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7. AUTHOR Bahram Ravani, Ph.D.		6. PERFORMING ORGANIZATION CODE AHMCT Research Center, UC Davis
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The costs associated with corrosion to fleet equipment in winter maintenance operations are substantial as metallic corrosion increases maintenance and repair costs, reduces vehicle life, and results in downtime to equipment. Corrosion protection technology plays a key role in increasing the longevity of maintenance equipment and vehicles due to the corrosive nature of deicing materials and inherent existence of moisture combined with the use of chloride in winter operations. This report summarizes the results of a two-day workshop that was organized with the goal of developing specific understanding of the methods, equipment, and materials used for corrosion protection and their long-term effectiveness as well as their level of applicability within state Department of Transportations (DOTs). Presentations from 9 different agencies involved in using corrosion protection technology in winter operations provided data on some key parameters to consider for minimizing the adverse effects of corrosion on maintenance vehicles.

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Advanced Highway Maintenance and Construction Technology Research Center

Department of Mechanical and Aerospace Engineering
University of California at Davis

Workshop on Corrosion Protection Technology for Winter Maintenance - A Summary

Bahram Ravani, Ph.D., Principal Investigator

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ABSTRACT

The costs associated with corrosion to fleet equipment in winter maintenance operations are substantial as metallic corrosion increases maintenance and repair costs, reduces vehicle life, and results in downtime to equipment. Corrosion protection technology plays a key role in increasing the longevity of maintenance equipment and vehicles due to the corrosive nature of deicing materials and inherent existence of moisture combined with the use of chloride in winter operations. This report summarizes the results of a two-day workshop that was organized with the goal of developing specific understanding of the methods, equipment, and materials used for corrosion protection and their long-term effectiveness as well as their level of applicability within state Department of Transportations (DOTs). Presentations from 9 different agencies involved in using corrosion protection technology in winter operations provided data on some key parameters to consider for minimizing the adverse effects of corrosion on maintenance vehicles.

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LIST OF ACRONYMS AND ABBREVIATIONS

Acronym	Definition
AASHTO	Association of State Highway and Transportation Officials
AHMCT	Advanced Highway Maintenance and Construction Technology Research Center
Caltrans	California Department of Transportation
CARC	Chemical Agent Resistant Coating
CPT	Corrosion Protection Technology
DOT	Department of Transportation
DRISI	Caltrans Division of Research, Innovation and System Information
SICOP	Snow and Ice Cooperative Program
UC-Davis	University of California-Davis
URL	Uniform Resource Locator

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EXECUTIVE SUMMARY

This report summarizes the findings of a workshop on Corrosion Protection Technology (CPT) in winter maintenance operations organized by the Advanced Highway Maintenance and Construction Technology (AHMCT) Research Center at the University of California-Davis (UC-Davis) through the sponsorship of the California Department of Transportation (Caltrans).

The participants consisted of representatives from state Department of Transportations (DOTs), researchers, and other stakeholders with experience in CPT as well as interested groups within Caltrans. The workshop provided a forum for peer exchange of information and identified some of the practices in the use of CPT among various organizations and agencies. The workshop had a two day duration and resulted in networking, exchange of knowledge, and this final report. The discussions and interactions with the participants also provided data on some of the best practices as well as parameters to consider in implementing CPT for winter maintenance vehicles. Such information is important for Caltrans to develop proper planning in considering using CPT in winter maintenance operations.

CPT plays a key role in increasing the longevity of maintenance equipment and vehicles in winter maintenance operations due to the corrosive nature of deicing materials and inherent existence of moisture combined with the use of chloride in winter operations. The deteriorating effects of corrosion impacts various structural, electrical, and hydraulic components of winter maintenance equipment and vehicles, degrading their performance and adversely affecting their longevity.

The workshop presentations provided insights into some of the issues and most successful practices for corrosion mitigation in winter maintenance operations. A summary of the key conclusions is provided below:

1. Develop a fleet management plan that will consider corrosion mitigation. Consider rotating vehicles and equipment out of high corrosion environments. Pay attention to equipment procurement specifications to avoid designs that are more susceptible to corrosion (for example, procure vehicles with single rail frame designs as compared to double or nested “C” channel frames) and include corrosion assessment as part of vehicle replacement criteria.
2. Develop life cycle management programs that include corrosion related training, systematic review of equipment for corrosion damage, assessment of repair needs, address repairs, and consider storage that avoids thaw cycles, and provide frequent washing.
3. Develop a maintenance program that includes preventive maintenance and differential maintenance schedules for equipment in high corrosion environments. Repair scrapes, dings, and areas of exposed metals to protect raw metal from corrosion.
4. In designing and building components, use stainless steel, aluminum, and other non-ferrous materials (fiberglass, plastic composites, metalized plating) on components that are particularly susceptible to corrosion such as:
 - a. Battery cases

- b. Differentials covers
- c. Hydraulic controller cases
- d. Oil pans

Move electrical items, like controllers, components, and connectors into the cab or other protected areas and use waterproof electrical connectors and dielectric grease. Isolate dissimilar metals. Also consider using lower cost alternatives to stainless steel/aluminum for intermediate component lives, for example, using CorTen metals (CorTen is a trade name for a corrosion resistant steel produced by United States Steel) for beds as a lower cost/shorter life alternative to stainless steel.

- 5. Perform periodic washing and drying of vehicles using low pressure/high volume water (300 PSI/300 Cubic Feet per Minute) and store in cool, dry locations.
- 6. In relationship to coating, use zinc-rich primers on all components made of steel. Use a thick primer and top paint coating. Use sacrificial coatings and/or tape/sealers to protect hydraulic connectors.
- 7. Use less corrosive chemicals as a deicing method.

INTRODUCTION

This report summarizes the findings of a workshop on Corrosion Protection Technology (CPT) in winter maintenance operations organized by the Advanced Highway Maintenance and Construction Technology (AHMCT) Research Center at the University of California-Davis through the sponsorship of the California Department of Transportation (Caltrans). The aim of the workshop was to provide a forum for peer exchange of information and identification of best practices and areas where most benefits have been gained from the use of CPT. The participants consisted of representatives from state Department of Transportations (DOTs), researchers, and other stakeholders with experience in CPT as well as interested groups within Caltrans. The workshop lasted for two days and resulted in networking and exchange of knowledge.

CPT plays a key role in improving the longevity of vehicles and equipment used in the winter maintenance operations, which have a shorter lifespan due to the corrosive nature of the environment due to moisture and use of chemical deicers.

The main goal of the workshop was to develop an understanding of the state of the art technologies in the use of CPT by other agencies and DOTs in implementing this technology for winter maintenance.

Through a series of presentations from state DOTs as well as some other agencies, the workshop provided a complete understanding of the ways CPT is being used for winter maintenance. The discussions and interactions with the participants also provided data on some of the best practices as well as parameters to consider in implementing methods for corrosion prevention to protect winter maintenance equipment and vehicles. Such information is important for Caltrans to develop proper planning and methods to increase the longevity and life cycle of its winter maintenance fleet and equipment.

Background

CPT plays a key role in increasing the longevity of maintenance equipment and vehicles in winter maintenance operations due to the corrosive nature of deicing materials and inherent existence of moisture combined with the use of chloride in winter operations. The deteriorating effects of corrosion impacts various structural, electrical, and hydraulic components of winter maintenance equipment and vehicles, degrading their performance and adversely affecting their longevity. Although some recent research [1-4] has provided an evaluation of the literature and a survey of some of the best practices among DOTs, there is still a need for additional efforts to develop a more specific understanding of the methods, equipment, and materials used for CPT and their long term effectiveness as well as their level of applicability for DOTs.

APPROACH

Key personnel involved in corrosion prevention for winter maintenance vehicles and equipment from various DOTs and other agencies were invited to present at the workshop. The invited presenters submitted abstracts or outlines of their presentations, which then formed the basis of developing the workshop's agenda.

Agenda

The final agenda for the workshop was as follows:

<i>Corrosion Protection Technology(CPT) for Winter Maintenance</i>		
<i>A Peer Exchange Workshop</i>		
<i>Agenda</i>		
Thursday, April 5th – Day 1		
9:00 AM	Introduction and Announcements	Prof. Bahram Ravani, AHMCT-UC-Davis
9:15 AM	State of Caltrans Problems with Corrosion in Winter Maintenance Equipment	George Edwards & Geno Cervantes, Caltrans
10:00 AM	Corrosion Mitigation – Lessons from Utah and Other State DOTs	Henry Canipe, The Kercher Group Inc.
10:45 AM	Break	
11:00 AM	Recycle Rinse Water	Russell Modrell, Caltrans
11:30 AM	Question and Answer Session	All
12:15 PM	Lunch	All
1:30 PM	Best Practices in Preventing and Mitigating the Corrosion Risk of Roadway Deicers to Winter Maintenance Equipment	Prof. Xianming Shi, Washington State University, Pullman, WA
2:15 PM	What is WSDOT Doing to Minimize Impacts of Corrosion	Greg Hansen, Washington State DOT
3:00 PM	Coffee Break	
3:15 PM	TBA	Doug Burke, Ohio DOT
4:00 PM	Question and Answer Session	All
5:00 PM	End of Day 1	

Friday, April 6th – Day 2

9:00 AM	Remarks	Jim Appleton, Division Chief, DRISI, Caltrans
9:15 AM	Review of Questions for Participants	Prof. Bahram Ravani, AHMCT-UC-Davis
9:45 AM	Corrosion Prevention Methods	James Chupas, Connecticut DoT
10:30 AM	Break	All
10:45 AM	DOT Practices Associated with Reactive and Proactive Corrosion Control Strategies	Rick Nelson, AASHTO
11:30 AM	Chemical Agent Resistance Coating – How the USMC Paints Vehicles	Andrew Sheetz, Naval Surface Warfare Center
12:15 PM	Questions & Answers	All
12:45 PM	Lunch	All
1:15 PM	Workshop Summary & Minnesota Truck Washing Video	Prof. Bahram Ravani, AHMCT-UC-Davis
2:30 PM	Open Forum and Networking	All
3:30 PM	Workshop Commencement	

SUMMARY OF INVITED PRESENTATIONS

A short summary of the invited presentations is provided in this section. Complete details of the invited presentations are provided on the CPT workshop website (url: <http://ahmct.ucdavis.edu/cpt/>). These presentations can be accessed, and if used for research purposes, please properly reference their corresponding authors as what follows are only brief summaries of each presentation.

Caltrans (Presentation by George Edwards & Geno Cervantes)

This presentation provided an overview of the state of corrosion in winter maintenance equipment within Caltrans. In California, corrosion is a problem in the western part of the state due to its proximity to the Pacific Ocean as well as in the Sierra Nevada Mountains due to snow precipitation during the winter months. Common areas where corrosion has occurred on maintenance vehicles include:

- On the truck beds and tailgates where chains are mounted and rub the paint off the body panels exposing metal to moisture and resulting in corrosion.
- Side of the truck bodies and other areas where the paint comes off.
- Body seams where surfaces come together.
- Truck frame rails.
- Weldments.
- Winches, wiring harnesses and connectors, brake valves and chambers, hydraulic motors, and oil pans.
- Trucks parked outside in coastal areas.

Caltrans has taken the following steps to minimize corrosion in its fleet:

- Pilot project to utilize fiberglass utility bodies in appropriate maintenance vehicles
- Using E-coated vehicle bodies when warranted
- Manufacturing accessories and parts from stainless steel due to their corrosion resistant characteristics
- Blasting components in a blast cabinet to improve their paint adhesion
- Establishing paint and coating standards
- Using epoxy primer paint

Kercher Group (Presentation by Henry Canipe)

This presentation provided a summary of some of the experiences gained from operations of the Utah DOT with some comparisons with the Illinois and Missouri DOTs. The State of Utah has a corrosion assessment program where vehicles that are over six years old are assessed on a yearly basis according to a multi-point assessment. Utah has also adopted a vehicle replacement standard, recommending a lifespan of nine years for vehicles. The State of Utah has traditionally used trucks with double or nested “C” channel frames. They observed frame cracks, due to corrosion, in vehicles with such frame designs. Therefore, they have moved to vehicles with single rail frame designs. Any frame designs that water can get in but not out has problems with corrosion. They have also observed corrosion in oil pans, differential cases, and the brake shoes of vehicles. The Utah DOT has moved wiring junction boxes into the cab of the vehicles. They found that when

maintenance vehicles are parked inside in bad weather conditions, the freeze/thaw cycle had an adverse effect on corrosion. Illinois and Missouri use similar winter maintenance vehicles as Utah, but do not have similar corrosion problems. Missouri vehicles show more rust than those from Illinois, but both vehicles from Missouri and Illinois show less rust than those from Utah. Some of the differences are that the Utah DOT does not perform maintenance on their winter maintenance vehicles during the summer since their vehicles sit in the yard for their six non-winter months while in Illinois the winter maintenance vehicles move and get maintenance year round. Furthermore, Utah uses all heavy-duty class-8 trucks while Illinois and Missouri use more lower class trucks, and snow in the west is wet as compared to the snow in the mid-west.

Findings from a survey of state DOTs indicated that:

- Going from dry chemicals to wet chemicals was a major problem.
- Magnesium chloride has been found to especially impact copper wiring.
- Redmond salt and brine were next worse for increasing corrosion.
- Keeping water and chemicals out of the connectors is a key factor in corrosion protection.
- Post-storm washing was found to be effective in minimizing corrosion.
- Pressure washing methods can push sands and other corrosive agents into cracks and overlap areas and should be avoided.
- Powder coating was not effective in corrosion protection.
- Stainless steel bodies moved the rust into the chassis.
- The use of neutralizing chemicals and increasing the frequency of preventive maintenance were effective measures.

In summary, many variables effect corrosion on winter maintenance vehicles, including transportation, infrastructure, environment, and the type of vehicles used.

Caltrans (Presentation by Russell Modrell)

This presentation was focused more on the use of brine in California. When winter maintenance vehicles come in for a shift change, they are washed. The California Storm Water Act mandates treating recycled water from vehicle washing. Recycled water from wash racks are used to make brine solutions that can be stored for six months. Using brine cuts down use of salts by ½ to 1/3. Approximately 22,000 tons of salt was used in California last year. Caltrans is considering using more brine instead of salt, sand, and cinders. There are some concerns, however, that in certain areas the use of brine could damage bridges.

Washington State University (Presentation by Prof. Xianming Shi)

This presentation also addressed the magnitude of the corrosion problem in terms of the desired level of service. The desired level of service should consider safety and mobility as well as environmental stewardship. Deicers are used at the current level of approximately 20 million tons per year in the US, on highways and local roads. They are mainly chloride based, and the cost of the resulting corrosion from them to a state DOT can be approximately up to \$14 million per year. Approximately 20 to 30% of these costs can be avoided by having a proper corrosion protection program. A major problem is that most corrosion protection methods used by state DOTs are

reactive while preventative methods are more desirable. Corrosion and rust can reduce the strength of metals and can result in fatigue failure (called rust jacking) and stress corrosion cracking.

Methods to mitigate corrosion can include:

- Appropriate training and facility management.
- Use of anti-corrosion coating.
- Periodic washing with hot water at low pressure but with high volume and fast drying.
- Use improved designs: select corrosion resistant metals, avoid sharp corners, and remove stress concentrations and avoid contact between dissimilar metals.

Washington DOT (Presentation by Greg Hansen)

This presentation emphasized the idea that there is no magic solution to eliminating corrosion and that one needs to minimize its effects. The basic idea to consider on any such problem is that if you cannot measure it, you cannot improve it. One way to measure it is to include the cost of corrosion in the life cycle costs of a vehicle in a fleet. The American Trucking Association (ATA) has established ten categories for vehicle maintenance costs, including one for corrosion damage. In calculating such costs, fleet hours are more important than the age of the vehicle. Based on maintenance cost data from 2017, Washington DOT found that there seems to be a correlation between the corrosion costs and the use of chlorides such that as chloride use increases the corrosion costs increases. Most of corrosion costs were associated with:

- Drive train group
- Body group
- Electricals
- Equipment attachments
- Chassis group
- Engine group

The best way to prevent corrosion in winter maintenance vehicles is to be proactive and consider the following:

- Including mitigation in contract specifications, for example, requiring:
 - Single frame rails rather than “C” channel designs.
 - Sealed frame rails.
 - Aluminum wheels in the front.
 - Aluminum fuel tanks and zinc-alloy engine oil pans.
- Performing in-service checks using service check sheets
- Utilizing plastics and composites for parts whenever possible
- Not compromising wiring integrity
- Using high quality weather proof terminals on electric connections
- Eliminating junction boxes or mounting them in weather friendly locations
- Utilizing dielectric products
- Using Denzo tapes on all hydraulic components
- Using compression fittings

Ohio DOT (Presentation by Doug Burke)

The Ohio DOT operates 1,600 snow plow trucks with a replacement cycle of 160 trucks per year. They found that corrosion was the number one cause of truck downtime. Electricals were the main cause of a truck's downtime during storms. Corrosion problems were electrical and structural. They also had problems with fires since pressure washing would push salt into the power boxes, shorting the circuits and causing fires. They redesigned and relocated these boxes into the cab to avoid such problems. They also had rust jacking or stress cracking in double frame rail designs. They have cut one inch holes in front of the truck beds to allow air to dry out the frames and help improve the problem. The wiring harness between the engines and transmissions has also been a problem. Using an integrated wire harness has fixed some of these problems. They have also taken additional counter measures to reduce the cost of corrosion that include:

- Using epoxy coted oil pans.
- Utilizing aluminum tanks and straps.
- Spraying fluid films outside of the engines on a yearly basis.
- Having a dedicated wash bay in facilities.
- Using single frame rail trucks.
- Recycling stainless steel parts from decommissioned vehicles into replacement vehicles.

Connecticut DOT (Presentation by James Chupas)

In Connecticut they use a lot of corrosive chemicals in the winter and corrosion is a major problem. Extended snow and ice equipment is replaced approximately every 17 years. Rust jacking and splitting frames have also been a problem there. They have taken many steps for corrosion mitigation that include:

- Developing centralized repair facilities with sand blasting and painting capabilities.
- Developing painting standards requiring using two-part urethane primer and paint (using 3 Mils primer and 3 Mils paint thicknesses).
- Periodic sand blasting and repainting components.
- Using corrosion inhibitor fluid films on frames and undercarriages every fall.
- Moving electronics into the cabs.
- Washing trucks inside repair facilities.
- Moving towards using powder coated wheels, aluminum fuel tanks, and oil pans.

AASHTO (Presentation by Rick Nelson)

This presentation was based on Snow and Ice Pooled Fund Cooperative Program (SICOP) from the Association of State Highway Officials (AASHTO). They did a survey of common practices in corrosion mitigation and 26 states responded. The findings from survey included the following (complete survey responses can be found on SICOP's website <https://sicop.transportation.org/resources/surveys/>):

- All respondents used materials resistant to corrosion
- 44% of the respondents used corrosion resistant coatings
- 80% of the respondents used some form of preventive measures
- 44% of the respondents had some sort of special program related to corrosion
- 60% of the respondents had a policy requiring washing
- 80% of the respondents used corrosion inhibitors
- 44% of the respondents indicated that they did other things not asked in the survey

The SICOP website (<https://sicop.transportation.org/>) has a lot of useful information.

Naval Surface Warfare Center (Presentation by Andrew Sheetz)

This presentation discussed some of the experiences gained in implementing the Marine Corps Corrosion Prevention and Control (CPAC) Program. In this program, preventing corrosion starts during the equipment or vehicle acquisition process and is continued throughout the life cycle of the equipment or vehicle. The aim of the program is to extend the useful life of the equipment or vehicle. Medium-sized trucks are kept for approximately 30 years, and they are repainted only a few times during this period. In this program, corrosion assessment is performed based on five categories:

1. Items requiring no corrosion repairs or preservation.
2. Items requiring surface preparation, spot painting, and preservation at level of an organizational unit.
3. Items requiring field level maintenance performed beyond the organizational unit's capability.
4. Items requiring field level maintenance performed beyond the organizational unit's capability, which include repairs to sheet metal, major frame components, paint, blasting, and undercoating.
5. Items that are degraded to a degree that are non-mission capable, requiring depot level repair or replacement based on the deterioration caused by corrosion.

Some of the corrosion prevention measures used in CPAC include:

- Spraying the bed liners and using zinc based primers. Requires 3 to 5 Mils of primer.
- Switching from solvent coatings to single component coatings. Chemical Agent Resistant Coating (CARC) is the top coating material used.
- Using wash racks and portable washers.
- Drying new paints.
- Using electro-deposition coating for frames and cabs.
- Using encapsulations for hydraulic fittings and wirings.

Questions and Answers

During the workshop, responses to several questions were solicited from the participants and speakers. These questions and the summary of some of the responses are provided below:

1. When using galvanized metal, what are some of the design considerations to keep in mind? Also when mounting a galvanized part to a vehicle, what precautions should be taken to prevent galvanic corrosion? This will also apply to the mounting of aluminum truck bodies.

Response: In terms of design consider the added weight and heat warping of the parts. In order to avoid galvanic corrosion consider using separators when mounting galvanized parts to a vehicle.

2. Welds are hard to coat and time consuming to grind and prepare correctly for coating. What are the advancements in adhesives for building bodies out of sheet metal or light gauge metal, such as utility bodies, cargo bodies, and etc.?

Response: Perform the coating before you weld. Once you weld you cannot reach all areas. Weld through primers. Train technicians to use fume elimination while grinding.

3. What are best management practices, from start to finish, that prepare equipment for corrosion prevention?

Response: In procurement of vehicles specify single rail frames, develop a life cycle process for vehicles that would avoid thaw cycles, include frequent washing for the vehicles and the equipment in their operations, and develop proper training methods for corrosion protection.

4. What type of systems can we put in place to prevent or slow down further corrosion?

Response: Develop good strategies for selecting the right equipment and standard practice on the method and frequency of cleaning or washing the equipment. Develop condition assessment systems and methods.

5. What type of materials do you select/use that will reduce corrosion?

Response: Use less corrosive chemicals as a deicing method; for equipment use stainless steel, fiberglass, plastic composites, and metalized plating.

6. What are maintenance practices for corrosion prevention?

Response: Washing; coating; drying; parking in dry, cool places, and unloading sand at the end of the day.

7. What are corrosion costs vs. life cycle costs?

Response: Base the life cycle costs on sales cost, and major cost issues are with added parts and components and not necessarily with Original Equipment Manufacturer (OEM) parts. Life cycle costs should include the cost to the environment and the public,

but such costs might be hard to quantify. The life cycle costs should also include the cost of corrosion mitigation, cost of spares and vehicle downtime.

8. What is the best synergistic use of washing and inhibitors?

Response: Periodic washing with low pressure and immediate drying is recommended. Use zinc based primers on all steel parts and other coatings as corrosion inhibitors. Wash racks will be useful near the coasts in California because they may only need to change their water every few months.

CONCLUSIONS

The workshop was successful in providing a forum for exchange of information and addressing some of the issues and questions for Caltrans in relationship to corrosion protection for winter maintenance equipment. Participants from some of the key state DOTs as well as some other organizations who have experience in implementation of CPT shared ideas and discussed information on lessons learned that can benefit CPT implementation and operational improvements in the future.

The key conclusions from the workshop can be summarized as follows:

1. Develop a fleet management plan that will consider corrosion mitigation. Consider rotating vehicles and equipment out of high corrosion environments. Pay attention to equipment procurement specifications to avoid designs that are more susceptible to corrosion (for example, procure vehicles with single rail frame designs as compared to double or nested “C” channel frames) and include corrosion assessment as part of vehicle replacement criteria.
2. Develop life cycle management programs that would include corrosion related training, systematic review of equipment for corrosion damage, assessment of repair needs, address repairs, and consider storage that would avoid thaw cycles, and include frequent washing.
3. Develop a maintenance program that would include preventive maintenance and differential maintenance schedules for equipment in high corrosion environments. Repair scrapes, dings, and areas of exposed metals to protect raw metal from corrosion.
4. In designing and building components, use stainless steel, aluminum, and other non-ferrous materials (fiberglass, plastic composites, metalized plating) on components that are particularly susceptible to corrosion such as:
 - a. Battery cases
 - b. Differentials covers
 - c. Hydraulic controller cases
 - d. Oil pans

Move electrical items, like controllers, components, and connectors into the cab or other protected areas and use waterproof electrical connectors and dielectric grease. Isolate dissimilar metals. Also consider using lower cost alternatives to stainless steel/aluminum for intermediate component lives, for example using CorTen metals (CorTen is a trade name for a corrosion resistant steel produced by United States Steel) for beds as a lower cost/shorter life alternative to stainless steel.

5. Perform periodic washing and drying of vehicles using low pressure/high volume water (300 PSI/300 Cubic Feet per Minute) and store in cool, dry locations.

6. In relationship to coating, use zinc-rich primers on all components made of steel. Use thick primer and top paint coating. Use sacrificial coatings and/or tape/sealers to protect hydraulic connectors.
7. Use less corrosive chemicals as a deicing method.

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