sheet-steel members. This reduction in sheet-metal thickness, in both body and support members, is probably the basic reason for the increase in early corrosion perforation that began in American-produced vehicles in the mid-1950s. A subsidiary and initially equivalent probable cause was the lack of anticorrosion measures in both the design and manufacture of vehicles.

The lack of anticorrosion measures can be illustrated by considering the amount of galvanized steel used by the automotive industry. In 1955, galvanized steel was not in common use; in that year, the industry used 25 Gg (27 000 tons). This is equivalent to an average of 2.7 kg/vehicle (6 lb/vehicle) for trucks, buses, and automobiles. Today, approximately 73 kg (160 lb) of galvanized steel are used in the construction of the average automobile. Automotive manufacturing practices before 1970 are summarized elsewhere (5, 13).

Figure 8 is a speculative distribution based on inferences from the documents in the study file. It is an attempt to show the distribution of times at which American automobiles of a given model year would have visible perforation corrosion in a severely corrosive environment. For instance, the extreme left end of the chart indicates that corrosion in 1951 models would follow an approximately normal distribution with corrosion first appearing in some 1951 model automobiles when they were about 1.5 years old.

The average 1951 automobile (according to this speculative distribution) would begin to show perforation corrosion at about 3 years, and some would not perforate until they were 4.5 years old. To the extreme right, the schematic shows a predicted relatively flat distribution. The 1986 models of American automobiles are expected to begin to show corrosion perforation after 4 years of use, and the last of this model year will perforate after 8 years of use.

The dip that begins with the 1955 models and develops into a fairly consistent, moderately skewed distribution represents the adoption of lighter gauge steel and unibody construction by automotive manufacturers, before the development of adequate corrosion-resistant materials. The slow upswing before the mid-1960s is based more on the adoption of good design practices for

Figure 8. Time to corrosion perforation of American automobiles.

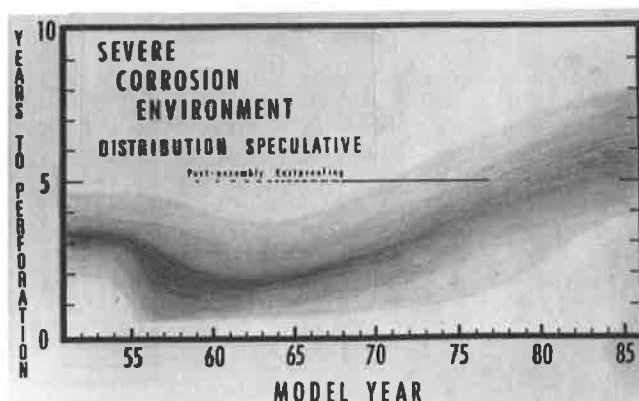
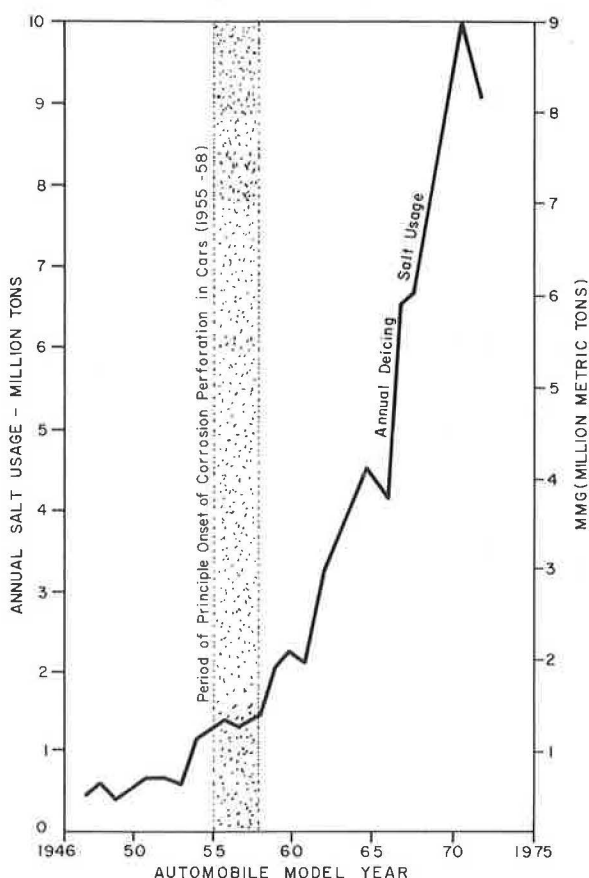


Figure 9. Use of deicing salt in the United States.



reducing corrosion than on the successful incorporation of new materials.

DEICING SALTS

Figure 9 (14) indicates why the argument that deicing salts are responsible for the increase in corrosion just depicted is questionable. Salt use was fairly constant during the period from 1947 to 1953, at 450 to 635 Gg/year (500 000 to 700 000 tons/year). Between 1953 and 1955, salt use roughly doubled, but it then stayed relatively constant until 1958. This doubling has been used as the justification for implicating deicing salt as the cause of the high incidence of corrosion occurring in

1955 to 1958 model automobiles (shown by the vertical bar).

Galvanized steel is only one of many ways in which an automobile manufacturer improves the corrosion resistance of the product at present. In 1955, the average vehicle (including trucks and buses) contained about 2.7 kg (6 lb) of this material. By 1965, the average automobile contained 46 kg (101 lb), and today it contains 73 kg (160 lb).

If salts were the cause of the sudden increase in corrosion between 1955 and 1958, then why did not automobiles literally fall apart in the years following? If we use 1953 as the base year, salt use had increased sevenfold by 1965. Yet there was no corresponding increase in corrosion damage. Were the changes in corrosion protection so extensive between 1958 and 1965 that this apparently highly corrosive element had been neutralized, or was there some other reason?

This period was not typified by major advances in anticorrosion technology, but was a period of trial and error with most of the emphasis being placed on improved anticorrosion design practice. It is unrealistic to assume that the efforts of the automotive industry in this period—1958 to 1965—could have counteracted the sevenfold increase—1953 to 1965—in deicing salt use, if salts were in fact the principal cause of corrosion.

ANSWER TO QUESTION ONE

Let us return to the original question: Is the opinion that deicing salts are the principal cause of vehicle corrosion legitimate?

Fromm showed that deicing salts and air pollution contribute about equally to corrosion damage. The change in automobile manufacturing procedures beginning in 1955 is well documented. The arguments that fixed the blame for the increase in corrosion between 1953 and 1956 on deicing salt should also be applicable to the subsequent multifold increase in deicing salt use in the following years, and the impact on vehicles should have been significantly greater than it was.

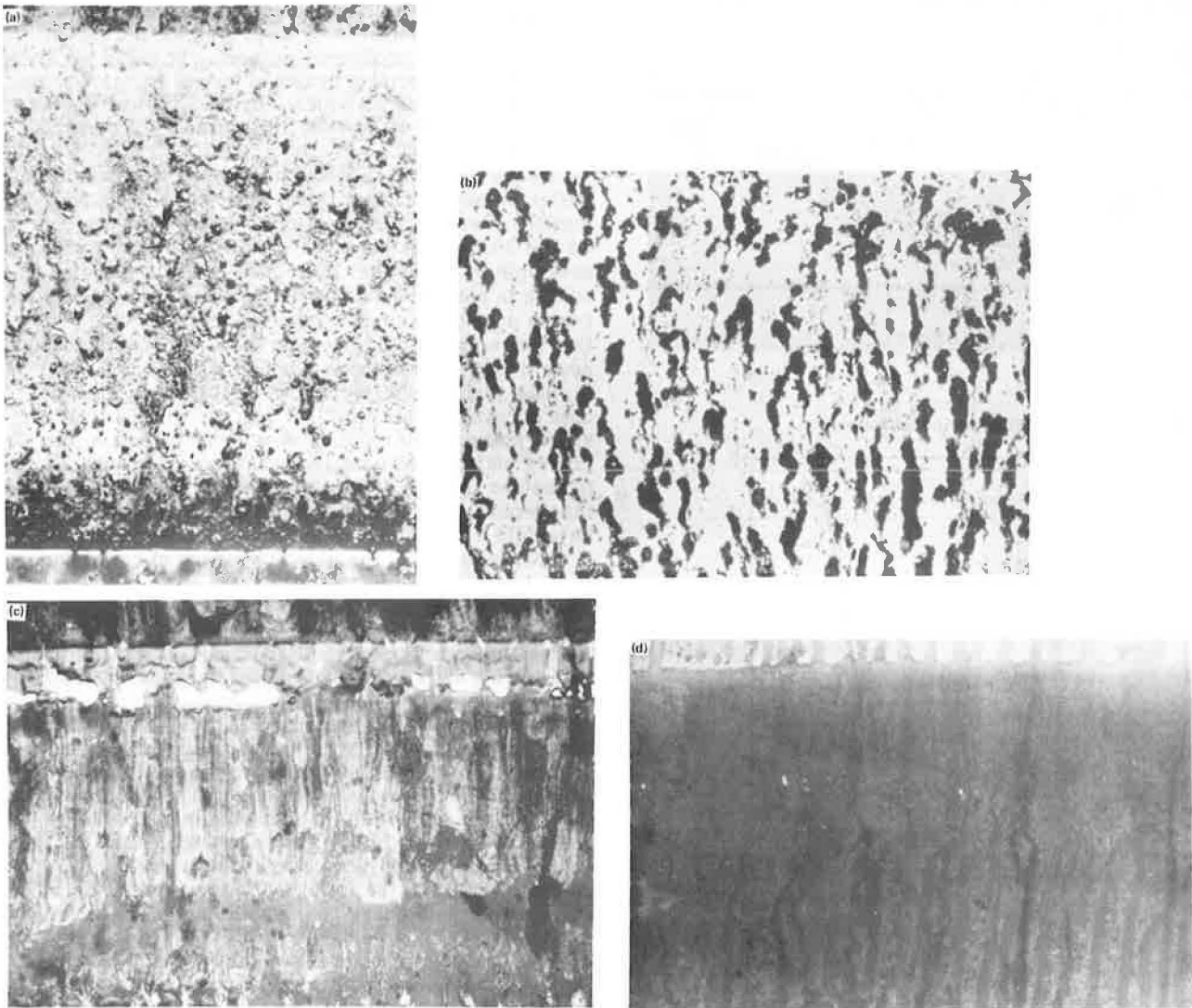
Perhaps the best argument against totally blaming deicing salts comes from a review of areas in which deicing salts are not used, such as the Gulf Coast, that have equally severe corrosive environments. In semi-tropical and tropical climates, the upper portions of the automobile body are more subject to attack than are the lower portions; in areas in which deicing salts are used, the lower portions are attacked more than the upper (7). If deicing salts were the principal cause of the increased corrosion between 1953 and 1956, then vehicles on the Gulf Coast should have fared better, but they did not.

Thus, the answer of the first question is that deicing salts undoubtedly contribute to vehicle corrosion. But the principal cause of premature corrosion perforation is probably attributable to the method of manufacture adopted by the American automotive industry in the period beginning in 1955.

The improvement in corrosion resistance of the automobile that has occurred since 1958 is also attributable to the automotive industry and its suppliers. Figure 10 shows four samples that were subjected to 250 h in a salt fog chamber (15).

Figure 10a shows the kind of damage incurred by the rust-susceptible areas of an automobile having the average protection available before the early 1960s. During the late 1950s and early 1960s, galvanized steel began to be substituted in those portions of the body to which it could be adapted. Its use increased until the

Figure 10. Samples of steel after 240 h in salt spray chamber: (a) unprotected cold-rolled, (b) galvanized, (c) zinc-rich primed, and (d) coil coated.



late 1960s and has held fairly constant since then. Figure 10b shows the damage incurred by this type of material.

Zinc-rich primers were first sprayed on some interior components, such as the interiors of doors, at about the same time that galvanized steel began to be incorporated into the underbody members, and by the late 1960s, dip tanks using electrocoating procedures were installed, and the consistency of application of corrosion-resistant coatings improved. Figure 10c shows the damage incurred by this type of material.

The next major step in improving corrosion resistance was introduced in 1975. The process, referred to as coil coating, is being incorporated on an increased scale in 1977 models. Figure 10d shows the damage incurred by these materials. The improved corrosion resistance shown in Figure 5 for the late-1970s and 1980s is based on the eventual adoption of this type of product or its equivalent.

ANSWERS TO QUESTION TWO

Let us now return to the second half of the original

question: How much damage can be assessed against deicing chlorides?

Proposition One

It can be argued (in brief) that the maximum cost of damage assessed cannot be greater than the capitalized investment paid out to protect against the damage.

One company has had available a process with a 5-year guarantee against perforation corrosion since the mid-1960s. The cost of this process in the 1960s was approximately \$100, and at present, it is about \$150.

Ackerman and others have shown that vehicle depreciation follows an approximately exponential decay curve (16). By the end of the fifth year of the lifetime of an automobile, its resale value is approaching the low end of its economic value. It is doubtful that corrosion perforation after that time could decrease its resale value very much. Even if all of the increased depreciation in the period following the fifth year were assigned to the corrosive environment, the maximum amount assignable to deicing salts could not exceed 50 percent of the increased depreciation because no more

TRANSPORTATION RESEARCH BOARD
National Research Council
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Transportation Research Record 589

page ii
Under Library of Congress Cataloging in Publication
Data, change card number from **76-456671** to
76-45671

Transportation Research Record 617

page 7, column 1, line 3 after Abstract
Change **effect** to **affect**
page 71, column 2, line 39
Insert **from** after **eliminating**
page 71, column 2, line 41
Change : after **1970** to ,

Transportation Research Record 630

page iii, line 5
page 7, title of Abridgment
Change **County** to **Countywide**
page 7, authorship of Abridgment
Change **Florida** to **Detroit**

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page 39, column 2, line 7
Change **\$1.32 to \$2.46/liter to 9 cents to 17 cents/L**

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page 107, column 1, last line of Abstract
Change **load factor** to **average individual delay**

✓ **Transportation Research Record 651**

page 39, column 2, lines 50-51
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page 42, column 2, line 12
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mittee on Coatings, Signing, and Marking Materials**

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page 30, column 2, lines 24-25
Change **Committee on Transportation Programming,
Planning, and Evaluation to Committee on Bus
Transit Systems**

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page iii, third paper listed
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Discussions
Anthony James Catanese 15
Anthony R. Tomazinis 15

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page iii, line 18
Change **Francis X. McKelvey and William C. Taylor**
to **Francis X. McKelvey, William C. Taylor, and
Kunwar Rajendra**
page iii, line 26
Change **Robert E. Paaswell to Robert E. Paaswell,
J. Falcocchio, R. Knighton, D. Hartgen, D. Teixeira,
R. Stevens, J. Burkhardt, and A. Lago**

page 30, authors of Abridgment

Add **Kunwar Rajendra, Planning Department, City
of Lansing, Michigan**

page 38, authors of paper

Add

**J. Falcocchio, Department of Transportation Engi-
neering, Polytechnic Institute of New York**

**R. Knighton and D. Hartgen, Planning and Research
Bureau, New York State Department of Transpor-
tation**

D. Teixeira and R. Stevens, A.R.I., Inc., Boston

**J. Burkhardt and A. Lago, Ecosometrics, Inc.,
Bethesda, Maryland**

Transportation Research Record 664

page ii

Change Library of Congress data given to
**Library of Congress Cataloging in Publication Data:
Bridge Engineering Conference, St. Louis, 1978
Bridge engineering.
(Transportation research record; 664-665)**

**1. Bridges—Congresses. I. National Research
Council. Transportation Research Board. II. Title.
III. Series.**

**TE7.H5 no. 664-665 [TG5] 380.5'08s [624.2]
78-71939**

ISBN 0-309-02696-2 (v. 1)

ISBN 0-309-02697-0 (v. 2)

Transportation Research Record 665

page ii

Change Library of Congress data given to
**Library of Congress Cataloging in Publication Data:
Bridge Engineering Conference, St. Louis, 1978
Bridge engineering.
(Transportation research record; 664-665)**

**1. Bridges—Congresses. I. National Research
Council. Transportation Research Board. II. Title.
III. Series.**

**TE7.H5 no. 664-665 [TG5] 380.5'08s [624.2]
78-71939**

ISBN 0-309-02696-2 (v. 1)

ISBN 0-309-02697-0 (v. 2)

NCHRP Report 188

page 39, first figure

Add caption: **Figure A-9. Fillet-weld end details
of specimen.**

NCHRP Synthesis of Highway Practice 42

page 65, Equation A-1

Change **(+ sin ϕ)** to **(1 + sin ϕ)**

page 67, footnote to table

Change **N_{σ}^* to N_c^* and N_c to N_{σ}**

NCHRP Synthesis of Highway Practice 53

pages 47 and 48

Figure shown as B-3 is B-4; figure shown as B-4 is B-3.

than 50 percent of the increased corrosion damage can be assigned to deicing salts (17). The assessed portion of costs against deicing salts of a postconstruction corrosion-proofed vehicle, therefore, will have to be small.

Also, since consumers have not taken advantage of the available postconstruction rust-proofing process, the apparent costs of corrosion to them must be less than the additional costs of postconstruction protection and increased depreciation. Therefore, the costs assessed against deicing salts cannot be greater than the costs assignable to rust proofing a vehicle.

Proposition Two

The corrosion resistance of the average automobile is significantly better now than it was in 1955. So much so that one motor company is offering a 36-month warranty against perforation corrosion on all of its passenger automobile lines in Canada. On the basis of this warranty offering and the general improvement in technology, as shown by the metal coupons in Figure 10, it can be assumed that the average well-manufactured automobile today should be able to withstand at least 2 years in a severely corrosive area without perforating, and in the near future, 3 years.

The differences between this proposition and proposition one are these: (a) the depreciation assignable to corrosion would at present begin in the third year of the lifetime of the automobile and in the near future in the fourth year, and (b) there would be no charges assignable to postconstruction rust proofing.

SUMMARY

It is reasonable to assume that changes in manufacturing practices were more responsible than deicing salts for the high rust susceptibility of automobiles manufactured after 1955. However, in the last 20 years, the corrosion resistance of the average automobile has been improved substantially. And, if the manufacturers continue their present trend in adopting new corrosion technology, the automobile should continue to improve in corrosion resistance for some time to come. As the population of vehicles with improved corrosion resistance increases, the costs assignable to the corrosive environment, with or without deicing salts, will be reduced, eventually to the capitalized investment of manufacturer-installed corrosion protection.

In the spring of 1976, the cost to coil coat all the

nongalvanized body parts of an automobile [approximately 270 kg (600 lb) of sheet steel] would have been approximately \$35 dollars.

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Publication of this paper sponsored by Committee on Corrosion.

Preformed Elastomeric Joint Sealers for Bridges

George S. Kozlov and Bruce Cosaboom, Division of Research and Development, New Jersey Department of Transportation

A proven effective solution to the problem of sealing joints in bridge decks is described. The basis of the solution is the use of specially designed joint armor in combination with currently available, preformed elastomeric sealers. The approach is adequate for simple-span, composite, concrete, or steel structures having span lengths up to 52 m (170 ft). The special armored-joint system was field tested on three struc-

tures. Two of these were monitored both manually and with automatic instrumentation to determine the causes and range of magnitudes of bridge-end movements; they were also tested for leakage with dyes at periodic intervals over a 5-year time span. The third structure was used to conduct load tests on the joint armor and armor anchorage components. Application of the results led to the development of practical