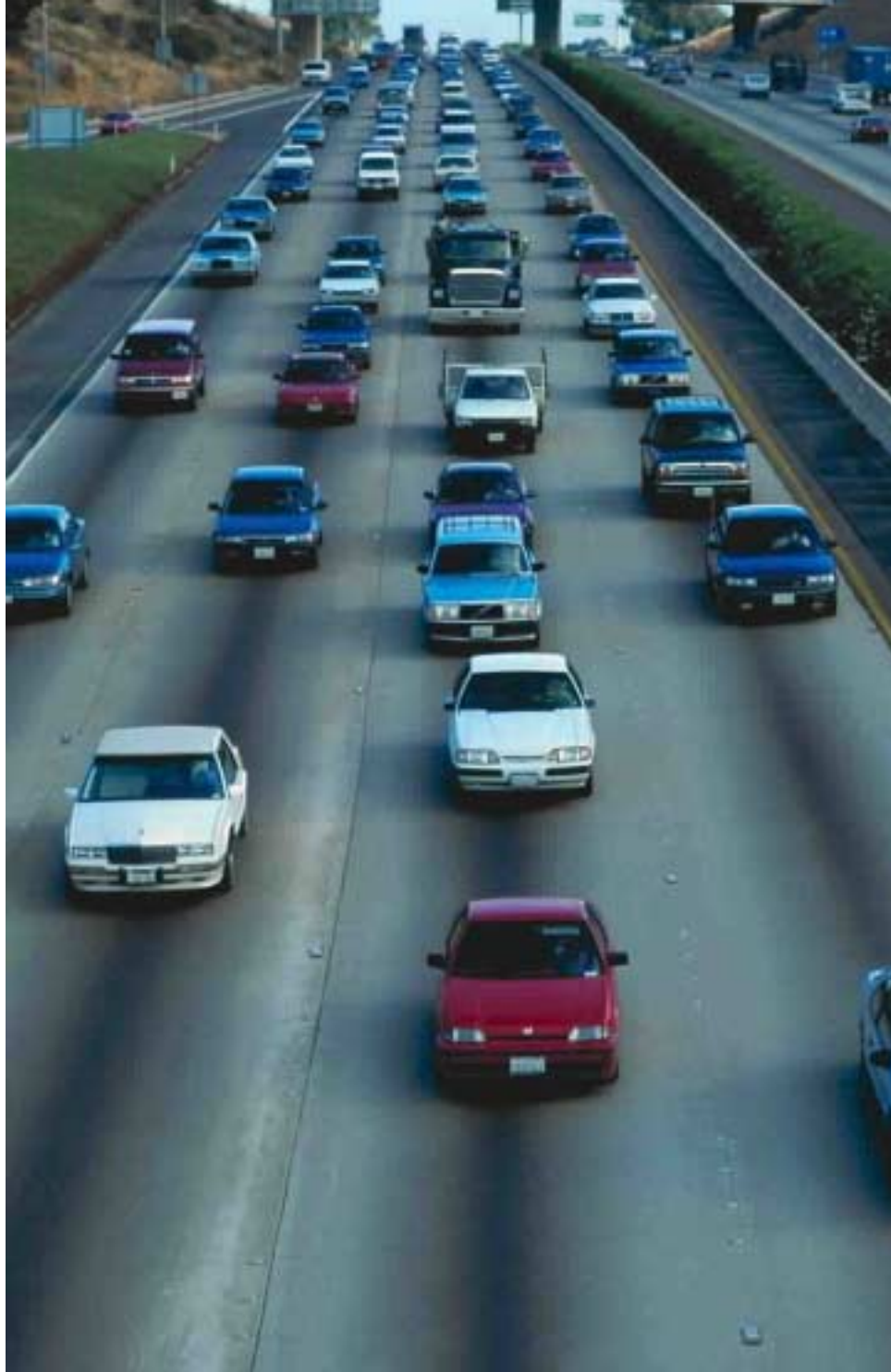


APPENDIX N
MOTOR VEHICLES





Well-maintained old-timer



Corroded window wiper



Commercial truck



Decorative coatings on recreational vehicles



Area of corrosion on a bus



Tailpipe



Corrosion at reflector



Corrosion under damaged coating



Corrosion under damaged coating

MOTOR VEHICLES

JOSHUA T. JOHNSON¹

SUMMARY AND ANALYSIS OF RESULTS

Corrosion Control and Prevention

The corrosion-related cost to American consumers with regard to automobiles is estimated to be approximately \$23.4 billion per year. This is divided up into three components: (1) increased manufacturing cost due to corrosion-resistant materials and engineering (\$2.5 billion), (2) repairs and maintenance necessitated by corrosion (\$6.5 billion), and (3) corrosion-related depreciation (\$14.4 billion).

American consumers, businesses, and government organizations own more than 200 million registered vehicles. Assuming a value of \$5,000 for each vehicle allows an estimate that Americans have more than \$1 trillion invested in their motor vehicles, making our automobiles one of the largest investments collectively among Americans.

Until the late 1950s, corrosion of motor vehicles was a concern limited to marine environments; however, with the increased use of deicing salts, vehicles in snowbelt areas started to corrode and fall apart within years of their initial purchase. In the late 1970s, automobile manufacturers started to increase the corrosion resistance of vehicles by using corrosion-resistant materials, employing better manufacturing processes, and designing more corrosion-resistant vehicles through anti-corrosion engineering knowledge. Because of the steps taken by manufacturers, today's automobiles have very little visible corrosion, and most vehicles survive structurally until a vehicle wears out mechanically. The annual cost of corrosion in this sector, however, is substantial and more can be done to reduce this cost.

Opportunities for Improvement and Barriers to Progress

Very few opportunities exist for combating general corrosion in motor vehicles since the majority of the steps that could be taken to increase corrosion resistance have already been implemented. Motor vehicles could be made more corrosion-resistant; however, the significant cost increases would probably not be worth the small incremental benefits. As long as automakers learn from the past and the improvements made in the past 25 years are not removed, motor vehicle bodies should remain corrosion-resistant.

The few areas for improvement are in individual systems in automobiles. Automobile manufacturers have been upgrading the materials used for fuel and brake systems as well as the corrosion resistance of the electrical systems in automobiles. Many of the failures of electrical or electronic components in these systems are due to corrosion. Since the corrosion damage to these components is typically not visible, very little public outcry exists to increase the corrosion resistance beyond the slow product upgrading by the manufacturers.

Recommendations and Implementation Strategy

The most important recommendation that can be made in the automotive sector is that automobile manufacturers should not forget what made today's corrosion-resistant vehicles. To that end, every new vehicle

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produced should be designed to minimize corrosion, be built in a high-quality manner, and be constructed with corrosion-resistant materials where appropriate.

Current trends may force automobile manufacturers to increase the level of corrosion resistance in the electrical system and other component systems in new automobiles. One of these trends involves increasing the length of warranties on new automobiles. A second related trend is that automobiles are becoming more complex and more expensive; therefore, consumers are demanding longer life from automobiles to offset this higher cost. Better consumer understanding of the cause of electrical and other system failures may increase the pace in which these corrosion control upgrades are made; however, the competitive nature of the automobile industry ensures that the balance between corrosion resistance and cost will probably be met.

Summary of Issues

Increase consciousness of corrosion costs and potential savings.	Total cost of corrosion in the automotive sector is \$23.4 billion.
Change perception that nothing can be done about corrosion.	Examine the cause of failure of electrical and other components. Convince the public that corrosion is still causing problems in automobiles.
Advance design practices for better corrosion management.	Increase the use of specialty metals in electrical systems and other components.
Change technical practices to realize corrosion cost-savings.	Continue to update technical practices based on new materials and design considerations.
Change policies and management practices to realize corrosion cost-savings.	Show management, through various studies, that small expenditures on corrosion can provide huge cost-benefits.
Advance life prediction models and performance assessment methods.	Assess the percentage of electronic component failures that are due to corrosion to determine the extent of the problem.
Advance technology (research, development, and implementation).	Use advanced alloys and materials from other industries for certain critical components.
Improve education and training for corrosion control.	Educate the public and technicians that not all corrosion on automobiles involves red rust.

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SECTOR DESCRIPTION

Background

Forty years ago, the streets and highways in the northern part of the United States were kept travelable by using abrasives and plowing to remove snow from the roads. Starting in the late 1950s, the use of sodium chloride and calcium chloride to help keep the roads clear became common in the snowbelt region of the United States. While the use of road deicing salts has allowed states and municipalities to keep roads and highways free of snow and ice and to make winter travel relatively safe, the use of deicing salts created a considerable problem for vehicle manufacturers and consumers. Before 1950, catastrophic corrosion of automobiles (i.e., corrosion damaging enough to end the life of the vehicle) was uncommon, particularly for those vehicles away from marine and coastal environments. By the 1970s, however, acid rain, the increased use of deicing salts, and thinner sheet metal in automobiles, which was used to reduce weight and increase fuel efficiency, had led to major body perforations within a few years of purchase. In the Battelle-NBS study, a significant part of the national cost of corrosion was assigned to the cost of premature replacement of personal and commercial motor vehicles.⁽¹⁻²⁾ Since the late 1970s, better designs, better materials, and better manufacturing practices have significantly increased the corrosion resistance of most motor vehicles.

As of 1995, there were more than 200 million registered vehicles on America's roads and highways.⁽³⁾ These 200 million registered vehicles included 134,981,000 passenger cars, 65,465,000 trucks, 670,000 buses, and 18,195,000 trailers of various types. If each of these vehicles were assumed to have an average value of \$5,000, the combined value of motor vehicles in the United States would be more than \$1 trillion. This value represents one of the largest personal capital investments in the United States; therefore, the design and actual service life of these vehicles have a major impact on both personal finances and the national economy.

Corrosion Modes

Corrosion in motor vehicles is present in several different forms. The most obvious form of corrosion for vehicles is general corrosion of the painted steel body panels (see figure 1). This general corrosion can result in perforations in the body and can reduce the resale value of a vehicle due to the cosmetic effects of red rust. General corrosion also affects the underside and frame of a vehicle, leading to possible floorboard perforation and weakening of the frame.



Figure 1. Example of general corrosion of painted steel automobile body panel.

Pitting corrosion occurs when chlorides and other chemical species are in contact with metal. This can cause a corrosion reaction on a localized scale, resulting in several small, but potentially deep, pits. Pitting corrosion produces small cavities that can cause leaks in the radiator and in the muffler and tail pipe.

Galvanic corrosion occurs between dissimilar metals where one of the metals is electrochemically more active and corrodes, while the second metal is protected by the corroding metal. Galvanic corrosion was a cosmetic concern when more metal was used for trim and decoration on vehicles than is used today. Galvanic corrosion can be reduced through careful design and must be considered because of the number of different materials used in a motor vehicle.

Crevice corrosion occurs when a fluid enters a tight space between two surfaces, such as between a washer and a steel beam. This fluid can concentrate in a narrow crevice, resulting in highly accelerated corrosion in the crevice area.

Corrosion Causes

Several factors lead to the various types of corrosion in motor vehicles, specifically the design process, the manufacturing process, and the operating conditions.

Design Process

Designers of motor vehicles make a multitude of choices that influence how susceptible a vehicle may be to corrosion. During the design of the vehicle, engineers should strive to reduce dissimilar metal contacts, crevices, stresses, poor drainage, and locations where salt and dirt can build up. An example of a faulty design that allows road dirt and corrosion products to build up is shown in figure 2. The choice of materials in the design will also dramatically affect the corrosion performance of vehicles. The use of corrosion-resistant metals, coated steels, and polymers, as well as the avoidance of dissimilar metal contacts, will allow vehicles to operate for many years without significant corrosion problems. One of the most critical considerations in the design process that affects corrosion performance involves the choice of primers, paints, and sealers. The use of corrosion-resistant primers over the entire body and special chip-resistant coatings for the wheel well and the lower surface of the car have become standard in the industry in order to reduce the initiation of corrosion.



Figure 2. Photograph of poultrice build-up of road contaminants in the wheel area of a bus.

Manufacturing Process

Several elements of corrosion protection added in the design phase can be rendered useless if the quality of the manufacturing is low. A few elements of the manufacturing process are of specific importance. First, the quality of the welding will affect the presence of crevices where corrosion process can occur. Secondly, the surface pretreatment must be done properly to ensure good adhesion of the primer and the final coating. Finally, several of the special coatings, such as the chip-resistant coatings and the body sealants, are applied by hand and the quality of this work is highly dependent on the skill and attention of the applicator.

Operating Conditions

The corrosivity of the local environment will strongly affect the corrosion performance of the vehicle.⁽⁴⁻⁵⁾ Figure 3 shows a map of the United States, pointing out the locations where corrosive environments are possible due to acid rain, deicing salts, or marine environments. In these corrosive environments, personal driving habits and diligent maintenance of the vehicle, such as regular washing and replacement of fluids, can have a significant effect on the reduction of corrosion.

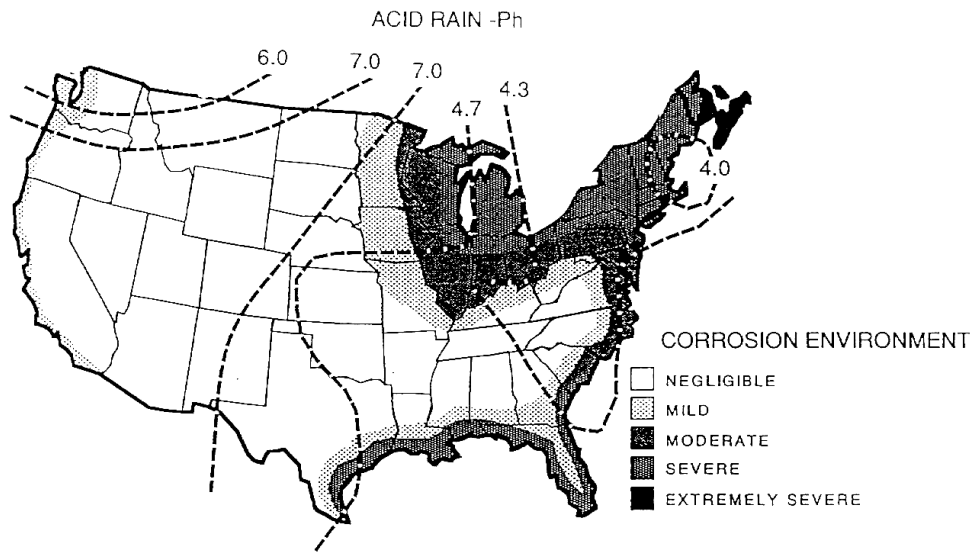


Figure 3. Level of corrosive environment and pH level due to acid rain in the United States.⁽⁴⁾

AREAS OF MAJOR CORROSION IMPACT

The primary cost of corrosion in the automotive sector can be broken down into three major elements:

1. The cost of corrosion engineering and materials added into the cost of new automobiles. These costs include corrosion-resistant materials such as galvanized steel and aluminum, coatings beyond what is needed for appearance, and testing of materials and designs.
2. The cost of repairs and maintenance due to corrosion. This includes the cost of repairing or replacing components of the car, such as radiators, exhaust systems, and electrical/electronic components, due to non-accident-related failures. This cost also includes the periodic

replacement of cooling fluids, which need to be changed due to the degradation of corrosion inhibitors rather than a loss of coolant function.

3. The detrimental cosmetic effects of corrosion causes reduced resale values, which often leads to premature replacement of the automobile. Corrosion damage is not likely to necessitate the replacement of a vehicle; however, the reduced value of a vehicle due to corrosion will cause major repairs such as engine or transmission replacement, which often costs more than the car's value. This leads to scrapping of automobiles that might have been worth repairing if corrosion had not occurred.

An additional cost element that was not calculated for this study is the cost due to reduced safety in automobiles due to corrosion. Deterioration of various systems in automobiles may lead to accidents or cause certain systems to be inoperable, which could lead to accidents. An example is corrosion of the electrical components of an anti-lock braking system (ABS), which can cause the system to become inoperable. If the driver was counting on the ABS system to help stop him or her on a wet road and the system was inoperable, an accident resulting in extensive damage and possible injury could result. Accidents that were caused by or influenced by corrosion have resulted in numerous injuries and many lawsuits. The resulting cost of this reduction in safety is probably an extremely high amount; however, it is nearly impossible to estimate. While an estimate was not prepared, the costs due to these incidents should be considered when justifying further corrosion resistance in automobiles.

In this sector discussion, the cost for each of the three elements above were determined in order to estimate the total cost of corrosion in the automotive sector. Element one was calculated by working with representatives from the major U.S. automakers to determine the amount spent on an average automobile for corrosion prevention. This average cost per vehicle was multiplied by the number of new motor vehicles sold annually in the United States in order to estimate the total cost.

Element two costs were determined by gathering data on the annual expenditures for replacement radiators, exhaust components, electrical/electronic components, and coolant. Estimates of what percentage of these repairs is due to corrosion were made so that the total cost of these repairs that are due to corrosion can be made.

Element three costs were determined by examining data on the value of used cars of the same make and model in different areas of the country. By comparing values in the Midwest, the Atlantic and Gulf Coasts, and the Southwest desert area, an estimate of the total depreciation due to corrosion was obtained.

Previous Cost Estimates

Several estimates of the cost of the corrosion protection built into new vehicles have been performed over the past 25 years. The Battelle-NBS study⁽¹⁻²⁾ reported that rust-resistant metals, special paint, protective coatings, and other corrosion control features added approximately \$100 to the cost of a new automobile in 1975. This \$100 figure represented approximately 2 percent of the cost of a new vehicle in 1975.

Special Report 235 from the Transportation Research Board (TRB), *Comparing Salt and Calcium Magnesium Acetate* (published in 1991) estimated the cost of corrosion protection built into each new automobile to protect automobiles from road salts.⁽⁶⁾ Cost estimates per new vehicle were calculated at \$250 to \$800, based on the use of precoated steels and plastics, electrodeposited primers, splash shields, body and electrical sealers, special metals and coatings for the engine, ignition components and fuel systems, and special bumper supports and trim metals. An average value of \$500 per vehicle represents approximately 3.5 percent of the average cost of a new vehicle in 1991.

This \$500 figure can be multiplied by the number of new vehicles sold in 1991 in the United States to estimate the national cost of corrosion protection in automobiles. In 1991, approximately 8.8 million motor vehicles were

sold; 5.4 million of those were cars. Thus, the total cost of corrosion, based on data from 1991, was estimated at \$4.4 billion per year (\$500 x 8.8 million).

Menzies (1991) examined the average depreciation in different regions of the country to estimate the average cost of corrosion due to road salts.⁽⁷⁾ He compared automobiles in the North Atlantic region of the country to automobiles in the Southern Atlantic and Gulf Coast regions. This comparison was designed to ignore corrosion due to marine environments and only investigate corrosion due to road salts. By comparing the values of the same 12 vehicles, he came to an estimate of \$17 of corrosion damage per year for each vehicle in the snow belt region. Approximately 60 percent of the 200 million vehicles in the United States are in the “snow belt”. By using Menzies’ estimate, the cost of corrosion damage due to road salts was estimated at \$2.04 billion per year (60 percent x 200 million x \$17).

The TRB estimated that about half of the corrosion damage was due to road salts, while the other half was attributed to the effects of acid rain, marine environments, and other sources. This damage can be assumed to affect every vehicle in the country. If the average damage for non-road salt corrosion is the same as road salt corrosion, the estimate of \$17 per vehicle per year can be used. This leads to an estimate of \$3.4 billion per year.

Current Cost Estimates

Design and Manufacture

A major automobile manufacturer was approached for this project to calculate the cost of corrosion protection for an average vehicle. This cost estimate was made by identifying changes made to automobiles where corrosion was the primary factor for the change that caused a cost increase. A total of \$150 per vehicle was calculated with the largest portion of the cost being the cost of replacing plain steel with two-sided galvanized steel for all major inner and outer body panels and structural members. During the calculation, it was noted that several changes had been made to vehicles that have resulted in increased corrosion resistance; however, these changes were made primarily for other reasons, such as marketing, design, or performance. These costs were not included in the \$150 estimate.

This \$150 estimate is much lower than the \$500 estimate made during the 1991 TRB report. There are several reasons for this discrepancy. In 1991, automakers were still in the process of switching over to two-sided galvanized steel. The switch to two-sided galvanized steel was very costly because almost all aspects of the manufacturing were affected. In addition, the steel manufacturers charged a much higher price for two-sided galvanized steel at this time to cover the cost of modifying their facilities to manufacture the galvanized steel. Currently, since all of the changes have been made in the automobile factories and steel mills, the cost of using galvanized steel has dropped dramatically. Another change since 1991 is that less supplemental coating is needed to improve corrosion resistance in trouble areas. Because of improved design, fewer areas need these supplemental coatings. Improved design has also allowed manufacturers to use thinner (and lower cost) galvanizing than was used 10 years ago. Other changes, such as the use of plastic fuel tanks instead of galvanized steel, have also produced cost-savings over the past 10 years.

It is interesting to note that not only has the actual cost of corrosion protection fallen in the past 10 years, the cost of corrosion protection as a percentage of the price of a new vehicle has fallen dramatically as well. The \$150 found in this study is approximately 0.7 percent of the average price of a new automobile. The Battelle-NBS study put the cost of corrosion protection at about 2 percent of the total cost, while the 1991 TRB study found that the cost of corrosion protection was about 3.5 percent of the cost of a vehicle. Thus, the cost of corrosion protection as a function of automobile cost is the lowest it has been in more than 25 years. The two main reasons for this reduction are: (1) the price and complexity of vehicles have increased dramatically over the past decades, and (2) designers who now pay much more attention to avoiding corrosion problems and using intelligent designs dramatically reduces the need for extra coatings and other corrosion prevention additions. The end result of these changes is that

today's vehicles are extremely corrosion-resistant and the cost of this protection is minimal as a percentage of the cost of a vehicle.

To evaluate the total cost of corrosion due to increased corrosion protection in automobiles, the number of new vehicles sold in 1999 can be multiplied by the \$150 figure. In 1999, approximately 16.9 million motor vehicles were sold. The cost of corrosion based on the 1999 data is then \$2.5 billion per year ($\150×16.9 million).

Repair and Maintenance

Estimates from the American Automobile Manufacturers Association⁽³⁾ indicate that approximately 17.5 million exhaust systems are replaced each year. Of these exhaust systems, it was estimated that 80 percent of the repairs (14 million exhaust systems) are the result of corrosion. The remaining 20 percent are replaced because of accidents or other physical impact damage. Estimates on the average cost of an exhaust system repair were obtained from several establishments that perform exhaust services. While the price of an exhaust repair can be extremely high, particularly on the more expensive cars, an estimate of \$150 for the average exhaust repair/replacement was assumed. Multiplying this average cost by the number of repairs yields an annual cost of \$2.1 billion (80 percent \times 17.5 million \times \$150) due to the repair or replacement of corrosion-damaged exhaust systems.

Furthermore, estimates from the American Automobile Manufacturers Association⁽³⁾ indicated that approximately 4 million radiators are replaced each year. Of these radiators, it is estimated that 50 percent, or 2 million, of the radiators are replaced due to corrosion. The other 50 percent are replaced due to front-end collisions or other damage. Estimates on the average cost of radiator replacement were obtained from several establishments, where it was found that the cost of radiator replacement could vary greatly, depending on the type of motor vehicle. An average cost of \$300 per radiator was assumed. Multiplying this average by the number of repairs and replacements yields an annual cost of \$600 million (50 percent \times 4 million \times \$300).

Another aspect of corrosion repair and maintenance is the replacement of engine coolant. Manufacturers suggest that automotive coolant be replaced every 2 years, not because the coolant loses its effectiveness over time, but because the corrosion inhibitors added to the coolant lose their effectiveness over time, rendering the coolant corrosive. Taking into account that many people never change their coolant in their vehicle, or change it less often than the recommended time intervals, it was estimated that, on average, the coolant is changed every 4 years. Based on this estimate, it follows that 50 million of the 200 million vehicles will have their coolant changed every year. The cost of changing coolant is mostly a function of who performs the maintenance. Coolant flushes and fills cost approximately \$40 when they are performed by a garage, while a "do-it-yourselfer" could complete the job for approximately \$10. The average cost of coolant maintenance is then estimated at about \$25 for each change. Multiplying the \$25 cost by the 50 million cars serviced each year, an annual cost of \$1.25 billion was estimated as the cost of corrosion due to coolant replacement.

A final aspect of repair and maintenance costs due to corrosion is in the area of corrosion damage to electrical components and electronics in an automobile. According to the Freedomia Group, the average automobile manufactured in 1997 contained \$1,796 worth of electronics.⁽⁸⁾ This amount is expected to grow to more than \$2,400 worth of electronics per car by the year 2002. When older vehicles were considered, the average vehicle contained \$1,406 worth of electronics in 1997. When multiplied by the 200 million vehicles in the country, it is estimated that \$281 billion worth of electronics are present in automobiles.

Experts in automotive electronics indicate that almost all electronic failures are caused by corrosion, not by damage to the vehicle from an accident. The value of these failures is difficult to measure because, in most instances, corrosion is not recognized as the cause of the failure. If corrosion attacks a control board in a modern vehicle, the contacts in the circuit board could easily be destroyed and the board would require replacement. These boards, however, are not examined for the cause of failure, as the corrosion causing the failure would be microscopic in nature. Instead, the board is just replaced and the vehicle owner has no idea that corrosion caused

the problem. Another difficulty in calculating the cost due to replacement of corroded electronics is that vehicle makers do not have information available on how many electrical components need to be replaced each year.

Due to the difficulties in obtaining accurate figures on the cost of corrosion of electrical devices in vehicles, an estimate was made by making a number of assumptions. The assumptions were discussed with experts in the automotive electronics field and were considered reasonable. The first assumption was that 50 percent of the failures in electronics were due to corrosion, with the remainder due to accidents and other damage to the electrical system. The second assumption made was that each vehicle, on average, undergoes \$25 of electrical repairs per year. While many vehicles will not have an electrical failure during their lives, some repairs, such as repairing the control board for a dashboard system, can cost hundreds of dollars. Combining these assumptions with the 200 million vehicles in the country leads to a cost of \$2.5 billion (50 percent x 200 million x \$25) due to corrosion of electronics.

In summary, the estimated cost of corrosion due to repair and maintenance of exhaust systems, radiators, engine coolant systems, and automotive electronics was calculated to be \$6.45 billion.

Cosmetic Damage

To assess the cost of corrosion due to cosmetic damage and depreciation, a study was conducted on the prices of used vehicles in different areas of the country, similar to the study performed by Menzies.⁽⁷⁾ In 1999, 10 different passenger vehicles were used for this study to obtain a good representation of the U.S. vehicle fleet. The 10 vehicles investigated were the Honda Accord four-door LX, Chevrolet S10 Blazer, Chevrolet Lumina, Ford Taurus LX, Ford Escort LX hatchback, Dodge Grand Caravan LE, Toyota Corolla four-door LE, Buick Park Avenue, Pontiac Grand Am two-door SE, and the Volkswagen Jetta GL. Price estimates were made assuming typical equipment levels and mileage of 19,093 km (10,000 mi) per year. The 1999 price information was found for the following six different cities in different geographic areas: Boston, MA; Bangor, ME; Chicago, IL; Miami, FL; Las Vegas, NV; and Phoenix, AZ. By comparing the vehicle values in the marine and snowbelt environments with those in desert environments, a cost difference between the two areas could be calculated. This value difference can be assumed to be due to corrosion. An estimate for the total cost due to depreciation can be done based on the number of vehicles. Automobile model years from 1990 to 1996 were studied for each of the 10 vehicles in each of the markets to obtain the average amount of depreciation due to corrosion.

The results of the study for each vehicle are presented in table 1, where some cost observations were made based on the data. The average depreciation due to corrosion in the high corrosion areas (i.e., Boston and Bangor), where both marine conditions were prevalent and road salt was used, was \$141.09 per vehicle per year. In the areas where either road salt (Chicago) or marine conditions (Miami) existed, the average cost of corrosion was \$109.11 per vehicle per year. Using these averages and the fact that 20 percent of the vehicles in the United States are in the high corrosion areas and 40 percent of the vehicles are in the lower corrosion areas, an annual cost of corrosion of \$14.4 billion was estimated [(40,000,000 vehicles x \$141.09 per vehicle) + (80,000,000 vehicles x \$109.11 per vehicle)]. This value appears to be much higher than the value that Menzies estimated. Menzies compared Northern Atlantic areas to Southern Atlantic areas to get an estimate of \$17 per car due to road salt. Comparing the high corrosion areas to the lower corrosion areas in this study would be the same as the comparison that Menzies made. This comparison yielded a difference of \$31.98, which, if present day values are considered, is very similar to the value that Menzies found.

Table 1. Results of used automobile value survey.

Honda Accord 4D LX

RESALE VALUE IN U.S. DOLLARS				PERCENTAGE CHANGE BETWEEN	
MODEL YEAR	BOSTON AND BANGOR	CHICAGO AND MIAMI	LAS VEGAS AND PHOENIX	BOSTON/BANGOR & LAS VEGAS/PHOENIX	CHICAGO/MIAMI & LAS VEGAS/PHOENIX
90	3,475	3,475	4,175	-16.77	-16.77
91	4,325	4,325	5,125	-15.61	-15.61
92	5,250	5,250	6,175	-14.98	-14.98
93	6,100	6,150	7,125	-14.39	-13.68
94	7,250	7,425	8,150	-11.04	-8.90
95	8,600	9,050	9,625	-10.65	-5.97
96	10,250	10,625	11,300	- 9.29	-5.97

Chevrolet S10 Blazer

RESALE VALUE IN U.S. DOLLARS				PERCENTAGE CHANGE BETWEEN	
MODEL YEAR	BOSTON AND BANGOR	CHICAGO AND MIAMI	LAS VEGAS AND PHOENIX	BOSTON/BANGOR & LAS VEGAS/PHOENIX	CHICAGO/MIAMI & LAS VEGAS/PHOENIX
90	2,625	2,625	3,200	-17.97	-17.97
91	4,195	4,195	4,970	-15.59	-15.59
92	5,190	5,190	6,065	-14.43	-14.43
93	6,185	6,235	7,160	-13.62	-12.92
94	7,160	7,335	7,985	-10.33	-8.14
95	10,970	11,495	12,195	-10.05	-5.74
96	12,445	12,845	13,520	-7.95	-4.99

Ford Taurus LX

RESALE VALUE IN U.S. DOLLARS				PERCENTAGE CHANGE BETWEEN	
MODEL YEAR	BOSTON AND BANGOR	CHICAGO AND MIAMI	LAS VEGAS AND PHOENIX	BOSTON/BANGOR & LAS VEGAS/PHOENIX	CHICAGO/MIAMI & LAS VEGAS/PHOENIX
90	2,170	2,170	2,620	-17.18	-17.18
91	2,770	2,770	3,345	-17.19	-17.19
92	3,395	3,395	4,095	-17.09	-17.09
93	4,195	4,245	4,945	-15.17	-14.16
94	5,215	5,365	5,890	-11.46	-8.91
95	6,295	6,545	7,120	-11.59	-8.08
96	7,395	7,695	7,995	-7.50	-3.75

Table 1. Results of used automobile value survey (continued).

Ford Escort LX

RESALE VALUE IN U.S. DOLLARS				PERCENTAGE CHANGE BETWEEN	
MODEL YEAR	BOSTON AND BANGOR	CHICAGO AND MIAMI	LAS VEGAS AND PHOENIX	BOSTON/BANGOR & LAS VEGAS/PHOENIX	CHICAGO/MIAMI & LAS VEGAS/PHOENIX
90	1,015	1,015	1,265	-19.76	-19.76
91	1,225	1,225	1,600	-23.44	-23.44
92	1,915	1,915	2,365	-19.03	-19.03
93	2,365	2,415	2,940	-19.56	-17.86
94	3,040	3,140	3,515	13.51	-10.67
95	3,825	4,010	4,285	-10.74	-6.42
96	4,710	4,960	5,135	-8.28	-3.41

Pontiac Grand Am 2D SE

RESALE VALUE IN U.S. DOLLARS				PERCENTAGE CHANGE BETWEEN	
MODEL YEAR	BOSTON AND BANGOR	CHICAGO AND MIAMI	LAS VEGAS AND PHOENIX	BOSTON/BANGOR & LAS VEGAS/PHOENIX	CHICAGO/MIAMI & LAS VEGAS/PHOENIX
90	2,060	2,060	2,485	-17.10	-17.10
91	2,545	2,545	3,095	-17.77	-17.77
92	2,595	2,595	3,170	-18.14	-18.14
93	3,265	3,315	3,915	-16.60	-15.33
94	3,820	3,945	4,395	-13.08	-10.24
95	5,130	5,355	5,680	-9.68	-5.72
96	6,280	6,555	6,805	-7.71	-3.67

Chevrolet Lumina

RESALE VALUE IN U.S. DOLLARS				PERCENTAGE CHANGE BETWEEN	
MODEL YEAR	BOSTON AND BANGOR	CHICAGO AND MIAMI	LAS VEGAS AND PHOENIX	BOSTON/BANGOR & LAS VEGAS/PHOENIX	CHICAGO/MIAMI & LAS VEGAS/PHOENIX
90	1,055	1,055	1,430	-26.22	-26.22
91	1,465	1,465	1,940	-24.48	-24.48
92	1,990	1,990	2,590	-23.17	-23.17
93	2,665	2,690	3,315	-19.61	-18.85
94	3,610	3,760	4,335	-16.72	-13.26
95	5,315	5,565	5,965	-10.90	-6.71
96	6,640	6,940	7,240	-8.29	-4.14

Table 1. Results of used automobile value survey (continued).

Dodge Grand Caravan LE

RESALE VALUE IN U.S. DOLLARS				PERCENTAGE CHANGE BETWEEN	
MODEL YEAR	BOSTON AND BANGOR	CHICAGO AND MIAMI	LAS VEGAS AND PHOENIX	BOSTON/BANGOR & LAS VEGAS/PHOENIX	CHICAGO/MIAMI & LAS VEGAS/PHOENIX
90	3,000	3,000	3,575	-16.08	-16.08
91	3,900	3,900	4,600	-15.22	-15.22
92	4,750	4,750	5,575	-14.8	-14.80
93	5,840	5,890	6,740	-13.35	-12.61
94	6,985	7,160	7,935	-11.97	-9.77
95	8,575	8,850	9,375	-8.53	-5.60
96	12,490	12,940	13,615	-8.26	-4.96

Toyota Corolla 4D LE

RESALE VALUE IN U.S. DOLLARS				PERCENTAGE CHANGE BETWEEN	
MODEL YEAR	BOSTON AND BANGOR	CHICAGO AND MIAMI	LAS VEGAS AND PHOENIX	BOSTON/BANGOR & LAS VEGAS/PHOENIX	CHICAGO/MIAMI & LAS VEGAS/PHOENIX
90	2,225	2,225	2,700	-17.59	-17.59
91	2,775	2,775	3,375	-17.78	-17.78
92	3,375	3,375	4,100	-17.68	-17.68
93	5,090	5,115	5,915	-13.95	-13.52
94	6,165	6,315	6,990	-11.80	-9.66
95	7,305	7,555	8,180	-10.70	-7.64
96	8,325	8,650	8,975	-7.24	-3.62

Volkswagen Jetta GL

RESALE VALUE IN U.S. DOLLARS				PERCENTAGE CHANGE BETWEEN	
MODEL YEAR	BOSTON AND BANGOR	CHICAGO AND MIAMI	LAS VEGAS AND PHOENIX	BOSTON/BANGOR & LAS VEGAS/PHOENIX	CHICAGO/MIAMI & LAS VEGAS/PHOENIX
90	1,950	1,950	2,450	-20.41	-20.41
91	2,375	2,375	2,950	-19.49	-19.49
92	3,200	3,200	3,800	-15.79	-15.79
93	4,175	4,200	4,925	-15.23	-14.72
94	5,150	5,325	5,850	-11.97	-8.97
95	7,020	7,420	7,870	-10.80	-5.72
96	8,120	8,420	8,770	-7.41	-3.99

Table 1. Results of used automobile value survey (continued).

Buick Park Avenue

MODEL YEAR	RESALE VALUE IN U.S. DOLLARS			PERCENTAGE CHANGE BETWEEN	
	BOSTON AND BANGOR	CHICAGO AND MIAMI	LAS VEGAS AND PHOENIX	BOSTON/BANGOR & LAS VEGAS/PHOENIX	CHICAGO/MIAMI & LAS VEGAS/PHOENIX
90	2,250	2,250	2,725	-17.43	-17.43
91	4,320	4,320	5,095	-15.21	-15.21
92	5,415	5,415	6,315	-14.25	-14.25
93	6,640	6,690	7,690	-13.65	-13.00
94	8,190	8,365	9,315	-12.08	-10.20
95	10,065	10,390	11,215	-10.25	-7.36
96	12,190	12,540	13,265	-8.10	-5.47

Summary

Totaling the costs for new vehicle corrosion protection (\$2.5 billion) plus corrosion-based repairs (\$6.45 billion) plus corrosion depreciation (\$14.4 billion) leads to an estimate of the cost of corrosion in automobiles of \$23.4 billion dollars per year. The Battelle-NBS study estimated the cost of corrosion in automobiles at \$6 billion, where \$1 billion is attributed to new automobiles and \$5 billion is attributed to used vehicles. The current estimate reflects how much more protection vehicle manufacturers are putting into new vehicles than was done 25 years ago. While the cost of corrosion in automobiles has increased in terms of straight dollar figures, there are approximately 55 percent more motor vehicles on the road today than in 1975. In addition, the average cost of a new vehicle is significantly higher today than in 1975 due to inflation and the increased complexity of motor vehicles. Considering these factors, the percentage of the gross domestic product (GDP) due to motor vehicle corrosion has decreased from 0.37 percent in 1975 to 0.27 percent in 1998.

CORROSION MANAGEMENT ASSESSMENT

The automobile industry, for the most part, has become one of the major success stories in corrosion engineering management over the past 25 years. While the total cost of corrosion is quite high, the decrease in cost, as a percentage of GDP, indicates the success of the industry in controlling both corrosion and the cost of preventing corrosion. The observation that the average cost of protecting a vehicle has fallen from \$500 to \$150, while providing a corrosion-resistant vehicle, attests to proper corrosion management practices. The product changes between 1975 and 2000 that led to increased corrosion protection are documented below. The most important change in the industry, however, is the integrated systems approach to total vehicle corrosion protection. Since 1975, the manufacturers have created a coordinated and balanced effort between advances in design, materials, and processing. As long as the lessons learned over the years are applied and a proper design is used with the appropriate materials and processing, vehicles should remain highly corrosion-resistant for years to come.

CHANGES FROM 1975 TO 2000

Extensive changes and advances have taken place since 1975 in several different areas in terms of increasing the corrosion performance of motor vehicles.⁽⁹⁾ These changes can be broken down into materials, processing, and

design. The end result of these advances are illustrated in figures 4 and 5. Figure 4 shows the change in the mean and median ages of automobiles from 1970 to 1994. The figure shows that there has been a consistently increasing average age of automobiles since 1970, with the mean age increasing from 5.6 years to 8.4 years and the median age increasing from 4.9 to 7.5 years. This trend is also shown in figure 5, which shows the percentage of vehicles remaining in service as a vehicle model year ages. Five model years are examined. They are 1966, 1971, 1976, 1981, and 1986. It can be clearly seen that the 1966 and 1971 automobiles showed the worst performance, while the 1976 and 1981 model years were improved, and the first 9 years of performance of the 1986 vehicles were better yet. The performance of the vehicles manufactured in the 1990s will probably be better yet due to the significant improvements that have been made over the past 25 years. The increased corrosion protection lifetime can also be demonstrated by table 2, which lists the length of the corrosion warranty for automobiles sold in the United States. The American Motor Company (AMC) offered the first 3-year warranty against perforation in the U.S. market in 1977. Today, almost every manufacturer offers at least a 5-year/100,000-mile warranty. One particular manufacturer (Audi) even offers a 12-year/unlimited mileage warranty against corrosion perforation. This increase in warranty length over the past 25 years is a clear indication of the confidence the manufacturers have in producing a corrosion-resistant vehicle.

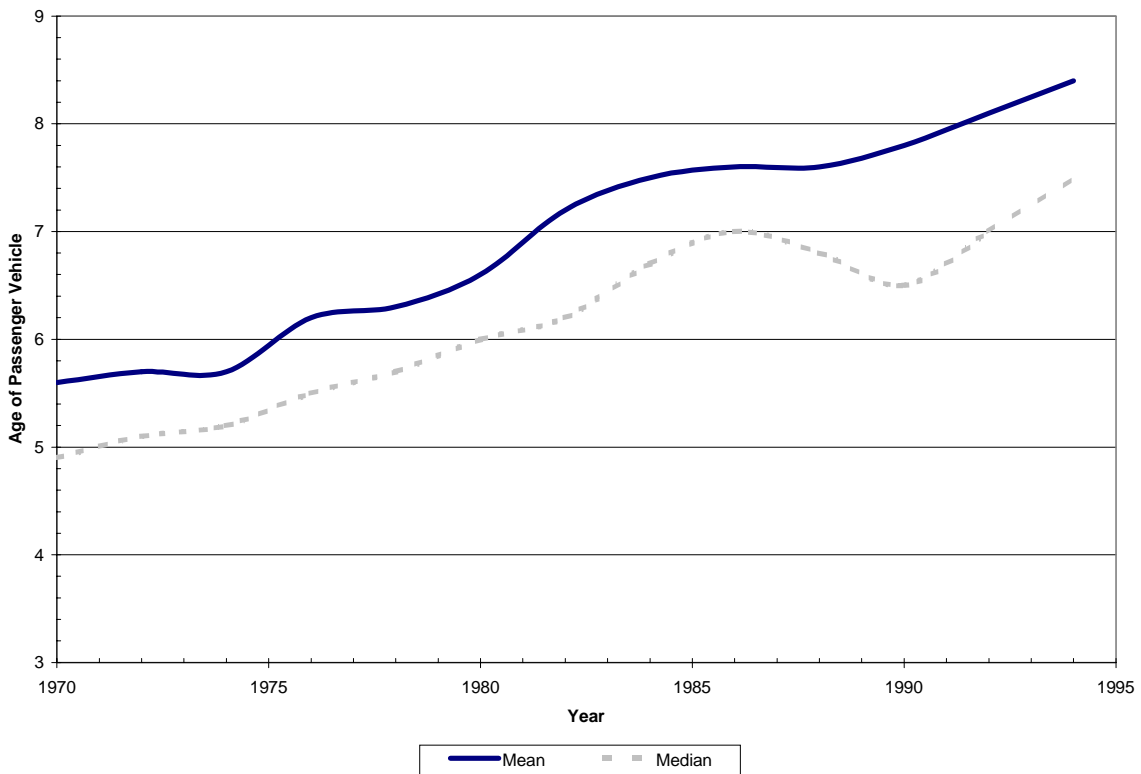


Figure 4. Average mean and median ages of passenger vehicles from 1970 to 1994.

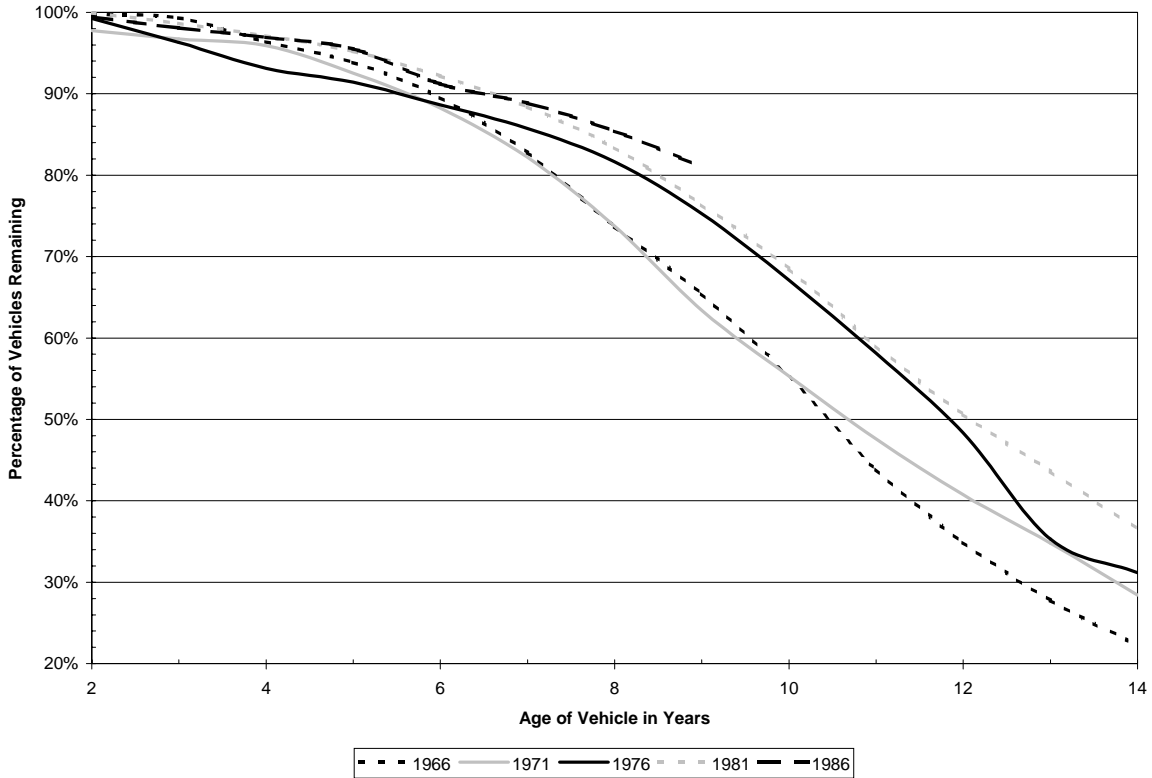


Figure 5. Percentage of vehicles remaining for the first 14 years of service for five different model years.

Table 2. Length of corrosion perforation warranties on model year 2000 automobiles sold in the United States.

MAKE	LENGTH OF WARRANTY		MAKE	LENGTH OF WARRANTY	
	YEARS	MILES		YEARS	MILES
Acura	5	Unlimited	Lincoln	5	Unlimited
Audi	12	Unlimited	Mazda	5	Unlimited
BMW	6	Unlimited	Mercedes-Benz	4	50,000
Buick	6	100,000	Mercury	6	Unlimited
Cadillac	6	100,000	Mitsubishi	7	100,000
Chevrolet	6	100,000	Nissan	5	Unlimited
Daewoo	5	Unlimited	Oldsmobile	6	100,000
Dodge	5	100,000	Plymouth	5	100,000
Ford	5	Unlimited	Pontiac	6	100,000
GMC	6	100,000	Porsche	10	Unlimited
Honda	5	Unlimited	Saab	6	Unlimited
Hyundai	5	Unlimited	Saturn	6	100,000
Infiniti	7	Unlimited	Subaru	5	Unlimited
Isuzu	6	100,000	Suzuki	3	100,000
Jaguar	6	100,000	Toyota	5	Unlimited
Kia	5	100,000	Volkswagen	6	Unlimited
Land Rover	6	100,000	Volvo	8	Unlimited
Lexus	6	Unlimited			

1 mi = 1.61 km

Materials

The most important change in materials over the past 25 years has been the transition from uncoated mild steel to zinc pre-coated steel and other corrosion-resistant metals. The first pre-coated steels used in the motor vehicle industry were hot-dip galvanized steels. These steels had good corrosion resistance, but they had a spangled surface, which resulted in a poor appearance after painting. Because of the painted appearance, these steels were only used in less visible areas of the car. Hot-dip galvanized steel is still used on most body structural members and the interior surface of major body outer panels.

Electrogalvanized steels became available in the mid-1970s. Once manufacturing capacity increased by the mid-1980s, most exterior body panels were made of electrogalvanized steel. Electrogalvanized steel is coated on both sides so it protects the panel from both cosmetic and perforation corrosion. The zinc coating is also smooth enough so that the steel may be painted after proper surface preparation is performed.

Some new pre-coated steel utilized what is referred to as a composite or “piggyback” coating. In these coatings, a thin layer of zinc or zinc alloy is applied to the steel and an organic barrier coating is applied over the zinc on the inside surface. These steels have the cosmetic corrosion protection of electrogalvanized steel and the increased perforation corrosion resistance because of the barrier coating.

Over the past 25 years, another change in materials has been the increased use of aluminum alloys as a replacement for steel. The benefit of using aluminum alloys in place of steel is twofold. First, aluminum alloys are much lighter than steel. Secondly, aluminum alloys are more corrosion-resistant. Aluminum alloys have seen limited use as a hood and rear deck lid material in the past because of the cost and strength of these materials as compared to steel. New designs and aluminum alloys have allowed at least two automobiles to be made entirely from aluminum, including the frame.

Polymers have also seen increased use, replacing steel as body panels. Polymer panels are corrosion- and dent-resistant, making them attractive to consumers. However, the automobiles must be designed to use the polymer panels, since the panels do not aid in the structural rigidity of the automobile.

Stainless steel use has increased over the past 25 years. Most of the exhaust system uses stainless steel or aluminized stainless steel for corrosion resistance. Increasingly, fuel systems have been made of galvanized or stainless steel.

The results of all of these changes in materials are summarized in table 3. This table shows the average weight of each material and the percentage of the automobile made of each material for a typical family car in 1978, 1985, and 1996. The table shows that the percentages of regular steel and iron have been reduced from 67.9 percent of a 1978 vehicle to 55.5 percent of a 1996 vehicle. The use of high-strength steel, stainless steel, plastics, aluminum, and copper, on the other hand, has dramatically increased from 1978 to 1996. These materials have replaced mild steels for greater strength, weight reduction, and corrosion resistance.

The demands on materials, due to the increased temperature and more aggressive conditions created by today's higher performance automobiles, have led to a new trend in the automotive industry. Automakers have started to turn to very expensive, high-performance alloys for some of the critical components in today's automobiles. An example of this is the flexible couplings used in exhaust systems. In order to achieve higher engine efficiency and lower emissions, the exhaust operating temperature has been increased over the years as corrosion rates have increased dramatically with temperature increases. Because of these temperature increases, the materials that have been used for flexible couplings (mostly stainless steel) are failing before the 10-year/100,000-mile warranties that most exhaust systems come with. The high temperatures and the high salt concentrations, along with the movement of the flexible couplings, have led to failures due to fatigue, corrosion fatigue, hot salt attack, chloride stress corrosion cracking, pitting, and general corrosion in 316 and 321 grades of stainless steel. To combat this attack, automakers have started to use nickel-based super-alloys such as Inconel[®] alloy 625LCF[®] and Incoloy[®] alloy 864[™].

These alloys, while often more expensive than stainless steel, have shown excellent resistance to corrosion attack in the modern automotive exhaust environment.

Table 3. Weight of material in a typical family vehicle, 1978 to 1996.

MATERIAL	1978		1985		1996	
	Weight (lb)	% of car	Weight (lb)	% of Car	Weight (lb)	% of Car
Regular Steel	1,915	53.6	1,485	46.5	1409	43.5
High- and Medium-Strength Steel	133	3.7	217.5	6.8	287	8.9
Stainless Steel	26	0.7	29	0.9	46.5	1.4
Other Steels	55	1.5	54.5	1.7	38.5	1.2
Iron	512	14.3	468	14.7	389	12.0
Plastics and Plastic Composites	180	5.0	211.5	6.6	245	7.6
Aluminum	112.5	3.2	138	4.3	195.5	6.0
Copper and Brass	37	1.0	44	1.4	45	1.4
Powder Metal Parts	15.5	0.43	19	0.60	29.5	0.91
Zinc Die Castings	31	0.87	18	0.56	15.5	0.48
Magnesium Castings	1	0.03	2.5	0.08	5.5	0.17
Fluids and Lubricants	198	5.5	184	5.8	197.5	6.1
Rubber	146.5	4.1	136	4.3	139	4.3
Glass	86.5	2.4	85	2.7	94	2.9
Other Materials	120.5	3.4	99	3.1	99.5	3.1
TOTAL	3,569.5	99.73%	3,187.5	100.4%	3,236	100.4%

Source: *American Metal Market*, copyright 1996. Capital Cities Media Inc.

1 lb = 0.454 kg

The automotive industry has found several other applications where the additional cost of specialty metals may be worth the benefit gained. These areas include manifolds and tailpipes, catalytic converters, high-temperature fasteners, exhaust valves, airbag inflators, and other critical electrical components. The future use of these materials will depend on the benefits found in service and the changes in automotive technology that affect the corrosion conditions that automobiles encounter.

Processing

Many improvements have been made over the past two decades in the way that vehicles are finished. The first step in the finishing of a vehicle is the clean/phosphate process. During this step, the vehicle parts are treated in a mixture of zinc, phosphoric acid, and some proprietary additives to clean the surface for painting and leave a very thin layer of zinc phosphate coating. A better understanding and control of the bath parameters have allowed improvement of these coatings for better corrosion resistance and paint adhesion. Systems have also been optimized for vehicles with mixed-material bodies, such as aluminum, coated steel, and plastic.

The second step in the finishing process is the application of primer paint. Before 1975, all body paints were applied with air-spray atomizers. This method gave a good finish on the exterior of the car, but the interior area often received no coverage, which led to corrosion-prone areas. In 1976, PPG Industries introduced a cathodic electrodeposition (ELPO) primer process. This method ensured that every location on a primed part would be

coated. Other advances in primer technology include using thicker “high-build” primers for increased corrosion protection and flaw-hiding capabilities.

The third step in the finishing process is body sealing and augmentation coatings. Vehicles have their body joints and exposed flanges sealed to reduce cosmetic and perforation corrosion. In the past, the work of sealing was done manually and was sensitive to the proficiency of the operator. Over the past 25 years, the sealing process has become a robotic operation to ensure the quality of the sealing job. Several augmentation coatings have been developed over the past 25 years to increase corrosion protection in particular areas of the vehicle. Among these are the anti-chip plastisols and urethane coatings that are applied in the rear of the wheel house before final painting. A second augmentation coating is the use of waxes applied to the interior body cavities. The earliest versions of these waxes were added by after-market rust-proofing companies using a handheld airless probe spray. Later, manufacturers started using waxes and applying them using automated wax coverage. These methods were less prone to operator error and increased the rust-through corrosion resistance.

The final step in the finishing process is the application of the topcoat. The topcoat is applied for cosmetic reasons and has little effect on the corrosion performance of the vehicle. There still have been advancements over the past 25 years that have led to better overall paint system performance. The use of robotic processing and control equipment has resulted in more uniform paint coverage and superior performance. Simplified vehicle design and optimization of the paint process have resulted in increased finish quality, which, in turn, increases corrosion resistance.

Design

Over the past 25 years, vehicle engineers have improved their designs to reduce the extent of corrosion. The designers have tried to remove crevices and locations where salt and soil can build up. Another concern of designers has been the removal of as many dissimilar metal contacts as possible. The number of “nose over” hoods, hood louvers, tuck-under areas, and other design features that promote chipping and corrosion have been reduced.

These changes, as well as the material and process changes, have greatly increased the corrosion resistance of American vehicles. Currently, vehicles in high-corrosion areas are driven 6 or more years with no signs of corrosion, compared to the 2 to 3 years common in the mid-1970s.

CASE STUDY

SAE Parking Lot Surveys

Introduction

While most observers and car owners would agree that automobiles have become much more corrosion-resistant over the past 25 years, it may be difficult to quantify the level of improvement. It may also be difficult to determine which of the changes made by automakers had the greatest effect on corrosion prevention and which changes had lesser effects. The Body Division of the Automotive Corrosion and Prevention (ACAP) Committee of the Society of Automotive Engineers (SAE) started a series of studies in 1985 to help quantify the improvements made in corrosion protection. These studies, along with information from the automakers on when corrosion-based improvements were made, can be used to determine the level of benefits resulting from the various changes made by automakers.

These studies were started in 1985 and consisted of biannual surveys of automobile body corrosion of vehicles in two college parking lots in Detroit. The survey consisted of checking approximately 20 body panels on each automobile for perforations, blisters, and surface rust. Five- and six-year-old automobiles were selected in the

parking lots for study (the year of the automobile was determined from the vehicle identification plate found on the top of the dashboard of every vehicle). The vehicle sample size for each survey was between 200 and 800 vehicles.

The initial study was conducted in 1985 on 1980 and 1981 model year vehicles. All of the surveys were conducted in the fall, because the average age of the 1980 vehicles was 6 years old and the 1981 vehicles averaged 5 years old. Five- and Six-year old vehicles were selected for study for two main reasons. First, most corrosion prevention systems used by automakers would show some sign of failure at this point. Second, very few vehicles would have been scrapped due to corrosion or other causes within 5 or 6 years.

The surveys were performed by individuals from the ACAP committee from SAE using clear plastic grids to measure the size of any perforations, blisters, or surface rust found. Because these surveys were done in parking lots, without the owner present, no investigation was performed on the interior body panels of the car. Only visual defects that could be seen without disturbing the car were tallied. Along with the number, type, and size of the corrosion defects, the investigators recorded the vehicle identification number (VIN), mileage, and whether there was any evidence of rust-proofing or repainting done on the automobile.

Survey Results

Figure 6 shows the overall trends in blisters, perforations, and surface rust found during the 10 years covered by the survey period. Except for the anomaly between the third and fourth survey (SAE believed that the data from the third survey might have been skewed lower), the survey results indicate a consistent improvement in each type of defect. Significant reductions are seen in many of the areas, including a decrease in perforations from 20 percent in the first survey to 3 percent in the fifth survey. A decrease from 61 percent to 38 percent was seen in blistering and a decrease from 78 percent to 50 percent was seen in surface rust between the first and fifth surveys.

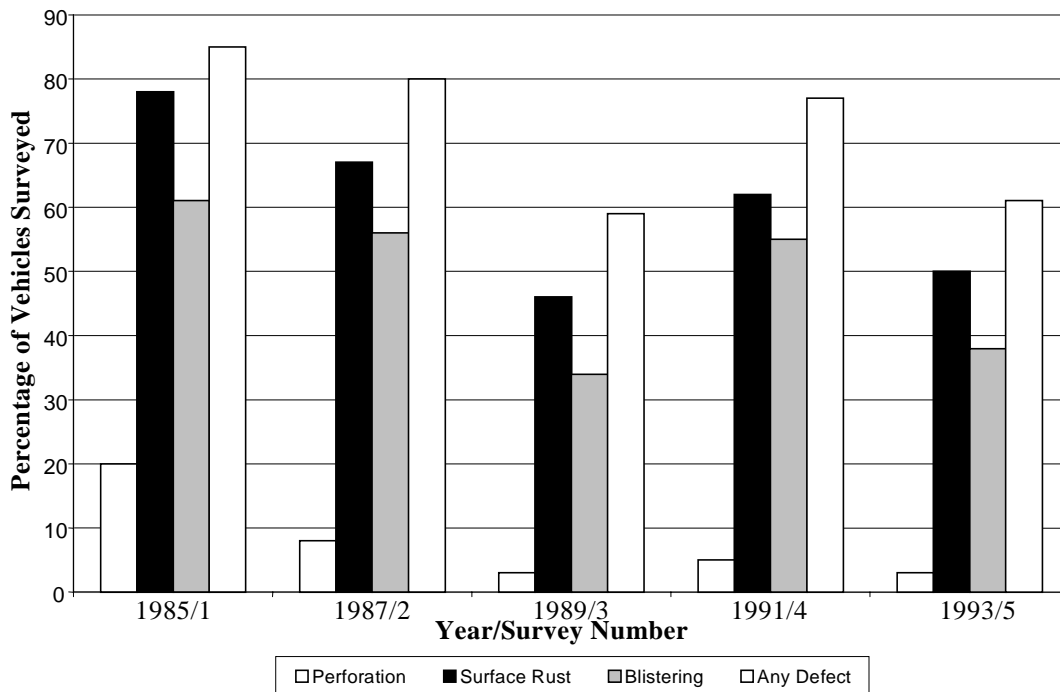


Figure 6. Percentage of vehicles with various types of corrosion defects for each of the five SAE ACAP surveys.

SAE was also able to correlate some of their results with automotive industry trends. One of the major areas examined was the change of materials used for panels. Prior to the 1980 model year, most vehicle body panels were made of uncoated carbon steel. Over the model years that the survey covered (1989-1999), major changes in manufacturing occurred. The first improvement was the use of pre-coated steel, which is steel that has a zinc-rich primer on the interior. These coatings gave way to steels that were coated on one side with zinc or a zinc alloy. Finally, automakers went to two-sided coated steel, which is used on almost all automobiles manufactured in the United States today.

The effect of these changes in materials was found to be dramatic. Figure 7 shows the average surface area of rust found on five major body panels that were either carbon steel, steel pre-painted with zinc-rich primer, or steel coated with zinc/zinc alloy. The data were from the 5- and 6-year-old vehicles surveyed in 1985 and 1993. The data clearly show that the amount of surface rust decreased dramatically when coated steels were used in place of plain carbon steels. This effect is further shown in figure 8, which shows the average number of perforations per automobile panel for the carbon steel, pre-painted, and zinc/zinc alloy-coated steel panels. The figure shows the superiority of pre-painted steel over plain carbon steel and that zinc/zinc alloy-coated steel is better. The SAE study did not differentiate between the two-sided and the one-sided zinc/zinc alloy-coated steel. It is likely that the two-sided steel would have resulted in an even higher performance.

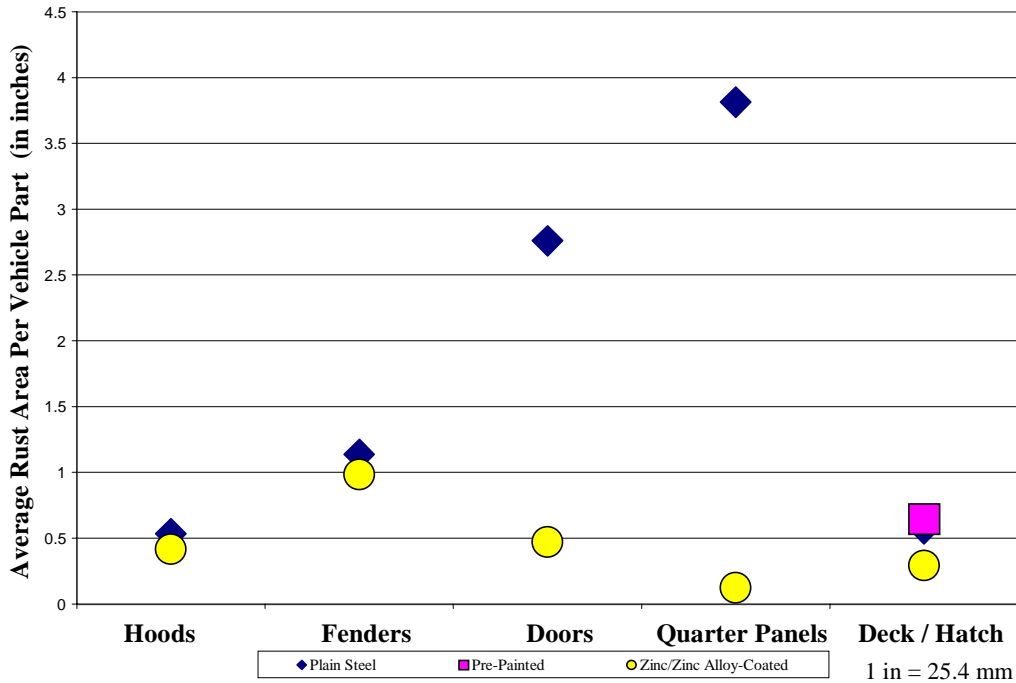


Figure 7. Average area of surface rust found on five different automobile body panels, comparing plain steel, pre-painted steel, and zinc/zinc alloy-coated steel.

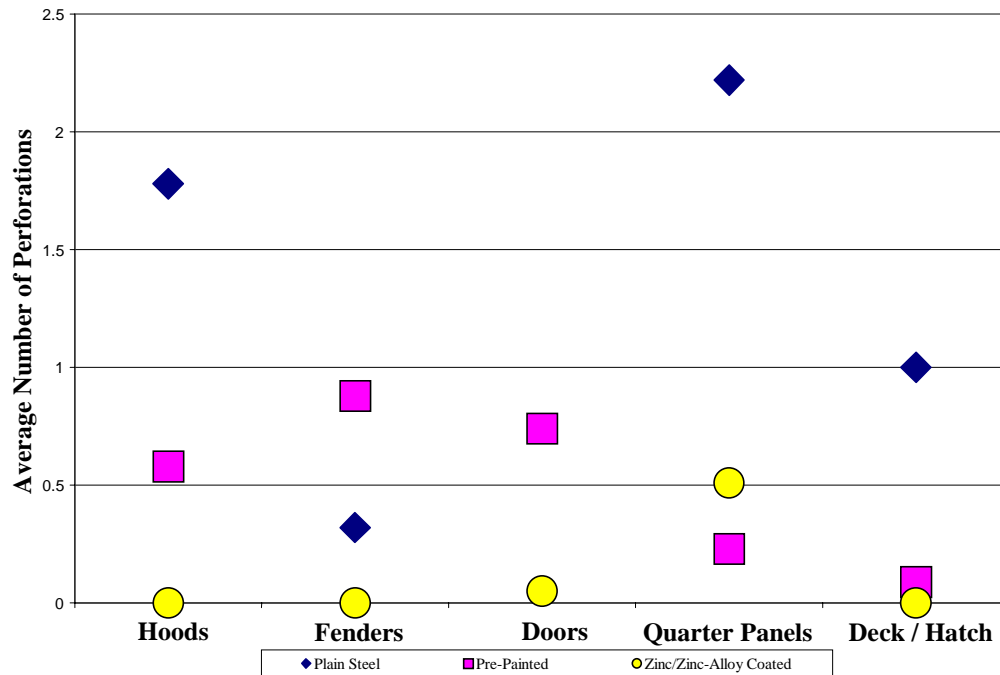


Figure 8. Average number of perforations found on five different automobile body panels, comparing plain steel, pre-painted steel, and zinc/zinc alloy-coated steel.

In terms of corrosion resistance, another major change made by automobile manufacturers in 1980 was the improvement made in the phosphating process. During the 1980s, the composition of the phosphate baths changed with the addition of manganese, nickel, and zinc to the baths, resulting in improved coating performance and corrosion resistance. A second major change in phosphating came with the change from spray systems to immersion systems. The immersion system allowed for more even coverage, as well as the ability to coat the entire surface, as compared to spray systems that could not reach tight spaces or interior locations. The changes in the chemical composition proved to be too difficult to evaluate because of the multiple changes and because the make-up of each manufacturer's bath is proprietary and difficult to track. It is possible, however, to examine the difference between the spray and the immersion systems.

All of the cars in the first study in 1985 were phosphated using the spray process that was standard in the 1980 and the 1981 model year automobiles. In the 1993 survey, nearly half of the automobiles were phosphated with an immersion system. Figure 9 compares the average defect area per car for automobiles with immersion and spray phosphate treatments. The age of the 1990 and the 1998 model year cars averaged 6 years, while the 1991 and the 1989 model year automobiles averaged 5 years. The figure indicates that cars that had immersion phosphating performed had significantly lower areas of corrosion-related defects, even for automobiles from the same model year.

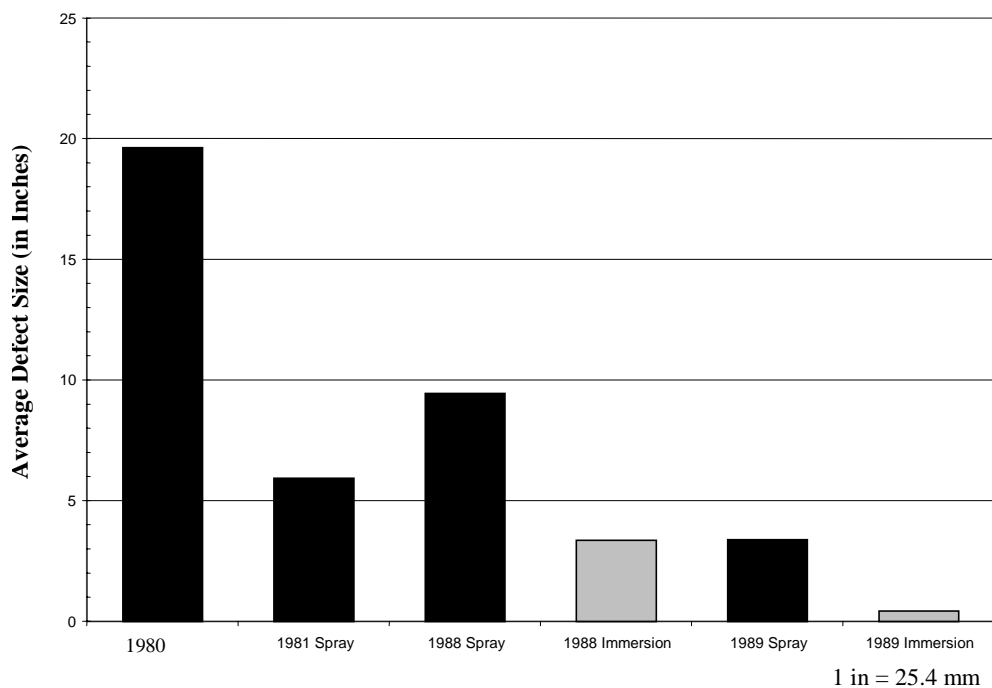


Figure 9. Average size of corrosion defects for automobiles that had undergone spray phosphating or immersion phosphating.

Another change in the automotive industry that led to increased corrosion resistance is the change in primers and paints used on automobiles. One measure of the improvement of paint systems and corrosion protection is that the survey revealed that 47.7 percent of 1980 model year automobiles had been repainted within 6 years, while only 10.6 percent of the 1988 model year automobiles were repainted after 6 years, which is a dramatic improvement over a relatively short time.

The use of electrocoat or e-coat paints and primers was another technology that increased in use in the 1980s. Electrocoated paint is applied by placing the part to be coated in a paint bath and applying a current to the part to draw the paint onto the part. This method allows very even paint coverage and allows complete coverage, even on small areas or interior areas that sprays would not cover. To investigate the effect of electrocoated paints, the non-repainted 1980 and 1981 models were grouped together and the non-repainted 1988 and 1989 models were grouped together. All of the 1988 and 1989 model year automobiles were electrocoated, while about half (52.2 percent) of the 1980 and 1981 automobiles were electrocoated. The survey found that the amount of surface rust was approximately three times higher on the 1980 and 1981 automobiles and the number of perforations was almost two times higher on the 1980 and 1981 automobiles than on the 1988 and 1989 automobiles where 100 percent of the vehicles were electrocoated. Some of these differences are the result of differences in the zinc coating on the steel and phosphating; however, the use of electrocoated paint systems has had a noticeable effect on corrosion resistance.

Summary

The results of the SAE ACAP parking lot surveys indicate that the frequency and extent of corrosion have decreased with the new technologies used by the automotive industry for corrosion control. This decrease is probably because of changes in design, materials, phosphating, and coating practices. The members of the committee also drew several specific conclusions from the survey data and analysis:

- The increase in the use of zinc metallic precoating has contributed to reductions in perforation when these coatings are on the inside of the panel.

- Metallic coatings on the interior of the panels are more effective in reducing perforations than paint coatings.
- Increased use of two-sided precoated steels has contributed to decreases in blistering and surface rusting.
- Increased use of immersion phosphating systems has contributed to the improvement in corrosion resistance of the vehicles surveyed. Blistering and surface rusting have been reduced 40 to 70 percent and no perforations were seen on 5- and 6-year-old cars phosphated using an immersion system.
- Improvements in materials use, design, phosphates, and paints have resulted in a dramatic decrease in the percentage of repainted cars at 5 and 6 years of age over the survey period. The reduction in repainted vehicles from model years 1980-1981 to 1988-1989 was approximately 70 percent.
- The overall improvement in corrosion performance over this 10-year survey period may be greater than the data reveals because of the considerable number of vehicles that were repainted in early surveys.

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