Best Practices
for the Prevention of Corrosion of Department of Transportation Equipment:

A User's Manual

Final Report
March 2015

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research for winter highway maintenance

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This document is the final report for the Clear Roads project entitled *Best Practices for the Prevention of Corrosion of Department of Transportation Equipment: A User's Manual*. The project team was led by researchers at the Western Transportation Institute at Montana State University (WTI) on behalf of Clear Roads, an ongoing pooled fund research effort focused on winter maintenance materials, equipment, and methods. Clear Roads research projects are managed and administered by the Minnesota Department of Transportation (MnDOT).

Through this project, the research team developed a user-friendly manual that documents best practices for managing the risk of equipment corrosion, especially in the presence of chemical deicers. The audience for this manual includes operators, mechanics and garage-level supervisors. The manual defines the basic corrosion conditions, with a focus on the need for managing corrosion risks, common modes of corrosion failure, and corrosion-prone parts (priorities) on DOT equipment. This manual addresses design considerations and material selection for corrosion risk management. This manual also lists some commercial products that have been used by DOTs, and presents some successful experiences of DOTs, the US Navy and private companies. It also presents preventive maintenance strategies and tactics.

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Executive Summary

In cold-climate regions such as the northern United States and Canada, winter maintenance is often the activity of highest priority for transportation agencies. Large amounts of solid and liquid chemicals (known as deicers) as well as abrasives are applied onto winter roadways to keep them clear of ice and snow. Abrasives are not deicers but serve to provide a temporary friction layer on the pavement. The deicers used by highway agencies are mainly chloride-based salts. Acetate-based deicers (potassium acetate, sodium acetate, and calcium magnesium acetate – CMA) have also been used on some winter roadways. In addition, formates (sodium formate and potassium formate) and bio-based products have emerged as potential alternative deicers.

Today's motor vehicles and winter maintenance application vehicles are constructed with a wide array of metals, e.g., steel (for frames, bumpers, brake lines, body panels, fuel tanks, fittings, exhaust systems, etc.), cast irons (for engines and drive train components, brake drums and disks, fittings, etc.), aluminum alloys (for body panels, fuel tanks, trim, radiators, wheels, engine and drive train components, fittings, etc.), magnesium alloys (for wheels, transmission housings, brackets and supports, etc.), and copper and copper alloys (for electrical wiring, radiators, brake line fittings, etc.), all of which are subject to the corrosive effects of snow and ice control materials (a.k.a., deicers). According to a recent NCHRP report, "crevice corrosion and poultice corrosion typically occur where dirt and moisture are trapped – between adjacent pieces of metal, under gaskets and at fasteners, or on the surface of motor vehicle components. This is compounded by ingress of snow and ice control chemicals and other ionic materials (e.g., acid rain) that increase the conductivity of the trapped moisture. Aluminum (Al) alloys are more prone to crevice corrosion and galvanic corrosion when coupled to steel." In a case study conducted by WTI, researchers investigated the corrosion of trucks exposed to deicers applied on Montana highways and observed significant crevice corrosion between the conjunction of winch frame and truck frame and in conjunctions on truck frame, as well as filiform corrosion under the coating near frame corners and on brake chambers. Researchers also observed other forms of less significant corrosion on the trucks, such as pitting corrosion on the outer surfaces of stainless steel parts and Al fuel tanks, galvanic corrosion and stress corrosion cracking (SCC) in the welding zones or conjunction of dissimilar metals. In a two-year field study of deicer corrosion to specimens mounted on winter maintenance equipment, the researchers observed intergranular corrosion attack on all 5182-O Al specimens and a few A356 cast Al specimens and general corrosion on all 1008 steel and most A356 cast Al specimens. A 0-12% decrease in tensile strength was observed among Al specimens evaluated (and other specimens in the first year), depending on severity of corrosion. The researchers concluded that materials loading, exposure miles, climatic conditions (humidity, temperature, etc.), washing frequencies, and other factors (e.g., abrasives and debris) all influenced the corrosion rates of vehicle-mounted specimens.

Corrosion prevention can start as early as the equipment acquisition phase. According to a survey of transportation professionals in 2012, the average cost of corrosion management was estimated for the following six areas: training programs ($190,938), materials selection ($320,667), design improvements ($45,000), corrosion monitoring and testing ($10,000), preventive maintenance ($171,424), and corrective maintenance ($325,000). As such, the total cost of current corrosion management related to deicer exposure is estimated to be $1,063,029 per year. For an "average agency," it is assumed that the empirical 20/80 rule may apply to the 25% of corrosion costs which can be avoided by best practices, in the absence of actual data

being available. In other words, it should be possible to reduce the current cost of corrosion risk related to deicer exposure by 80% × 25%, if the agency can increase its current investment in equipment corrosion control by 20%. This is possible by conducting risk analysis to identify the critical 20% of corrosion-related failures and focusing more on training and risk-based maintenance. In other words, efforts should be focused on efficient investment in corrosion cost avoidance. Improved staff training, preventive maintenance of DOT equipment, and other best practices (e.g., improved monitoring and inspection) are expected to lead to substantial cost reduction. Based on the data from the averaged survey responses, the benefit/cost ratio of further improving deicer corrosion control of DOT equipment fleet can be estimated to be: (80% × 25% × $14,050,368) / (20% × $1,063,029) = 13.2. This ratio is conservative since it does not take into account the indirect costs of equipment corrosion, which could be significantly higher than the direct costs. In this regard, indirect costs due to corrosion are estimated to be greater than ten times the cost of corrosion maintenance, repair, and rehabilitation.

Efforts have been made by maintenance agencies to reduce the vulnerability of their equipment fleet to the risk of deicer corrosion, preserve the value of their equipment asset, extend its service life, improve its performance and reliability, and ultimately reduce its life-cycle cost. There are a host of practices, technologies, and products available to mitigate the corrosion of metals, by enhancing the inherent corrosion resistance of the metal itself, or reducing the corrosivity of the service environment, or altering the metal/electrolyte interface (e.g., salt extracting agents also known as "salt neutralizers," corrosion inhibitors, anti-corrosion coatings, and surface treatment of metals). These countermeasures can be used individually or synergistically in the practices of managing the corrosive effects of deicers to motor vehicles and maintenance application equipment.

Through this project, the research team has developed a user-friendly manual that documents best practices of managing the risk of equipment corrosion, especially in the presence of chemical deicers. This manual serves as a "living document" that can be readily implemented and updated. The audience for this manual includes operators, mechanics and garage-level supervisors. The manual is written in a method that avoids chemical jargon, and focuses more on instruction and less on the science behind corrosion.

The manual defines the basic corrosion conditions, with a focus on the need for managing corrosion risks (cost/safety/reliability/readiness), common modes of corrosion failure (pitting corrosion, crevice corrosion, galvanic corrosion, cosmetic/filiform corrosion, SCC, corrosion fatigue, intergranular corrosion attack, and microbially influenced corrosion), and corrosion-prone parts (priorities) on DOT equipment.

This manual addresses design considerations and materials selection for corrosion risk management. Materials selection for corrosion resistance is one critical aspect of the overall design process. Construction materials should be economical yet provide adequate resistance to the specified service conditions and consider the likely corrosion mechanisms in the expected equipment/component's operational environment. When using multiple materials for equipment/components, one has to consider their compatibility.

This manual also lists some commercial products that have been used by DOTs, and presents some successful experiences of DOTs, the US Navy and private companies at reducing the effects of corrosion. It also presents preventive maintenance strategies and tactics. Winter maintenance agencies typically integrate a wide range of methods and procedures that may involve routine washing (possibly with salt neutralizer), reapplication of post-assembly coatings, grit blasting, mechanical removal of rust, or the use of rust removers to improve the service life of equipment. Where feasible, dehumidification and sheltering of the equipment can effectively modify the service environment and mitigate metallic corrosion. Surface treatments such as applying a protective coat of paint isolate vulnerable materials from their service environment, thereby preventing corrosion. Winter maintenance agencies have reported various modifications of specific components to mitigate impacts of chloride deicers to equipment. For instance, WSDOT has made substantial progress towards effective corrosion prevention methodologies and has been very preventive with various corrosion mitigation approaches such as appropriate deicer and corrosion inhibitor selection, equipment modification techniques, and regular maintenance schedules.

Some of the key findings of this report include:

- Agencies should consider revising the corrosion management information they currently collect if they desire a more rigorous understanding of the costs and benefits associated with deicer corrosion to equipment.
- Agencies should consider corrosion-resistance requirements at the stages of materials selection and design. Existing knowledge about the anti-corrosion performance of various materials and design configurations in various deicer-laden service environments should be utilized to refine the equipment purchasing specifications. Alternatively, modifications should be made to DOT equipment to mitigate the risk of deicer corrosion. Certain corrosion-prone components should use corrosion-resistant materials (e.g., stainless steel or non-metallic) or be inspected and replaced on a regular basis (e.g., replacing truck radiators every two years).
- Agencies should implement an extensive preventive maintenance program that may involve use of salt removers (also known as salt neutralizers) together with routine washing to keep the corrosive salt from building up; protecting of electrical components by sealing or moving them to inside the cab; reapplication of post-assembly coatings; spray-on corrosion inhibitors and many other operational changes to improve the service life of DOT vehicles. This can be supplemented by corrective maintenance practices to minimize the negative impact of deicer corrosion to equipment asset.
- Almost three-fourths of all coating failures happen as a consequence of poor surface preparation. In the surface preparation process prior to coating, use of salt remover (rust remover) effectively increases coating performance. Grit blasting is the best method of surface preparation. However, in situations where grit blasting is prohibited or unusable for safety and environmental reasons, rust removers should be used for surface preparation prior to coating. In maintenance environments, rust removers should be used instead of traditional hand and mechanical wire brushes. When time is very important, time can be saved by using rust converter. On the rusted surfaces, rust converters could be applied to the metal surface as a primer coat supplemented with oil based or epoxy paint. Rust converters are not suitable for damaged coatings.

- Whenever possible, agencies should consider storing equipment in a manner that minimizes exposure to excessive humidity. This is expected to minimize the risk of metallic corrosion and extend the service life of equipment and vehicles.

Chapter 1
Introduction

Report Purpose

This document is the final report for the Clear Roads project entitled *Best Practices for the Prevention of Corrosion of Department of Transportation Equipment: A User's Manual*. The project team was led by researchers at the Western Transportation Institute at Montana State University (WTI) on behalf of Clear Roads, an ongoing pooled fund research effort focused on winter maintenance materials, equipment and methods. Clear Roads research projects are managed and administered by the Minnesota Department of Transportation (MnDOT). This report summarizes all tasks and research conducted over the course of the project.

Research Problem and Background

Corrosion to maintenance equipment resulting from the use of chloride deicers is a tremendous problem for transportation agencies across North America. While there are many products, and much anecdotal guidance for the prevention of corrosion, there is not a consolidated guide that combines all of the available knowledge on corrosion prevention for use by snow and ice control practitioners. Such a manual would be applicable to the entire winter maintenance community and could aid agencies in the prevention of corrosion and the extension of equipment life cycles.

In the final report for Phase I of this project (*Best Practices and Guidelines for Protecting DOT Equipment from the Corrosive Effect of Chemical Deicers)*, the researchers identified the need for additional study to bridge some existing knowledge gaps relevant to this subject. These include research on the long-term effectiveness of best practices or products for corrosion protection; minimizing the risk of premature failure of the post-assembly coatings; the synergistic use of washing and inhibitors; and the study of metallic components. Finally, research was recommended to develop best practice guidelines (e.g., a user's corrosion management guide) on the best practices against deicer corrosion.

This project was initiated as a Phase II effort, focused on the development of a user's manual for corrosion prevention.

Research Goals and Approach

The overall goal of this project was to create an easy-to-use guide that summarizes best practices to prevent corrosion to maintenance equipment. The manual would be written in layman's terms, and targeted for use by maintenance personnel.

To create the manual, the basic approach consisted of developing best practice guidelines based on the information in the Phase I report, in conjunction with some additional research to identify updated and supplemental content.

Research Scope

The research scope comprised three primary tasks:

- Task 1 – Analyze and Review Research
- Task 2 – Develop a Manual

- Task 3 – Produce Final Report and Presentation

These tasks are described in greater detail in Chapter 2 (Methodology).

The primary deliverable for this project is the completed User's Manual. Additional deliverables include this final report, and a PowerPoint presentation summarizing recommendations in the manual, for the use of Clear Roads members at conferences and other meetings.

Project research was conducted from January – December 2014. Final versions of the manual and this report were approved and published in early 2015.

Report Organization

Chapter 2 describes the project methodology, while Chapter 3 summarizes the results of each task. Chapter 4 presents conclusions and recommendations based on project research and development of the manual. The User's Manual is available under separate cover as a standalone document.

Chapter 2
Methodology

This chapter describes the research approach for each of the three primary tasks.

Task 1 Approach: Analyze and Review Research

The research team's approach to Task 1 was to leverage and build on the results of the Phase I final report (*Best Practices and Guidelines for Protecting DOT Equipment from the Corrosive Effect of Chemical Deicers*). Analysis of information from the Phase 1 report was followed by a literature review to identify other relevant research that focuses on chloride corrosion. The review was designed to supplement the one conducted in Phase I and focused on recent literature and literature useful for developing the user's guide or manual, specifically the identification of "best practices, key recommendations and other highlights that will aid practitioners in preventing and reducing corrosion."

The team considered supplementing the literature review and analysis with practitioner interviews and limited laboratory research, if deemed necessary to generate key content for the manual.

Task 2 Approach: Develop a Manual

For this task, the research team's approach was to develop a user-friendly manual that documents best practices of managing the risk of equipment corrosion, especially in the presence of chemical deicers. This manual was designed to serve as a "living document" that can be readily implemented and updated after the completion of this project. The audience for this manual will be operators, mechanics and garage-level supervisors, with a focus on instruction rather than the science behind corrosion. The content was designed to address both preventive and corrective strategies and highlight their effectiveness, limitations, and other considerations, and specific recommendations for implementation.

The intent of the manual is to facilitate the adoption of the identified best practices into mainstream use by the intended audience. To communicate the best practices in an easy-to-use format, the user's guide was designed to include:

- Step-by-step procedures;
- Flow charts;
- Highlights of key recommendations
- Outlines of desired results for each procedure
- Lists of products, methods, and effectiveness of each; and
- Appropriate pictures of products and treatments.

Task 3 Approach: Final Report and Presentation

For this task, the research team's approach was to prepare a final report of the work completed, including an executive summary, introduction, methodology, results for each task, the user's manual, and concluding remarks. The review procedures called for the Clear Roads Technical Advisory Committee to review and provide feedback on a draft report, prior to preparation of a final report according to Minnesota DOT template guidelines.

The research team's approach also included coordinating a meeting with the TAC to present the draft final report findings, and preparing a PowerPoint™ to support presentations at conferences or national and regional meetings by Clear Roads members.

Chapter 3
Task Results

Task 1 Results: Analyze and Review Research

The research team compiled, reviewed, and analyzed the results of the Phase I final report and other relevant research that focuses on chloride corrosion. The literature search and synthesis were conducted to document the state of the practice and the state of the art related to this project, with a focus on: the corrosive effect of chloride and non-chloride deicers to metals, the assessment of deicer corrosion to metals (e.g., test protocols), the identification of corrosion-prone parts on equipment/vehicles and their common forms of corrosion and related failure, and the mitigation of such corrosion via design improvements, maintenance practices, or the use of coatings and corrosion inhibitors. Recent research conducted by international sources was reviewed wherever available, along with the ongoing research and existing documents published by the Department of Defense (DoD), National Association of Corrosion Engineers (NACE), automotive/trucking industry, DOTs, and other key agencies.

The research team conducted keyword searchers of several databases to gather relevant information including:

- Google (https://www.google.com)
- Google Scholar (http://www.scholar.google.com)
- ScienceDirect (http://www.sciencedirect.com/)
- Engineering Village (http://www.engineeringvillage.com/search/quick.url)
- NACE database
- SCIFinder Scholar (http://www.cas.org/SCIFINDER/SCHOLAR/)
- CorrDefense (http://www.corrdefense.org)
- Patent Office (http://patft.uspto.gov/netahtml/PTO/search-adv.htm) or Google Patents
- DOD STINET (http://stinet.dtic.mil/)
- Montana State University Library (http://www.lib.montana.edu/)

Through the review and analysis, the team identified extensive and up-to-date information for inclusion in the manual. Based on the findings and after consulting with the Technical Advisory Committee, the research team concluded that practitioner interviews and laboratory research were not necessary for development of the user's manual.

Task 2 Results: Develop a Manual

Utilizing the information and research compiled from Task 1, the research team produced the user's manual, entitled *Manual of Best Practices for the Prevention on Vehicles and Equipment used by Transportation Agencies for Snow and Ice Control*.

The format of the final manual includes the following components:

- Chapter 1: Introduction
- Chapter 2: Corrosion Defined – includes descriptions and photos of general corrosion and ten types of localized corrosion
- Chapter 3: Causes and Effects of Corrosion – describes and illustrates the conditions that lead to and/or expedite corrosion, as well as the parts on DOT equipment most prone to

corrosion. The chapter also contains numerous photos illustrating damage to vehicles and equipment caused by corrosion.

- Chapter 4: Materials Used for Snow and Ice Control – lists and describes the most commonly used materials for winter maintenance operations
- Chapter 5: New Equipment Specifications – discusses some of the proactive approaches to corrosion prevention and material selection, including the refined methods and design improvements
- Chapter 6: Repair, Rehabilitation and Retrofitting of Existing Equipment – Includes recommended procedures for managing existing equipment, including an evaluation process for deciding which equipment is cost-effective to keep and maintain
- Chapter 7: Preventive Maintenance Practices for Equipment – includes specific practices for operators, mechanics, and supervisors
- Chapter 8: Training and Facility Maintenance – recommends training requirements for operators, mechanics, and management; also includes recommendations for proper facility management.

The Appendices include additional resources for reference, including

- Test Methods and Online Monitoring Techniques
- U.S. Marine Corps Corrosion Prevention and Control Plan
- Fleet Composition and Replacement Example Audit
- Practical Examples of Replaced or Modified Equipment

The User Manual is available under separate cover as a standalone document.

Task 3 Results: Final Report and Presentation

This document has been prepared and submitted as the final report for this project. The contents include all the components called for in the approach.

The PowerPoint™ presentation has been prepared and submitted to the Clear Roads TAC, and is included in this report as Appendix A as a pdf file.

The meeting with the TAC will be scheduled upon approval of this report.

Chapter 4
Conclusion and Recommendations

In light of the findings from the manual section, we provide the following conclusions and recommendations:

- Agencies should track the data relevant to analyzing the direct costs of deicer corrosion to their equipment assets and the direct benefits of countermeasures, so as to enable reliable, quantitative cost-benefit analysis. Currently, there is a clear absence of documented information, both in the published literature and in the practitioner community, which spells out such quantified values. Regardless of the issues that may be inherent to specific items, agencies should consider revising the corrosion management information they currently collect if they desire a more rigorous understanding of the costs and benefits associated with deicer corrosion to equipment.

- An evaluation process to determine fleet decisions includes a thorough inspection and operational check of each unit; an initial itemized list of repair/maintenance work for each vehicle; a general assessment rating using a standardized grading system (alpha-numerical or defined term); a priority ranking for each item, for example: Critical, Urgent, Needed, Recommended; a detailed cost estimate for each vehicle; a determination of expected service life if repairs/rehab are done; a decision as to course of action for each unit of equipment (Routine Maintenance Only; Selective Repairs; Full Repair/Rehab; Defer and Re-evaluate within __ days; No Maintenance or Repair-Deadline; Remove from Fleet by Sale, Trade-In, Transfer); and final cost estimate based on previous step.

- Supervisors are responsible for ensuring compliance with procedures and practices regarding vehicle inspection and operation. Frequent, random spot checks are one way to determine if employees are performing procedures properly. Counseling is recommended to correct deficiencies; the idea is to impress upon employees that the inspections are necessary to correct problems before they become worse. Supervisors should occasionally accompany an operator during an inspection as casual conversation often leads to mention of concerns by the operator of issues that have been noted before but not corrected.

- One especially important component of the dump truck chassis that must be checked is the frame; due to its design and construction, the frame members tend to collect rock salt. These accumulations, mostly in areas difficult to see or access, tend to be overlooked during washing. In the course of a few years, the corrosion can seriously weaken the structure and then the frame will break; too often this occurs when the truck has a full load of salt and is on the road.

- Wherever possible, agencies should consider using corrosion-inhibited products or non-chemical means for snow and ice control, so as to reduce the deicer corrosion to DOT equipment, other vehicles, and possibly transportation infrastructure.
- Agencies should consider corrosion-resistance requirements such as using stainless steel or non-metallic materials for corrosion-prone components at the stages of material selection and design. Existing knowledge about the anti-corrosion performance of various materials and design configurations in various deicer-laden service environments should be utilized to refine the equipment purchasing specifications developed by the transportation agencies. For instance, the zinc coating on aluminum and steel substrates can provide good anti-corrosion performance. Structures designed for resistance to atmospheric corrosion should always provide easy drainage from all exposed surfaces through the use of drainage holes or positioning techniques. Minimum diameter for all drains should be 9.525 mm (0.375 inches).
- General corrosion can be reduced by good material selection, anti-corrosion coatings, corrosion inhibitors and cathodic protection. Stress corrosion cracking (SCC) can be prevented by substituting a more resistant alloy, removing the tensile stress, or making the environment less aggressive. Removal of notches and other stress-concentrating features, rounded filets and angles, and corrosion control are the best ways to eliminate the corrosion fatigue. Crevice corrosion can be minimized by proper design of welded joints and gaskets that minimize crevices, and also sealing the crevices and periodic cleaning. Contact between dissimilar metals can lead to galvanic corrosion and should be avoided wherever possible. Where it is not possible, both metals should be coated. If feasible, dissimilar alloys should be electrically insulated from each other at their junction. Intergranular corrosion can be reduced by using the stabilized (321 or 347) or low-carbon (304L or 3I6L) stainless steels. “Lacquers” and “quick-dry” paints are most susceptible to the filform corrosion. Using steels containing Molybdenum, such as 316 stainless steel, can reduce pitting corrosion. The best way for reducing fretting corrosion is cleaning the affected surfaces and applying appropriate lubrication.
- Modifications should be made to DOT equipment to mitigate the risk of deicer corrosion. For instance, WSDOT implemented the following best practices: use of high-quality weather-proof terminations (e.g., buss-style connectors and compression fittings) in equipment specifications; elimination of junction boxes wherever possible, relocation of junction boxes to inside the cab off the floor; use of sealed brake canisters and sealed protective boxes surrounding hydraulic components and batteries; and use of high-quality weather-proof terminations and compression fittings in addition to shrink wrapping susceptible electrical wiring components.
- Some additional best practices by others include: eliminating areas where solids and liquids may accumulate; specifying rust-proof painted and epoxy-coated brake shoes when rebuilding; specifying self-healing undercoats for chassis; specifying fender liners

for chassis; using dielectric silicone for sealing damaged areas or connections; opening up closed areas (e.g. pillars) and allowing them to flush out easily; using welds to close and seal off certain areas that are difficult to drain; caulking welds prior to painting; avoiding any damage of wiring insulation; etc. Corrosion-prone components should be inspected and replaced on a regular basis. For instance any crack more than 1/16-inches wide and 1-1/2-inches long is cause for inspectors to place a vehicle “out of service.” Truck radiators should be replaced every two years, replacing rotating or strobe warning lights mounted directly on the cab roof with ones mounted on a cross-bar that clamps to the roof gutter channels. The same recommendation applies to radio antennas. This eliminates penetrations through the roof for screws and cables that are often difficult to keep weather-tight.

- Agencies should implement an extensive preventive maintenance program that may involve use of salt removers (also known as salt neutralizers) together with routine washing to keep the corrosive salt from building up; protecting of electrical components by sealing or moving them inside the cab; reapplication of post-assembly coatings; spray-on corrosion inhibitors and many other operational changes to improve the service life of DOT vehicles. This can be supplemented by corrective maintenance practices to minimize the negative impact of deicer corrosion to equipment assets.
- For surface preparation prior to coating, use of salt remover (rust remover) effectively increases coating performance. Grit blasting is the best method of surface preparation. However, in situations where grit blasting is prohibited or unusable for safety and environmental reasons; rust removers should be used for surface preparation prior to coating. In maintenance environments, rust removers should be used instead of traditional hand and mechanical wire brushes. When time is critical, time can be saved by using a rust converter. On the rusted surfaces, rust converters could be applied to the metal surface as a primer coat supplemented with oil based or epoxy paint. Rust converters are not suitable for damaged coatings.
- Wherever possible, agencies should consider de-humidified storage of their equipment and vehicles, or at least storage in a dry climate after washing. This is expected to minimize the risk of metallic corrosion and extend the service life of equipment and vehicles. Plows should be stored in a cool, dry place in the summer. A garage, pole barn, or lean-to are adequate storage locations. In the event you cannot store your plow under a roof or on concrete, make sure when it is stored outside that it is sitting securely on blocks or 2X4’s. In all stored locations plows should be covered; however, the cover should not be air tight. Tight covers can collect condensation underneath and can result in damage to the snow plow.
- Agencies should implement reactive maintenance practices to minimize the negative impact of deicer corrosion to their equipment and vehicles. For instance the following best practices should be implemented: neutralizing the existing corrosion (e.g., via

abrasive blasting and steam cleaning and/or chloride neutralizer spray) and cleaning the area or material that was corroded.

References

This final report includes information in the Executive Summary and Conclusion that is summarized from the Corrosion Manual. For source material information, please consult the reference list in the Corrosion Manual, available under separate cover as a standalone document.

Appendix A: Powerpoint Presentation

Manual of Best Practices for Corrosion Prevention on Vehicles used by Transportation Agencies for Snow and Ice Control

Manual of Best Practices for the Prevention of Corrosion on Vehicles and Equipment used by Transportation Agencies for Snow and Ice Control

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March, 2015

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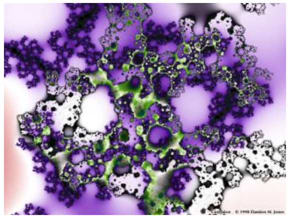
Outline

- Introduction
- Corrosion Definition
- Causes and Effects of Corrosion
- Materials Used for Snow and Ice Control
- New Equipment Specification
- Repair, Rehabilitation, and Retrofitting of Existing Equipment
- Preventive Maintenance Practices for Equipment
- Training and Facility Management
- Concluding Remarks

Introduction

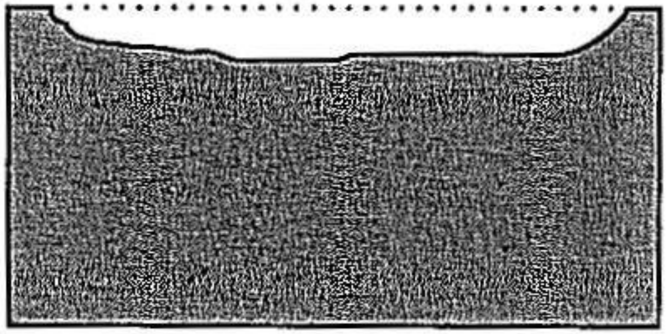
- Large amounts of deicers are applied onto winter roadways
- The deicers used by highway agencies are commonly chloride-based salts
- These corrosive salts are a major risk to DOT vehicles
- The benefit/cost ratio of further improving corrosion from deicers to DOT fleet equipment is estimated to be 13.2

Corrosion Definition



- Corrosion is deterioration of material due to the reaction with environment
- Carbon steel, cast iron, aluminum alloys, magnesium alloys, copper and copper alloys which are used in different components of winter maintenance vehicles can be corroded by deicers
- A variety of corrosion forms can take place in a vehicle which can be divided into specific groups.

General Corrosion

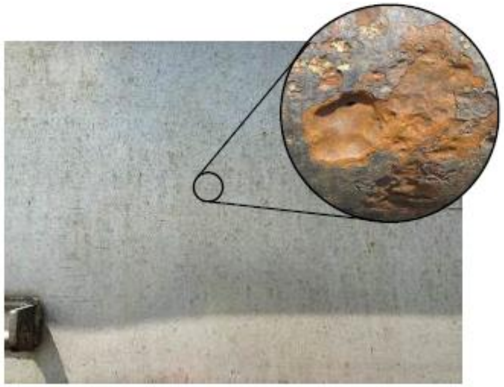
 

- Surface area deteriorates at the same rate: Due to poor material selection
- Can be included in design calculations, such as increasing wall thickness
- Easy to prevent by:
  - Good material selection
  - Coatings
  - Corrosion inhibitors

Localized Corrosion

- **Occurs on confined areas of a surface whereas the other parts of the surface experience a much lower amount of corrosion.**
- **It can cause unexpected failures**
- **Localized corrosion can be divided into many subclasses such as pitting, filform, intergranular, galvanic, stress corrosion cracking (SCC), fatigue, fretting, crevice, etc.**

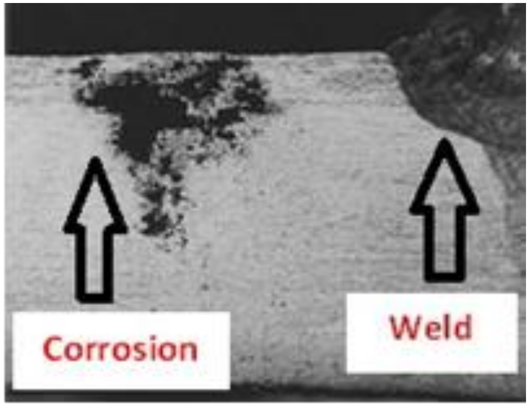
Pitting corrosion **is a severe form of localized corrosion in which damage in the shape of deep holes occurs.**



Crevice corrosion **occurs at the interface of a metal and another surface, often where a small volume of stagnant solution is contained.**

Filform corrosion **is a special form of crevice corrosion which happens beneath some types of coatings.**

Intergranular corrosion **occurs at grain boundaries. (Specifically for stainless steel this occurs in heat affected zones a short distance from the weld.)**

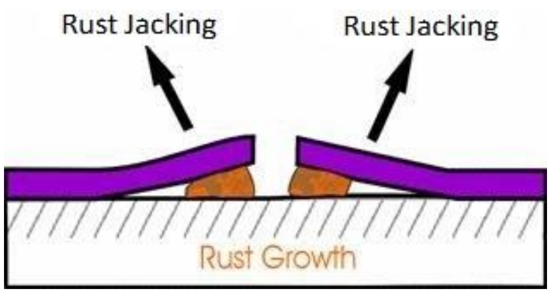


Galvanic corrosion **occurs when two dissimilar metals are in contact. The less resistant metal corrodes much more than the more resistant metal which corrodes very little or not at all.**

Stress corrosion cracking (SCC) **is the damage caused by the interaction of mechanical stress and corrosion.**

Corrosion fatigue **is a special kind of SCC caused by the combined effects of cyclic stress and corrosion.**

- **Rust jacking (a kind of corrosion fatigue) is the displacement of building elements due to the expansion of corrosion products.**



Fretting corrosion **happens at the interface between contacting, loaded metallic surfaces in the presence of slight vibratory motions.**

Causes and Effects of Corrosion

- Chloride deicers are easily available, relatively inexpensive, and easier to use for winter maintenance than non-chloride deicers despite their higher risk to vehicles and equipment
- The average estimated annual costs per agency for corrosion management:

✓ Training programs ($190,938)

✓ Materials selection ($320,667)

✓ Design improvements ($45,000)

✓ Corrosion monitoring and testing ($10,000)

✓ Proactive maintenance ($171,424)

✓ Reactive maintenance ($325,000)

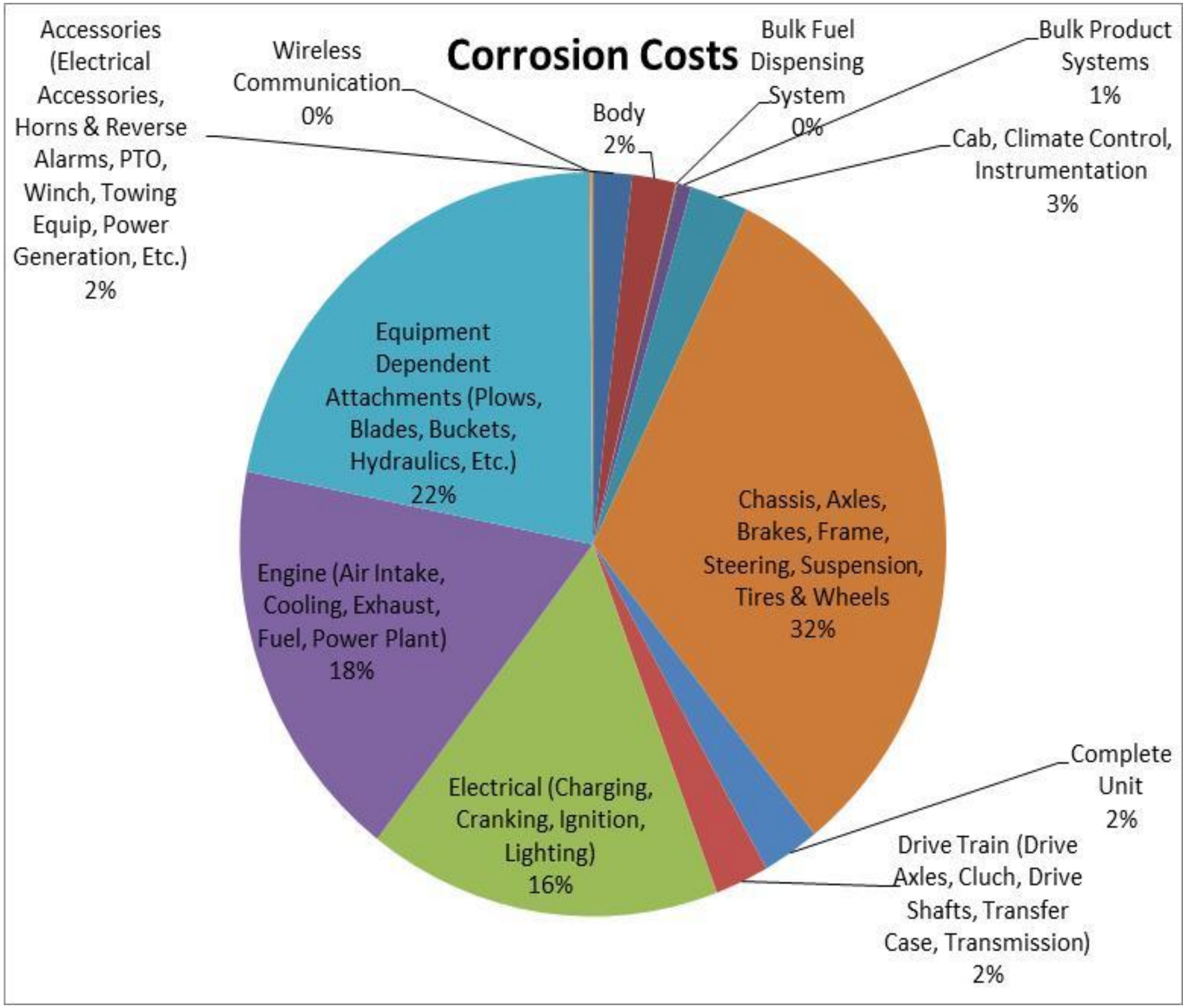
Corrosion-prone parts

Most Severe

- electrical wiring
- frames
- brackets and supports
- brake air cans
- spreader chute

High Repair Costs

- chassis
- axles
- brakes
- frame
- suspension
- tires & wheels
- electrical components



Cost-Benefit Analysis of Mitigating Deicer Corrosion to DOT Equipment

- For an average agency, it is assumed that the empirical 20/80 rule may apply to the 25% of corrosion costs which can be avoided by best practices, in the absence of actual data being available.
- In other words, you can reduce the current cost of corrosion risk related to deicer exposure by 80% × 25%, if the agency can increase its current investment in corrosion control by 20%. ***This is possible by conducting risk analysis to identify the critical 20% of corrosion-related failures and focusing more on training and risk-based maintenance.***
- Based on the data from the survey responses, **the benefit/cost ratio of further improving corrosion from deicers to DOT fleet equipment can be estimated as follows: (80% × 25% × $14,050,368) / (20% × $1,063,029) = 13.2**

Materials Used for Snow and Ice Control

- Generally, the materials used for snow and ice control are either chemically inert or active.
- ***Inert materials*** have no de-icing properties; they simply provide temporary traction on icy pavement such as sand.
- ***Chemically active*** de-icing materials are:
  - Sodium chloride
  - Calcium Chloride
  - Magnesium Chloride
  - Potassium Acetate
  - Calcium Magnesium Acetate
  - Sodium Acetate
  - Potassium Formate

New Equipment Specification; Build to Last

Is It Worth The Cost? YES

Many of these design and construction recommendations may add to the overall cost of purchasing a new vehicle in the range of 10-20% over an agency’s current specifications. However, this increase in capital equipment outlay is justified by the long-term reduction in maintenance (repair, replacement, and reconditioning) due to corrosion.

1. ***Metal Materials Selection***
2. ***Design Improvements***
3. ***Considerations for welded joints***
4. ***Coatings for Corrosion Protection***

Metal Materials Selection

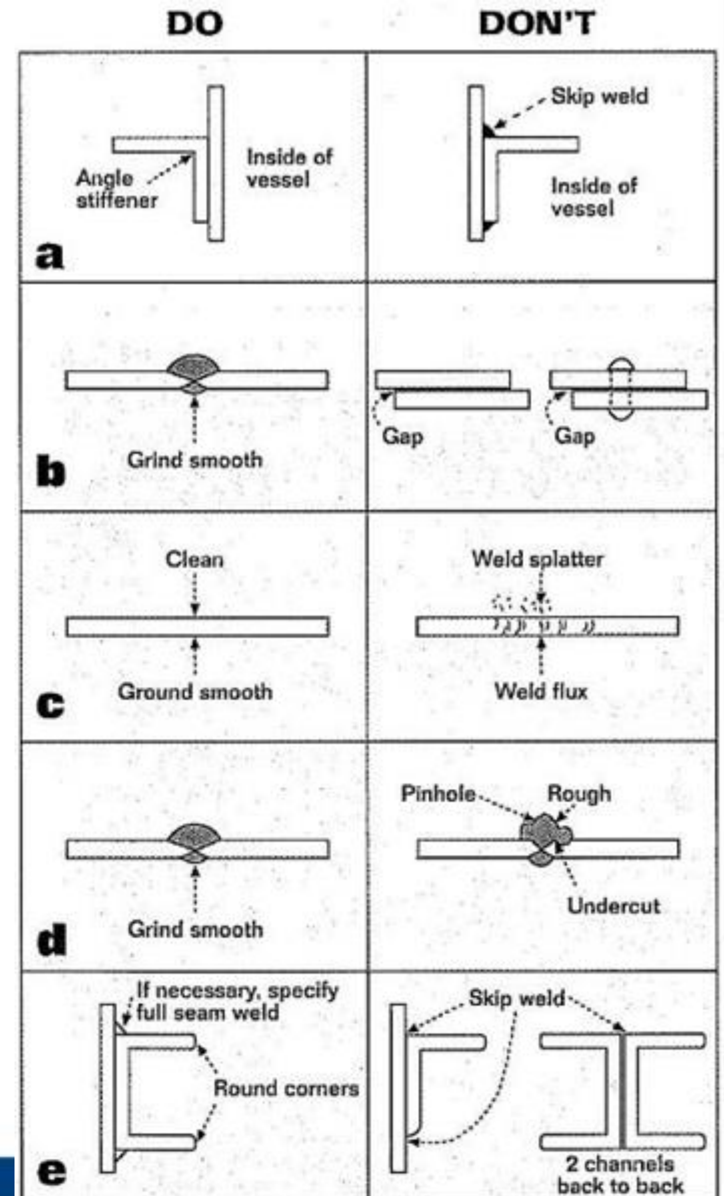
- Magnesium alloys and mill product forms of aluminum alloys 2020, 7079, and 7178 should not be used for structural applications.
- The use of 7xxx-T6 Al alloys should be limited to a thickness of no more than 0.080 inches. Where stress corrosion cracking is the main problem, 7075-T6 can be replaced by 7050-T7451.
- Higher carbon content and hardness in steel would make it susceptible to SCC or embrittlement. In SCC of austenitic stainless steel (300 series stainless steel) by chlorides, substitution of duplex stainless steels will often eliminate the problem.
- Using steels containing molybdenum such as stainless steel 316 can reduce pitting corrosion. Intergranular corrosion can be reduced by using the stabilized (321 or 347) or low-carbon (304L or 3I6L) stainless steels.

Design Improvements

- Where water may accumulate, include holes for drainage. Minimum diameter for all drains should be 9.525 mm (0.375 inches). The drainage holes should be shielded or oriented to avoid direct road splash.
- Avoid sharp corners that make it difficult for protective coatings to function.
- Remove notches and other stress-concentrating features. Rounded filets and angles also reduce stress concentrations.
- Crevice corrosion can be minimized by proper design of welded joints and gaskets that minimize crevices, sealing the crevices and periodic cleaning.
- Contact between dissimilar metals should be avoided. Where it is not possible, both metals should be coated.
- Use a coating with low water vapor transmission characteristics and excellent adhesion. Zinc-rich coatings can be considered for carbon steel because of their cathodic protection ability.

Considerations for welded joints

- Eliminate the weld splatter using blasting or chipping.
- Rough welding should be ground smooth.
- If feasible, welds should be double coated.
- Where corrosion is possible, use continuous welds instead of discontinuous welds (tack or skip welds).
- Remove brackets and extra metal followed by ground smoothing areas of previous contact.
- Remove weld flux after finishing welding.



Protect Your Asset by a Professional Coating!

Coatings for Corrosion Protection

- Coatings must meet many requirements including long-lasting, easy application, environmentally friendly, cost-effective, and high performance.
- An ordinary coating that is applied to a well prepared surface may perform better than a high-quality coating which is installed over a substrate with inappropriate or poor surface preparation.
- Use of salt remover (rust remover) effectively increases coating performance.
- In situations where grit blasting is prohibited or unusable for safety and environmental reasons; rust removers should be used for surface preparation prior to coating.
- When time is critical, time can be saved by using a rust converter.
- Rust converters could be applied to the metal surface as a primer coat supplemented with oil based or epoxy paint.
- Rust converters are not suitable for damaged coatings.

Repair, Rehabilitation and Retrofitting of Existing Equipment

- Evaluation Process for Fleet
  - A thorough inspection and operational check of each unit;
  - An initial itemized list of repair/maintenance work for each vehicle;
  - A general assessment rating using a standardized grading (alpha-numerical or defined term);
  - A priority ranking for each item, for example: Critical, Urgent, Needed, Recommended;
  - A detailed cost estimate for each vehicle;
  - A determination of expected service life if repairs/rehab is done;
  - A decision for the course of action for each unit of equipment; and
  - Final cost estimate based on evaluation
- Repair and Restoration
  - Restoration means replacing a component.
- Modifications
  - Such as replacing strobe warning lights mounted on the cab roof with ones mounted on a cross-bar.

Protect Equipment Assets by Preventive Maintenance!

Preventive Maintenance Practices for Equipment

- Two primary ways to deal with corrosion are reactive and preventive.
- ***Reactive methods*** are used to deal with existing corrosion by cleaning corroded parts with a rust removing compound, or replacing the ones that are too far gone for rehabilitation.
- A reactive treatment may in some cases be the most cost effective means of dealing with corrosion if the parts are easy to clean, or easily replaced and fairly inexpensive.
- ***Preventive methods*** are the proactive strategies which may involve the use of corrosion resistant materials for equipment components, dielectric grease, enclosed wiring connections, the use of sacrificial anodes, the use of coatings, the use of corrosion inhibited products, and frequent and regular washing of equipment.



Wash Vehicle Daily!


Washing

- Washing should be concentrated on trouble spots like frame rails, brake components, underneath of the chassis and other areas that tend to collect materials.
- Perform routine washing preferably with hot water and then fast drying.
- Preferably do not use a pressure washer, because water can be forced into areas and cannot escape which leads to corrosion.
- Use low pressure wash and high volume (flow rate) of about 300 psi/300 gpm.
- Use physical action together with washing to remove the road salt.
- Use salt removers (neutralizers) to remove the salt captured in crevices.
- The effectiveness of salt neutralizers is alloy specific.
- More cleaning liquid is not necessarily better, a high concentration of washing compound may attack some of the plastic components.
- Once active corrosion of metals has started, washing should be coupled with other means, e.g., applying spray-on corrosion inhibitor.

Electrical issues

- Eliminate the junction boxes wherever possible, and relocate them to inside the cab off the floor.
- Install modified protective cover for battery.
- Use high-quality weather-proof terminations (e.g., buss-style connectors) and compression fittings in addition to shrink wrapping susceptible electrical wiring components.
- Do not probe the wires to test for continuity and avoid any damage of wiring insulation.
- Apply a non-conductive; non-sodium based di-electric grease on all electrical connections (e.g. plugs, sockets, battery terminals, etc.).
- Make clean the electrical connectors on a regular basis (at least every six month) with water (not soap) and a wire brush, and re-grease with dielectric grease.
- Minimize connectors to the extent possible by using continuous wiring.
- Use anti-corrosive spray for protecting the battery posts and terminals.
- Do not apply paint to the rubber seals around lights.

Brake components/chassis

- Inspect all brake components even by removing brake drums to checking the entire lining surface, the brake shoe web, rollers, cam, etc.
- Be careful about automatic slack adjusters (ASA). Make sure ASAs are thoroughly lubed and there is no evidence of internal rusting.
- Require throttle, brake, and clutch pedals to be suspended in specifications.
- Install corrosion sealed air brake chambers and spray on protective coatings on all brake valves.
- Pull brake drums on a regular basis.
- Use rubberized undercoating for aluminum brake valves.
- In the rebuilding process specify rust-proof painted and epoxy-coated brake shoes.
- Specify self-healing undercoats, full fenders and fender liners for chassis.
- Install a large full width, full height under chassis sand guard on all front discharge sanding bodies.

Frame/body/beds and other parts

- Carbon steel fuel, hydraulic and air tanks can be replaced with aluminum tanks.
- Replace standard E-coat steel painted wheels with powder coated versions. Use powder coating for fuel tank and frame rails.
- Use stainless steel truck boxes, pre-wetting tanks, and sanders.
- Use zinc anodes in solution tanks and zinc nickel alloy engine oil pan.
- Use stainless steel couplers, under tailgate spreaders and cooler lines.
- Use poly faced snow plows to reduce corrosion and also lessen weight. Use stainless steel.
- Use greaseable tailgate linkages and attach them to on board automatic lube system.
- Replace radiators every two years (based on Washington State DOT recommendations).
- Install grit guards on wheels.
- Wrap hydraulic fittings with anticorrosive wrap.
- Use glad hand seals with dust flaps for air system.

In-field success of some proactive maintenance methods (a) aluminum fuel tank, (b) stainless steel hydraulic pipes, (c) poly tandem fender guards, (d) E-coated frame rail.

Training and Facility Management

- ***Operators,*** including contractors, need to know the basic characteristics of each product being used, including inert abrasives.
- ***Mechanics*** who repair and maintain the fleet need basic information on the materials used and the associated characteristics, especially an understanding of the corrosiveness of each chemical.
- ***Supervisors and managers*** are responsible for making sure that operators and mechanics and others involved in transporting, handling, and storing materials have the proper training.
- ***Good housekeeping*** should be an every-day standard at any agency facility where materials are stored and handled.

Accelerated durability test by US Army

Testing Condition

- **Gravel Road** ⇒ Cause s damage to coating
- **Rolling Hills Course** ⇒ Exposes vehicle to twist and turns
- **High Speed Track** ⇒ Simulates high speed travel and introduces high frequency vibrations
- **Frame Twister** ⇒ Promotes initiation of corrosion in stressed joints and seams

Based on GM tests that accurately simulate 10 years of cosmetic corrosion and 3 years of crevice corrosion

Concluding Remarks

- Agencies should track the data relevant to analyzing the direct costs of deicer corrosion to their equipment assets and the direct benefits of countermeasures, to enable reliable, quantitative cost-benefit analysis.
- Agencies should implement an extensive preventive maintenance program that may involve use of salt removers (neutralizers) together with routine washing; protecting of electrical components by sealing or moving them to inside the cab; reapplication of post-assembly coatings; spray-on corrosion inhibitors and many other operational changes which can be supplemented by corrective maintenance practices to minimize the negative impact of deicer corrosion to equipment asset.
- Supervisors are responsible for ensuring compliance with procedures and practices regarding vehicle inspection and operation, and also staff and contractors training.

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Q&A