Avoiding Corrosion of Electrical Connectors on Winter Maintenance Equipment

Synthesis Report

CLEAR ROADS

research for winter highway maintenance

CTC & Associates LLC

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16. Abstract

The electrical connectors of lighting systems used on snowplows and other winter maintenance equipment are exposed to the elements during winter operations. While lighting systems can fail because of mechanical or environmental issues, a more significant concern is the impact of corrosion.

A survey of winter maintenance professionals and review of relevant literature gathered information to aid transportation agencies in reducing—or avoiding—the corrosion of electrical connectors. The survey received responses from almost two-thirds of the 38 Clear Roads members and a small number of other agencies. Respondents described up to three electrical connector products their agencies use. Deutsch (TE Connectivity) and Weather Pack (Aptiv) connectors are the most frequently used by respondents, who also reported using a range of other connectors.

Respondents' best practices to avoid corrosion of electrical connectors were often echoed in the literature:

- Relocate electrical connectors to the interior of the vehicle's cab or other protected areas.
- Use modular electrical systems that can expand easily through standardizing wiring segments with connectors and have reservoirs of dielectric grease to deter moisture.
- Insulate electrical lighting and harness connectors with heat shrink tubing or use waterproof electrical connectors and high-quality, weatherproof terminals with dielectric grease.
- Avoid piercing or slicing cable wiring, which can open areas to corrosion.
- Inspect cables and wiring regularly for oxidation, corrosion, loose connectors and broken wires.
- Clean (and replace, if necessary) connectors frequently and apply dielectric grease or spray after cleaning.
- Establish a preventive maintenance program that maintains the vehicle's electrical system throughout the year.

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Executive Summary

The electrical connectors of the lighting systems used on wing plows, tow plows and other winter maintenance equipment are exposed to the elements during winter operations. While failures in winter maintenance equipment lighting systems can be the result of mechanical or environmental issues, a more significant concern is the impact of corrosion resulting from harsh winter operating conditions.

This synthesis project used a survey of winter maintenance professionals and a review of relevant literature to gather information that will aid transportation agencies in reducing—or avoiding—the corrosion of electrical connections on winter maintenance equipment. The survey received responses from almost two-thirds of the 38 Clear Roads members and a small number of other agencies. Survey respondents described up to three electrical connector products their agencies use and offered their feedback on effective practices to keep electrical connectors corrosion-free and extend their service lives.

Electrical Connector Use

Electrical connectors support the electrical systems in equipment used in a wide range of applications, from agriculture and construction to mining and marine applications. For public agency winter maintenance professionals, a reliable and corrosion-free electrical connector system is crucial to keeping winter maintenance equipment operating without interruption over successive snow seasons.

The electrical connectors most commonly used by respondents in their winter maintenance equipment are circular, cylindrical or rectangular. Most use crimp (solderless) connectors that require the wires to be crimped or staked to them. Soldered connectors use a heated filler material—the solder—to join the wires.

Contacts are typically male (pin) and female (socket) components that are installed in plug connectors attached to a cable end or in receptable connectors.

Two connector product lines are most frequently used by survey respondents:

- Deutsch (TE Connectivity)
- Weather Pack (Aptiv)

Both products are marketed as sealed connectors designed for use in harsh operating environments.

Deutsch Electrical Connectors

Benefits and Challenges

The 14 respondents describing their use of the Deutsch product were most impressed with its sealing capabilities and waterproof and dustproof (also referred to as “weatherproof”) properties. While several respondents described the ease of connection and disconnection as a benefit, others described challenging installation requirements, including the need for special tools and difficulties with crimping the pins.

Installation

Respondents also offered recommendations to aid the installation and ensure a good result. Agencies are encouraged to take care in not stripping more insulation than needed; inspect for tears, dirt and debris; and carefully apply dielectric grease. Users also noted the benefits of upfitting (augmentations

for an existing vehicle setup) to complete an installation and described custom fabrication of wiring harnesses and other supplemental equipment.

The Deutsch connector can be installed relatively quickly, as can most of the connectors described in this report. While installation times ranged from five to 60 minutes, most respondents complete installation of a Deutsch connector in 30 minutes or less.

Durability and Frequency of Corrosion

As was the case with much of the survey findings, respondents differed in their assessment of the durability of the Deutsch connector, with more respondents considering it very durable or even better than the few who noted the connector tends to corrode after several years. Some respondents qualified their assessments, noting that the frequency of corrosion depends on where and how often a truck is used, how well the connector assembly is sealed, and whether dielectric grease has been used to install and maintain the connector assembly.

Note: While the survey asked about the cost to purchase, the data provided for each of the connectors described varied widely and is not summarized in this executive summary. Electrical connector users are advised to check manufacturer or commercial websites for actual costs.

Weather Pack Electrical Connectors

Benefits and Challenges

The 15 Weather Pack users responding to the survey reported benefits that are similar to those described by Deutsch users—ready availability, ease of connection and disconnection, and the connector's weathertight or weatherproof properties. Like Deutsch users, Weather Pack user responses differed with regard to the ease of installation. While several respondents described the ease of connection and disconnection as a benefit, others highlighted challenges with crimping the pins or releasing them from the connector.

Installation

Weather Pack users also noted the importance of the use of dielectric grease when installing the connector and highlighted the need for special tools to crimp the pins. Installation time varied, with several respondents noting it is minimal or negligible and three respondents reporting an hourlong installation, particularly for complicated connectors. One respondent noted that the connectors "require a fair amount of time and dexterity" to install.

Durability and Frequency of Corrosion

Responses about durability also differed among Weather Pack users. More than half of Weather Pack users find the system to be very durable or better, with several noting that proper installation is key to better durability in the field. One respondent described "exceptional" durability if the connector is properly maintained, washed and coated with dielectric grease, while two respondents described marginal or fair durability. Though some reported rare or limited corrosion, more respondents noted that the frequency of corrosion is dependent on a range of factors: proper installation, truck location, the extent to which vehicles are cleaned and washed, and the use of dielectric grease.

Other Types of Electrical Connectors

Butt Splice and Heat Shrink Connectors

Four responding agencies install butt splice connectors. These solderless connectors provide what has been described as "a compression-type electrical connection between two opposing wire ends." Heat

shrink tubing can be used in conjunction with butt splice connectors to create a seal, insulating wires and protecting connections and terminals from harsh environmental conditions.

Users uniformly described these connectors as quick and easy to install and inexpensive, but differed in their assessment of durability and frequency of corrosion. Some consider the product's durability to be low to moderate while others describe it as "good," keeping assemblies free of corrosion for two to three years or longer.

Soldered Connectors

Most of the responding agencies use crimp connectors. Wires are joined and inserted into the connector and then crimped, sometimes with a special tool supplied by the manufacturer. Soldering connectors—heating a filler material to join wires—offers an alternative to crimping them.

Three agencies described the use of soldered connectors, with each reporting good results in terms of increasing durability and delaying—or eliminating—corrosion. Installation time varied, with one agency reporting just minutes of installation time while the others reported that an hour, possibly two, is needed to complete the installation. Heat shrink tubing is applied after soldering the connection. While the two most commonly used connectors (Deutsch and Weather Pack) are crimp connectors, at least two respondents solder them, either in place of crimping or to supplement it. For at least one agency that solders connections, this practice is limited to new installations because of the controlled environment the shop offers and the time needed to complete the installation.

Other Electrical Connectors

The connectors described in Appendix B are either used only by the agency describing them or are not specifically identified by the product name or vendor producing them. While these connectors varied in terms of their durability and frequency of corrosion, this group of seven respondents echoed the observations and concerns noted by other respondents, including the benefits of dielectric grease and dielectric silicone, and the importance of taking time and exercising care to regularly maintain the electrical connector assembly.

The only international respondent, from Norway, noted the use of Vaseline spray on all terminals during installation and the application of silicone grease, both before summer storage and during the winter operating season. Nonacid Vaseline is also used to fill the terminals and junctions.

Practices to Limit Corrosion

Agencies select products and establish maintenance practices that are intended to limit corrosion of electrical connectors. The most common of these practices among survey respondents is to install a waterproof or weatherproof connector, with only two respondents not making this product choice. Among the other most frequently mentioned practices is the use of dielectric silicone and dielectric grease for sealing connections, and the application of heat shrink tubing to cover the crimped area where a new terminal meets a wire.

Respondents elaborated on other practices used to limit corrosion, including their agencies' efforts to:

- **Relocate junction boxes**. Almost three-quarters of respondents relocate junction boxes inside the cab and off the floor. For those not doing so, a respondent offered one possible reason: The components in use may preclude moving junction boxes inside the cab. Most respondents able to relocate junction boxes reported the change has helped reduce corrosion, in one case "significantly."

- **Use continuous wiring**. Slightly more than 80% of respondents use continuous wiring to minimize the number of connectors.
- **Employ innovative practices and custom fabrication**. Most respondents described an innovative practice or custom fabrication that has successfully limited corrosion and extended electrical connector life. Some highlighted practices previously discussed (relocating junction boxes), while others reported on practices not widely used (using drip loops) or some type of customization (designing custom cables or wiring harnesses, repurposing an outboard motor boot).

Successes and Challenges

Common themes noted previously in this report are clearly evident in a more targeted examination of agency successes in preventing corrosion. The use of dielectric grease and ensuring proper maintenance are cited most frequently by respondents, with other common themes of cleaning and washing equipment, connector selection and the use of heat shrink tubing also represented.

Practices that are known to help limit corrosion of electrical connectors can also be an impediment to meeting that goal if an agency encounters resistance to implementing these practices. Maintenance and the regular cleaning and washing of equipment are such activities. Ensuring that staff take the time required for effective maintenance and thoroughly clean equipment on a regular basis is challenging for many agencies. Similarly, while dielectric grease is one of the most commonly used tools in the corrosion-fighting toolbox, it is effective only when properly applied and consistently used during regular periodic maintenance.

Examining the Literature

A literature search supplemented the information gathered in the survey of winter maintenance professionals. In addition to evaluating products and practices available in the winter maintenance environment, the search included products and resources used in maritime, military, freight, agricultural and other sectors that operate in harsh environments. Results of the search are presented in two categories: innovative technologies and products, and best practices.

Innovative Technologies and Products

Several new technologies and materials were reviewed that are designed to minimize corrosion in electrical connector assemblies, especially corrosion resulting from chemical deicers, dirt and moisture:

Aluminum. In the automotive industry, aluminum technology has evolved in response to the need to reduce vehicle weight in compliance with carbon dioxide emission control requirements and to reduce the use of copper to meet the increasing demand from electric vehicles. SMC (Selective Metal Coating) terminal technology replaces copper wiring with aluminum wiring, but galvanic corrosion can occur at crimped terminals. In a recent study, researchers monitored the behavior of these aluminum wires and will use the results to develop an effective anti-corrosion treatment that could increase the area where aluminum wires can be used.

Graphene coatings. Because of its "excellent chemical stability," graphene is considered an appropriate corrosion protective layer for metallic connectors and electrical terminals. In a recent study, thin graphene layers were grown on gold and silver terminals and thin-film devices that underwent mechanical, thermal/humidity and electrical tests. Researchers also studied the corrosion of metallic surfaces exposed to various materials, including saltwater. The corrosion rate in all samples with a graphene layer was substantially reduced compared to the uncoated samples.

NiobiCon. Winner of the 2021 *Materials Performance* (MP) Magazine Corrosion Innovation of the Year Award, NiobiCon technology is expected to "significantly disrupt the traditional connector market for any application that operates in a corrosive environment." NiobiCon connectors are designed for both underwater and above-water equipment that operate in corrosive environments. These connectors are reportedly "less expensive, smaller, lighter, more reliable and safer than current technology connectors," and can be mated and de-mated frequently without requiring maintenance.

Connectors developed using the NiobiCon technology are available through iCONN Systems, the first nonexclusive licensee of the patented technology.

Plastics. Crastin HR HFS—a new polybutylene terephthalate (PBT) hydrolysis resistance technology—improves the melt stability of plastics during molding. Commonly used in the automotive industry for electrical and electronic components, the new PBT hydrolysis resistance technology allows more stable manufacturing processes and quality improvements.

SuperCORR-A. SuperCORR-A is a "self-healing" compound that lubricates and protects electrical and electronic components and other products from moisture, salts, chlorides, acids and oxidation. The ultra-thin film coating (approximately 7 microns) protects components used in a range of industries, including transportation, marine, aerospace and military sectors. SuperCORR-A protects components from wear, moisture, and general and fretting corrosion, and does not attract contaminants.

Best Practices

Tips and Techniques Best Practices From the Literature

In the literature, the best practices for sustaining electrical connectors exposed to winter weather were similar to those reported by the winter maintenance professionals surveyed for this synthesis. Design considerations, materials selection and maintenance strategies are key in this effort. Among the practices most frequently mentioned:

- Relocate electrical components, such as connectors, to the interior of the vehicle's cab or other protected areas.
- Use modular electrical systems that can expand easily through standardizing wiring segments with connectors and have reservoirs of dielectric grease to deter moisture.
- Insulate electrical lighting and harness connectors with heat shrink tubing or use waterproof electrical connectors and high-quality, weatherproof terminals with dielectric grease.
- Avoid piercing or slicing cable wiring, which can open areas to corrosion.
- Inspect cables and wiring regularly for oxidation, corrosion, loose connectors and broken wires.
- Clean (and replace, if necessary) connectors frequently and apply dielectric grease or spray after cleaning.
- Establish a preventive maintenance program that maintains the vehicle's electrical system throughout the year.

Best Practices in Other Sectors

The search provided limited strategies and experiences from other sectors. A 2013 study reported that a U.S. Navy project developed cost-effective, corrosion-resistant boxes to protect electrical equipment, indicator lights and connectors used on its ships. The U.S. Marine Corps has established the Corrosion Prevention and Control Plan Program to mitigate the impact of corrosion and prolong the useful life of its ground equipment. Specific guidance for electrical connectors was unavailable. A Transport Canada Civil Aviation Safety Alert reported electrical connector corrosion on Dash-8-401 and Dash-8-402 series airplanes. The safety bulletin recommended electrically bonding cable shields to the aircraft structure at both ends of the cable harness. Colorado DOT introduced a bio-based corrosion inhibitor to its salt brines to reduce repairs and overall costs. These inhibitors, however, did not prevent moisture and debris from corroding electrical connectors.

Other Research

Other research provided an overview of corrosion-prone structural, hydraulic and electrical components and current approaches to manage deicer corrosion. A new Clear Roads pooled fund research project currently underway will compare information about anti-corrosion coatings to update corrosion management guidance for snow and ice control maintenance equipment.

Costs and equipment downtime related to corrosion were also reviewed. Electricals were among the top six categories reporting vehicle maintenance costs related to corrosion with an apparent “correlation between the corrosion costs and the use of chlorides.”

1 Introduction

1.1 Background

The electrical connectors of the lighting systems used on wing plows, tow plows and other winter maintenance equipment are exposed to the elements during winter operations. While lighting system failures can be the result of mechanical or environmental issues, a more significant concern is the impact of corrosion resulting from harsh winter operating conditions.

Clear Roads members requested this synthesis to explore the availability of an electrical connector assembly that, when properly installed and maintained, can avoid corrosion and survive the plowing environment for an entire winter season—and preferably longer.

1.2 Project Description

CTC & Associates employed a two-part strategy to gather information for this synthesis:

- *Survey of winter maintenance professionals*. A survey of Clear Roads member states, members of the Snow and Ice List-Serv and representatives of the Norwegian Public Roads Administration gathered information about experiences with electrical connectors exposed to winter weather (salt, wind and extreme cold) and the impact of corrosion. The survey sought information about a range of issues, including:
    - Connector types and the benefits and challenges of their use
    - Installation practices, costs, durability and frequency of connectors corroding
    - Innovative practices or custom fabrication that extend connector life

    Respondents could describe up to three different electrical connectors their agencies use.

- *Literature search*. An examination of publicly available domestic and international resources and in-progress research supplemented survey findings. In addition to the types of information available from or about public transportation agencies, this search sought information about experiences in other sectors and industries.

1.3 Survey Response

The survey received 27 responses from 26 agencies:

State Departments of Transportation

- Arizona (partial response)
- Colorado
- Connecticut
- Delaware
- Idaho
- Iowa
- Kansas
- Maine
- Massachusetts
- Michigan
- Minnesota
- Montana
- Nebraska
- Nevada (two responses)
- North Dakota
- Ohio
- Oregon
- Rhode Island
- South Dakota
- Texas
- Vermont
- Wyoming

Municipalities

- City of Bozeman (Montana)
- City of Farmington Hills (Michigan)
- City of West Des Moines (Iowa)

International Agencies

- Norwegian Public Roads Administration (Survey responses were provided by representatives from Veidekke, one of the largest maintenance contractors in Norway.)

Survey questions are provided in Appendix A. The full text of survey responses, including respondent contact information, is presented in a supplement to this report.

1.4 Organization of This Synthesis Report

A general description of electrical connectors and the terminology appearing in this synthesis report begins Chapter 2. This chapter continues with detailed assessments of the two most commonly used connectors among respondents—Deutsch and Weather Pack—followed by descriptions of the connectors less frequently used.

Chapter 3 continues the presentation of survey findings with respondents' practices to limit corrosion; in Chapter 4, respondents' successes and challenges are summarized. Chapter 5 supplements survey findings with a summary of relevant literature. The report's appendix provides the survey questions and descriptions of the connectors less frequently used by respondents.

While the survey conducted for this synthesis received responses from almost two-thirds of the 38 Clear Roads members, as well as responses from a small number of other agencies conducting winter maintenance, the survey findings do not serve as a representative sampling of all public transportation agencies. These results will, however, inform the practices of winter maintenance managers eager to limit corrosion on electrical connectors and keep their winter maintenance equipment on the road in successive winter seasons without interruption.

2 Electrical Connector Use

2.1 Introduction

Electrical connectors support the electrical systems in equipment used in a wide range of applications, from agriculture and construction to mining and marine applications. Equipment owners and operators across industries are eager to ensure these connectors that connect various circuits, systems and applications can withstand harsh operating environments and challenging terrain. For public agency winter maintenance professionals, a reliable and corrosion-free electrical connector system is crucial to keeping snowplows and other winter maintenance equipment on the road over successive snow seasons.

General Description

The electrical connectors most commonly used by respondents in their winter maintenance equipment are either circular, cylindrical or rectangular. Most use crimp (solderless) connectors that require the wires to be crimped or staked to them.

The typical connector has three main components:

- Main body of the connector (shell)
- Rubber or plastic insert
- Removable metal contacts

Figure 1. Deutsch DT Series Two-Way Female Connector

Contacts are typically male (pin) and female (socket) components that are installed in plug connectors attached to a cable end or receptable connectors. Figures 1 and 2 provide one example of a vendor's pin and socket components.

Figure 2. Deutsch DT Series Two-Way Male Connector

Terminology

Some of the terms used by respondents and appearing in this synthesis are presented below.

Butt splice connectors connect electrical wires and provide what has been described as "a compression-type electrical connection between two opposing wire ends."

Connector accessories include connector boots that are used when additional protection is needed, such as when pressure washers are used to clean equipment; dust caps and plugs to keep receptacles and plugs protected when not in use; mounting clips and brackets; and sealing (or filler) plugs for sealing unused cavities.

Contact cavities are the small holes in the connector that house a contact. When installed, each contact will have been crimped or soldered onto a wire or contain a filler plug if the cavity is unused.

Contacts are the pins and sockets that carry the current in the connector assembly. Pins and sockets are selected based on wire size, type (solid or stamped and formed), and application. Solid contacts are often selected when the installer plans to solder the connections.

Crimp connectors are used to connect one wire to another, safely terminating the wires by inserting them into the connector and then "crimping" the connector, sometimes with a special crimping tool supplied by the manufacturer, sometimes with pliers.

Heat shrink tubing is a plastic tube that can be shrunk with the addition of heat and placed around a crimped connection to create a seal, insulating wires and protecting connections and terminals from harsh environmental conditions.

IP (ingress protection) ratings are an indication of an electrical connector's resistance to moisture and contaminants. See page 12 for more information.

Soldered connectors offer an alternative to crimping. Filler metal—the solder—is heated up to join wires that have been twisted together or wrapped around one another. Once the solder cools and the operator confirms that the solder has penetrated all wires to be joined, the connection may be sealed with heat shrink tubing to prevent corrosion.

Wire size is measured using the American Wire Gauge (AWG) standard. Electrical connectors will accommodate different automotive wire sizes in a range from 000 (largest) to 40 (smallest).

Commonly Used Connector Products

Two connector product lines are most frequently used by survey respondents:

- Deutsch (TE Connectivity)
- Weather Pack (Aptiv)

An examination of respondents' use of Deutsch connectors begins below, followed by a similar presentation of survey findings about Weather Pack connectors, beginning on page 16. A review of other connectors used by respondents, often not identified by vendor or product name, begins on page 21 with butt splice and heat shrink connectors, followed by soldered connectors. The remaining connectors used by respondents are summarized on page 25; details of each of these less commonly used connectors are provided in Appendix B.

2.2 Deutsch Connectors

Designed and manufactured by TE Connectivity, Deutsch commercial connectors are described by the manufacturer as "environmentally sealed electrical connectors" that "are designed for harsh operating environments and critical applications where dirt, moisture, salt spray and rough terrain can otherwise contaminate or damage electrical connections."

Figure 3. Example of a Deutsch Connector

TE Connectivity describes two of the commercial product lines in the Deutsch portfolio that are marketed as withstanding rugged environmental conditions:

- DT products are "rugged rectangular connection systems with cantilever latches [that] utilize separate wedge locks."
- HD products are "robust circular connection systems with quick connect/disconnect bayonet coupling."

While a few respondents specified a series or model number—DT Series (*Colorado*, *Montana*) and Deutsch HD36-24-23SN-059 (*Kansas*)—most respondents did not identify the product line or type of Deutsch connectors they use. (The South Dakota respondent noted that Deutsch connectors are compatible with another connector brand, Amphenol AT circular connectors.)

Thirteen* state DOT respondents and one municipal respondent described their use of Deutsch connectors:

- Colorado
- Connecticut
- Delaware
- Iowa
- Iowa (West Des Moines)
- Kansas
- Minnesota
- Montana
- Nevada
- North Dakota
- Oregon
- Rhode Island
- South Dakota
- Wyoming

* While Vermont Agency of Transportation also uses Deutsch DT connectors, the respondent did not describe the agency's experience with them.

Product Benefits

Respondents were most impressed with the Deutsch connector's sealing capabilities and its waterproof and dustproof (also referred to as "weatherproof") properties. The ease with which the product can be connected and disconnected was also mentioned by several respondents, as was the product's ready availability. Table 1 summarizes survey responses.

Table 1. Benefits of Deutsch Connector Use

Type of Benefit	State and Description
Availability	*Connecticut*. More configurations are readily available at most auto parts stores. *Montana*. Unnecessary to stock different seal sizes. *South Dakota*. Availability of connectors with many terminals in them. *Wyoming*. Easy to access.
Easy to Use/Easy to Connect and Disconnect	*Connecticut*. Easy to connect and disconnect without any special tools. *Delaware*. Easy to connect and disconnect; also easy to add on wires or change out connectors. *Montana.* One action to connect and crimp saves time and effort. *Nevada* *Rhode Island*. Easy to use.
Reliability	*Kansas*. Very reliable.

Type of Benefit	State and Description
Sealing Capabilities	*Colorado, Iowa*. Better sealing design. *Montana*. Dual seal connector. *Nevada*. Good at keeping out dirt and moisture. *North Dakota*. Great sealing. *Rhode Island*. Environmental seal.
Strength and Durability	*Montana*. Pins are strong and durable. *Rhode Island*. Impact-resistant.
Weatherproof	*Delaware*. Waterproof and dustproof. *Minnesota*. Waterproof. *Oregon*. Product's IP 65 rating prevents moisture intrusion; also approved by the Society of Automotive Engineers. (See below for information about **IP Ratings**.) *Rhode Island*. Designed for harsh environments; weatherproof. *Wyoming*

IP Ratings

Ingress protection (IP) ratings were developed in Europe and are used internationally as a way to compare levels of sealing and the relative protection of electrical enclosures. An IP rating typically has two numbers, with the first number indicating protection from solid objects and the second rating protection from liquids. Generally, a rating of IP 65 translates to:

- 6 Dust-tight.
- 5 Water projected in jets against the enclosure from any direction will have no harmful effects.

The International Electrotechnical Commission offers more information about this rating scheme.

Product Challenges

Respondents using Deutsch connectors clearly differ with regard to the ease of installation. While several described the ease of connection and disconnection as a benefit (see Table 1), many more respondents described challenging installation requirements, including the need for special tools and difficulties with crimping the pins. Even with almost two-thirds of Deutsch users expressing concern about installing these connectors, two state DOT users—Minnesota and Rhode Island—find nothing challenging about this connector product. Table 2 summarizes survey responses.

Table 2. Challenges of Deutsch Connector Use

Type of Challenge	State (City) and Description
Cleanliness	*Colorado*. Maintaining cleanliness when servicing the connectors.
Cost	*Iowa*. More expensive.

Type of Challenge	State (City) and Description
Installation Requirements	*Iowa* (*West Des Moines)*. Crimping and pinning. *Kansas*. Can be "a little touchy" to hook up. *Montana*. Secondary lock to hold the pin in the connector body can be difficult to remove or install. *Nevada*. Requires "a good amount of dexterity and time" to assemble. *North Dakota*. Crimping the pins. *Oregon*. Must be free of dirt and dust before reassembly.
Special Tools Required	*Connecticut*. Requires correct tooling to install. *Delaware*. Requires correct skinning and crimping tools. Skinning back too much insulation leaves wire exposed outside the connector. *Iowa*. Requires a special crimper. *South Dakota*. Requires special crimp tools for the tab and barrel connector styles.
None	*Minnesota*, *Rhode Island*

Installation Practices

After describing their installation practices, both before and during installation, and the time it takes to install a Deutsch connector, respondents also offered recommendations to aid the installation and ensure a good result. These practices are summarized below.

Preparing for the Installation

- Clean the area with soap and water and dry it (*Colorado*).
- Do not strip more insulation than needed (*Wyoming*).
- Inspect for tears, dirt or debris before insertion (*Oregon*).
- Match the seal with the gauge of wire (*Minnesota*).

Installing the Connector

- Apply dielectric grease (*Iowa*) on the pins (*North Dakota*) and in the correct amount; too much dielectric grease can cause connector seal failure (*Delaware*).
- Fill the pins with solder to connect the wires rather than crimping them (*South Dakota*).
- Solder and crimp pins *(North Dakota*).
- Use home run cable and solid contacts; plug unused cavities (*Kansas*).

Special Tools

- Match the right pins for wire size and use a special crimping tool, using caution given the relatively little wire to crimp to (*South Dakota*).
- Use the correct crimping tool for the connector (*Minnesota*).

The Rhode Island respondent recommended fabricating a custom harness and installing a premade connector with heat shrink-wrapped butt splices. Two respondents provided an abbreviated start-to-finish description of a typical installation:

- Clean the area with soap and water and dry it, and select the correct plugs. Use proper pin sizing and the properly sized tool. Crimp the pins and assemble the connector using dielectric grease (*Colorado*).
- Cut harness to length and cut back harness insulation to proper length. Remove wire insulation from wire tips, crimping ends on wire tips. Push pins into the back of connectors in sequence (*Nevada*).

Installation Time

The time required for installation ranges from five to 60 minutes, with most respondents describing an installation of 30 minutes or less. One of the Nevada respondents noted that installation is time-consuming and "requires dexterity to assemble" the component parts. Other respondents noted that installation time varies based on the repair location, the wires needed, and the number of connectors and their size.

Figure 4. Portion of Deutsch Connector Assembly on Wing Plow
(*Source*: Delaware DOT)

Durability

Respondents were generally satisfied with the durability of the Deutsch connector, with some noting "robust" durability that is supported by an annual inspection (*Oregon*) and identifying it as the "best product we know of for connectors" (*Rhode Island*). Almost two-thirds of users consider the Deutsch connector to be very durable or better. None reported marginal or fair durability. Respondent comments are provided below.

Very Durable or Better

- Depending on abuse, the connector assembly typically lasts five years with no issues (*Kansas*).
- Described as the "best product we know of for connectors"; new repairs typically last longer than a season (*Rhode Island*).
- Durability of many years (*North Dakota*).
- High durability (*Iowa (West Des Moines), Minnesota*).
- Holds up very well in winter operations (*Delaware*).
- Robust durability, but inspect annually (*Oregon*).
- Very durable (*Nevada*).
- Very durable. Many manufacturers use this connector for original equipment manufacturer connections. Deutsch connectors outlast Weather Pack connectors when exposed to outdoor elements (*South Dakota*).

Figure 5. Deutsch Connector on Wing Plow
(*Source*: Delaware DOT)

Relatively Durable

- Durability of one year or more after service (*Colorado*).
- Good durability (*Iowa*).
- Tends to corrode after several years in operation and must be replaced (*Wyoming*).

Tips and Techniques Factors Impacting Durability and Corrosion

Common themes among users of Deutsch and Weather Pack connectors suggest that the following can enhance the durability of an electrical connector assembly and limit its corrosion:

- Select a weatherproof connector
- Follow appropriate installation procedures, which may mean purchasing special crimping tools
- Use dielectric grease
- Make sure the connector assembly is sealed
- Tie up the connector assembly to prevent it from pulling apart with the buildup of snow and ice
- Perform regular maintenance
- Keep the connector assembly as clean as possible

Frequency of Corrosion

For the most part, respondents find that the Deutsch connector resists corrosion, though the Wyoming respondent reported corrosion after two to three years. Other respondents noted that corrosion was dependent on a range of factors, including the level of use, proper sealing, and proper installation and maintenance. Responses are summarized below by the frequency of corrosion reported by respondents.

Rare or Limited

- Almost never corrodes provided the seal integrity is present (*Oregon*).
- Corrosion inside Deutsch connectors is very rare (*Nevada*).
- Low frequency of corrosion (*Iowa (West Des Moines)*).

After Several Years

- Corrosion after two to three years (*Wyoming*).

Factor-Dependent

- Corrosion is very limited but can happen if wires are not clean and dry (*South Dakota*).
- Depends on use of dielectric grease (*Kansas*).
- Depends on location on the truck; “better than Weather Pack” (*Iowa*).
- When sealed will provide many years of service. If not sealed properly, the connector can corrode in a year *(North Dakota*).
- With low use, a connector lasts 10 years or more. Frequent use causes water, salt and dirt to enter the connector and pin corrosion begins (*Minnesota*).

Cost to Purchase

Respondents offered a range of data on the cost and general affordability of the Deutsch connectors and accessories, with some noting these products are “fairly expensive” (*Nevada*) and “two to three times the cost of Weather Pack” (*Colorado*), while others noted that the cost was “middle of the road” (*Iowa*) and “moderate” (*Iowa (West Des Moines)*). Actual costs are available on the manufacturer's website. Deutsch products are also available from other sources, including national automotive parts chains and online retailers.

2.3 Weather Pack Connectors

The connectors now marketed by Aptiv as Weather Pack were previously known as Delphi or Delphi Packard Weather Pack connectors. A connector supplier describes this connector as "seal[ing] against moisture, dust and dirt. Weather Pack [c]onnectors can withstand exposure to extreme temperatures, moisture, harsh engine compartment fluids and chemicals, making them ideal for industrial, heavy equipment and marine applications."

Weather Pack connectors "are made of a self-lubricating silicone and are multiribbed to prevent moisture and other contaminants from entering the connector and causing terminal corrosion. The seal is placed on the wire and then the terminal is crimped to the seal."

Figure 6. Weather Pack Connector Used By Massachusetts and Oregon DOTs

Tips and Techniques Ordering a Weather Pack Connector

The connector supplier Waytek, Inc. offers this list of things to think about when ordering the Weather Pack connector:

1. Determine how many contacts are required.
2. Select the receptable and plug connector bodies.
3. Select the wire gauge of the terminals.
4. Order one terminal for each contact location in each connector body.
5. Choose cable seals based on the wire gauge.
6. Select the Weather Pack crimping tool required for the terminals and seals.
7. Purchase cavity plugs for all unused pin locations.

The supplier recommends protecting the wires within the connector application with the use of heat shrink tubing that protects against flame, abrasions, chemicals and automotive fuels.

Respondents from 14 state DOTs and one municipality described the use of Weather Pack connectors:

- Arizona
- Connecticut
- Idaho
- Iowa
- Iowa (West Des Moines)
- Kansas
- Maine
- Massachusetts
- Michigan
- Montana
- Nevada (two responses)
- North Dakota
- Oregon
- South Dakota
- Vermont

Product Benefits

Benefits of the Weather Pack connector system are similar to those described by Deutsch users, including ready availability, ease of connection and disconnection, and the connector's weathertight or weatherproof properties. Table 3 summarizes survey responses.

Table 3. Benefits of Weather Pack Connector Use

Type of Benefit	State (City) and Description
Availability	*Connecticut*. Universal design; readily available at most auto parts stores. *Iowa*. Comes with wires and seals. *Michigan*. Parts are readily available with multiple configurations. *Montana*. Readily available; common connector. *South Dakota*. Easily available.
Cost-Effective	*Arizona*. Never have to change them. *Connecticut*. Very cost-effective. *Montana*. Inexpensive. *Vermont*. Cost-effective for the longevity expected.
Easy to Connect and Disconnect	*Maine*. Easy to swap out lights by having to only pry apart connection. *Nevada*. Provides a break-apart point in the harness. *North Dakota*. Easy disconnect.
Sealing Capabilities	I*owa (West Des Moines)* *Nevada*. Makes a good seal against moisture. *North Dakota*. Sealed connection.
Weatherproof	*Idaho*. Usually pretty weatherproof overall. *Maine*. Seals the connection against moisture and dirt. *Massachusetts*. Weatherproof; protects against corrosion. *Michigan*. Watertight. *Nevada*. Keeps moisture from reaching connector.

Product Challenges

Like the users of Deutsch connectors, Weather Pack users differ with regard to the ease of installation. While several respondents described the ease of connection and disconnection as a benefit (see Table 3), others highlighted challenges with crimping the pins or releasing them from the connector. The North Dakota respondent expressed concern about multiple connectors needed for many wires. Still, four state DOT users—Arizona, Iowa, Michigan and South Dakota—find nothing challenging about using the Weather Pack connector. Table 4 summarizes survey responses.

Table 4. Challenges of Weather Pack Connector Use

Type of Challenge	State (City) and Description
Availability	*Idaho*. Finding exact replacement connectors/pins needed.
Installation Requirements	*Iowa (West Des Moines).* Crimping the pins. *Montana*. Larger in size. Must use correct tool and seal size; easy to compromise seal when crimping. *Nevada*: • Releasing pins from connector. • Require a fair amount of time and dexterity to assemble. *North Dakota*. Multiple connectors needed for many wires.
Part Size	*Vermont*. Small parts that, if not installed properly, pull apart and allow water and salt to enter.
Post-Installation Issues	*Maine*. Taking a connector apart after installation can be a challenge.
Special Tools Required	*Connecticut*. Special crimping tool required to properly crimp wire ends.
None	*Arizona*, *Iowa*, *Michigan, South Dakota*

Installation Practices

Weather Pack Installation practices, both before and during installation, are similar to those described by other connector users. These practices are summarized below.

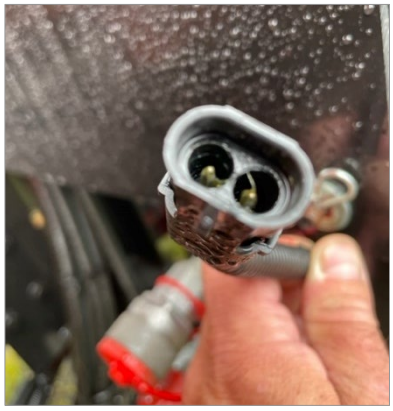

Figure 7. Interior View of Connector
(*Source*: Vermont Agency of Transportation)

Installing the Connector

- Apply dielectric grease (*Arizona, Iowa*) on terminals (*North Dakota*) and all connections (*Vermont*).
- Never cut or piece the cable (*Arizona*).
- Solder terminals and use correct wire seals (*North Dakota*).
- Solder the pins for better connection (*South Dakota*).

Special Tools

- Use proper crimping tools (*Vermont*).
- Use special tools to install pin and connectors (*Idaho*).

The Massachusetts respondent noted that installation is a bit more cumbersome than for other connectors, but the Weather Pack connectors "work well to protect against dirt, corrosion and moisture." Montana DOT uses these electrical connectors on lights, sensors and valves.

Tips and Techniques To Solder or Not Solder Connections?

Most of the responding agencies are opting for solderless connections in the electrical connector assemblies they install. The survey did not specifically address an agency's soldering practices, and it's not clear why agencies fall into one of the two camps. However, a state DOT using both approaches may shed light on one reason soldered connections are used less frequently by respondents—the need for a **more controlled environment** to install them.

Texas DOT solders connections in new installations, a more time-consuming practice that must be done in the shop where the environment can be controlled. When immediate repairs have to be made in the field—when mechanics and operators can't control the environment—the agency uses butt splice connectors that are crimped—not soldered—to safely seal them.

Installation Time

Installation time varied, with several respondents noting it is minimal or negligible (*Iowa, Michigan*, respectively, or a few seconds to a few minutes, depending on the wire condition (*South Dakota*). Three respondents reported an hourlong installation (*Maine, Vermont*), particularly for complicated connectors (*Idaho*). One of the Nevada respondents noted that the connectors "require a fair amount of time and dexterity" to install.

Durability

Respondents differed on the durability of the Weather Pack connector system, falling generally into the three categories below. More than half of these users find the system to be very durable or better, with several noting that proper installation is key to better durability in the field.

Very Durable or Better

- Durability is exceptional if properly maintained and washed and coated with dielectric grease (*Massachusetts*).
- Durability on these connectors has proven to be excellent (*Nevada*).
- If installed correctly these connectors hold up well (*Montana*).
- Life of the unit (*Arizona*).
- Overall very good (*Idaho*).
- Rated as "high" durability (I*owa (Des Moines)*).
- Very durable (*Maine*).
- Very good (*Michigan*).

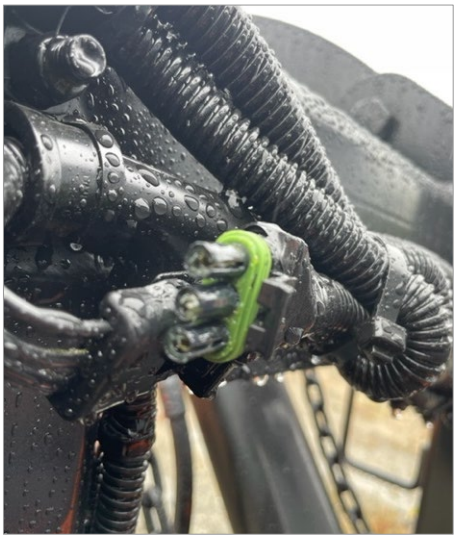

Figure 8. Installed Weather Pack Connector (*Source*: Vermont Agency of Transportation)

Relatively Durable

- Multiple years of service (*North Dakota*).
- Pretty dependable. Over time Weather Pack connectors get somewhat brittle from the outdoor elements (*South Dakota*).
- Seals are relatively durable if installed properly and tied up to prevent snow and ice buildup from pulling the connector apart (*Vermont*).

Marginal or Fair

- 3 out of a scale to 10 (*Connecticut*).
- Marginal (*Iowa*).

Frequency of Corrosion

For the most part, respondents find that the Weather Pack connector resists corrosion, with some noting that the frequency of corrosion depends on proper installation, where the connector is installed on the truck, and regular cleaning and washing of vehicles. Responses are summarized below by frequency of corrosion reported by respondents.

Rare or Limited

- Corrosion on these connector pins is almost nonexistent (*Nevada*).
- Corrosion seldom occurs (*Michigan*)
- Infrequent corrosion (*Nevada*).
- No corrosion (*Arizona*).

Figure 9. Installed Weather Pack Connector
(*Source*: Vermont Agency of Transportation)

After One to Two Years

- Typically occurs every one to two years; may vary based on connector location (*Maine*).

Factor-Dependent

- Corrosion occurs only when damage to gasket occurs and water gets in (*Idaho*).
- Depends on the location on the truck (*Iowa*).
- If clean, dried and out of elements, corrosion is very limited (*South Dakota*).
- If the vehicles are cleaned and washed properly, connectors will last the life cycle of the vehicle (*Massachusetts*).
- Minimal as long as connectors are pinned and seated correctly (*Iowa (Des Moines)*).
- When installed correctly, it may take years for corrosion; if the seal is not installed correctly, corrosion can occur in a year (*North Dakota*).
- With use of dielectric grease and properly secured, connectors should last many years (*Vermont*).

Cost to Purchase

The cost to purchase the Weather Pack connector and its accessories is deemed minimal or moderate by several respondents. The Massachusetts respondent noted that the Weather Pack product is a "few times more expensive" than nonweathertight connectors, and the Idaho respondent noted that costs can range from $10 to $200 depending on connector size and specialization. Actual costs are available from national automotive parts chains and online retailers.

Weather Pack Anti-Ice Applicator

Kansas DOT uses Weather Pack connectors that are described as "anti-ice applicators." It's unclear how the anti-ice applicator differs from the Weather Pack products described by other respondents. While

the Kansas respondent noted that installation of this connector requires just 30 minutes and is "easy to install" by crimping on pins, it "doesn't hold up [to a] corrosive environment." The product offers "fair" durability, with corrosion occurring within a year.

2.4 Butt Splice and Heat Shrink Connectors

A small group of respondents installs butt splice connectors that are often used in conjunction with heat shrink tubing. Use of these solderless connectors is described below by respondents from the city of West Des Moines, Iowa, and three state DOTs—Maine, Nevada and Rhode Island.

Iowa (City of West Des Moines)

Use of the butt splice connector described in Table 5, while quick to install and inexpensive, produces moderate to high corrosion.

Table 5. Connector Description: Butt Splice and Heat Shrink Tubing

Factor	Description
Connector Type:	Butt splice and heat shrink tubing.
Benefits of Use:	Fast; cheap.
Challenges of Use:	Higher frequency of corrosion.
Installation Practices:	Installed on the equipment's exterior.
Installation Time/Cost:	Low
Durability:	Low to moderate.
Frequency of Corrosion:	Moderate to high.
Cost to Purchase:	Low

Maine Department of Transportation

The heat shrink wire connector described in Table 6 is quick and easy to install but may corrode during a single winter season.

Figure 10. Maine DOT Connector

Table 6. Connector Description: Heat Shrink Wire Connector

Factor	Description
Connector Type:	Heat shrink wire connector.
Benefits of Use:	Quick, easy and affordable.
Challenges of Use:	None
Installation Practices:	Coat with heat shrink tubing.
Installation Time/Cost:	One hour.
Durability:	Not the best.
Frequency of Corrosion:	Annual corrosion is possible.
Cost to Purchase:	Kit of 300 is approximately $30.

Nevada Department of Transportation

Heat shrink tubing is used in the high-temperature connectors described in Table 7. Unlike the heat shrink tubing described in tables 5 and 6, the product described below is more durable and, when assembled properly, less likely to corrode during a single winter season.

Table 7. Connector Description: High-Temperature Connector With Heat Shrink Tubing

Factor	Description
Connector Type:	High-temperature connector with heat shrink tubing.
Benefits of Use:	Quick to install and effective at deterring corrosion and moisture.
Challenges of Use:	Requires a heat source to shrink the heat shrink tubing, which is required for these connectors.
Installation Practices:	• Cut wires and heat shrink tubing to length. • Install heat shrink tubing on wire ends. • Crimp connectors on wire tips. • Slide heat shrink tubing over connectors. • Apply heat source to heat shrink tubing until it shrinks evenly around wiring and connectors.
Installation Time/Cost:	Sometimes minutes; very affordable.
Durability:	Assembled properly, these connectors with heat shrink tubing effectively protect from moisture and corrosion for a minimum of two to three years, and longer.
Frequency of Corrosion:	Not frequent.
Cost to Purchase:	Inexpensive

Rhode Island Department of Transportation

The butt splice connectors described in Table 8 are purchased in bulk, easy to use and quick to install, and provide good durability.

Table 8. Connector Description: Butt Splice Connector

Factor	Description
Connector Type:	Butt splice connector.
Benefits of Use:	Easy to use and can be installed quickly; shrink wrapped.
Challenges of Use:	None
Installation Practices:	Strip wire, crimp on, heat shrink the splice and coat with additional heat shrink tubing.
Installation Time/Cost:	10 minutes.
Durability:	Good
Frequency of Corrosion:	New repairs last a long time.
Cost to Purchase:	Bulk purchase.

2.5 Soldered Connectors

Most of the responding agencies use crimp connectors. Wires are joined and inserted into the connector and then crimped, sometimes with a special tool supplied by the manufacturer. Soldering connectors—heating a filler material to join wires—offers an alternative to crimping them.

Before soldering, wire ends are prepared for the solder by removing a small amount of the shielding and the wires are twisted together or wrapped around one another. If it will be used to seal the assembly, heat shrink tubing is placed before connecting the wires.

The soldered connectors used by three state transportation agency respondents—Idaho, Kansas and Texas—are described below, followed by a discussion of other agency practices to add solder to a crimped connector or solder a connection when crimping might be recommended.

Idaho Transportation Department

Table 9 describes the agency's unspecified product and how it is used.

Table 9. Connector Description: Solder and Heat Shrink Tubing

Factor	Description
Connector Type:	Solder and heat shrink tubing.
Benefits of Use:	Easy to stock parts to repair wire, with "hardly any problems with corrosion when done correctly."
Challenges of Use:	Sometimes hard to get into tight spaces to repair a wire.
Installation Practices:	Strip wires, solder connection and install heat shrink over connection.
Installation Time/Cost:	Typically 5 minutes or less.
Durability:	Very good if done correctly.
Frequency of Corrosion:	Almost none if done correctly.
Cost to Purchase:	Minimal; perhaps $1 for a repair.

Kansas Department of Transportation

Table 10 describes another soldered connector that is used specifically for wing plow lights. This product appears to be more expensive than most of the connectors described by respondents.

Table 10. Connector Description: Phillips Coiled Cord

Factor	Description
Connector Type:	Phillips coiled cord for wing plow lights (19-4708).
Benefits of Use:	Fairly durable during use with wing plow moving in and out and up and down.
Challenges of Use:	Connection at truck plug socket not sealed very well.
Installation Practices:	Solder and heat shrink as much as possible.
Installation Time/Cost:	30 minutes.

Factor	Description
Durability:	Used for about eight years with good success.
Frequency of Corrosion:	Corrosion-free for two to three years if the operator applies dielectric grease when needed.
Cost to Purchase:	$50

Texas Department of Transportation

Texas DOT uses different types of connectors based on where they are installed—in the shop's controlled environment or in the field.

Connections are soldered in new installations, a more time-consuming practice that is done in a controlled environment. When the operating environment can't be controlled—for repairs in the field that require immediate attention—the agency uses butt splice connectors that are crimped to safely seal them. Table 11 describes the Tifco Industries connectors the agency uses.

Table 11. Connector Description: Tifco Industries Connector

Factor	Description
Connector Type:	Primarily use Tifco Industries' red, blue and yellow connectors.
Benefits of Use:	Fast repair; does a very good job keeping moisture out.
Challenges of Use:	It is time-consuming to solder new installations, which must also be done in a controlled environment in the shop. Challenges specifically associated with butt connectors used in the field include price and the impacts of brine on the wiring.
Installation Practices:	*For new installations in the shop*, the agency solders all connections and applies heat shrink tubing. When in the field, the agency checks for corrosion and any repairs needed and ensures the wiring is dry. *For repairs in the field*, the agency uses moisture-resistant sealant-filled butt connectors. These nylon-insulated connectors with insulation grip require no outside heat source or additional protective materials. The push-in butt connection requires the operator to simply strip the wires and push both ends into the butt connector.
Installation Time/Cost:	If in the shop and with the use of butt connectors: Two hours of mechanic time; approximately $80.
Durability:	Sealant-filled butt connectors work very well sealing the wire connection.
Frequency of Corrosion:	Typically, corrosion is caused by rubbed wires or a hole made by a light testing device where brine attacks the wire and causes corrosion. This type of corrosion is very frequent during winter weather operations.
Cost to Purchase:	Red: $0.93 each; blue: $1.04 each; and yellow: $1.47 each.

Other Agency Practices to Solder Connections

State transportation agencies in Montana, North Dakota, South Dakota and Vermont also described soldering connections:

- *Montana DOT s*olders connections "where possible."
- *North Dakota* DOT and *South Dakota* DOT use Deutsch and Weather Pack connectors. While these products are marketed as crimped connectors, both agencies solder them:
    - *Deutsch*. North Dakota DOT solders and crimps the pins; South Dakota DOT fills the pins with solder to connect the wires rather than crimping them.
    - *Weather Pack*. North Dakota DOT solders the terminals and uses the correct wire seals; South Dakota DOT solders the pins "for better connection."
- All wiring repairs made by *Vermont Agency of Transportation* require the operator to hard solder bare butt connecters and seal with high-quality adhesive-lined heat shrink tubing.

2.6 Other Electrical Connectors

Seven respondents described electrical connectors that did not fall into one of the connector categories previously presented in this synthesis report. With the exception of one of the respondents below, who described multiple products in a single response, these agencies are the sole user of the connector the respondent describes:

State Departments of Transportation

- Arizona
- Nebraska (multiple products addressed in a single description)
- Ohio
- South Dakota

Municipalities

- City of Farmington Hills (Michigan)
- City of Bozeman (Montana)

International Agencies

- Norwegian Public Roads Administration

These connectors are described in detail in Appendix B.

3 Practices to Limit Corrosion

3.1 Introduction

Selecting the right product is just one aspect of an agency protocol designed to limit corrosion of the electrical connectors installed on winter maintenance equipment. Carefully considering a range of factors when making product selections and performing the right type of maintenance at the right time are critical to limiting corrosion and keeping electrical connector assemblies in good working order throughout the winter season.

3.2 Common Practices to Limit Corrosion

Agencies select products and establish maintenance practices that are intended to limit corrosion of electrical connectors. The most common of these practices among survey respondents is to install a waterproof or weatherproof connector. Only the Vermont and Norway respondents did not report making this type of product choice. (Vermont Agency of Transportation primarily uses Weather Pack connectors, which are marketed as being weathertight and considered by other survey respondents using them to be so.)

Among the other most frequently mentioned practices is the use of dielectric silicone and dielectric grease for sealing connections, and the application of heat shrink tubing to cover the crimped or soldered area where a new terminal meets a wire. Table 12 summarizes survey responses.

Table 12. Common Practices to Prevent or Address Corrosion

State or Nation (City)	Apply Heat Shrink Tubing[1]	Clean Both Terminals	Install Sealed Wiring Harness	Install Covers or Shields Over Electrical Connectors	Install Waterproof or Weatherproof Connectors	Replace Both Terminals	Replace Wire Leading Into Terminals
Colorado	X	X	X	X	X	X	X
Connecticut	X				X		
Delaware					X		
Idaho	X	X	X		X	X	X
Iowa	X	X	X		X	X	X
Iowa (West Des Moines)	X	X	X	X	X	X	X
Kansas	X	X	X	X	X		
Maine	X	X	X	X	X	X	X
Massachusetts	X	X	X		X	X	
Michigan	X	X	X	X	X	X	X
Michigan (Farmington Hills)	X	X		X	X	X	X
Minnesota			X		X	X	
Montana	X	X	X	X	X	X	X
Montana (Bozeman)	X	X	X		X	X	X
Nebraska	X	X	X		X	X	X
Nevada	X	X	X	X	X	X	X

State or Nation (City)	Apply Heat Shrink Tubing[1]	Clean Both Terminals	Install Sealed Wiring Harness	Install Covers or Shields Over Electrical Connectors	Install Waterproof or Weatherproof Connectors	Replace Both Terminals	Replace Wire Leading Into Terminals
North Dakota	X	X			X	X	X
Ohio		X			X	X	
Oregon	X	X	X		X	X	X
Rhode Island					X		
South Dakota	X	X	X	X	X	X	X
Texas	X	X	X	X	X	X	X
Vermont	X		X			X	X
Wyoming					X	X	
Norway	X	X					
TOTAL	**20**	**19**	**17**	**10**	**23**	**20**	**16**

1 The full response option included in the survey: *Apply heat shrink tubing to cover the crimped area where a new terminal is soldered onto the cleaned wire*.

Table 12. Common Practices to Prevent or Address Corrosion (continued)

State or Nation (City)	Seal Connection Wires	Use a Fixed Terminal Cleaning Tool Kit	Use an Appropriate Wire Brush and Aerosol Contact Cleaner	Use Dielectric Silicone for Sealing Connections	Use Drip Loops	Use Electrical Connector Boots That Can Be Sealed	Use Nonconductive Dielectric Grease
Colorado	X	X	X	X		X	X
Connecticut				X			X
Delaware				X			
Idaho				X			X
Iowa	X			X		X	X
Iowa (West Des Moines)	X	X	X	X	X	X	X
Kansas	X		X	X		X	X
Maine	X	X	X	X		X	X
Massachusetts	X		X	X	X	X	X
Michigan	X	X	X	X	X	X	X
Michigan (Farmington Hills)	X		X	X		X	X
Minnesota	X		X			X	
Montana	X	X	X	X	X		X
Montana (Bozeman)	X	X	X	X		X	X
Nebraska	X		X	X			X
Nevada	X	X	X	X	X	X	X
North Dakota		X		X			X
Ohio	X			X		X	X
Oregon	X						

State or Nation (City)	Seal Connection Wires	Use a Fixed Terminal Cleaning Tool Kit	Use an Appropriate Wire Brush and Aerosol Contact Cleaner	Use Dielectric Silicone for Sealing Connections	Use Drip Loops	Use Electrical Connector Boots That Can Be Sealed	Use Nonconductive Dielectric Grease
Rhode Island							X
South Dakota	X		X	X		X	X
Texas	X		X	X		X	X
Vermont				X			X
Wyoming				X			
Norway				X			X
TOTAL	**17**	**8**	**14**	**22**	**5**	**14**	**21**

Tips and Techniques Upfitting to Prevent Corrosion

Careful product selection and thorough, consistent maintenance contribute to keeping corrosion at bay. Some respondents are taking it a step further and upfitting connector assemblies to better meet agency needs. Nissan describes an upfit as "a set of vehicle accessories or augmentations for an existing vehicle that are customized to the worker's needs."

In Minnesota, the DOT's custom wiring harnesses are used to upfit all auxiliary equipment for snowplow trucks. The Rhode Island DOT respondent described two types of upfitting. In the first, the agency runs PVC pipes as a chase for wires that go the rear of the truck. A second upfit relocates the master distribution center within the cab under the passenger seat, with the rear junction box mounted upside down at the rear of the truck.

3.3 Other Corrosion-Fighting Practices

Respondents described other practices used to limit corrosion, including their agencies' efforts to:

- Relocate junction boxes.
- Use continuous wiring.
- Employ innovative practices and custom fabrication.

Relocate Junction Boxes

Relocating the junction boxes that enclose wire connections from the truck's exterior to inside the cab has been recommended in guidance documents to safeguard the box and its contents from the harsh winter operating environment.

Figure 11. Junction Box Inside Cab
(*Source*: Delaware DOT)

Relocation Practices

Almost three-quarters of respondents relocate junction boxes inside the cab and off the floor. For those not doing so, the Farmington Hills, Michigan, respondent offered one possible reason: The components in use may preclude moving junction boxes inside the cab. Other respondents offered a few details of agency practice:

Figure 12. Junction Box at Battery Box
(*Source*: Delaware DOT)

- *Colorado DOT* hangs electronics and junction boxes on a panel located on the seat frame under the passenger seat.
- For its auxiliary wiring harness, *Minnesota DOT* uses a power distribution module (PDM) that is mounted behind the seat on an aluminum panel the agency constructs. Older junction boxes have also been relocated.
- *Montana DOT* just started moving junction boxes inside the cab this year.
- *Rhode Island DOT* locates the master distribution center for the upfit within the cab under the passenger seat. A rear junction box is mounted upside down at the rear of the truck.
- *South Dakota DOT's* technicians will try to keep junction boxes in the cab or in a sealed box placed in the dump box.
- *Texas DOT* houses both junction boxes and switches for snowplows inside the cab.

Figure 13. Junction Box in Tow Plow
(*Source*: Delaware DOT)

Relocation Impacts

More than half of the respondents relocating junction boxes described how this change has impacted corrosion, with most reporting the change has helped reduce corrosion, in some cases "significantly" (*Delaware*) or has produced a "drastic" reduction (*Connecticut*). Other respondents reported these impacts:

- Reduced corrosion has resulted from the additional cost to have the transmission electronic control unit mounted in the cab (*Iowa*).
- For over 20 years, the agency's use of home run wiring from the cab has produced "a big benefit," including much less repair time (*Kansas*).
- A transmission control module located in the cab along with a quality junction box protects against the elements (*Massachusetts*).
- Electrical connectors are "much less prone to corrosion" as a result of the relocation (*Michigan*).
- This practice limits the amount of contamination that comes in contact with boxes and/or their connectors (*Nebraska*).
- This practice "definitely helps with preventing corrosion" (*Nevada*).
- While the agency has moved some boxes off the floor, the biggest benefit is associated with simply relocating junction

Figure 14. Exterior-Mount Junction Box
(*Source*: Vermont Agency of Transportation)

boxes, power modules and control modules from outside the cab to inside of the cab. This has dramatically increased their reliability (*Ohio*).

- Relocating wiring has eliminated corrosion affecting strobe lighting used on winter maintenance equipment. The agency's Whelen lighting system is set up so that all wiring enters the junction box in the cab (*Vermont*).

Tips and Techniques Relocating Junction Boxes

Junction box relocation is a common practice among respondents and appears to be yielding good results. Some customize the placement, hanging the junction box on the seat frame or on a panel the agency constructs. If specific components preclude placing the junction box inside the cab, at least one respondent places a junction box in a sealed box placed in the truck's dump box.

This relatively simple practice is reducing corrosion, which reduces repair time and keeps more of an agency's winter maintenance fleet on the road without interruption during the winter season.

Continuous Wiring

Slightly more than 80% of respondents use continuous wiring to minimize the number of connectors. Among the state DOTs not employing this practice are Iowa, Minnesota and Texas.

Tips and Techniques Using a Custom Wiring Harness

A wiring harness is described by a connector supplier as "an organized set of wires, terminals and connectors that run throughout the entire vehicle and relay information and electric power playing a critical role in connecting a variety of components." Some respondents have found ways to optimize this critical component of an electrical connector assembly:

- **Minnesota DOT** works with MNSTAR Group, a Minnesota company specializing in custom wiring harnesses, to manufacture the harnesses the agency designs for all auxiliary equipment in plow trucks. The harnesses have no splicing or butt connectors, but there are connection points for ease of repair.
- **West Des Moines, Iowa**, collaborates with a local truck building company that has introduced the agency to custom truck harnesses with sealed connections. When wires need to be replaced, they can be removed, repaired and reinstalled to power lights and other accessories.
- **Ohio DOT** is working with Truck-Lite to create an integrated wiring harness for all lighting directed to the back of a snowplow truck and lighting for the truck body, sander and front plow.

Innovative Practices and Custom Fabrication

Most respondents described an innovative practice or custom fabrication that has successfully limited corrosion and extended electrical connector life. Some highlighted practices previously discussed (relocating junction boxes), while others reported on practices not widely used (using drip loops) or some type of customization (designing custom cables or wiring harnesses, repurposing an outboard

motor boot). Table 13 summarizes survey responses. While some of the practices described below may not be widely considered to be innovative (washing vehicles, for example), they are no less effective.

Table 13. Innovative Practices and Products

Practice or Product	State (City) and Description
Adhesive Tape	*Oregon*. Use polyolefin adhesive tape to wrap up the connector, sealing out moisture intrusion.
Custom Cables	*Kansas*. Use cables on a chassis custom-built by Whelen, Force or Certified/Cirus.
Dielectric Grease	*Maine*, *Massachusetts*, *Michigan* (external connectors), *Rhode Island*, *South Dakota*, *Texas*, *Vermont* *Montana (Bozeman)*. Treat connectors exposed to the elements with dielectric grease when connecting or disconnecting them. (The Oregon DOT respondent noted that dielectric grease had previously been used by the agency, but deicer chemicals dissolve it.)
Drip Loops	*Montana*
Eliminate Connectors When Possible	*Vermont*
Haldex Boxes	*North Dakota* (The respondent did not further describe this product. A variety of suppliers provide Haldex hydraulic pumps and power units.)
Heat Shrink Tubing	*North Dakota*, *Oregon*, *Maine*
Installation Practices	*Rhode Island*: • Use long runs whenever possible, avoiding sections. • Run PVC pipes as a chase for wires that go the rear of the truck for the upfit.
Junction Box Location	*Montana*. Move junction boxes to keep moisture from collecting on them. *Nevada*. Mount junction boxes inside the operator station when possible. When not possible, mount boxes in locations that aren't exposed to dust and moisture. *Wyoming*. Build a console inside the cab for all added lights and fuses.
Product Selection	*Iowa*. Consider new connector styles installed by the manufacturer. (New trucks purchased by the agency over the last four years have a new style of connector that is installed by the manufacturer.) *Michigan (Farmington Hills)*. Change flat-type connector to a seven-pin round-type connector. *Rhode Island*. Use an outboard motor boot for exit of wires from the cab.
Proper Maintenance	*Massachusetts*. Employ proper maintenance practices during preventive maintenance intervals. *Nevada*. Apply corrosion preventative on battery clamps and other connections with high risk of corrosion. *South Dakota*. Clean all connections with plug cleaner when corrosion is present.
Silicone	*South Dakota*. Use silicone in all connectors.

Practice or Product	State (City) and Description
Solder or Solder With Heat Shrink Tubing	*Idaho*. Use solder and heat shrink or heat shrink butt connectors will fail. *Montana*. Solder connections where possible. *Vermont*. Hard solder bare butt connecters and seal with high-quality adhesive-lined heat shrink tubing when performing repairs. (The Wyoming respondent noted heat shrink can be a vehicle to trap moisture and induce corrosion.)
Washing	*Massachusetts*. Ensure vehicles are properly washed after each event.
Wiring and Wiring Shields	*Michigan (Farmington Hills)*. Use heavier gauge wire. (The city has worked with Monroe Truck Equipment, the truck manufacturer, which "has helped some.") *Texas*. Build shields to cover wiring.

3.4 Electrical Connector Specifications

None of the responding agencies provided formal specifications that consider the potential for corrosion of electrical connectors. Oregon DOT's electrical specifications examine wiring and identify forbidden connectors but do not formalize water intrusion details for these connectors. Nevada DOT considers the electrical connector rating for the appropriate amperage draw of the wires depending on the gauge of the wire. Neither agency provided supporting documentation.

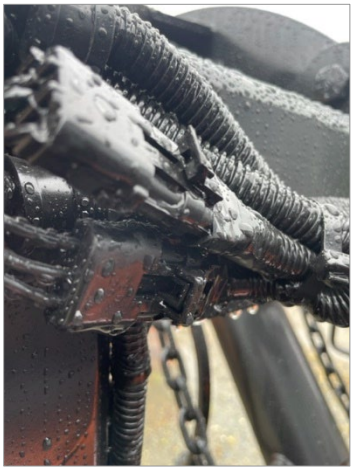

Figure 15. Example of a Wiring Harness
(*Source*: Vermont Agency of Transportation)

4 Successes and Challenges

4.1 Introduction

Previous chapters briefly examined the benefits and challenges of the electrical connectors reported by the responding agencies. This chapter takes a more focused look at the successful practices and challenging circumstances respondents experience when installing, maintaining and replacing electrical connectors.

4.2 Successes in Preventing Corrosion

Common themes noted previously in this report are clearly evident in a more targeted examination of agency successes in preventing corrosion. The use of dielectric grease and ensuring proper maintenance are cited most frequently by respondents, with other common themes of cleaning and washing equipment, connector selection and the use of heat shrink tubing also represented. Table 14 summarizes survey responses.

Table 14. Successful Practices or Products That Prevent Corrosion

Practice or Product	State (City) and Description
All Practices in Table 12 (see page 26)	*Iowa (West Des Moines), Michigan, Michigan (Farmington Hills)*
Clean/Wash Equipment	*Colorado* *Nebraska*. Clean equipment after storm events to remove as much deicing material residue as possible.
Connector Selection	Two respondents recommend a specific connector brand: • Deutsch (*Rhode Island*). • Weather Pack (*Maine*).
Custom Harness	*Minnesota*. The agency's custom harnesses are made by a company for upfitting all auxiliary equipment for snowplow trucks. *Montana*. Use molded wire harness.
Dielectric Grease	*Iowa, Maine, Massachusetts, North Dakota* *Montana (Bozeman)*. Supply operators with tubs of dielectric grease to treat connectors when installing or removing them. *Nevada*. Apply dielectric grease on electrical terminals and connections. *Vermont*. Apply nonconductive dielectric grease to all electrical connections, including sealed connectors, before a unit is placed in service; ensure the same application is made for all subsequent repairs.
External Factors	*Connecticut*. Minimize exposure to corrosive environments. *Idaho*. Use less salt. *South Dakota*. Keep connectors out of elements as much as possible.
Heat Shrink Tubing	*Oregon, Rhode Island, Texas*
Junction Boxes	*Nevada*

Practice or Product	State (City) and Description
Maintenance	*Delaware*. Ensure connectors remain properly connected; use dummy connectors when not in use. *Nebraska*. Perform proper maintenance. *Ohio*. Perform routine checking, cleaning and regreasing of the terminals. Do not use pressure washers around connectors. Instead, use a low-pressure garden hose or fire hose with high volume and low pressure. *Norway*. Perform proper maintenance to ensure good sealing so moisture will not penetrate.
Splicing	*Rhode Island*. Use butt splice terminal wire connectors. *Wyoming*. Do not splice connectors.
Weatherproof or Weather-Resistant Connectors	*Massachusetts, Ohio, South Dakota*, *Texas* *Oregon*. Use IP 65 weatherproof connectors; if needed, apply heat shrink tubing.

Tips and Techniques **Dielectric Silicone and Dielectric Grease—Key Players in the Fight Against Corrosion**

Some consider it an innovative practice, others consider it a best practice, but most respondents use dielectric silicone and dielectric grease when installing electrical connectors. While nearly the same number of respondents use both practices, many more elaborated on their use of dielectric grease when installing and repairing connectors, describing protocols to treat connectors with dielectric grease when connecting or disconnecting them, applying the grease consistently but not applying too much, and ensuring adequate supplies of the product are available to operators and mechanics.

Oregon DOT is among the small number of responding agencies not using dielectric grease. While other agencies tout the effectiveness of dielectric grease as a corrosion fighter, the Oregon DOT respondent reported the tendency of deicer chemicals to dissolve it. None of the other respondents reported this concern, and the literature search identified dielectric grease as an effective tool to combat corrosion. The literature search also identified another lubricant—SuperCORR-A—that provides corrosion protection for components used in a range of industries. See page 38 for details.

4.3 Challenges in Preventing Corrosion

Practices that are known to help limit corrosion of electrical connectors can also be an impediment to meeting that goal if an agency encounters resistance to implementing these practices. Maintenance and the regular cleaning and washing of equipment are such activities. Ensuring that staff take the time required for effective maintenance and thoroughly clean equipment on a regular basis is challenging for many agencies. Similarly, while dielectric grease is one of the most commonly used tools in the corrosion-fighting toolbox, it is effective only when properly and consistently applied. Table 15 summarizes respondents' challenges in preventing corrosion.

Table 15. Challenges in Preventing Corrosion

Type of Challenge	State (City) and Description
Clean/Wash Equipment	*Massachusetts*. Keeping the truck washed; this is among "the most important" challenges. *Montana*. Performing overall cleaning of equipment on a regular basis to keep corrosion at a minimum. *Nebraska*. Thoroughly cleaning equipment.
Connections	*Connecticut*. Frequent disconnection/connection. *Iowa (West Des Moines)*. Keeping moisture out when connections are taken apart and put together frequently. *Michigan (Farmington Hills).* Keeping corrosion out of the terminal or connector at any place with a connection. *North Dakota*. Nonsoldered connections.
Dielectric Grease	*Delaware*. Ensuring operators do not overapply dielectric grease. *Iowa*. Applying dielectric grease on all connectors. *Vermont*. Applying dielectric grease consistently.
Installation	*Vermont*. Consistency within the agency and its vendors to properly install connectors. *Norway*. Improperly mounting connectors.
Maintenance	*Colorado*. Ensuring that mechanics clean and take the time required to maintain equipment. *Maine*. Keeping wire connectors in usable condition. *Massachusetts*. Adhering to preventive maintenance practices and using proper setup procedures. *Montana*. Encouraging operators to clean connectors when installing or servicing sanders or wings. *Nebraska*. Encouraging operators to report small issues before they become major failures. *Ohio*. Encouraging operators and technicians to follow agency best practices.
Product Selection	*Kansas*. Finding connectors to use at rear of the truck that preclude the intrusion of salt brine into the connector. *Oregon*. Ensuring technicians use the proper connector, not what the manufacturer provides.
Repair	*Michigan*. Ensuring proper repairs of damaged wiring. *Texas:* • Breaks in wiring from section that have had some repairs • Use of test light that leaves holes in wiring.
Storage	*Montana*. Keeping exposed connections capped when in storage. *Montana (Bozeman)*. Improperly storing electrical connectors without cleaning and treating with dielectric grease.
Weatherproof	*Maine*. Keeping things dry and weatherproof.

Type of Challenge	State (City) and Description
Winter Maintenance Operations and Materials	*Idaho*. The amount of salt on the roads. *Minnesota*. Use in the field during snow and Ice. *Nevada*. Preventing corrosion from salts. *South Dakota*. Road chemicals migrating into the connection points. *Texas*. The agency's "worst enemy is the brine and salt we use during winter operations."

5 Examining the Literature

A literature search examined in-process and published research and other resources that address corrosion in electrical connector assemblies in winter equipment lighting systems. The search extended outside of the winter maintenance environment to products and practices implemented in other sectors and industries that operate in harsh environments, including maritime, freight and agricultural applications.

Results of the literature search are presented below in two categories: innovative technologies and products, and best practices.

5.1 Innovative Technologies and Products

Below is information about the following new technologies and materials designed to minimize corrosion in electrical connector assemblies, especially in the presence of chemical deicers, dirt and moisture:

- Aluminum
- Graphene coatings
- NiobiCon
- Plastics
- SuperCORR-A

Aluminum

To comply with carbon dioxide emission control requirements, automotive manufacturers have been tasked with reducing vehicle weight. They also face a growing demand for copper because of the increase in electric vehicles, which use significant amounts of copper in motors and wiring. To address these concerns, manufacturers have been partially replacing copper wire with aluminum wire, which is lighter and less expensive. SMC (Selective Metal Coating) offers an innovative technical solution for a vehicular wiring harness equipped with aluminum cable (Gaertner 2015). Developed by Aptiv (formerly Delphi Automotive), SMC terminal technology replaces copper wiring with aluminum wiring, providing an overall reduction in vehicle weight. But galvanic corrosion can occur at crimped terminals. Researchers conducted a study of the corrosion behavior of these aluminum wires and will use the results to develop an effective anti-corrosion treatment that could increase the area onto which aluminum wires can be used (Kawaguchi 2019).

Graphene Coatings

Graphene coatings have been used as a corrosion protection barrier for metallic terminals in automotive vehicles (Zhang et al. 2021). In a recent study, researchers noted that graphene's "excellent chemical stability" makes it an appropriate corrosion protective layer to prevent electrochemical oxidation of metallic connectors and electrical terminals. Thin graphene layers were grown by plasma-enhanced chemical vapor deposition on gold and silver terminals and thin-film devices, which were then subjected to mechanical, thermal/humidity and electrical tests. Researchers also conducted a systematic corrosion study of various metallic surfaces exposed to saltwater, sulfuric liquid phase and EIA 364-65B class IIA gas phase. In all tested cases, the graphene layer substantially reduced the corrosion rate compared to the samples without a graphene coating.

NiobiCon

Unlike traditional electrical connector assemblies, which are at risk in corrosive environments, connectors developed using NiobiCon technology are designed for underwater and above-water equipment exposed to these environments (Northrop Grumman, undated).

When the contacts of the NiobiCon connector are exposed to water, a chemical reaction causes a thin insulation layer to develop around the contacts, preventing electricity from flowing through the water surrounding the contacts and preventing the contacts from corroding (Air Electro 2020). Made from niobium, NiobiCon can reportedly be mated and de-mated numerous times without maintenance.

NiobiCon, which was developed by Northrop Grumman, is billed as "less expensive, smaller, lighter, more reliable and safer than current technology connectors." The technology offers the following benefits:

- No seals, O-rings or oil
- Wet-mate above water or fully submerged
- Nearly infinite number of mates/de-mates without maintenance
- Mate and de-mate while power is on
- Can be designed for loose alignment tolerances
- Low mating force
- Not susceptible to corrosion

The technology is the winner of the 2021 *Materials Performance* (MP) Magazine Corrosion Innovation of the Year Award (*Materials Performance* Magazine 2021). The magazine noted that "this technology [is expected] to significantly disrupt the traditional connector market for any application that operates in a corrosive environment. … Electrical systems [that] aren't necessarily always immersed, but may be subject to alternate wet conditions, could have their reliability considerably improved by using this technology. Certain connectors in automotive, aquaculture (like fish farming), oil and gas, and agricultural applications will get huge maintenance savings by not having to periodically replace the connectors."

Connectors developed using the NiobiCon technology are available through iCONN Systems, the first nonexclusive licensee of the patented technology.

Plastics

Thermoplastic polyesters are used for many types of electrical and electronic components in the automotive industry. But in environments with high humidity and temperature, polybutylene terephthalate (PBT) and other thermoplastic polyesters are susceptible to hydrolytic attack. Crastin HR HFS—a new PBT hydrolysis resistance technology developed by DuPont—improves melt stability during molding, allowing more stable manufacturing processes and quality improvements (Mcilvaine and Warner 2014).

SuperCORR-A

The lubricant SuperCORR-A provides corrosion protection solutions for components used in a range of industries, including transportation, marine, aerospace and military sectors. Developed by Corr-eX, this compound is a "'self-healing,' ultra-thin film coating that lubricates and protects metals, motors, avionic, electrical and electronic components from moisture, salts, chlorides, acids and oxidation" (Corr-eX LLC, undated). The lubricant forms a super thin (approximately 7 microns), hydrophobic and nonflammable

coating with anti-corrosive properties that comply with U.S. Environmental Protection Agency and other agency regulations. It includes the following benefits and properties:

- Displaces both fresh and saltwater moisture
- Is nonconductive, nontoxic, nonflammable and nonhazardous
- Will not freeze or harden
- Retains properties in high-altitude applications
- Is self-healing
- Does not attract contaminants
- Is inert and will not increase or decrease contact resistance
- Protects against wear, moisture, and general and fretting corrosion

5.2 Best Practices

Like the common practices used by the DOTs surveyed for this synthesis, best practices for sustaining electrical connectors exposed to winter weather are related to design considerations, materials selection and maintenance strategies.

Key parameters to consider for minimizing the adverse effects of corrosion in winter equipment lighting systems include relocating electrical components, such as connectors, to the interior of the vehicle's cab or other protected areas; insulating electrical connectors with a heat-shrink coating or using waterproof electrical connectors and dielectric grease; and proper washing practices (Ravani 2018, Mehdi et al. 2015, Shi et al. 2013).

Previous research provided an overview of corrosion-prone parts—structural, hydraulic and electrical components—and current approaches available to proactively manage the risk of deicer corrosion in winter maintenance equipment (Jungwirth et al. 2016). A Clear Roads Pooled Fund research project currently underway will compare information about anti-corrosion coatings to update corrosion management guidance for snow and ice control maintenance equipment.

Tips and Techniques Best Practices From the Literature

The literature supports what many survey respondents reported—there are ways to minimize the adverse effects of corrosion in winter equipment electrical systems. Here is a short list of relatively simple things to do to limit corrosion:

- Relocate electrical connectors to the interior of the vehicle's cab or other protected areas
- Insulate electrical connectors with a heat-shrink coating
- Use weatherproof electrical connectors and dielectric grease
- Incorporate mounting systems with gaskets
- Avoid pierced or spliced cable wiring and keep connections tight
- Maintain proper washing practices and conduct frequent inspections

Additional resources examined costs and equipment downtime related to corrosion. A 2018 workshop presentation by Washington State DOT examined the cost of corrosion in the life cycle costs of a vehicle

in a fleet (Ravani 2018). Electricals were among the top six categories reporting vehicle maintenance costs related to corrosion. The agency found an apparent "correlation between the corrosion costs and the use of chlorides such that as chloride use increases the corrosion costs increases."

Recommendations for preventing corrosion included using high-quality weatherproof terminals on electric connections, eliminating junction boxes or mounting them in weather-friendly locations, and utilizing dielectric products. A presentation by Ohio DOT noted that electricals "were the main cause of a truck's downtime during storms" (Ravani 2018). Corrosion issues were electrical and structural. The agency redesigned and relocated the vehicle's power boxes into the cab.

Manufacturers and suppliers of advanced electrical system components used in commercial vehicles noted that pierced or spliced cable wiring, compromised or improperly sealed connectors, and loose lighting connections resulting from road vibration can invite corrosion. Corrosion prevention solutions included sealed lighting and harness connectors (using heat shrink terminals or heat shrink tubing) with a secondary lock to "ensure the connector is fully engaged and protected from road spray"; frequent inspections for visible oxidation, corrosion, loose connectors and broken wires, and then cleaning or replacing components as necessary; applications of dielectric grease or spray to harness terminals; and a preventive maintenance program that maintains the vehicle's electrical system throughout the year (Grabarek 2021).

Additional practices included using modular electrical systems that can expand easily through standardized wiring segments with connectors and have reservoirs of dielectric grease to deter moisture. Modular nose boxes feature consolidated, multipin connectors and water-resistant modular plugs, "incorporate[ing] mounting systems with gaskets to prevent the migration of moisture" (Kolman 2014).

Practices Used in Other Sectors

Limited strategies and experiences from other sectors were uncovered in the literature, including the U.S. military. In a review of military equipment corrosion-prevention and mitigation projects conducted by the U.S. Department of Defense, the U.S. Government Accountability Office (GAO) reported that a U.S. Navy project developed cost-effective, corrosion-resistant boxes to protect electrical equipment, indicator lights and connectors used on its ships (GAO 2013).The U.S. Marine Corps has established the Corrosion Prevention and Control Plan Program to mitigate the impact of corrosion and prolong the useful life of ground equipment. Although specific guidance for electrical connectors was unavailable, the mission of the program is to "reduce maintenance requirements and associated costs through the identification, implementation and development of corrosion prevention and control products, materials, technologies and processes."

In addition, a Transport Canada Civil Aviation Safety Alert reported electrical connector corrosion on Dash-8-401 and Dash-8-402 series airplanes, providing information and recommendations to aircraft operators and maintenance workers (Transport Canada 2021). According to the safety bulletin, cable "shields must be electrically bonded to the aircraft structure at both ends of the cable harness for the shielding to be effective."

In the freight industry, deicing chemicals (especially calcium chloride and magnesium chloride), moisture and debris are the leading causes of corrosion to undercarriage wiring and electrical components of heavy-duty trucks (Grabarek 2021). State transportation agencies also contend with corrosion from deicing materials. In 2016, Colorado DOT began adding a bio-based corrosion inhibitor to its salt brines

to reduce repairs and overall costs. These inhibitors, however, did not prevent moisture and debris from corroding electrical connectors (Lajeunesse 2016).

Cleaning Practices

Several resources promoted truck washing practices during the winter maintenance season to diminish the effects of salt and winter weather on components of snowplows and winter maintenance equipment. These resources typically discuss solutions to corrosion management in general with some mention of the impact on electrical systems. In a 2016 Clear Roads pooled fund study, winter maintenance experts provided information about wash bay use, installation requirements and costs, treatment of wash bay wastewater and the effectiveness of truck washing alternatives in reducing or preventing corrosion (CTC and Associates 2016). A quantitative analysis of corrosion reduction data evaluated the impact of salt neutralizer solutions on winter maintenance equipment (Monty et al. 2014).

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Appendix A: Survey

The survey below was provided in an online format to Clear Roads members, participants in the Snow and Ice List-Serv and the Norwegian Public Roads Administration.

1. Please describe the electrical connectors your agency uses with its snowplows and other winter maintenance equipment. You may describe up to three types of connectors below.

Note: If available, please attach or provide image files as requested below that show the electrical connector as it is installed or how it has been impacted from field use.

Electrical Connector 1
Connector Type:
Benefits of Use:
Challenges of Use:
Cost to Purchase:
Installation Practices:
Estimated Time/Cost to Install:
Durability (based on field experience):
Frequency of Corrosion:
Related Image(s):

Electrical Connector 2
Connector Type:
Benefits of Use:
Challenges of Use:
Cost to Purchase:
Installation Practices:
Estimated Time/Cost to Install:
Durability (based on field experience):
Frequency of Corrosion:
Related Image(s):

Electrical Connector 3
Connector Type:
Benefits of Use:
Challenges of Use:
Cost to Purchase:
Installation Practices:
Estimated Time/Cost to Install:
Durability (based on field experience):
Frequency of Corrosion:
Related Image(s):

2. Has your agency made an effort to relocate junction boxes inside the cab, off the floor?
    - No
    - Yes (Please briefly describe how this change has impacted corrosion.)
3. Does your agency use continuous wiring to minimize connectors?
    - No
    - Yes

4. Has your agency identified an innovative practice or used custom fabrication to successfully limit corrosion and extend electrical connector life?
    - No
    - Yes (Please describe the innovative practice and/or custom fabrication.)
5. What actions are typically taken to prevent corrosion from forming or when corrosion is found on electrical connections? Select all that apply.
    - Apply heat shrink tubing to cover the crimped area where a new terminal is soldered onto the cleaned wire
    - Clean both terminals
    - Install a sealed wiring harness
    - Install covers or shields over electrical connectors
    - Install waterproof/weatherproof connectors
    - Replace both terminals
    - Replace the wire leading into the terminals
    - Seal connection wires
    - Use a fixed terminal cleaning tool kit
    - Use an appropriate wire brush (based on the type of terminal) and an aerosol contact cleaner
    - Use dielectric silicone for sealing connections
    - Use drip loops
    - Use electrical connector boots that can be sealed
    - Use nonconductive dielectric grease to help prevent corrosion from forming
    - Other (Please describe.)
6. What has your agency found to be most successful in preventing corrosion on electrical connectors?
7. What has your agency found to be most challenging when attempting to prevent corrosion on electrical connectors?
8. Has your agency developed electrical connector specifications?
    - No
    - Yes (Please provide a link to these specifications or send an electronic copy to chris.kline@ctcandassociates.com.)
9. Please use this space to provide any comments or additional information about your previous responses.

Appendix B: Other Connectors

Seven respondents described electrical connectors that did not fall into one of the connector categories previously presented in this synthesis report. With the exception of one of the respondents below, who described multiple products in a single response, these agencies are the sole user of the connector the respondent describes:

State Departments of Transportation

- Arizona
- Nebraska (multiple products addressed in a single description)
- Ohio
- South Dakota

Municipalities

- City of Farmington Hills (Michigan)
- City of Bozeman (Montana)

International Agencies

- Norwegian Public Roads Administration

Arizona Department of Transportation

While the Arizona DOT respondent did not specify the series or model number of the Cannon plug the agency uses, a review of the product lines produced by the Cannon manufacturer, ITT Inc., identifies a likely option. ITT offers its CTC Series as a "high-performance, cost-effective cable to cable solution for use in harsh environment applications where reliable signal circuits are critical to operating performance." The Cannon CTC product requires no special installation tools or the use of wedge locks or blind seals and provides a sealing rating up to IP 69K. (This IP rating indicates that the equipment installed in road vehicles can withstand high-pressure cleaning.)

Tables B1 and B2 describe the Cannon plugs Arizona DOT uses.

Table B1. Connector Description: Cannon Plug and Receptacle

Factor	Description
Connector Type:	Cannon plug and receptacle.
Benefits of Use:	Multiple pins; weathertight.
Challenges of Use:	Users don't replace connector covers after connecting/disconnecting or repair.
Installation Practices:	Installed on the side of the bed.
Installation Time/Cost:	One hour.
Durability:	Good
Frequency of Corrosion:	Connectors last about three to four years.

Factor	Description
Cost to Purchase:	No response.

Table B2. Connector Description: Cannon Rate Sensor

Factor	Description
Connector Type:	Cannon plug (rate sensor).
Benefits of Use:	Multiple pins.
Challenges of Use:	Pins rust and connectors lose connectivity with moisture intrusion.
Installation Practices:	"Lots" of dielectric grease is applied during installation.
Installation Time/Cost:	30 minutes.
Durability:	Two years.
Frequency of Corrosion:	Every year.
Cost to Purchase:	No response.

Michigan (Farmington Hills)

The city of Farmington Hills, Michigan, uses two types of connectors—flat and round. Neither one was described as being provided by a particular manufacturer. The flat-type connector is described in Table B3 followed by a brief summary of the round connectors the city uses.

Table B3. Connector Description: Unspecified Flat-Type Connector

Factor	Description
Connector Type:	Flat-type connector (The agency has installed these connectors on 17 front-line vehicles.)
Benefits of Use:	Connect electronics to controller from swap loader skid.
Challenges of Use:	Corrosion from liquid deicers.
Installation Practices:	Installed when changing from tanks to a V-box spreader for a pre-wet application to address certain conditions of a winter event.
Installation Time/Cost:	Two to four hours per vehicle per season.
Durability:	Not very durable; in discussions with Monroe Truck Equipment about upgrading the manufacturer's connectors.
Frequency of Corrosion:	Couple times a season if not coated with dielectric grease.
Cost to Purchase:	Not known.

Round Connectors

The city of Farmington Hills also uses round seven-pin connectors. Benefits and challenges of this type of connector mirror those of the flat-type connector described in Table B3. The connector types differ in their durability (the round connector is somewhat more durable) and the frequency of corrosion (round connectors incur corrosion at least once during a winter season as opposed to multiple times for flat-type connectors).

Montana (Bozeman)

The city of Bozeman, Montana, uses a recreational vehicle (RV)-type connector for the sander controls and lighting on its snowplows, and uses room temperature volcanizing (RTV) silicone where wiring enters connectors. (Vulcanization makes rubber material more stable as it cures.) Table B4 describes the round RV connector the city uses. These connectors are most often replaced due to damage rather than corrosion.

Table B4. Connector Description: Round RV Connector

Factor	Description
Connector Type:	Nine-pin round RV connector for sander controls and lighting.
Benefits of Use:	Locally sourced, easy to replace and generally robust.
Challenges of Use:	Cleaning if improperly stored.
Installation Practices:	RTV is used where wiring enters connectors. “Copious” amounts of dielectric grease are applied during installation and whenever connecters are unmarried for storage.
Installation Time/Cost:	Female end: .5 to 1.5 hours; male end: .25 to .75 hours.
Durability:	Typically, only the female receptacle cover is damaged during normal use. This is often broken from either hyperextension of the cover or the male connecter being pulled out without first lifting the cover.
Frequency of Corrosion:	Fairly rare, maybe two to three seasons of operation. Typically replaced from damage rather than corrosion.
Cost to Purchase:	Male end: $14.81; female end: $15.30. Purchased at NAPA Auto Parts.

Nebraska Department of Transportation

Rather than providing separate descriptions for the different connectors used by the agency, the Nebraska DOT respondent provided a single description for a variety of connector products. Table B5 describes the various connectors that are sealed with heat shrink tubing.

Table B5. Connector Description: Multiple Connectors

Factor	Description
Connector Type:	The agency uses connector brands such as Deutsch, Weather Pack, Metri-Pack or other terminal sealed with heat shrink tubing.
Benefits of Use:	The seals and/or shrink tubing limits the amount of moisture that wicks to the copper wire, limiting or reducing corrosion.
Challenges of Use:	Many connector pins require brand-specific crimping tools and installers must follow correct procedure for assembly.
Installation Practices:	Use of dielectric grease is recommended for contact points of metal pins or connecting points within junction boxes.
Installation Time/Cost:	5 to 15 minutes.
Durability:	No response.
Frequency of Corrosion:	No response.
Cost to Purchase:	Cost varies based on connector type and number of conducting wires.

Ohio Department of Transportation

Only the Ohio DOT respondent described the use of a Metri-Pack connector, another commonly available commercial electrical connector. A connector supplier noted a key difference between Metri-Pack and Weather Pack connectors—their terminals. Metri-Pack male terminals have flat tabs, similar to a quick-disconnect system, whereas Weather Pack connectors use round pins. Table B6 presents the agency's experience with the Metri-Pack connector.

Table B6. Connector Description: Metri-Pack Connector

Factor	Description
Connector Type:	280 Series Metri-Pack connector
Benefits of Use:	Standardized the use of one connector with all wiring and major chassis manufacturer, which helps with stocking small parts. Weather-resistant.
Challenges of Use:	Currently parts availability. Corrosion may occur when pressure washers are used.
Installation Practices:	Add dielectric grease at assembly. The agency's greasing policy helps ensure connectors are greased. (The respondent notes that with this policy "corrosion hasn't set in.")
Installation Time/Cost:	No response.
Durability:	Depends on where the truck is located in the state and how often greasing inspections are performed. Ranges from one season to the life of the truck.
Frequency of Corrosion:	Depends on where the truck is located in the state and how often greasing inspections are performed. Ranges from one season to the life of the truck.
Cost to Purchase:	$2 to $10 depending on connector size.

South Dakota Department of Transportation

The AMP connectors described in Table B7 are manufactured by TE Connectivity, which also manufactures the Deutsch connector, one of the two most commonly used connectors among respondents. The AMP connector does not receive the positive feedback garnered by the Deutsch connector, with the respondent noting that the AMP is not weather-resistant and must be replaced at least annually due to corrosion.

Table B7. Connector Description: AMP Connector

Factor	Description
Connector Type:	AMP connector (TE Connectivity).
Benefits of Use:	Several terminals in a connector.
Challenges of Use:	Not really weather resistant.
Installation Practices:	Used for interior and exterior use.
Installation Time/Cost:	Few minutes to 30 minutes based on wire condition and access.
Durability:	Pretty dependable if out of elements.

Factor	Description
Frequency of Corrosion:	Not weather-resistant unless the back of the cavity is filled with silicone or putty. Replace at least annually due to corrosion.
Cost to Purchase:	Depends on the quantity needed.

Norwegian Public Roads Administration

Clear Roads contacts at the Norwegian Public Roads Administration asked representatives of Veidekke, one of the largest maintenance contractors in Norway, to respond to the survey. Tables B8 through B10 describe three products used by this Norwegian contractor. Table B8 presents the most durable of the three connectors described.

Table B8. VBG 14-Terminal Connector

Factor	Description
Connector Type:	VBG 14-terminal connector.
Benefits of Use:	Simple, good and durable.
Challenges of Use:	No response.
Installation Practices:	Vaseline spray is used on all terminals. Connectors are dried and maintained with silicone grease before summer storage; silicone grease may also be used during the winter. Lanolin may be sprayed on terminals inside and out; nonacid Vaseline (it must be nonacid) may be used to fill the terminals and junctions. Avoid junction boxes when possible, placing them when needed in a nonexposed area. Mounting the junction boxes in the cab with lightning/warming is a good solution. 
Installation Time/Cost:	Maintenance with Vaseline, grease and spray is quick (minutes) and affordable.
Durability:	More durable than the other connectors described below.
Frequency of Corrosion:	Can last for 10 to 12 years with good maintenance.
Cost to Purchase:	$150

Table B9. Nato Socket Connector

Factor	Description
Connector Type:	Nato socket connector.
Benefits of Use:	Big capacity (power).
Challenges of Use:	Corrosion, which results in the connection not working.

Factor	Description
Installation Practices:	Vaseline spray is used on all terminals. Connectors are dried and maintained with silicone grease before summer storage; silicone grease may also be used during the winter. Lanolin may be sprayed on terminals inside and out; nonacid Vaseline (it must be nonacid) may be used to fill the terminals and junctions.  Avoid junction boxes when possible, placing them when needed in a nonexposed area. Mounting the junction boxes in the cab with lightning/warming is a good solution.
Installation Time/Cost:	Maintenance with Vaseline, grease and spray is quick (minutes) and affordable.
Durability:	Varied experiences. Some require socket replacement after two tears.
Frequency of Corrosion:	Metal will corrode after a couple of years despite frequent maintenance.
Cost to Purchase:	$120

Table B10. Seven-Terminal Connector

Factor	Description
Connector Type:	Ordinary seven-terminal connector.
Benefits of Use:	Simple and cheap.
Challenges of Use:	Not very water-resistant.
Installation Practices:	Vaseline spray is used on all terminals. Connectors are dried and maintained with silicone grease before summer storage; silicone grease may also be used during the winter. Lanolin may be sprayed on terminals inside and out; nonacid Vaseline (it must be nonacid) may be used to fill the terminals and junctions.  Avoid junction boxes when possible, placing them when needed in a nonexposed area. Mounting the junction boxes in the cab with lightning/warming is a good solution.
Installation Time/Cost:	Maintenance with Vaseline, grease and spray is quick (minutes) and affordable.
Durability:	Not as durable as the VBG terminal.
Frequency of Corrosion:	If properly installed and maintained, can last for 10 to 12 years. Corrosion will occur within a couple of months if terminals are not filled with grease.
Cost to Purchase:	$10

research for winter highway maintenance

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