# Identification and Recommendations for Correction of Equipment Factors Causing Fatigue in Snowplow Operations

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16. Abstract

The objective of this project was to recommend cost-effective equipment solutions to mitigate fatigue experienced by winter maintenance operators. A questionnaire collected the opinions on the relationship between equipment and fatigue from 2,011 winter maintenance operators in 23 Clear Roads states. An analysis of the existing literature and questionnaire results produced eight cost-effective equipment solutions and eight non-equipment solutions to mitigate winter maintenance operator fatigue. These 16 solutions are believed to be the most promising to mitigate fatigue at low cost (in no particular order): (1) provide dimmable interior cab lighting, (2) use light emitting diode (LED) bulbs for exterior lighting, (3) equip winter maintenance vehicles with warning lights that have a nighttime setting (i.e., dimmable), (4) install a compact disc player or satellite radio in all winter maintenance vehicles, (5) equip winter maintenance vehicles with a heated windshield, (6) install snow deflectors on front plows, (7) install LED narrow-beam bulbs on auxiliary lighting, (8) use an ergonomically designed seat with vibration dampening/air-ride technology, (9) instruct winter maintenance operators to take a 15- to 30-minute break every 4 to 5 hours, (10) provide education and training to winter maintenance operators to identify early signs of fatigue, (11) investigate reduced shift lengths, start/end times, and overtime rules/limits, (12) create an agency-wide fatigue management policy, (13) investigate methods to provide early notifications of an impending swing shift, (14) encourage heathy lifestyles, (15) encourage winter maintenance operator input in equipment purchases, and (16) provide a dedicated place for winter maintenance operators to rest at each garage/terminal.

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# Identification and Recommendations for Correction of Equipment Factors Causing Fatigue in Snowplow Operations

## Task 11: Draft Final Report

## CR 15-02

**Matthew C. Camden, Jeffrey S. Hickman, Susan A. Soccolich, and Richard J. Hanowski**

Virginia Tech Transportation Institute
3500 Transportation Research Plaza
Blacksburg, VA 24061

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# ABBREVIATIONS, ACRONYMS, AND SYMBOLS

| **Acronym** | **Definition** |
|---|---|
| AVL | automated vehicle location |
| BLS | Bureau of Labor Statistics |
| CAS | collision avoidance system |
| CB | citizen’s band |
| CD | compact disc |
| DOT | Department of Transportation |
| EEG | electroencephalogram |
| EM-active | electromagnetically active |
| FMCSA | Federal Motor Carrier Safety Administration |
| GPS | Global Positioning System |
| Hz | hertz |
| HOS | hours-of-service |
| HUD | head-up display |
| K | kelvin |
| LCD | liquid crystal display |
| LDW | lane departure warning |
| LED | light-emitting diode |
| NAFMP | North American Fatigue Management Program |
| NTSB | National Transportation Safety Board |
| nm | nanometer |
| SR | sleep-related |
| TR | task-related |

| | |
|---|---|
| TRID | Transportation Research International Documentation |

# EXECUTIVE SUMMARY

## BACKGROUND

During the winter months, maintenance workers drive trucks equipped with snowplows or snow blowers to clear the roads of snow and ice. Driver fatigue among winter maintenance operators during winter emergencies can be prevalent, as these workers are not bound by prescriptive hours-of-service (HOS) rules. During these winter weather events, winter maintenance operators work long, stressful hours, and fatigue can be a major problem.[1] Theoretically, these factors may result in higher crash rates,[2,3] lower productivity,[4] and increased health issues.[5] Thus, winter maintenance operator fatigue is a serious issue that can affect the safety of all drivers and passengers on the roads. A recent body of research in fatigue management indicates that other factors, including in-cab and external equipment, contribute to driver fatigue. There is no one simple solution to mitigate winter maintenance operator fatigue and improve safety performance. Instead, a comprehensive approach is needed to address the many sources of operator fatigue. Furthermore, many state Departments of Transportations (DOTs) are facing budget challenges due to a decrease in revenues and an increase in winter-maintenance costs; this puts an enormous strain on a limited workforce and increases winter maintenance operator fatigue.

## PROJECT SUMMARY

The goal of this project was to identify snowplow equipment (in-cab and external) associated with winter maintenance operator fatigue and make cost-effective recommendations to reduce, eliminate, or correct these factors. Two tasks were completed to accomplish this objective. First, an in-depth literature review of equipment factors related to fatigue was completed. The purpose of this literature review was to inform the development of a winter maintenance operator questionnaire. Second, a questionnaire collected winter maintenance operators' opinions and perceptions about equipment factors related to fatigue. The results of this study may be used by state DOTs to inform decisions related to the purchasing of snowplow equipment.

## METHODS

Based on the results from the literature review, a questionnaire was developed to collect winter maintenance operators' opinions about equipment factors associated with fatigue. This questionnaire was designed to assess equipment that may increase or decrease fatigue. The questionnaire contained questions about experience in winter maintenance operations, winter maintenance equipment frequently used, prevalence of fatigue, shift length and schedule, vibration-related equipment, noise-related equipment, visibility-related equipment, and in-cab equipment.

This questionnaire was distributed to 33 Clear Roads member states. The research team worked with the Clear Roads representative from each of these states to recruit winter maintenance operators to respond to the questionnaire. Both online and paper-based versions of the questionnaire were provided to these Clear Roads representatives. The Clear Roads representatives subsequently sent the questionnaire to the winter maintenance operators in their state.

## RESULTS

A total of 2,011 winter maintenance operators from 23 different states provided responses to the questionnaire. Overall, approximately 94% of winter maintenance operators reported feeling fatigued at some point while operating a snowplow during winter emergencies. Table 1 presents a summary of some of the key results.

**Table 1. Summary of Key Results**

| Domain | Research Question | Study Findings |
|---|---|---|
| **Winter Maintenance Operator Shifts** | Do winter maintenance operators that work night shifts report higher levels of fatigue than winter maintenance operators that work day shifts? | Yes, night shift operators reported higher levels of perceived fatigue. |
| | Do winter maintenance operators that work longer shift lengths report higher levels of fatigue than winter maintenance operators that work shorter shift lengths? | Yes, operators with shifts longer than 16 hours reported higher levels of perceived fatigue. |
| **Equipment Vibration** | What snowplow equipment increases perceived levels of fatigue while driving due to vibration? | Non-automatic tire chains and the front plow. |
| | What snowplow equipment decreases perceived levels of fatigue while driving due to vibration? | Air-ride seats, air-cushioned seats, rubber-encased blades, and blade float device. |
| **Noise from Equipment** | What snowplow equipment increases perceived levels of fatigue while driving due to noise? | Noise from the plow or engine and the music/radio turned off. |
| | What snowplow equipment decreases perceived levels of fatigue while driving due to noise? | Music/radio turned on, citizen's band (CB) or DOT radio, and audible alerts. |
| **Visibility** | What snowplow equipment increases perceived levels of fatigue while driving due to reduced visibility? | Exterior strobe lights, exterior flashing lights, interior vehicle lighting, and windshield wipers. |
| | What snowplow equipment decreases perceived levels of fatigue while driving due to reduced visibility? | Anti-glare glass, heated mirrors, heated windows, heated windshield, and snow deflectors. |
| **In-Cab Equipment** | What in-cab snowplow equipment increases perceived levels of fatigue while driving? | The placement and number of equipment controls and the placement of and light from liquid crystal displays (LCDs). |
| | What in-cab snowplow equipment decreases perceived levels of fatigue while driving? | A mobile phone, presence of a collision avoidance system, assistance staying within a lane, and back-up cameras. |

## DISCUSSION

The vast majority of winter maintenance operators reported feeling fatigued at some point while operating a snowplow during a winter emergency. Winter maintenance operators most frequently reported they "sometimes" felt fatigued while driving. However, 12% to 15% of winter maintenance operators reported feeling fatigued "most of the time" or "always" while driving. The current study also found winter maintenance operators with shifts lasting 16 hours or longer reported significantly higher levels of fatigue compared to all other shift lengths. This fatigue may be the result of sleep debt, a lack of sleep over one or more days (i.e., sleep-related fatigue), sustained activity over a long period of time (i.e., task-related fatigue), or some combination of these.

Winter maintenance operators suggested a number of possible equipment solutions to reduce or eliminate vibration-related fatigue, including an improved vehicle suspension system (e.g., air-ride suspension), a blade float device, rubber-encased blades, limiting the use of tire chains to specific situations, and an air-ride/vibration dampening seat. All of these possible solutions support previous research examining the relationship between sustained, low-frequency vibrations and fatigue.[6,7]

Winter maintenance operators recommended several equipment solutions to reduce fatigue caused by equipment-related noise. These solutions included increased cab insulation, equipment alerts (i.e., high-frequency, intermittent sound), the use of a communication device (e.g., CB or DOT radio), and listening to the radio or music.

Winter maintenance operators suggested the use of dimmable warning lights with a nighttime setting, light-emitting diode (LED) bulbs in all exterior lights, and snow deflectors on plows to decrease fatigue caused by reduced visibility. Furthermore, winter maintenance operators reported that snow and ice buildup on the windshield was a significant cause of fatigue. Possible solutions included heated windshield wipers and a heated windshield.

Finally, winter maintenance operators provided one solution for fatigue caused by in-cab equipment. The primary cause of fatigue associated with interior equipment was LCD lighting. Winter maintenance operators suggested providing dimmer switches for all LCDs that would allow the LCDs to be dimmed to near black or to be turned all the way off.

## RECOMMENDATIONS

Below are the cost-effective, equipment-related solutions to mitigate winter maintenance operator fatigue. Based on a review of the extant literature and results from the current questionnaire, these solutions were believed to be the most promising to mitigate fatigue at low cost (in no particular order).

- **Dimmable interior lighting.** Interior lightings, including LCDs, should be dimmable to near black or have the ability to be turned off. Winter maintenance operators should be instructed to dim the interior lights according to their individual preference during nighttime operations.

- **Use LED bulbs for exterior lighting**. Winter maintenance agencies should replace headlights, plow lights, and other auxiliary light bulbs with LEDs.
- **Dimmable warning lights.** Winter maintenance vehicles should be equipped with warning lights that have a nighttime setting (i.e., dimmable). Winter maintenance operators should be instructed to use the nighttime setting during night driving in winter emergencies to reduce back-reflected light from the warning lights.
- **Install a CD player or satellite radio.** All winter maintenance vehicles should have a CD player or satellite radio installed (a simple AM/FM radio may also work in locations with a wide variety of radio stations and good reception). Winter maintenance managers should instruct winter maintenance operators to listen to their preferred music/radio selections while operating the snow plow. However, listening to music/talk radio should be considered a short-term fatigue countermeasure.
- **Heated windshield.** Winter maintenance vehicles should be equipped with heated windshields. Winter maintenance operators should be instructed to use the heated windshield to prevent snow and ice buildup.
- **Install snow deflectors**. Snow deflectors should be installed on plows to reduce the amount of snow blown onto the windshield.
- **Narrow-beam auxiliary lighting.** Winter maintenance agencies should install LED narrow-beam spot lights to reduce back-reflected light.
- **More ergonomically designed seat with vibration dampening/air-ride technology.** Winter maintenance vehicles should be equipped with an ergonomically designed seat that includes vibration dampening or an air-ride technology.

**Non-Equipment Solutions**

- **Encourage the use of breaks.** Winter maintenance operators should be instructed to take a 15 to 30 minute break every 4 to 5 hours (at a minimum) or when they experience the early signs of being fatigued.
- **Train winter maintenance operators to identify signs and symptoms of fatigue.** Winter maintenance operators should be provided education and training in identifying signs of fatigue. The North American Fatigue Management Program (NAFMP) driver module (Module 3) provides a free resource that may be used by managers (see www.nafmp.org).
- **Investigate reduced shift lengths, start and end times, and overtime rules/limits.** Winter maintenance agencies should limit shift lengths to a maximum of 12 consecutive hours. Additionally, winter maintenance operators should be provided with an opportunity to obtain two full nights (i.e., between 12:00 a.m. and 6:00 a.m.) of sleep after 7 consecutive days of restricted sleep. Finally, shift start times between 12:00 a.m. and 6:00 a.m. should be avoided. If a 12-hour shift length is not feasible, winter maintenance operators should be instructed to take more frequent (e.g., every 3 to 4 hours) mandatory breaks.

- **Create a fatigue management policy.** All winter maintenance agencies should create a written policy regarding shift lengths, mandatory breaks, number of consecutive days performing snow removal operations, operator training, etc.
- **Investigate methods to provide winter maintenance operators with earlier notification of an impending swing shift.** If possible, winter maintenance operators that work night shifts during winter emergencies should not come in to work the morning prior to the first snow removal shift (e.g., swing shift).
- **Encourage healthy lifestyles (e.g., diet, exercise, sleep).** Winter maintenance operators should be encouraged to avoid fried and processed food with excessive amounts of saturated fat and sodium. Better food options include whole grains, fruits, vegetables, low-fat milk products, lean meats, fish, and nuts. They should also be encouraged to get at least 2.5 hours of exercise per week and 7 to 8 hours of sleep per night.
- **Encourage winter maintenance operator input in equipment purchases.** Winter maintenance operators are the primary users of equipment; thus, they have insight that will assist in equipment purchases that are likely to reduce fatigue.
- **Provide a dedicated place for operators to rest at each terminal.** If possible, each terminal should have a room where operators can rest or nap when time allows. This room should have a comfortable place for winter maintenance operators to lie down, limit light from entering, dampen outside noise, and be temperature controlled.

# 1. INTRODUCTION

Fatigue can be defined as a combination of symptoms, including impaired performance and subjective feelings of alertness. Although a National Transportation Safety Board (NTSB) study found that truck driver fatigue was the primary cause of 31% of fatal-to-the-driver heavy vehicle crashes, a more recent study conducted by the Federal Motor Carrier Safety Administration (FMCSA) found that fatigue was a contributing factor in 13% of large-truck crashes.[2,3] Regardless of this discrepancy, it appears that fatigue-related crashes among truck drivers are endemic given drivers' extended driving periods and work hours combined with shifts that can start at various times of the day and night.

During the winter months, maintenance workers drive trucks equipped with snowplows or snow blowers to clear the roads of snow and ice. Driver fatigue among winter maintenance operators during winter emergencies can be prevalent, as these workers are not bound by prescriptive hours-of-service (HOS) rules. During these winter weather events, winter maintenance operators work long, stressful hours, and fatigue can be a major problem.[1] Theoretically, these factors may result in higher crash rates,[2,3] lower productivity,[4] and increased health issues.[5] Thus, winter maintenance operator fatigue is a serious issue that can affect the safety of all drivers and passengers on the roads. A recent report investigating fatigue in winter maintenance operations found that other factors, including in-cab and external equipment, contribute to driver fatigue.[1] There is no one simple solution to mitigate winter maintenance operator fatigue and improve safety performance. Instead, a comprehensive approach is needed to address the many sources of operator fatigue. Furthermore, many state Departments of Transportations (DOTs) are facing budget challenges due to a decrease in revenues and an increase in winter-maintenance costs; this puts an enormous strain on a limited workforce and increases winter maintenance operator fatigue.

## 1.1 WHAT IS FATIGUE?

As discussed in Camden et al., the terms *drowsiness* and *fatigue* are often used interchangeably.[1,8] However, it is important to distinguish the differences between the two terms. For the purposes of this project, the authors consider fatigue and drowsiness as two separate but related concepts. Fatigue is defined as a global reduction in physical or mental arousal that results in a performance deficit and a diminished capacity to perform a task.[9,10] In the context of driving, fatigue is related to the physical tasks of driving, as well as the attention and alertness necessary for the driving conditions.[11] In contrast, drowsiness is defined as the physiological drive to sleep.[12] Drowsiness, which may also be referred to as sleepiness, is a naturally occurring biophysiological process. Although it is possible for a person to be fatigued without being drowsy, drowsiness may be a product of a variety of factors, including fatigue, the body's natural circadian rhythm, or sleep quantity or quality.[13] One of the more dangerous outcomes of driver drowsiness is rapid-onset microsleeps.[14] These are periods lasting up to minutes in which the person loses consciousness and directly enters a sleeping period. People often have no memory of these events and, of course, have limited control over the vehicle when they occur. Hereafter, the authors use the term fatigue to reflect drowsiness as well as fatigue. Although the etiology of each is different, the consequences of drowsiness and fatigue are similar.

Fatigue may be separated into two categories: task-related (TR) fatigue and sleep-related (SR) fatigue, as shown in Figure 1.(11,15,16) TR fatigue may be further divided into physical (i.e., active TR fatigue) and perceptual (i.e., passive TR fatigue).(11,16) Active TR fatigue results from cognitive overload or overarousal of the senses.(11,16,17) Cognitive overload may develop with complex work tasks or sustained driving in demanding conditions. For example, winter maintenance operators may experience active TR fatigue when clearing roads in poor visibility or high-density traffic. Passive TR fatigue results from cognitive underload or underarousal of senses.(11,16,17) Passive TR fatigue often develops when an operator experiences boredom during a monotonous task.

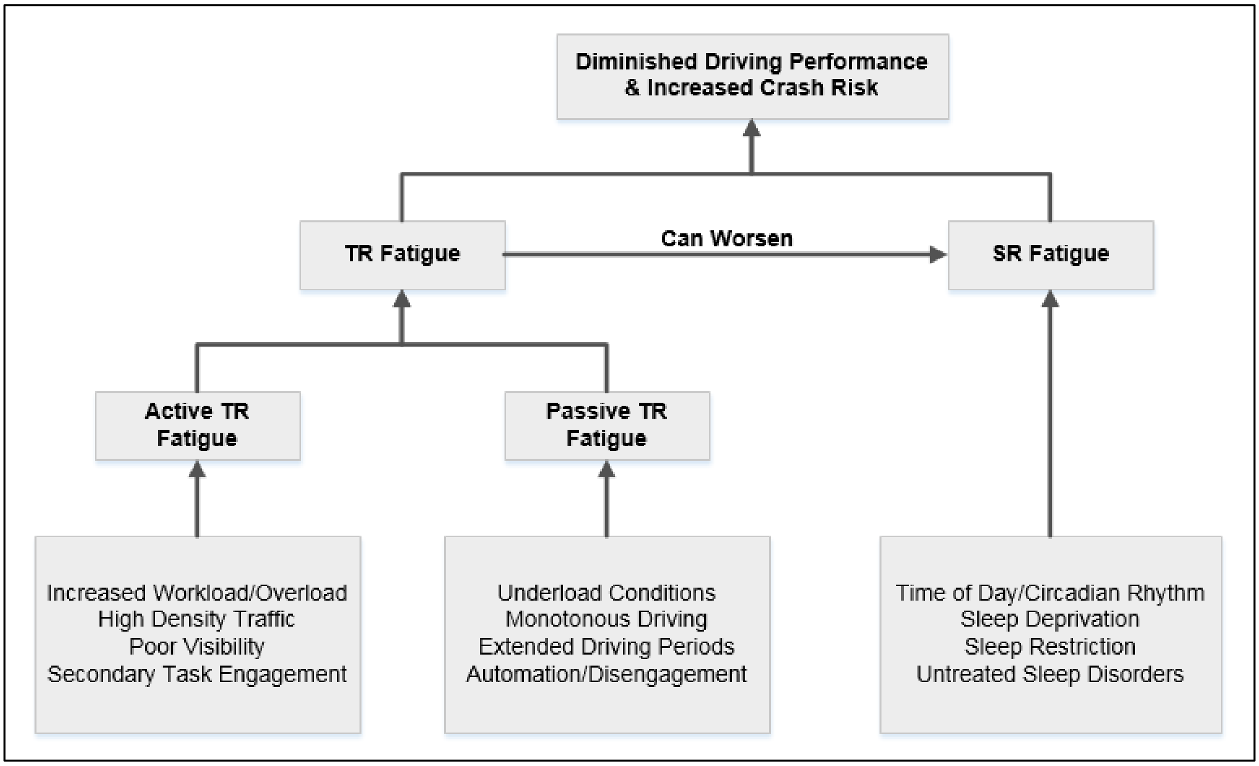



**Figure 1. Model of fatigue (adapted from May & Baldwin, 2009).**

## 1.2 HOW DOES FATIGUE IMPACT DRIVING?

Research has shown that fatigue adversely impacts employee productivity and safety. Fatigue has been shown to decrease performance, impair reasoning, hinder decision making, impede situational awareness, and degrade the ability to adequately assess risk.(15,18,19,20) Fatigued drivers have been found to experience higher rates of uninitiated lane deviations,(21,22,23,24,25,26) have significantly slower reaction times and delayed responses to a lead vehicle,(25,27) experience greater variations in speed,(28) experience decreased visual scanning patterns or "tunnel vision,"(21) and be more likely to fall asleep while driving.(29,30) These dangerous outcomes have led to an increased interest in identifying effective countermeasures to driver fatigue. Some of the effective countermeasures identified include developing work schedules that include opportunities for breaks or naps,(18,31,32,33) redesigning the work environment (i.e., the truck cab),(34) changing task complexity in overload/underload conditions,(35,36) and implementing a comprehensive fatigue management program.[37] The National Academies of Science, Engineering, and Medicine recently convened a panel to discuss driver fatigue in commercial vehicle operations.[38] The report provides a detailed synthesis of research results, research needs, and future directions in studying driver fatigue.

## 1.3 IMPACT OF FATIGUE IN WINTER MAINTENANCE OPERATIONS

Camden et al. conducted a three-part project that examined the factors that cause fatigue in winter maintenance operators during winter emergencies.[1] Included in Camden et al. was a literature review, a naturalistic driving study, and a questionnaire of winter maintenance operators and managers.[1] The results from this project found that sleep, noise, vibration, and task complexity were contributing factors to the development of winter maintenance operator fatigue. However, Camden et al. did not investigate specific equipment that might contribute to winter maintenance operator fatigue.[1]

## 1.4 PROJECT OBJECTIVE

The goal of this project was to identify snowplow equipment (in-cab and external) associated with operator fatigue and make cost-effective recommendations to reduce, eliminate, or correct these factors. Two tasks were completed to accomplish this objective. First, an in-depth literature review of equipment factors related to fatigue was completed. The purpose of this literature review was to inform the development of a winter maintenance operator questionnaire. Second, a questionnaire collected winter maintenance operators' opinions and perceptions about equipment factors related to fatigue. The results of this study may be used by state DOTs to inform decisions related to the purchasing of snowplow equipment.

# 2. LITERATURE REVIEW

This chapter reviews the existing literature on equipment factors that may be associated with driver fatigue. The major information sources for the literature review included (i) the Transportation Research International Documentation (TRID); (ii) U.S. government technical reports; (iii) industry groups, such as Clear Roads and the American Transportation Research Institute; and (iv) academic journals (e.g., *Accident Analysis and Prevention* and the *Journal of Safety Research*).

All research obtained in the literature review was assessed to determine whether it contained (i) a description of the equipment factor investigated and (ii) how the equipment factor was associated with fatigue. Literature that did not contain these two pieces of information was eliminated from further review. Additionally, the literature review was limited to driver fatigue when possible. Some of the studies produced multiple reports, journal articles, and conference presentations (i.e., the same study was published in different journals, conference proceedings, etc.). Where possible, priority was given to a final report over journal articles and conference proceedings (which tend to provide less information). Typically, these secondary documents were removed from consideration or noted as duplicate works.

This research expanded the work completed in Camden et al. and focused on specific equipment factors related to driver workload, vibration, noise, visibility/vehicle lighting, distraction, and automated technologies.(1) These equipment factors are discussed in the following sections.

## 2.1 WORKLOAD AND DRIVER FATIGUE

Winter maintenance operators often experience a complex and stressful work environment. Operators are required to perform many tasks while driving in demanding driving situations with limited visibility due to inclement weather. Additionally, some operators may be required to operate several plows and spreaders simultaneously. All of these factors are likely to increase the complexity of the operator's workload. Traditionally, research investigating the effects of workload has focused on productivity.(39) However, there are an increasing number of studies examining the relationship between perceived workload/complexity and fatigue. For example, Åkerstedt et al. surveyed 5,720 individuals on risk factors associated with cardiovascular health.(40) They found that high work demands (i.e., perceived workload) significantly increased fatigue. Matthews and Desmond found similar results for drivers in a simulator.(41) They had 80 participants drive a simulator under normal driving conditions and high-workload conditions. Their results showed that high workload tasks were associated with increased levels of subjective ratings of fatigue. However, Matthews and Desmond did not see any association between high workload and driving performance decrements.(41)

Nunes et al. tracked air-traffic controller work demands, performance, and fatigue over a 6-day workweek.(35) They found that when task demands were high, individuals exhibited increased fatigue. Unlike Matthews and Desmond,(41) Nunes et al. did see driving performance decrements related to workload.(35) Results showed the most errors occurred during low task-demanding shifts (i.e., monotony) followed by high task-demanding shifts.

Other research suggests that the relationship between task demands and fatigue is more complex. Grech et al. performed a field study with 20 naval ship operators.(42) The operators performed a nonroutine, high-demand naval patrol for 5 days, followed after 10 days by a 4-day normal patrol. Grech et al. found three important results.(42) First, self-rated fatigue decreased when operators went from low to moderate workload. Fatigue likely decreased in this scenario due to the removal of passive TR fatigue. Secondly, fatigue increased when operators went from a moderate to a high workload. This increase was likely due to active TR fatigue. Finally, there was a relationship between shift, workload, and fatigue. At the beginning of a shift, low workload increased fatigue. However, at the end of a shift, high workload increased fatigue.

To summarize, research supports a relationship between workload and fatigue. Many of the equipment-related factors discussed in the following sections may be related to a winter maintenance operator's workload, and subsequently, operator fatigue.

## 2.2 VIBRATION AND DRIVER FATIGUE

Chronic and sustained whole-body vibration has been shown to contribute to adverse health risks, including driver fatigue.(34) Sustained vibrations ranging from 0.5 to 80 Hz can cause the muscles in the area that are experiencing vibrations to contract, either voluntarily or involuntarily, leading to muscle fatigue.(43) In fact, vibrations are the primary cause of lower back pain and muscle fatigue in vehicle operators; however, not all vibrations may contribute to the development of fatigue.(44,45) It is possible that some vibrations may be an effective countermeasure to fatigue.(46) Research has shown that intermittent or random vibration can increase driver alertness.(6,47,48) These vibrations may interrupt passive TR fatigue and provide stimulation in underload conditions. Furthermore, haptic alerts (i.e., intermittent vibrations in a driver's seat) have been found to effectively provide information to a driver.(49,50) Thus, haptic alerts may be designed to alert a driver to fatigue onset.

Conversely, monotonous and low-frequency vibration around 3 Hz has been shown to increase fatigue.(6,7) Constant low-frequency vibration may contribute to active TR fatigue by increasing an operator's workload. Similarly, the International Organization for Standardization (ISO) maintains that vibrations near 5 Hz should be avoided in the design of vehicle suspensions (ISO 2631-1:1997).

In a vehicle, vibrations are often transferred to a driver through the seat while sitting down or through the feet on the pedals. Researchers, equipment manufacturers, and vehicle manufacturers have recognized the importance of integrating vibration countermeasures into vehicle cabs. Some of the most common countermeasures to combat vibration are new or updated equipment, vibration dampeners, and increased maintenance.(34) In Camden et al., winter maintenance operators and managers suggested the following specific equipment factors to reduce vibration: air-ride seats, rubber plow blades, and improved tire chains.(1)

### 2.2.1 Operator Seats

In Camden et al. winter maintenance operators and managers indicated that seat type was a critical source of operator fatigue during winter emergencies.(1) One of the most common seat designs to counter vibration is the air-ride seat. Air-suspension seats use air-filled containers to lessen vibrations transferred to the driver through the seat. Air-ride seats have been widely adopted in the heavy vehicle industry. In fact, Peterson recommended all winter maintenance vehicles be equipped with air-ride seats,[51] and 80% of respondents in Camden et al. reported having air-ride seats in their snow removal vehicles.[1]

Blood, Ploger, and Johnson compared the ability of an air-suspension seat and mechanical seat in reducing whole body vibrations in forklift operators.[52] The study consisted of 12 forklift operators using an air-ride or traditional seat during normal working conditions on a standardized 3.5-km test track. Results showed that both seat types reduced vibrations from the floor of the forklift by 50%. However, the air-ride suspension seat significantly reduced low-frequency vibrations compared to the mechanical seat.

In another study of air-ride seats, Blood, Yost, Camp, and Ching investigated the reduction in vibrations associated with three heavy vehicle seat types: an air-ride large bus seat, an air-ride large truck seat, and an electromagnetically active (EM-active) seat.[53] EM-active seats are relatively new and use sensors to detect vibrations and an attenuator to electromagnetically dampen the vibrations. Blood et al. used a simulator to estimate the amount of vibrations a heavy vehicle operator would experience during an 8-hour workday.[53] Results showed the EM-active seat reduced overall vibrations by 30% compared to air-ride seats. Furthermore, EM-active seats reduced more low-frequency vibrations (1 to 5 Hz) compared to air-ride seats. However, air-ride seats reduced higher frequency vibrations (14 to 18 Hz) significantly more than the EM-active seat.

Although different than air-ride seats, air-filled seat cushions have also been found to reduce vibrations. Boggs and Ahmadian performed a field operational test comparing the effects of an air-filled seat cushion to a traditional foam-filled seat cushion.[54] Twelve heavy vehicle operators completed their normal delivery routes while using an air-filled seat cushion for half the route and a foam-filled seat cushion for the second half of the route. Boggs and Ahmadian found that air-cushioned seats reduced subjective ratings of fatigue by 14% compared to traditional foam-cushioned seats.[54]

### 2.2.2 Rubber Blades

In Camden et al., operators commented that plows are a significant source of vibration in winter maintenance operations.[1] These operators suggested rubber-encased blades as an effective countermeasure to vibrations caused by the plow hitting the road. However, there is a paucity of published research examining the effects of rubber-encased blades on driver fatigue. A report released by the Minnesota DOT did synthesize several research efforts regarding rubber-encased blades.[55] This report summarized pilot test projects related to the use of rubber-encased blades in Ohio, Iowa, Wisconsin, Missouri, Minnesota, Maine, and Canada. There was a general consensus between pilot projects that rubber-encased steel blades resulted in less vibration, noise, and in some cases, driver fatigue. Despite the lack of empirical research, rubber-encased blades likely reduce vibrations and may be an effective fatigue countermeasure for winter maintenance operators.

### 2.2.3 Tire Chains

Questionnaire results from Camden et al. also showed the use of tire chains to be a significant source of vibration during winter maintenance operations.[(1)] A number of operators suggested the increased use of drop/automatic tire chains as a method to reduce vibrations. Automatic tire chains contain a small gear with several lengths of chain attached to the axle near the tire. These chains spin under the tire as the truck moves and provide increased traction similar to traditional tire chains. Unlike traditional tire chains, automatic chains can be activated/deactivated by a switch in the cab, and thus can limit vibrations when extra traction is not needed.

Similar to rubber-encased blades, there is limited research investigating the effects of tire chains on driver fatigue. However, Blood, Rynell, and Johnson investigated whole body vibration associated with two types of tire chain configurations: ladder chains and basket chains.[(56)] Blood et al. had 12 heavy vehicle operators drive a front end loader with ladder and basket chains in three different scenarios to mimic highway driving, snowplowing, and scooping/dumping.[(56)] Results showed that basket chains produced significantly less vibration during highway driving and plowing snow compared to ladder chains. However, these improvements were limited during slow speeds.

## 2.3 SOUND AND DRIVER FATIGUE

In-cab and external sounds have been shown to affect an operator's level of fatigue,[(17,57)] and were reported by winter maintenance operators and managers to be important sources of fatigue in winter operations.[(1)] However, sound can affect fatigue differently depending on the type and frequency of the sound.[(58)] Low-frequency, continuous sound has been found to increase fatigue.[(59,60,61,62)] Examples of low-frequency, continuous sounds in vehicles include those originating from diesel engines or vehicle-produced vibrations.[(63)] Similar to vibration, low-frequency, continuous sound may increase an operator's active TR fatigue by increasing cognitive workload. High-frequency, intermittent sound, on the other hand, has been found to increase alertness and vigilance.[(64,65)] Horns are one example of high-frequency, intermittent sounds in vehicles. These types of sounds may decrease passive TR fatigue through stimulation and by interrupting monotony. High-frequency sound may also decrease SR fatigue through audible alerts. This is likely the reason that most collision avoidance systems and drowsiness detection systems include a high-frequency, audible alert.

The effects of sound on a driver's level of fatigue are moderated by the driver's level of arousal.[(17)] If an operator is fatigued due to low arousal (i.e., passive TR fatigue or SR fatigue), sound can function as a fatigue countermeasure. However, if an operator is fatigued due to high arousal (i.e., active TR fatigue), sound can increase fatigue.

Equipment manufacturers have used these results when designing vehicle safety systems. This is why most vehicles have cab insulation to dampen exterior monotonous sounds that contribute to noise-induced fatigue and audible, high-frequency alerts to garner a driver's attention. In terms of winter maintenance operations, Peterson and Camden et al. found increased cab insulation to be an effective countermeasure to exterior noise.[(1,51)] However, the literature review only found research on one equipment factor, the radio, related to sound and fatigue. Interactions with a citizen's band (CB) radio and cell phone are discussed in subsequent sections of this review.

### 2.3.1 Music/Radio

Drivers frequently suggest listening to the radio as an effective countermeasure to fatigue. Operators in Camden et al. reported frequently listening to the radio/music as a means to counter fatigue; however, the same operators reported the radio/music to be only sometimes effective in reducing fatigue.(1) Similarly, other research has found limited support for the effectiveness of listening to the radio/music to reduce fatigue.(66,67)

Fagerström and Lisper investigated the effects of music and talking on driver fatigue.(66) The authors had 12 participants drive approximately 3 hours on a Swedish roadway while listening to silence, music, or talk radio. Results showed that listening to music and talk radio improved reaction times compared to silence. However, the radio was not an effective countermeasure for all individuals.

Reyner and Horne performed a simulator study with 16 drivers, restricting each driver's sleep to 5 hours on the night prior to the study.(67) The following afternoon, each participant drove a vehicle simulator for 2.5 hours in a monotonous scenario. After 30 minutes of driving, each participant was instructed to turn on the car radio. The authors found the car radio reduced the participant's subjective ratings of fatigue; however it did not significantly reduce the number of lane deviations.

Similarly, Schwarz et al. conducted an on-road evaluation to investigate the effects of the radio to reduce operator fatigue.(68) Twenty-four operators completed two driving sessions: one during the day and one during the night. The results reported by Schwarz et al.(68) confirmed the findings of Reyner and Horne.(67) More specifically, the radio did slightly reduce subjective ratings of fatigue, but the reductions diminished as soon as the radio was turned off.

## 2.4 LIGHTING/VISIBILITY AND DRIVER FATIGUE

Winter maintenance operators often experience limited visibility as a result of frozen precipitation. Reduced visibility may led to active TR fatigue due to increased workload, sustained attention, eye strain, and glare. Camden et al. found equipment lighting to be an important source of fatigue for winter maintenance operators, and Peterson recommended equipment to improve lighting and visibility of snowplow operators.(1,51)

There is some research connecting lighting and visibility to increased driver fatigue. Eyestrain and eye discomfort have been found to increase subjective ratings of fatigue and rates of unintentional lane deviations.(69) It has also been speculated that glare from lighting contributes to driver fatigue. However, research has shown that glare does not uniformly contribute to driver fatigue.(70,71) Shiftlett et al. found that glare produced fatigue for some individuals, but not consistently.(71) This likely indicated other factors (e.g., sleep loss, vibrations, and high-demand conditions) contributed to glare's effect on susceptibility to fatigue.

There is a growing body research that investigates the potential of equipment lighting to decrease fatigue. Specific types of lighting equipment that may decrease fatigue are interior blue lights and light-emitting diode (LED) headlamps. Research on these types of lighting is discussed below.

### 2.4.1 Interior Vehicle Lighting

Short-wavelength light in the 424 nm to 477 nm range (i.e., blue light) has been linked to the suppression of melatonin.(72,73,74) Intrinsically photosensitive ganglion cells in the eye have been found to be similar to cells responsible for the suppression of melatonin, which plays a large role in the regulation of circadian rhythms.(75) Thus, it is plausible these ganglion cells could process light that regulates the circadian rhythm.(76,77)

Brainard et al. investigated the effects of two wavelengths of blue light, 420 nm and 460 nm, on melatonin suppression in a laboratory experiment.(73) The authors measured participants' melatonin levels before, during, and after exposure to (a) darkness, (b) 420 nm blue light, and (c) 460 nm blue light from 12:00 a.m. to 3:30 a.m. Results supported the relationship between blue-light and melatonin suppression. However, 460 nm blue light was found to suppress melatonin significantly more than 420 nm blue light. Additionally, the effects of blue light may diminish with older adults.

Chellappa et al. linked the suppression of melatonin and subjective sleepiness to blue light.(72) They exposed 16 participants to complete darkness, dim light (less than 8 lux), compact fluorescent blue light (6500 K), and compact fluorescent yellow-light (2500 K). Chellappa et al. found that blue light suppressed melatonin and increased subjective ratings of sleepiness.(78) Interestingly, results also showed that blue light was related to improved cognitive performance and alertness.

Figueiro et al. was one of two studies to investigate the effects of blue light specifically on driver fatigue.(79) Figueiro et al. had 16 participants operate a driving simulator during the daytime and nighttime.(79) Each driving session lasted 3.5 hours. Participants were exposed to two 436 nm blue light intensities (6.5–8.5 lux and 2.5–4.5 lux) and a red light (630 nm, less than 2 lux) condition. Results showed that the blue light and red light did not impact participants' melatonin levels, subjective ratings of sleepiness, or driving performance. These results support Brainard et al.'s results, which found that longer wavelength blue light (460 nm to 470 nm) was more effective in melatonin suppression compared to shorter wavelength blue light (420 nm to 440 nm).(73)

Taillard et al. had 48 adults drive an instrumented vehicle for 4 continuous hours (with a 15 minute break after 2 hours) between 1:00 a.m. and 4:15 a.m. on two different nights.(80) During each drive, participants were exposed to 468 nm blue light or ingested caffeine or a caffeine placebo. The results showed that the use of blue light and caffeine, independently, resulted in fewer lane deviations compared to darkness and a caffeine placebo.

Based on the entirety of these results, blue light in the 460 to 470 nm wavelengths may be an effective in-cab countermeasure to driver fatigue. It is possible that vehicle and equipment manufacturers will incorporate this research when designing dashboard/in-vehicle equipment lighting.

### 2.4.2 Exterior Vehicle Lighting

In addition to interior lighting, exterior vehicle lighting plays an important role in a winter maintenance operator's visibility, especially during nighttime operations with falling snow and ice. During darkness, falling snow and ice often reflect light back to the driver that can contribute to eye discomfort and possibly fatigue.[81] Bullough and Rae conducted a literature review of forward vehicle lighting research related to visibility in winter conditions.[81] The majority of literature reviewed was directly related to snowplow operations. Bullough and Rae found three factors that influence visibility in winter conditions related to headlamps: headlamp location, light beam spread, and light color.[81] Auxiliary lights mounted away from the operator's direct line of sight (i.e., on the passenger side) reduced back-reflected light and eye discomfort.[82,83] Additionally, narrow beam light (i.e., spot lights) produced less back-reflected light compared to wide beams of light.[84,85] Finally, longer wavelength light (i.e., amber and red) reduced back-reflected light.[86,87] However, the effects of forward lighting color were limited compared to the impacts related to light positioning and beam spread.[83]

More recently, Muthumani, Fay, and Bergner conducted a survey of winter maintenance agencies on snowplow exterior lighting.[88] Their results support many of the results discussed above. Winter maintenance operators indicated that auxiliary lights produced less back-reflected light when placed outside the driver's line of sight, and the majority of operators indicated a preference for passenger-side mounted auxiliary lighting. Additionally, auxiliary lights with a narrow beam (i.e., spot light) were preferred and reportedly produced less back-reflected light. Operators also preferred LEDs compared to halogen bulbs for auxiliary lighting. LEDs produced greater visibility that was similar to daylight. Finally, yellow fog lights were suggested by operators to reduce back-reflected light. However, light color was not an important factor to improve visibility during snow removal operations. Auxiliary lighting placement and beam spread were much more important.

In addition to headlamps and auxiliary lighting, winter maintenance vehicles are also equipped with warning lights. Warning lights increase the conspicuity of the winter maintenance vehicle during limited visibility. No research was found that examined warning lights' effect on driver fatigue, including strobe lights. However, longer wavelength light (e.g., red, green, yellow) may be better since it limits the amount of back-reflected light to the driver.

### 2.4.3 Snow Deflectors

In addition to lighting, equipment that prevents snow and ice buildup may prevent fatigue. Thompson and Nakhla found that snow deflectors with an angle less than 50 degrees reduced the amount of accumulating snow on a winter maintenance vehicle's windshield by 50%, a significant reduction.[89] Reducing snow buildup on the windshield likely improves the operator's visibility and may decrease workload. However, no research was found directly investigating snow deflectors' effects on driver fatigue.

## 2.5 DISTRACTION AND DRIVER FATIGUE

There is a significant amount of research showing the dangers of driver distraction in heavy vehicle operations.[e.g., 90,91,92] Naturalistic truck studies have shown that conversations with others via a cell phone or CB radio may be effective fatigue countermeasures. For example, Olson et al. analyzed naturalistic truck driving data from 203 drivers and 55 heavy vehicles.[92] They found that CB radio use had a significant protective effect for heavy vehicle operators. CB radio use was associated with a 45% reduction in safety-critical events. Furthermore, an eye-glance analysis supported the idea that CB radio use may increase a heavy vehicle driver's attention to the roadway. The results showed that drivers maintained their eyes on the forward roadway more frequently while talking and listening to the CB radio.

Chan and Atchley studied the effects of a verbal task on passive TR fatigue using a light vehicle simulator.(93) Participants heard and verbally repeated a total of thirty-six 20-second narratives. Chan and Atchley found that the verbal task improved driving performance typically associated with fatigue.(93) For example, the verbal task during monotonous driving conditions was associated with improvements in lane positioning and decreased lane deviations.

Jellentrup, Metz, and Rothe examined whether phone conversations during monotonous driving conditions increased alertness.(94) In this study, 18 participants operated an instrumented vehicle for 6 hours on a test track. Results showed that 83% of the participants reported that telephone conversations were very important in reducing fatigue during the driving task. Additionally, data from an electroencephalogram (EEG) and eye-lid opening measure indicated that phone calls reduced driver fatigue. This reduction in fatigue lasted for 20 minutes after the phone call ended. These results suggest that a conversation may be a short-lasting countermeasure to fatigue during monotonous conditions.

Similarly, Young compared drivers' observed rating of drowsiness and secondary task engagement with involvement in safety-critical events.(95) To accomplish this task, Young used data collected in the 100-Car Naturalistic Driving Study in Klauer et al.(95,96) Young found that moderate engagement in a secondary task (i.e., no more than two glances away from the roadway or no more than two button presses, including a cell phone or other handheld device) reduced the crash risk associated with drowsy driving by 36%.(95) Additionally, talking and listening to a conversation on a cell phone reduced drowsiness compared to no talking or listening.

## 2.6 ADVANCED TECHNOLOGIES FOR SNOWPLOW OPERATIONS AND DRIVER FATIGUE

Increasingly, DOTs are employing advanced safety technologies on their winter maintenance vehicles. Some advanced safety technologies being incorporated into winter maintenance vehicles include collision avoidance systems (CASs) and automated vehicle location (AVL) systems.(97) Several studies were found that investigated the effects of these technologies on snowplow driver fatigue. These studies are described in the following sections.

### 2.6.1 Collision Avoidance Systems

CASs use vehicle-based sensors (e.g., cameras, radar, sonar, or LIDAR) to detect objects that may pose a hazard to the vehicle. Many of these systems may be especially useful during limited visibility because they have the ability to "see" through the thick snow and ice. This information may help ease operators' workloads and provide a surrogate for increased visibility.

Ye et al. conducted a literature review and survey on the adoption of advanced safety technologies in winter maintenance operations.(97) The authors surveyed 13 state DOTs and one Canadian agency that had experience with advanced snowplow technologies. The results of the literature review and survey showed that CASs might decrease operator fatigue associated with increased workload. Nookala field tested a newly developed CAS, Guidestar, on snowplows in Minnesota.(98) The Guidestar system included forward collision warning, rear collision warning, and side detection warning. The system was pilot tested with only two snowplow operators during a winter with minimal snow. Results showed that operators believed the CAS provided valuable information that may be useful in limited visibility. The participants believed data on unseen threats increased their confidence in the safe operation of the vehicle. Additionally, the participants did not believe the CAS increased workload.

Cuelho and Kack modeled the costs and benefits associated with a CAS in snowplow operations, specifically the Roadview™ system.(99) Roadview™ incorporated radar-based object detection and lane positioning information via magnetic strips (no longer available) placed on lane lines. Benefits and cost data were obtained from five locations, including crash data, snowplow maintenance records, and road closure historical data. Additionally, Cuelho and Kack assessed snowplow operator opinions of the potential benefits and costs of Roadview™.(99) Survey respondents were only provided with a description of Roadview™ and did not have personal experience with the system. The results showed that operators welcomed snowplow CASs. Conceptually, these operators believed CASs might decrease their workload by providing information about upcoming unseen threats in limited visibility.

Many CASs include a driver interface, some of which include head-up displays (HUDs). HUDs project information on the windshield so the driver can maintain a view of the forward roadway. However, no research was found that specifically examined the effects of HUDs on driver fatigue.

Finally, lane departure warning (LDW) systems have been shown to be effective in reducing unintentional lane deviations and run-off-road crashes for heavy vehicles.(100,101,102) These crash types are indicative of possible driver fatigue. The LDWs assessed in these studies were vision-based systems that monitor the vehicle's position within a roadway using lane markings. However, lane markings are likely covered during winter emergencies. Thus, these results may not be applicable to winter maintenance operations. One solution to this problem is to provide snowplow operators with lane positioning information by overlaying data from a Global Positioning System (GPS) on a geospatial database with roadway information.(103) This type of LDW system coupled with haptic alerts and forward radar was investigated by Yen et al.(103) They installed the advanced driver assistance system on two snowplows during four winter seasons and tested its effectiveness in a location known for frequent heavy snows and whiteout conditions. Unfortunately, data were very limited due to unusually low snowfall and significant icing on the forward radar. Despite these limitations, operators believed the lane positioning data and haptic alerts provided beneficial information. Future research is needed to fully investigate the effectiveness of this system and its effects on operator fatigue.

### 2.6.2 Automated Vehicle Location Systems

AVL systems combine data from an onboard GPS with other vehicle sensors (e.g., plow position, material application rates, and surface temperature) to monitor and record vehicle activities. Regarding snowplow operations, AVL systems have the ability to provide valuable information to the driver and dispatch regarding road conditions, material usage, and routing.(91) Recently, many municipalities began using AVL data to inform the general public of snowplow operations.

The literature review only found two studies that examined the effect of AVLs on driver fatigue, both of which suggested that AVLs decrease operator fatigue. Wayne County, Michigan, pilot tested AVL systems in snowplows. In addition to operational benefits associated with routing, operators reported reduced fatigue during high demand situations.(91)

Veneziano and Strong also conducted a pilot test of an AVL system in snowplow operations.(104) The pilot test consisted of 16 operators performing their normal routes and job duties. Veneziano and Strong collected participant surveys to assess the effect of AVLs on operator fatigue.(104) The results showed the AVL system did not significantly increase driver workload. However, operators suggested that an AVL system requiring frequent operator input might increase workload. Integrating vehicle sensors (applications, plow position, and temperature) might provide significant reductions in operator workload. Additionally, operators suggested that AVL mapping could provide useful information that may decrease stress.

## 2.7 CONCLUSIONS

The published literature was reviewed to examine the relationship between internal and external snowplow equipment and operator fatigue. This literature search expanded on the questionnaire results found in Camden et al.(1) Operators and managers in Camden et al. suggested that equipment factors related to driver workload, vibration, noise, visibility/vehicle lighting, distraction, and automated technologies were associated with fatigue.(1) This review suggested that each of these equipment factors is associated with operator fatigue. However, more data are needed to quantify the impact of each equipment factor in winter maintenance operations.

# 3. QUESTIONNAIRE METHODS

Based on the results from the literature review, a questionnaire was developed to collect winter maintenance operators’ opinions and perceptions regarding equipment factors associated with fatigue. This questionnaire was designed to assess equipment that may increase or decrease fatigue. The complete questionnaire is shown in Appendix A and summarized below:

- Years of experience in winter maintenance operations
- Make, model, and year of winter maintenance equipment most frequently used (e.g., tractor, pick-up truck, grader, front-end loader, and dump truck with plows and/or spreaders)
- How often fatigue is experienced while driving
- Shifts (e.g., time of day, length, and the part of shift when fatigue is most often experienced)
- Impact of vibration-related equipment on their fatigue (e.g., air-suspension seat, air-cushioned seat, automatic tire chains, non-automatic tire chains, rubber-encased blades, blade float device, segmented blades, belly plow, wing plow, tow plow, and front plow)
- Impact of equipment-related noise on their fatigue (e.g., noise from plow or engine, music, CB or DOT radio, and audible alerts from equipment)
- Impact of visibility-related equipment on their fatigue (e.g., anti-glare glass, exterior strobe and flashing lights, interior vehicle lighting, auxiliary lighting, windshield wipers, heated mirrors and windshield/windows, and snow deflectors)
- Impact of in-cab equipment on their fatigue (e.g., number of and placement of equipment controls, mobile phone, a collision avoidance system, a system to assist with lane positioning, back-up cameras, HUD, and liquid crystal display [LCD] displays)
- Additional suggestions to decrease fatigue

Additionally, the research team contacted nine winter maintenance equipment manufacturers to assess how equipment manufacturers consider (and plan for) winter maintenance operator fatigue when designing equipment. However, no winter maintenance equipment manufacturers were able to respond to our queries citing proprietary information involved in the development of equipment. However, five manufacturers confirmed that operator fatigue, in general, is considered during the development of equipment.

## 3.1 QUESTIONNAIRE DISTRIBUTION

There were 33 member states in Clear Roads when the questionnaire was distributed. The research team worked with a Clear Roads representative in each of these states to recruit winter maintenance operators to complete the questionnaire. Online and paper-based versions of the questionnaire were provided to these Clear Roads representatives. The Clear Roads representatives subsequently sent the questionnaire to winter maintenance operators in their state. Participation in the questionnaire was voluntary and all responses were anonymous (no personally identifying information was collected). Responses to the online version of the questionnaire were entered automatically into a secure online database. Responses to the paper version of the questionnaire were mailed to the research team, which entered the responses into the secure online database.

Participates were given the opportunity to enter a random drawing for one of ten $50 gift cards. To enter the drawing, winter maintenance operators provided the research team with their contact information on a separate form that was not linked to the questionnaire. Four months after distributing the questionnaire, the research team randomly selected 10 participants in the raffle, each winning a $50 gift card. The gift card was mailed to each raffle winner.

## 3.2 QUESTIONNAIRE ANALYSES

Questionnaire responses were analyzed to assess the relationship between winter maintenance equipment and the development of fatigue. Chi-square tests and Fisher's exact tests were performed to identify significant differences in the distributions in responses. Pair sample *t*-tests were also performed to assess how each equipment type impacted the development of fatigue. First, winter maintenance operators' ratings of how often each type of equipment impacted the development of fatigue (termed fatigue impact) were given a numerical score. This numerical score translated the categorical responses into a Likert scale (always increases = 5, sometimes increases = 4, never impacts = 3, sometimes decreases = 2, and always decreases = 1). Average ratings for each type of equipment were calculated using the numerical values from all winter maintenance operators who responded for that particular equipment type. The average rating was tested against a null hypothesis of the equipment having no fatigue impact ("never impact" or an average score of 3 using the corresponding numerical score value) using a *t*-test.

# 4. QUESTIONNAIRE RESULTS

A total of 2,011 winter maintenance operators from 23 different states provided responses to the questionnaire (out of 33 Clear Roads states). Questionnaires were completed by winter maintenance operators in the states highlighted in Figure 2. Responses were not obtained from California, Idaho, Indiana, Iowa, Massachusetts, Minnesota, Missouri, Rhode Island, Washington, and Wisconsin.

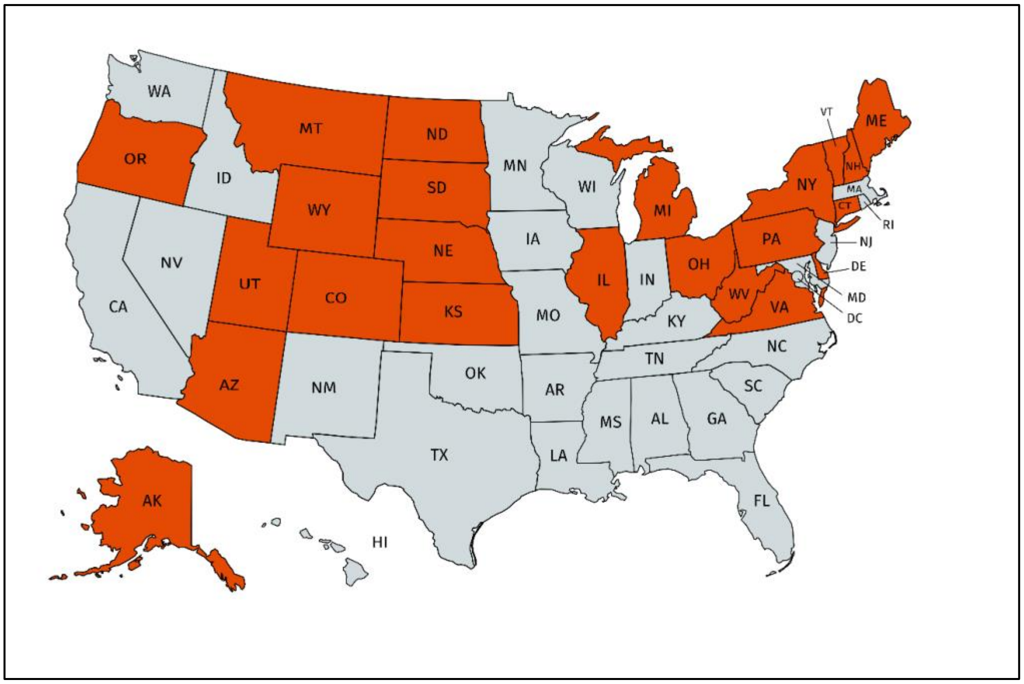



**Figure 2. Participating states.**

The number of participants per state is shown below in Table 2. A small portion of the winter maintenance operators (14) chose not to provide their state.

**Table 2. Distribution of Participating States**

| State | Number of Winter Maintenance Operators | Percentage of Winter Maintenance Operators |
|---|---|---|
| Alaska | 65 | 3.23% |
| Arizona | 24 | 1.19% |
| Colorado | 265 | 13.18% |
| Connecticut | 5 | 0.25% |
| Delaware | 138 | 6.86% |
| Illinois | 131 | 6.51% |
| Kansas | 63 | 3.13% |
| Maine | 80 | 3.98% |
| Michigan | 10 | 0.50% |
| Montana | 150 | 7.46% |

| State | Number of Winter Maintenance Operators | Percentage of Winter Maintenance Operators |
|---|---|---|
| Nebraska | 77 | 3.83% |
| New Hampshire | 10 | 0.50% |
| New York | 119 | 5.92% |
| North Dakota | 38 | 1.89% |
| Ohio | 1 | 0.05% |
| Oregon | 42 | 2.09% |
| Pennsylvania | 57 | 2.83% |
| South Dakota | 91 | 4.53% |
| Utah | 48 | 2.39% |
| Vermont | 32 | 1.59% |
| Virginia | 466 | 23.17% |
| West Virginia | 48 | 2.39% |
| Wyoming | 37 | 1.84% |
| Blank | 14 | 0.70% |
| Total | 2,011 | 100.00% |

Nearly all winter maintenance operators were employed by a state DOT (99.5% or 2,001 winter maintenance operators). The other 10 winter maintenance operators were independent contractors employed by a city/county or other employer. The distribution of winter maintenance operators by their employer is displayed in Table 3 below.

**Table 3. Distribution of Winter Maintenance Operators' Places of Employment**

| Who do you work for? | Number of Winter Maintenance Operators | Percentage of Winter Maintenance Operators |
|---|---|---|
| State DOT | 2,001 | 99.5% |
| Contractor | 6 | 0.3% |
| City/County | 2 | 0.1% |
| Other | 2 | 0.1% |
| Total | 2,011 | 100.0% |

Winter maintenance operators' years of experience in winter operations is shown in Figure 3. More than one-third (37.2% or 747) of the winter maintenance operators had at least 15 years' experience working in winter maintenance operations. Approximately one-quarter (25.5%) of winter maintenance operators had 1 to 5 years' experience in winter maintenance operations, 17.30% had 6 to 10 years' experience, 13.3% had 11 to 15 years' experience, and 5.9% had less than a year of experience.

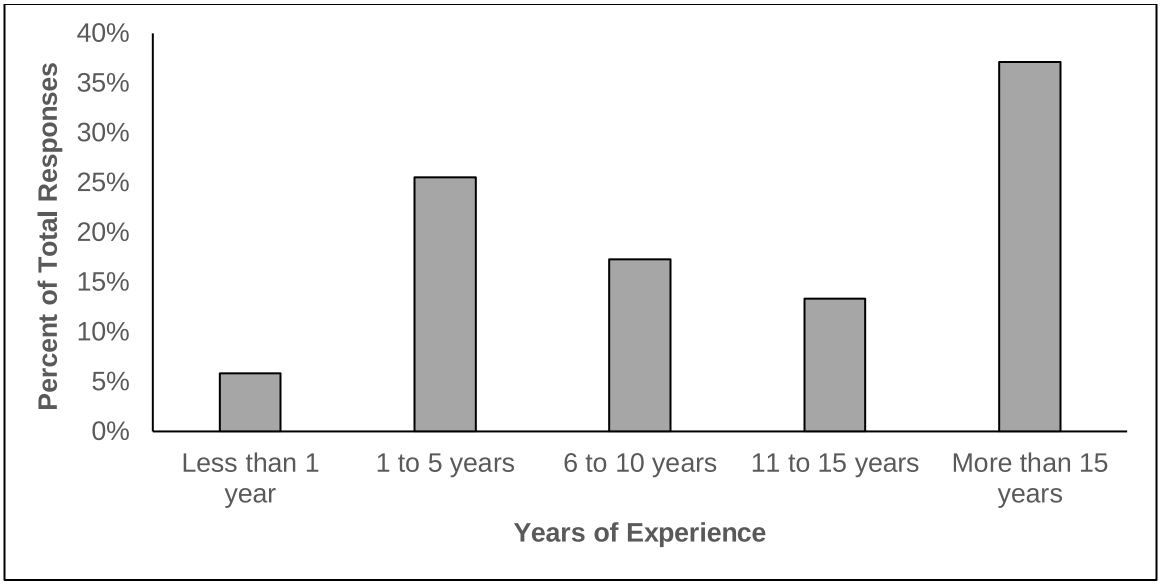



**Figure 3. Distribution of winter maintenance operators' experience in winter operations.**

Table 4 shows the types of equipment winter maintenance operators reported using during winter maintenance operations. The most common type of equipment used was a dump truck with one plow/spreader (50% of winter maintenance operators reported this type). Front-end loaders and trucks with multiple plows and spreaders were reported by approximately one-quarter of winter maintenance operators (27% and 26%, respectively). Other vehicle or equipment types included trucks with multiple plows (20%), grader (18%), pick-up truck (16%), tractor (5%), truck with multiple spreaders (3%), and other equipment types (3%).

**Table 4. Winter Maintenance Vehicles and Equipment Used by Winter Maintenance Operators**

| Vehicle/Equipment Type | Number of Winter Maintenance Operators | Percentage of Total Winter Maintenance Operators |
|---|---|---|
| Tractor | 101 | 5% |
| Pick-up truck | 322 | 16% |
| Grader | 353 | 18% |
| Front-end loader | 546 | 27% |
| Dump truck with one plow/spreader | 1,009 | 50% |
| Truck with multiple plows | 408 | 20% |
| Truck with multiple spreaders | 66 | 3% |
| Truck with multiple plows and spreaders | 528 | 26% |
| Other | 55 | 3% |

Figure 4 shows winter maintenance operators' responses regarding their normal shift time of day (day, night, or both). The majority of winter maintenance operators reported shifts during day and night (58.9% or 1,184 winter maintenance operators). Another 22.2% (447 winter maintenance operators) of winter maintenance operators reported having the majority of shifts during the day, and 17.9% (360 winter maintenance operators) reported a majority of shifts during the night. Only a small percentage (1% of or 20 winter maintenance operators) did not respond to this question.

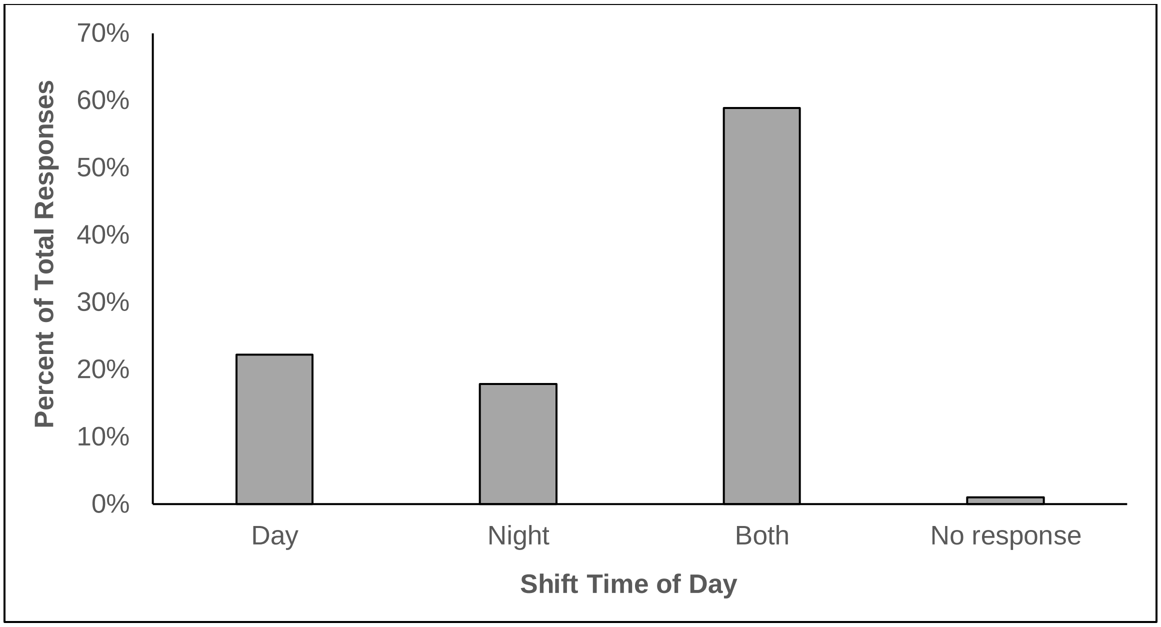



**Figure 4. Distribution of shift time of day.**

Typical shift lengths during winter emergencies ranged from less than 8 hours to more than 16 hours (see Figure 5). The most commonly reported shift length was 12 hours (37.8% or 761 winter maintenance operators), followed by shifts between 8 and 12 hours (29.8% or 600 winter maintenance operators) and shifts between 12 and 16 hours (20.6% or 414 winter maintenance operators). Very few winter maintenance operators reported shifts less than 8 hours (1.1% or 20 winter maintenance operators), 8 hours (2.5% or 51 winter maintenance operators), 16 hours (1.7% or 34 winter maintenance operators), or more than 16 hours (5.9% or 118 winter maintenance operators).

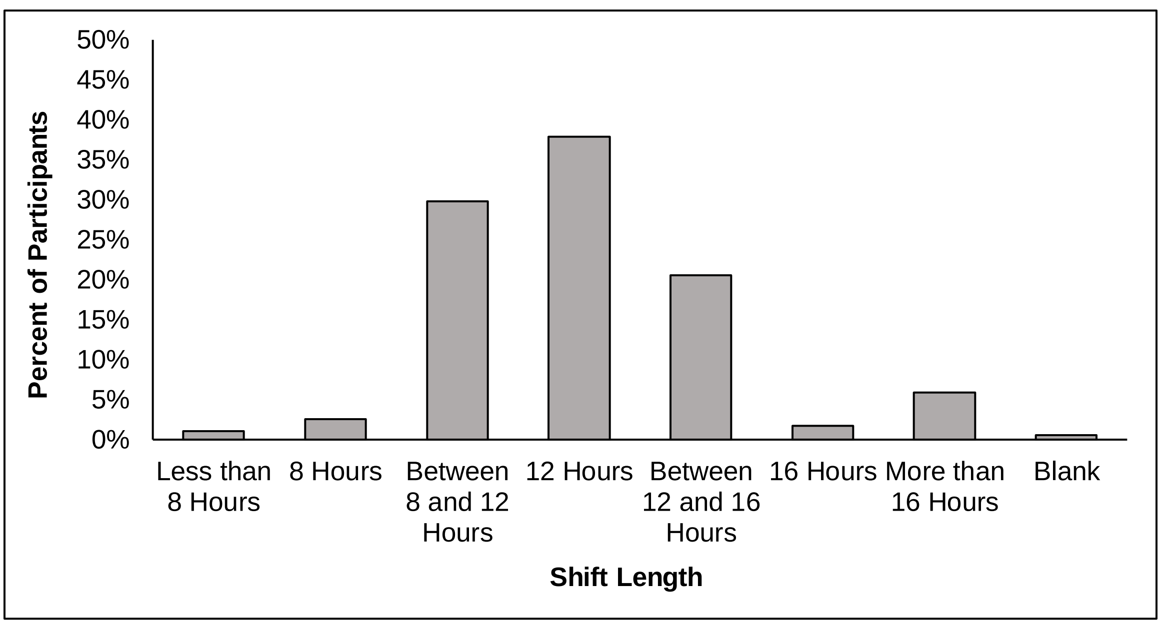



**Figure 5. Typical shift length during winter emergencies.**

## 4.1 WINTER MAINTENANCE OPERATOR FATIGUE

Figure 6 shows how frequently winter maintenance operators reported becoming fatigued while operating a snowplow during winter emergencies. Overall, approximately 94% of winter maintenance operators reported feeling fatigued at some point while operating a snowplow during winter emergencies. The most frequently reported answer was "sometimes" (61.97% or 1,237 winter maintenance operators). Just over 18% of winter maintenance operators reported feeling fatigued "half the time" (364 winter maintenance operators). Approximately 10% of winter maintenance operators felt fatigued "most of the time" (199 winter maintenance operators), and approximately 4% of winter maintenance operators felt fatigued "always" (79 winter maintenance operators). Less than 6% of winter maintenance operators never felt fatigued during their shift (117 winter maintenance operators).

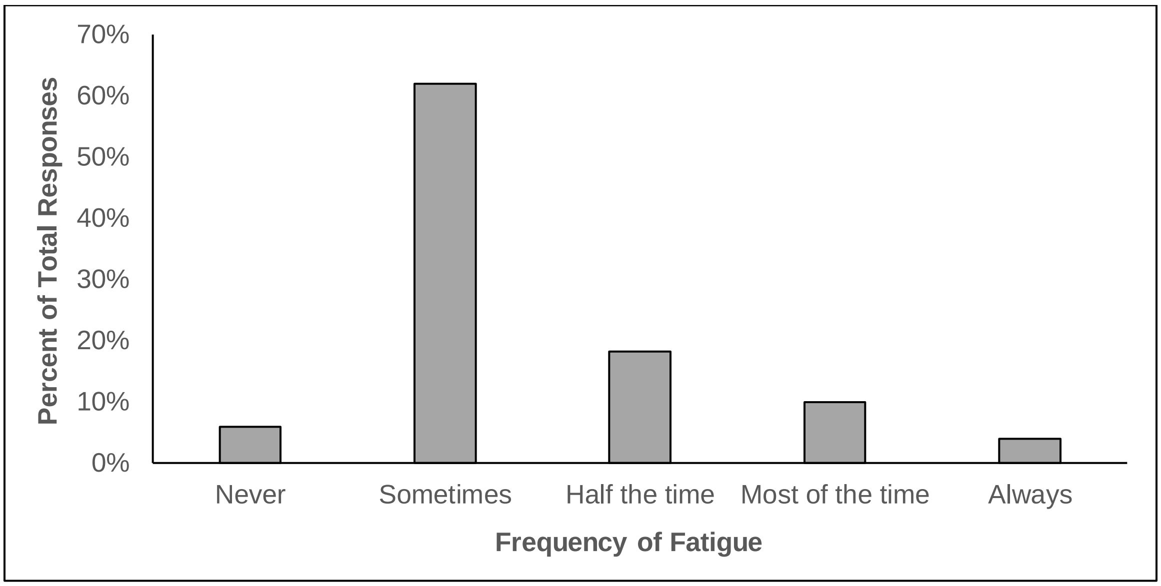



**Figure 6. Frequency of self-reported fatigue during a winter emergency shift.**

Winter maintenance operators also reported the timing of fatigue onset during a shift (see Figure 7). Approximately 3% of winter maintenance operators reported feeling fatigued at the start of a shift (59 winter maintenance operators). Almost one-third of the winter maintenance operators reported feeling fatigue in the middle of a shift (641 winter maintenance operators). Over half the winter maintenance operators reported fatigue occurrence at the end of the shift (1,084 winter maintenance operators). Nearly 2% of winter maintenance operators reported feeling fatigued during the entire shift (42 winter maintenance operators). Finally, 7.5% of winter maintenance operators reported never feeling fatigued during their shifts (149 winter maintenance operators).


**Figure 7. Part of shift when fatigue was most often experienced.**

Table 5 below shows the shift time of day by fatigue frequency. Although all three shift time categories showed generally similar distributions in fatigue frequency, shifts with night driving had higher proportions of fatigue than day shifts. For example, approximately 1.6% of day shift winter maintenance operators, 5.6% of night shift winter maintenance operators, and 4.4% of winter maintenance operators who work both shifts always felt fatigued. Similarly, winter maintenance operators with day shifts reported lower proportions of fatigue. For example, approximately 7.6% of day shift winter maintenance operators, 6.4% of night shift winter maintenance operators, and 5.0% of winter maintenance operators who work both shifts reported never feeling fatigued.

**Table 5. Frequency of Self-Report Fatigue by Shift Time of Day**

| Frequency of Self-Reported Fatigue | Majority Day Shift | Majority Night Shift | Both Day and Night Shift |
|---|---|---|---|
| Always | 1.57% | 5.57% | 4.43% |
| Most of the time | 6.71% | 12.26% | 10.64% |
| Half of the time | 12.30% | 19.78% | 20.00% |
| Sometimes | 71.81% | 55.99% | 59.91% |
| Never | 7.61% | 6.41% | 5.02% |

The distribution of fatigue frequency was compared to the shift times using a chi-square test. The results are shown in Table 6 below. The test results confirm the pattern observed above. Winter maintenance operators working mostly day shifts showed a significantly different distribution in fatigue ratings than winter maintenance operators working night shifts ($\chi^2 = 31.42$, $p < 0.0001$) and winter maintenance operators working a mix of day and night shifts ($\chi^2 = 34.26$, $p < 0.0001$). Winter maintenance operators with mostly night shifts did not report significantly different fatigue ratings than winter maintenance operators with a mix of day and night shifts ($\chi^2 = 3.13$, $p = 0.5355$).

**Table 6. Chi-Square Test Results for Fatigue Frequency Rating by Shift Time**

| Shift Time Comparison | $\chi^2$ | *df* | *p* |
|---|---|---|---|
| Day vs. Night | 31.4152 | 4 | <0.0001 |
| Day vs. Day & Night | 34.2575 | 4 | <0.0001 |
| Night vs. Day & Night | 3.1348 | 4 | 0.5355 |

In Figure 8, the distribution of self-reported fatigue frequency is shown by shift length. As the shift length increases from less than 8 hours to more than 16 hours, the percentage of "always" and "most of the time" reporting fatigue responses increased. The relationship between these two variables changes for the "never" fatigue response: as the hours increase, the "never" fatigue response percentage decreased.

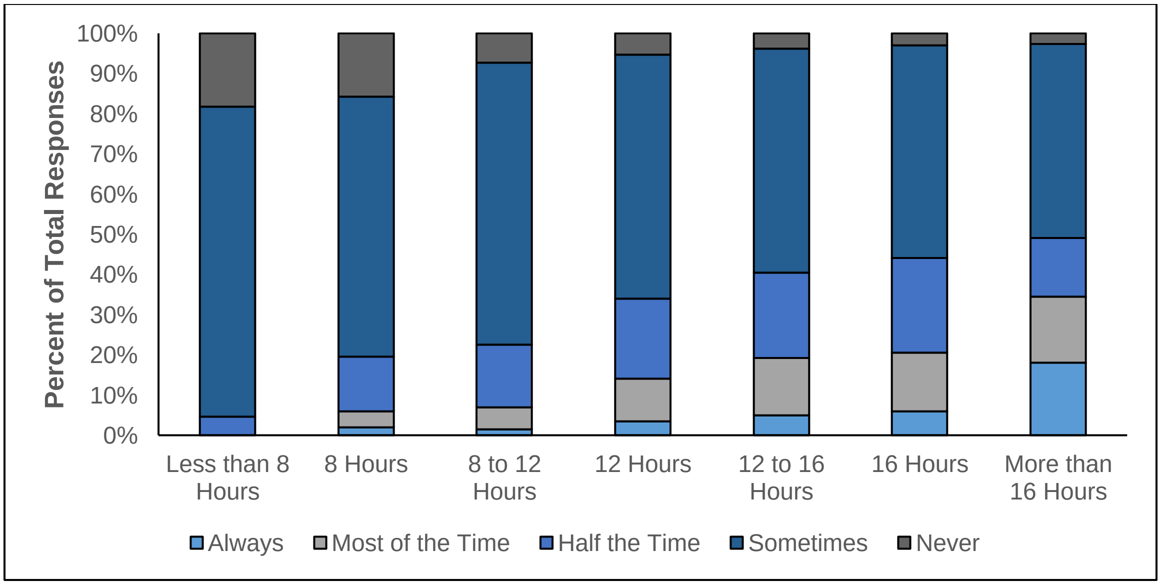



**Figure 8. Frequency of fatigue by shift length.**

Table 7 shows the results from a series of Fisher tests used to identify significant differences in the overall distribution of self-reported fatigue by shift length (as shown in Figure 8). For example, a Fisher test was used to identify if the overall distribution of self-reported fatigue for shifts less than 8 hours was significantly different than the overall distribution of self-reported fatigue for shifts longer than 16 hours (comparing the first bar in Figure 8 to the last bar in Figure 8). Due to the large number of comparisons, an adjusted critical value was used to determine significance (critical values for the tests below was set at 0.0024). The significant results have an "*" in the right-most column. Shifts longer than 16 hours were found to be significantly different in reported fatigue when compared to all other shift lengths. Shifts between 8 and 12 hours showed significant differences from 12-hour shifts ("always" and "most of the time" fatigued rated at approximately half the value seen in 12-hour shifts) and 12- to 16-hour shifts ("always" and "most of the time" fatigued rated at approximately one-third the value seen in 12- to 16-hour shifts).

**Table 7. Fisher Test Results for the Overall Distribution of Fatigue Frequency Ratings by Shift Length**

| Shift Length Comparison 1 | Shift Length Comparison 2 | $\chi^2$ | *p* | Statistically Significant |
|---|---|---|---|---|
| Less than 8 hours | 8 hours | 0.0152 | 0.7599 | |
| Less than 8 hours | 8 to 12 hours | 0.0017 | 0.1962 | |
| Less than 8 hours | 12 hours | <0.0001 | 0.0171 | |
| Less than 8 hours | 12 to 16 hours | <0.0001 | 0.0024 | |
| Less than 8 hours | 16 hours | <0.0001 | 0.0112 | |
| Less than 8 hours | More than 16 hours | <0.0001 | 0.0003 | * |
| 8 hours | 8 to 12 hours | 0.0005 | 0.3006 | |
| 8 hours | 12 hours | <0.0001 | 0.0325 | |
| 8 hours | 12 to 16 hours | <0.0001 | 0.0025 | |
| 8 hours | 16 hours | 0.0002 | 0.0625 | |
| 8 hours | More than 16 hours | <0.0001 | <0.0001 | * |
| 8 to 12 hours | 12 hours | <0.0001 | <0.0001 | * |
| 8 to 12 hours | 12 to 16 hours | <0.0001 | <0.0001 | * |
| 8 to 12 hours | 16 hours | <0.0001 | 0.0186 | |
| 8 to 12 hours | More than 16 hours | <0.0001 | <0.0001 | * |
| 12 hours | 12 to 16 hours | <0.0001 | 0.1361 | |
| 12 hours | 16 hours | <0.0001 | 0.0015 | * |
| 12 hours | More than 16 hours | <0.0001 | <0.0001 | * |
| 12 to 16 hours | 16 hours | 0.0034 | 0.9738 | |
| 12 to 16 hours | More than 16 hours | <0.0001 | 0.0003 | * |
| 16 hours | More than 16 hours | 0.0006 | 0.3504 | |

Fatigue was also assessed for differences by years of experience. In Table 8, the distribution of self-reported fatigue is shown by years of experience. Winter maintenance operators with less than 1 year of experience reported never feeling fatigued at 2 to 8 times the rate of winter maintenance operators with more experience. Winter maintenance operators with 6 or more years of experience reported feeling "always" fatigued at approximately 2 to 4 times the rate of winter maintenance operators with 5 years or less of experience. A chi-square test showed experience in winter operations impacted the frequency of self-reported fatigue ($\chi^2 = 78.96$, $df = 16$, $p < 0.0001$).

**Table 8. Percentage of Fatigue by Years of Experience**

| Fatigue Frequency | >1 Year Experience | 1 to 5 Years' Experience | 6 to 10 Years' Experience | 11 to 15 Years' Experience | <15 Years' Experience |
|---|---|---|---|---|---|
| Always | 1% | 2.54% | 4.61% | 4.53% | 4.99% |
| Most of the time | 2% | 7.83% | 11.24% | 10.19% | 12.26% |
| Half of the time | 16.38% | 15.66% | 22.77% | 22.26% | 16.58% |
| Sometimes | 64.66% | 65.56% | 55.62% | 58.11% | 63.61% |
| Never | 16.38% | 8.41% | 5.76% | 4.91% | 2.56% |

Chi-square post hoc tests were performed to test for significant differences in the overall distribution of self-reported fatigue by winter maintenance operators' years of experience (see Table 9). For example, in the first row of Table 9, the overall distribution in self-reported fatigue was compared for winter maintenance operators' with less than 1 year of experience and winter maintenance operators with 1 to 5 years of experience. The test was used to see if significant differences existed in the distributions shown in Columns 1 and 2 of Table 8 (do winter maintenance operators with less than 1 year of experience report different levels of fatigue than winter maintenance operators with 1 to 5 years' experience?). The critical value was adjusted for these comparisons to account for the large number of post hoc tests ($p = 0.005$), and significant results are indicated in the last column of the table with an "*." The results support what was observed in Table 8. Winter maintenance operators with less than 1 year of experience had significantly different distributions of self-reported fatigue than winter maintenance operators with 6 or more years of experience. Winter maintenance operators with 1 to 5 years of experience had significantly different results from winter maintenance operators with more than 15 years of experience.

**Table 9. Chi-Square Results for the Overall Distribution of Frequency of Fatigue by Years of Experience**

| Experience Comparison 1 | Experience Comparison 2 | $X^2$ | *df* | *p* | Statistically Significant |
|---|---|---|---|---|---|
| Less than 1 year | 1 to 5 years | 12.5633 | 4 | 0.0136 | |
| Less than 1 year | 6 to 10 years | 26.7489 | 4 | <0.0001 | * |
| Less than 1 year | 11 to 15 years | 25.3585 | 4 | <0.0001 | * |
| Less than 1 year | More than 15 years | 57.4066 | 4 | <0.0001 | * |
| 1 to 5 years | 6 to 10 years | 16.1586 | 4 | 0.0028 | |
| 1 to 5 years | 11 to 15 years | 12.0265 | 4 | 0.0172 | |
| 1 to 5 years | More than 15 years | 31.5160 | 4 | <0.0001 | * |
| 6 to 10 years | 11 to 15 years | 0.5427 | 4 | 0.9692 | |
| 6 to 10 years | More than 15 years | 14.4064 | 4 | 0.0061 | |
| 11 to 15 years | More than 15 years | 8.6254 | 4 | 0.0712 | |

## 4.2 FATIGUE AND WINTER MAINTENANCE EQUIPMENT

Winter maintenance operators were asked how their fatigue during winter emergencies was influenced by various types of equipment. These questions and winter maintenance operators' responses are described below. Additionally, the relationship between these questions and fatigue are discussed.

### 4.2.1 Equipment-Related Vibration and Fatigue

Winter maintenance operators were asked to rate how their fatigue was affected by vibration caused by snowplow equipment (see Table 10). Nearly 50% of winter maintenance operators (974 winter maintenance operators) responded that vibration never caused fatigue while driving.

Almost 6% of winter maintenance operators reported that vibration always caused fatigue or caused fatigue most of the time while driving. Approximately 8% of winter maintenance operators reported that vibration caused fatigue half the time while driving. Finally, 37% of winter maintenance operators reported that vibration sometimes caused fatigue while driving.

**Table 10. Responses to the Question, "How Often Does Vibration Caused by Snowplow Equipment Make You Tired During Winter Emergencies?"**

| How often vibration caused by snowplow equipment makes operator tired during winter emergency? | Observation Counts | Observation Percentage |
|---|---|---|
| Always | 25 | 1.27% |
| Most of the time | 93 | 4.71% |
| Half the time | 157 | 7.95% |
| Sometimes | 726 | 36.76% |
| Never | 974 | 49.32% |
| Total | 1,975 | 100.00% |

#### *4.2.1.1 Equipment that May Cause Vibration*

Table 11 shows the ratings for types of equipment related to vehicle vibration. Non-automatic chains and the front plow had the most ratings associated with the development of fatigue while driving. For these equipment types, at least one-quarter of winter maintenance operators rated the equipment as "sometimes" or "always" increasing fatigue while driving. Air-suspension seat, air-cushioned seat, rubber-encased blades, and blade-float device were rated as decreasing fatigue while driving. For these equipment types, 18% to 30% of winter maintenance operators felt they "sometimes" or "always" decreased fatigue while driving.

**Table 11. Impact of Vibration from Equipment on Fatigue**

| Vibration-Related Equipment | Always Increases | Sometimes Increases | Never Impacts | Sometimes Decreases | Always Decreases |
|---|---|---|---|---|---|
| Air-suspension seat | 1% | 9% | 59% | 16% | 14% |
| Air-cushioned seat | 1% | 9% | 64% | 14% | 13% |
| Automatic tire chains | 4% | 7% | 78% | 5% | 7% |
| Non-automatic tire chains | 7% | 18% | 63% | 6% | 7% |
| Rubber-encased blades | 1% | 6% | 66% | 13% | 13% |
| Blade float device | 1% | 5% | 76% | 9% | 9% |
| Segmented blades | 1% | 6% | 80% | 6% | 7% |
| Belly plow | 2% | 13% | 72% | 6% | 7% |
| Wing plow | 3% | 17% | 66% | 8% | 7% |
| Tow plow | 2% | 9% | 80% | 4% | 6% |
| Front Plow | 3% | 22% | 63% | 6% | 6% |

Table 12 shows the results of *t*-tests evaluating the average rating for how vibration from each type of equipment impacted the development of fatigue while driving (termed fatigue impact). Winter maintenance operators indicated that air-suspension seats ($M$ = 2.6656), air-cushioned seats ($M$ = 2.7021), rubber-encased blades ($M$ = 2.6868), and blade float devices ($M$ = 2.8876) all significantly decreased their perceived fatigue while driving. However, winter maintenance operators indicated that non-automatic tire chains ($M$ = 3.1077) and the front plow ($M$ = 3.1071) significantly increased their perceived levels of fatigue while driving.

**Table 12. Statistical Analyses for Vibration-Related Equipment and Levels of Fatigue (rating of 1 = always decreases; 5 = always increases)**

| Vibration-Related Equipment | *n* | Average Rating | *df* | *t* | *p* | *Significance* |
|---|---|---|---|---|---|---|
| Air-suspension seat | 1,794 | 2.6656 | 1793 | -16.31 | <0.0001 | * |
| Air-cushioned seat | 1,363 | 2.7021 | 1362 | -13.19 | <0.0001 | * |
| Automatic tire chains | 393 | 2.9644 | 392 | -0.98 | 0.3300 | |
| Non-automatic tire chains | 956 | 3.1077 | 955 | 3.79 | 0.0002 | * |
| Rubber-encased blades | 843 | 2.6868 | 842 | -11.02 | <0.0001 | * |
| Blade float device | 1,083 | 2.7867 | 1082 | -9.99 | <0.0001 | * |
| Segmented blades | 1,023 | 2.8876 | 1022 | -5.45 | <0.0001 | * |
| Belly plow | 633 | 2.9874 | 632 | -0.43 | 0.6684 | |
| Wing plow | 1,279 | 3.0094 | 1278 | 0.43 | 0.6684 | |
| Tow plow | 388 | 2.9691 | 387 | -0.94 | 0.3494 | |
| Front Plow | 1,765 | 3.1071 | 1764 | 5.69 | <0.0001 | * |

Differences in fatigue impact for all types of vibration-related equipment were also explored across shift time of day, shift length, how frequently winter maintenance operators experienced fatigue, and the part of a shift most often associated with fatigue. These analyses also used the average ratings of fatigue impact as described above (where “always increases” was equal to 5 and “always decreases” was equal to 1). Figure 9 shows the average rating of fatigue impact for each type of vibration-related equipment across each shift time of day. The breakdown by shift time of day showed fairly consistent ratings of fatigue impact for each type of equipment across all three shift time of day levels.

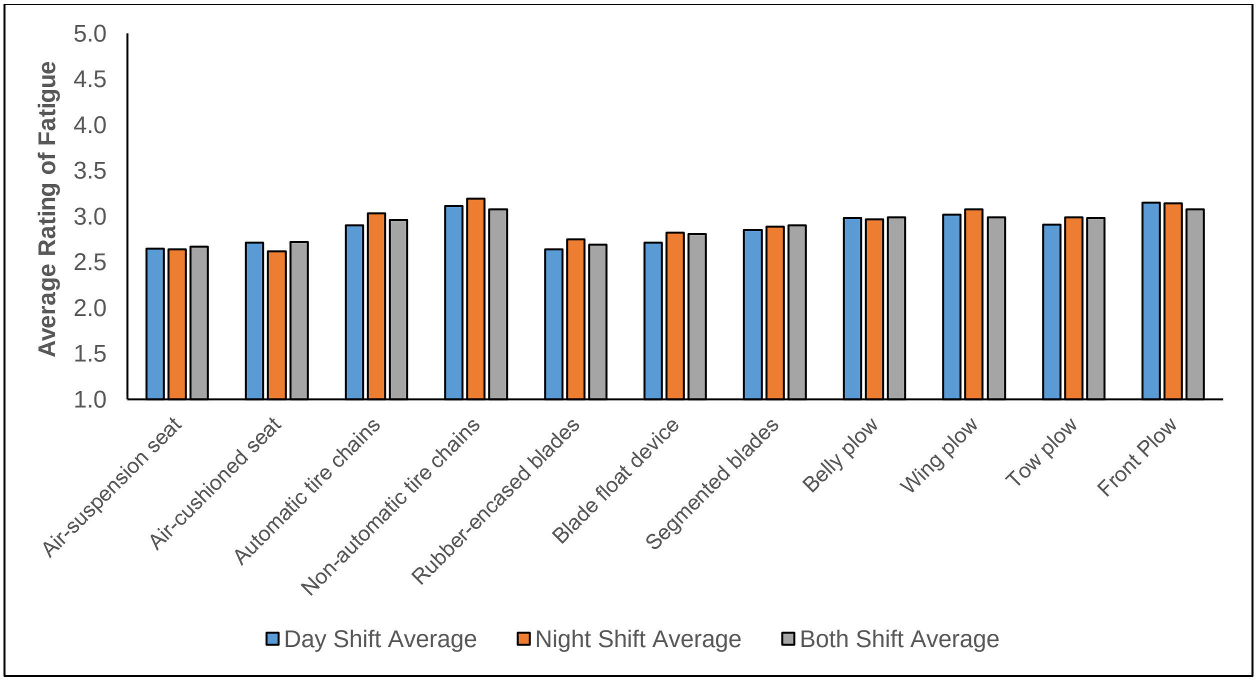



**Figure 9. Average ratings of fatigue by vibration-related equipment and shift time of day (rating of 1 = always decreases; 5 = always increases).**

Figure 10 shows the average ratings of fatigue impact for each type of vibration-related equipment by shift length. Rubber-encased blades showed a slightly increased fatigue impact for shorter shift lengths, and automatic tire chains showed a slightly increased fatigue impact for longer shift lengths. Otherwise, ratings of fatigue impact were fairly consistent across shift lengths.

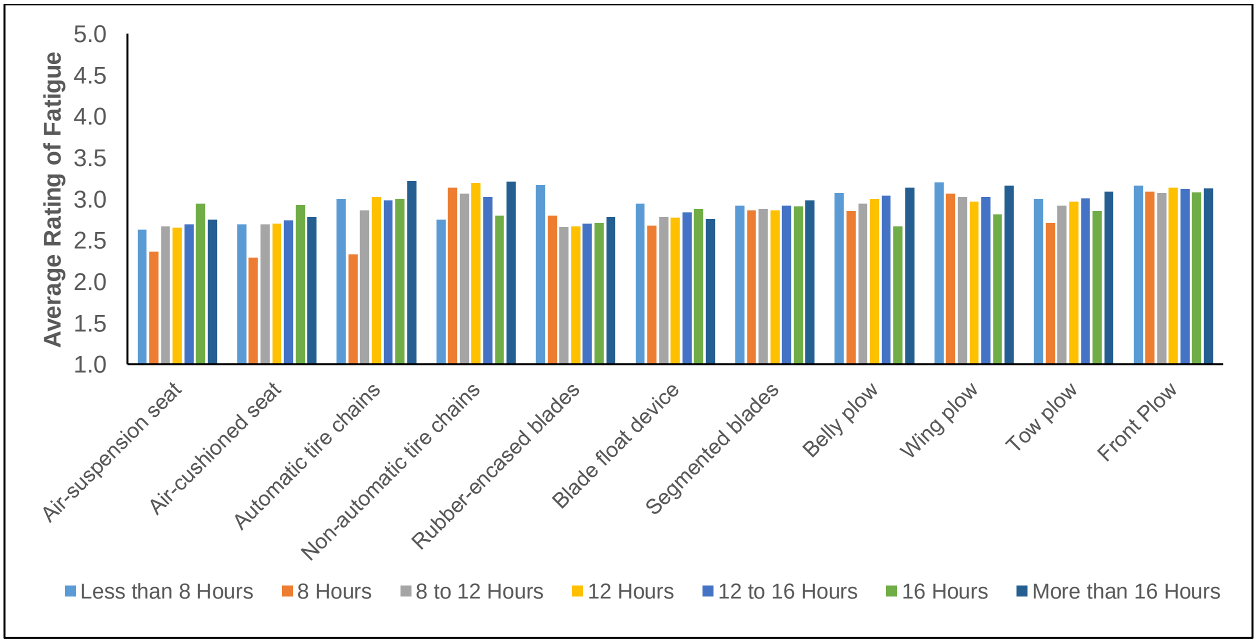



**Figure 10. Average ratings of fatigue by vibration-related equipment and shift length (rating of 1 = always decreases; 5 = always increases).**

Figure 11 shows the average ratings of fatigue impact associated with each type of vibration-related equipment by how frequently the winter maintenance operator felt fatigued during a winter emergency. Winter maintenance operators who reported being "always" fatigued also reported an increased fatigue impact for all types of vibration-related equipment. This pattern was not observed for winter maintenance operators that reported less frequent fatigue.

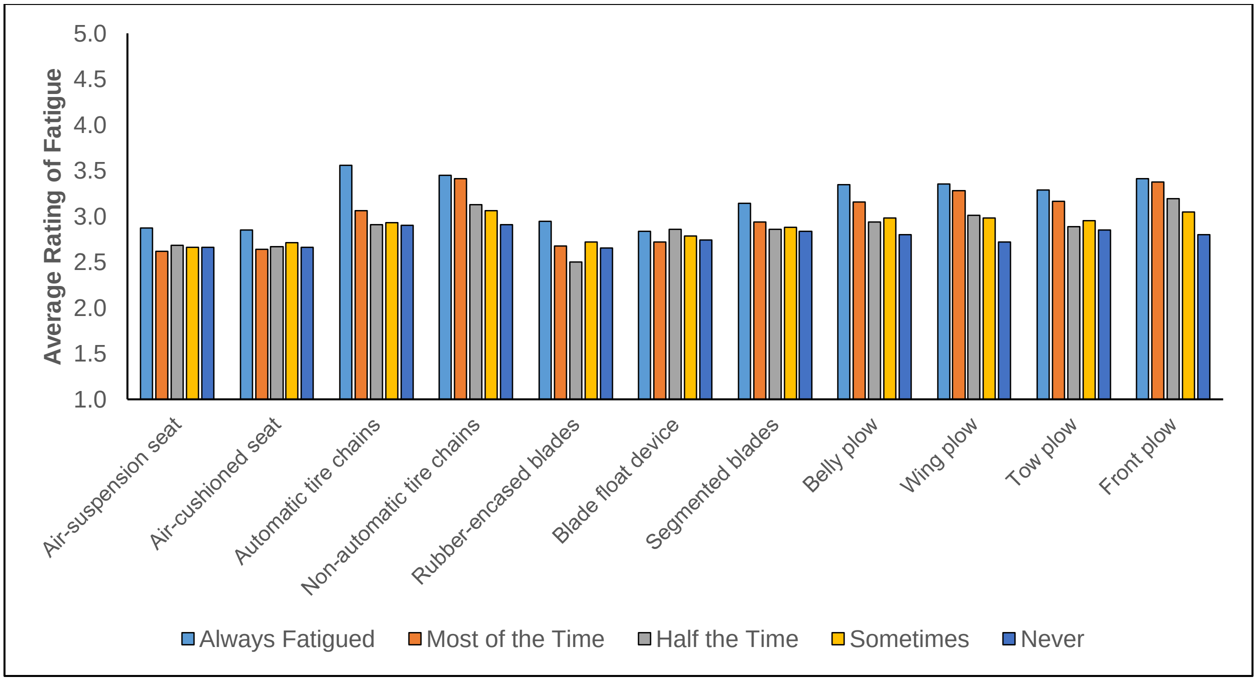



**Figure 11. Average rating of fatigue by vibration-related equipment and frequency of fatigue (rating of 1 = always decreases; 5 = always increases).**

Figure 12 shows the average ratings of fatigue impact for each type of equipment by the part of a shift most often associated with fatigue. Like the previous analysis, winter maintenance operators who reported being "always" fatigued also reported increased ratings of fatigue impact for all types of vibration-related equipment. This pattern was not observed in winter maintenance operators who reported most often experiencing fatigue during specific parts of their shift.

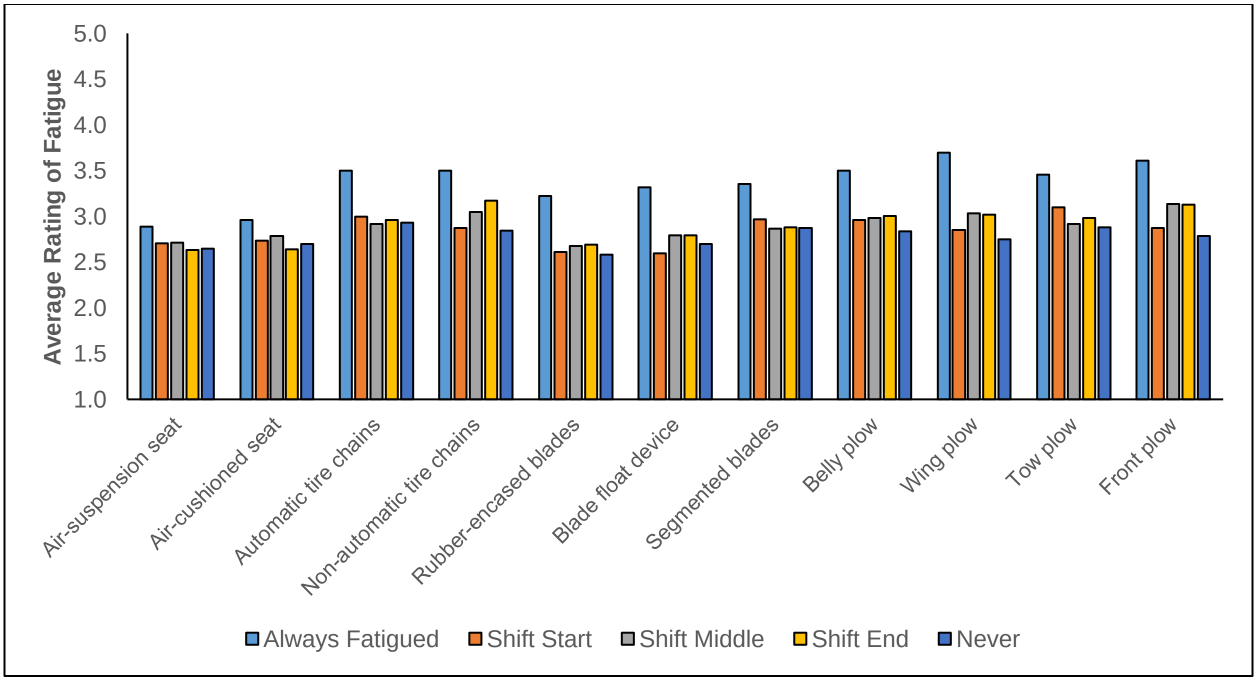



**Figure 12. Average ratings of fatigue for vibration-related equipment by part of shift most often associated with fatigue (rating of 1 = always decreases; 5 = always increases).**

#### *4.2.1.2 Winter Maintenance Operator Recommendations to Reduce Vibration-Related Fatigue*

Winter maintenance operators provided a total of 276 comments related to vibration and fatigue. Figure 13 shows the general themes of these comments. The majority of the comments (32%) were related to truck-based suggestions to reduce vibration. A large number of comments were also related to external equipment (22%) and vehicle seats (21%). Fewer comments were related to the road (7%), the truck's tires (3%), other solutions (1%), and no solution to reduce fatigue caused by vibration (14%). Specific comments related to each of these themes are discussed in more detail below.

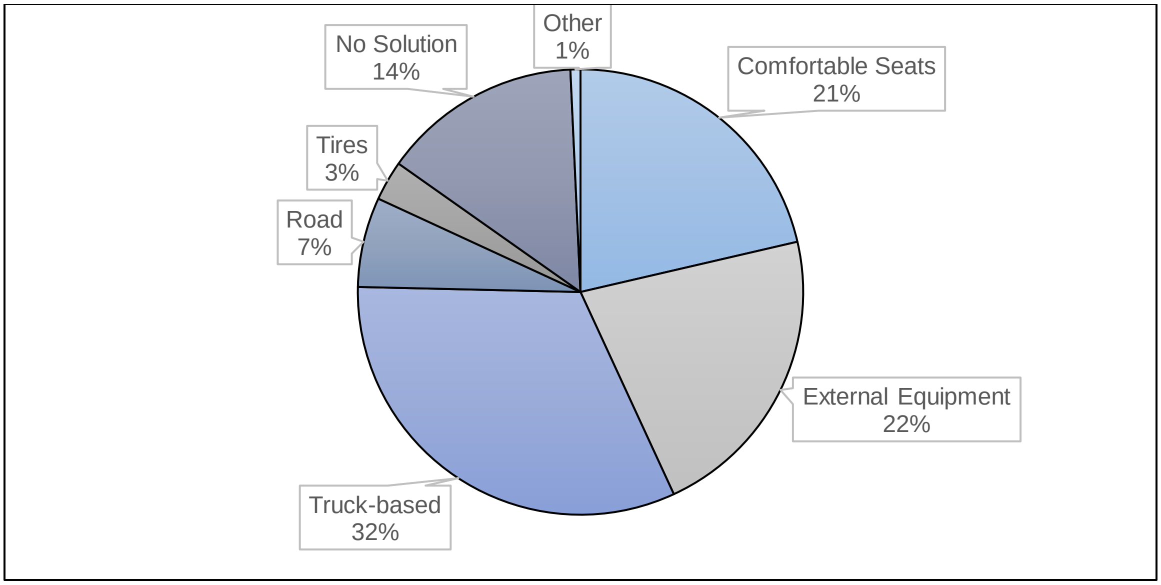



**Figure 13. Themes for operator recommendations to reduce vibration-related fatigue.**

Figure 14 shows the seven subthemes for the 59 comments related to seat comfort as a means to reduce vibration-causing fatigue. Winter maintenance operators provided 32 general suggestions to improve seat comfort.

- "…a wore out seat causes body fatigue which increases operator fatigue, if your body is uncomfortable for long period of time you get tired."

Twelve comments suggested air-ride seats.

- "an upgraded air ride seat would be helpful"

There were five comments associated with the ability to adjust seat position.

- "Seat does not have reclining setting making you sit straight up puts tension on back and neck making it uncomfortable."

Other comments were related to lumbar support (*n* = 3), ergonomically-designed seats (*n* = 3), bench seats (*n* = 2), and heated/massage seats (*n* = 3).

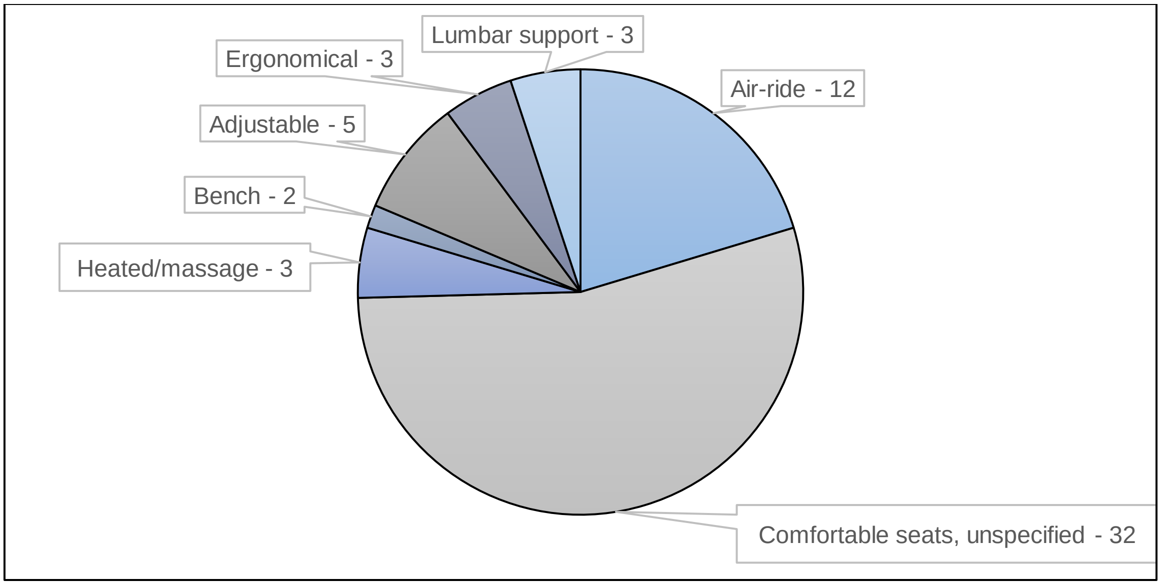
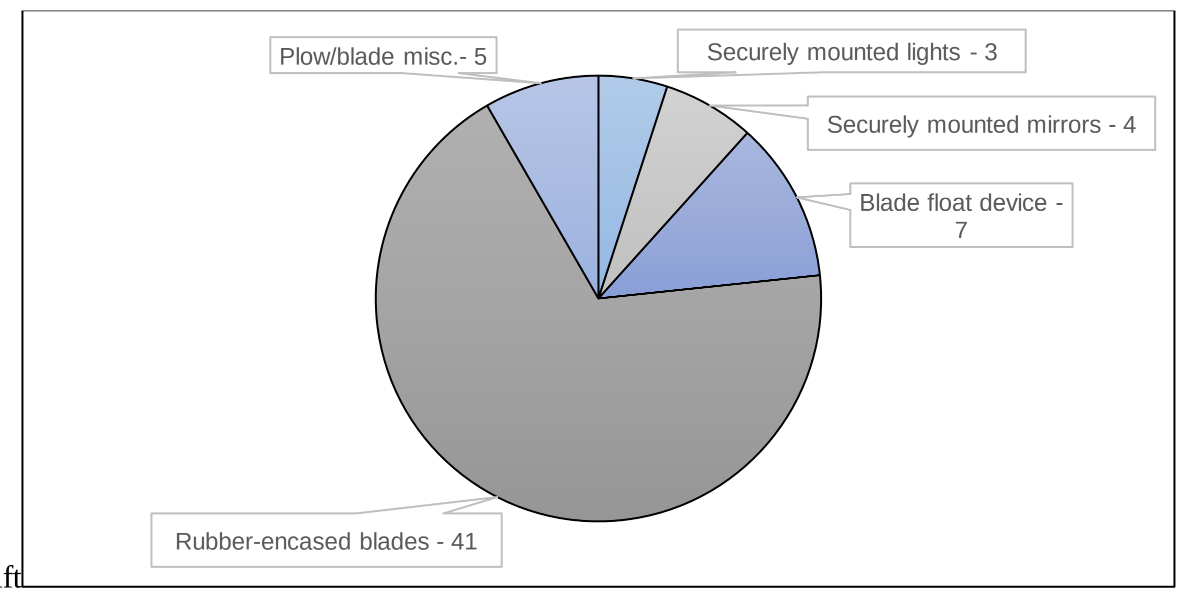



**Figure 14. Comments suggesting comfortable seats to reduce vibration-related fatigue.**

Figure 15 shows the five subthemes for the 60 comments related to external equipment as a means to reduce vibration. Almost 70% of the comments (*n* = 41) suggested the use of rubber-encased blades.

- "We use rubber edges on our front plows and that seems to help a lot."

Fewer comments suggested securely mounting the exterior lighting (*n* = 3) and exterior mirrors (*n* = 4), using a blade float device (*n* = 7), and other various blade/plow factors (*n* = 5).




shift

**Figure 15. Comments related to external equipment to reduce vibration-related fatigue.**

Figure 16 shows the eight subthemes for the 89 comments offering truck-based recommendations to reduce vibration. Nearly 57% of the comments were associated with the truck's suspension system. Forty percent of these comments (*n* = 35) specifically mentioned equipping the trucks with air-ride or vibration dampening suspension.

- "I have noticed a marked difference between the truck that have air ride suspension over the older models that do not have these features."

The other 17% of these comments (*n* = 15) involved unspecified improvements to the truck's suspension.

- "good truck suspension is a key factor"

Additionally, there were 23 comments requesting the purchase of new equipment/trucks.

- "The newer the equipment the less the vibration is my opinion. Equipment for the most part gets better and more comfortable. Air ride seats, armrests, high back seat make a big difference."

Other comments included automatic transmission (*n* = 2), more horsepower (*n* = 4), unspecified better equipment (*n* = 3), better maintenance (*n* = 2), and miscellaneous other recommendations (*n* = 5).

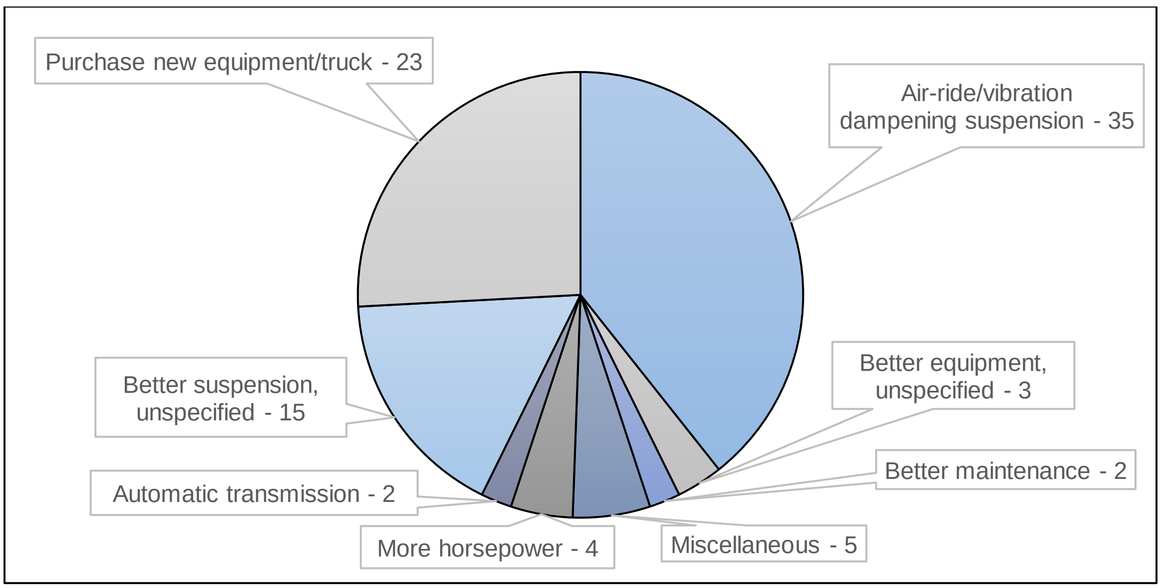



**Figure 16. Truck-related recommendations to reduce vibration-related fatigue.**

Figure 17 shows the four subthemes for the 18 road-related comments to reduce vibration that cause operator fatigue. Approximately 83% of these comments suggested better road maintenance (*n* = 8) or installing recessed highway reflectors (*n* = 7).

- "the equipment is only bad because the roads are horrendous"
- "Eliminate or reset raised roadway reflectors. Lower them so the plow does not jump over them."

Additional comments involved removing rumble strips (*n* = 2) and installing round roadway reflectors (*n* = 1).

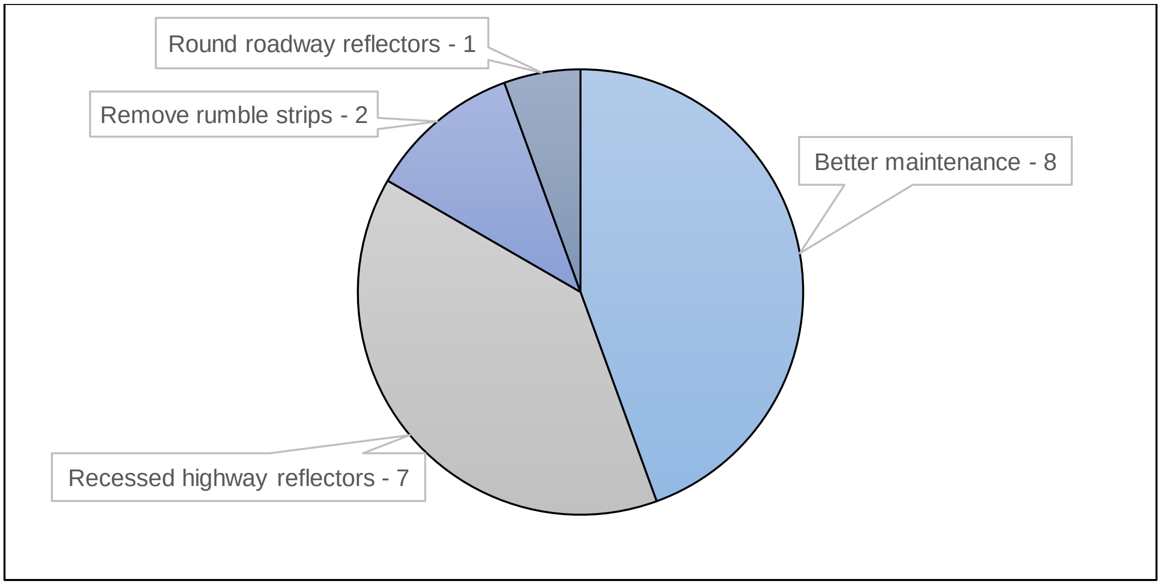



**Figure 17. Road-related recommendations to reduce vibration-related fatigue.**

Figure 18 shows the two subthemes for the eight tire-related comments to reduce vibrations. Two of the eight total comments suggested using basket chains.

- "I would recommend getting away from ladder style tire chains and go with a full wrap style chain. They reduce vibration and wear and tear on equipment."

The other six comments varied, but included limiting the use of chains, properly inflating tires, using cable chains, balancing the tires, the use of automatic chains, and good tires.

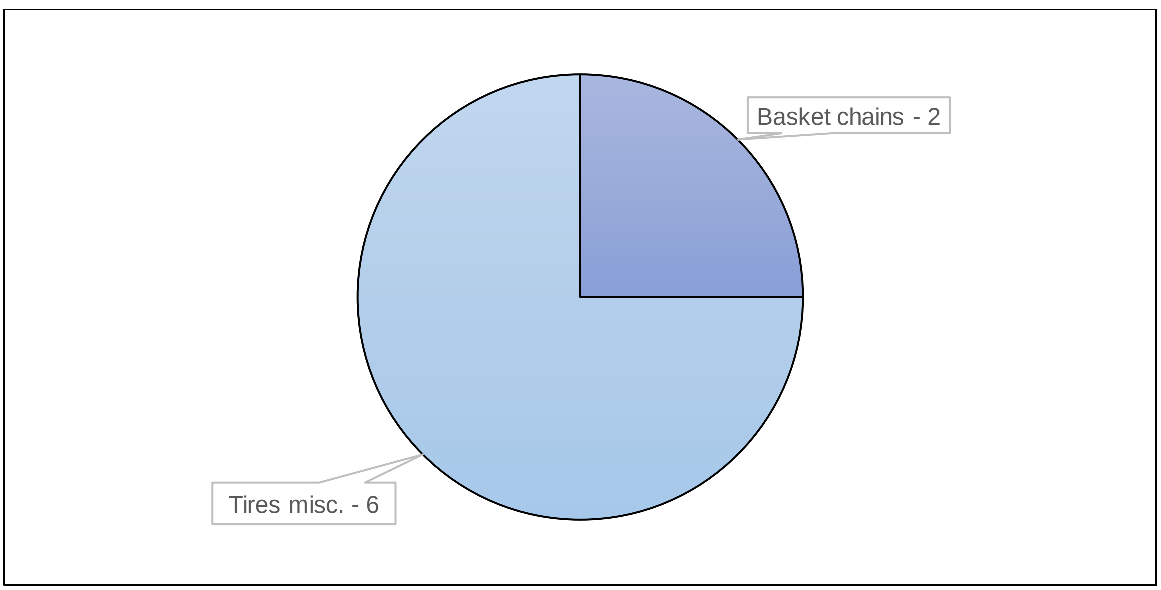



**Figure 18. Tire-related recommendations to reduce vibration-related fatigue.**

The last group of 40 comments suggested there were no recommendations to improve vibration in snowplow operations (see Figure 19). There were 21 comments specifically stating vibration did not impact operator fatigue.

- “I don’t think vibration is the problem, it’s more lack of good rest when off knowing that the public is depending on us to get the roads cleaned and passable in a timely manner.”

Seven comments suggested that vibration is a countermeasure to fatigue.

- “The vibrations from snow plow will help keep me alert, it is at the end of the shift that you know that it is time for the shift to end that I start shutting down and getting tired.”

Six comments stated that vibration from the snowplow is unavoidable.

- “no, but it is our job and that is something that goes along with the job”

Other comments suggested that vibrations alert the operator to any issues or problems ($n$ = 2), winter maintenance operators had not considered vibration’s relationship to fatigue ($n$ = 4), and winter maintenance operators were unsure if vibration was related to fatigue ($n$ = 2).

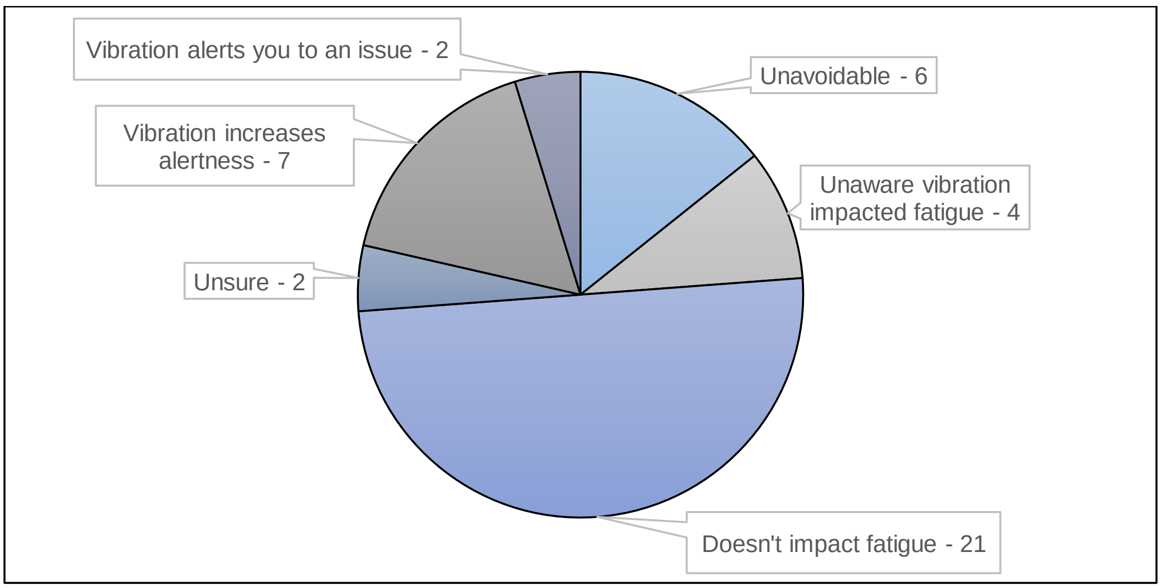



**Figure 19. Comments suggesting vibration does not impact fatigue.**

### 4.2.2 Equipment-Related Noise and Fatigue

Winter maintenance operators were asked rate how fatigue was affected by noise caused by snowplow equipment. Winter maintenance operators’ responses are shown in Table 13. Like vibration-related equipment, nearly half of winter maintenance operators (49.15% or 949 winter maintenance operators) responded that noise never affected their level of fatigue while driving. The next most frequent response was “sometimes” (37.70% of 728 winter maintenance operators). Just under 8% of winter maintenance operators reported noise affected them “half the time” while driving (7.87% of 152 winter maintenance operators), and 5.28% reported being affected “most of the time” while driving. Very few winter maintenance operators reported noise “always” affected their fatigue while driving (1.45% or 28 winter maintenance operators).

**Table 13. Responses to the Question, "How Often Does Noise Caused by Snowplow Equipment Make You Tired During Winter Emergencies?"**

| How often noise caused by snowplow equipment makes operator tired during winter emergency | Observation Counts | Observation Percentage |
|---|---|---|
| Always | 28 | 1.45% |
| Most of the time | 102 | 5.28% |
| Half the time | 152 | 7.87% |
| Sometimes | 728 | 37.70% |
| Never | 949 | 49.15% |
| Total | 1,931 | 100.00% |

#### *4.2.2.1 Equipment that May Cause Noise*

The equipment-related noise reported to have the largest impact on fatigue was having music or the radio turned on or off (see Table 14). Approximately 50% of winter maintenance operators stated having music or the radio on decreased their fatigue while driving ("sometimes" at 26% or "always" at 24%). Conversely, just under half the winter maintenance operators stated having music or the radio turned off increased fatigue while driving ("sometimes" at 31% or "always" at 14%). Other noises that decreased fatigue while driving included the CB radio (20% of winter maintenance operators rated as "sometimes" or "always" decreased fatigue) and the DOT radio (27% of winter maintenance operators rated as "sometimes" or "always"). Noise from the plow or engine increased fatigue in winter maintenance operators (35% and 36%, for the noise types, respectively, rated as "sometimes" or "always").

**Table 14. Impact of Noise from Equipment on Fatigue**

| Noise-Related Equipment | Always Increases | Sometimes Increases | Never Impacts | Sometimes Decreases | Always Decreases |
|---|---|---|---|---|---|
| Noise from plow | 4% | 31% | 54% | 6% | 6% |
| Noise from engine | 5% | 31% | 56% | 5% | 4% |
| Music/radio turned on | 0% | 4% | 45% | 26% | 24% |
| Music/radio turned off | 14% | 31% | 47% | 5% | 3% |
| CB radio | 2% | 7% | 71% | 11% | 9% |
| DOT radio | 4% | 10% | 60% | 17% | 10% |
| Audible alerts from snow/ice/safety equipment | 2% | 8% | 68% | 12% | 10% |

Table 15 shows the results of *t*-tests that evaluated how the average ratings of fatigue were affected by equipment-related noise. Noise-related equipment that was found to significantly decrease perceived fatigue while driving included the music/radio turned on ($M$ = 2.3044), CB radio ($M$ = 2.8171), DOT radio ($M$ = 2.8097), and audible alerts from snow/ice/safety equipment ($M$ = 2.7929). Noise-related equipment found to significantly increase perceived levels of fatigue while driving included noise from the plow or engine ($M$ = 3.2182 and $M$ = 3.2734, respectively) and having the music/radio turned off ($M$ = 3.4794).

**Table 15. Statistical Analyses for Equipment-Related Noise and Levels of Fatigue (rating of 1 = always decreases; 5 = always increases)**

| Equipment-Related Noise | *n* | Average Rating | *df* | *t* | *p* | *Significance* |
|---|---|---|---|---|---|---|
| Noise from plow | 1,884 | 3.2182 | 1,883 | 11.23 | <0.0001 | * |
| Noise from engine | 1,880 | 3.2734 | 1,879 | 14.99 | <0.0001 | * |
| Music/radio turned on | 1,820 | 2.3044 | 1,819 | -32.97 | <0.0001 | * |
| Music/radio turned off | 1,771 | 3.4794 | 1,770 | 22.20 | <0.0001 | * |
| CB radio | 924 | 2.8171 | 923 | -7.31 | <0.0001 | * |
| DOT radio | 1,823 | 2.8097 | 1,822 | -9.15 | <0.0001 | * |
| Audible alerts from snow/ice/safety equipment | 1,405 | 2.7929 | 1,404 | -9.89 | <0.0001 | * |

Differences in ratings of fatigue impact for all types of equipment-related noise were also explored across shift time of day, shift length, how frequently winter maintenance operators experienced fatigue, and the part of a shift most often associated with fatigue. These analyses of fatigue impact also used the averaged ratings of fatigue impact. Figure 20 shows the average ratings of fatigue impact for each equipment-related noise by shift time of day. As shown in the figure, it is clear that shift time of day did not have a strong relationship with fatigue impact across all equipment-related noises (the average rating of fatigue impact within each equipment-related noise was consistent across all three shift times of day).

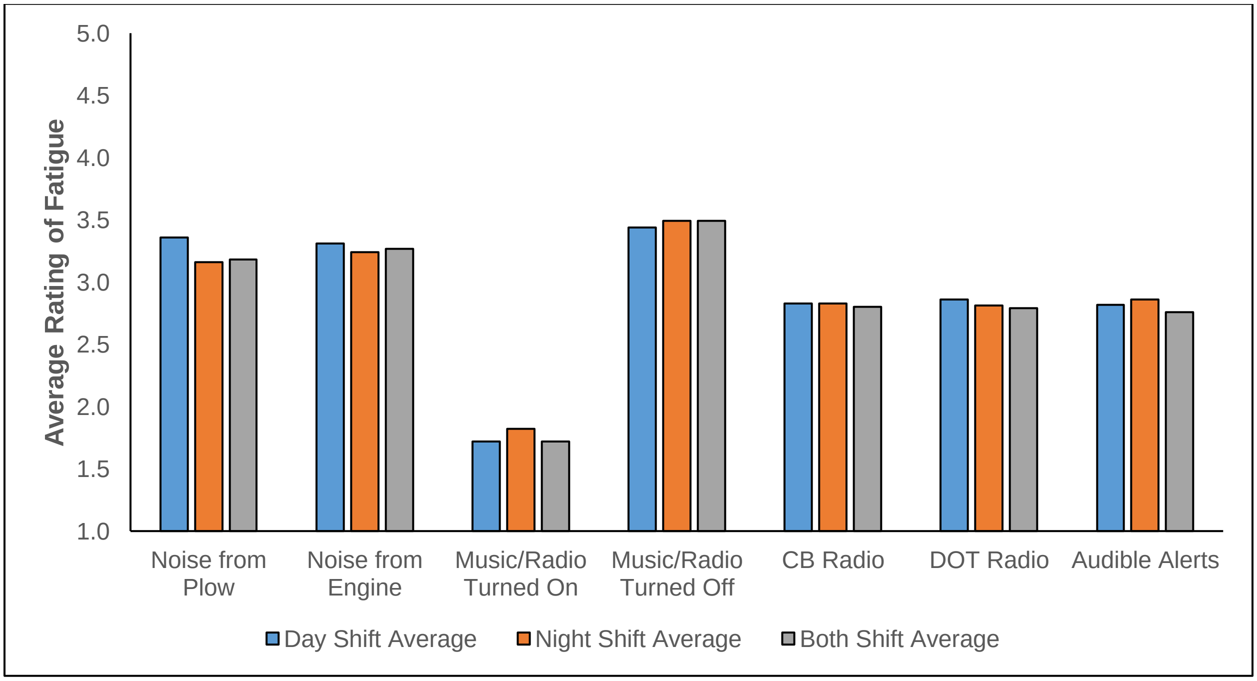



**Figure 20. Average ratings of fatigue by equipment-related noise and shift time of day (rating of 1 = always decreases; 5 = always increases).**

Figure 21 shows the average ratings of fatigue impact for each equipment-related noise by shift length. Similar to the finding for shift time of day, winter maintenance operators' ratings of fatigue impact did not appear to change consistently with shift length.

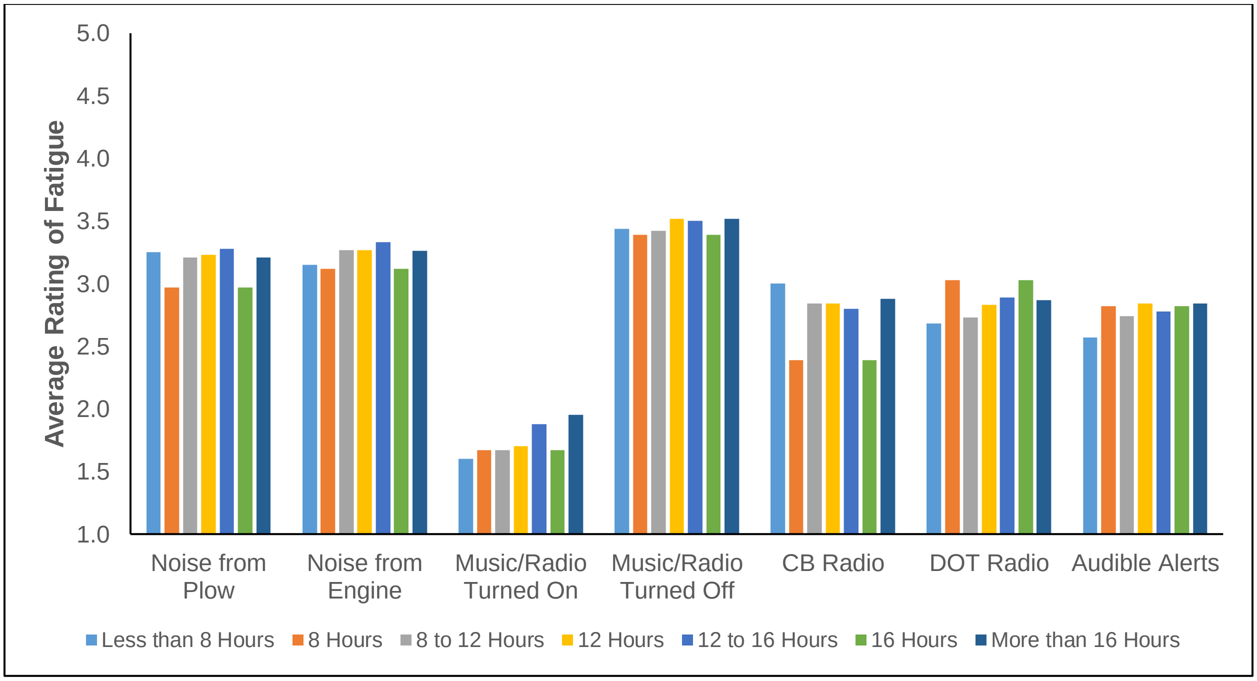



**Figure 21. Average rating of fatigue by equipment-related noise and shift length (rating of 1 = always decreases; 5 = always increases).**

Figure 22 shows the average ratings of fatigue impact for each equipment-related noise by how often winter maintenance operators felt fatigued during a winter emergency. The findings in Figure 22 echo those found for vibration-related equipment. Winter maintenance operators who reported feeling "always" fatigued also reported an increased fatigue impact for most equipment-related noises. As the frequency of self-reported fatigue decreased, each equipment-related noise's impact on fatigue also decreased.

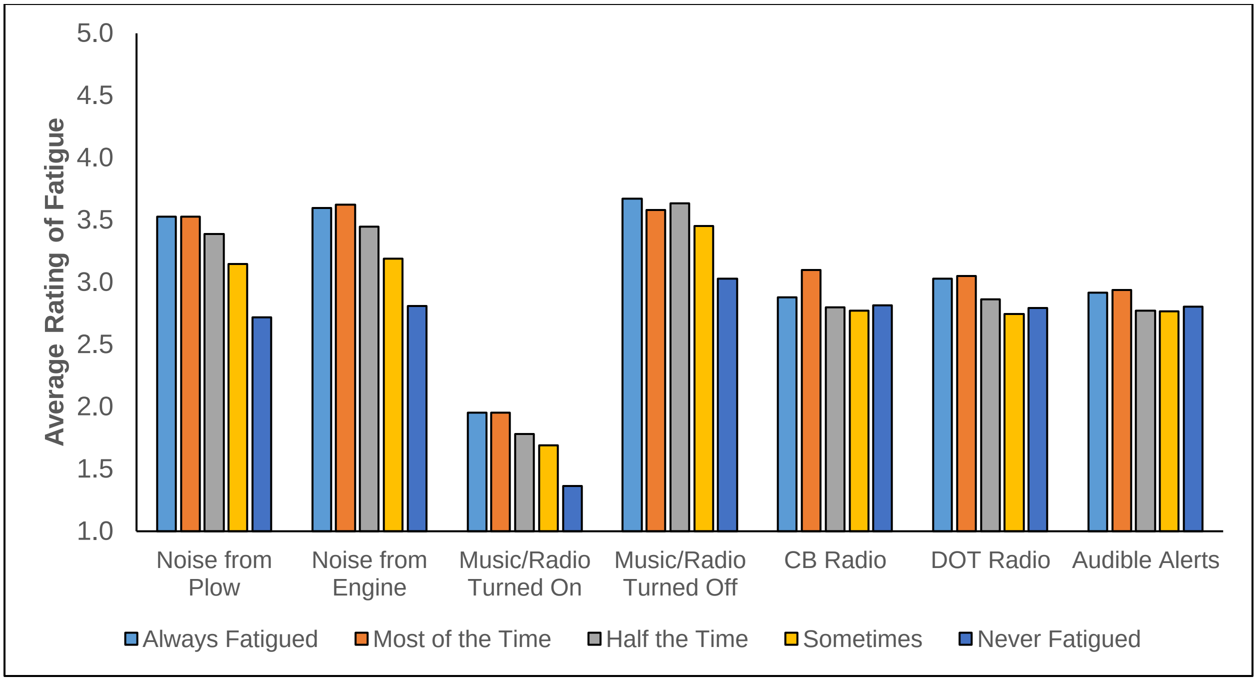



**Figure 22. Average rating of fatigue by equipment-related noise and frequency of becoming fatigued (rating of 1 = always decreases; 5 = always increases).**

Figure 23 shows the average ratings of fatigue impact for each equipment-related noise by the part of a shift most often associated with fatigue. As expected, winter maintenance operators who reported feeling "always" fatigued also reported increased ratings of fatigue impact for the different equipment-related noises. Similarly, winter maintenance operators who reported "never" feeling fatigued reported lower ratings of fatigue impact for most of the equipment-related noises.

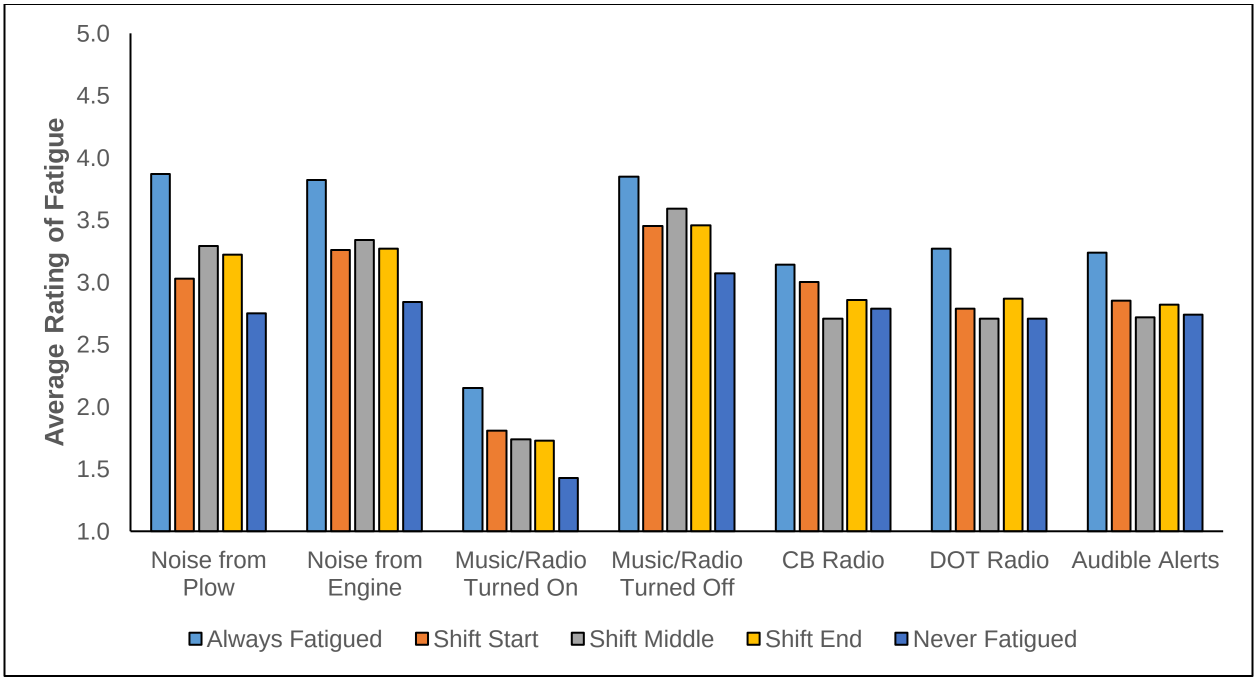



**Figure 23. Average ratings of fatigue by equipment-related noise and part of shift most often associated with fatigue (rating of 1 = always decreases; 5= always increases).**

#### *4.2.2.2 Winter Maintenance Operator Recommendations to Reduce Noise-Related Fatigue*

Winter maintenance operators provided a total of 307 comments related to noise and fatigue. Figure 24 shows the general themes of these comments. The majority of the comments (36%) were related to using music or having a radio in the trucks to reduce fatigue. A large number of comments were also related to truck noises or noises from external equipment (39%). Other comments were related to internal equipment (6%), the road (3%), other solutions (3%), and there is no solution to reduce fatigue caused by noise (13%). Specific comments related to each of these themes are discussed in more detail below.

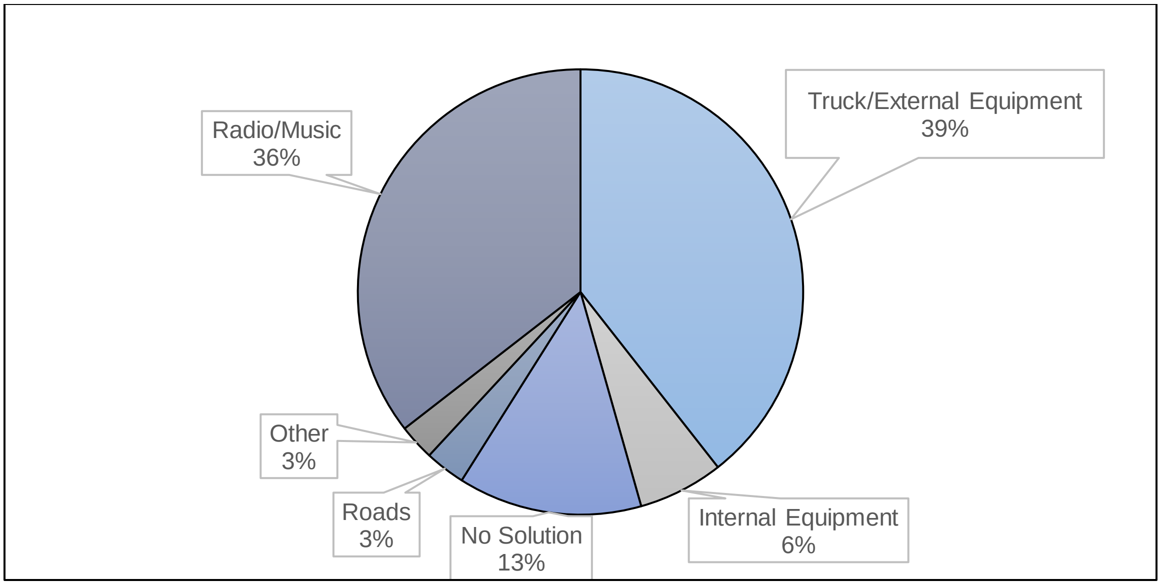



**Figure 24. Overall themes for causes of noise-related fatigue.**

Figure 25 shows the 10 subthemes for the 121 comments related to noise from the truck or external equipment. Fifty percent of the comments involved improved cab insulation ($n$ = 60).

- "Better insulated cabs help keep out noise which can have an impact on tiredness/alertness over a long period."

Approximately 18% of the comments suggested the use of rubber-encased blades ($n$ = 22).

- "I have used Joma snow plow blades and it absolutely has reduced my headaches, and tiredness from plowing."

Another 16% of comments mentioned purchasing new trucks and equipment ($n$ = 19).

- "older trucks have louder cabs in general the newer trucks seem to be better equipped to lessen the noise and vibrations of snow plow operations"

Fewer comments included rolling the windows up ($n$ = 2), good truck maintenance ($n$ = 3), upgrading the truck muffler ($n$ = 5), moving the exhaust system ($n$ = 2), installing a heated windshield ($n$ = 3), tightly securing the interior monitors and gauges ($n$ = 2), and using an air-ride suspension ($n$ = 3).

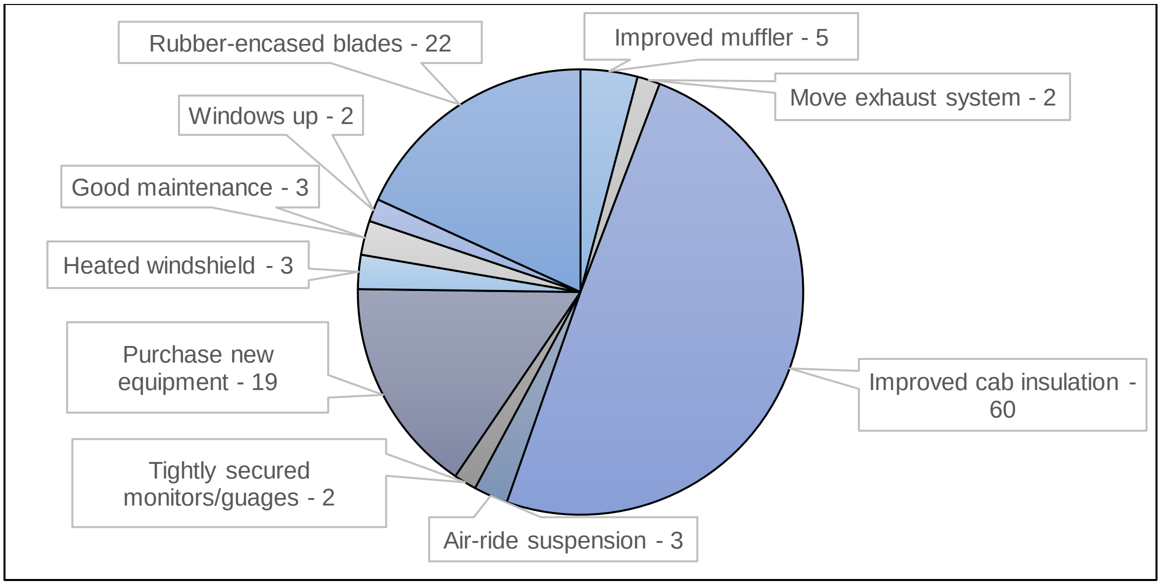



**Figure 25. Truck and external equipment recommendations to reduce noise-related fatigue.**

Figure 26 shows the three subthemes for the 19 comments related to interior equipment-related noise. Fourteen of these comments suggested the use of ear plugs or hearing protection.

- "emergency equipment such as fire trucks and ambulances are equipped with ear muffs with microphones that block out exterior sound but allow radio operations. There would help to eliminate outside noise."

Fewer comments suggested removing audible alerts ($n = 3$) and allowing for adjustable volume on audible alerts ($n = 2$).

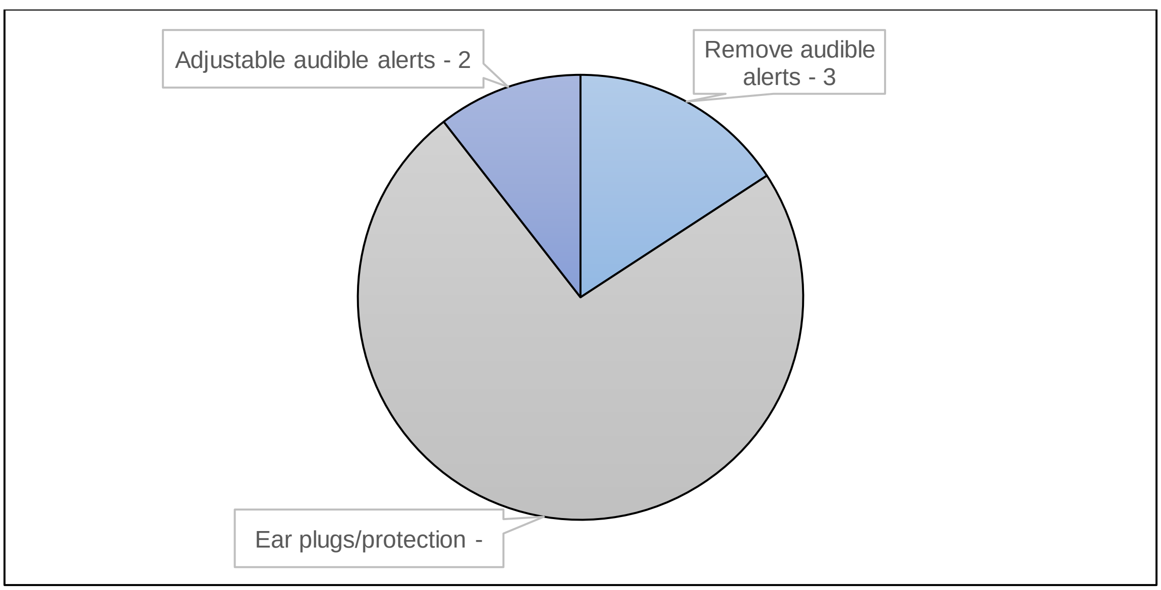



**Figure 26. Interior equipment recommendations to reduce noise-related fatigue.**

Figure 27 shows the two subthemes for the nine comments related to the roadway. Eight of these comments suggested installing recessed highway reflectors.

- “Centerline reflector in pavement causes plow to jump up and down when they are hit. This is very loud and causes a lot of noise and vibration to truck and operator.”

The other comment suggested good road maintenance to reduce noise-related fatigue.

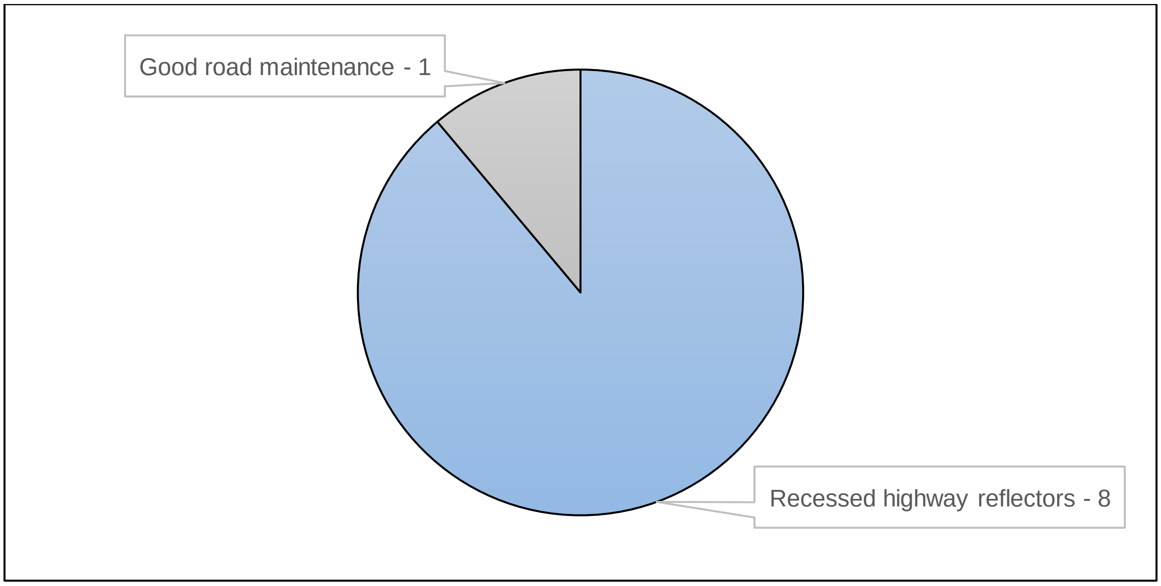



**Figure 27. Road-related recommendations to reduce noise-related fatigue.**

Figure 28 shows the six subthemes for the 109 comments associated with the use of music/radio to reduce fatigue. The majority of these comments suggested installing a better stereo system and/or a compact disc (CD) player in the truck ($n$ = 61).

- “I think you should have good AM/FM radios in the truck. I think you don’t have to hear the truck noise as much. Much less monotonous.”

Nineteen other comments suggested satellite radios.

- “I use satellite radio in the truck because of the lack of radio stations in our area. I believe this helps to find a station to fit your mood and fatigue level to keep the shift from dragging out.”

Additionally, 11 comments suggested unspecified music.

- “the radio being on helps reduce tiredness keeping you more awake”

Other comments were related to limiting chatter on the DOT radio ($n$ = 9), purchasing better DOT radios ($n$ = 6), and installing CB radios ($n$ = 3).

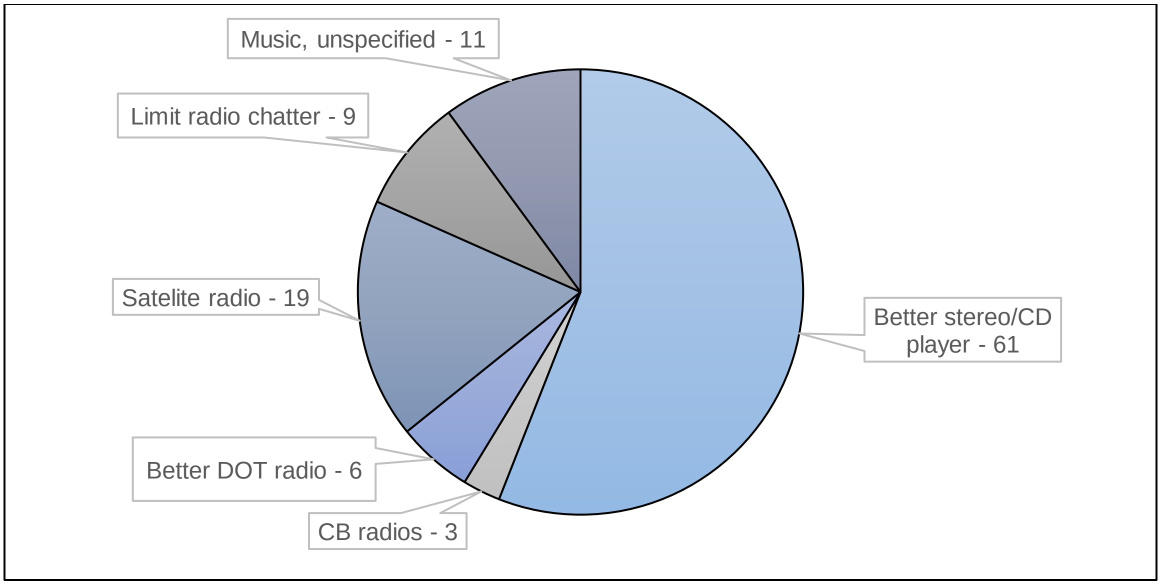



**Figure 28. Music/radio recommendations to reduce noise-related fatigue.**

Figure 29 shows the four subthemes for the 41 comments suggesting that noise was not associated with fatigue. Twenty-two comments suggested that noise may increase alertness.

- “Actually it seems like the more noise there is the less tired I get because I have that constant background noise to prevent more from getting tired.”

Twelve comments suggested that noise is unavoidable in snowplow operations.

- “Noise happens. It is the monotony of it all. And lack of change during it, in long periods of operations.”

Other comments suggested noise does not impact fatigue (*n* = 6) and winter maintenance operators were unaware noise was associated with fatigue (*n* = 1).

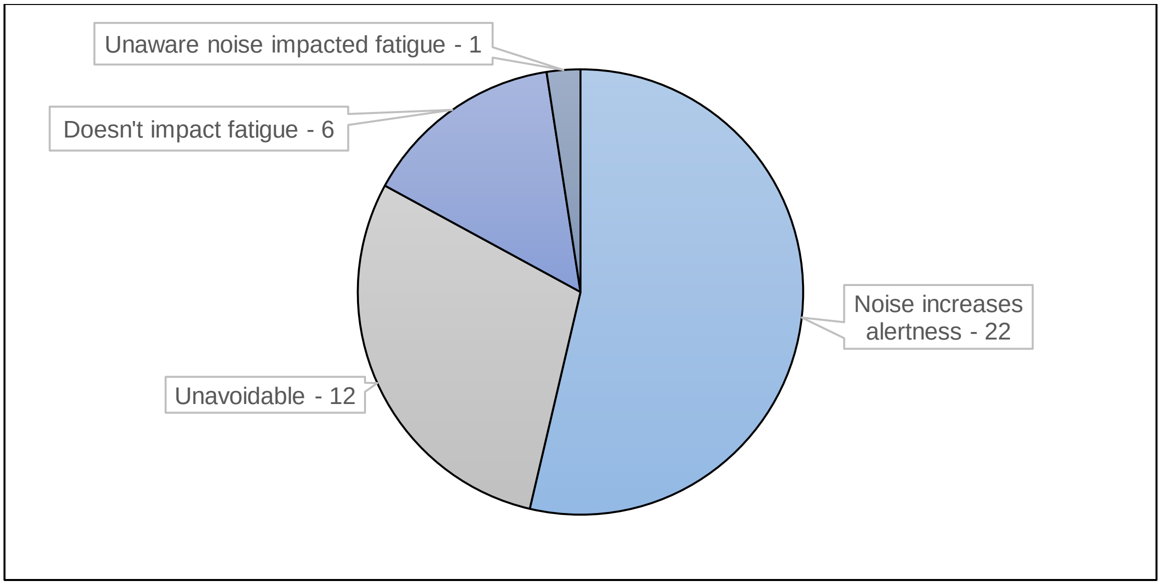



**Figure 29. Comments suggesting noise does not cause fatigue.**

### 4.2.3 Equipment-Related Visibility and Fatigue

Winter maintenance operators were asked how often reduced visibility made them fatigued during winter emergencies. Table 16 shows the distribution of these responses. More than one-quarter of the winter maintenance operators stated that reduced visibility made them "always" (9.81%) fatigued or fatigued "most of the time" (16.38%) while driving. The rating "half the time" was chosen by 15.77% of winter maintenance operators, and "sometimes" by 40.45% of winter maintenance operators. Reduced visibility was never an issue for 27.41% of winter maintenance operators while driving.

**Table 16. Responses to the Question, "How Often Does Reduced Visibility Make You Tired During Winter Emergencies?"**

| How often noise caused by snowplow equipment makes operator tired during winter emergency | Observation Counts | Observation Percentage |
|---|---|---|
| Always | 176 | 8.93% |
| Most of the time | 294 | 14.92% |
| Half the time | 283 | 14.36% |
| Sometimes | 726 | 36.83% |
| Never | 492 | 24.96% |
| Total | 1,971 | 100.00% |

#### *4.2.3.1 Visibility-Related Equipment*

Few types of visibility-related equipment were rated as having a strong impact on decreasing fatigue while driving (see Table 17). Anti-glare glass was rated by 22% of winter maintenance operators as "sometimes" (13%) or "always" (9%) decreasing fatigue while driving. However, several types of equipment were rated as "sometimes" increasing fatigue while driving. These types of equipment included exterior strobe lights (33%), exterior flashing lights (31%), interior vehicle lighting (18%), and windshield wipers (30%). Most often winter maintenance operators reported visibility-related equipment never impacted their feelings of fatigue while driving (ranged between 51% and 84% of winter maintenance operators).

**Table 17. Impact of Visibility-Related Equipment on Fatigue**

| Visibility-Related Equipment | Always Increases | Sometimes Increases | Never Impacts | Sometimes Decreases | Always Decreases |
|---|---|---|---|---|---|
| Anti-glare glass | 2% | 12% | 65% | 13% | 9% |
| Exterior strobe lights | 7% | 33% | 51% | 5% | 4% |
| Exterior flashing lights | 6% | 31% | 54% | 5% | 4% |
| Interior vehicle lighting | 2% | 18% | 69% | 7% | 4% |
| Auxiliary exterior lighting | 2% | 15% | 71% | 6% | 5% |
| Windshield wipers | 4% | 30% | 57% | 5% | 4% |
| Heated mirrors | 0% | 2% | 82% | 7% | 9% |
| Heated windshield | 0% | 2% | 84% | 6% | 7% |
| Heated windows | 1% | 3% | 84% | 5% | 8% |
| Snow deflector | 1% | 6% | 80% | 6% | 6% |

Table 18 shows the results of *t*-tests evaluating how the average ratings of fatigue were affected by visibility-related equipment. Several types of equipment were found to significantly decrease perceived levels of fatigue while driving. These included anti-glare glass ($M$ = 2.8543), heated mirrors ($M$ = 2.7790), heated windows ($M$ = 2.8360), heated windshield ($M$ = 2.6306), and snow deflectors ($M$ = 2.6656). Visibility-related equipment rated as significantly increasing perceived levels of fatigue while driving included exterior strobe lights ($M$ = 3.3310), exterior flashing lights ($M$ = 3.3001), interior vehicle lighting ($M$ = 3.0718), and windshield wipers ($M$ = 3.2604).

**Table 18. Statistical Analyses for Visibility-Related Equipment and Levels of Fatigue (rating of 1 = always decreases; 5 = always increases)**

| Vibration-Related Equipment | *n* | Average Rating | *df* | *t* | *p* | *Significance* |
|---|---|---|---|---|---|---|
| Anti-glare glass | 1,167 | 2.8543 | 1,166 | -6.11 | <0.0001 | * |
| Exterior strobe lights | 1,837 | 3.3310 | 1,836 | 16.88 | <0.0001 | * |
| Exterior flashing lights | 1,826 | 3.3001 | 1,825 | 15.64 | <0.0001 | * |
| Interior vehicle lighting | 1,811 | 3.0718 | 1,810 | 4.31 | <0.0001 | * |
| Auxiliary exterior lighting | 1,764 | 3.0295 | 1,763 | 1.76 | 0.0786 | |
| Windshield wipers | 1,885 | 3.2604 | 1,854 | 14.58 | <0.0001 | * |
| Heated mirrors | 1,760 | 2.7790 | 1,759 | -14.46 | <0.0001 | * |
| Heated windshield | 1,554 | 2.6306 | 1,553 | -17.58 | <0.0001 | * |
| Heated windows | 951 | 2.8360 | 950 | -8.19 | <0.0001 | * |
| Snow deflector | 1,794 | 2.6656 | 1,793 | -16.31 | <0.0001 | * |

Differences in average ratings of fatigue impact for all types of visibility-related equipment were also explored across shift time of day, shift length, how frequently winter maintenance operators experienced fatigue, and the part of a shift most often associated with fatigue. Figure 30 shows, for each type of visibility-related equipment, the average rating of fatigue impact by shift time of day. As shown in the Figure 30, shift time of day did not appear to have an effect on winter maintenance operators' average rating of fatigue impact for visibility-related equipment.

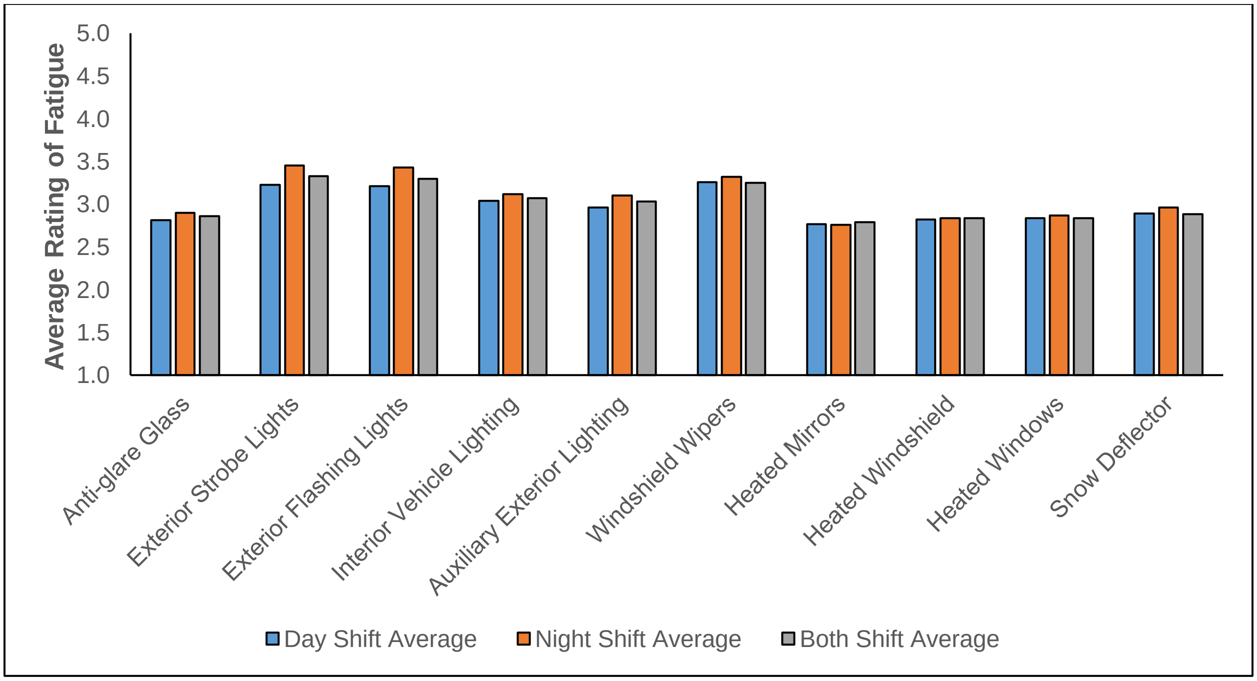



**Figure 30. Average rating of fatigue for visibility-related equipment by shift time of day (rating of 1 = always decreases; 5 = always increases).**

Figure 31 shows the average ratings of fatigue impact for each type of visibility-related equipment by shift length. As shown in Figure 31, winter maintenance operators indicated that mid-length shifts (shifts between 8 and 16 hours long) had higher ratings of fatigue impact associated with visibility-related equipment. Winter maintenance operators' with shift lengths longer than 16 hours also had higher ratings of fatigue impact for many of the types of visibility-related equipment.

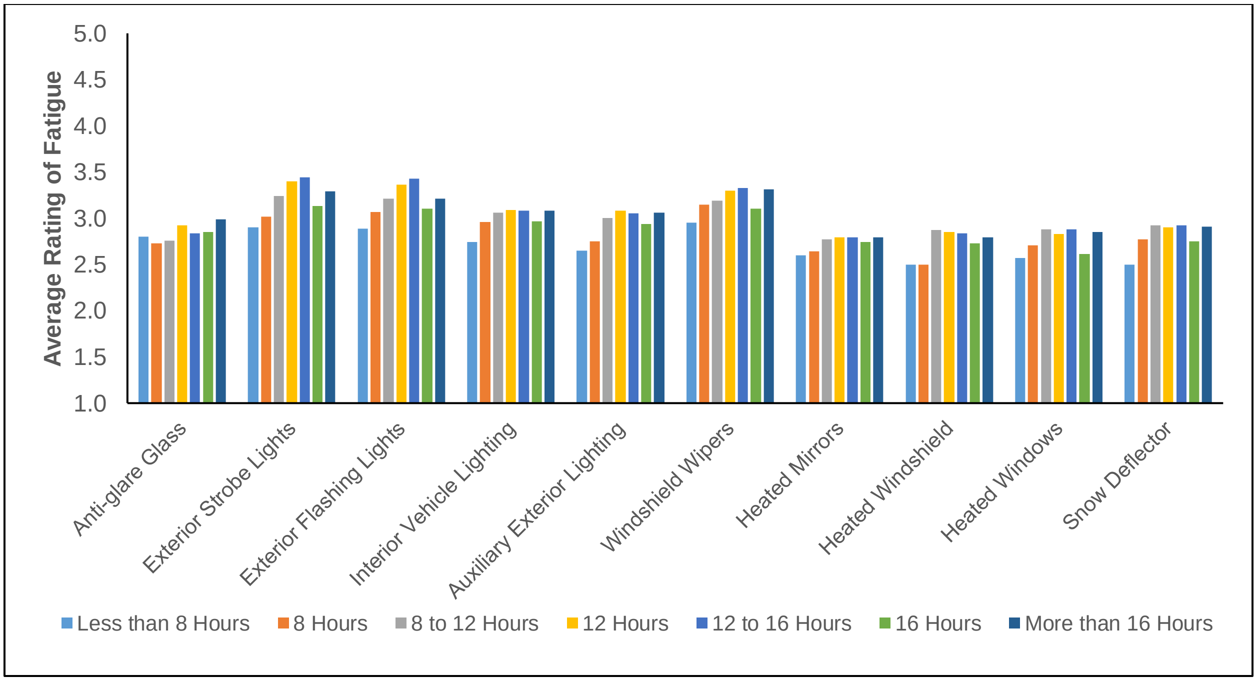



**Figure 31. Average ratings of fatigue for visibility-related equipment by shift length (rating of 1 = always decreases; 5 = always increases).**

Figure 32 shows the average ratings of fatigue impact for each type of visibility-related equipment by how often winter maintenance operators felt fatigued during a winter emergency. Winter maintenance operators who reported feeling fatigued "always" or "most of the time" also reported feeling an increased fatigue impact for all types of visibility-related equipment.

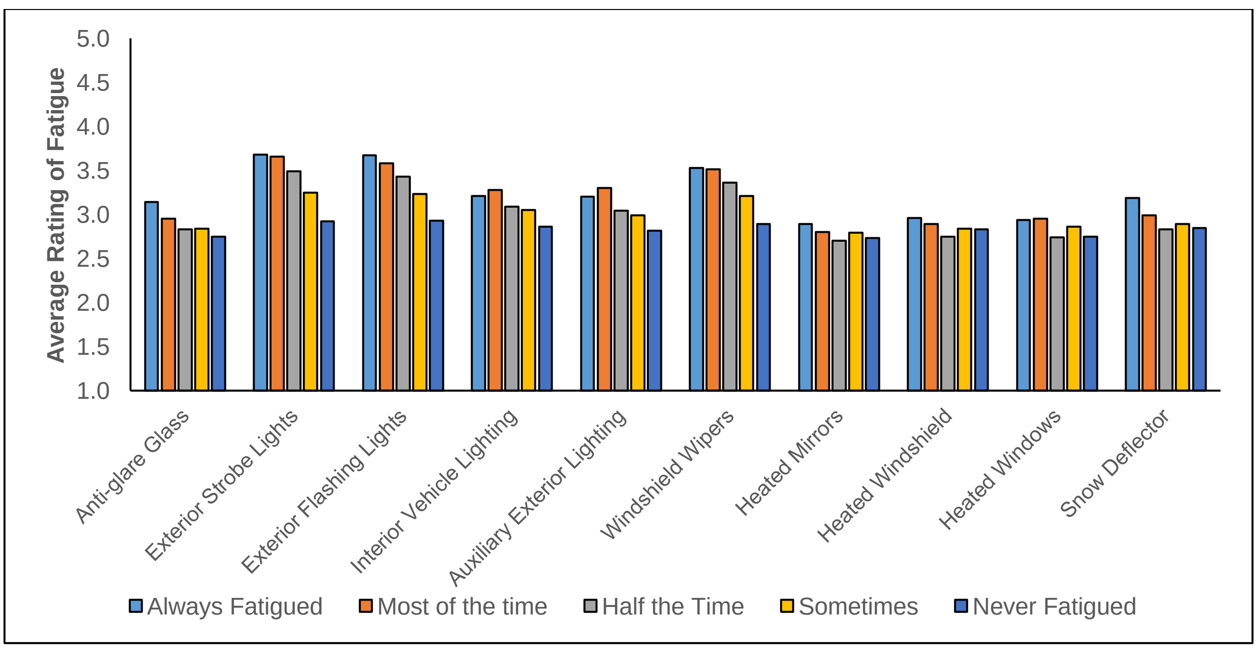



**Figure 32. Average ratings of fatigue for visibility-related equipment by frequency of becoming fatigued (rating of 1 = always decreases; 5 = always increases).**

Figure 33 shows the average ratings of fatigue impact for each type of visibility-related equipment by the part of a shift most often associated with fatigue. Winter maintenance operators who reported feeling "always" fatigued also reported much higher ratings of fatigue impact for all types of visibility-related equipment. Winter maintenance operators that reported feeling fatigue most often during other parts of a shift reported varying fatigue impacts for the different types of visibility-related equipment.

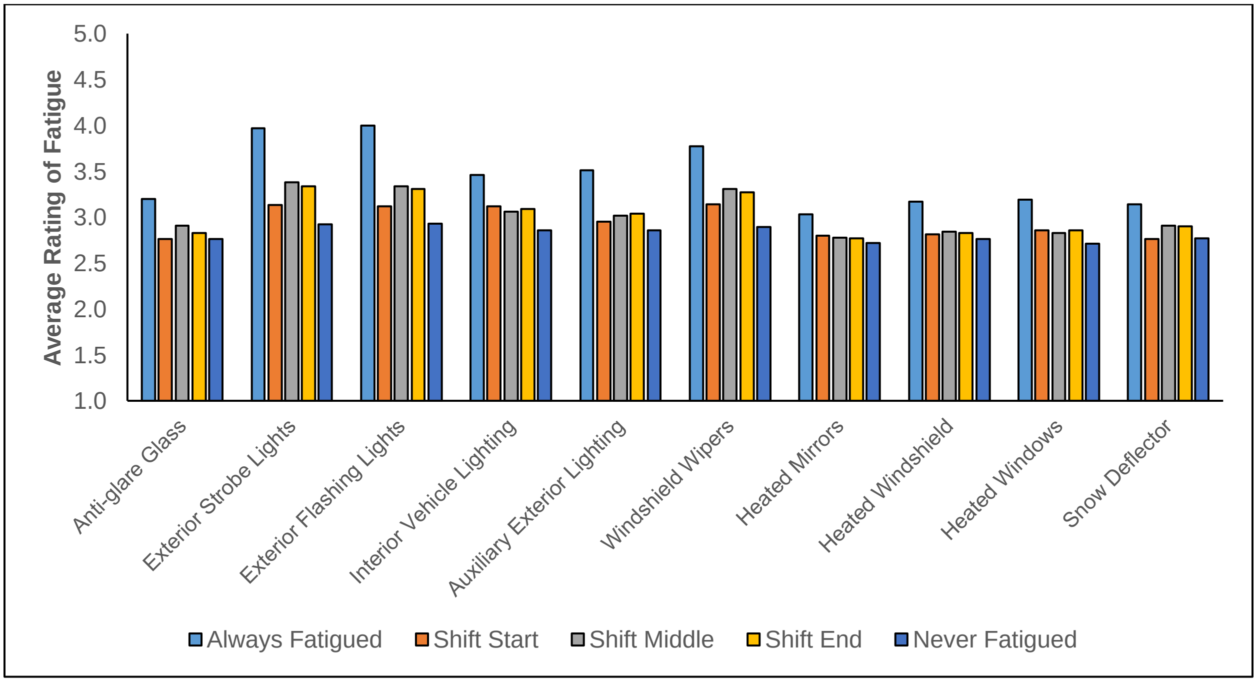



**Figure 33. Average ratings of fatigue for visibility-related equipment by part of shift most often associated with fatigue (rating of 1 = always decreases; 5 = always increases).**

#### *4.2.3.2 Winter Maintenance Operator Recommendations to Reduce Fatigue from Visibility-Related Equipment*

Winter maintenance operators provided a total of 600 comments related to visibility and fatigue. These comments were grouped into 12 themes as shown in Figure 34. The largest number of comments (40%) were related to increasing or improving lighting on the exterior of the snowplow. Of these comments, 21% specifically mentioned auxiliary lighting, 13% specifically mentioned headlights, and 6% specifically mentioned the use of LED lights. In addition to comments related to improvements in exterior lighting, 16% of the comments were related to improvements for the windshield, windows, or mirrors, and 14% of the comments suggested windshield wiper improvements. Other comments were related to internal equipment (8%), warning lights (7%), plow/blade/snow deflectors (2%), visibility systems (2%), recommendations for the snowplow operator (2%), no solution to improve visibility (5%), and other various comments (4%). Specific comments related to each of these themes are discussed in more detail below.

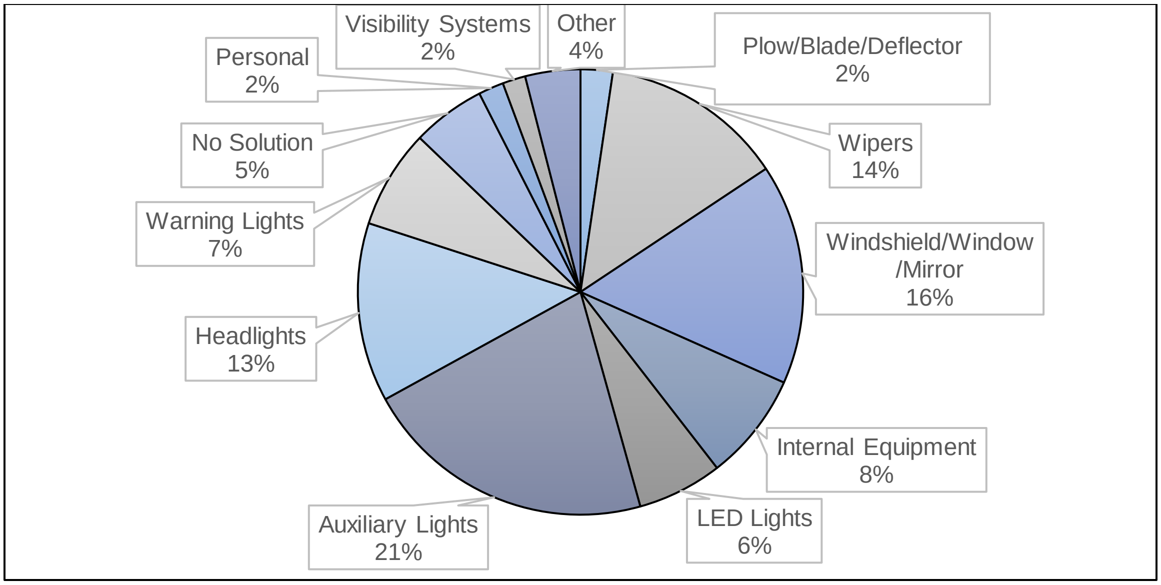



**Figure 34. Overall themes for causes of visibility-related fatigue.**

Figure 35 shows the three subthemes for the 14 comments related to the plow, blade, or snow deflector. Seven of these comments suggested the use of an improved snow deflector.

- “the snow deflectors are minimal at best”

The other comments suggested an improved plow design to limit snow blowing on to the windshield ($n$ = 4) and improved flaps on the snow plow ($n$ = 3).

- “If there is some way to design a snow plow that will keep snow from coming up and over the top creating a bunch of snow covering the windshield at 25 to 30 mph would be an improvement.”
- “longer main plow flap with bars so it doesn’t blow up”

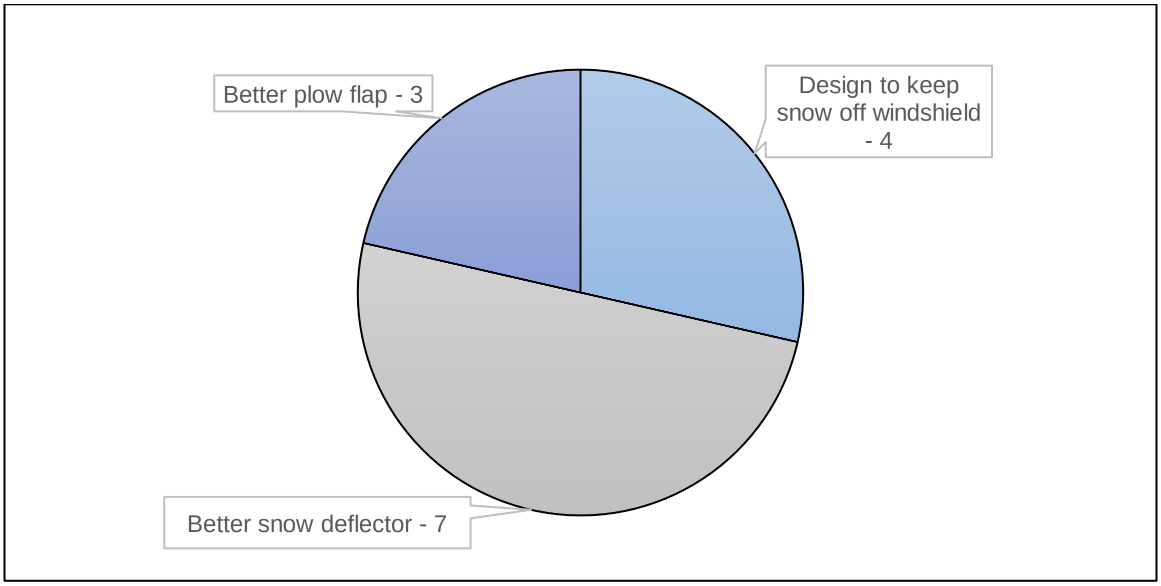



**Figure 35. Plow/blade-related recommendations to reduce visibility-related fatigue.**

Figure 36 shows the five subthemes for the 80 comments related to windshield wipers. Over 80% of the comments suggested installing heated wipers (*n* = 35) or purchasing improved wipers (*n* = 34).

- "Heated wipers. My wipers freeze up often. It usually gets an ice ball on the end, which I can reach from the operator's seat and 'flick' the wiper as it goes by, but it gets old, and is dangerous."
- "Better windshield wipers. If we had some that fit the windows better and cleaned better, it would be great. Sometimes we have to get out every couple of miles to find the windows and lights."

Other wiper suggestions included vibrating wipers (*n* = 4), replacing wiper regularly (*n* = 2), and other various wiper improvements (*n* = 5).

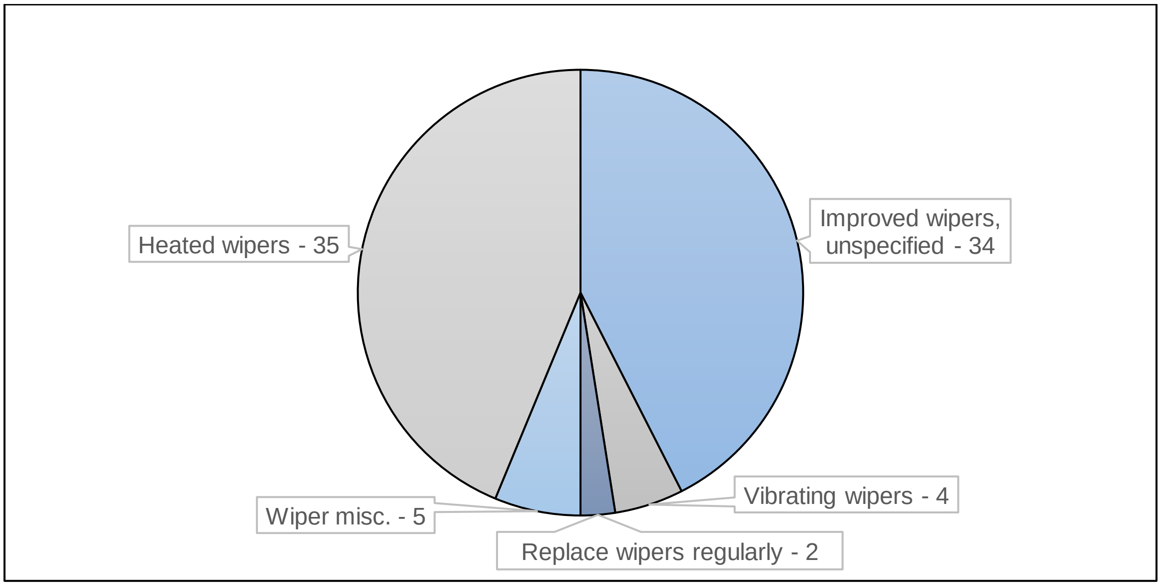



**Figure 36. Wiper-related comments to reduce visibility-related fatigue.**

Figure 37 shows the five subthemes for the 96 comments related to the snowplow's windshield, windows, and/or mirrors. The majority of these comments suggested the use of a heated windshield and/or windows (*n* = 61).

- "Heated windshields would be great. You have the defrost heat up high to keep windshield clean, and the high heat makes you tired."

Additionally, 16% of the suggestions involved heated mirrors (*n* = 15).

- "I feel that heated mirrors should be required on every piece of snow removal equipment for the safety of the driver and the public."

Other comments suggested improving the window/windshield design (*n* = 8), using anti-glare glass (*n* = 8), and various other improvements to the windshield, windows, and/or mirrors (*n* = 4).

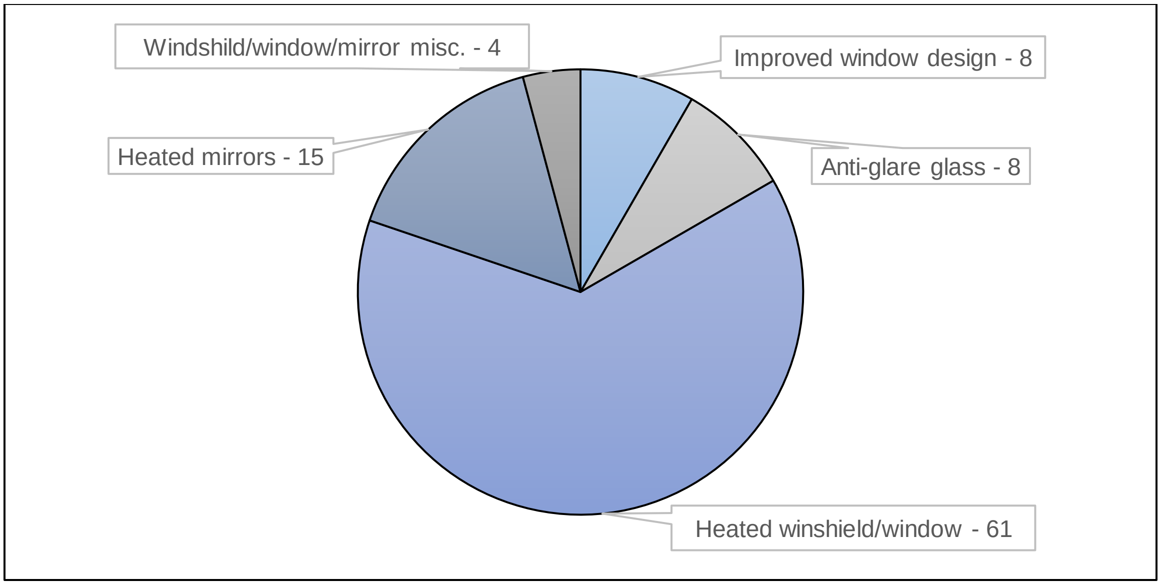



**Figure 37. Windshield/window/mirror recommendations to reduce visibility-related fatigue.**

Figure 38 shows the four subthemes for the 47 comments related to internal equipment. The majority of the comments suggested improvements to the snowplow's defroster (*n* = 32).

- "The wind shield collects alot of snow. In order to fight this I have to run the defroster on high which in my opinion is the number one cause of tiredness. If you could figure out a way to not heat the cab so hot that would probably help."

Other suggestions involved wearing yellow sun glasses to reduce glare (*n* = 8), using indirect interior lighting (*n* = 5), and using the air conditioning to keep the windshield cold instead of hot (*n* = 2).

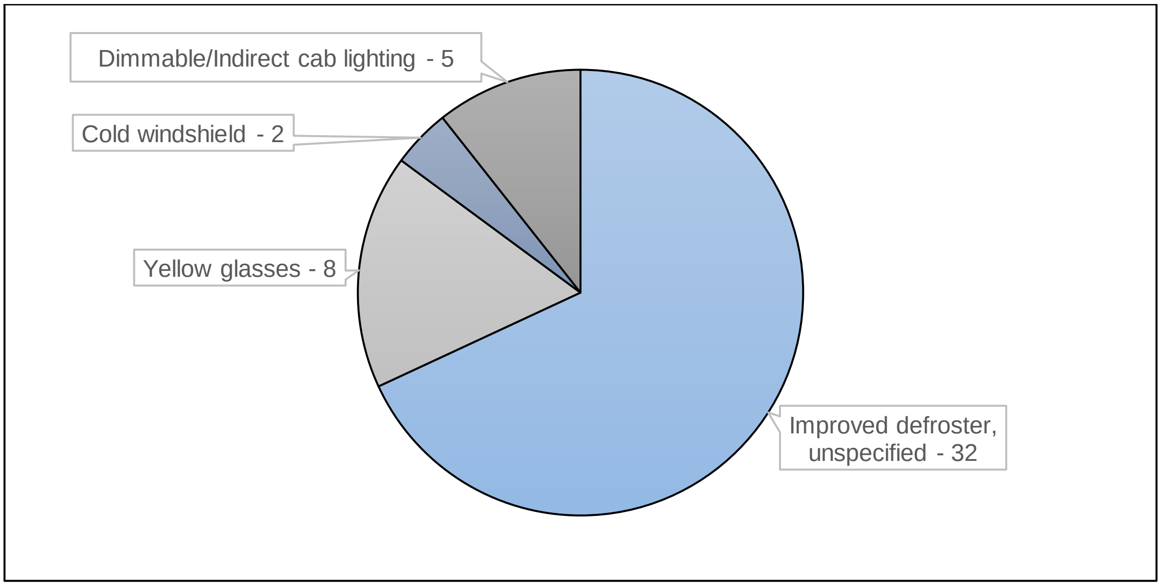



**Figure 38. Internal equipment recommendations to reduce visibility-related fatigue.**

Figure 39 shows the four subthemes for the 37 comments related to the use of LED exterior lighting. Approximately 40% of these comments recommended the use of LED lights during winter emergencies, but did not specify which types of exterior lighting should be LED (*n* = 15).

- "I have been installing LED lights on my own equipment. This I have noticed to be very helpful. In my opinion."

There were 10 suggestions related to LED headlights.

- "When we got LED headlights they helped us see alot better of nights reducing the strain of trying to see and so also reducing the tired factor"

Additionally, there were suggestions for LED plow lights (*n* = 6) and unspecified LED auxiliary lighting (*n* = 6).

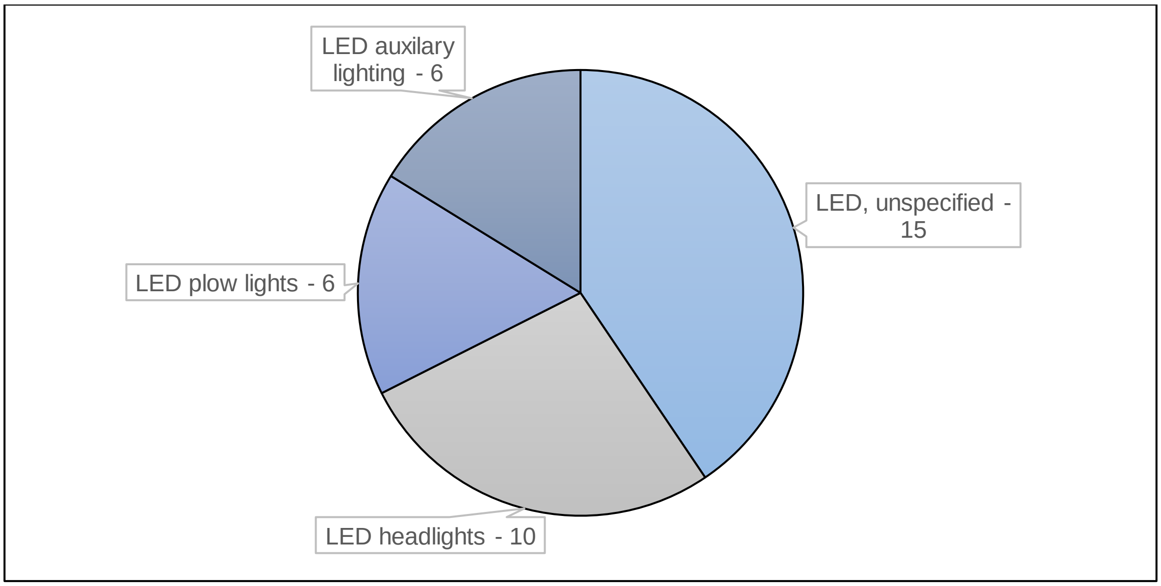



**Figure 39. LED recommendations to reduce visibility-related fatigue.**

Figure 40 shows the nine subthemes for the 128 comments related to auxiliary lighting. Nearly 50% of these comments suggested improved auxiliary lighting without specifics (*n* = 60).

- "better lights would help eye fatigue. We should have the best lighting on the market. we only drive in the absolute worst conditions"

Winter maintenance operators provided 28 comments that suggested the need for improved plow lights.

- "Plow lights with their short lumaning distances makes you look to the road instead out in front."

Comments from 12 winter maintenance operators suggested changing the placement for auxiliary lights.

- "Also getting the lights mounted over the top of the plow and as much forward as possible would help. Lights mounted up on the hood are less effective when it is snowing heavily or snow dust is coming up and over the plow causing an hypnosis type of situation."

There were 11 comments that suggested the use of fog lights.

- "Fog lights mounted high on equipment to cut through the fog or blinding snow"

Fewer comments suggested brighter rear lighting (*n* = 5), additional auxiliary lighting (*n* = 6), brighter spot lights (*n* = 3), using yellow lights (*n* = 2), and using plow lights with adjustable brightness (*n* = 1).

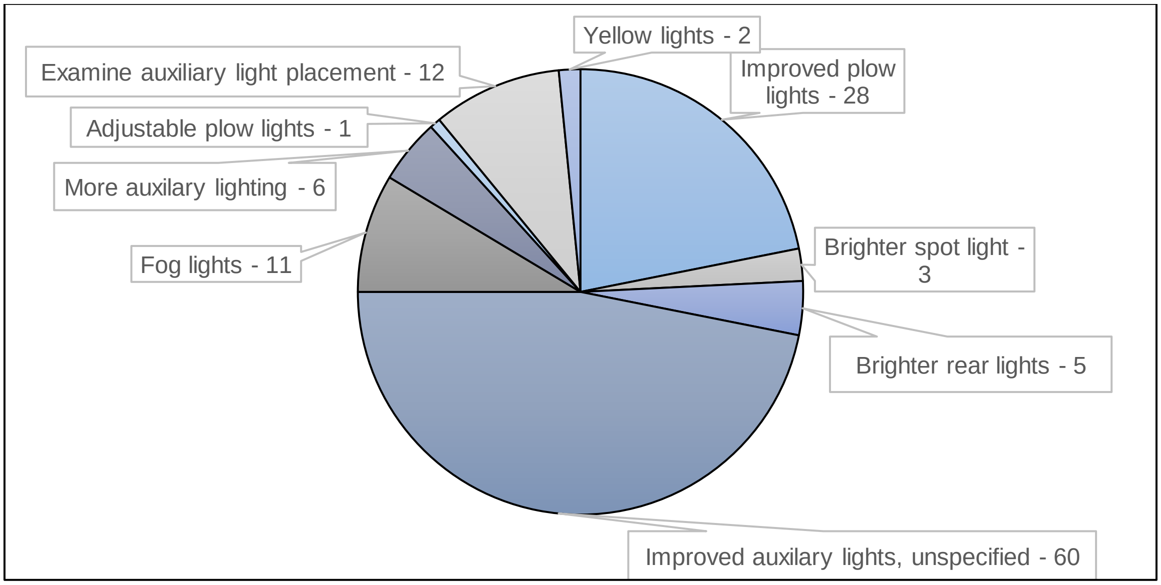



**Figure 40. Auxiliary lighting recommendations to reduce visibility-related fatigue.**

Figure 41 shows the five subthemes for the 78 comments related to headlights. The vast majority of these comments were related to the use of improved headlights without specifying the detailed improvements (*n* = 60).

- "Better headlights on trucks. I can see better and farther when another vehicle passes me with their headlights than I can with mine especially in a blizzard."

Fewer comments suggested heated headlights (*n* = 9), wipers on headlights (*n* = 1), having a more focused headlight beam (*n* = 2), and placing the headlights lower on the truck (*n* = 6).

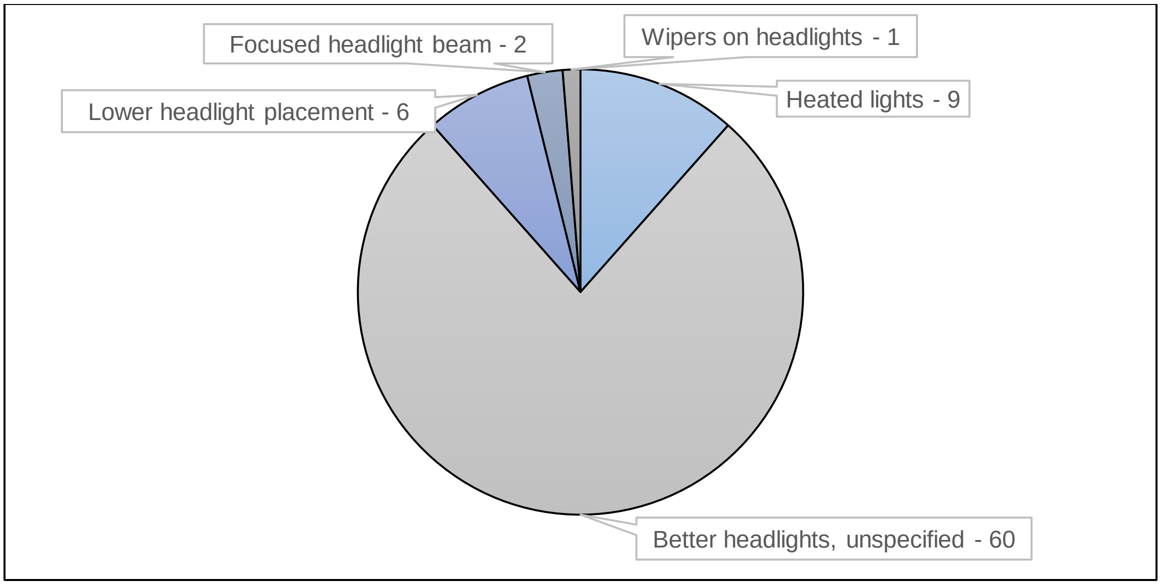



**Figure 41. Headlight recommendations to reduce visibility-related fatigue.**

Figure 42 shows the five subthemes for the 43 comments related to snowplow warning lights. Approximately half of these comments suggested installing warning lights where winter maintenance operators can turn off the forward facing lights while keeping the rear facing lights on (*n* = 20).

- "having strobes on separate switches so you could turn off the forward facing strobes to cut down on the reflection."

There were also 15 comments that suggested installing warning lights that could be dimmed or the flashing patterns could be changed.

- "The new LED lights on new trucks are so bright you can't see what you are doing or where you are going on the HWY. Ever had a state trooper in front of you with someone pulled over?? SUPER BRIGHT!! You can't see!! Yes! Troopers turn these lights on when on a accident or emergencies. They do not have them on there whole work shift. Think about what this would do to a operator on a full 8-12 hour shift in a snowplow, loader, grader, etc."

Additional comments suggested the use of flashing warning lights instead of strobes (*n* = 3), locating warning lights in a different location (*n* = 4), and decreasing the number of warning lights (*n* = 1).

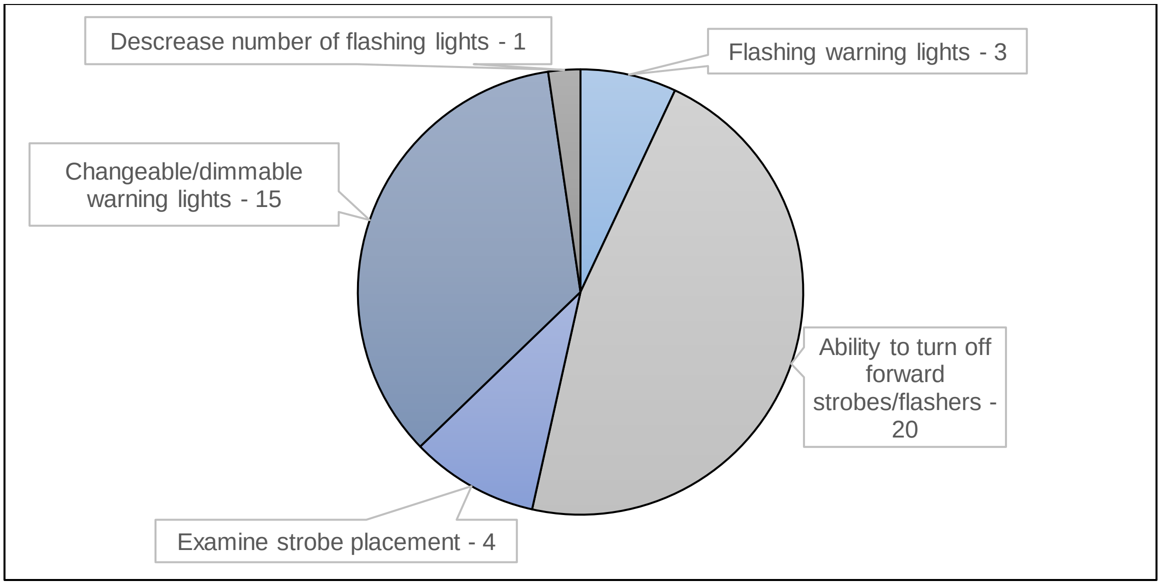



**Figure 42. Warning lighting recommendations to reduce visibility-related fatigue.**

Figure 43 shows the three subthemes for the 11 comments regarding things the operator can do to improve visibility. Five comments suggested that a break may help reduce fatigue associated with reduced visibility.

- "Take a break – heavy snow fall is hard on the eyes when operating in the dark using lights for visibility. Give your eyes a break your mind will thank you."

Other comments suggested reducing the vehicle speed (*n* = 4) or making sure to get annual eye exams or using glasses (*n* = 2).

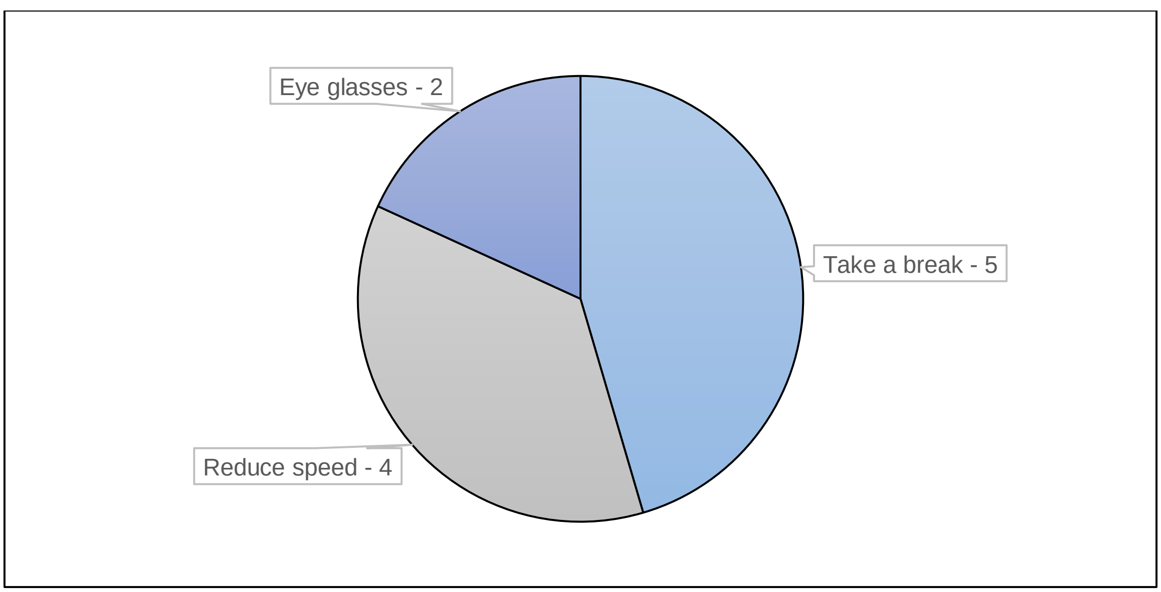



**Figure 43. Personal recommendations to reduce visibility-related fatigue.**

Figure 44 shows the three subthemes for the 10 comments related to the use of advanced visibility systems. Eight of these comments suggested the use of a GPS road location system ($n$ = 4) or a back-up camera ($n$ = 4).

- "Some states have a screen that shows you the road ahead I would like to try that we some times have to pull over and wait until it lets up so we can see"
- "Would like to have back up cameras available"

The last two comments suggested using thermal/infrared imaging.

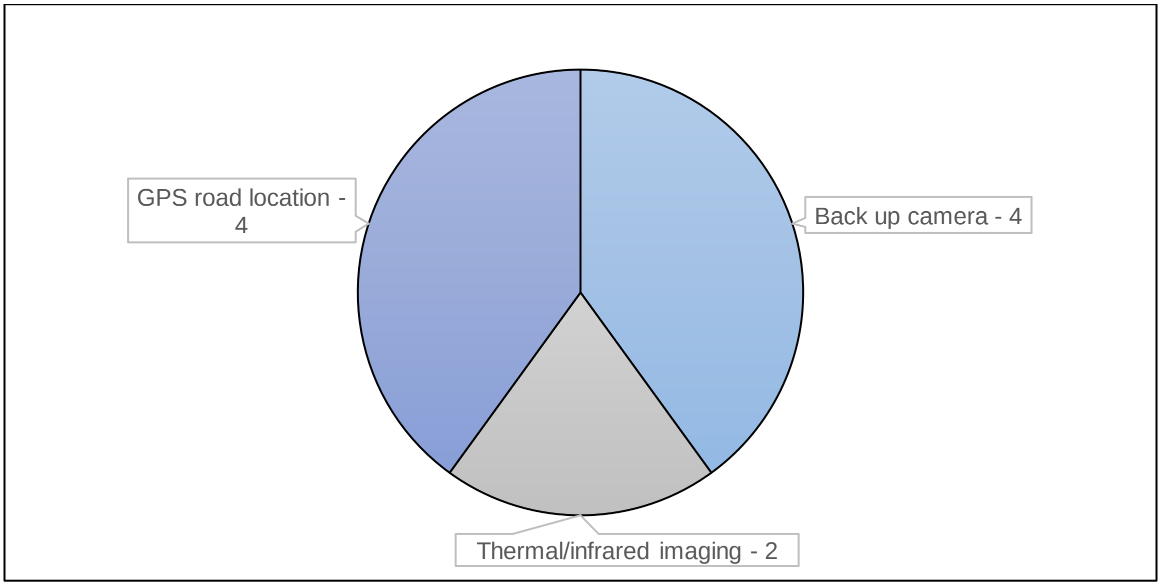



**Figure 44. Advanced visibility system recommendations to reduce visibility-related fatigue.**

Figure 45 shows the four subthemes of 32 comments that suggested visibility was not associated with fatigue. Winter maintenance operators provided 14 comments that reduced visibility was unavoidable during winter emergencies.

- "There are also times when visibility is just plain terrible, and no fault of the equipment. Whiteout conditions are highly stressful."

Other comments suggested waiting until visibility improved ($n$ = 9), that reduced visibility increased alertness ($n$ = 7), and that visibility does not impact fatigue ($n$ = 2).

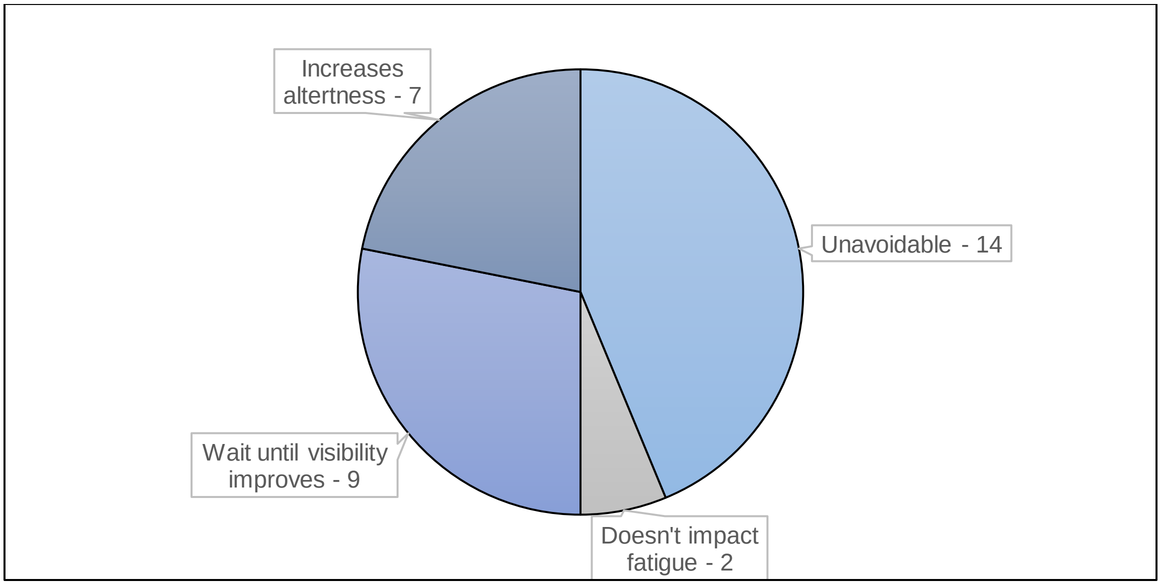



**Figure 45. Comments suggesting visibility does not cause fatigue.**

### 4.2.4 In-Cab Equipment and Fatigue

Winter maintenance operators were asked to rate how often in-cab equipment impacted their level of fatigue during winter emergencies. Winter maintenance operators' responses are shown in Table 19. Almost half of winter maintenance operators reported that in-cab equipment never made them fatigued (49.30% or 944 winter maintenance operators) while driving. For 41.93% of winter maintenance operators (803 winter maintenance operators), the in-cab equipment "sometimes" made them fatigued while driving. The remaining options of "half the time," "most of the time," and "always" were chosen by 6.58% (126), 2.19% (42), and 0.78% (15) of winter maintenance operators, respectively.

**Table 19. Responses to the Question, "How Often Does In-Cab Equipment Make You Tired During Winter Emergencies?"**

| How often does in-cab equipment make the operator tired during winter emergency? | Observation Counts | Observation Percentage |
|---|---|---|
| Always | 15 | 0.78% |
| Most of the time | 42 | 2.19% |
| Half the time | 126 | 6.58% |
| Sometimes | 803 | 41.93% |
| Never | 944 | 49.30% |
| Total | 1,915 | 100.00% |

#### *4.2.4.1 In-Cab Equipment that May Cause Fatigue*

Winter maintenance operators rated several types of in-cab equipment and their impact on fatigue while driving (see Table 20). For each type of in-cab equipment, two-thirds of winter maintenance operators felt there was never an impact on fatigue while driving (ranged from 65% to 84%). Placement and number of equipment controls sometimes increased fatigue while driving for 21% and 18% of winter maintenance operators, respectively. LCD displays also affected levels of fatigue while driving: placement of LCD displays sometimes increased fatigue for 20% of winter maintenance operators, and light from LCD displays increased fatigue for 24% of winter maintenance operators. The percentages of winter maintenance operators rating “always increases,” “sometimes decreases,” or “always decreases” was fairly consistent across each type of equipment.

**Table 20. Impact of In-Cab Equipment on Fatigue**

| In-Cab Equipment | Always Increases | Sometimes Increases | Never Impacts | Sometimes Decreases | Always Decreases |
|---|---|---|---|---|---|
| Placement of equipment controls | 2% | 21% | 69% | 5% | 3% |
| Number of equipment controls | 2% | 18% | 72% | 5% | 3% |
| Mobile phone | 1% | 4% | 83% | 8% | 4% |
| Presence of a collision avoidance system (e.g., forward collision warning) | 1% | 5% | 82% | 5% | 8% |
| Assistance to stay within lane via a lane departure warning system | 1% | 8% | 78% | 6% | 7% |
| Back-up cameras | 2% | 5% | 81% | 6% | 6% |
| HUDs | 1% | 10% | 79% | 5% | 4% |
| Placement of interior LCD displays | 3% | 20% | 70% | 5% | 3% |
| Light from LCD displays (other than back-up cameras) | 4% | 24% | 65% | 5% | 3% |

Table 21 shows the results of *t*-tests evaluating how the average ratings of fatigue were affected by in-cab equipment. The adjusted alpha was equal to 0.0045. In-cab equipment associated with a decreased perceived level of fatigue while driving included a mobile phone ($M$ = 2.8901), presence of a collision avoidance system ($M$ = 2.8584), assistance to stay within lane ($M$ = 2.9155), and back-up cameras ($M$ = 2.9080). In-cab features rated as significantly increasing perceived levels of fatigue while driving included the placement and number of equipment controls ($M$ = 3.1336 and $M$ = 3.1086, respectively) and placement of and light from LCD displays ($M$ = 3.1372 and $M$ = 3.1937, respectively).

**Table 21. Statistical Analyses for In-Cab Equipment and Levels of Fatigue (rating of 1 = always decreases; 5 = always increases)**

| In-Cab Equipment | *n* | Average Rating | *df* | *t* | *p* | *Significance* |
|---|---|---|---|---|---|---|
| Placement of equipment controls | 1,842 | 3.1336 | 1,841 | 8.45 | <0.0001 | * |
| Number of equipment controls | 1,832 | 3.1086 | 1,831 | 6.96 | <0.0001 | * |
| Mobile phone | 1,456 | 2.8901 | 1,455 | -7.49 | <0.0001 | * |
| Presence of a collision avoidance | 551 | 2.8584 | 550 | -5.13 | <0.0001 | * |

| In-Cab Equipment | *n* | Average Rating | *df* | *t* | *p* | *Significance* |
|---|---|---|---|---|---|---|
| system (e.g., forward collision warning) | | | | | | |
| Assistance to stay within lane via a lane departure warning system | 521 | 2.9155 | 520 | -2.88 | 0.0041 | * |
| Back-up cameras | 511 | 2.9080 | 510 | -3.28 | 0.0011 | * |
| HUDs | 648 | 2.9923 | 647 | -0.32 | 0.7497 | |
| Placement of interior LCD displays | 1,115 | 3.1372 | 1,114 | 6.85 | <0.0001 | * |
| Light from LCD displays (other than back-up cameras) | 1,301 | 3.1937 | 1,300 | 9.68 | <0.0001 | * |

Differences in average ratings of fatigue impact were examined across shift time of day, shift length, how frequently winter maintenance operators experienced fatigue, and the part of a shift most often associated with fatigue. Like the analyses for other equipment types, these assessments of fatigue impact also used the numerical score (where "always increases" was equal to 5 and "always decreases" was equal to 1). Figure 46 shows the average ratings of fatigue impact for each type of in-cab equipment or design by shift time of day. The breakdown by shift time of day showed fairly consistent ratings of fatigue impact for each type of in-cab equipment or design across all three shift time of day levels.

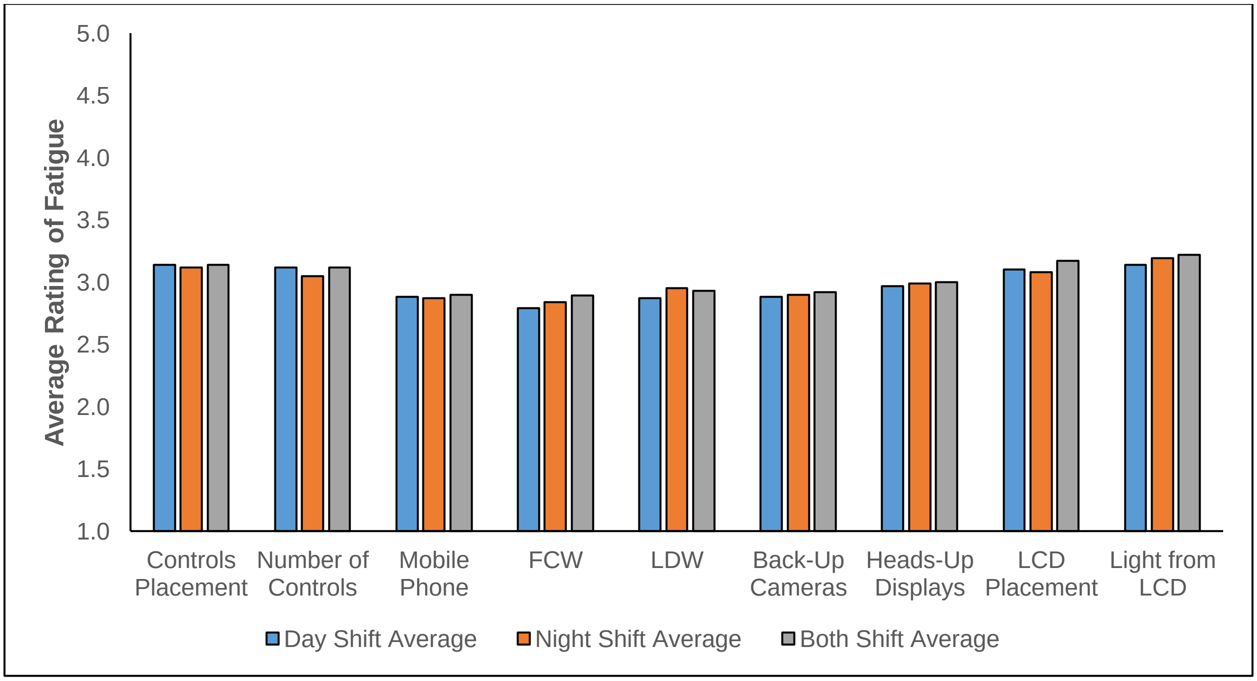



**Figure 46. Average ratings of fatigue for each type of in-cab equipment by shift time of day (rating of 1 = always decreases; 5 = always increases).**

Figure 47 shows the average ratings of fatigue impact for each type of in-cab equipment by shift length. The figure shows no clear relationship between the average rating of fatigue impact for all types of in-cab equipment or design and shift length.

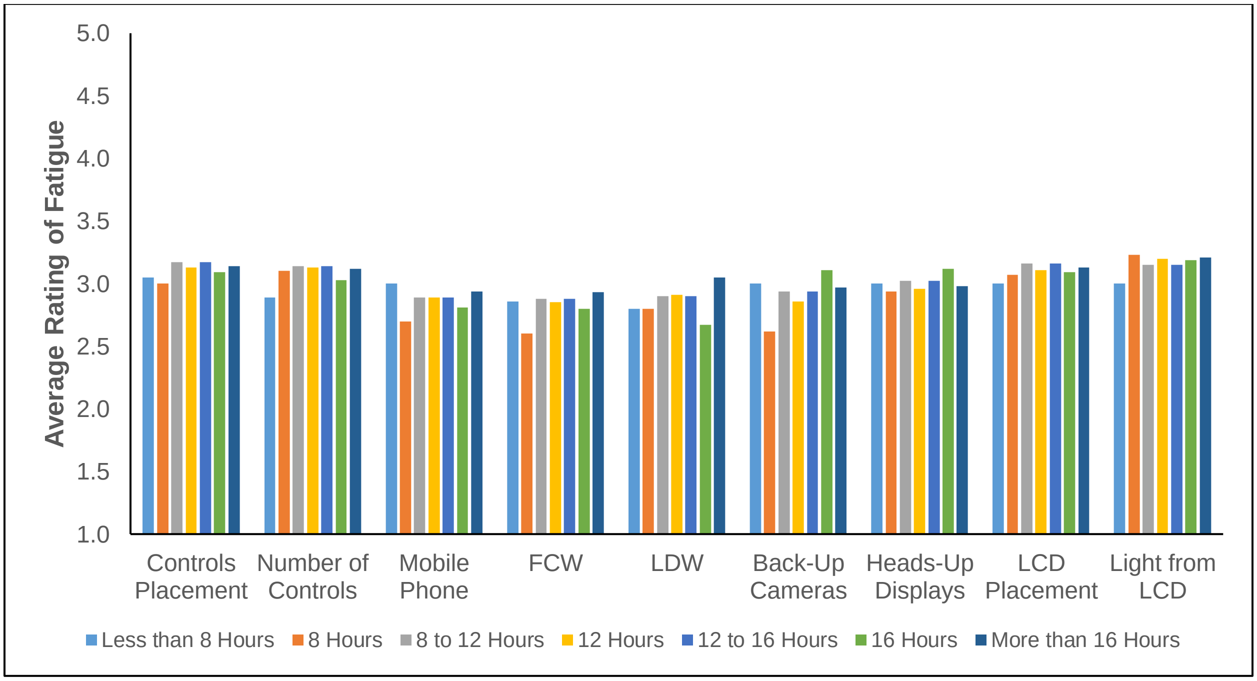



**Figure 47. Average ratings of fatigue for each type of in-cab equipment by shift length (rating of 1 = always decreases; 5 = always increases).**

Figure 48 shows the average ratings of fatigue impact for each type of in-cab equipment by how frequently winter maintenance operators felt fatigued during winter emergencies. Interestingly, for many types of in-cab equipment or designs, winter maintenance operators that reported feeling fatigued "most of the time" during winter emergencies also reported higher average ratings of fatigue impact from the equipment. However, it is important to note the average ratings of fatigue impact were within a small range for all types of in-cab equipment or designs.

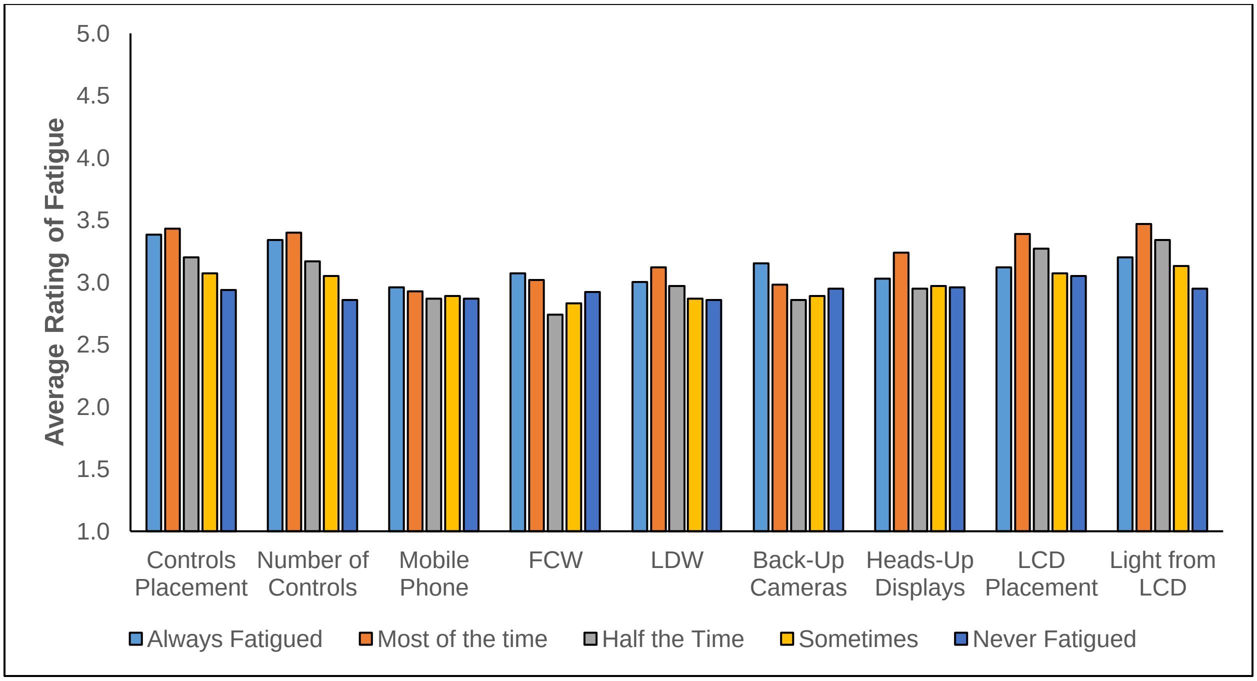



**Figure 48. Average ratings of fatigue for each type of in-cab equipment by how frequently winter maintenance operators become fatigued (rating of 1 = always decreases; 5 = always increases).**

Figure 49 shows the average ratings of fatigue impact for each type of in-cab equipment by the part of a shift most often associated with fatigue. For each equipment or design type, winter maintenance operators who reported feeling "always" fatigued also reported increased average ratings of fatigue impact from the equipment. There were not strong relationships between the specific parts of a shift most often associated with fatigue and the average ratings of fatigue impact for the types of in-cab equipment of design.

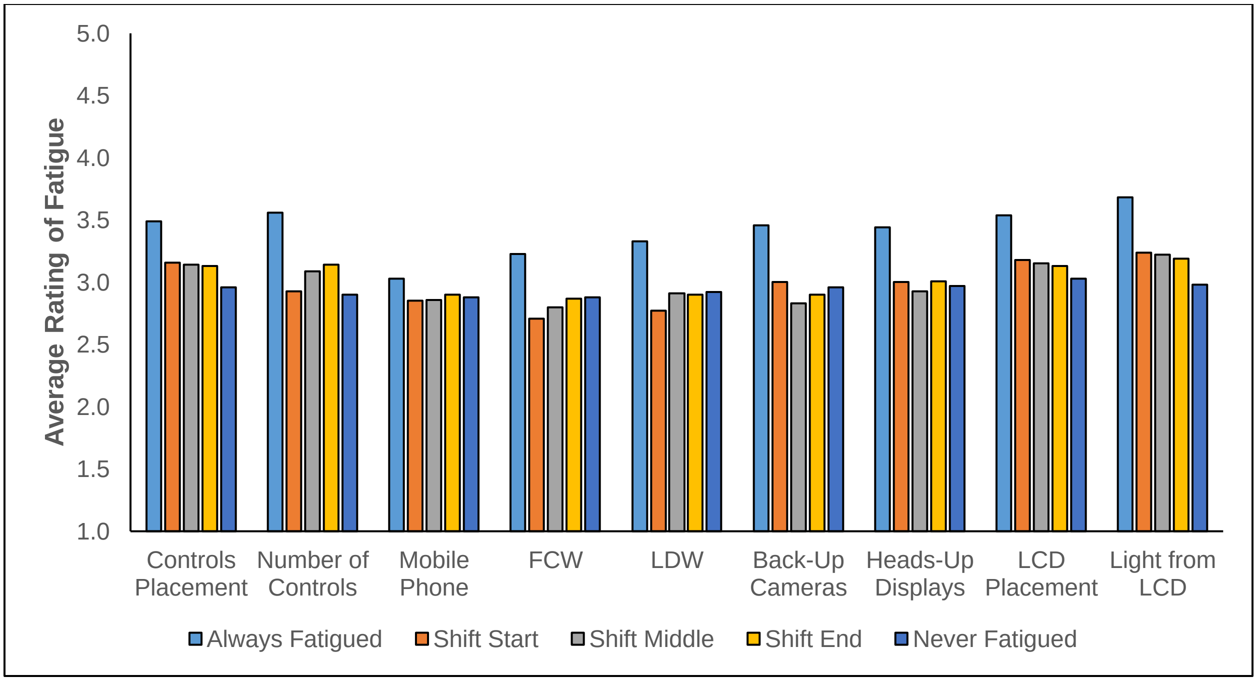



**Figure 49. Average ratings of fatigue for each type of in-cab equipment by part of shift most often associated with fatigue (rating of 1 = always decreases; 5 = always increases).**

#### *4.2.4.2 Winter Maintenance Operator Recommendations to Reduce Fatigue from In-Cab Equipment*

Winter maintenance operators provided a total of 553 comments related to in-cab equipment and fatigue. These comments were grouped into seven themes as shown in Figure 50. The largest number of comments (32%) were related to interior monitors/display screens or interior lights. Approximately 20% of the comments involved improvements or changes to the cab design. Another 13% of the comments were related to the operator's seat. Other comments provided suggestions associated with equipment controls (8%), advanced technology (6%), the radio/music (9%), and various other suggestions (13%). Specific comments related to each of these themes are discussed in more detail below.

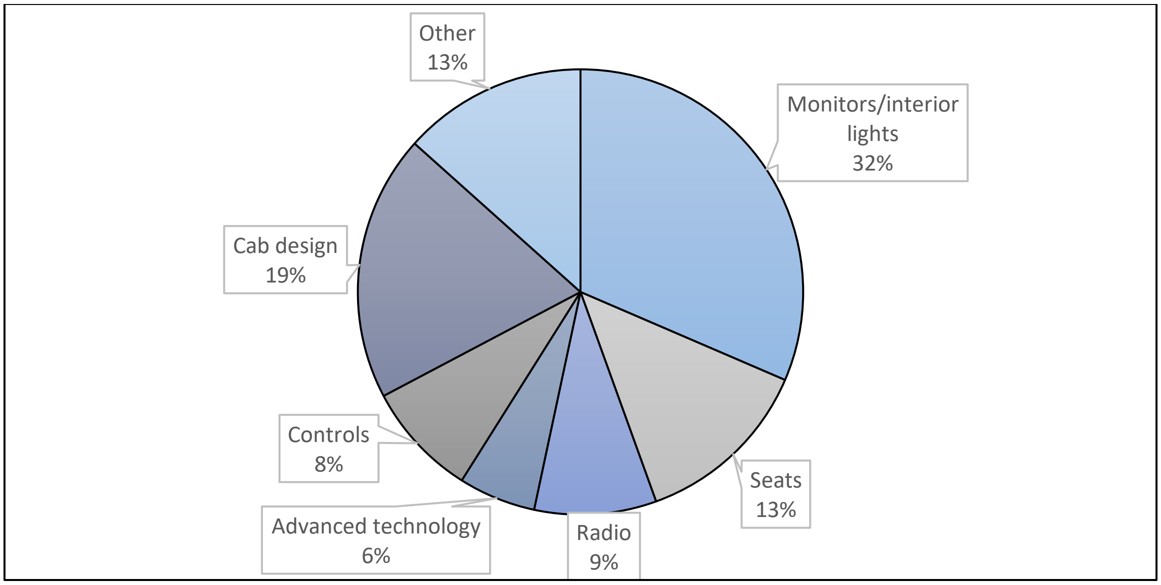



**Figure 50. Overall themes of comments related to in-cab equipment and fatigue.**

Figure 51 shows the seven subthemes for the 174 comments on monitors or interior lighting. The majority of the comments (*n* = 105) suggested dimmable lights on all interior monitors and light sources.

- "Need to be able to dim things done more than we already can. The lights for the dash panel and other screens in the cab get to be too bright at night."

Similarly, 10 comments suggested the ability to completely turn off monitors.

- "I believe the LCD screens are too bright during non-daylight hours. That is most of the day in Alaska. We are not able to dim them enough to make a difference. I would like to be able to black them out when no needed."

Another 20 comments suggested limiting the number of displays or electronics in the cab of the snowplow.

- "The amount of screens in the cabs is ridiculous! We need to be concentrating on the snow outside, rather than all the screens inside! This would help prevent accidents!"

Winter maintenance operators also provided 20 comments suggesting changing the color of interior lighting/monitors, most specifically mentioning red light.

- "Interior red lights in cab to reduce glare. I do use them and they work well."

Fewer comments suggested larger screens on monitors (*n* = 5), investigating the best placement for monitors inside the cab (*n* = 9), and HUDs (*n* = 3).

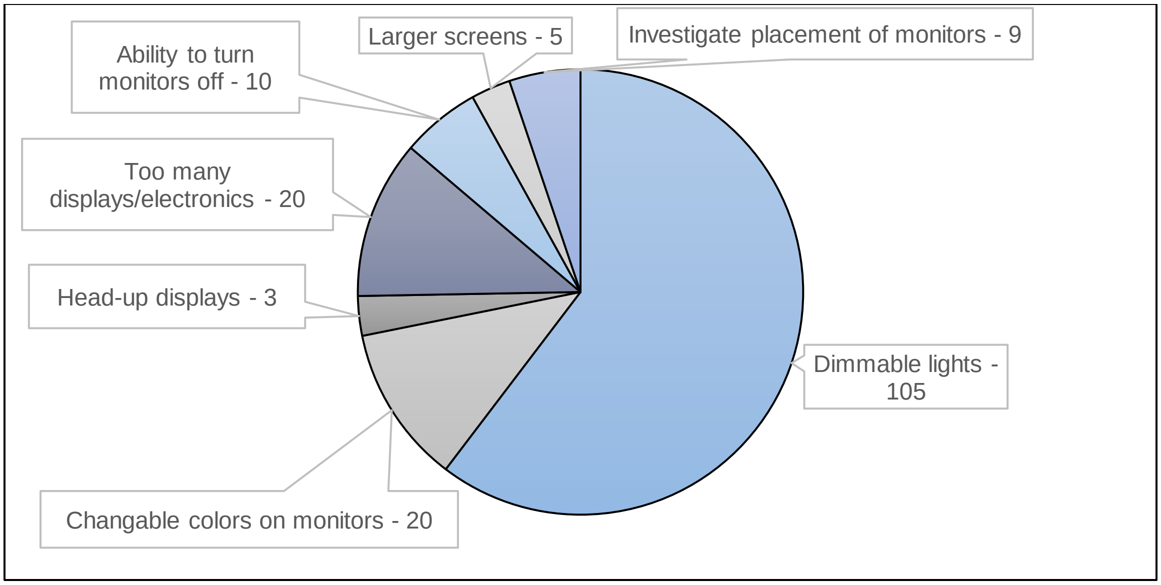



**Figure 51. In-cab equipment comments related to monitors/interior lights and fatigue.**

Figure 52 shows the five subthemes for the 72 comments related to improving the operator's seat to reduce fatigue. The majority of the comments (*n* = 49) suggested a more comfortable seat.

- "More comfortable seats would really be helpful in helping fight the tiredness/fatigue"

Other comments suggested an arm rest of all seats (*n* = 9), seats that recline (*n* = 8), air-ride seats (*n* = 2), and heated seats (*n* = 4).

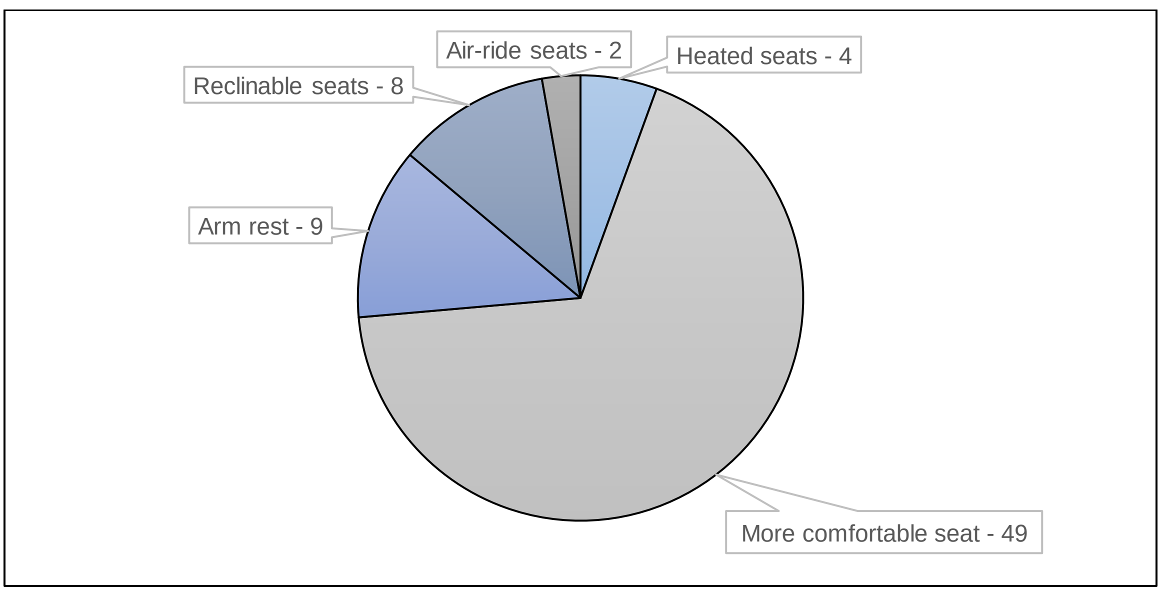



**Figure 52. In-cab equipment comments regarding seats and fatigue.**

Figure 53 shows the three subthemes for the 49 comments related to the use of radios to reduce fatigue. Approximately 71% of comments (*n* = 35) suggested a better radio system or CD player.

- "Every truck should have a am/fm radio so it can help driver awake"

Additionally, 11 comments suggested installing a satellite radio.

- "all trucks should have sirius radio cause rural areas don't have radio stations"

Only three comments suggested using a CB radio.

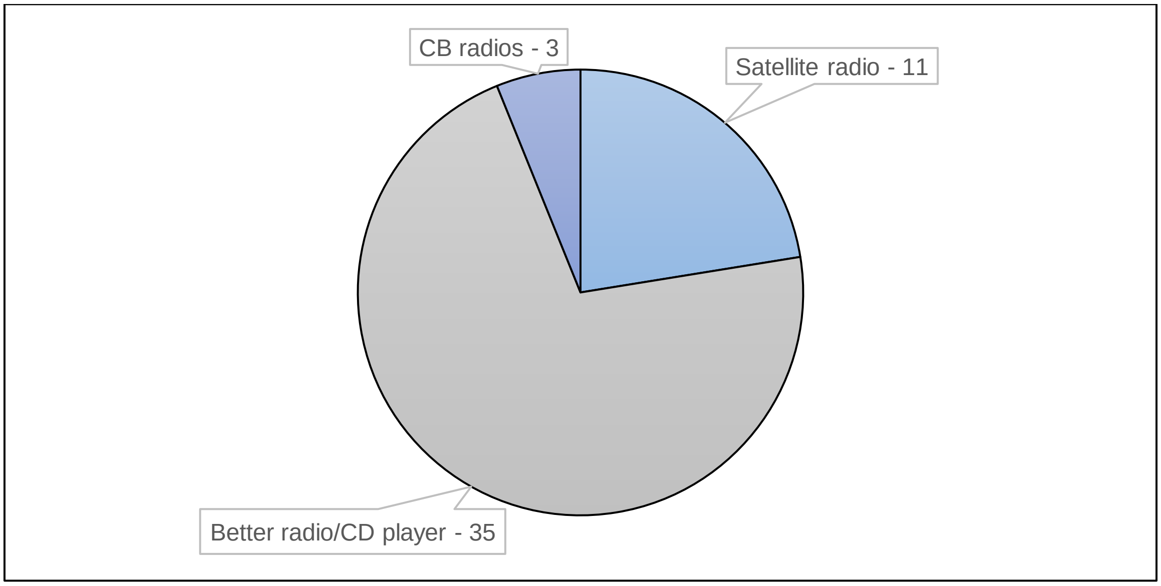



**Figure 53. In-cab equipment comments about the radio and fatigue.**

Figure 54 shows the six subthemes for the 31 comments related to using advanced technologies to reduce fatigue. Nine comments suggested the use of a back-up camera.

- "Backup camera would make it safer when we get to the end of RT and have to turn around"

Eight comments suggested installing a lane locating technology or lane departure warning.

- "Develop/use guidance systems to allow operators to know where they are at on the road and on their route pin pointing dangerous areas such as bridge joints, guard rails, posts, drains, etc."

Fewer comments suggested alerts from a fatigue-detection monitoring system ($n$ = 4), the ability to adjust audible alerts ($n$ = 3), installing a collision avoidance system ($n$ = 3), and power mirrors to increase visibility ($n$ = 4).

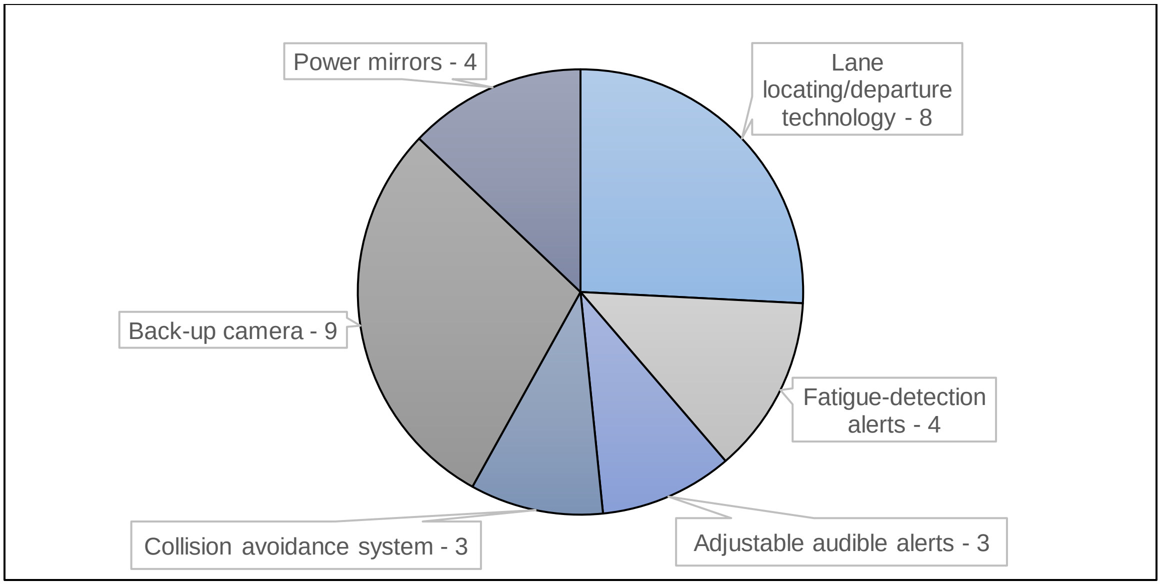



**Figure 54. In-cab equipment comments about advanced technologies and fatigue.**

Figure 55 shows the three subthemes for the 46 comments related to equipment controls. Approximately 75% of the comments (*n* = 34) suggested more ergonomically placed equipment controls.

- "Placement of controls within comfortable reach of the operator without blocking other controls and features"

Other comments suggested the use of joystick controls (*n* = 5) and ensuring uniform placement of controls across all trucks (*n* = 6).

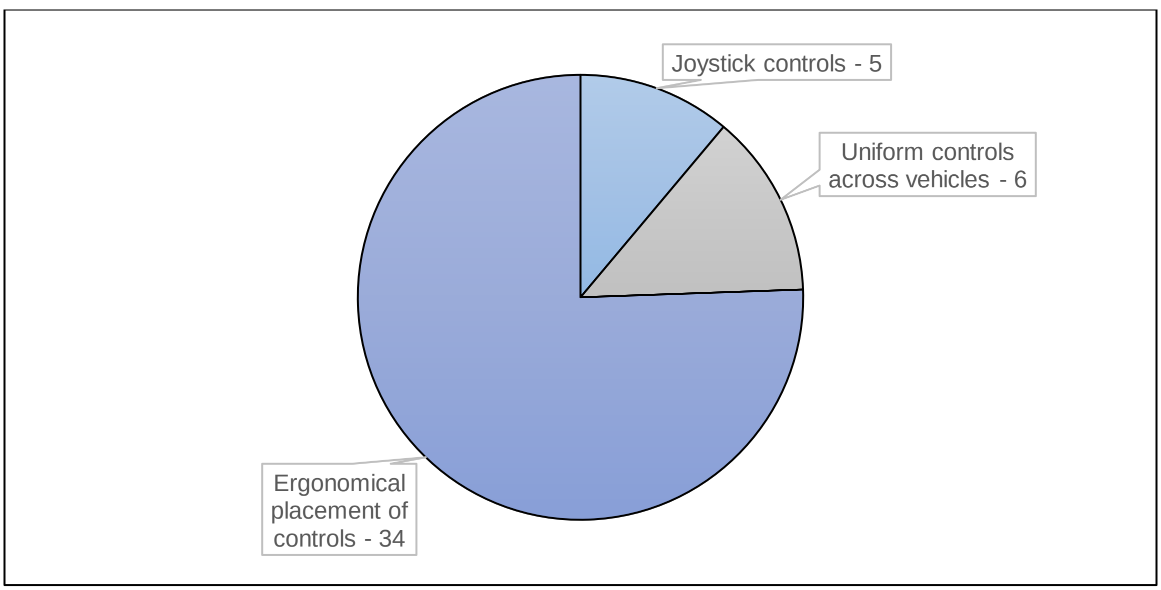



**Figure 55. In-cab equipment comments about equipment controls and fatigue.**

Figure 56 shows the 13 subthemes for the 107 comments related to the design of the snow plow's cab. Over 40% of the comments suggested a larger cab with additional leg room (*n* = 40).

- “There is not enough range of adjustment in the seat/steering wheel for me to get comfortable. With the seat at maximum height, my legs are still to low, which causes a tremendous amount of fatigue, and back pain. I have the seat far back to make legs as comfortable as possible, but it makes the reach to the steering wheel uncomfortable.”

Similarly, 10% of the comments (*n* = 11) suggested an improved ergonomic cab configuration.

- “redesign the cab to fit and have all the things i need within a hands reach. Make the cab more user friendly design it like a over the road truck.”

Additionally, 14 comments suggested an improved defroster.

- “Come up with some way to cut down on running heater wide open on defrost making temp in cab running over 100 degrees”

Fewer comments suggested additional interior lights (*n* = 2), anti-glare glass (*n* = 2), better air flow inside the cab (*n* = 4), better cab insulation (*n* = 2), better floor heat (*n* = 4), a larger cup holder (*n* = 2), an improved A/C system (*n* = 7), a moveable fan (*n* = 4), an onboard sleeping compartment (*n* = 5), and a telescoping steering wheel (*n* = 5).

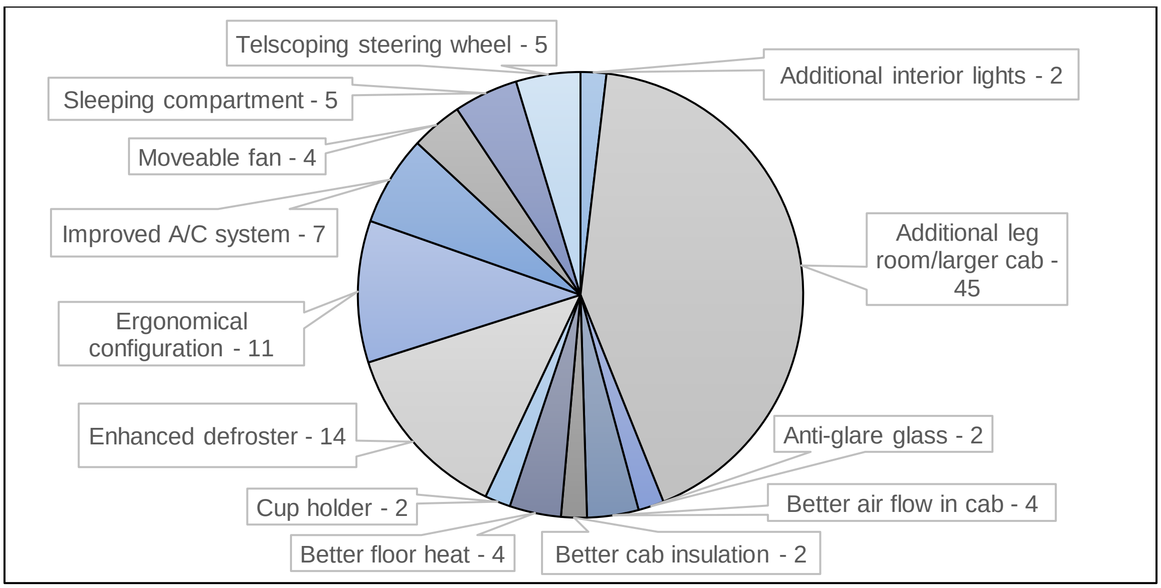



**Figure 56. In-cab equipment comments about the cab design and fatigue.**

Figure 57 shows the seven subthemes for the 74 comments with various other recommendations. The most common comment (*n* = 29) suggested opening the window to let fresh air into the cab.

- “When starting to feel tired I will roll down my window about half way and let some cool air into the cab of the truck. That help me out quite a bit.”

Similarly, there were 13 comments suggesting keeping the cab cool instead of hot.

- “Adjust in-cab heating level to be comfortable, not warm.”

Fewer comments suggested trucks with automatic transmission (*n* = 2), standard transmission (*n* = 2), Bluetooth (*n* = 6), purchasing new trucks (*n* = 6), and miscellaneous other comments (*n* = 16).

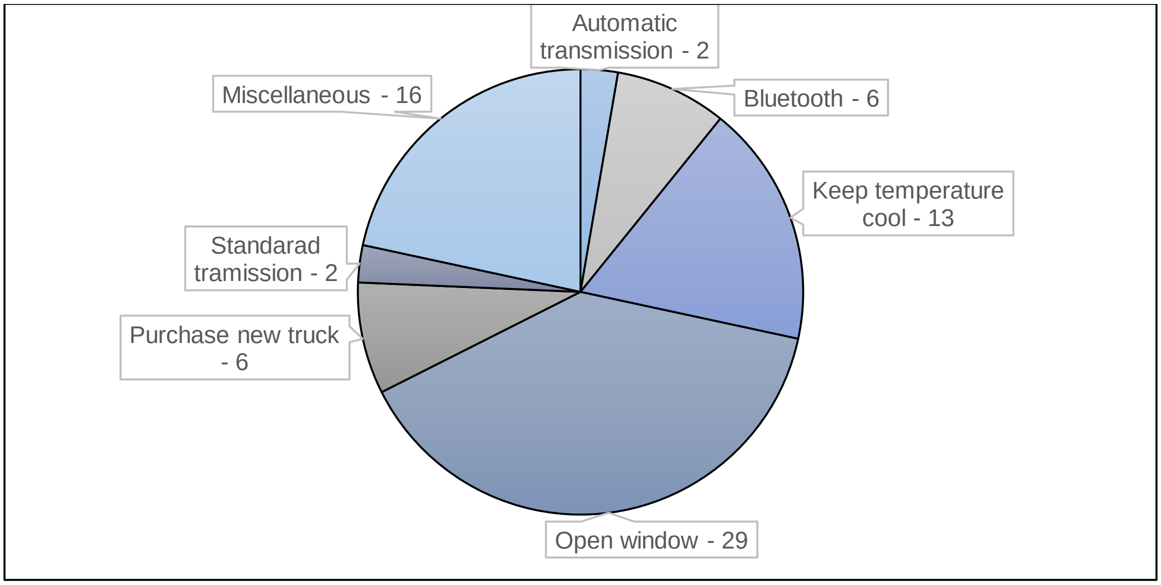



**Figure 57. Other comments about in-cab equipment and fatigue.**

#### 4.2.5 Winter Maintenance Operators' Fatigue-Related Recommendations/Comments

The last section of the questionnaire allowed winter maintenance operators the opportunity to provide additional suggestions to reduce fatigue during winter emergencies. A total of 1,071 comments were provided that related to six general themes as shown in Figure 58. Approximately 275 comments (25%) have been provided in previous sections above. Over 370 of these comments (35%) suggested a non-equipment countermeasure for fatigue. Additionally, 229 comments (21%) mentioned shift-related issues as major contributing factors to fatigue. Other comments suggested the importance of winter maintenance operators' health and wellness (7%), management-related procedures/policies (4%), and various other recommendations (4%). Specific comments related to each of these themes are discussed in more detail below.

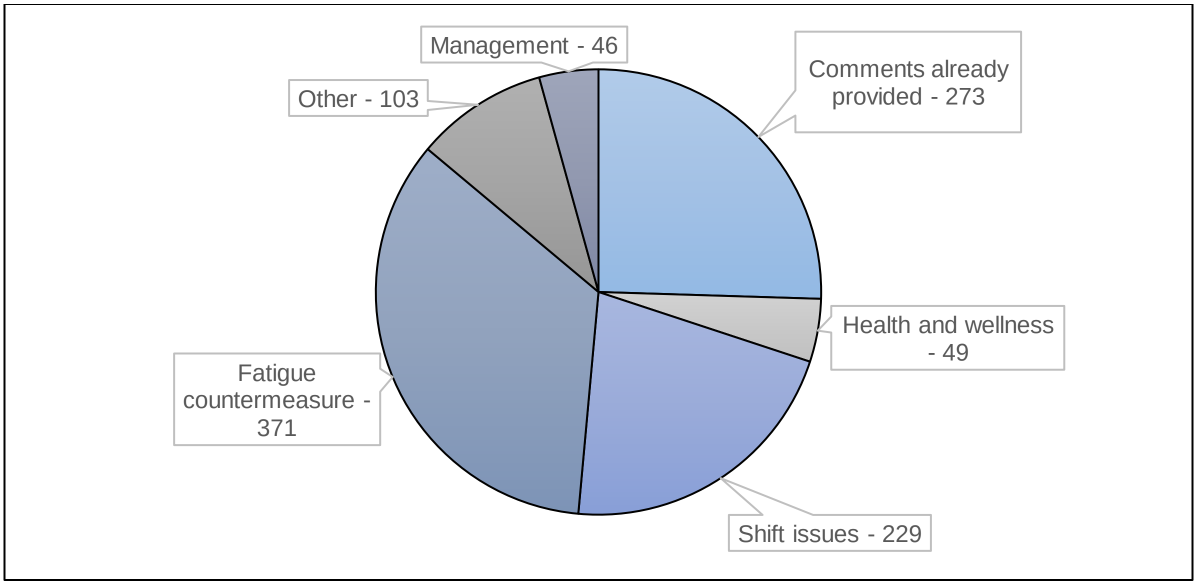



**Figure 58. Overall themes of comments related to additional strategies to reduce fatigue.**

Figure 59 shows the six subthemes for the 273 comments containing a suggestion that has been previously discussed in this report. Over 41% of these comments (*n* = 113) suggested an improvement in the truck design.

- "We have just started using heated wiper blades and love them."

Another 25% of comments (*n* = 71) suggested improved external lighting.

- "The visibility is always a struggle between bright lights in your eyes, or not near bright enough headlight for plow operations. A 20" LED light bar would do a great good for external sight. They seem to reduce fatigue by removing the stress of not seeing."

Additionally, 16% of the comments (*n* = 43) were related to in-cab equipment.

- "Better radios. The newer ones have auxillary ports for ipods. As a music lover, it would help if I could plug ion my ipod when I plow…"

Other comments suggested the use of an advanced technology to reduce fatigue (*n* = 8), improvements or adjustments to snow/ice external equipment (*n* = 9), or other various suggestions (*n* = 29).

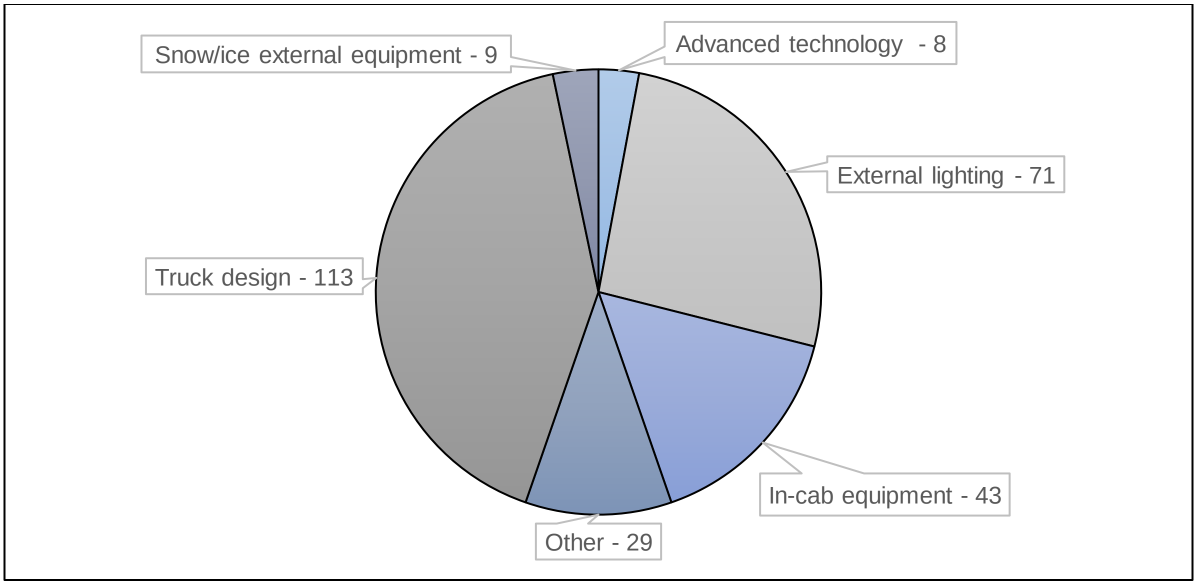



**Figure 59. Comments previously suggested.**

Figure 60 shows the three subthemes for the 49 comments related to operator health and wellness. Over half of these comments (*n* = 25) suggested the importance of a healthy diet in combating fatigue.

- "I also feel that eating the right foods and not overeating to make you tired also help."

There were also 18 comments that suggested staying hydrated.

- "Drink plenty of water."

Additionally, there were six comments suggesting a daily exercise routine.

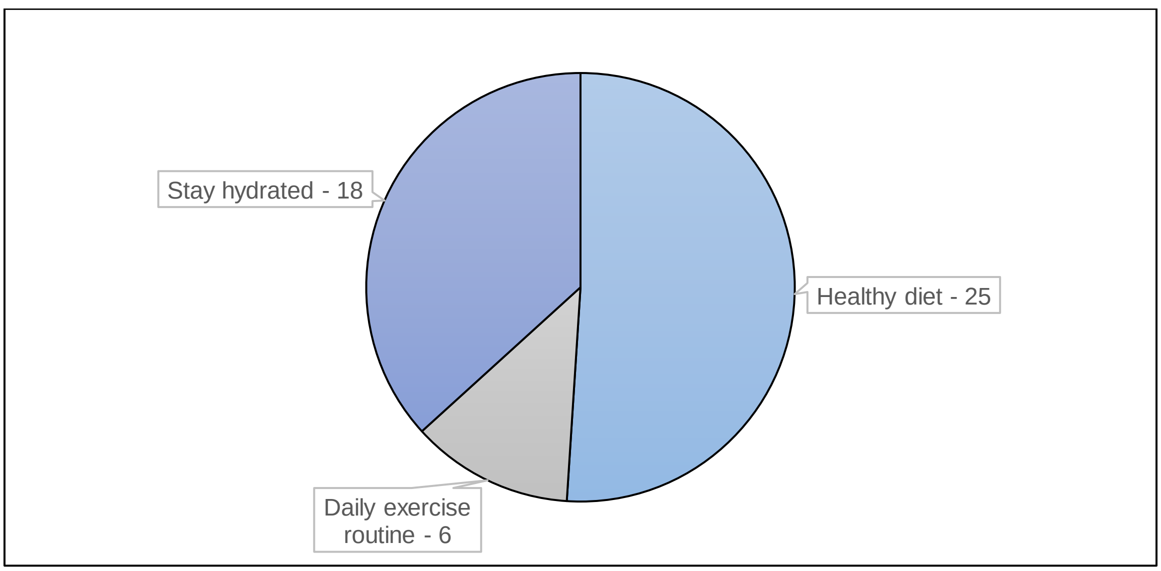



**Figure 60. Operator health and wellness suggestions to reduce fatigue.**

Figure 61 shows the 11 subthemes for the 229 comments that related to winter emergency shifts. Nearly half the comments (*n* = 109) suggested decreasing the overall shift length.

- "Limit the number of hours in a shift and increase the time between shifts. Anything more that 12 hours is too long and getting only 4 hours between shifts is way too short. Note, these conditions may or may not happen all the time but often enough to be dangerous."

There were 48 comments about the use of swing shifts. Of these comments, 12 suggested eliminating swing shifts during the winter months, and the other 36 comments suggested more rest time before being called back in to work the swing shift.

- "Allow night shift to stay on night time operations during non-winter weather. During winter months night shift workers have to switch between day and night shift sometimes within a single 24 hour period. If allowed to stay on night shift I believe workers would be better rested and more alert."
- "It would help if night shift was notified about working at a good time. We are notified 2 to 3 hours before having to come in that we are working."

Additionally, there were 17 comments suggesting their state DOT investigate better shift start and end times.

- "Changing times they want us to start, keeping shifts the same."

Ten comments suggested following federal hours-of-service regulations for heavy vehicle winter maintenance operators.

- "Follow federal DOT guidelines on cdl hours"

There were also 17 comments that suggested team driving during winter emergencies where two winter maintenance operators are in the truck.

- "second person in cab to talk to communicate and a second set of eyes. Reduces tiredness and work load"

Other shift-related comments suggested not plowing until the roads are covered in snow (*n* = 9), including winter maintenance operators in the process of scheduling shifts (*n* = 3), providing winter maintenance operators with extended time off (e.g., 36+ hours) during long storms (*n* = 6), having winter maintenance operators alternate night shifts by week (*n* = 3), and decreasing the number of night shift hours (*n* = 7).

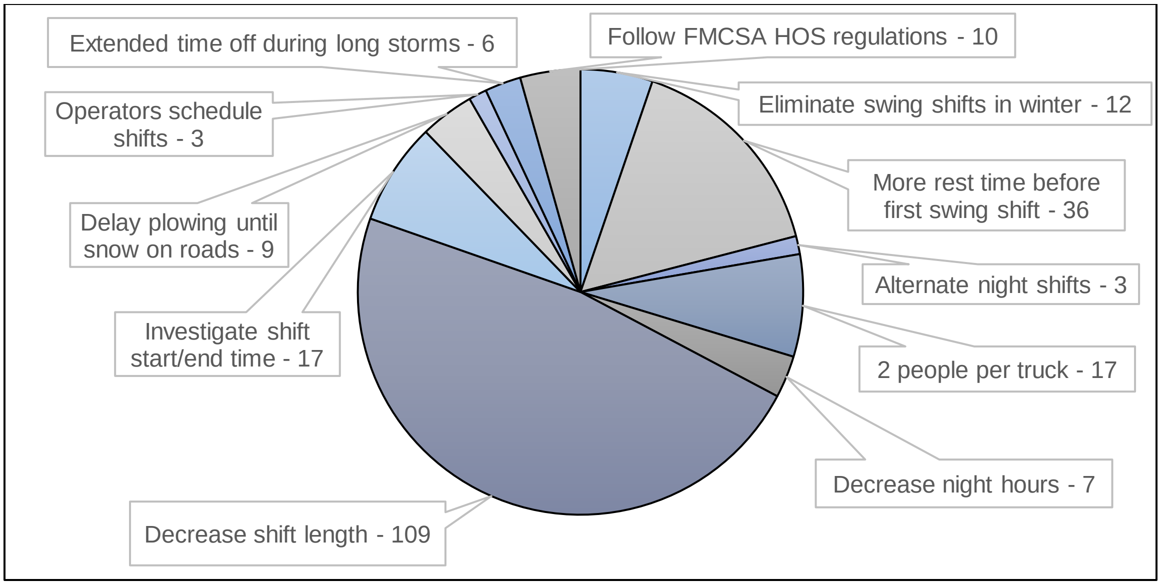



**Figure 61. Shift-related suggestions to reduce fatigue.**

Figure 62 shows the eight subthemes for the 371 comments related to general fatigue countermeasures. Over 70% of the comments involved off-duty sleep (*n* = 108), a short nap (*n* = 11), or taking a break (*n* = 144).

- "I personally believe that equipment has little effect on fatigue. I believe it is more operator preparedness and rest between shifts."
- "I have found that once you get that tired the only thing that helps is pulling over and take a 15 min nap."
- "Breaks throughout the day to 'stretch' your legs and just get some fresh air. I always stop at the far end of my route for a cup of coffee and a walk around of the truck. Seems to relax me and get me ready for the return trip. Only take 5-10 minutes and makes a big difference."

Winter maintenance operators also provided 46 comments that suggest opening the window and keeping the cab cool.

- "I personally push snow at night. I leave my defroster on high and the heat makes me tired, but I have found if I leave the window down it helps me stay more alert."

Many winter maintenance operators also suggested using caffeine to remain alert (*n* = 37).

- "drink some coffee or something with caffeine"

Additionally, 15 comments suggested remaining active to maintain awareness.

- "constantly scan the road, gauges and mirrors, rather than focusing on just the road or plow and sander controls."

Other comments suggested talking to someone on the radio or phone (*n* = 6) or chewing gum or sunflower seeds (*n* = 4).

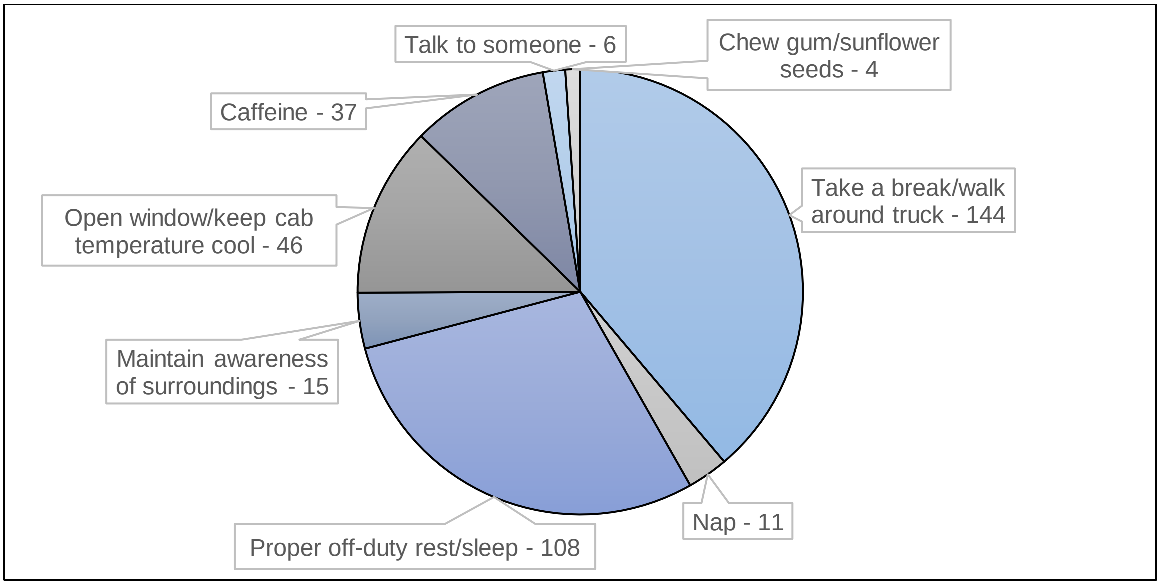



**Figure 62. General fatigue countermeasure suggestions.**

Figure 63 shows the seven subthemes for the 46 comments related to management policies/practices. Fifteen of these comments suggested hiring additional winter maintenance operators.

- "hire and maintain more crew to drive equipment when drivers get over tired"

There were nine comments each for eliminating penalties for idling or taking brakes or providing facilities for sleep at the snowplow terminals.

- "Allow 15-20 minute breaks at turn arounds to close eyes and rest. Every couple of hours, without being worried about idle time and being penalized for idling the truck."
- "some sleeping quarters. We sleep in our vehicles"

Other comments suggested that management participate in a snowplow ride-along at least once a year to understand why fatigue develops ($n$ = 2), having increased funding from the state for winter maintenance operations ($n$ = 4), soliciting and using operator input when making equipment purchasing decisions ($n$ = 3), and offering higher pay for snowplow winter maintenance operators ($n$ = 4).

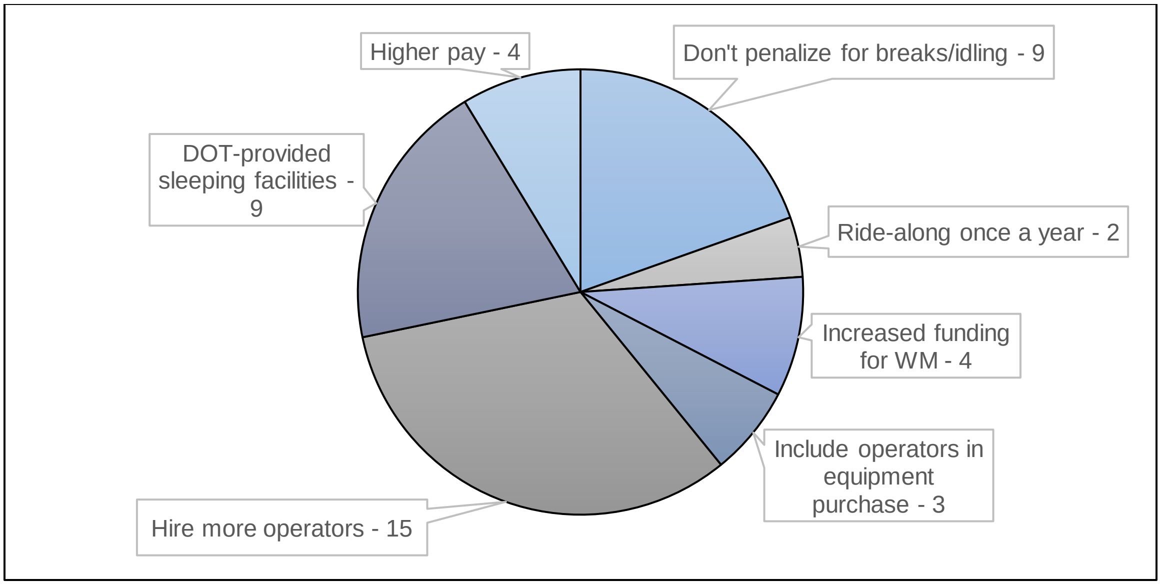



**Figure 63. Management-related suggestions to reduce fatigue.**

Figure 64 shows the four subthemes for the 132 comments providing various other recommendations. Thirty-six of these comments suggested that fatigue was an unavoidable part of a snowplow operator's job.

- "Most often my tiredness is caused by a continuous, repetitive driving pattern, such as non-stop plowing during a storm. You work extended hours, doing a repetitive task, while everyone is trying to get home, you're out to open roads. It's the name of the game. Work makes people tired, this is our work."

Another 14 comments suggested the need for proper cold/winter weather attire.

- "The coats and muck boots were helpful. Being warm and dry is nice."

Winter maintenance education for the general public was suggested in 13 comments.

- "make the public more aware of emergence plow operations, they need to move over when strobe lights are on and truck is plowing. We are emergency vehicles, looking out for the public is the biggest concern!"

Other comments included miscellaneous other suggestions ($n$ = 40).

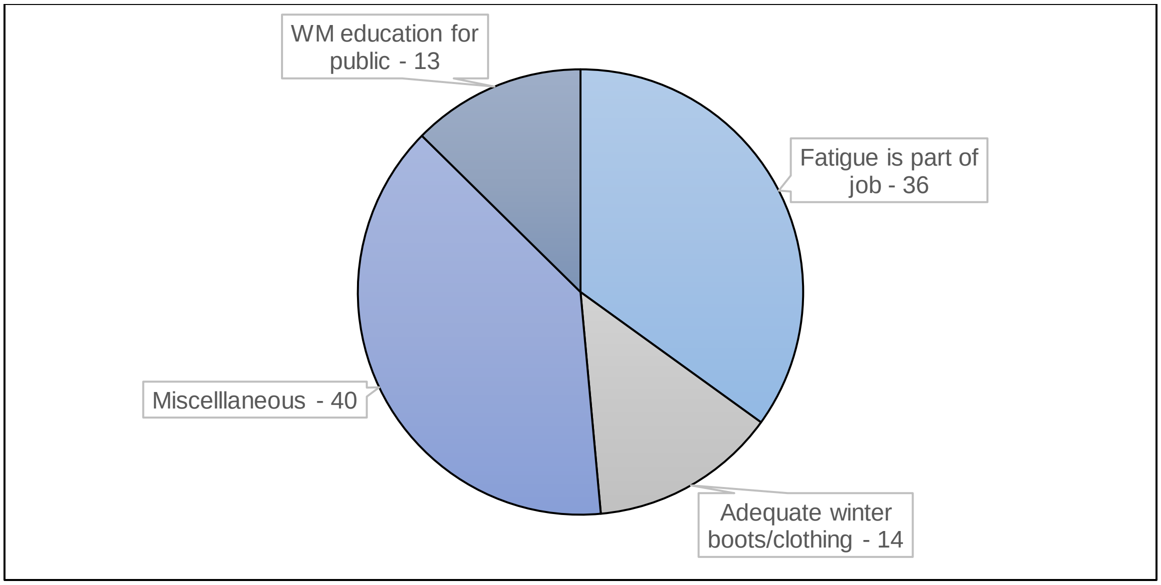



**Figure 64. Various other suggestions/comments related to fatigue.**

# 5. EQUIPMENT SOURCES AND POTENTIAL SOLUTIONS TO WINTER MAINTENANCE OPERATOR FATIGUE

The results from the literature review and questionnaire were used to (1) develop ordinal rankings for the sources of winter maintenance operator fatigue due to equipment and (2) assess the costs and benefits for the equipment solutions identified in the literature review and questionnaire.

## 5.1 SOURCES OF FATIGUE

Ordinal rankings for the sources of winter maintenance operator fatigue due to equipment were developed using the results from the literature review and questionnaire. The steps used to develop ordinal rankings for the sources of winter maintenance operator fatigue due to equipment are listed below.

1. The research team rank ordered the equipment based on the average winter maintenance operator ratings on the questionnaire for how much the equipment impacted fatigue.
2. The research team rank ordered the equipment based on the number of comments provided by the winter maintenance operators on the questionnaire.
3. The average of these two rankings was calculated. If a type of equipment did not have an average rating for how much it impacted fatigue, the number of comments was used to determine the final ordinal ranking. For example, some types of equipment were not specifically asked about in the questionnaire. However, winter maintenance operators provided comments about that type of equipment. Thus, that equipment type would only have a ranking based on the number of comments.

As shown in Table 22, winter maintenance operators reported silence (or a lack of music/talking) as the number one source of fatigue. The top five sources of winter maintenance operator fatigue due to equipment included bright interior light, standard windshield wipers, misplaced or insufficient auxiliary lighting, and an old or uncomfortable seat. Other sources of winter maintenance operator fatigue due to equipment were the standard windshield defrost system, limited cabin insulation, traditional snowplows and their blades, non-adjustable warning lights (strobe lights and flashing lights), the placement and type of equipment controls, an old or worn out vehicle suspension system, exterior halogen light bulbs, and traditional tire chains.

**Table 22. Ordinal Ranking of Equipment Sources of Fatigue**

| Equipment Source of Fatigue | Questionnaire Ratings | # of Comments | Rank based on rating | Rank based on comments | Average Rank | Final Ordinal Ranking |
|---|---|---|---|---|---|---|
| Silence | 3.48 (45% increase fatigue) | 144 | 1 | 4 | 2.5 | 1 |

| Equipment Source of Fatigue | Questionnaire Ratings | # of Comments | Rank based on rating | Rank based on comments | Average Rank | Final Ordinal Ranking |
|---|---|---|---|---|---|---|
| Bright interior lighting (placement and light from) | 3.10–3.20 LCD (28% increase fatigue) | 181 | 6 | 2 | 4 | 2 |
| Standard wipers | 3.26 (34% increase fatigue) | 110 | 4 | 5 | 4.5 | 3 |
| Auxiliary lighting | 3.03 (17% increase fatigue) | 236 | 9 | 1 | 5 | 4 |
| Old seat | Not included | 158 | N/A | 3 | - | 5 |
| Standard defrost system | Not included | 93 | N/A | 6 | - | 6 |
| Limited cab insulation | 3.27 (35% increase fatigue) | 68 | 3 | 8 | 5.5 | 7 |
| Traditional blades/plows | 3.11 - 3.22 (25%–35% increase fatigue) | 70 | 5 | 7 | 6 | 8 |
| Warning lights (strobes and flashing) | 3.33 (37%–40% increase fatigue) | 43 | 2 | 12 | 7 | 9 |
| Equipment controls | 3.11 (24% increase fatigue) | 66 | 8 | 9 | 8.5 | 10 |
| Worn out vehicle suspension | Not included | 60 | N/A | 10 | - | 11 |
| Halogen light bulbs | Not included | 52 | N/A | 11 | - | 12 |
| Traditional tire chains | 3.11 (25% increase fatigue) | 8 | 7 | 13 | 10 | 13 |

## 5.2 COMPARING COSTS AND BENEFITS OF POTENTIAL EQUIPMENT SOLUTIONS TO WINTER MAINTENANCE OPERATOR FATIGUE

Using the results from the literature review and questionnaire, potential equipment solutions were identified to combat the sources of fatigue listed in Table 22. Note that these are potential equipment solutions and not final equipment recommendations. Each solution was assessed to identify the costs (i.e., equipment costs and likelihood to adversely impact winter maintenance operator fatigue) and benefits (i.e., effectiveness to reduce winter maintenance operator fatigue). The research team assigned a rating for each equipment solution's cost and benefit based on the definitions shown in Table 23. In the second column, the ratings for each equipment solution's likelihood to increase fatigue ranged from a negligible impact (i.e., 1 = less than 5% of winter maintenance operators may experience an adverse impact) to a major impact (i.e., 5 = more than

50% of winter maintenance operators may experience an adverse impact). The third column shows the rating for each equipment solution's cost ranged from an insignificant cost per vehicle (i.e., 1 = $0 and $500) to a significant cost per vehicle (i.e., 5 = more than $30,000). The last column shows the ratings for each equipment solution's effectiveness in reducing winter maintenance operator fatigue ranged from highly effective (i.e., 1 = the solution may be effective more than 50% of the time) to minimally effective (i.e., 5 = the solution may be effective less than 10% of the time).

**Table 23. Assessment Rating Definitions**

| Rating | Risk of Increasing Fatigue | Cost | Effectiveness |
|---|---|---|---|
| 5 | May increase fatigue in >50% of operators | >$30,000 per vehicle | May reduce fatigue <10% of the time |
| 4 | May increase fatigue in 25% to 50% of operators | Between $10,000 and $30,000 per vehicle | May reduce fatigue between 10% and 20% of the time |
| 3 | May increase fatigue in 15% to 25% of operators | Between $5,000 and $10,000 per vehicle | May reduce fatigue between 20% and 35% of the time |
| 2 | May increase fatigue in 5% to 15% of operators | Between $500 and $5,000 per vehicle | May reduce fatigue between 35% and 50% of the time |
| 1 | May increase fatigue in less than 5% of operators | Between $0 and $500 per vehicle | May reduce fatigue >50% of the time |

### 5.2.1 Overview of Potential Solutions

Table 24 shows the cost-benefit assessment for each of the potential equipment solutions to winter maintenance operator fatigue. A description of the cost-benefit assessment for each solution is provided after Table 24. The research team surveyed the project's advisory committee for estimated equipment installation and training time for each of the potential solutions. Estimations were received from five states. These estimates were averaged to identify the approximate time required to install each potential equipment solution and train operators on its use.

The installation cost was estimated using the Bureau of Labor Statistics' (BLS) 2016 median per hour for diesel service technicians and mechanics ($21.72).[(105)] Fringe benefits (37.1%) were added to the hourly rate.[(106)] Thus, the total labor costs per hour were $29.78. Training costs for each of the potential equipment solutions below were minimal (typically less than 30 minutes per driver). Thus, training costs were not included and would not significantly impact the cost estimates. Note these are only potential equipment solutions identified in the literature review and questionnaire; they are not recommendations. The research team's final equipment recommendations are provided in the discussion section.

**Table 24. Matrix of Equipment Solutions**

| Equipment Solution | Risk of Increasing Fatigue (1 = lowest risk; 5 = highest risk) | Cost to Implement (1 = lowest cost; 5 = highest cost) | Effectiveness to Prevent Fatigue (1 = highest effectiveness; 5 = lowest effectiveness) |
|---|---|---|---|
| 1. Install music/radio/CD player in all WM equipment | 1 | 1 | 2 |
| 2. Device to communicate with coworkers (e.g., Bluetooth, CB radio) | 2 | 1 | 2 |
| 3. Nighttime dimmer switch for forward-facing warning lights | 1 | 2 | 2 |
| 4. Heated wipers | 1 | 1 | 3 |
| 5. Heated windshield | 1 | 2 | 1 |
| 6. Redesigned snow deflectors/flaps | 2 | 1 | 1 |
| 7. More noise suppression cab insulation | 2 | 2 | 4 |
| 8. Rubber-encased blades | 2 | 2 | 3 |
| 9. Plow float controller/device | 2 | 1 | 4 |
| 10. Dimmable interior lighting | 1 | 1 | 1 |
| 11. Anti-glare visor | 2 | 1 | 5 |
| 12. Mount auxiliary lighting on passenger side | 2 | 1 | 2 |
| 13. Use narrow-beam auxiliary lighting | 1 | 1 | 3 |
| 14. More ergonomically designed seat with vibration dampening/air-ride technology | 1 | 2 | 1 |
| 15. Consolidate interior displays | 2 | 2 | 4 |
| 16. Limit the use of tire chains | 2 | 1 | 4 |
| 17. Air-ride/vibration dampening suspension | 1 | 3 | 1 |
| 18. Use LED bulbs for all exterior lighting | 1 | 1 | 1 |
| 19. Purchase new truck | 1 | 5 | 1 |

#### *5.2.1.1 Install Music/Radio/CD Player in all Winter Maintenance Equipment*

- *Risk of Increasing Fatigue: 1 (Less than 5% risk of increasing fatigue).* Winter maintenance operators have the ability to turn the radio off or on depending on their preference or situation.
- *Costs: 1 (Less than $500).* An average priced vehicle radio/CD receiver can be purchased for $100 to $150. Additionally, a number of winter maintenance operators suggested the use of satellite radio. An averaged priced vehicle radio receiver with CD/MP3/Bluetooth/satellite can be purchased for $150 to $250. Installation costs per vehicle are minimal. Satellite radio also requires a monthly or yearly subscription. Monthly subscriptions range from $10 to $20 per radio. However, it is possible for operators to cover this recurring cost. Installation of the music radio, wiring, antenna, and speakers was estimated to take 3 hours. The total labor installation cost was estimated to

be $89.34 per vehicle. Thus, the total cost for equipping trucks with a music/CD player, including an average monthly subscription, was $419.34 to $519.34.

- *Effectiveness: 2 (Prevent between 35% and 50% of fatigue).* Previous research has shown that listening to the radio can be an effective countermeasure for fatigue.(66,67,68) However, the effectiveness of listening to the radio is limited: (a) it is not always effective; (b) it may only be effective at reducing self-reported fatigue (not objective measures of fatigue); (c) it may not reduce driving-related behaviors associated with fatigue (e.g., lane deviations); and (d) the reduction in fatigue is not long lasting.

#### 5.2.1.2 Device to Communicate with Coworkers (e.g., Bluetooth, CB or DOT radio)

- *Risk of Increasing Fatigue: 2 (Between 5% and 15% risk of increasing fatigue).* Between 9% and 14% of winter maintenance operators reported a CB radio or a DOT radio increased fatigue, respectively. A Bluetooth device for a mobile phone would have less of an adverse impact because it would it only be used sparingly. A CB or DOT radio is on all the time and the operator is subject to hearing all conversations, not those only directed to him/her. However, some states ban the use of all cell phones (hands-free and handheld) while driving. Thus, it may not be feasible to offer Bluetooth cell phone communications as a method to reduce fatigue.
- *Costs: 1 (Less than $500).* CB radios kits (including the antenna/connector) can be purchased for $200 to $300. An average priced Bluetooth device for a mobile phone can purchased for $20 to $50. Installation of the CB/DOT radio, wiring, antenna, and speakers was estimated to take 2.5 hours. The total labor installation cost was estimated to be $74.45 per vehicle. Thus, the total cost for equipping trucks with a CB/DOT radio was $274.45 to $374.45.
- *Effectiveness: 2 (Prevent between 35% and 50% of fatigue).* Previous research has found that conversations with others via a Bluetooth cell phone or CB/DOT radio reduced safety-critical events by 45% for heavy vehicle drivers.(92) Other research found similar effects.(90,94,95) However, the reduced fatigue was short-lived.

#### 5.2.1.3 Nighttime Setting and Dimmer Switch for Forward-Facing Warning

- *Risk of Increasing Fatigue: 1 (Less than 5% risk of increasing fatigue).* Nine percent of winter maintenance operators reported that strobe or flashing lights decrease fatigue. However, the comments from these drivers revealed that the light (and not the glare) helped to reduce fatigue. Thus, reducing the glare from forward-facing warning lights would likely decrease fatigue to a greater extent for these winter maintenance operators.
- *Costs: 2 (Between $500 and $5,000 per vehicle).* Cost will vary depending on whether LED warning lights are currently installed on the truck or not. If LED warning lights are already employed, costs will only include the installation of a dimmer switch. A dimmer switch can be purchased for $60. If LED warning lights are not installed, they would need to be purchased along with the dimmer switch. LED warning light bars can be purchased for an average of $300. It was estimated that the installation of a dimmer switch and LED warning lights would require 6 hours. The total labor installation cost was estimated to be $178.68 per vehicle. Thus, the total estimated cost for installing LED warning lights with a nighttime dimmer switch is $538.68. However, it is possible that

some LED warning lights already include a nighttime dimming capabilities and operators are unaware of this function. In this case, costs would be minimal to train operators to use the dimmer switch (no new purchase of warning lights required).

- *Effectiveness: 2 (Prevent between 35% and 50% of fatigue).* No previous research has examined the effect of flashing/strobe warning lights on fatigue. There was research examining the association between glare and fatigue.(69,70,71) However, this research did not examine glare from warning lights, and the results from this research have been inconsistent. Considering that winter maintenance operators are exposed to extended use of warning lights, reducing the glare would likely provide an effective means of mitigating fatigue.

#### *5.2.1.4 Heated Windshield Wipers*

- *Risk of Increasing Fatigue: 1 (Less than 5% risk of increasing fatigue).* Winter maintenance operators were not specifically asked about heated wipers in the questionnaire. However, the only comments received were in favor of heated wipers; there were no comments suggesting that heated wipers increased fatigue.
- *Costs: 1 (Less than $500).* Multiple vendors offer heated wipers for $150 to $300. Installation of the heated windshield wipers was estimated to take 3 hours. The total labor installation cost was estimated to be $89.34 per vehicle. Thus, the total estimated cost for equipping trucks with heated windshield wipers is $239.34 to $389.34.
- *Effectiveness: 3 (Prevent between 20% and 35% of fatigue).* No study has examined the effectiveness of heated windshield wipers to reduce fatigue. However, winter maintenance operators reported that windshield wipers are a major cause of fatigue. A number of comments ($n$ = 37) provided by winter maintenance operators specifically mentioned that heated windshield wipers greatly reduced fatigue associated with constantly clearing off ice/snow and reduced visibility. One study did find mixed reviews for the effectiveness of heated wiper blades in removing snow and ice buildup.(107) However, that study was completed in 2006, and it is likely that the technology has improved.

#### *5.2.1.5 Heated Windshield*

- *Risk of Increasing Fatigue: 1 (Less than 5% risk of increasing fatigue)*. Only 2% reported that a heated windshield increased fatigue.
- *Costs: 2 (Cost between $500 and $5,000).* Equipment vendors offer heated windshields for $500 to $1,000. Installation of a heated windshield was estimated to take 5 hours. The total labor installation cost was estimated to be $148.90 per vehicle. Thus, the total estimated cost for equipping trucks with a heated windshield is $648.90 to $1,148.90.
- *Effectiveness: 1 (Prevent more than 50% of fatigue).* Although no research has examined the effectiveness of a heated windshield in reducing fatigue, there are some indications that heated windshields could be very effective in preventing snow/ice buildup on the windshield.(107) It is likely that fatigue is greatly reduced if excessive snow/ice buildup is eliminated.

#### 5.2.1.6 Install Snow Deflectors

- *Risk of Increasing Fatigue: 2 (Between 5% and 15% risk of increasing fatigue).* Seven percent of winter maintenance operators reported that snow deflectors increase fatigue. However, it is likely that a redesigned snow deflector will cause less fatigue.
- *Costs: 1 (Less than $500).* Snow deflectors can be purchased for less than $100. Installation of a snow deflector/flap was estimated to take 2 hours. The total labor installation cost was estimated to be $59.56 per vehicle. Thus, the total estimated cost for equipping trucks with a snow deflector/flap is $159.56.
- *Effectiveness: 1 (Prevent more than 50% of fatigue).* Previous research has found that snow deflectors/flaps were effective in reducing blow-over snow by 50%.[89,107] Reducing blow-over snow should improve visibility and decrease mental workload. Winter maintenance operators suggested adjusting the plow as far forward as possible (at least a 50 degree angle) for the most benefit from deflectors.

#### 5.2.1.7 More Noise-Suppressing Cab Insulation

- *Risk of Increasing Fatigue: 2 (Between 5% and 15% risk of increasing fatigue).* Between 9% and 12% of winter maintenance operators reported that noise from the engine or plow decreased fatigue, respectively.
- *Costs: 2 (Cost between $500 and $5,000).* Aftermarket sound-dampening/deadening solutions exist for heavy vehicles, typically through the use of sound absorbing padding. A set of this padding can be purchased for less than $200. However, a snowplow would likely require the purchase of many sets of padding, and they may not be effective at reducing noise produced by plowing snow. Assuming that each snowplow would require a minimum of five sets of padding (engine compartment [two sets], cab, driver side door, and passenger side door), the total purchase price may be $1,000. Installation of the sound dampening was estimated to take 16 hours. The total labor installation cost was estimated to be $476.48 per vehicle. Thus, the total estimated cost for equipping trucks with a sound-dampening padding is $1,476.48.The other option would be to negotiate upgraded cab noise suppression in the purchase of new trucks.
- *Effectiveness: 4 (Prevent between 10% and 20% of fatigue).* Improved cab insulation could reduce the amount of noise in the cab from outside sources (e.g., engine, plow). However, the amount of noise prevented would depend on many factors (e.g., amount and type of insulation, road surface and condition, vehicle maintenance, type of plow/blade, weather conditions, etc.). Despite such variations, it is likely that additional cab insulation would be effective in reducing some fatigue associated with low-frequency noise.[59,61]

#### 5.2.1.8 Rubber-Encased Blades

- *Risk of Increasing Fatigue: 2 (Between 5% and 15% risk of increased fatigue).* Seven percent of winter maintenance operators reported that rubber-encased blades increased fatigue.

- *Costs: 2 (Cost between $500 and $5,000).* Each rubber-encased blade costs $500 to $1,000. Previous research has estimated that three to five blades are needed each winter season, costing an average of $3,400 per year including labor installation.[108]
- *Effectiveness: 3 (Prevent between 20% and 25% of fatigue).* Approximately one-quarter of winter maintenance operators (26%) reported that rubber-blades decreased fatigue. Although research shows that rubber-encased blades reduce vibration,[55] no study has quantified the effectiveness of rubber-encased blades to reduce fatigue.

#### *5.2.1.9 Plow Float Controller/Device*

- *Risk of Increasing Fatigue: 2 (Between 5% and 15% risk of increasing fatigue).* Six percent of winter maintenance operators reported that a blade float device increased fatigue.
- *Costs: 1 (Less than $500).* Several vendors offer float controllers for less than $200. Installation costs should be minimal. Installation of a plow float controller was estimated to take 2.5 hours. The total labor installation costs was estimated to be $74.45 per vehicle. Thus, the total estimated cost for equipping trucks with a blade float controller is less than $274.45.
- *Effectiveness: 4 (Prevent between 10% and 20% of fatigue).* Less than one-fifth of winter maintenance operators (18%) in this study reported a float mode for the plow reduced fatigue. No other study has quantified the effectiveness of a plow float device to reduce fatigue.

#### *5.2.1.10 Dimmable Interior Lighting*

- *Risk of Increasing Fatigue: 1 (Less than 5% risk of increasing fatigue).* Eight percent of winter maintenance operators reported that light emanating from an interior monitor decreased fatigue. Thus, eliminating interior lighting would increase fatigue with these winter maintenance operators. However, adjustable interior light can be dimmed/increased when needed.
- *Costs: 1 (Less than $500).* A number of vendors offer snowplow systems that can be dimmed. Truck manufacturers also have interior lights that can be dimmed. However, some comments ($n$ = 16) from winter maintenance operators reported that these monitors/lights do not dim enough. Additionally, winter maintenance operators preferred the option to black out a monitor. It is possible that these functionalities do exist in some current systems. In this case, costs would be minimal to train operators to use the dimmer switch (no new purchase of a dimmer switch needed). Incorporating these features into other systems may require working with truck original equipment manufacturers or snowplow system manufacturers. Additionally, dimmer switches are available for an average of $50. Installation of a dimmer switch was estimated to take 2 hours. The total labor installation cost was estimated to be $59.56 per vehicle. Thus, the total estimated cost for equipping trucks with interior light/monitor dimmer switch is $109.56.
- *Effectiveness: 1 (Prevent more than 50% of fatigue).* There were 186 separate comments from winter maintenance operators suggesting a feature to dim interior light from

monitors/dash lights. Dimming interior lights should be effective in reducing fatigue from bright interior lights/glare.[69,70]

#### 5.2.1.11 Anti-Glare Visor

- *Risk of Increasing Fatigue: 2 (Between 5% and 15% risk of increasing fatigue).* Fourteen percent of winter maintenance operators reported that anti-glare glass increased fatigue.
- *Costs: 1 (Less than $500).* An anti-glare visor can be purchased for less than $30 and installed along with the sun visor for a minimal cost. Installation of an anti-glare visor was estimated to take 1 hour or $29.78. Thus, the total estimated cost for installing an anti-glare visor is $59.78.
- *Effectiveness: 5 (Prevent less than 10% of fatigue).* The anti-glare visor does not cover the entire windshield or windows. Anti-glare coatings are available; however, it is likely these coatings would not be effective during winter weather. A better solution may be wearing polarized, yellow glasses for nighttime driving.

#### 5.2.1.12 Mount Auxiliary Lighting on Passenger Side

- *Risk of Increasing Fatigue: 2 (Between 5% and 15% risk of increasing fatigue).* Although winter maintenance operators were not specifically asked about auxiliary light placement in the questionnaire, 17% of winter maintenance operators said that auxiliary lighting in general increased fatigue. Several prior studies suggested placing auxiliary lighting on the passenger side to reduce back-reflected light and eye discomfort.[81,82,83] This may improve visibility, reduce mental workload, and possibly reduce winter maintenance operator fatigue. However, it is possible that some winter maintenance operators may prefer auxiliary lighting placed in other locations.
- *Costs: 1 (Less than $500).* This solution does not require purchasing additional auxiliary lighting. However, labor to mount lighting away from the winter maintenance operator's line of sight will be required. Additionally, new mounting brackets may be needed. It is estimated that moving auxiliary lighting would require 4.5 hours, for a total cost of $134.01. However, if multiple lights need to moved, this cost may exceed $500.
- *Effectiveness: 2 (Prevent between 35% and 50% of fatigue).* Previous research found that the majority of winter maintenance operators prefer auxiliary lights to be placed away from the operator's line of sight.[81,82,83] However, this research did not quantify the effectiveness that auxiliary light placement had on fatigue.

#### 5.2.1.13 Use Narrow-Beam Exterior Lighting

- *Risk of Increasing Fatigue: 1 (Less than 5% risk of increasing fatigue).* Winter maintenance operators were specifically asked about narrow-beam exterior lighting in the questionnaire. However, 17% of winter maintenance operators said that auxiliary lighting in general increased fatigue. Previous research has suggested that narrow-beam lighting reduces fatigue.[84,85] No winter maintenance operators provided comments suggesting that narrow-beam lights increase fatigue.
- *Costs: 1 (Less than $500).* LED spotlights are available from $20 to $300. Installation of an LED spot light was estimated to take 3 hours for a total of $89.34. Thus, the total

estimated cost for equipping trucks with narrow-beam spot lights is between $109.34 and $389.34.

- *Effectiveness: 3 (Prevent between 20% and 35% of fatigue).* Spotlights greatly reduce the back-reflected light compared to flood lights.[84,85] Although the effectiveness of spotlights in reducing fatigue has not been quantified, it is possible that reducing glare from back-reflected light could reduce eye strain and fatigue while improving concentration.

#### *5.2.1.14 More Ergonomically Designed Seat with Vibration-Dampening/Air-Ride Technology*

- *Risk of Increasing Fatigue: 1 (Less than 5% risk of increasing fatigue).* Winter maintenance operators were not specifically asked about seats in the questionnaire. However, there were very few winter maintenance operators (1% to 2%) who suggested that uncomfortable seats prevent fatigue.
- *Costs: 2 (Cost between $500 and $5,000).* Air-ride seats can be purchased for $1,000 to $3,000. However, seats with new vibration cancelling technology can exceed $5,000. DOTs may be able to negotiate a lower price with a large purchase order. Installation of a vibration-dampening seat was estimated to take an average of 4.5 hours for a total of $134.01. Thus, the total estimated cost for installing an air-ride seat is between $1,134.01 and $3,134.01.
- *Effectiveness: 1 (Prevent more than 50% of fatigue).* Winter maintenance operators provided 158 comments specifically recommending a more comfortable seat as a way to significantly reduce fatigue. Many winter maintenance operators reported that after 12 or more hours sitting, a good seat was very important to reduce the back/neck pain that leads to fatigue. Also, a comfortable seat could allow operators to take a quick nap if needed between plowing routes.

#### *5.2.1.15 Consolidate Interior Displays*

- *Risk of Increasing Fatigue: 2 (Between 5% and 15% risk of increasing fatigue).* Winter maintenance operators were not asked about reducing the number of interior displays in the questionnaire. Although integrating information from multiple displays could make it more difficult to navigate through the menus (thereby requiring increased concentration and mental workload), winter maintenance operators did not provide any comments suggesting that limiting the number of monitors would increase fatigue.
- *Costs: 2 (Cost between $500 and $5,000).* Snowplow equipment manufacturers may have the ability to create a single (or a limited number) display to control and monitor all snowplow equipment (compared to multiple displays controlling different equipment). However, this would likely require working with manufacturers to create a custom display. The cost of this customization may require a large upfront cost with diminished costs once the customized display is created. It was estimated that a solution could be installed in 20 hours for a total cost of $595.60.
- *Effectiveness: 4 (Prevent between 10% and 20%).* Reducing the number of devices that emit light inside the cab should reduce eye strain and fatigue.[69,70] However, it is possible

that increasing the functionality of a monitor may increase the difficulty to navigate menus, thereby increasing fatigue and inattention.

#### *5.2.1.16 Limit the Use of Tire Chains*

- *Risk of Increasing Fatigue: 2 (Between 5% and 15% risk of increasing fatigue).* Thirteen percent of winter maintenance operators reported that tire chains decrease fatigue. Although tire chains may increase fatigue, they may also decrease crash risk. Furthermore, some state DOTs may require the use of tire chains. Thus, limiting the use of tire chains may not be feasible in all states.
- *Costs: 1 (Less than $500).* No extra costs are required to limit the situations when tire chain use is recommended. However, three winter maintenance operators suggested the use of basket chains instead of ladder chains. The cost to purchase basket chains is less than $400 per truck.
- *Effectiveness: 4 (Prevent between 10% and 20% of fatigue).* Although limiting vibration and noise caused by tire chains may decrease fatigue, removing the tire chains may increase the winter maintenance operator’s workload in other situations. The operator may also be required to put on or take off the chains more often.

#### *5.2.1.17 Air-Ride/Vibration-Dampening Suspension*

- *Risk of Increasing Fatigue: 1 (Less than 5% risk of increasing fatigue).* Winter maintenance operators were not asked about air-ride or other vibration-dampening suspensions. A few winter maintenance operators (1%) suggested that vibration increased alertness.
- *Costs: 3 (Cost between $5,000 and $10,000).* Although upgrading to an air-ride suspension system typically occurs with the purchase of a new truck, it is possible to retrofit older trucks. It was estimated that retrofitting an older truck would cost $7,500 plus 30 hours of labor. Thus, the total estimated cost to equip an older truck with air-ride suspension is $8,393.40. Upgrading a new truck to an air-ride suspension is likely to cost less, and DOTs may be able to negotiate the price in a large bulk order.
- *Effectiveness: 1 (Prevent more than 50% of fatigue).* Air-ride suspensions would eliminate much of the fatigue associated with low-frequency vibrations.[6,7]

#### *5.2.1.18 Use LED Bulbs for all Exterior Lighting*

- *Risk of Increasing Fatigue: 1 (Less than 5% risk of increasing fatigue).* Winter maintenance operators were not specifically asked about LED light bulbs in the questionnaire. However, only a few winter maintenance operators (1%) suggested that LED lights increased fatigue.
- *Costs: 1 (Less than $500).* LED bulbs cost less than $40. Installation costs should be minimal. Replacing all exterior lighting with LED bulbs was estimated to take 2.5 hours for a total cost of $74.45. Assuming that six lights need replacement (i.e., two headlights, two plow lights, and two spot lights), the total estimated cost for equipping a truck with LED bulbs is $314.45.

- *Effectiveness: 1 (Prevent more than 50% of fatigue).* LEDs have been shown to greatly improve night visibility.[(88)] However, LEDs produce less heat, which may cause snow to build up on LED enclosures and fixtures. Heated lights may be a solution to snow buildup on LED enclosures and fixtures. However, in temperatures less than 15 degrees Fahrenheit, a heated lens creates a layer of ice over the light enclosure. Thus, an on/off switch is important for all heated lights.

#### *5.2.1.19 Purchase a New Truck*

- *Risk of Increasing Fatigue: 1 (Less than 5% risk of increasing fatigue).* Winter maintenance operators were not asked about purchasing a new truck in the questionnaire. However, winter maintenance operators provided 58 comments that suggested purchasing a new truck. There were no comments that suggested a new truck would increase fatigue.
- *Costs: 5 (More than $30,000).* A new truck is very expensive. A new truck may range from $70,000 to more than $100,000 depending on the optional equipment and number of axles.
- *Effectiveness: 1 (Prevent more than 50% of fatigue).* The technology available on a new truck may include many of the other solutions recommended above (e.g., new seat, LED lights, heated windshield, music player, and increased cabin insulation). A new truck may also have a larger cab as suggested in the comments.

# 6. DISCUSSION

The objective of this project was to recommend cost-effective equipment solutions to mitigate fatigue experienced by winter maintenance operators. Two tasks were completed to accomplish this objective. First, a literature review identified prior research on equipment sources and solutions to winter maintenance operator fatigue. Second, a questionnaire collected winter maintenance operators' opinions on the relationship between equipment and fatigue. The questionnaire was distributed to 33 Clear Roads member states. Completed questionnaires were received from over 2,000 winter maintenance operators in 23 states.

Similar to the results from Camden et al., the vast majority of winter maintenance operators reported feeling fatigue at some point while operating a snowplow during a winter emergency.(1) In both studies, winter maintenance operators most frequently reported they "sometimes" felt fatigued while driving. However, 12% to 15% of winter maintenance operators reported feeling fatigued "most of the time" or "always" while driving. Additionally, both studies found that new winter maintenance operators reported feeling less fatigued than more experienced winter maintenance operators. This result may indicate that more experienced winter maintenance operators are more likely to identify the signs of fatigue. Alternatively, new winter maintenance operators may be less willing to identify the more subtle signs of fatigued. Finally, age and experience are often highly correlated, and thus, the more experienced winter maintenance operators may also be older winter maintenance operators. Reimer et al. indicated that as individuals age, they are more susceptible to negative impacts associated with sleep deprivation and varying sleep schedules.(109)

The winter maintenance operators in this study reported similar shifts compared to those in Camden et al.(1) The majority of winter maintenance operators worked day and night shifts (56% in Camden et al.(1) and 58% in the current study). However, 67% of winter maintenance operators in Camden et al.(1) reported shift lengths longer than 12 hours compared to 28% of winter maintenance operators in this study. The current study found winter maintenance operators with shifts lasting 16 hours or longer reported significantly higher levels of fatigue compared to all other shift lengths. This fatigue may be the result of sleep debt (lack of sleep over one or more days; i.e., SR fatigue), sustained activity over a long period of time (i.e., TR fatigue), or some combination of these.

## 6.1 WINTER MAINTENANCE EQUIPMENT AND FATIGUE

This project identified the extent to which fatigue was associated with equipment-related vibrations and noise, reduced visibility, and in-cab equipment. Additionally, equipment solutions were identified to eliminate fatigue associated with vibration, noise, visibility, and in-cab equipment.

### 6.1.1 Equipment-Related Vibration

Previous research has indicated that sustained, low-frequency vibrations contribute to the development of fatigue.(6,7,34) These results were supported by winter maintenance operators' opinions from Camden et al.(1) and the current study. Approximately 50% of the winter operators in the current study reported that vibrations caused fatigue at some point. One method to reduce sustained, low-frequency vibrations is to upgrade or improve the snowplow’s suspension. Previous research found that air-ride truck suspensions significantly reduced vehicle vibrations.[110,111] Winter maintenance operators provided over 70 comments in Camden et al.[1] and the current study that suggested an improved truck suspension would reduce vibration-causing fatigue.

A snowplow blade float device may be another countermeasure to reduce sustained, low-frequency vibrations. A blade float device attaches to the snowplow and automatically adjusts the pressure and position of the plow based on the roadway. Although there is no published research examining the effectiveness of a blade float device in reducing fatigue, winter maintenance operators in this study indicated that they significantly reduce fatigue. They also may help alleviate the fatigue winter maintenance operators associated with the front plow. However, some winter maintenance operators may override the float device to get more downward pressure on the snow plow blade to make the road as clear as possible. In this scenario the winter maintenance operator would create higher levels of vibrations than intended with the float device.

Rubber-encased snowplow blades have also been shown to reduce sustained vibrations and noise.[55] Camden et al. found that rubber blades were an effective countermeasure for plow vibrations.[1] Results from this study confirmed that winter maintenance operators believed that rubber-encased blades significantly reduce fatigue. Schneider et al. examined the costs associated with the purchase, replacement, and installation of various snowplow blades.[108] They found that rubber-encased blades may not be cost-effective given the high purchase and replacement costs. However, Schneider et al. did not factor in benefits associated with reduced fatigue (e.g., increased productivity and crash costs) from the use of rubber-encased blades. These added benefits may improve the cost-benefit of rubber-encased blades.

Previous research also showed that the use of tire chains impacts vibration and fatigue.[1,56] Similarly, winter maintenance operators in the current study reported that non-automatic tire chains significantly increased fatigue but that automatic tire chains did not increase or decrease fatigue. This suggests that limiting the use of tire chains may be a valid method to reduce fatigue associated with vibrations. Additionally, three winter maintenance operators suggested using basket chains instead of ladder chains. Blood et al. found that basket chains significantly reduced vibrations during highway plowing compared to ladder chains.[56] Figure 65 below shows the tire chain configurations tested in Blood et al.[56]

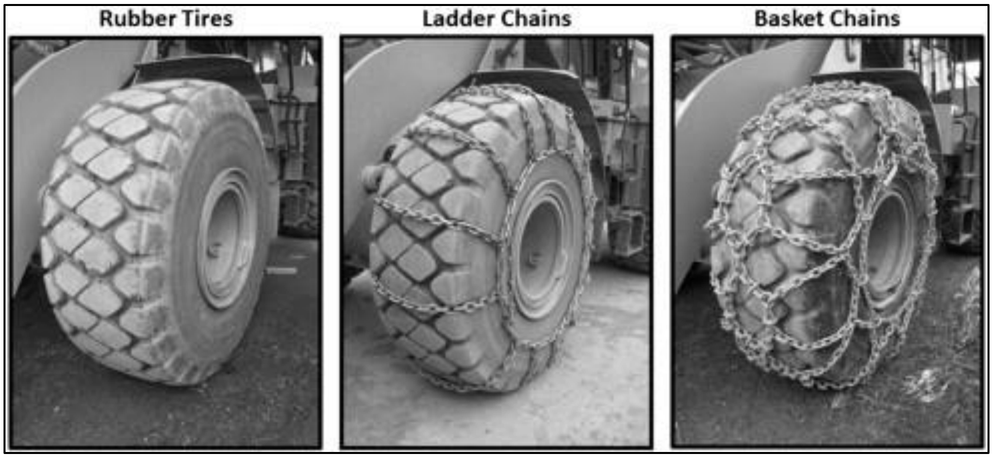



**Figure 65. Tire chain configuration tested in Blood et al.[56]**

Winter maintenance operators in the current study indicated that an air-ride/vibration dampening seat may be the most effective solution to reduce fatigue associated with vibration. This finding is supported by Camden et al.[1] and Peterson.[51] Additionally, several other studies demonstrated the importance of an operator's seat in reducing vibrations.[52,53] Blood et al. found that air-ride seats significantly reduced low-frequency vibrations compared to a traditional seat.[52] On the other hand, Blood et al. found that electromagnetically active seats reduced vibration by 30% over air-ride seats; however, both types of vibration-reducing seats reduced vibrations compared to a traditional seat.[53]

### 6.1.2 Equipment-Related Noise

Previous research has found that, similar to vibration, noise can adversely impact fatigue.[57,58] In particular, low-frequency, continuous noise has consistently been found to increase self-reported fatigue and driver behaviors associated with fatigue.[59,60,61,62] Winter maintenance operators in the current study reported that noise from the engine and plow significantly increased fatigue. This is likely why Camden et al. found that noise was an important source of fatigue in winter maintenance operations.[1]

One solution to reduce noise-related fatigue is to increase cabin insulation. Nearly 70 comments in the current study suggested that additional cab insulation may decrease noise. Similarly, there were over 180 comments in Camden et al. to reduce noise with increased cab insulation.[1] Additionally, Peterson recommended increased cab insulation as an effective countermeasure to exterior snowplow noise.[51]

However, prior research has demonstrated that every noise does not necessarily increase fatigue.[58] Unlike low-frequency sound, high-frequency, intermittent sound increases alertness and vigilance.[64,65,66] Winter maintenance operators in the current study indicated that alerts (i.e., high-frequency, intermittent sound) from snow, ice, or safety equipment significantly decreased fatigue.

The current study also found that the use of a CB or DOT radio significantly reduced fatigue. A communication device (regardless if it is a CB radio, DOT radio, or cell phone) would allow the winter maintenance operator to converse with others, and thus, provide stimulation in monotonous conditions. This result somewhat contradicts the winter maintenance operators' opinions in Camden et al,[1] which found that 62% of winter maintenance operators believed that conversations on a CB/DOT radio or cell phone were rarely effective or never effective at reducing fatigue.[1] However, the results from the current study support previous research with heavy vehicles[90,92] and light vehicle drivers.[93,94,95] In all of these studies, the use of a CB radio or cell phone conversation decreased subjective ratings of fatigue; however, the effects often lasted less than 30 minutes. It is also important to note that some states ban cell phone use while driving. Thus, it is not feasible or recommended to have a cell phone conversation while operating the snow plow during a winter emergency.

According the winter maintenance operators in the current study, a radio or music (or lack thereof) had the largest impact on winter maintenance operator fatigue. Operators indicated that fatigue significantly increased when the radio was turned off, whereas fatigue significantly decreased when the radio was on. Similar to the CB radio, these results somewhat contradict Camden et al,[1] which found that winter maintenance operators frequently used the radio or music to mitigate fatigue. However, those same winter maintenance operators reported that the radio or music was only "sometimes" effective in reducing fatigue. However, other research has shown that listening to the radio or music may be effective in reducing fatigue for some individuals for a limited amount of time.[66,67,68]

Previous research did not identify a specific genre of music that was most effective in reducing fatigue. An individual's preferred music was found to reduce fatigue for limited amounts of time.[66,67,112,113,114] For example, Fagerström and Lisper found that an individual's preferred talk radio show or music improved reaction time over no music or radio.[66] Reyner and Horne found that listening to preferred music significantly reduced subjective sleepiness, especially during the first 30 minutes.[67] Oron-Gilad et al. found that drivers began developing fatigue after driving 45 minutes without music; however, drivers who listened to their preferred music were able to maintain alertness.[112] Dibben and Williamson found that fewer drivers were involved in crashes while listening to their preferred music compared to drivers who were listening to music other than their preferred genre.[113] Hasegawa and Oguri found that highly preferred music with a fast tempo increased driver vigilance, and music with a low preference and a slow tempo significantly reduced driver vigilance.[114] In addition to music preference, Turner et al. found that drivers had quicker reaction times to an unexpected event when music was played at a moderate sound level (i.e., 70 dBA) compared to quieter or louder sound levels (i.e., 60 dBA and 80 dBA, respectively).[115]

### 6.1.3 Visibility-Related Equipment

Winter maintenance operators in the current study and in Camden et al.[1] indicated that visibility was an important source of fatigue. Nearly 75% of participants in the current study reported that reduced visibility caused fatigue at some point. Reduced visibility may be associated with an increase in task-related fatigue.[11] In other words, reduced visibility may be associated with cognitive overload conditions. Previous research has shown that eye strain and discomfort from reduced visibility and glare increased subjective ratings of fatigue for some individuals.[69,70,71] For these reasons, Peterson recommended improving the lighting and visibility of winter maintenance vehicles.[51]

Several studies identified ways to improve visibility and reduce glare in winter maintenance vehicles. Bullough and Rae concluded there were three important lighting factors associated with improved visibility in winter maintenance operations: light location, light beam spread, and light color.[81] Auxiliary lights should be placed outside of the winter maintenance operator's line of sight (i.e., locate lights on the passenger side of the vehicle).[82,83,88] Exterior lights should have narrow-beam spread bulbs (i.e., spot lights).[84,85,88] Some research suggested that longer wavelength light (e.g., amber and red) reduced the amount of reflected light from warning lights; however, the effects from light color were limited compared to placement and beam spread.[86,87] Winter maintenance operators in the current study reported that warning lights significantly increased fatigue. However, most comments suggested that the brightness of the warning lights increased fatigue rather than the light color. A possible solution to the brightness of warning lights is to install dimmable warning lights with a dimmer switch inside the cab. This would allow winter maintenance operators to use a nighttime setting for the forward-facing warning lights at night when other vehicles are not around the snowplow.

Another way to improve visibility is with LED bulbs. Muthumani et al. found that winter maintenance operators preferred LEDs compared to traditional halogen bulbs for all exterior lighting.[88] These winter maintenance operators reported that LED lights produced greater visibility similar to daylight. Similarly, winter maintenance operators in the current study provided 37 comments that specifically suggested the use of LED lights for all exterior lights.

In addition to lighting, winter weather can restrict a winter maintenance operator's visibility. Blowing snow or snow/ice buildup on the windshield has the potential to significantly reduce visibility. Thus, it is critical that winter maintenance vehicles have equipment that prevents snow from spraying up from the plow. Thompson and Nakhla found that snow deflectors with an angle less than 50 degrees eliminated 50% of the accumulating snow on a vehicle's windshield by reducing the amount of snow blown over the plow.[89] This study also found that snow deflectors significantly reduced fatigue.

Windshield wipers are equally important for maintaining visibility during winter maintenance operations. The current study found that traditional windshield wipers significantly increased fatigue. The comments provided by the winter maintenance operators showed that most windshield wipers did not adequately remove snow and ice. Winter maintenance operators provided 35 comments specifically recommending heated windshield wipers. Another 34 comments provided unspecified recommendations for improved windshield wipers. One previous study found that heated windshield wipers may be effective at removing snow and ice buildup; however, winter maintenance operators offered mixed reviews of this technology.[107]

A heated windshield offers another method to eliminate snow and ice buildup on the windshield. Heated windshields use built-in heated strips to melt snow and ice. Traditionally, most vehicles use heated air blown on the interior of the windshield to melt snow and ice. Winter maintenance operators in the current study reported that traditional defrost systems were ineffective in heavy snow. Additionally, the traditional defrost system heats the cab, which results in increased fatigue. One solution to this as suggested by three winter maintenance was blowing cold air through the defrost system. Although a cold windshield is likely to reduce the amount of snow and ice sticking to the windshield, extended exposure to cold temperatures coupled with fatigue has been found to decrease cognitive functioning.[116] Alternatively, the current study found that a heated windshield significantly reduced fatigue. Although no other studies have previously examined the effectiveness of heated windshield in reducing fatigue, Thomas et al. found that heated windshields were very effective at preventing snow and ice buildup in winter maintenance operations.(107)

### 6.1.4 In-cab Equipment

In-cab equipment may increase or decrease a winter maintenance operator's workload. Previous research found that high task demands significantly increased subjective ratings of fatigue.(35,40,41,42) Similarly, winter maintenance operators in the current study indicated that lots of equipment controls and hard-to-reach equipment controls significantly increased fatigue. This may suggest that increased task demands (e.g., having more controls to monitor or frequently change position to reach controls) of winter maintenance operators increases their fatigue.

Winter maintenance operators also reported that interior LCD monitors significantly increased fatigue. The comments provided by the winter maintenance operators suggested that monitor brightness and the monitor's glare increased fatigue. This result supports previous research that found that eye discomfort and strain from glare increased subjective ratings of fatigue.(69,70,71) To alleviate this fatigue, winter maintenance operators in the current study requested dimmer switches for all LCD monitors so brightness levels could be adjusted depending on the lighting conditions.

Several other types of in-cab equipment were found to significantly reduce fatigue, including presence of a collision avoidance system, a lane departure warning system, and a back-up camera. However, the reduction appeared to be rather small. Previous research examining the effectiveness of collision avoidance systems and lane departure warning systems in winter maintenance operations has been limited. All previous studies were small-scale pilot studies. However, the results of these studies found that winter maintenance operators believed these types of systems may decrease workload and fatigue.(97,98,99,103) Although there was not any previous research investigating the effect of back-up cameras in winter maintenance vehicles on fatigue, it is possible that the reduced fatigue associated with back-up cameras may be due to decreased workload.

## 6.2 NON-EQUIPMENT SOURCES OF AND SOLUTIONS TO WINTER MAINTENANCE OPERATOR FATIGUE

Although the objective of this project was to identify equipment solutions to mitigate fatigue, winter maintenance operators provided approximately 800 comments with non-equipment recommendations to reduce fatigue. Many of these comments discussed the importance of sleep or breaks in preventing fatigue. These comments supported previous research that sleep and rest are critical to recover from fatigue.(11,13,19,33,117,118,119) As non-equipment sources of fatigue were not included in the literature review, discussions related to shift length, time of day, and driver breaks are discussed in more detail below. A more detailed discussion on non-equipment sources and solutions of winter maintenance operator fatigue can be found in Camden et al.(1) and Kline.(120)

### 6.2.1 Shift Length and Restricted Sleep

Many of the comments (*n* = 229) provided shift/scheduling recommendations to increase opportunities for sleep and rest. Specifically, winter maintenance operators recommended limiting the maximum number of hours in a shift. Extremely long hours limit winter maintenance operator's opportunities for sleep and recovery. Dinges et al. found that accumulated sleep loss over several nights increased daytime sleepiness in a laboratory setting.[117] Specifically, Dinges et al. found that individuals with sleep restricted to 5 hours for 7 consecutive days reported higher rates of mental exhaustion and stress and exhibited slower reaction times.[117] These changes were found to be greatest during the bookends (i.e., first and second days and sixth and seventh days) of sleep restriction. Furthermore, Dinges et al. found that the effects of sleep restriction were diminished after two normal nights of sleep.[117] These results are of interest to winter maintenance operations in several ways. First, during winter emergencies, winter maintenance operators may experience sleep restriction, especially during the first or second day of snow removal. Thus, winter maintenance agencies should develop schedules that provide winter maintenance operators with an opportunity to obtain a full night's sleep prior to the first shift of snow removal during a winter emergency. This research suggests that winter maintenance operators who work night shifts should not come into work the morning before their first snow removal shift (e.g., swing shift). Second, after seven days of snow removal operations with restricted sleep, winter maintenance operators should be provided an opportunity to obtain two full nights of sleep.

Crum and Morrow examined the effects of various scheduling factors on truck driver fatigue.[119] Crum and Morrow found that scheduling policies that prohibited a driver from obtaining enough sleep (e.g., 7 to 8 hours) significantly increased fatigue.[119] Furthermore, the results showed that drivers who started the work week already tired were more likely to be involved in safety-related events. This finding also supports the need for winter maintenance operators to obtain several consecutive nights of full sleep after a week of snow removal operations with restricted sleep.

Other research has found that crash risk increases in the 11$^{th}$ hour of continuous driving.[33] Jovanis et al. compared commercial truck duty status records from drivers involved in a crash and drivers not involved in a crash.[33] Jovanis et al. found no differences in crash risk during the first 10 hours of continuous driving.[33] However, the 11$^{th}$ hour of continuous driving had an odds ratio of 3.26. In other words, after 10 hours of continuous driving, drivers were 3.26 times more likely to be involved in a crash. Furthermore, Jovanis et al. found an increase crash risk after 6 hours of continuous driving that ended between 4 a.m. and 6 a.m.

These findings supported the winter maintenance operators' comments regarding a limit to the length of a winter maintenance shift. Based on these findings, research suggests that winter maintenance agencies should develop a maximum shift length. Kline found that many winter maintenance agencies have a maximum shift length, with 12 hours being the most common.[120] However, 14 states reported longer maximum shift lengths. A winter maintenance maximum shift length of 12 hours should be encouraged as it more closely aligns with the findings from Jovanis et al.[33] Additionally, winter maintenance agencies should provide winter maintenance operators with an opportunity to obtain two full nights of sleep after 7 days of continuous snow removal. These recommendations are based on commercial vehicle operations, and a study on the crash risk of different winter maintenance operator schedules is needed.

### 6.2.2 Time of Day

The time of day when driving takes place may be an equally important cause of fatigue. The body experiences circadian rhythms that result in natural lulls in a person' energy.[11,13] This lull in energy increases the body's propensity to sleep and occurs overnight (between 2:00 a.m. and 6:00 a.m.).[20,121] Research has shown an increased crash risk during the circadian low.[122] Folkard analyzed previous studies to identify crash risk associated with varying times of day.[122] He found that fatigue-related crashes peaked between 2 a.m. and 4 a.m. However, Horne and Reyner suggested that individuals who typically work night shifts experience the greatest sleepiness between 4 a.m. and 6 a.m.[121] Additionally, Ferguson et al. examined the effects of time awake, sleep deprivation, and time of day in a laboratory.[13] Ferguson et al. found that extended time awake, inadequate amount of sleep, and time of day all increased fatigue.[13]

Shift start and end times are another factor that may adversely impact fatigue. Research has not identified a consensus on optimal start and end times.[123] However, most research indicates that shifts should not start early in the morning (e.g., before 6:00 a.m.).[123,124,125]

This research shows that circadian rhythm significantly affects a driver's propensity to fall asleep. Thus, winter maintenance agencies should take extra precautions for those winter maintenance operators who work nighttime shifts. Ensuring that these winter maintenance operators are provided an opportunity for a full night's sleep prior to a night shift will help winter maintenance operators through the circadian lows. Additionally, caffeine has been shown to have a protective effect against involvement in safety-related events.[126] Another strategy to counter the circadian low is through the use of breaks (discussed below).

### 6.2.3 Driver Breaks

Despite the importance of sleep in reducing fatigue, breaks from driving also reduce fatigue. Even a 15 minute break from driving (e.g., stopping to get a cup of coffee, getting out of the vehicle to stretch, talking to coworkers, etc.) can reduce fatigue. In fact, heavy vehicle research has shown the only reliable non-sleep method to reduce the impact of fatigue was via a break.[11,13,19]

A number of studies have investigated the effectiveness of breaks to reduce driver fatigue and improve safety. Lin et al. modeled commercial truck drivers' crash risk using logistic regression.[127] The results showed that a break before the sixth hour of driving significantly reduced crash risk after the sixth hour. Jovanis et al. also modeled the effectiveness of driving breaks in commercial truck operations.[33] Jovanis et al. found that breaks from driving reduced the risk of a crash by 32% and 51% for truckload and less-than-truckload operations, respectively.[33] Furthermore, two breaks per 11 hours of driving significantly reduced crash risk, but one or three breaks did not.

Two other studies also found that multiple breaks over 11 hours of driving effectively reduced fatigue and crash risk.[128,129] Chen and Xie examined commercial truck drivers' crash risk by driving hour, up to the 11$^{th}$ hour.[128] Over 11 hours of driving, one, two, and three breaks reduced the risk of a crash by 68%, 83%, and 85%, respectively, compared to drivers that did not take a break. Driver breaks ranged from 15 minutes to 2 hours. These results show that the first two breaks in 11 hours significantly reduced crash risk; however, the third break did not significantly reduce crash risk beyond the benefits provided by the second break. Thus, the results indicate that a break from driving every 4 to 5 hours was beneficial. Similarly, a second study by Chen and Xie showed that two breaks over 10 hours of driving were sufficient to reduce crash risk.(129) These results also showed that longer rest breaks lowered crash risk more than shorter breaks; however, 30-minute breaks were effective in reducing crash risk.

Watling et al. performed a driving simulator study to investigate the effectiveness of naps or active breaks in reducing driver fatigue.(130) Fatigue was assessed using objective (e.g., EEG and driving performance) and subjective (e.g., self-report sleepiness) data. Watling et al. found that active rest breaks (i.e., walking on a track for 10 minutes) did not reduce objective fatigue, but a 15 minute nap did reduce objective measures of fatigue.(130) However, both the active rest break and nap decreased subjective feelings of sleepiness.

Other non-driving related studies have investigated the effectiveness of breaks in reducing fatigue.(131,132) Penn and Bootzin conducted a literature review to identify best practices to reduce fatigue in shift work.(131) In an industrial setting, breaks lasting 10 minutes per hour were found to effectively sustain vigilance. Additionally, the research showed that the timing of break was dependent on the tasks being conducted and varied across individuals. These findings highlight the importance of educating drivers to recognize fatigue so they can implement countermeasures at the first sign fatigue. Additionally, Neri et al. performed a simulator study with airline pilots.(132) The results showed that 15-minute breaks effectively reduced subjective and objective signs of fatigue. However, the effects were short lived, and typically lasted less than 25 minutes.

Finally, many state/territory agencies and private organizations provide guidance for drivers regarding breaks. The majority of organizations recommend that drivers take a 15-minute break from driving every 2 hours. It is unclear how these organizations have determined that this schedule of breaks is effective. Some examples of this recommendation are from the Texas Department of Insurance,(133) a commercial truck driver school,(134) a private insurance company,(135) the Queensland Department of Transport and Main Roads,(136) and the Motor Accident Commission South Australia.(137)

In terms of winter maintenance operations, these research results indicate that breaks are likely to effectively reduce winter maintenance operator fatigue. Winter maintenance operators should be encouraged to take a break from driving every 5 hours (at a minimum). Breaking once every 4 hours would likely be more beneficial, and should be feasible given that winter maintenance operators complete routes and return to terminals to reload their sand and deicing materials. Breaks should last between 15 and 30 minutes.

#### 6.2.4 Motor Carrier Hours-of-Service Regulations

In the U.S., interstate commercial truck drivers are bound by prescriptive HOS regulations.(138) These regulations are designed to reduce or prevent commercial vehicle driver fatigue. Although winter maintenance operators are exempt from these regulations, they may provide guidance on daily driving and work limits, limits on consecutive days of driving, and breaks from driving. An easy-to-read summary table of the HOS regulations can be found at https://www.fmcsa.dot.gov/regulations/hours-service/summary-hours-service-regulations. HOS provisions that may relate to winter maintenance operations include:

- 11-hour rule: Drivers are limited to 11 hours of driving following 10 consecutive hours off duty.
- 14-hour rule: Drivers cannot drive beyond the $14^{th}$ hour after starting work following 10 consecutive hours off duty.
- Rest break: Drivers are required to take a 30-minute break at or before 8 hours of consecutive driving. However, this break does not apply to short-haul operations.
- 60/70 hour rule: Drivers may not drive more than 60 hours in a 7-day period or 70 hours in an 8-day period. However, the 7/8-day period may be restarted with 34 consecutive hours off duty.

### 6.2.5 North American Fatigue Management Program

As mentioned above, drivers should be educated on fatigue management, particularly on identifying the early signs of fatigue. The NAFMP is a completely free resource that was designed for use by commercial motor carriers of all sizes. Although the NAFMP targets commercial truck operations, many of the topics are directly related to fatigue in winter maintenance operations. The NAFMP provides educational information for managers, drivers, and driver families. The NAFMP can be viewed at http://www.nafmp.org/index.php?lang=en.

The driver education module (Module 3) provides much information that may be of interest to winter maintenance operators. Some topics that may be of interest include:

- Objective signs of fatigue (slides 29 and 30)
- Health effects of fatigue and sleep deprivation (slides 31 and 32)
- How to recover from sleep deprivation (slide 35)
- Fatigue's impact on crashes (slides 37 to 43)
- Information on obstructive sleep apnea (slides 74 to 77; Module 8 provides more detailed information on sleep disorders)
- Diet, nutrition, and exercise (slides 91 to 94)
- Strategies to improve sleep and alertness (slides 120 to 124)

## 6.3 LIMITATIONS

Although the literature review and questionnaire in this study were extensive, several factors provided constraints to the final recommendations. These limitations are discussed below.

- Although over 2,000 winter maintenance operators provided responses to the questionnaire, these winter maintenance operators may not have been representative of all winter maintenance operators. These winter maintenance operators should be considered a convenience sample. Other winter maintenance operators may have different experiences and opinions regarding fatigue. However, responses on the questionnaire showed a wide variety of opinions regarding fatigue, suggesting a large cross-section of winter maintenance operators.

- The questionnaire collected subjective ratings and opinions of fatigue. It is possible that objective measures of fatigue (e.g., psychomotor vigilance task, actigraph devices, fatigue-related incidents and crashes, etc.) would result in different recommendations. Despite this limitation, subjective opinions of fatigue are important in understanding the role and magnitude of fatigue in winter maintenance operators.
- The cost and effectiveness data represent the generation of technologies at the time when data were collected. Future generations of technology may have a different impact on fatigue.

## 6.4 FINAL RECOMMENDATIONS

The following list of cost-effective solutions to mitigate winter maintenance operator fatigue was derived from the literature review and questionnaire.

### 6.4.1 Equipment Solutions

Below are the cost-effective equipment-related solutions to mitigate winter maintenance operator fatigue. These solutions are believed to be the most promising to mitigate fatigue at low cost (in no particular order).

- **Dimmable interior lighting.** Interior lighting, including LCDs, should be dimmable to near black or have the ability to be turned off. Winter maintenance operators should be instructed to dim the interior lights according to their individual preference during nighttime operations. Dimming the interior lights will reduce the amount of interior light reflected on the windshield and windows.
- **Use LED bulbs for exterior lighting**. LED lighting has been found to greatly improve nighttime visibility. Winter maintenance agencies should replace headlights, plow lights, and other auxiliary light bulbs with LEDs.
- **Dimmable warning lights.** Winter maintenance vehicles should be equipped with warning lights that have a nighttime setting (i.e., dimmable). Winter maintenance operators should be instructed to use the nighttime setting during night driving in winter emergencies to reduce back-reflected light from the warning lights.
- **Install a CD player or satellite radio.** All winter maintenance vehicles should have a CD player or satellite radio installed. A simple AM/FM radio may also work in locations with a wide variety of radio stations and good reception. If winter maintenance operators work in locations with poor reception or a lack of radio station options, a CD player or satellite radio is a better option. Winter maintenance managers should instruct winter maintenance operators to listen to their preferred music or radio selections while operating the snowplow. However, listening to music or talk radio should be considered a short-term fatigue countermeasure.
- **Heated windshield.** Winter maintenance vehicles should be equipped with heated windshields. Heated windshields have been found to greatly reduce the buildup of snow and ice on the windshield. Heated windshields will also allow a more comfortable interior cab temperature, which decreases winter maintenance operator fatigue.

- **Install snow deflectors**. Snow deflectors should be installed on plows to reduce the amount of snow blown onto the windshield.
- **Narrow-beam auxiliary lighting.** Winter maintenance agencies should install LED narrow-beam spotlights to reduce back-reflected light.
- **More ergonomically designed seat with vibration dampening/air-ride technology.** Winter maintenance vehicles should be equipped with an ergonomically designed seat that includes vibration dampening or an air-ride technology. Air-ride seats reduce vibration experienced by the winter maintenance operator. Furthermore, an ergonomically designed seat will alleviate back, neck, and/or leg pain.

### 6.4.2 Non-Equipment Solutions

Based on comments from winter maintenance operators, the research team also recommends several non-equipment solutions to mitigate fatigue. The recommendations to mitigate the factors that have the largest impact on winter maintenance operator fatigue are provided below.

- **Encourage the use of breaks** (not penalizing winter maintenance operators for idling or taking a break). Winter maintenance operators should be instructed to take a 15 to 30 minute break every 4 to 5 hours (at a minimum) or when they experience the early signs of being fatigued.
- **Train winter maintenance operators to identify signs and symptoms of fatigue.** Winter maintenance operators should be provided education and training in identifying signs of fatigue. The NAFMP driver module (Module 3) provides a free resource that may be used by managers (see www.nafmp.org).
- **Investigate reduced shift lengths, start and end times, and overtime rules/limits.** Winter maintenance agencies should limit shift lengths to a maximum of 12 consecutive hours. Additionally, winter maintenance operators should be provided an opportunity to obtain 2 full nights of sleep after 7 consecutive days of snow removal with restricted sleep. Finally, shift start times between 12:00 a.m. and 6:00 a.m. should be avoided. If a 12-hour shift length is not feasible due to limited manpower or vehicles, winter maintenance operators should be instructed to take more frequent (e.g., every 3 to 4 hours) and longer (e.g., 30 minutes) mandatory breaks.
- **Each winter maintenance agency should create a Fatigue Management Policy.** All winter maintenance agencies should create a written policy regarding shift lengths, mandatory breaks, number of consecutive days performing snow removal operations, operator training, etc. A written policy will create accountability and demonstrate the importance of fatigue management.
- **Investigate methods to provide winter maintenance operators with earlier notification of an impending swing shift.** If possible, winter maintenance operators that work night shifts during winter emergencies should not come into work the morning prior to the first snow removal shift (e.g., swing shift).
- **Encourage healthy lifestyles (e.g., diet, exercise, sleep).** Winter maintenance operators should be encouraged to avoid fried and processed food with excessive amounts of saturated fat and sodium. Better food options include whole grains, fruits, vegetables,

low-fat milk products, lean meats, fish, and nuts. They should also be encouraged to get at least 2.5 hours of exercise per week and 7 to 8 hours of sleep per night.

- **Encourage winter maintenance operator input in equipment purchases.** Winter maintenance operators are the primary users of the equipment; they have insight that will assist in equipment purchases that are likely to reduce fatigue.
- **Dedicated place for operators to rest at each terminal.** If possible, each terminal should have a room where operators can rest or nap when time allows. This room should have a comfortable place for winter maintenance operators to lie down, limit light from entering, dampen outside noise, and be temperature controlled.

# APPENDIX A: QUESTIONNAIRE

Under sponsorship of the Clear Roads Pooled Fund, the Virginia Tech Transportation Institute (VTTI) is conducting a questionnaire on how equipment factors impact your level of tiredness during winter operations. Clear Roads is a national research consortium of 33 States focused on rigorous testing of winter maintenance materials, equipment, and methods used by highway maintenance crews.

Tiredness (also called fatigue) is the feeling resulting from lack of sleep or physical activity. The goal of this project is to collect opinions and perceptions from snowplow operators regarding equipment that causes tiredness during winter maintenance operations. Your opinions will be used to make recommendations to improve your equipment so that you feel less tired.

As a snowplow operator, your experience and opinions are needed to identify equipment that makes you tired. The current questionnaire, which will take about 20 minutes to complete, asks about your experience with tiredness during winter operations, equipment installed on your truck, and the impact the equipment has on your ability to maintain your alertness (or increase your tiredness).

The data gathered in this research will be treated with anonymity and no names will be linked to the questionnaires. You may skip any question you do not wish to answer. Also, your participation in this questionnaire is optional. Your participation or lack of participation in the questionnaire has no influence on your job status.

If you chose to complete the questionnaire you will have the opportunity to be entered into a random drawing to win one of ten $50 gift cards. Your odds of winning one of the gift cards is estimated to be 1 in 200. Matt Camden will oversee random selection of winners, and Rebecca Hammond will observe the drawing to ensure the selections are not biased. If you chose to be entered into this drawing, you will be required to provide your contact information. If you are selected as a winner, you will be asked to provide payment information in order for us to process payment, and this will include your social security number. This information will not be associated with your questionnaire responses.

If you have any questions, please feel free to contact Matt Camden, mcamden@vtti.vt.edu, or 540-231-1503.

The Virginia Tech Institutional Review Board has approved this project. If you have any questions about the protection of human research participants regarding this project, you may contact Dr. David Moore, moored@vt.edu, or 540-231-4991.

Thank you, in advance, for your help and cooperation with this project.

1. Please select the choice that best represents who you work for during winter operations.
    a. State DOT
    b. Contractor
    c. City/County
    d. Other (Please specify): ________________________________________

2. What state do you perform most of your work in winter operations?

    ________________________________________________________________

3. How many years have you been working in winter maintenance operations (for seasonal operators, each full season is equal to one year)?
    a. Less than 1 year
    b. 1 to 5 years
    c. 6 to 10 years
    d. 11 to 15 years
    e. More than 15 years

4. What type of winter maintenance equipment do you drive? Please select the type of equipment you drive most often.

| | Make | Model | Year |
|---|---|---|---|
| **Tractor** | | | |
| **Pick-up truck** | | | |
| **Grader** | | | |
| **Front-end loader** | | | |
| **Dump truck with one plow/spreader** | | | |
| **Truck with multiple plows** | | | |
| **Truck with multiple spreaders** | | | |
| **Truck with multiple plows and spreaders** | | | |
| **Other (please specify)______________** | | | |

5. While operating the snowplow during winter emergencies, the majority of your shift is during the:
   a. Day
   b. Night
   c. Both

6. . On average, what is your typical shift length during winter emergencies?
   a. Less than 8 hours
   b. 8 hours
   c. Between 8 and 12 hours
   d. 12 hours
   e. Between 12 and 16 hours
   f. 16 hours
   g. More than 16 hours

7. How often do you become tired during winter emergencies while operating a snowplow?
    a. Never
    b. Sometimes
    c. About half the time
    d. Most of the time
    e. Always

8. While operating the snowplow during winter emergencies, when do you often become tired?
    a. At the start of your shift during winter emergencies
    b. At the end of your shift during winter emergencies
    c. In the middle of your shift during winter emergencies
    d. I do not become tired during winter emergencies
    e. I’m tired during the entire shift during winter emergencies

9. In your opinion, how often does vibration caused by the snowplow equipment make you tired during winter emergencies?
    a. Never
    b. Sometimes
    c. About half the time
    d. Most of the time
    e. Always

10. How often does the following vibration-related equipment impact your level of tiredness (please mark all that apply)?

| | Always Increases Tiredness | Sometimes Increases Tiredness | Neither decreases or increases Tiredness | Sometimes decreases Tiredness | Always decreases Tiredness | Do not have on truck |
|---|---|---|---|---|---|---|
| Air-suspension seat | □ | □ | □ | □ | □ | □ |
| Air-cushioned seat | □ | □ | □ | □ | □ | □ |
| Automatic tire chains | □ | □ | □ | □ | □ | □ |
| Non-automatic tire chains | □ | □ | □ | □ | □ | □ |
| Rubber-encased blades | □ | □ | □ | □ | □ | □ |
| Blade float device | □ | □ | □ | □ | □ | □ |
| Segmented blades | □ | □ | □ | □ | □ | □ |
| Belly plow | □ | □ | □ | □ | □ | □ |
| Wing plow | □ | □ | □ | □ | □ | □ |
| Tow plow | □ | □ | □ | □ | □ | □ |
| Front plow | □ | □ | □ | □ | □ | □ |
| Other (please specify): ____________________ | □ | □ | □ | □ | □ | □ |
| Other (please specify): ____________________ | □ | □ | □ | □ | □ | □ |

11. Do you have any equipment-related recommendations to reduce tiredness caused by vibration during winter emergencies?

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_______________________________________________________________

12. In your opinion, how often does noise caused by the snowplow equipment make you tired during winter emergencies?
    a. Never
    b. Sometimes
    c. About half the time
    d. Most of the time
    e. Always

13. How often does the following equipment-related noise impact your level of tiredness (please mark all that apply)?

| | Always Increases Tiredness | Sometimes Increases Tiredness | Neither decreases or increases Tiredness | Sometimes decreases Tiredness | Always decreases Tiredness | Do not have on truck |
|---|---|---|---|---|---|---|
| Noise from plow | □ | □ | □ | □ | □ | □ |
| Noise from engine | □ | □ | □ | □ | □ | □ |
| Music/radio turned on | □ | □ | □ | □ | □ | □ |
| Music/radio turned off | □ | □ | □ | □ | □ | □ |
| CB radio | □ | □ | □ | □ | □ | □ |
| DOT radio | □ | □ | □ | □ | □ | □ |
| Audible alerts from snow/ice/safety equipment | □ | □ | □ | □ | □ | □ |
| Other (please specify): ____________ | □ | □ | □ | □ | □ | □ |
| Other (please specify): ____________ | □ | □ | □ | □ | □ | □ |

14. Do you have any equipment-related recommendations to reduce tiredness caused by noise during winter emergencies?

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15. In your opinion, how often does reduced visibility make you tired during winter emergencies?
    a. Never
    b. Sometimes
    c. About half the time
    d. Most of the time
    e. Always

16. How often does the following visibility-related equipment impact your level of tiredness (please mark all that apply)?

| | Always Increases Tiredness | Sometimes Increases Tiredness | Neither decreases or increases Tiredness | Sometimes decreases Tiredness | Always decreases Tiredness | Do not have on truck |
|---|---|---|---|---|---|---|
| Anti-glare glass | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Exterior strobe lights | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Exterior flashing lights | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Interior vehicle lighting | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Auxiliary exterior lighting | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Windshield wipers | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Heated mirrors | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Heated windshield | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Heated windows | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Snow deflectors | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Other (please specify): ________________ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Other (please specify): ________________ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

17. Do you have any equipment-related recommendations to reduce tiredness caused by limited visibility during winter emergencies?

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18. In your opinion, how often does in-cab equipment make you tired during winter emergencies?
    a. Never
    b. Sometimes
    c. About half the time
    d. Most of the time
    e. Always

19. How often does the following in-cab equipment or cab design impact your level of tiredness (please mark all that apply)?

| | Always Increases Tiredness | Sometimes Increases Tiredness | Neither decreases or increases Tiredness | Sometimes decreases Tiredness | Always decreases Tiredness | Do not have on truck |
|---|---|---|---|---|---|---|
| Placement of equipment controls | □ | □ | □ | □ | □ | □ |
| Number of equipment controls | □ | □ | □ | □ | □ | □ |
| Mobile phone | □ | □ | □ | □ | □ | □ |
| Presence of a collision avoidance system (e.g., forward collision warning) | □ | □ | □ | □ | □ | □ |
| Assistance to stay within lane via a lane departure warning system | □ | □ | □ | □ | □ | □ |
| Back-up cameras | □ | □ | □ | □ | □ | □ |
| Head-up displays | □ | □ | □ | □ | □ | □ |
| Placement of interior LCD displays | | | | | | |
| Light from LCD displays (other than back-up cameras) | □ | □ | □ | □ | □ | □ |
| Other (please specify): ____________ | □ | □ | □ | □ | □ | □ |
| Other (please specify): ____________ | □ | □ | □ | □ | □ | □ |

20. Do you have any in-cab recommendations to reduce tiredness during winter emergencies?

21. Please write any additional suggestions you may have to decrease operator tiredness during winter emergencies.

Thank you for completing the questionnaire.

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